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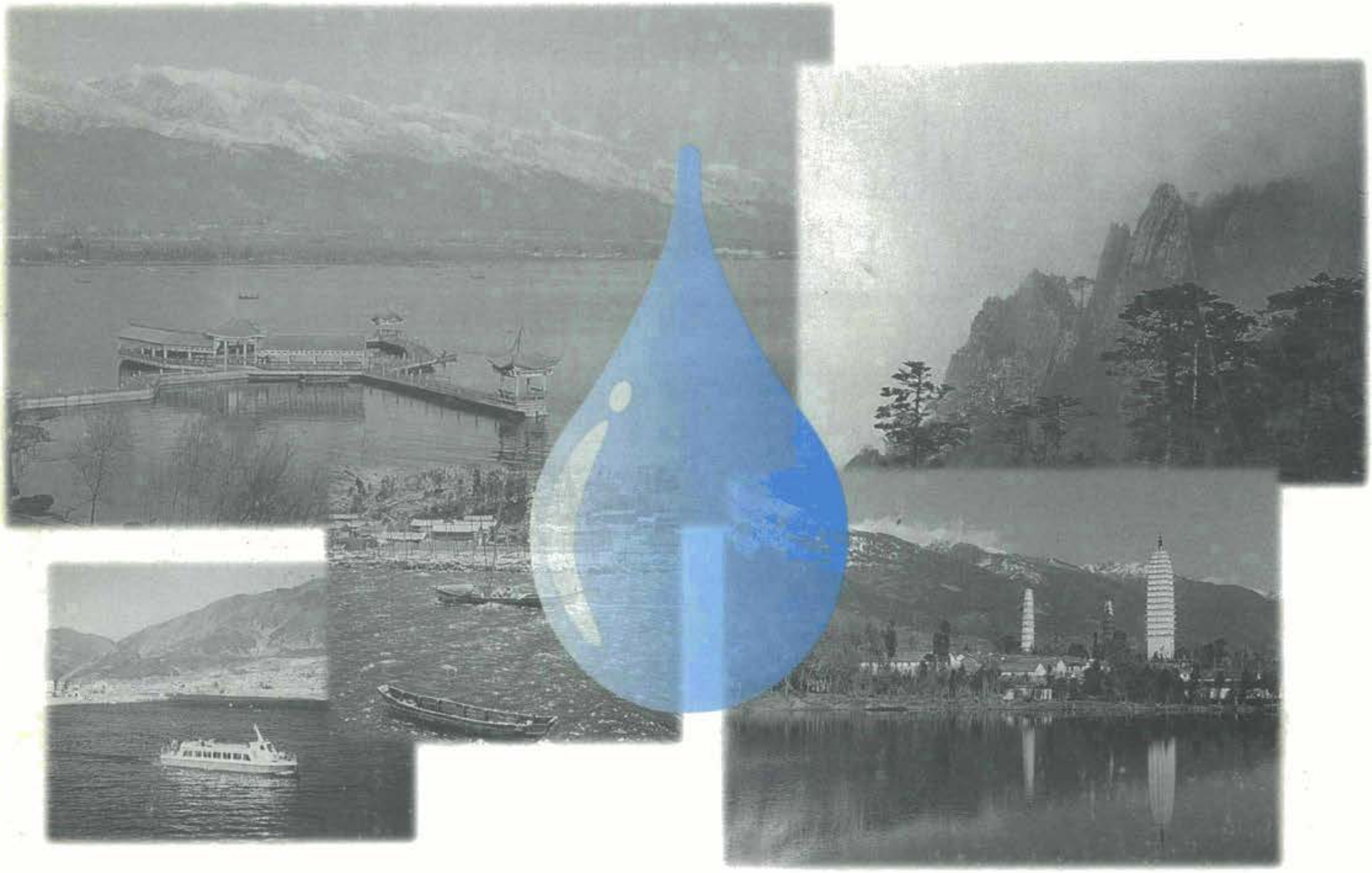
Environmentally Sound Management of Lake Erhai and Xier River Basin



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ENVIRONMENTALLY SOUND MANAGEMENT OF LAKE ERHAI AND THE XI'ER RIVER BASIN

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FOREWORD

Lake Erhai is a freshwater lake nestled like a pearl on a plateau in the central part of the Dali Bai Autonomous Prefecture, Yunnan Province, People's Republic of China. The Lake has a surface area of 250 km^2, average depth of 10.2 m, and a capacity of 2.93 billion m^3. Its drainage area includes parts of Eryuan County including the City of Dali. Despite the numerous streams draining into Lake Erhai from the Cangshan Mountains, the Lake has only one outlet, the Xier River, which flows into the Lancangjiang River and, ultimately, into the Mekong drainage system. Lake Erhai is famous for its beautiful scenery and has a long history associated with the distinctive culture of the people of Bai nationality. The steep, snow–covered Cangshan Mountains and the clean blue waters of the Lake, reflecting the 2,200 meter mountain peaks and forming the habitats for various plants and wildlife, form a very beautiful picture and people can hardly tear themselves away from its beauty.

Unfortunately, this picture has been marred in recent decades by a number of environmental problems that have emerged from the economic development of the area. However, because of the great importance attached to the environment of the drainage area of Lake Erhai, the people of China have joined together with international institutions to protect and restore this unique jewel while maintaining and enhancing the quality of life of its people in a sustainable manner.

This report is the integrated result of the investigations, analyses, and syntheses carried out in the area by relevant departments of the Country, in cooperation with international agencies. It reports on the outcome of the environmental planning program carried out under the auspices of the United Nations Environment Programme-International Environmental Technology Centre (UNEP-IETC), and the success of pilot-scale projects for the development of environmental infrastructure conducted under the auspices of the United Nations Development Programme (UNDP). It is hoped that the suggested actions set forth herein would be considered by the government of People's Republic of China in partnership with the international community, and continue to play an important role in the sustainable socio-economic development and environmental management of the Lake and its drainage basin.

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ENVIRONMENTALLY SOUND MANAGEMENT OF LAKE ERHAI AND THE XI'ER RIVER BASIN

CONTENTS

Chapter 1

Socio-Economic Development and Major Environmental Problems of the Lake Erhai Region

1.1 Geography and Natural History

Lake Erhai is a through-flow lake located within a 2,565 km^2 drainage basin situated upstream of the 146 km^2 Xi'er River watershed, between latitudes 25^0 25'N and 26^0 16'N, and longitudes 99^0 32'E and 100^0 27'E. The 23 km long Xi'er River flows out of Lake Erhai, forming part of the Lancangjiang River drainage system, which, in turn, is part of the headwaters system of the Mekong River. The Lake Erhai drainage basin is bounded by the Jinsha-Yangtze and Yuanjiang river basins draining from the north to the east, and to the southeast, respectively. Since 1992, water abstracted from Lake Erhai has been used to augment the water resources of Binchuan County, at a rate of $50 \times 10^6\ m^3\ yr^{-1}$. The study area, shown in Figures 1 and 2, includes Dali City, Dali County and part of Eryuan County within the Dali Prefecture, Yunnan Province, Peoples' Republic of China.[1] The area has a population of 716,900.

Surfacial Geology and Topography

The Dali Prefecture is characterized by a mountainous topography, with three principle ridges running in an approximately northwesterly-southeasterly direction through the Prefecture. These ridges are formed by the Laojun, Diancang, and Ailao

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[1] For administrative reasons, recommendations given in this report regarding environmental management within the study area are made at the Prefectural level. Such recommendations, therefore, are wider in scope than the Lake Erhai and Xi'er River system. However, as many of the recommendations also apply to the Lancangjiang River drainage basin and the Mekong River, this level is considered appropriate to meeting the objectives of the project.

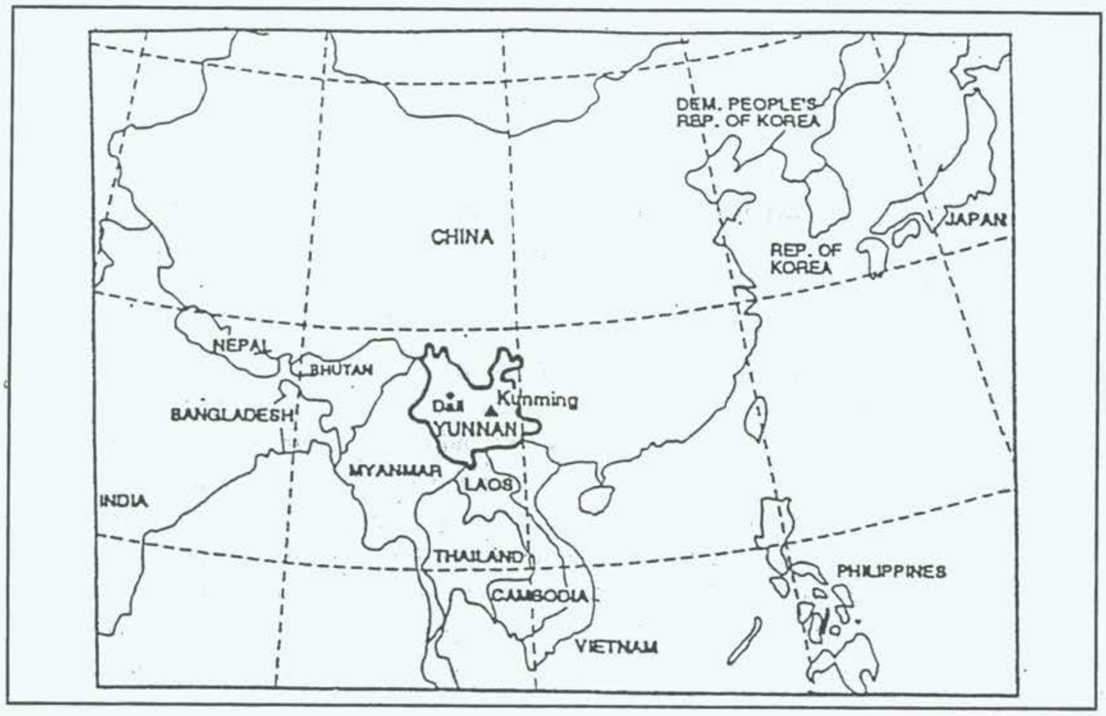

Figure 1. Location of the study area.

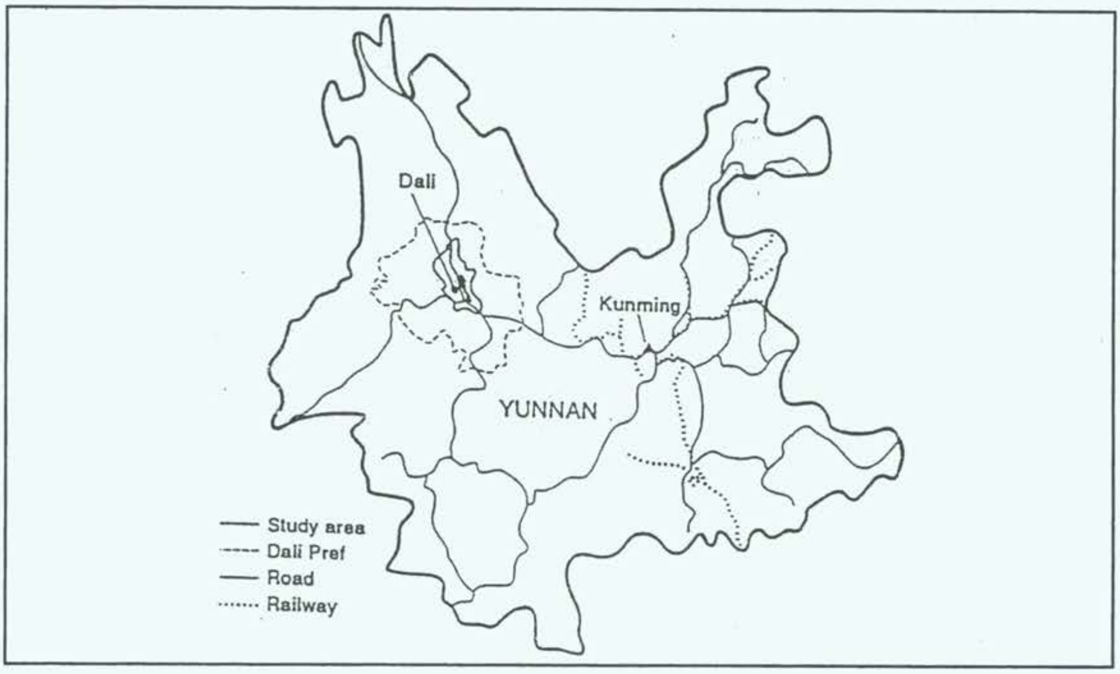

Figure 2. Location of the Lake Erhai and Xi'er River basins within the study area.

mountain ranges (Figure 3). The eastern part of the Dali Prefecture lies on the Yangtze paraplatform at an altitude of 2,800 m above sea level, while the western part of the Prefecture lies within the Shanjiang fold at an altitude of 3,074 m to 4,122 m above sea level. Lake Erhai lies in a deep valley between these two features.

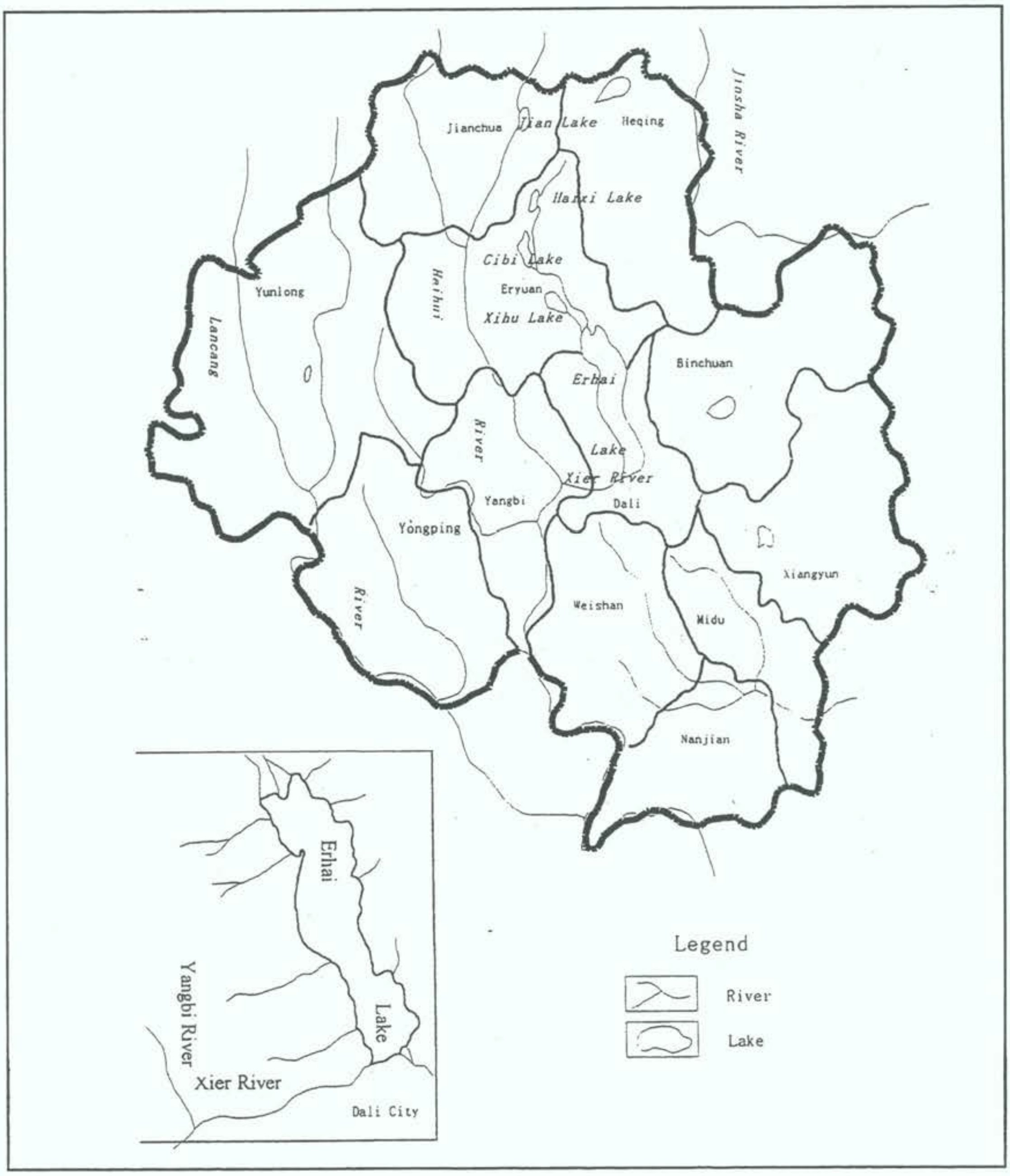

Figure 3. Topographic and geographic features of central Yunnan Province.

The study area is situated within a gorge located in the southwestern portion of the southern Hengduan Mountains. It is bordered on the west by the Cangshan Mountain range; lacustrine, alluvial and proluvial deposits accumulating on the eastern slopes of the Cangshan Mountains formed Lake Erhai during the early Pleistocene. The gorge in which the lake is situated slopes from the plateau in the northwest in a southeasterly direction. Thus, three categories of landform--mountain, basin, and valley--exist within the study area. Among the surrounding mountain peaks, Yunling to the northwest of the lake, is the dominant one.

Climate

The study area lies within the low latitude, subtropical monsoonal climatic zone. The annual mean temperature is about 15°C, ranging from 5°C during the coldest month (January) to 25°C during the hottest month (July), with an average relative humidity of 66 percent. The average annual sunshine is between 2,250 to 2,480 h yr^{-1}. Prevailing winds are from the southwest at an average velocity of 2.3 m s^{-1}. The average annual precipitation is 1,048 mm, concentrated during the period between June and October. The area has abundant sunshine and an equitable climate.

Hydrology

The study area is part of the Lancangjiang River drainage system. There are 117 tributary rivers in this system, including the Fengyu, Mizu, Yong'an, Luoshi, and Xi'er rivers. Lakes in the study area include Erhai, Cibi, Haixihai, and Xihu lakes. The average annual surface runoff in the Lake Erhai area is 1.5×10^9 m^3. In general, water quality is fairly good in the lakes, although the Xi'er River is seriously polluted by industrial wastewater and sewage discharges.

Water entering Lake Erhai is derived mainly from rainfall and snowmelt. Lake Erhai is the fourth lake in a chain of lakes that includes, from north to south, Cibi, Xihu and Haixihai. They drain to Lake Erhai via the Mizu, Luoshi and Yong'an rivers, and through the Eryuan and Dengchuan basins. To the west of Lake Erhai are 18 montane rivers draining to the lake from the slopes of the Cangshan range, while, to the south and east, the Boluo, Haichao and Yulong rivers and several smaller streams flow into the lake.

The only outflow of Lake Erhai is the Xi'er River, which flows into the Heihui River at Yangbi Pingpo, a drop in altitude of 610 m. The Heihui River then joins the Lancangjiang River as part of the Mekong River system. In the early 1990s, a diversion tunnel was constructed on the southern shore of the lake to divert water to Binchuan County. The diversion is 8,263 m in length, 7,745 m of which is tunneled. The designed water flow through this diversion is 10 m^3 s^{-1}, with an annual yield of 50 x 10^6 m^3.

Soils

The soils in the study area consist of red earth, purple soil, brown earth, dark brown earth, paddy soil, limestone soil and subalpine steppe soil. The areas and proportions of these soils in the Dali Prefecture are shown in Table 1.

Table 1. Proportions of Different Soils in Dali Prefecture

Type	Red Soil	Brown Soil	Yellow Soil	Yellow Brown Soil	Dark Brown Soil	Purple Soil	Dry Red Soil	Limestone Soil	Alluvial Soil	Subalpine Steppe Soil	Paddy Soil
Area (ha)	1,180.0	479.7	17.6	460.6	139.5	1,352.1	28.2	77.1	11.4	4.8	196.9
Proportion (percent)	26.7	10.9	0.004	10.4	3.2	30.6	0.6	1.7	0.3	0.1	4.5

Biodiversity and Ecology

The Cangshan Mountains and the Lake Erhai district of the Dali Prefecture is a national natural reserve. The reserve is located between latitudes 25^0 26' and 26^0 00' N and longitudes 90^0 57' and 100^0 18' E, within the area of study. This area, like the study area, lies within the low latitude, subtropical monsoonal climatic zone, at a relative altitude of 2,652 m above sea level. As a consequence of the varied topography and typical stereoscopic climate of high mountains, there are a number of rich and diverse ecosystems in the area, including forest, meadow, desert, plateau and wetland ecosystems. The Cangshan Mountains, bordering the study area, form one of the habitat types, being a well-known example of an high mountain floral system. Similarly, Lake Erhai is the second largest upland lake in China, and is a typical representative of upland freshwater lakes.

The Cangshan and Erhai natural reserve is also rich in animal and plant resources. To date, 2,330 species of seed plants, belonging to 755 genera in 170 families (15 percent of the total number of seed plants in Yunnan Province) have been identified within the study area. Of these plant species, 46 species, belonging to 46 genera of 27 families, are hydrophytes present in Lake Erhai. There are also 195 species of algae, belonging to 42 families, in the lake. Within the natural preserve, there are 26 species of rare and endangered wildlife and a large quantity of various crop species of economic import. Four of these crop species are under second grade national protection and ten are under third grade national protection. Three crop species are endemic species to China; four are found only in Yunnan Province, and five only in the Cangshan Mountain preserve. The area is also rich in floral resources, including all eight of the flowers for which Yunnan Province is famous: camellias, rhododendrons, magnolias, primroses, lilies, gentians, orchids, and French poppies. As a center for rhododendrons, the Cangshan Mountain area boasts 44 kinds of different rhododendron, accounting for 10 percent of the total number of variants in China and 18 percent of the total number in Yunnan. In addition, 601 species of medicinal plants, belonging to 199 families, grow in the area.

Based on wildlife inventories, there are 285 species within the natural reserve (consisting of 82 species of mammals, 170 species of birds, and 33 species of fish). In addition, there are 148 species of lower animals. Of the total number of wildlife species present in the study area, eight are under first grade national protection and 15 under second grade national protection. Aquatic animal species also abound, with 33 fish species present, belonging to 20 genera of 6 families. The Dali bow fish and Erhai carp are endemic species to Lake Erhai and are under second grade national protection, while the Dali carp and spring carp are under second grade provincial protection.

1.2 Natural Resources and Land Use

Mineral Resources

The Dali Prefecture, located along a geosyncline in western Yunnan Province, has abundant mineral resources. Major non-metallic mineral reserves include 69 million tons of coal, about 100 million m^3 of marble, about 10 million tons of gypsum, 6 million tons of clay, and 36 million tons of rock salt. In the Lake area, marble, limestone, and coal are extensively exploited. The reserves of marble are especially rich and of good quality, having an even, fine-grained structure and texture, capable of being extracted in large-scale quarries. These reserves have the potential to be developed to supply the building material industry in the area.

There are also more than 200 metallic mineral deposits in the area, including deposits of manganese extending over 35 km^2, and reserves of iron, tin, mercury, lead, copper and gold estimated at about 9 million tons, 22 thousand tons, 24 tons, 286 tons, 163 thousand tons, and 5 tons, respectively. Other ore reserves include antimony, copper-nickel, copper-cobalt, silver, palladium, platinum, and aluminum.

The exploitation and development of mineral resources is an integral part of the economic development of the region. However, such development, if not carefully managed and controlled, can bring about problems of ecosystem destruction and soil erosion, which merit much attention.

Forest Resources

The second soil survey of the Dali Prefecture showed that the land area devoted to forestry usage within the Lake Erhai basin was 132,493 ha, or 44.6 percent of the total area. Of these lands, 32,218 ha, or 24 percent of the lands, were woodlands; 16,117 ha, or 11 percent of the lands, were open forest; 73,664 ha, or 25 percent of the lands, were bush; 10,391 ha were seedlings; and, 100 ha were managed forest. The non-forested area was 164,707 ha, or 55.4 percent of the basin. The total living timber reserves in the Lake Erhai area are estimated to be 1.6 million m^3. About 727 thousand m^3 of timber, or 46 percent of the reserves, are located in the northern portion of the basin; 99.8 thousand m^3, or 6 percent, in the eastern portion; 198 thousand m^3, or 13 percent, in the southern portion; and, 558 thousand m^3, or 35 percent, in the western portion of the basin.

Tourism Resources

In terms of tourism development, Dali City is one of the leading tourist destinations in China's southwest border region. It is a national historic city. The rivers, hills, waters, and shining mountains characteristic of the diverse landscape, and the scenic beauty of the city, attract tourists to the "Cangshan Erhai" resort area from throughout Yunnan Province. The inherent tourism potential of the region has been developed during the period of the eighth five-year plan and attracts increasing numbers of tourists. In 1995, almost three million tourists from home and abroad visited the region. The numbers of tourists, the total income from tourism, and the value of foreign exchange earned place tourism second in terms of economic importance to Yunnan Province.

Land Use

The existing land use of the Lake Erhai region, as inventoried during the second soil survey of the basin, is shown in Table 2 and Figure 4. In general, the basin has a large population but limited farmland with limited potential for expansion. Non-agricultural industries occupy large areas of the basin.

Active farms occupy 43,100 ha, of which 28,200 ha are paddy fields. Per capita farmland area is 0.01 ha per person, or 0.08 ha per person within the agricultural sector of the population. Such a per capita area is 80 percent of the national average. Because mountainous lands and non-arable grasslands comprise about 13,000 ha of the basin, the 667 ha of potentially arable grassland are considered to be insufficient

Table 2. Present Land Use in Lake Erhai Basin

Type	Farmland					Forested Lands					
	Paddy	Dry Land	Vegetable Land	Vacant Land for Rotation	Subtotal	Forest	Young Forest	Open Forest	Bush	Economic Forest	Subtotal
Area (10^4ha)	42.6	12.3	1.7	8.1	64.6	48.3	15.6	24.2	110.5	0.15	198.75
Ratio (percent)	9.5	2.8	0.4	1.8	14.5	10.8	3.5	5.4	24.8	0.03	44.53
Per Capita Area (ha)	0.60	0.17	0.02	0.11	0.90	0.67	0.22	0.34	1.54	0.002	2.77

Type	Urban Lands			Other Lands				Total
	Residential Land	Transportation Lands	Industrial and Other Lands	Barren Mountains	Grasslands	Wetlands	Unused Lands	
Area (10^4ha)	11.8	2.2	27.8	79.3	11.2	42.5	7.7	445.8
Ratio (percent)	2.7	0.5	6.2	17.8	2.5	9.5	1.7	100.0
Per Capita Area (ha)	0.17	0.03	0.39	1.11	0.16	0.59	0.11	6.23

to sustain an agricultural population during a period of population growth. Even though new agricultural lands are opened up every year, because these lands are located on slopes and hillsides with poor quality soils, the total area of farmland remains the unchanged from year to year. For this reason, the trend in recent years has been toward development of non-agricultural industries.

Within the agricultural sector, production of grain crops is the dominant activity, while forestry, animal husbandry and fisheries are of subordinate status. Economic forests, market gardens, grazing lands, and vegetable gardens make up a fairly low percentage of the lands devoted to agricultural uses. In comparison to grain crop production, forestry, animal husbandry and fisheries in the area is quite limited. The forests, particularly, are in poor condition, and reforestation is urgently needed to effectively prevent soil erosion. China's *Forest Law* stipulates that the forest coverage rate in mountain areas should reach 70 percent. At present, the basin has about 32,240 ha of woodlands, or a forest coverage rate of only 11 percent.

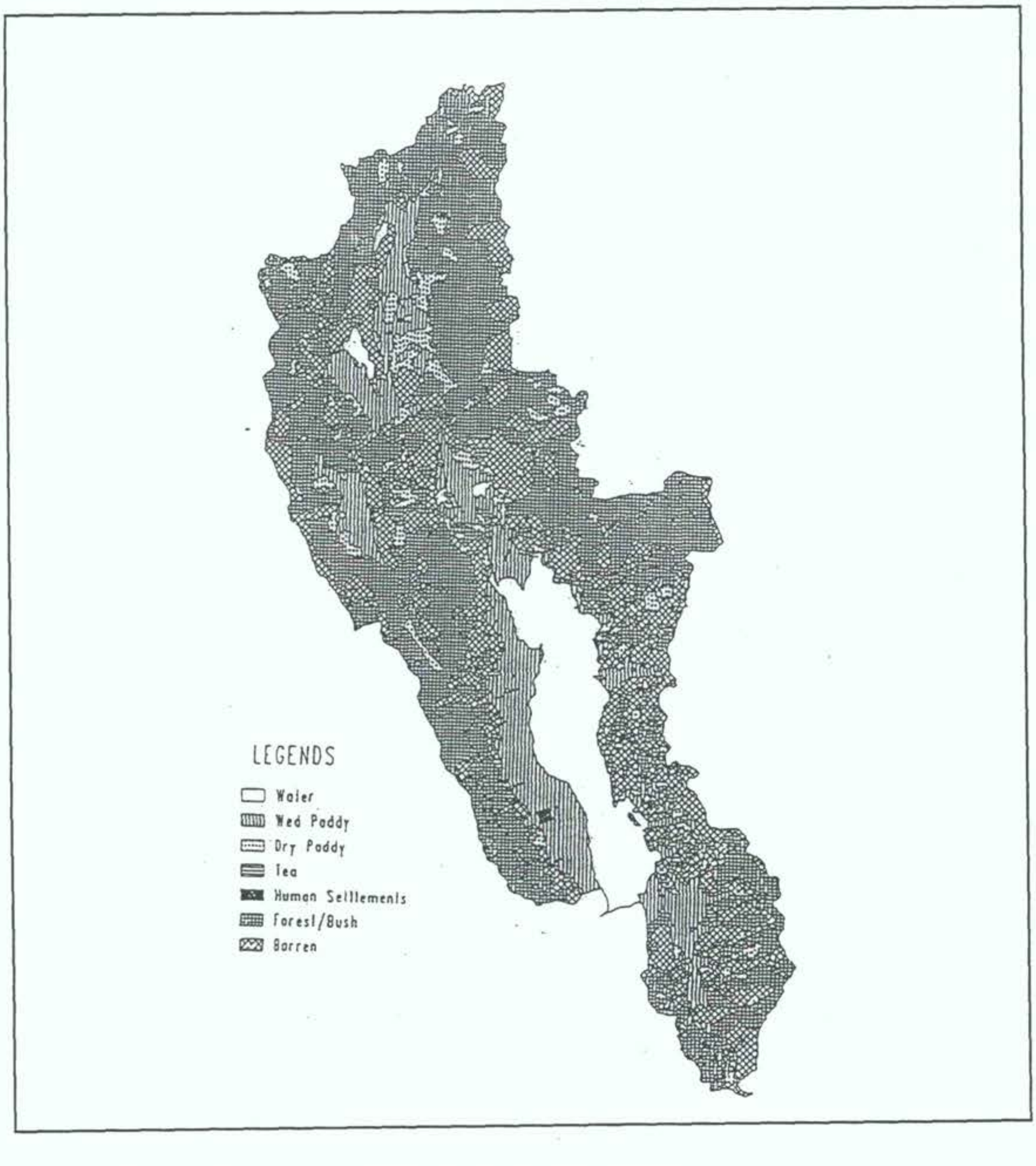

Figure 4. Current land usage within the Lake Erhai basin.

Table 2 shows that the area of land used for industrial, transportation, and residential purposes amounts, respectively, to 18,536 ha, 1,481 ha, and 7,897 ha, or to 6.2 percent, 0.5 percent, and 2.7 percent of the basin area. The level of industrialization and urbanization in the area, whilst increasing, remains low compared with that of the Lake Taihu basin. Ineffective traffic management and a poor transportation infrastructure has become a bottleneck to the development of the economy of the area, especially to the development of tourism. Transportation in the area should be greatly improved in order to promote development of the economy and tourism in the area that is proportionate to Dali's status as a national historic city and tourist attraction. This situation has attracted the attention of the governments of Yunnan Province and Dali Prefecture, who are working toward the completion of the Dali civil airport, the Guangda railway, the Chuda highway, the Dali secondary highway, and the highway round the Lake Erhai.

In recent decades, land use in the area has intensified as a result of an increasing population. The population density of the area has increased from 78 persons/km^2 in 1952 to 241 persons/km^2 in 1997. Such an increase in population density effectively reduces the area of land available per capita from 1.28 ha/person in 1952 to 0.42 ha/person in 1997. The per capita area of farmland has also decreased, from 0.12 ha to 0.06 ha in the same period. The total area of farmlands remains at about 40,020 ha, but cropped lands have increased from 51,032 ha to 66,020 ha, or a net increase of 14,988 ha.

The occupation of agricultural lands by non-agricultural industries has increased, gradually decreasing the area of potential agricultural land available for future expansion. As the scale of economic development and urban land usage has grown, and people's living standards have increased, greater areas of former productive farmland has been occupied by non-agricultural land uses, extending the agricultural frontier into marginal lands so as to maintain a fairly constant total area of farmed land. In effect, this has replaced high-yield lands with less productive, newly opened lands that exacerbates problems of fertilization and irrigation, and reduces the total output from the available farmland.

In addition to the expansion of urban land uses and its effects on agricultural lands, satellite data suggest a 2 percent decrease vegetation coverage between 1974 and 1989, indicating that approximately 96.2 km^2 of vegetation was destroyed. Those areas most seriously affected by loss of vegetation coverage are Shanying, Niujie, Yousuo, and Shuanglang in Eryuan County, and Fengyi and Handong in Dali County. In contrast, vegetation on the upper slopes of the Cangshan Mountains and around the western shore of Lake Erhai has recovered as a result of reforestation practices, yet of the 80 percent of townships in the area that have suffered vegetation loss, only 20 percent of them have completed restoration works. A significant contributor to vegetation loss has been the over-harvesting of mature trees for lumber. Nearly half of the remaining, existing forests are comprised of young-growth forest, open forest, and brush, while old-growth forests account for only a small proportion of the forested lands. Broad-leaved evergreen forests, originally wide spread in the valleys, are now found scattered only along some valley margins, reducing the quality of the forest lands.

Land Use Planning

Use of the land in such a way as to conform to its natural conditions and constraints, and to promote rational, sustainable and efficient production, requires planning that will optimize the land's potential. Such planning takes cognizance of the current land uses in the area and takes into consideration the social-economic development goals as stipulated in the ninth five-year plan. In addition, such planning develops a long-term vision through the year 2010.

Based on these considerations, the current ratio of farmland to grassland to forested land to other lands is 6:2:1:1. After building water conservancy projects and improving irrigation, the planned ratio is anticipated to be 6:1.5:1.25:1.25, or a shift from grass lands to more forested and other lands. Such a shift is expected to occur as a result of the implementation of the *General Plan of Cangshan-Erhai National Natural Reserve in Dali* within the 797 km^2 Cangshan-Erhai natural reserve.

To maintain the steady growth in grain production, the total area of farmland is expected to remain at 43,360 ha, even though, at the same time, low-yielding farmlands are to be rehabilitated using scientific farming practices to increase the agricultural output per unit area of land. The proportion of economic forests, market gardens, pastures, and vegetable gardens as a percentage of agricultural land usage is to be increased, in part through a reduction in the area of paddy fields used by towns. Vigorous popularization of sustainable agricultural-ecological projects, in order to develop good quality, high-yield agriculture and to establish green food production as a basis for the protection of the environment, will proceed through the program for the "rich and culturally progressive new countryside."

Grasslands, which currently occupy 20.3 percent of the total land area, may be cultivated as the result of improvements in irrigation conditions, although reforestation and revegetation will be emphasized. In places not suited to planting trees, such as in areas with red and brown soils, grasses are to be planted. An increase in the area of forested lands, therefore, is anticipated, especially as a result of the development of economic forests. Measures that include closing hillsides in order to facilitate reforestation are planned, along with large-scale tree planting: the degraded hillsides on the eastern shore of Lake Erhai are expected to be re-vegetated within five years, and the whole drainage area in 10 years. At the same time, production of pears, chestnuts, and fevergum is intended to be built up in Dali County, while production of plums and timber forests is intended to be built up in Eryuan County.

Non-agricultural uses of land are also expected to increase due to the continued growth of urban areas and the related development of industry, transportation, and living quarters. Nevertheless, planned development will occupy as little productive farmland as possible.

1.3 Pollution Source Analysis

Industrial Pollution Sources

According to the *Statistical Yearbook of Dali Prefecture (1995)*, there are, in the whole prefecture, more than 3,000 industrial enterprises. These enterprises are categorized into seven economic types; i.e., state-owned, collective-owned, share-holder owned, foreign-owned, privately-owned, wholly-owned by self-employed individuals, and owned by businesses based in Hongkong and Macao. Among these, 385, or 1.2 percent, are of at least county level significance.

Based on the 1995 environmental statistics, 81 enterprises in the Dali Prefecture were listed as major pollutant sources. Most of these were located in Dali City, Heqing, Yunlong, Xiangyun, Midu, and Jianchuan. Due to few industries being located in Eryuan County, no industrial pollution and industrial wastewater sources were reported from that portion of the basin.

Industrial pollution sources within Dali City are quantified in Table 3. Of the 557 enterprises located in the city, 65 discharged about 58,900 tons/day of wastewater, containing 7,682 tons/year of COD (Chemical Oxygen Demand, based on an average discharge rate of 92.3 tons/day and a concentration of 1,567 mg/l) and 4,693 tons/year of SS (Suspended Solids, based on an average discharge rate of 19.6 tons/day and a concentration of 267 mg/l). Within the study area, the Dali Pulp and Paper Mill, Erbin Pulp and Paper Mill, and Yunnan Chemical Fiber Plant discharged directly to the Xi'er River. Based on monitoring data obtained by the Dali Environmental Protection Bureau, wastewater from these three enterprises accounted for 71.6 percent of the total volume of wastewater discharged in the region, and 89.3 percent of the total mass of pollutants discharged.

The main raw materials used for pulp production at the Dali Pulp and Paper Mill are Yunnan pine, eucalyptus, and recycled cardboard. The plant produces 30,000 tons/year of pulp, consumes 19,000 m^3/d of water, and discharges 17,000 m^3/d of wastewater. Each ton of pulp produced results in 250 m^3 of wastewater, discharged directly to the Xi'er River without treatment. COD, BOD (Biological Oxygen Demand) and SS loads carried in this effluent stream amount to 41, 10, and 8 tons/d, respectively.

The Yunnan Chemical Fiber Plant in Dali City was built in 1965, and produces 5,000 tons/year of viscose fiber. It consumes water from Xi'er River at a rate of

12,000 tons/d, or 600 tons of water for each ton of product produced. The plant generates wastewater at a rate of 8,000 tons/d. Its wastewater contains high concentrations of COD and BOD, which receive no treatment prior to being discharged directly into Xi'er River. Table 4 shows the mass of pollutants discharged by the plant into the river.

Table 3. Discharge of Wastewater in Dali City

Year	Total Volume (10^4 tons/year)	Industrial Wastewater Volume (10^4 tons/year)	Pollutants Discharged					
			COD (ton/year)	As (kg/year)	Pb (kg/year)	R-OH (kg/year)	CN (kg/year)	Petroleum (ton/year)
1991	1,618	1,114	11,187	-	3	3,753	-	5.0
1992	1,464	1,098	12,372	1	2.2	3,727	0.13	4.5
1993	1,785	1,234	14,786	-	2	3,797	-	4.1
1994	1,842	1,334	15,562	-	1.5	4,194	0.09	2.5
1995	2,253	1,600	16,437	-	1	4,165	-	3.6

Erbin Paper Mill was built in 1958. The mill is located near Xi'er River. It uses rice straw, Chinese pine and used gunnysacks as raw materials; consuming some 3,900 tons/year of rice straw and 1,100 tons/year of gunnysacks. The plant consumes 1,200 m^3 of water per ton of product, and discharges wastewater at a rate of 8,800 tons/d. Table 5 shows the mass of pollutants generated by this mill which are discharged directly into Xi'er River without treatment. There is a significant amount of SS in the wastewater since the straw contains silicon dioxide.

The pollution-related impacts of these three plants contribute to serious water pollution problems in the Xi'er and Heihui rivers, and, through these systems, create secondary impacts in the Lancangjiang River system. Among these secondary impacts is the corrosion of downstream power generation equipment as a consequence of high alkali and SS concentrations (pH = 10.5, SS = 200 mg/l).

Table 4. Pollutants Discharged from the Yunnan Chemical Fiber Plant

Pollutants	Mass of pollutant discharged (tons/d)	(tons/year)	Mass of pollutant discharged per ton of product (kg/ton product)
COD	33	11,000	2,500
BOD	10	3,500	800
SS	3	1,000	220
Zinc	0.6-5	4.8-40	0.3-3.1
Phenol	0.5-1.7	4-14	0.3-1.1
Chlorine	0.5-2	4-16	0.3-1.3
Sulfur	1-10	8-80	0.6-6.2

Table 5. Pollutants Discharge from the Erbin Paper Mill

Pollutants	mg/l	tons/d	kg/ton paper
COD	1,000	8.8	800
BOD	400	3.5	320
SS	600	5.3	480

In addition to the pulp and paper mills and fiber production plant, township level industrial enterprises play an important role in the economy of the Dali Prefecture. These types of enterprises grew at an annual rate of 5 percent per year during both 1995 and 1996. In 1995, there were 91,945 township enterprises, a 17 percent increase over the number in existence during the previous year. Township enterprises have brought a remarkable economic benefit to the Erhai region, accounting for almost 60 percent of the total income in the countryside, and contributing nearly 50 percent of the total output value of the area's industry. Township enterprises are of various types, including agricultural, construction, transportation, commercial, catering, and service businesses. Among industrial enterprises are those engaged in smelting, quarrying, cement and brick making, Chinese herbal medicine production, tanning, and agricultural product processing. Dali City has the most township enterprises, totaling 17,726, with a total annual output valued at 1,400 million Yuan, or 44.4 percent of the prefecture's total annual economic output. Notwithstanding, township enterprises also generate a significant volume of wastewater, amounting to 115,600 tons/year, which is randomly discharged without treatment to area rivers and, eventually, to Lake Erhai.

Urban Pollution Sources

Sewage

The amount of sewage discharged in the drainage area of Lake Erhai is estimated, on the basis of population data, to be about 16 million tons/year, as shown in Table 6 for the period between 1990 and 1994. This volume of effluent is estimated to contain 26,000 tons/year of COD. Most of this sewage is discharged to the Xi'er River through sewerage systems. Some of the sewage from the old city of Dali, Xiaguan and the Town of Fengyi is discharged into the Lake Erhai through ditches and the Luojiang River. These latter discharges have a definite impact on the water quality of Lake Erhai.

Solid Waste

Based on an investigation of public facilities carried out by the City Planning Bureau and General Survey Office of Dali City, the rate at which solid waste is disposed of ranges from about 0.85 kg/capita/day in Fengyi and Xizhou, to about 0.98 kg/capita/day in the old city of Dali, to about 0.99 kg/capita/day in Dali City, to about 1.00 kg/capita/day in Xiaguan. This rate is expected to increase by 10 percent per year after the year 2000. About 97,282 tons of solid waste were produced in Dali City during 1994, 413 tons of which were hazardous wastes, 65,068 tons garbage, and 31,801 tons other solid wastes (such as coal ash). A further 5,160 tons/year of solid waste was disposed of in Eryuan County. These rates are expected to increase over time as shown in Table 7.

Table 6. Sewage Discharge in the Lake Erhai Study Area

Index	Source	1990	1991	1992	1993	1994
Sewage Discharge Coefficient (m^3/c.d)	Non-Agricultural Population	0.105	0.105	0.112	0.119	0.119
	Agricultural Population	0.028	0.028	0.035	0.035	0.035
	Tourists	0.077	0.084	0.091	0.098	0.105
COD Discharge Coefficient (kg/c.d)	Non-Agricultural Population	0.1	0.1	0.1	0.1	0.1
	Agricultural Population	0.09	0.09	0.09	0.09	0.09
	Tourists	0.1	0.1	0.1	0.1	0.1
Sewage Volume Discharged (10^4tons/year)	Non-Agricultural Population	558.01	585.22	657.35	725.36	756.2
	Agricultural Population	602.16	605.74	768.93	762.41	765.35
	Tourists	15.23	22.55	27.01	27.25	
	Total	1,175.41	1,231.51	1,453.28	1,515.03	
COD Discharged (10^4tons/year)	Total	2,486.05	2,531.22	2,593.84	2,597.85	2,603.51

Table 7. Solid Waste Disposal (tons/year) in Dali City

District	1995	1997	2000	2005	2010
Xiaguan	47,500	57,500	76,500	112,300	165,000
Old City	4,900	5,900	7,900	11,600	17,100
Fengyi	4,300	5,200	6,900	10,200	15,000
Xizhou	1,900	2,500	3,100	4,500	6,700
Total	58,600	70,900	94,400	138,600	203,800

Solid wastes in the study area are either piled in dumps or buried in landfills. Dumps are generally situated near surface water bodies in close proximity to the towns from which the wastes are generated. Poor management of such dumps causes a number of environmental problems in such settings. Few landfill operations exist. Of those that do exist, few employ seepage prevention measures. Thus far, no industrial solid waste reuse programs exist, and illegal dumping is rife. As a result, some of the solid wastes are washed directly into Lake Erhai, highlighting the need to strengthen the management of solid wastes and to build standardized sanitary solid waste disposal sites.

Nonpoint Sources

The main nonpoint pollution sources include runoff from farmlands and animal husbandry operations including aquaculture operations, soil loss resulting from the destruction of vegetation, and contamination due to sewage and garbage disposal from the towns and tourist resorts. It is estimated that between 5,000 and 7,000 tons/year of nitrogen, and between 5,000 and 5,500 tons/year of phosphorus, are generated from these sources. Of the 1,000 tons/year of T-N and 100 tons/year of T-P that enter Lake Erhai, nonpoint sources of pollution are estimated to produce more than 97 percent and 92 percent of the nitrogen and phosphorus loads, while point sources contributed only 3 percent and 5 percent of the total loadings, respectively. On this basis, nonpoint source pollutants are considered to be the main cause of water quality degradation in Lake Erhai.

Nonpoint sources of pollution within the Lake Erhai basin are concentrated in four regions:

- the northern region, where the pollutants are carried into the lake by runoff from the two inflowing rivers and direct surface runoff to the lake;
- the western region, characterized by low-lying, flat lands, where the pollutants are carried into the lake by the 18 streams draining the Cangshan Mountains, by farmland runoff, by sewage discharges from villages, and by direct surface runoff to the lake;
- the southeastern region, where pollutants are carried into the lake by the Boluo River and other rivers, and direct surface runoff; and
- the southern region, where the pollutants are carried into the lake by discharges from animal husbandry operations, by sewage discharges from villages, and by direct surface runoff to the lake.

The distribution of N and P sources in the area is shown in Figure 5.

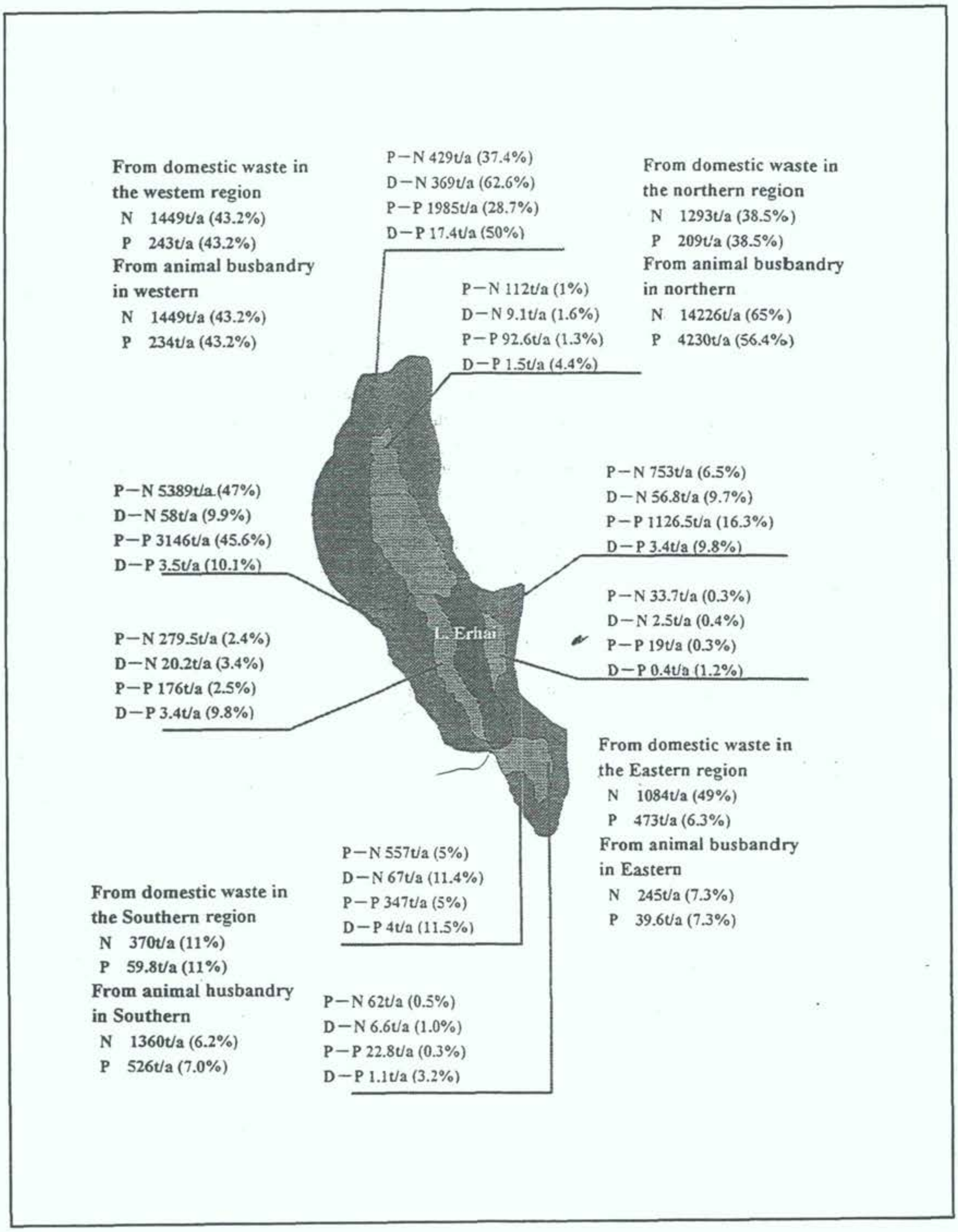

Figure 5. Phosphorus and nitrogen loads and sources in the Lake Erhai basin.

The Northern Region

Most of the area in this region consists of low-lying, flat lands in agricultural production. Farmland in this region is used for growing various crops. Large volumes of agricultural wastewater flow into Lake Erhai through the Mizu River, the Luoshi River, and other streams. The water flowing into Lake Erhai from these rivers supplies about 50 percent of the water entering Lake Erhai. Nutrients such as N and P, discharged through these rivers, account for about 50 percent of the total nutrient load to the lake, and comprise the largest single nutrient source to the lake. In addition to the agricultural sources, N and P also come from soil erosion. Felling of trees and reclamation of waste slopes both cause soil erosion and which also accelerates the rate of sedimentation within the lake. It is estimated that about 30 percent of this region suffers from soil erosion, amounting to an annual soil loss of millions of tons. The fan-shape delta of the Mizu River at its debouchement into Lake Erhai now extends about 4 km into the lake bed.

The Western Region

The western region is also characterized low-lying, flat lands in agricultural use. These farmlands are used for intensive cropping and other rural economic development programs. Nonpoint pollution sources include farmland, animal husbandry operations, aquaculture operations (fishponds above the shoreline of Lake Erhai), and village garbage. Pollutants entering Lake Erhai from these sources include large quantities of N, P, toxic organic substances, pesticides, and herbicides. In addition, soil eroded by the 18 montane brooks draining the Cangshan Mountains as a result of the destruction of vegetation on the steep slopes of the mountain range is also an important factor affecting the water quality of Lake Erhai. Surface runoff from the farmland and the mountain range carries large quantities of silt into Lake Erhai, which settles on the lake bottom, accelerating its aging and diminishing its volume.

The Southeastern Region

Pollutant sources in this region include solid waste from Dali City, surface runoff from the urban districts, and wastewater and garbage from villages. The Xi'er River, the only outflow of the lake, is polluted by industrial wastewater and sewage from this region. Because of the clockwise current in the southern portion of Lake Erhai, some of the polluted water of the Xi'er River flows back into Lake Erhai. The main river flowing into Lake Erhai in this region is the Boluo River, which also brings large quantities of nutrients, salts, and silt into the lake. Deposition of this silt has already raised part of the riverbed.

The Southern Region

Caged culture of commercially important fishes within the lake is one of the most important pollution sources in this region. Cages of different sizes are distributed throughout the lake. Over-feeding of the caged fishes is the main cause for the increased nutrient concentrations observed in these portions of the lake, and a major contributor to the serious ecological degradation and environmental pollution problems experienced in Lake Erhai. It is estimated that feeding exceeds food demand of the caged fishes by as much as 60 percent. Grass carp are the principle aquacultured species. As a consequence, these fishes have also contributed to an observed change in the aquatic plant communities. Caged culture of fishes was banned by the Government of Dali Prefecture in March 1997 because of its ecosystem and pollution-related impacts.

Wastewater, tail gases, and oil leakage from boats and ships on the lake are another type of non-point pollution experienced in this region. Pollution from tourism-related activities (e.g., from tourist attractions, hotels and holiday villages, etc.) further contributes to the pollution of the lake. Continued growth of tourism and lake shipping, without regard to solid waste and wastewater management, will lead to further degradation of water quality in Lake Erhai.

Causes of Nonpoint Source Pollution

Based upon the foregoing analysis, the causes of nonpoint source pollution affecting Lake Erhai are similar to those affecting other lakes in China. These causes include the following factors:

- Soil erosion caused by destruction of forest vegetation.
- Soil erosion caused by overgrazing of pastures.
- Soil erosion caused by development activities on steeply sloping lands.

- Fertilizer, pesticide and herbicide runoff as a result of unscientific application methods.
- Sewage and industrial wastewater discharges from towns and villages.
- Domestic garbage disposal by watershed inhabitants.
- In-situ pollution from caged fish culture and over-feeding of cultured fishes.
- Waste oil and solid matter discharges from tourist activities and lake transportation.
- Direct precipitation.
- Shoreline soil loss, especially during storm events.
- Soil erosion from areas subject to landslide activity.

1.4 Social and Economic Development Planning

Based upon the ninth five-year plan and long term goals through the year 2010, the Government of Dali Prefecture formulated the following economic development goals for the region:

- The GDP shall reach 14.697 billion Yuan (1995 fixed price) by the year 2000, with an annual rate of increase of 17 percent over the five years, and 32.376 billion Yuan by the year of 2010, with an annual rate of increase of 8.2 percent over the ten years.
- The total value of industrial and agricultural outputs shall reach 9.07 billion Yuan (1990 fixed price) by the year of 2000, with an annual rate of increase of 8.9 percent over the five years; the total value of industrial outputs shall be 6 billion Yuan, with an annual rate of increase of 12 percent, and the total value of agricultural outputs shall be 3.07 billion Yuan, with an annual rate of increase of 4 percent. By the year 2010, the total value of industrial and agricultural outputs shall reach 19.688 billion Yuan, with an annual rate of increase of 8.1 percent over the ten years; the total value of industrial outputs shall be 15.562 billion Yuan, with an annual rate of increase of 10 percent, and the total value of agricultural outputs shall be 4.126 billion Yuan, with an annual rate of increase of 3 percent.
- The total revenue of the Prefecture shall be increased by 10 percent annually,

with the rate of increase of Prefectural expenditure being slightly lower than that of the rate of increase in revenue.

According to the ninth five-year plan and long term goals through the year 2010, industry is to be restructured to promote the vigorous development of tertiary industries, while steadily developing secondary industries. This approach is designed to structure industries within the Prefecture such that they will develop toward higher performance, with more value-added and high-technology content. By the year 2000, the ratio between the primary industries, secondary industries, and tertiary industries is expected to be 24:40:36. The value of industrial output then will account for more than 60 percent of the total combined output value of industry and agriculture.

Planned Industrial Development

Tertiary Industries

Of the tertiary industries, tourism should be developed vigorously to become the mainstay of the area's economy. Tourism, if well-managed, has a low pollution impact but generates significant economic benefits. Besides tourism development, industrial development in the information, finance, real estate, commercial, insurance, and storage sectors should be developed to improve the function of the area and to consolidate the central position of Dali City in western Yunnan Province. These should be combined with tourism to further promote the development of secondary and tertiary industries.

The affirmation of Yunnan Province as an important tourist destination is planned to be achieved during the ninth five-year plan. An overall plan to promote and support sustainable tourism in the Lake Erhai basin should be prepared to document the necessary steps to achieve this goal. Attention should be paid to consequences of tourism as well as to the protection and maintenance of key attractions. The tourism development plan should also take note of different attractions in different counties within the region, in order to ensure, insofar as possible, complementarity between destinations. Such coordination is essential to an integrated tourism development program that covers catering, hotels and accommodation, touring, shopping, and recreation. The number of tourists received is expected to reach 4.93 million by the year of 2000, with an annual rate of increase of 12 percent. Of this number, 84 thousand will be tourists from abroad. Foreign tourism is expected to increase at an average annual rate of 15.6 percent. The total income from tourism should reach one billion Yuan.

Major actions needed to achieve the successful development of a sustainable tourism industry include the following:

- Increase investment. The construction of tourist attractions and accommodations at Lake Erhai and at Jizushan, at the Cibi Lake hot springs convalescent area, and of other hotels in the vicinity of Dali City is needed to create a tourist network and receiving system.
- Develop special attractions such as the Three Tower Temple and Dali Old Town. The transport system and hygienic conditions need to be improved so as to create a more conducive tourist environment.
- Upgrade the cultural content of the tourism experience. Enriching the tourism experience by combining a visit to the lake area with an exposure to the culture of the ethnic national minorities can provide an additional incentive for tourists to select Lake Erhai as their holiday destination. Special tourism opportunities involving folk customs and recreation, holiday spending, sight-seeing, religious worship, and "scientific" inspection should be developed.
- Create an ethnic handicrafts market. Production of ethnic handicrafts like bandanas, and wood and stone carvings, could be developed around tourism. Catering, transportation, and commercial support facilities could also be developed to support and encourage tourism, and to maximize the overall economic advantages of tourism.
- Link tourist destinations. Creation of circles linking Kunming to the east, Dehong to the west, Banna to the south, and the Lijiang to the north, in combination with, and in support of, the tourist layout of "four lines and five regions" in Yunnan Province could minimize transportation difficulties in the region. The creation of a circular airline route between and among regional destinations would also support regional tourism.

Secondary Industries

Of the secondary industries, cigarette-making and food processing should be developed as key industries within the Prefecture. The value of outputs from these industries should reach 2.5 billion Yuan. As for industries such as pulp and paper making, chemical fiber production, tanning, textiles, and cement making, their technical reform should be speeded up under the guidance of regional "consolidation, upgrading, and development" plans, so that their relative impacts will be minimized and economic benefit increased.

During the period of the ninth five-year plan, the tobacco industry shall become one of the leading industries of the area. Based on locally-grown, high-quality flue-cured tobacco, a system of cigarette rolling, linking, wrapping, laying, and marketing will be developed. By the year 2000, the annual cigarette output will reach 600,000 boxes, having a total output value of 1.5 billion Yuan. This level of output will generate over one billion Yuan in taxes and profit.

In addition, the development of food processing industries in the area should optimize utilization and development of the rich natural resource base of the Prefecture. For example, edible mushroom production could be encouraged while maintaining dairy production. The development of the primary biological-resources, and their integration with secondary food processing industries, could increase output value of this industry to 1.5 billion Yuan by the year 2000.

Primary Industries

Of the primary industries, the structure of the agricultural industry should be readjusted so as to promote agricultural-ecological projects, and to establish a basis for green food production. Crops of high yield, good quality, and high germination efficiency, as well as alternative or diversified farming activities, should be developed further. Attention should also be paid to the development of related township enterprises so that grain and tobacco production, forestry production, and animal husbandry activities will be coordinated with the development of the appropriate secondary industries that will process and market the agriculture-based products. Inclusion of fisheries activities within the sphere of a restructured agricultural industry, and development of a secondary industry based upon fish processing, is foreseen. Such integration between production and processing will provide a solid foundation for regional development.

The Dali Prefecture also has abundant reserves of building materials, and is especially famous for quality marbles. In addition, the Prefecture has an abundant capacity for cement production. During the period of the ninth five-year plan, the Dianxi Cement Factory will be completed and placed in operation. Its capacity will eventually reach 1.83 million tons/year. Development of the building materials industry is based upon an existing foundation that employs modern and efficient technologies. The total value of outputs from the building materials industry is expected to reach one billion Yuan by the year 2000.

Finally, during the period of the ninth five-year plan, light industry will continue to be developed, with the production of paper and plastics, printing, and wrapping and decorating materials being key industrial sectors. Production capacity should be raised to increase the economic benefits currently derived from these industries. The value of outputs from light industry will reach 0.5 billion Yuan, with an annual rate of increase of 9.3 percent.

Planned Social Development

The population of the Dali Prefecture is expected to reach 3.45 million persons by the year 2000, slowly increasing to 3.80 million persons by the year 2010, at a natural growth rate of less than 0.1 percent. The proportion of the population participating in family planning should reach 95 percent, with the number of multiple-child families decreasing to below 0.4 percent of the population. The number of multiple-child families without a family plan should decrease to below 0.2 percent of the population.

During the period of the ninth five-year plan, educational reform will continue, extending reforms to optimize educational administrative structures, to improve the conditions of schools, and to strengthen the number and quality of teachers. Primary education should be made universal, and vocational education and adult education should be vigorously developed; higher education would also be developed according to the plan. The objective of the plan is to comprehensively raise the quality of education so as to promote economic and social progress within the entire region.

Primary Education

The dissemination of six-year and nine-year primary compulsory education should be undertaken as the most important element of the task of educational reform. The annual plan of the Prefecture should be developed at the township level, with the township level plans being implemented within each school.

Vocational and Technical Education

The schools of agriculture, industry, hygiene, finance, and urban construction, and schools for technical education, should form a complete set to ensure the availability of the skilled persons required to carry out the development plan in the region. The ratio between general senior high school graduates and vocational school graduates at the same level shall surpass 1:1.2 by the year 2000.

Adult Education

To raise the overall quality of human resources in the Prefecture, employers in all professional areas should establish in-service and orientation training so that employees from the countryside and surrounding towns will receive on-going training in relevant fields. The rate of illiteracy among young and middle-aged should drop to below 5 percent of the population. Radio and television broadcasting schools should be developed, as about 80 percent of townships shall have television receiving stations and a network for television-based education by the year 2000.

To carry out the strategy of "making the prefecture prosperous through science and technology", stress must be laid on the opening up of markets for science and technology, and on giving support to science programs capable of yielding short-term results. Support should also be given to key industries and the development of township enterprises that make use of local resources. Such support will favor the rapid translation of scientific and technological activities into production processes, and underpin the readjustment of the industrial base of the region. By the year 2000, the technical and economic index of the mainstay industries of the Prefecture should be increased to an advanced level, and the reform of traditional industries basically completed. The proportion of the contribution of applied science and technology in industrial production will be raised from 35 percent at present to 45 percent. The use of technology in the administration of key industries will also reflect advanced technological condition of the province, with the rate of new product development reaching 60 percent of all products produced.

In developing this technology-based culture, the principles of "serving the people", "the dictatorship of the proletariat", and "letting a hundred flowers blossom and a hundred schools of thought contend" will strengthen the development and administration of markets and contribute to the further development of the region's culture. The period of the ninth five-year plan will see the realization of the plan for a "thousand-li [600-km] cultural corridor along the border area" and the development of a cultural network at the levels of the prefecture, the county and the township. Cultural and art centers, and libraries to state standard, shall be built in the county seats.

Finally, health care reform will be shifted to the countryside with the implementation of the health care elements of the plan. Over 30 percent of the villages should establish various forms of medical insurance systems, with medical cooperatives as the principal form, and 100 percent of the villages will have clinics. Snail fever, leprosy, and illness caused by lack of iodine shall be all but eliminated. Over 80 percent of the rural population shall benefit from improvements in potable water sources and 40 percent of the rural population shall have piped water supplies. Public toilets shall be built in over 40 percent of all the villages.

1.5 Major Environmental Problems

Comprehensive and sustainable development must take into consideration the relationship between social-economic progress and environmental protection. The key issue becomes one of managing the environment during a period of socio-economic transition. While social-economic development places greater demands on the environment of the region, and will ultimately ensure the availability of funds for environmental protection purposes, the current, poor economic situation limits the availability of funds needed for environmental protection and remediation in the immediate term. Though there has been significant progress in economic development during the past forty years, and especially during the last decade, the overall level of the area's economy is still fairly low and comparatively weak. As a consequence, the environment of the Lake Erhai drainage area has been, and continues to be, seriously damaged by rapid population growth in the basin and unsustainable economic growth. This disconnect between economic development and environmental protection has become increasingly obvious, and has become a serious barrier to the sustainable development of the economy. The principal manifestation of this disconnect is an irrational industrial and distribution structure, based upon out-dated production techniques, that contribute to the irrational development and use of resources within the Lake Erhai basin.

Unsustainable Exploitation and Use of Resources

The irrational use of resources is manifested by the inappropriate use of water resources and the degradation of forest resources.

Improper Development of Water Resources

The total water resources of the Lake Erhai drainage area are 1.09 billion m^3, which volume can be considered to be quite abundant considering the size of the population and level of social-economic development. However, the contradiction between the volume of the resource and the volume of the available water supply seems to have intensified during the past decade. This situation has developed as a consequence of the improper, sectoral utilization of the water resources of the basin. For example, the construction of the hydraulic power station on the Xi'er River at the outlet of the lake resulted in the hydropower generation sector using Lake Erhai solely as a balancing reservoir for the water needed for power generation. As a result, the water level of the lake was lowered, water quality deteriorated, and the structure and number of communities of aquatic organisms in the lake changed. Investigations, commissioned in response to public concerns over the deterioration observed in the lake, showed that the surface area of Lake Erhai decreased from 257 km^2 to 250 km^2, and the volume decreased from 3.0 billion m^3 to 2.9 billion m^3. Historically, the lake area and lake volume had remained relatively constant. However, after 1977, the bed of the Xi'er River was successively deepened on three occasions to increase the ability of the hydropower station to meet demands for the generation of electricity. The bottom of the sluice gate was lowered from its original designed elevation of 1,972.5 m to 1,969.5 m. During the early 1980s, a drastic decline in the water level of the lake alarmed the government to such a degree that hydropower generation was halted for six months in 1982. The lowest water level reached by the lake was recorded in 1983, when the surface area of the lake reduced by 36.4 percent, its volume by 23.8 percent, and 1,000 ha of the lake bottom was exposed. Water quality monitoring data gathered subsequently showed that the lake had declined from an oligotrophic status in 1985 to a mesotrophic status in 1988.

Destruction of Forest Resources

Analysis of satellite photographs taken during 1974 and during 1989 shows that the rate of decline in forest coverage rate averaged 2.0 percent per year for the basin as a whole. Soil erosion became more severe during the same period. Forest coverage in the area between Lake Erhai and the Cangshan Mountains was only 11.4 percent of land cover. Previously forested lands on the eastern shore of the lake have been turned into barren hillsides during this period. The timber reserves within the forest conservation areas were being depleted by nearly 10,000 m^3 per year.

Over a longer period, the rate of decline in forest coverage has been even more striking. In Eryuan County, where forested lands amounted to 37 percent of the land cover in early 1950s, forested lands had been reduced to 33 percent of the land cover by the end of 1950s, and further reduced to 23 percent of land cover by the end of 1970s. Forested lands comprised only 20 percent of land cover by 1988. The average annual rate of loss of forested lands over the past forty years was about 0.25 percent per year. As a result of recent reforestation initiatives, however, forested lands have been restored to 27.2 percent of land cover.

Investigations conducted between 1963 and 1988 indicated that forest cover was reduced from 47,000 ha to 16,250 ha during the 25-year period. During the same period, the timber stocks were reduced from 7.948 million m^3 to 0.414 million m^3. These declines in forest cover and associated timber stocks have contributed to an economic loss within the forestry industry estimated at 87.865 million Yuan. As the remaining forests have little value in terms of soil conservation potential, about 30 percent of the forested areas suffer from soil erosion, sending millions of tons of sediment in Lake Erhai every year. Such soil erosion accelerates the process of eutrophication and poses a significant threat to Lake Erhai.

To sum up, unplanned and over-exploitation of resources has created a series of environmental problems, not only damaging the basis for sustainable development of the area, but also affecting the development of tourism around Lake Erhai and the Cangshan Mountain, including the Jizu Mountain scenic sites. At some localities, even the supply of drinking water has become limited as a result.

Uncoordinated Industrial Production and Distribution Structures

The industrial structure of the region has undergone significant changes during last 40 years. The dominance of agriculture with little industry has been changed. A new pattern of industrialization, characterized by manufacturing and commerce, has been formulated. Notwithstanding, the Lake Erhai area is still considered to be in the initial stages of industrialization, and the structure of the industrial sector remains far from ideal. The abundant resources of the basin have not yet been fully utilized to best advantage.

Although the proportionate value of industrial outputs from secondary industries within the GNP has risen remarkably, the level of processing and its associated technologies is still fairly low. The ability of industries to employ new advances in science and technology is limited. Industrial development in the basin is not yet mature and remains at the stage of the primary processing of resources. As for the structure of the secondary industries, industries with a fairly low technical content, like pulp and paper making, chemical fiber production, tanning, textiles and building materials, comprise a large proportion of the GNP. As a result, in some localities, water pollution from these industries has become very serious.

Tertiary industry also has undergone rapid development. Nevertheless, the capacity of the service sector is still limited. To further develop tertiary industries within the basin, tourism is seen as having the greatest potential. For this reason, attention should be given to the protection of the natural scenery and places of historic interest, which would be degraded as a consequence of traditional industrialization processes. On the other hand, without adequate environmental controls and appropriate infrastructure, tourism, itself, could bring about environmental problems. One potential threat lies in the over-exploitation of tourist resources, exceeding the carrying capacity of the environment. Such over-exploitation could damage not only the natural scenery of the Cangshan Mountains and Lake Erhai, but also damage the underlying basis of sustainable development in the area.

In addition to the foregoing concerns, the inappropriate siting of industries also constrains the sustainable development of the area. Because of historical factors, most of industries in the Dali Prefecture are concentrated in Dali City. Major pollution producers, like the Yunnan Artificial Fiber Factory, Dali Paper Mill, Erbin Paper Mill, and Tianxi Textile Mill, are all located within the drainage area of Lake Erhai. The rapid and unplanned development of township enterprises further intensifies the problems associated with an inappropriate distribution of production forces. Some of these enterprises are not only poorly sited but also produce products that contribute to the pollution of Lake Erhai. Investigations have revealed that about 20 percent of the township enterprises are actively causing pollution of the environment, some seriously. This is compounded by the fact that, at present, only 46.6 percent of the industrial wastewater in Dali City is treated. Some industrial wastewater, with high concentrations of pollutants, is not treated at all before it is discharged into Lake Erhai and/or the Xi'er River. Some 2.83 million m^3/year of industrial wastewater is discharged directly or indirectly into Lake Erhai by twenty enterprises located around the lake. This waste stream delivers 8.2 tons of nitrogen;

3.2 tons of phosphorus; 3,631 tons of COD; 684 tons of BOD; 587 tons of solids; and, 3.8 tons of volatile phenols to the lake each year. Monitoring data showed that, while the waters of the lake are fairly clean at present, the rate of eutrophication is increasing. As previously noted, the trophic status of the lake has changed from oligo-mesotrophic in mid-1980s to mesotrophic by the end of that decade, with further degradation to an eutrophic state expected. Likewise, the water quality of the Xi'er River does not meet the standard of a Grade V water.[2]

Though there are various types of industries in the area, most of them are traditional processing industries developed during the 1970s, lacking advanced techniques and new technologies. Based on an industry survey, of a total investment of 1.87 billion Yuan in industrial equipment, 16 percent was made during the 1960s or before, and 50 percent during the 1970s or before. Investments made during the 1980s account for only 26 percent of the total investments in industrial equipment. Most enterprises currently face the problem of aging equipment and inefficient production techniques. Township enterprises, developed during the 1980s, are more workshop-like, with both inefficient techniques and an high rate of energy consumption. For example, the average energy consumption per ten thousand Yuan of output value in the Prefecture is 4.0 tons of standard coal, but that of township industries is as high as 24.5 tons of coal. Given that most township enterprises lack wastewater treatment capabilities, these industries also cause serious pollution. The extensive environmental management measures likely to be required to mitigate such levels of contamination hardly fit into the economics of intense market competition in the area, and, hence, are not expected to reduce the current levels of environmental degradation.

Over-abstraction of Lake Erhai Water

The average water level of Lake Erhai during the 44-year period from 1952 through 1995 was 1,973.5 m, within a range from 1,970.5 m on July 13, 1983 to

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[2] See "Environmental Quality Criterion for Surface Water" set forth in the Appendix.

1,975.6 m on September 7, 1966. The average inflow volume to the lake during this period was 825 million m^3/year, while the average outflow volume was 863 million m^3/year. In recent years, domestic water demand has been 40 million m^3/year, with an average throughput of water by the hydropower stations of 700 million m^3/year. The net result of these flows has been a decline in lake level over the 44-year period. The lake surface elevation averaged 1,974.1 m between 1952 and 1968, 1,973.5 m between 1970 and 1979, and as low as 1 972.2 m in 1986. In 1982 and 1983, the lake level remained below 1,971.0 m for 15 consecutive months. The lowest recorded water level was observed in Lake Erhai during July 1983, when the surface area of the lake was reduced by 36.4 percent, and the water volume by 23.8 percent. These fluctuations and the overall decline in water level have created numerous ecological problems and accelerated the eutrophication process by shrinking of the area and volume of the lake. The lake was assessed as oligo-mesotrophic in 1985 but was determined to be mesotrophic by the mid-1990s. These changes in trophic state are shown in Table 8 and Figure 6, and are detailed below.

Table 8. The Trophic Status of Lake Erhai by Year

Year	1985	1986	1987	1990	1995
State	Oligo-mesotrophic	Oligo-mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic

The conflict between water demand and water supply is already intense. The water levels of the lake remain low and more water continues to be consumed than is replenished. The water balance of Lake Erhai has been summarized above and is shown in Tables 9 and 10. Over the years, 825 million m^3/year of water, on average, entered Lake Erhai, but 863 million m^3/year was taken out.

Table 9. Water Balance of Lake Erhai

Decade	Average Water Level		Inflow	Outflow	Balance
	Elevation (m)	Change	(10^8 m^3)	(10^8 m^3)	(10^8 m^3)
1950s	1974.09	-	7.71	7.70	+0.01
1960s	1973.65	-0.44	10.11	10.09	+0.02
1970s	1973.37	-0.72	7.65	7.99	-0.34
1980s	1972.17	-1.92	6.15	6.90	-0.75
1990s	1972.74	-1.35	8.54	9.33	-1.2

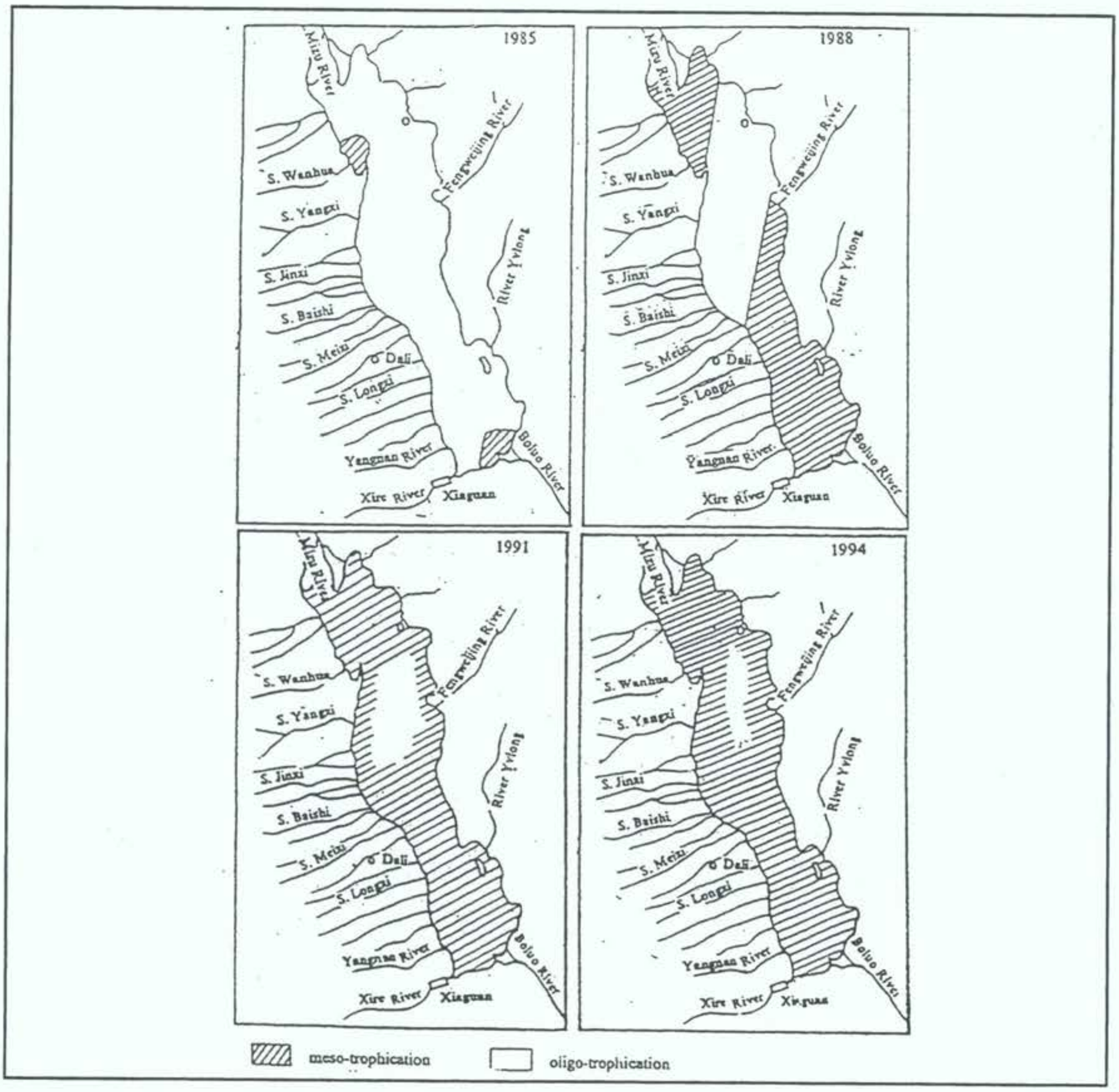

Figure 6. Eutrophication of Lake Erhai between 1985 and 1994.

Table 10. Assessment of Water Resources Development and Usage

Drainage Area	Water Resources (10^8 m^3)	Development Rate (percent)	Water Conservancy Rate (percent)	Water Consumed (percent)			
				Agriculture	Industry	Towns and Villages	Power generation
Lake Erhai	8.531	90.7	80.8	8.6	0.6	0.3	90.5
Lake Dianci	5.454	62.7	70.2	87.7	9.0	3.3	-

The actual water balance of Lake Erhai might be worse than this estimate based upon long term averages. Assuming the live volume of the lake to be about 800 million m^3, the active volume or flood prevention capacity would be about 400 million m^3. Further, even during high flow years (and annual water inflows have not approached the maximum recorded inflow of 1.88 billion m^3 in recent years), much of the inflow is not retained within the lake but is passed through Lake Erhai without contributing to the available capacity of the lake. Taking this situation, as well as guaranteed yields, into account, the annual runoff to the lake may be estimated at 522 million m^3, at the 75 percent assured yield level, and at 359 million m^3, at the 90 percent yield level. Thus, even assuming that about 500 million m^3 of water is available annually at an assured yield of 75 percent, adjustments will be needed among water consumers to ensure continued supplies. Even then, in about 25 percent of years when the water inflow is expected to be less than 500 million m^3/year, further emergency measures may be expected to be required.

Despite this assessment, water demand in the lake area increased during 1995 by 12.8 million m^3/year for domestic use, and by 5 to 8 million m^3/year for industrial use. The water diversion project, supplying from Lake Erhai to Binchuan County, withdrew a further 50 million m^3/year, which demand is expected to increase in the longer term to 150 million m^3/year. Further, there is a trend toward intercepting and diverting waters that previously contributed to Lake Erhai inflows in the upstream reaches of the river systems. The reconstruction of the Haixihai Reservoir and the newly built Meihe irrigation channel will reduce the inflow to Lake Erhai by 120 million m^3/year. Based upon this long-term view, the increased demand for water to sustain an increasing population and developing economy, and a reduction in inflow from the watershed will create a more serious water deficit and intensify the conflict between water uses and water users all the more.

The Eutrophication of Lake Erhai

The serious drought that occurred in the Lake Erhai basin during 1987 and 1988 reduced the lake level and increased the loads of N and P relative to the volume of the lake. Aquatic plants grew luxuriously and the biomass of higher vascular plants increased by 84,000 tons, compared with that measured during 1985. The algal abundance also increased by more than three-fold, averaging 1.5 million/l. Cyanophyta and Chlorophyta dominated and increased in abundance, leading to the assessment of the lake as mesotrophic during this period. Localized algal blooms appeared, especially in the southern portion of the lake, suggesting a further transition to a eutrophic state. As a consequence, it is estimated that the entire lake would become eutrophic within ten years, should not further action be taken to mitigate this enrichment. Within this period, the trophic state of southern part of the lake and the nearshore area would decline from a mesotrophic state to a eutrophic state, and the northern part of the lake would become a swamp.

Water Quality Monitoring

There are 37 surface water environmental monitoring stations within Dali Prefecture. Most of them are located in the Lake Erhai basin, as shown in Figure 7. Among these stations, 22 stations are in the Lake Erhai basin; 6 are in the basins of other lakes such as Lake Cibi, Lake Haixihai, Lake Xihu, and Lake Mutunhai; 6 river stations, including 1 station on the Mizu River and 5 on the Xi'er River. The monitoring frequency is six times per year, with monitoring being conducted twice per month during the monitoring season: March, August, and November.

The Mizu River is one of the main tributaries of Lake Erhai, draining an area of 1,388.8 km^2. The average runoff volume of precipitation in the Mizu River watershed is 1.5 billion m^3, which maintains an average depth in the river of 368.6 mm and results in an average annual discharge of 0.51 billion m^3/year. Water quality evaluations have been carried out in this river since 1991. Table 11 presents the results of these evaluations through 1995. These data suggest that the water quality of the Mizu River is deteriorating. The main cause of this deterioration is runoff of nonpoint source pollutants from farmland, which are especially rich in phosphorus and ammonia.

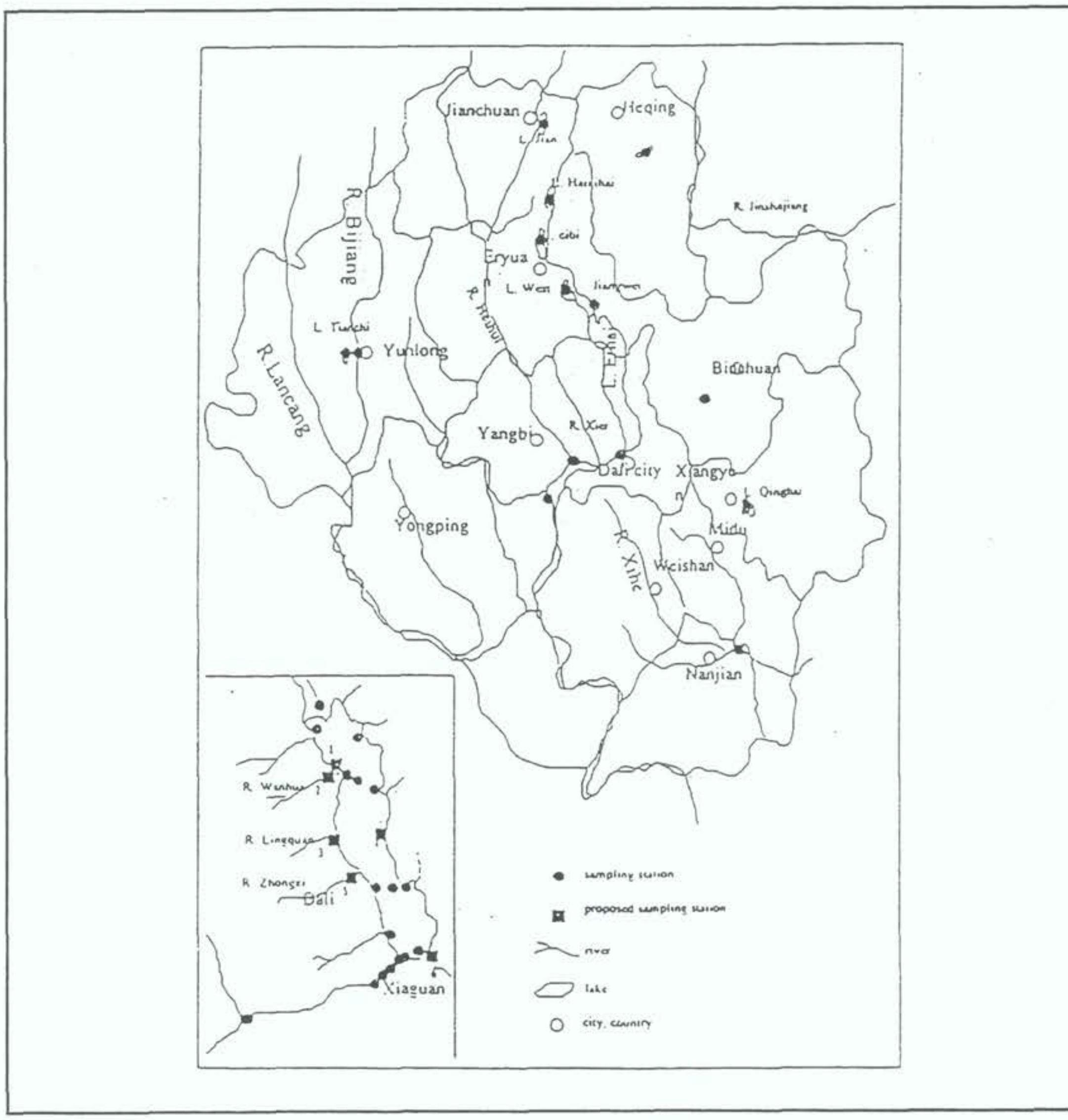

Figure 7. Locations of water quality monitoring stations within the Lake Erhai and Xi'er River basins.

Table 11. Water Quality Evaluation of the Mizu River Based on National Standard Grades

Year	DO	COD	BOD	Pb	Cd	NH_3-N	Total P	Overall Evaluation
1991	I	II	I	I	I	I	II	II
1992	II	I	I	I	I	I	II	II
1993	I	II	I	I	I	I	III	III
1994	I	I	I	I	I	I	II	IV*
1995	I	I	I	II	II	IV	II	IV

* Caused by an abnormally high pH value

Lake Erhai is part of the Lancangjiang River system. The lake has a drainage area of 2,565 km^2. In addition to surface runoff entering the lake, summarized in Table 9, the lake receives 0.26 billion m^3/year as direct precipitation onto the lake surface; the mean annual precipitation in the basin is 1,048 mm/year. Mean annual evaporation losses from the lake surface total 0.302 billion m^3/year. Table 12 presents the general characteristics of Lake Erhai, averaged over the period from 1952 to 1988.

Table 12. General Characteristics of Lake Erhai

Water level (m)	Lake area (km^2)	Lake volume (0.01 km^3)	Average water depth (m)	Lake surfac e area (km)	Inflow (0.01km^3)	Outflow (0.01km^3)	Length of lake shore (km)
1973.5	246	27.7	11.3	6.3	8.02	8.16	115

There are eleven environmental monitoring stations located in three areas of Lake Erhai. These stations are shown on Figure 7. Tables 13 through 15 present the water quality monitoring data from these locations within Lake Erhai during the different water seasons. An evaluation of the water quality data, based upon national standard grades, is also shown.

Table 13. Water Quality Data and Assessment Results During the Wet Season of 1995

Station	COD_{Mn} [(mg/l)/Grade]	BOD_5 [(mg/l)/Grade]	NO_2-N [(mg/l)/Grade]	Total P [(mg/l)/Grade]
Xizhou	1.103 / I	0.835 / I	0 / I	0.005 / I
Lake Center 1	1.045 / I	0.538 / I	0 / I	0.025 / II
Kanglang	1.270 / I	0.243 / I	0.0003 / I	0 / I
Longkan	1.100 / I	1.068 / I	0.0005 / I	0.005 / I
Lake Center 2	1.138 / I	0.603 / I	0 / I	0.005 / I
Tacun	1.143 / I	0.720 / I	0.0003 / I	0.003 / I
Xiaoguanyi	1.380 / I	0.918 / I	0.0003 / I	0.003 / I
Lake Center	0.580 / I	0.0003 / I	0.0100 / I	31.448 / I
Shifangzi	1.270 / I	0.480 / I	0.0003 / I	0.008 / I
Shaping	2.975 / II	1.605 / I	0.0120 / I	0.005 / I
Shuanglang	1.070 / I	0.320 / I	0.0025 / I	0.020 / I

Table 16 shows the results of water quality assessments of the lake between 1991 and 1995. In 1995, pH, DO, Total P, Total N, and Cu exceeded the water quality standards. Organic pollution was mainly from COD, BOD, ammonia-nitrogen, and Total P. While these results indicate that water quality in Lake Erhai is generally better than that of other waterbodies in the basin, the concentrations of nitrogen and phosphorus in the lake may exceed the standards for nonpoint source pollutant discharges from a number of human activities. Such excesses may potentially cause eutrophication problems.

Table 14. Water Quality Data and Assessment Results During the Dry Season of 1995

Station	COD_{Mn} [(mg/l)/Grade]	BOD_5 [(mg/l)/Grade]	NO_2-N [(mg/l)/Grade]	Total P [(mg/l)/Grade]
Xizhou	1.285 / I	0.093 / I	0.0005 / I	0.028 / II
Lake Center 1	1.310 / I	0.340 / I	0.0003 / I	0.028 / II
Kanglang	1.285 / I	0.145 / I	0.0003 / I	0.020 / I
Longkan	1.485 / I	0.498 / I	0.0005 / I	0.030 / II
Lake Center 2	1.513 / I	1.333 / I	0.0010 / I	0.035 / II
Tacun	1.395 / I	0.698 / I	0.0028 / I	0.030 / II
Xiaoguanyi	1.620 / I	0.925 / I	0 / I	0.025 / II
Shifangzi	1.510 / I	0.805 / I	0.0023 / I	0.025 / II
Shuanglang	1.495 / I	0.788 / I	0.0060 / I	0.040 / III

Table 15. Water Quality Data and Assessment Results During the Level Season of 1995

Station	COD_{Mn} [(mg/l)/Grade]	BOD_5 [(mg/l)/Grade]	NO_2-N [(mg/l)/Grade]	Total P [(mg/l)/Grade]
Xizhou	1.425 / I	0.155 / I	0.0005 / I	0.010 / I
Lake Center 1	1.353 / I	0.050 / I	0.0013 / I	0.010 / I
Kanglang	1.255 / I	0.405 / I	0.0005 / I	0.010 / I
Longkan	1.288 / I	0.530 / I	0.0003 / I	0.010 / I
Lake Center 2	1.618 / I	0.228 / I	0.0015 / I	0.013 / I
Tacun	1.328 / I	0.353 / I	0.0033 / I	0.013 / I
Xiaoguanyi	1.380 / I	0.603 / I	0.0025 / I	0.010 / I
Lake Center 3	1.390 / I	0.203 / I	0.0020 / I	0 / I
Shifangzi	1.373 / I	0.460 / I	0.0030 / I	0.010 / I
Shaping	1.960 / I	1.665 / I	0.0075 / I	0.010 / I
Shuanglang	1.463 / I	0.175 / I	0.0030 / I	0.015 / I

Table 16. Water Quality Assessment Results for Lake Erhai Between 1991 and 1995

Year	DO	COD	BOD	Cd	Total P	Overall Evaluation
1991	I	I	I	I	III	III
1992	I	I	I	II	I	II
1993	I	I	I	I	I	I
1994	II	I	I	I	I	II
1995	II	I	I	II	I	II

The occurrence of eutrophication within Lake Erhai is suggested by the development of blue-green algal blooms throughout the lake during the autumn of 1996. During that period, concentrations of Total P and Total N at eight of the monitoring stations ranged between 0.01 and 0.05 mg/l, and 0.44 and 0.70 mg/l, respectively. The lake transparency decreased to between 1.0 and 2.8 m. Dissolved oxygen concentrations in some sections of the lake were as low as 2.6 mg/l, and numbers of algae as high as 2,120,000 to 4,690,000/l. During winter (November 1996), the lake water quality remained poor, with low concentrations of dissolved oxygen. The lowest DO value was 1.7 mg/l. The results of the comprehensive assessment of lake water quality during this period indicated that water quality in most of the sections of the lake was Grade III, with some results indicating Grade IV. The number of algae ranged from 511 to 2,100 per liter with the dominant species being blue-green algae. If assessed using the trophic state criteria proposed by Carlson, almost the entire lake could be considered to be eutrophic.

There were many factors contributing to the onset of lakewide eutrophication, including water level, water temperature, insolation, and ambient nutrient concentrations. Nevertheless, the sudden deterioration in the water quality of Lake Erhai during this period has clearly shown that the lake's water quality is in a critical state. In order to prevent further eutrophication, control of point and non-point source pollution by engineering and administrative measures is necessary.

The drainage area of the Xi'er River includes 40 percent of the population of Dali Prefecture and most of the Prefecture's industries. Industrial pollution sources include wastewater from pulp and paper mills and textile factories. All of the wastewater from Dali City is discharged into the Xi'er River without treatment. Monitoring results from four locations along the Xi'er River suggest that the concentrations of DO, COD_{Mn}, BOD_5, NH_3-N, R-OH, total Pb, total Cd, and Cu all exceed the standard of Grade V surface waters. These results are summarized in Table 17. The levels of organic pollution and toxic substance pollution are the highest in the Lancangjiang River drainage area. Environmental statistics further suggest that industrial wastewater discharges from Dali City are one of the largest pollutant sources within the Lancangjiang River basin. In 1992, industrial wastewater discharges into the Xi'er River accounted for about 15 percent of the total amount of industrial wastewater received by the Lancangjiang River. Among the most serious polluters are the Yunnan Artificial Fiber Factory (one of the most serious polluters in China, ranking 255), the Dali Paper Mill, and the Erbin Paper Mill, which all discharge into the Xi'er River.

The Halazuo River is a branch of the Yangbi River, which joins the Heihui River downstream of its confluence with the Xi'er River. At the Halazuo River monitoring station, SS, COD, BOD, ammonium-nitrogen, and ammonia-nitrogen exceeded the national water quality standards by 50 percent, 17 percent, 17 percent, 67 percent, and 67 percent, respectively, indicating a level of contamination. The pollutant sources include pollutants carried by Xi'er River, as well as residential wastewater discharges from the Villages and/or Towns of Jianchuan, Shaxiba, Yangbihuanan and Machang. It is estimated that the mass of contaminants passing the Halazuo River monitoring station is about 35 million tons/year. Though diluted by fresh water flowing in the upstream portions of the Heihui River, the upper reaches of the Xi'er River contribute 37 percent of the COD, 21 percent of the BOD, 52 percent of the NH_3-N, 11 percent of the total P, and 80 percent of the F loads carried by the combined river system. The deleterious influence of the Xi'er River on the Heihui River is transferred to the Lancangjiang River and the Mekong River drainage system. As the flow of combined Heihui River system is only 4 m^3/s during the dry season, these levels of pollution are all the more serious, and demand immediate attention.

Table 17. Assessment of Water Quality in the Xi'er River during 1995

Station	Ammonia	DO	COD_{Mn}	R-OH	Pb	Cd	Cu	Zn	Overall Evaluation
Museum	IV	I	II	I	IV	II	IV	IV	IV
Sluice Gate	IV	III	I	I	II	II	I	I	IV
Heilong Bridge	IV	III	III	I	--	II	IV	IV	V
Grade One	IV	IV	III	III	--	II	IV	IV	V
Grade Two	IV	IV	--	IV	--	V	II	II	V

From the long-term point of view, the next fifteen years will be a period of extraordinary economic development in the Xi'er River drainage area. As noted above, the population and rate of economic growth are expected to double. Forestry and related industries, already quite common in western Yunnan Province, will increase further in the foreseeable future. Increased discharges of wastewater from expanding urban centers, pulp mills, and related industrial developments will occur. As a consequence, Lake Erhai and the Xi'er River, located in the upper reaches of the Mekong River system, will have a great impact on the water quality of the upper section of the Mekong River. Thus, there is an urgent need for measures to be taken to improve and protect the waters of Lake Erhai and the Xi'er River in order to protect the entire downstream system.

Loss of Biodiversity and Habitat

The Cangshan-Erhai National Natural Preserve is located between the transverse mountain ranges of Dali Prefecture and the Central Yunnan Plateau. It is a tropical highland influenced by the southwestern monsoon. Due to the complexity of the terrain and the typical alpine climate, this area contains diverse biological resources. The Cangshan Mountains are one of the principle sources of alpine plants in China, and are well known for their biological value.

In the Dali Cangshan-Erhai National Natural Preserve, there are about 2,330 species of plants from 755 genera representing 170 families. Among these, 64 species, from 46 genera representing 27 families, are aquatic. There are 159 species of algae, representing 42 families, in Lake Erhai. Also, the area contains 26 endangered species and numerous multipurpose plants of economic value. Among them, 14 species are under protection, with 4 species being grouped into Class II, and 10 into Class III, categories of protection. The area also hosts eight famous flower species, including *Camellia, Rhododendron, Magnolia, Primal, Lilium, Gentians, Cymbidium* and *Meconopsis*. There are 44 species of Cangshan Rhododendron, which are 10 percent and 18 percent of the total numbers of species in China and in Yunnan Province, respectively. The area also has a number of medicinal plants (601 species from 199 families) and fruit trees (including tea, walnut, chestnut, pomegranate, plum, apricot, and peach trees, etc.).

There are about 433 animal species in this area. Among these, 285 species (82 mammal species, 170 bird species, and 33 fish species) are vertebrates, and 148 species are invertebrates. Among the animal species, 8 species are under protection and grouped into Class I, and 15 species into Class II, categories of protection. Lake Erhai has abundant aquatic animal resources. There are 33 fish species, from 20 genera representing 8 families, within the lake.[3]

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[3] See "Name List of Biodiversity in Lake Erhai Basin", by the Biodiversity Section of Erhai National Nature Reserve, in the Appendix.

Fish

He Jichang recorded 31 species of fish in Lake Erhai belonging to 19 genera representing 7 families. Of these, 20 were aboriginal and 11 introduced. Because of the changes that have occurred in the lake environment, set forth above, the shoal areas of the lake where some fish used to spawn have been lost. As a result, the breeding success of some rare aboriginal fish like *Dali Schizothorax taliensis, Erhai Barbodes daliensis*, the Dali common carp, and *Cyprinus carpio chilia* is threatened and their numbers have greatly decreased, some even to the point of extinction. There have been three major changes in the fish community of Lake Erhai. The original community remained largely intact until the 1950s. This community consisted mainly of *Dali Schizothorax taliensis*, the Dali common carp, and *Erhai Barbodes daliensis*. The commercial catch of Dali common carp reached its peak in 1969, when 1,328 tons were harvested, then it dropped sharply thereafter to a few kilograms. By the end of 1970s, fish like *Gobiidae* and *Dorasbora parva* became dominant, occupying the shallow shoals along the shores of the lake. The catch of *Gobiidae* was 1,250 tons in 1970, when it, too, began to decline. By the 1980s, crucian carp had become dominant in the lake, accounting for over 70 percent of the catch, while some original fish species were rare and on the verge of extinction. The output of Erhai crucian carp also has followed this trend of first rising and then declining. In this case, the decline might be due to over-fishing, which has also diminished the size of the fish caught.

Phytoplankton

Li Shanghao and others maintained records of algae found in Lake Erhai between July and October 1957. The dominant algal species recorded were *Pediastrum simpex, Aphanitomono flos-aquae*, Yunnan *Leratium hirundinella*, and *Navicula*. They also recorded *Psephonema aenigmaticum* (unique to Yunnan Province), *Botrococus braunii*, *Lyngbya limnetica*, *Cosmarium acicu-lare var. subprorum*, and *Coelestrum spharirum*. A similar investigation in 1988 found 192 species of algae in Lake Erhai, belonging to 89 genera representing 42 families, 21 orders, 10 classes, and 8 phyla. Of these, 89 species were *Chlorophyta*, accounting for 46.5 percent of the total; 57 species were *Bacillariophyta*, accounting for 29.3 percent of the total; 26 species were *Cyanophyta*, accounting for 13.4 percent of the total; 5 species were *Chrysophyta*, accounting for 2.6 percent of the total; 5 species were *Euglenophyta*, accounting for 2.6 percent of the total; 4 species were *Pyrrophyta*, accounting for 2.1 percent of the total; 3 species were *Cryptophyta*, accounting for 1.6 percent of the total; and, 3 species were *Xanthophyta*, accounting for 1.6 percent of the total. The dominant communities during the period from July to October were *Chroomonas acuta*, *Cyclotella comta*, *C. meneghiniana*, *C. bodanica*, *Aphanifomono flos-aquae*. Other species observed during the 1957 study, *Pediastrum simpex,* Yunnan *Leratium hirundinella*, *Psephonema aenigmaticum*, *Botrococcus braunii*, *Lyngbya limnetica*, and *Cosmarium acicu-lare var. subprorum*, were not found. The number of algae present in the lake increased from 0.3 million/l to over 1.5 million/l between these two studies. Based upon algal abundance indices, Lake Erhai was considered to be slightly polluted during the 1957 study; however, during the 1988 study, the same index indicated that the lake had reached the second stage in the medium level of pollution. This suggested that the lake had become mesotrophic.

Aquatic Macrophytes

In 1957, there were no aquatic plants in Lake Erhai at depths greater than 3 m. By the early 1970s, the area of the lake covered by submerged plants was about 50 percent of the lake surface, with the biomass approaching 4 to 5 kg/m^2. After the water level of the lake dropped drastically in 1977, rooted aquatic plant growth pushed out to within 400 to 500 m of the center of the lake. Plants grew in parts of the lake having a water depth of over 10 m. In 1988, *Potamogeton maackianus* and *Hydrilla recticillata* covered the entire lake, with a biomass of nearly 20 kg/m^2. The community structure of the plant community also changed during this period. Species, like *Utricularia vulgaris*, *Limnophyla sessilifolia*, *Potamogeton pectinatus*, *Najas marina*, and *Ottelia acuminata*, that were originally found in the lake, gradually disappeared, and pollution-tolerant species like *Potamogeton maackianus*, *Hydrilla verticillata*, and *Vallisneria spiralis* became more abundant. The aquatic plant community in Lake Erhai is continuing to change. In 1985, the total plant biomass in the lake reached 479,000 tons, and 563,000 tons in 1988. The accumulation of decaying plant material is rapidly filling the lake basin and changing some areas of the lake into more of a wetland-type of condition. There are currently 51 species of aquatic vascular plants in Lake Erhai, belonging to 37 genera representing 21 families. Of these, 18 are submerged plants, 11 emergent plants, 7 leave floating plants, 4 fluitantes, 1 errantia, 10 hygrophytes, and an helophyte. The aquatic vegetation is formed of 3 mesofaunal units and 14 communities.

Terrestrial Woodlands

The present extent of forest coverage in the Lake Erhai basin, between Lake Erhai and the Cangshan Mountain, is only 11.4 percent of total land cover. The hills to the east of Lake Erhai are barren, completely lacking in forest cover. Over-harvesting of trees has resulted in an increase in the abundance of conifers and a decrease in the extent of broad-leaved forests. Similarly, there is an increase in young forests and a decrease in old-growth forests. The distribution of forested lands is also uneven: many forests are now confined in remote mountain areas with few on the slopes near human settlements. One of the ecological consequences of these changes in terrestrial vegetation coverage is soil erosion, which contributes to the nonpoint source pollution of the lake. This is further aggravated by the fact that the remnant forests have a poor capacity for supporting soil conservation practices; hence, their ecological benefit is also poor. This results in rapid changes in flow. During the dry season, the rivers experience a water deficit, while, during the rainy season, the rapid runoff washes away much soil.

Hundreds of square kilometers of formerly wooded lands are suffering from soil erosion in the Lake Erhai drainage basin. These lands amount to about 30 percent of the total area. The 18 brooks of Cangshan Mountains deliver up to between 2,700 and 5,400 tons/km^2 of sediment to Lake Erhai. Extrapolation of these values suggests that as much as 2.11 million tons of soil is lost each year in the area around Lake Erhai. In addition to these sediments, it is estimated that some 11,500 tons of particulate N and 6,900 tons of particulate P are transported into the lake. This intensifies the rate of eutrophication occurring in the lake and, combined with the heavy sediment load, damages the aquatic habitat in the bays and shallows where the fish live.

The determination of the nitrogen and phosphorus mass-balance of Lake Erhai in 1988 indicated that the N and P being delivered to the lake entered the lake primarily as the result of surface runoff from the rivers and their surrounding farmlands. The nitrogen load contributed by nonpoint pollution sources accounted for 57.5 percent of the total load, while that of phosphorus accounted for 70.4 percent of the total load, as shown in Table 18. The contributions from the point sources (industrial wastewater and sewage) accounted only for 3.0 percent and 8.0 percent of the total loads, respectively. Most of nonpoint source pollution resulted from soil erosion. The seriousness of nonpoint source pollution already creates difficulties for the prevention and rehabilitation of the lake. The restoration and protection of the lake environment becomes even more difficult in the face of the projected economic development of the area.

Table 18. Mass-balance of N and P in Lake Erhai during 1988

Item		Total N		Total P	
		Amount (tons/year)	percent	Amount (tons/year)	percent
Inputs:	In-flowing rivers	473.1	47.8	48.0	44.4
	Direct precipitation	280.8	28.4	14.6	13.5
	Farmland runoff	96.1	9.7	11.4	20.7
	Aquaculture	88.6	9.0	12.9	11.9
	Fishing and tourism	21.1	2.1	2.2	2.0
	Sewage	21.2	2.2	4.8	4.5
	Industrial wastewater	8.2	0.8	3.2	3.0
	Subtotal	989.1	100.0	108.1	100.0
Outputs:	Out-flowing rivers	257.0	59.0	14.7	26.8
	Fishing	124.8	28.7	37.0	67.5
	Agricultural consumption	42.2	9.7	2.4	4.4
	Industrial and domestic consumption	11.3	2.6	0.7	1.3
	Subtotal	435.3	100.0	54.8	100.0
Total		533.8		53.3	

1.6 Ecosystem and Biodiversity Protection

The need for environmental protection and rehabilitation within the Lake Erhai basin has been established. Implementation of this program of environmental protection and rehabilitation is proposed as a three-phased project, with activities identified for implementation during the short- or immediate-term (1997), medium-term (2000), and longer-term (2010). The goal of the short-term activities is to bring about the control of the ecological deterioration of the basin. In the medium-term, activities are designed to improve the environmental conditions within the basin, while, in the longer-term, the goal of the project activities is to rehabilitate degraded ecosystems.

Ecosystem Protection Project

The ecosystem protection project has three immediate goals; namely, (1) for the protection of water quality, (2) for reforestation, and (3) for control of soil erosion. Each goal has quantifiable objectives, with measurable milestones against which to assess progress in project implementation.

The objectives for water quality protection are:

- To achieve a Grade II surface water quality standard for Lake Erhai and Xi'er River upstream of the Tiansheng Bridge in the short term.
- To achieve a Grade V surface water quality standard for Xi'er River downstream of the Tianshang Bridge in the medium term, and to achieve a Grade IV surface water quality standard for the river in the longer term.

The objectives for reforestation are:

- To increase the woodland area in the basin from 45,753 ha, or 17 percent of the land area, to 80,102 ha, or 30 percent of the land area, in the medium term, and to 120,153 ha, or 45 percent of the land area, in the longer term.

The objectives for water and soil erosion control are:

- To reduce sediment inflows to the lake by 80,000 tons/year in the immediate term, and by 1,630,000 tons/year in the medium term.
- To reduce dissolved phosphorus inflows to the lake by 11.5 tons/year in the immediate term, and by 24 tons/year in the medium term.

Specific actions to achieve these goals and objectives have been identified. Based upon the inventory data reported above, the portion of the Lake Erhai watershed that drains the Cangshan Mountains has been identified as the most critical area for implementation of initial environmental management interventions. The Cangshan Mountains have a very serious soil erosion problem that accounts for 40 percent, or 1,182 ha of the 2,955 ha, of the eroded lands in the basin. These lands deliver almost one million tons/year, or 46 percent of the total mass, of debris to the lake through the 18 stream systems draining the mountainous area. Actions that have been identified as essential include:

- Reforestation of water source areas above an elevation of 2,400 m and protection of existing forests.
- Reforestation of 2,537 ha of lands within the area of origin of the debris flows, at elevations of between 2,100 m and 2,400 m.
- Construction of dams and stabilization of ditches, including installation of 15 silt dams, 146 shallow dams, 48.5 km of stabilized drainage ditches, and 45.2 km of stabilized stream courses.
- Provision of enhanced flood discharge and drainage in areas of sediment accumulation at elevations of between 1,980 m and 2,110 m.
- Reforestation with approximately 267,000 trees of the remaining 66.9 km of stream banks along the 18 streams draining the foothills of the Cangshan Mountains; about 23.5 km of the 94.4 km of stream course have been reforested to date.

The total investment required for these activities is projected to be US $ 6.5 million.

Comprehensive management measures should also be implemented in other watersheds and areas of the Lake Erhai basin. Soil conservation measures are required to be applied in the Mizu River, Wanglong River, and Boluo River basins. Measures required should include inhibition of logging and conversion of lands for economic purposes, inhibition of sand and soil extraction, reforestation of lands and stream banks, and implementation of forest management practices. The total investment needed to implement the above projects is estimated to be US $ 1 million.

East of the lake, the planting of scenic trees, commercial forests, arbors, and grasses on about 2,000 ha of lands in Dali City and 1,330 ha of lands in Eryuan County is required. The total investment required to achieve this level of revegetation in these areas is estimated at about US $ 1.6 million. This revegetation project is anticipated to be completed in the immediate to medium term and will contribute to the achievement of an overall increase in forest coverage in the eastern mountains from 11 percent to 86 percent.

Allied with this initiative is the construction of a forested buffer of 20 m width around 128.7 km of the lake shore. In the recent years, over one million trees have been planted around the lake, but more are needed. The total investment for this project is expected to be US $ 0.25 million. Other actions to protect existing forested lands in the vicinity of the source waters to Lake Erhai on the slopes of the Luoping, Biaoshan and Ma'an Mountains in Eryuan Country and Cangshan Mountains in Dali City also are envisioned. In the immediate term, about 18,000 ha of forest are to be planted along the water courses draining these hillsides, including 4,000 ha of commercial forests, at a cost of about US $ 5 million. Subsequently, in the medium term, a further 12,000 ha of forest will be planted, extending forest coverage by the year 2000 to 31 percent of the watershed. About 8,600 ha of commercial forest, 93 ha of forest to be used for the provision of construction and fuel woods, and 1,600 ha of special forest will be planted, at a total cost of about US $ 5 million.

Biodiversity Protection Project

In addition to the goals, objectives and actions proposed for the protection of water quality, other actions for the protection of biodiversity in the Lake Erhai basin have been identified. These actions include capacity building to achieve the goal of strengthening the integrity and management of the Cangshan-Erhai National Natural Reserve. Specific objectives relating to the achievement of this goal include:

- Creation of infrastructure, facilities, experimental equipment, and communications systems to support environmental management initiatives, according to local conditions, within the natural reserve.

- Determination of appropriate ecological monitoring protocols, based upon detailed investigations and analyses of local conditions, to provide the scientific bases to support environmental management and pollution control activities.

Specific activities envisioned to achieve these objectives include the development of administrative office and related facilities, boundary markers and fire prevention facilities, herbaria and arboreta, and other infrastructure and control systems.

The natural reserve encompasses the biological resources of approximately 550 km^2 of the Cangshan Mountains and 250 km^2 of Lake Erhai. The authorities tasked with the management of this reserve are responsible for developing a comprehensive management plan, a data collection system, biological resource and habitat protection plans, and an emergency response plan. To fulfill these responsibilities, an administrative center, including a fully-equipped laboratory, offices, vehicles and vessels, and dormitories will be required for the proposed staff of 50. The staff will serve the reserve headquarters, ecological monitoring laboratory, and three field stations (West Cangshan, East Cangshan, and Erhai, respectively). These latter stations will contribute to the establishment of fire prevention systems that will minimize forest fires within the reserve, enhance mobility for fire prevention and fire fighting personnel, and provide the basis of a fire hazard warning and response system. The administrative center will also serve to coordinate staff movements and centralize the storage of monitoring data and imagery files, and production of public information and education materials.

In January 1996, the Dali Botanical Arboretum was proposed to be initiated as a key measure for biodiversity conservation within the watershed. The general goal of this activity is the construction of a botanical arboretum as a center for biodiversity conservation through scientific research, public education, and tourism, which would bring both heightened environmental awareness and socio-economic benefit. It is proposed that the arboretum be located on an 18-ha site, approximately 1 km west of the Dali Old City. This location has an adequate supply of water, good quality soil for plant growth, and an existing vegetative canopy. Furthermore, this site is selfcontained, surrounded by a wall, and very close to Dali Old City and therefore convenient for tourists. A second arboretum is proposed to be constructed during the immediate to medium term at Huadianba to support alpine biodiversity conservation.

The Dali Arboretum is expected to include a protected area for rare and endangered plant species (5 ha), an area to house the collections of endemic subtropical plant species of the Cangshan Mountains (2 ha), a landscaped ornamental garden (5 ha), and a commercial sales area providing ornamental plant species for retail sale (2 ha). In the protected area, 7 nationally protected and 10 provincially protected plant species will be planted. To enhance their survivability, at least 60 seedlings will be planted under conditions similar to those in their natural habitats. They will be collected from different locations inside and outside of the reserve to enlarge the gene pool within each planted colony. These plants will form the basis for propagating new plants for reintroduction into appropriate natural habitats. In future, the collection may be gradually expanded to a total of 70 rare and threatened species from the region. In addition, collections of threatened endemic subtropical species of the Cangshan Mountains, from the subtropical forests below an elevation of 2,500 m, will be maintained for scientific studies and serve the purpose of a permanent biological resource pool. Up to 67 species of plants may be housed in this portion of the arboretum. Because Dali and its surrounding area is well regarded in China for its floral beauty, flowerbeds and a landscaped area is planned to be housed inside the arboretum. This part of the arboretum is designed to highlight the impressive and unique flowering plants of the Cangshan Mountains and to serve as the focal are for tourists. The gardens will be a tranquil and aesthetically pleasing break for tourists visiting the narrow streets inside the ancient city. It is also an opportunity to expose the public to the importance of biological conservation. The revenue generated from such tourism may also be used to protect and reintroduce endangered species. This part of the arboretum will highlight six groups of flowering plants of Cangshan Mountains: Camellias, Azaleas, Orchids, Magnolias, winter flowering plants (*Prunus conradinea*, *Luculia intermedia*, *Chimnonanthus praecox*), and bonsai. Using the collection in the arboretum, it is possible to grow these flowering plants in large numbers. Surplus seeds, seedlings, and/or mature plants can be used to generate revenue through the marketing of these unique flowering plants and the selection and development of plants that have commercial potential from of wild species.

The Alpine Botanical Arboretum will be built in Huadianba during the period from 1996 through 2000. This botanical arboretum will serve as a center for alpine biodiversity protection, supporting scientific research, facilitating public education, and attracting tourism. This arboretum will be built on a 47 ha site, that will focus on those plant species inhabiting the Cangshan Mountains at elevations above 2,500 m. Many plant species inhabiting this area have medicinal value and have been used as herbal medicine for a very long time. The arboretum in Huadianba will include administrative offices, laboratories, and staff housing. The collection will include sub-alpine rare and endangered plants, endemic to the Cangshan Mountains, as well as unusual plants that have aesthetic and ornamental values from Yunnan Province. The collection will contain precious medicinal plants, especially those traditional medicinal plants used by the indigenous Bai people. Sub-alpine nature, scenic, and hiking trails are proposed.

Wase Township Demonstration Project

Agricultural activities are the major contributors in the pollution of Lake Erhai. In order to protect the biodiversity and water quality of the lake, adoption of eco-agricultural practices for the sustainable development of rural communities is considered to the primary means of alleviating nonpoint source pollution loading to Lake Erhai. To demonstrate the value and utility of these practices, a pilot demonstration project is to be established in the Wase Township, which has a total area of 11,140 ha. In the immediate term, this project is expected to increase forest coverage in the township to 20 percent, improve the richness of the alpine biodiversity within the township, and shift 10 percent of farmsteads to an eco-agricultural basis of production. This will reduce the nonpoint source impacts of the township; specifically:

- Particulate nitrogen losses from (i) the land surface of the township will be reduced from 292 kg/ha to 263 kg/ha, and (ii) farmlands from 34 kg/ha to 31kg/ha.
- Dissolved nitrogen losses from (i) the land surface of the township will be

reduced from 2.2 kg/ha to 2 kg/ha, and (ii) from farmlands from 0.79 kg/ha to 0.70kg/ha.

- Particulate phosphorus losses from the land surface of the township from 477 kg/ha to 429kg/ha.
- Dissolved phosphorus losses from (i) the land surface of the township from 0.13kg/ha to 0.11 kg/ha, and (ii) farmlands from 0.13 kg/ha to 0.11 kg/ha.
- Applications of chemical fertilizers and agricultural chemicals will be reduced by 10 percent each, while achieving a decrease in the occurrences of plant diseases and insect pest infestations.

During the medium term, additional actions will extend these initial actions, converting up to 50 percent of farmsteads into sustainable eco-agricultural units. It is also anticipated that forest coverage will be increased to 30 percent, phosphorus loadings from the mountainous areas and agricultural lands of the township will be reduced by a further 20 percent from the levels achieved during period through the year 2000, and the amounts of chemical fertilizers and pesticides applied to farmlands will be less than those applied through the year 2000. These actions will further improve the integrity of the biodiversity of ecosystem.

Economically, it is anticipated that the foregoing actions will increase per capita production of grain to 400 kg/year in the immediate term. This level of production will yield an annual per capita income of US $ 175. In the medium term, between 2001 and 2010, these yields are expected to increase to 600 kg/capita/year, increasing the per capita annual income from this source to US $ 600/year.

Specific actions needed to achieve these objectives are based upon the effective management of small watersheds within the township. Management efforts will include protection and restoration of natural vegetation, including reforestation of steeply-sloped hillsides and mountainsides, conversion of farmland currently situated on steep slopes to forest cover, revegetation of riparian areas and stream banks, and planting of wind breaks around farmland on flat ground. In addition, the establishment of a sustainable eco-agricultural production system will be expected to improve the productivity of the remaining farmland through introduction of biological controls of pests and weeds, use of microbially-augmented organic fertilizers, and conversion of fuel systems from wood-based fuels to bio-gas fuels.

Environmental benefits to be achieved and demonstrated through this demonstration project include the protection of the biodiversity of the Cangshan Mountains and Lake Erhai, reducing the considerable risk of extinction of some indigenous species due to over-exploitation and pollution, and the reduction in nonpoint source pollutant loads to the lake. Maintenance or enhancement of plant cover on the middle and lower slopes of Cangshan Mountains will help also to control the serious erosion problems in the area and the associated siltation of Lake Erhai.

1.7 Principal Medium-Term Environmental Concerns

The analyses and overviews of projected social and economic development in the Lake Erhai and Xi'er River basin presented above suggest several trends that indicate further degradation of the environment of this region in the absence of interventions such as those described above. Forecasting the extent and severity of these impacts, based upon the identified trends, can be undertaken using several methodologies. Methods which predict the discharge of pollutants make various assumptions regarding the factors to be taken into consideration in the prediction of pollutant loads. Depending on the time period of the forecast, certain factors may be excluded from the analysis. For example, in the medium term, the social-economic situation of the basin may be expected to be relatively stable, and it may be possible to forecast future conditions by extrapolating past and current trends. For this reason, an assessment of pollutant discharges to the drainage areas of the Xi'er River and Lake Erhai in the medium term was undertaken, assuming continuity of current trends, using regression analysis.

The specific pollutant discharges examined in this way were the discharge of wastewater (Y_1 in 10^4 tons/year), the discharge of industrial wastewater (Y_2 in 10^4 tons/year), the discharge of COD in industrial wastewater (Y_3 in tons/year), the discharge of SO_2 (Y_4 in tons/year), and the discharge of particulates in smoke (Y_5 in tons/year). Data from the period between 1987 and 1995 were used in the analysis, and trends were calculated using a least-squares regression analysis program contained with the Times Series Program (TSP) software. Identified "errors" were analyzed and tested, and the equation of best fit chosen for use in developing the pollution forecasts. These equations had the highest coefficients of correlation:

- $Y_1 = 953.09 + (121.54)(T)$
- $Y_2 = 468.73 + (116.54)(T)$
- $Y_3 = 7\,324.91 + (1\,010.67)(T)$
- $Y_4 = 2\,023.41 + (438.49)(T)$
- $Y_5 = 1\,987.03 + (73.98)(T)$

The results of this analysis, presented in Table 19, indicate a likely doubling or trebling of pollutant loadings to Lake Erhai and the Xi'er River in the absence of mitigation measures.

Table 19. Forecast Pollutant Discharges in the Drainage Areas of Lake Erhai and the Xi'er River

Year	Wastewater (10^4 tons/year)	Industrial (10^4 tons/year)	COD (tons/year)	SO_2 (tons/year)	Smoke Dust (tons/year)
2000	2,654.7	2,100.3	21,474.3	8,162.3	3,022.7
2005	3,262.4	2,683.0	26,527.6	10,354.8	3,392.6
2010	3,870.1	3,265.7	31,580.9	12,547.3	3,762.5

Based upon these analyses, the principle pollution issues in the Lake Erhai area will be water pollution, followed by air pollution and solid wastes. The total amount of wastewater discharged in the area will reach 26.5 million tons/year by the year 2000, which mass represents an increase of about 20 percent over that experienced during 1995. Industrial wastewater is expected to contribute 21.0 million tons/year. This wastewater is estimated to contain 21.5 thousand tons/year of COD, or between 13 percent and 31 percent more COD than was measured during 1995. By the year 2010, the amount of wastewater discharged will be doubled, seriously degrading the water resources of the region. By the year 2000, the amount of SO_2 and smoke dust discharged into the atmosphere will reach eight thousand tons/year and three thousand tons/year, respectively, which represents an increase of 10 percent to 80 percent over 1995 levels. By the year 2010, waste gases and pollutants discharged into the atmosphere will be increased by one- to two-fold over current levels.

Industry is anticipated to be the major source of environmental pollutants by the year 2000. The principle industries contributing such pollutants in the area are expected to be the biological resource-related industries such as paper-making, food-processing, and leather-tanning industries, and the mineral resource-related industries such as building material production, coal mining, and chemical manufacturing. The industries with the greatest impact on water quality are expected to include paper-making, food-processing and beer-brewing, while those the greatest impact on air quality are expected to include building material production and paper-making. The industries with the greatest impact on generation of solid wastes are expected to include food-processing, paper-making, coal mining, and chemical manufacturing.

The next fifteen years, around the turn of the century, will be a period during which the economy of the Lake Erhai area is expected to experience unusual growth. By the year 2000, the GNP of the Dali Prefecture will probably reach 14,697 billion Yuan, 2.2 times that of 1995. Industrial outputs will reach 6 billion Yuan, or 1.76 times that of 1995. To achieve this growth, however, it is also estimated that the amount of pollutants discharged will increase by 50 percent over 1995 levels. Industries such as building material production, paper-making, and food-processing will undergo rapid development. Industrialization of the rural districts will be an important component of the area's economic development, with township enterprises rapidly becoming the mainstay of the rural economy. In addition, the exploitation of water-based energy sources, mineral resources, biological resources, and tourism will also have an inevitable impact on the environment. Of these, the greatest impacts on the Lake Erhai system will be from the exploitation of water resources and from the exploitation of bio-resources.

These impacts are already being manifested. "Red tides" have appeared in some localities in the western part of Lake Erhai during the late 1990s, provide visible evidence that the lake has entered a period of intensified eutrophication and water quality deterioration. Predictions based on the existing conditions and planned social-economic development suggest that, without effective measures to purify the water and restore the ecosystem, the pollution of Lake Erhai will worsen and that its waters will further deteriorate during the next decade. Even with the implementation of administrative measures such as improvements in the location of industries within the basin, further deterioration is anticipated.[4] While it is predicted that the central, deep-water portion of the lake can maintain a Grade II quality water, other parts of the lake are expected to be downgraded to a Grade III quality water. The southern part of the lake, and the nearshore areas of the lake, are likely to become mesotrophic, while the northern part of the lake is likely to become more marsh-like.

As noted above, because the water from Lake Erhai flows into the Lancangjiang River, the water quality of the lake directly influences the water quality of the Xi'er River-Lancangjiang River system. However, while eutrophication will immediately and severely impact the lake's ecosystem, the process will take some time to degrade the surface water resources of the entire system, and degradation of Lake Erhai is not expected to affect the water quality of the Lancangjiang River during the immediate term. Organisms such as algae that are indicative of eutrophic conditions decompose, and the deterioration in water quality caused by eutrophication is attenuated in the distant downstream reaches of the hydrologic system. Nevertheless, the predicted doubling in the amount of pollutants discharged in the Lake Erhai basin by the year 2010 suggests that the mass of these pollutants will overwhelm the capacity of the river to attenuate the pollutant loads, and that more of the pollutants will enter the Lancangjiang River through the Xi'er River and the Heihui River. It is predicted that the water quality at the Halazuo monitoring station will be decreased by one grade at that time.

Another possible threat to the Lancangjiang River is the implementation of the

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[4] An administrative, land use zoning policy to "strictly restrain [development] in the upper reaches, control [development in] the middle reaches and let be [encourage development in] the lower reaches" has been adopted for the Lake Erhai basin, and is currently being implemented.

Heihuijiang industrial corridor project. To protect the water quality of Lake Erhai, a land use zoning and environmental protection strategy has been employed by the Prefecture. In this industrial corridor, the Yunnan Artificial Fiber Factory and Erbin Paper Mill will build some new production facilities at Machang. Their wastewater will be discharged directly into the Heihui River. While these wastes will no longer be discharged to the Xi'er River, the potential impact on the water quality of the Lancangjiang River will be more direct and serious. Currently, a feasibility study on the control and reduction of pollution from these two factories is being completed. However, a lack of funds and the difficulties of treating wastewater from paper production plants will make the implementation of pollution controls unlikely in the foreseeable future.

In addition to these industrial impacts, the next fifteen years is likely to see the continued degradation of the ecosystem of the area as a consequence of the on-going destruction of forest vegetation, soil erosion, and the worsening of natural disasters. Damage to the biodiversity of the region is also likely to continue as a result of the over-exploitation of bio-resources.

Forests in the area are likely to suffer as a consequence of social-economic development, especially when the exploitation of natural resources is intensified. It is estimated that hundreds of thousands of cubic meters of logs will be consumed annually by paper industry by the year 2010. This volume is approaching the total volume of the present timber reserve. Similarly, the extraction of marble and the mining of other mineral resources will destroy the vegetation in the mining area, while the construction of infrastructure like railways, highways, and tourist facilities will inevitably cause some damage to forest vegetation. Likewise, population increases will consume more forest resources. This destruction of vegetative land cover will reduce the overall capacity of the land to conserve water and soil, and moderate the local climate. This fact, combined with the inappropriate management of resource exploitation and construction activities, will intensify soil erosion, for example, and result in more severe impacts on the communities from natural calamities such as floods and landslides with their consequences to loss of life and property.

Overlaid on the degradation of the natural resource base of the region is the fact that the exploitation of the water resources of the Lake Erhai basin is already up to 90.7 percent of the estimated sustainable yield. From the long-term point of view, the amount of inflow to Lake Erhai is likely to be reduced while water consumption will continue to increase. Thus the contradiction between water demand and water supply will be intensified. The present population of the area is 1.22 million. It is estimated that the population will grow to 1.36 million by the year 2000, and 1.44 million by the year 2010. During this period, also, the total value of industrial and agricultural outputs is also expected to increase several-fold. For this reason, it is estimated that the water demand will increase by between 5 and 8 million m^3/year. According to the development plan of Binchuan County, the volume of water to be diverted from Lake Erhai will increase from the present 50 million m^3/year to 150 million m^3/year, intensifying the shortage of available water.

To attempt to resolve this contradiction between available supply and increasing demand, and to meet the expected demand for water by industry and agriculture, it is likely that more of the capacity of Lake Erhai will be exploited. However, this practice will result in a further lowering of the lake's water surface and disturbance of its ecosystem, speeding the eutrophication process and fundamentally decreasing the very basis of sustainable development in the area. To protect the waters of Lake Erhai in the short term may mean temporarily restraining the economic development of the area. With a longer-term view, however, the absence of water, the natural consequence of continuing to develop in the face of a water deficit, will eliminate the development of the area's economy. Thus, the most practical way out of this dilemma is to explore alternative energy sources and to develop water-saving agricultural and industrial technologies.

Notwithstanding, the implementation of the national strategy for developing the central and western parts of the country means that the industrialization of rural areas will be an important part of the development of the drainage area of Lake Erhai during the coming 15 years. As noted, the rapidly developing township enterprises will become the main force in developing rural economy. There were 20,000 township enterprises in the lake area at the end of 1990, employing a work force of 65,000 people. Of these township enterprises, 1,066 are small-scale operations and over 18,000 are owner-operated concerns. The total revenue of these township enterprises was 33.781 million Yuan in 1995, accounting for 56 percent of the Prefecture's total income. The value of their outputs at that time was 313.16 million Yuan, or 57 percent of the total output of the Prefecture. Despite this high level of economic performance, most township enterprises are at the stage of primary capital accumulation and employ simple equipment and low-technology methods. This means, however, that the majority of these enterprises waste energy and resources, and cause more serious pollution, in comparison to more sophisticated operations. Hence, it will be vitally important to encourage these small-scale operations to adopt more sophisticated and less consumptive practices if the forecast point and nonpoint pollution sources are to be controlled, and the underlying natural resource and water resources base protected.

The destruction of forest vegetation, especially of natural forests, as a result of urbanization and the consumption of usable water resources as a result of industrialization will have significant impacts not only on the human development of the basin but also on the biodiversity of the Cangshan Mountains. It is estimated generally that one species is lost for every 700 ha of natural forest destroyed. However, in an area of concentrated diversity, such as is the case in the Cangshan Mountains-Lake Erhai region, the actual loss could be much greater. For example, water diversion projects affecting Lake Erhai may thoroughly alter the habitats of aquatic life and result in the demise of some unique species of aquatic life. Over-exploitation of the resources by tourists and the fishery industry will further increase the impact of human disturbance on the aquatic systems and will affect the normal breeding of some species. Thus, it can be expected that the exploitation of natural resources will decrease the biodiversity, and that the situation might become serious if no effective mitigation measures are taken.

It is also likely that, due to its location in the upstream reaches of the Xi'er River-Lancangjiang River, the destruction of the ecosystems in Lake Erhai area will affect the integrity of its structure and function of the ecological environment of the whole area of the Lancangjiang River. The combined effects of the destruction of forest, over-exploitation of water resources, and more frequent natural calamities vegetation in Lake Erhai area that result in increased soil erosion, not only degrades the aquatic habitat of Lake Erhai but also results in more silt being delivered to the Lancangjiang River. This will in turn increase the rate of siltation in the riverbed in the downstream reaches, affecting development and altering the river in a manner that will cause harm to industrial and agricultural production, and people's lives, along the river. In effect, the degradation of the headwaters of the system will create a cascade of negative impacts on the development of the Lancangjiang River basin.

Chapter 2

Environmental Planning for Sustainable Development in the Lake Erhai Basin

2.1 Guidelines and Objectives

Sustainable development in the Lake Erhai basin is the result of sound regional socio-economic development and environmental protection that begins with environmentally-sound planning. Environmentally-sound planning is based upon data collection, analysis, and interpretation that includes not only the assessment of current conditions but an evaluation of the likely socio-economic and environmental consequences of development in the lake basin. With regard to Lake Erhai, an evaluation of the water resources impacts would be a key element of such planning. One technique that has proven useful in extrapolating current conditions is systems analysis that identifies the relationships among the sectoral economic activities and environmental factors. This type of analysis provides the input for the formulation of optimization and simulation models.

The main objectives of the environmental planning in the Lake Erhai basin should be to protect lake water quality, maintain water quantity yields, and conserve biodiversity in the lake basin. Within Dali City, environmental planning would emphasize sustainable tourism development that will improve the economic condition of the study area, while preserving its aquatic resources. Aspects to be considered in environmentally-sound economic development will include, *inter alia*, the conservation of biodiversity, wastewater management, forestry, nonpoint source pollution control, and solid waste management. A key principle of environmental planning is the balance of sound science, common sense, and practical applications. Sound science implies that recommended actions are in accordance with science principles, based upon systems analysis, modelling, and interpretation of model solutions that reflect the real-world conditions of the Lake Erhai basin. Practicality implies that recommended actions are flexible and able to be to implemented using available technologies and in accordance with local cultural sensibilities.

Specific actions recommended as outputs of the environmental planning process must be based upon carefully diagnosis and assessment of environmental problems and their relevant impacts on the socio-economic development of the study area. As previously noted, the studies of the environmental and economic consequences of sectoral development should place special stress on tourism development in the lake basin. Outputs in this sector should formulate and interpret planning schemes that will be able to coordinate socio-economic development and environmental protection in the lake basin. Such schemes would suggest ways and means of improving environmental management in the lake basin based upon an evaluation of the current situation and development trends, and prediction of the impacts of different socio-economic development scenarios on the water quantity and water quality of Lake Erhai and Xi'er River. An essential element of this type of forecasting is the establishment of a dynamic, computer-based management information system. A further element of the successful implementation of environmental planning entails the training of technical and administrative personnel within local government.

2.2 A Modelling Framework

The current development regime of the study area is composed of ten main elements, including economic sectors such as agriculture, tourism, forestry, net-cage fish culture, manufacturing, quarrying, in-lake navigation and fisheries, lime-kiln/brick-kiln operations, water supply, and miscellaneous activities. Among these elements, six play very important roles in the whole system; namely, agriculture, tourism, forestry, net-cage fish culture, manufacturing, and water supply. The remainder occur in more localized areas of the drainage basin. Notwithstanding, in order to successfully forecast the combined impacts of human economic activities in the system, the relationships between and among the components that comprise each of the ten economic sectors must be identified, and their impact on the aquatic environment of Lake Erhai and the Xi'er River evaluated. These relationships are discussed below.

Analysis of Sectoral Impacts

Agriculture

Three major components of the agricultural sector are related to water quality and quantity in Lake Erhai and the Xi'er River; namely, soil use and cropping patterns, livestock management, and human activities (Figure 8). Generally, the main crops in the area are rice, wheat, corn, and vegetables. The main types of livestock are oxen, sheep, pigs, and domestic fowls (chickens, ducks, geese, and turkeys). Human activities in support of agricultural operations are related to the provision of water for irrigation. Irrigation water is allocated on the basis of types of farming activities, pipe capacities, and levels of potential economic returns. Water quality impacts are related to nonpoint source pollutants that arise from these agricultural activities. Soil erosion and wash-off of surplus nutrients from fertilizers and manure applied to the land surface are the principal pathways by which pollutants reach the aquatic environment. High dissolved- and particulate-phase nitrogen and phosphorus concentrations contribute to the eutrophication of surface and ground waters. Of these nutrients, nitrogen in the form of nitrate also can make water unsafe for human consumption. The concentrations of sediments and suspended solids, and of nitrogen and phosphorus must be managed in order to achieve the water quality objectives established for Lake Erhai and the Xi'er River.

Crop production and livestock husbandry are economic activities in that they provide nutrients for human consumption. Crop production also provides nutrients for livestock production. These nutrients are supplied in the form of agricultural products that contribute positively (= income) to the regional economy. Such production also contributes costs directly in terms of the costs of manure and fertilizers that must be purchased, and indirectly in terms of the consumption and contamination of water resources in the Lake Erhai system (for irrigation and as a result of nonpoint source pollution). Livestock husbandry also contributes to the regional economy through the production and sale of processed egg and meat products. However, these activities also convey costs that result from sewage discharges to Lake Erhai and process water consumed. Thus, there is a need to define the optimal levels of agricultural activity within the basin, and determine the optimal areas within which to expand and develop agricultural activities. These determinations should be based upon identified environmental and resource management objectives and restrictions, and upon their relationship to other economic activities in order to maximize agricultural benefits.

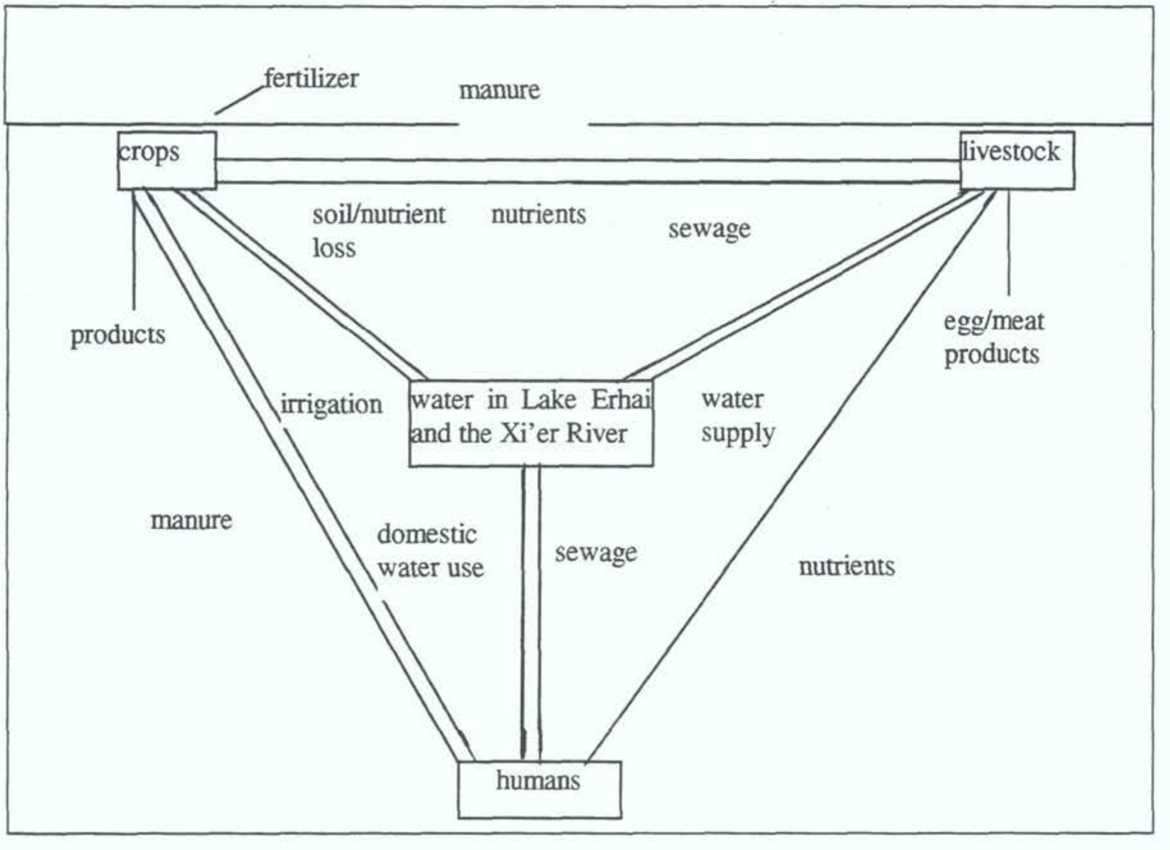

Figure 8. Relationships between the components of the agricultural sector.

Manufacturing and Industrial Activities

Figure 9 shows the relationships among and between industrial activities and other manufacturing sector components. Industries contribute economic benefits to the study area through the production (manufacturing) and marketing of a range of products. Many industries consume, as raw materials, production from the forestry and agricultural sectors, thus creating a value-added element within the regional economy. However, they also generate solid and hazardous wastes, and emit untreated or partially treated wastewater that does not completely meet the wastewater discharge standards, to Lake Erhai and the Xi'er River. The treatment, disposal, and resultant water pollution problems that should be considered as economic costs. The total amount of industrial wastewater generated within the Xi'er River basin is about 17.6 million tons/year, with the pulp and paper, chemical, food-processing, and leather and textile industries being the primary polluters. Industries also consume a large amount of Lake Erhai water. During the 1994/1995 fiscal year, industrial water consumption in the study area was about 23 million m^3/year (1995 data). Less than one-quarter of this volume, or about 4.3 million m^3, was recycled water.

Industrial and manufacturing activities are not only related to economic development but also to a number of environmental and resource protection and management concerns. Thus, there is a need to determine the optimal level of industrial and manufacturing activity within the basin, and to develop effective policies and regulations to achieve the water quality goals established for Lake Erhai and the Xi'er River. Achieving this balance between economic production and environmental protection will contribution to sustainable regional development.

In-Lake Net and Caged Fish Culture

In-lake net and cage fish culture is one of the major sources of organic contaminants entering Lake Erhai. Figure 10 shows the relationships among and between in-lake fish culture components. This activity contributes significant economic benefits to the regional economy through the sale of fish products. Costs include the direct costs of feeding the cultured fishes associated with caged fish culture as well as the indirect costs related conflicts experienced between fisheries activities and lake navigation. The indirect use of nutrients contributed to Lake Erhai from agricultural activities through nonpoint source pollution is an indirect benefit associated with this economic activity.

Notwithstanding the use of such nutrients as a natural food source, the principal environmental impact of caged fish culture is associated with the inefficient use of supplemental feed by the fishes. A significant proportion of the supplemental nutrients provided (estimated at between 70 and 80 percent) is not consumed by the fish. These excess nutrients contribute to the eutrophication of the lake and have impacts on in-lake recreation and other water uses. Further, of those nutrients consumed by the fishes, some portion is released back into the aquatic environment as excreta, exacerbating the level of organic pollution in the lake. Processing of farmed fishes also results in the discharge of wastewater to Lake Erhai and the Xi'er River, as noted above.

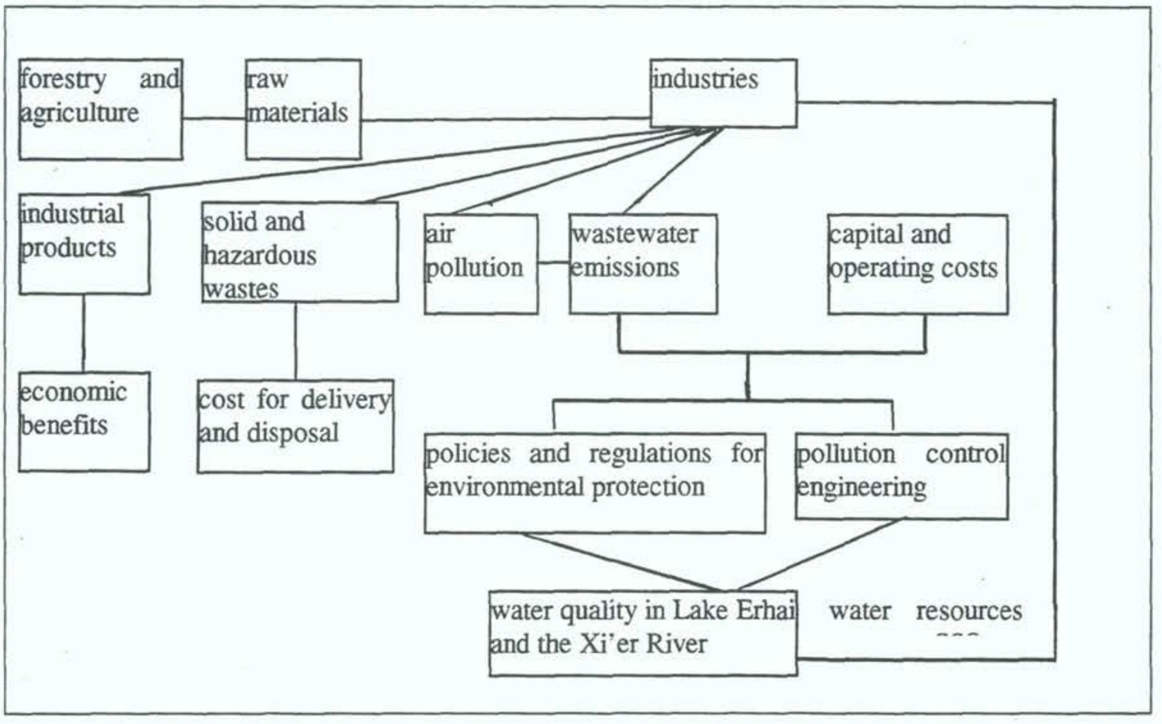

Figure 9. Relationships between industrial and manufacturing components.

Thus, conflicts exist between regional economic and environmental objectives with respect to this economic activity. Effective policies and regulations need to be determined for optimizing the economic benefits to be derived from fisheries activities while minimizing water quality impacts on Lake Erhai and the Xi'er River.

Tourism

The Dali Nationality Autonomous Prefecture was recently identified as a center for sightseeing and tourism by the central government. Thus, as has been noted, tourism is expected to become one of the most important economic sectors in the study area. Figure 11 shows the relationships among and between components of the tourism industry. The tourism industry will bring major economic benefits, in the form of the development and/or expansion of the service sector, souvenir industry, and lake-related recreational industry, to the study area.

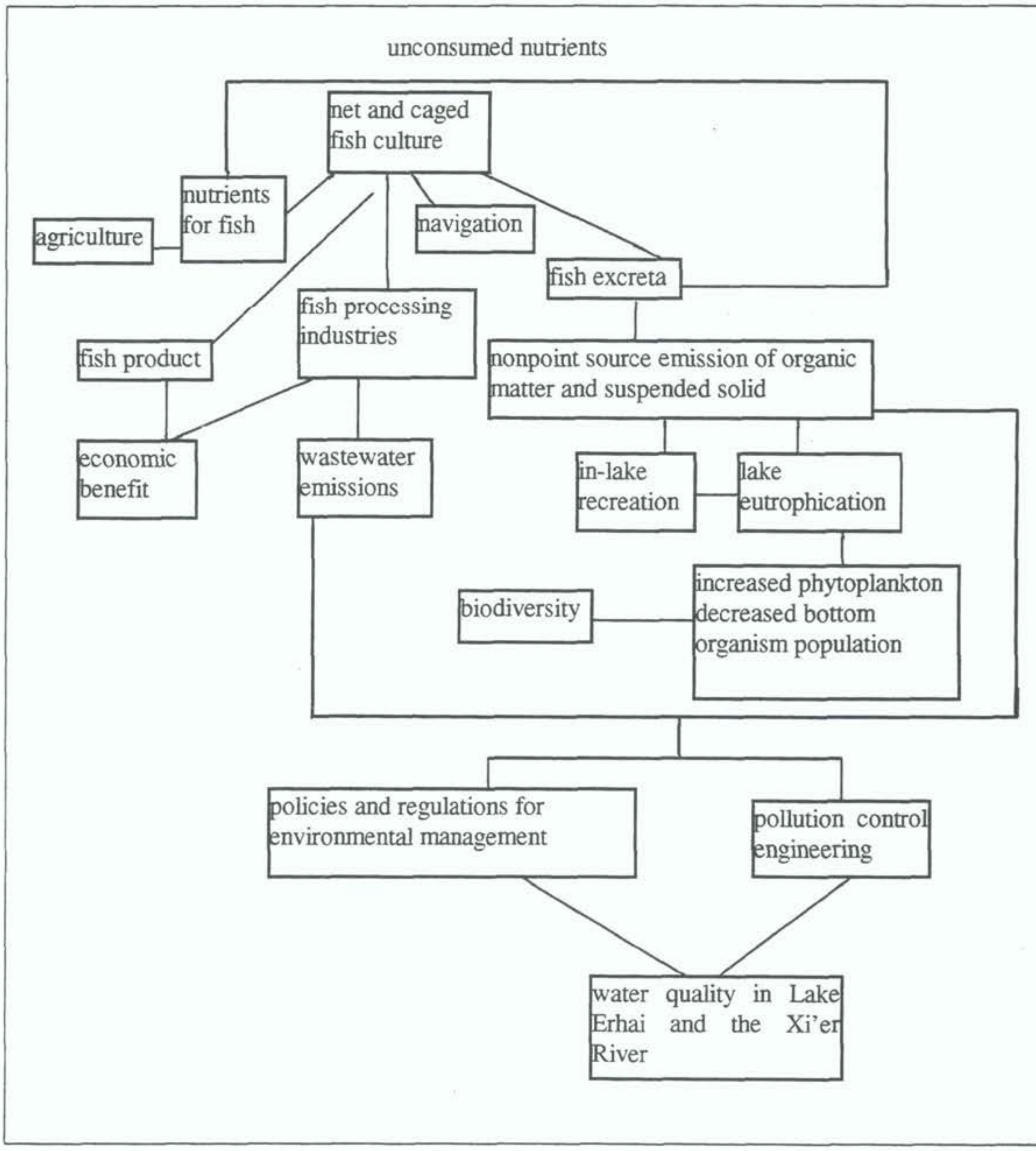

Figure 10. Relationships between net and caged fish culture components.

Tourism also contributes a number of environmental costs to the regional economy. The increased tourism, including increased in-lake recreational activity, will generate and discharge more sewage and garbage. Where such discharges occur within the lake, impacts on the quality and levels of production of the in-lake fisheries and net and caged fish culture industry can be anticipated. Provision of tourist infrastructure, while benefiting the construction industry, can reduce the available area of agricultural land, lead to a change in the pattern of agricultural production within the region, and cause increased compaction of the lands. For example, vegetable and fruit production may be increased in order to meet increased demand for these products from tourists, while lands in the vicinity of tourist sites may be subject to compaction by higher levels of vehicular and pedestrian traffic. Such changes can have additional impacts on the nature and amount of soil and nutrient losses, and impact biodiversity. Related souvenir production and tourist-related service industry activities may have further, indirect environmental impacts associated with the discharge of contaminants to the land, water, and air.

The planning and development of the tourism industry within the basin contribute varied benefits and costs related to environmental and resource management concerns that need to be carefully evaluated and considered. Effective policies and regulations need to be developed to manage tourism activities in order to maximize local economic development while minimizing water quality impacts on Lake Erhai and the Xi'er River.

Forestry

Figure 12 shows the relationships among and between forestry-related components. From the environmental management point of view, forest cover is a positive factor that helps to enhance soil conservation and maintenance of biodiversity in the basin. Forest cover also improves the aesthetics of the landscape, promoting the development of the tourism industry. In addition, sound forestry practices provide the raw materials for the manufacture of forest products, such as lumber and raw materials for pulp and paper production, that contribute significant economic benefits to the region. On the other hand, forestry competes with other economic activities for land. While forestry activities generally have a lower economic rate of return than the other economic activities, their roles in reducing soil and nutrient losses that currently contribute to the degradation of Lake Erhai, and in maintaining biodiversity, are important considerations. Such indirect benefits must be accounted for in the context of the sustainable development of the basin.

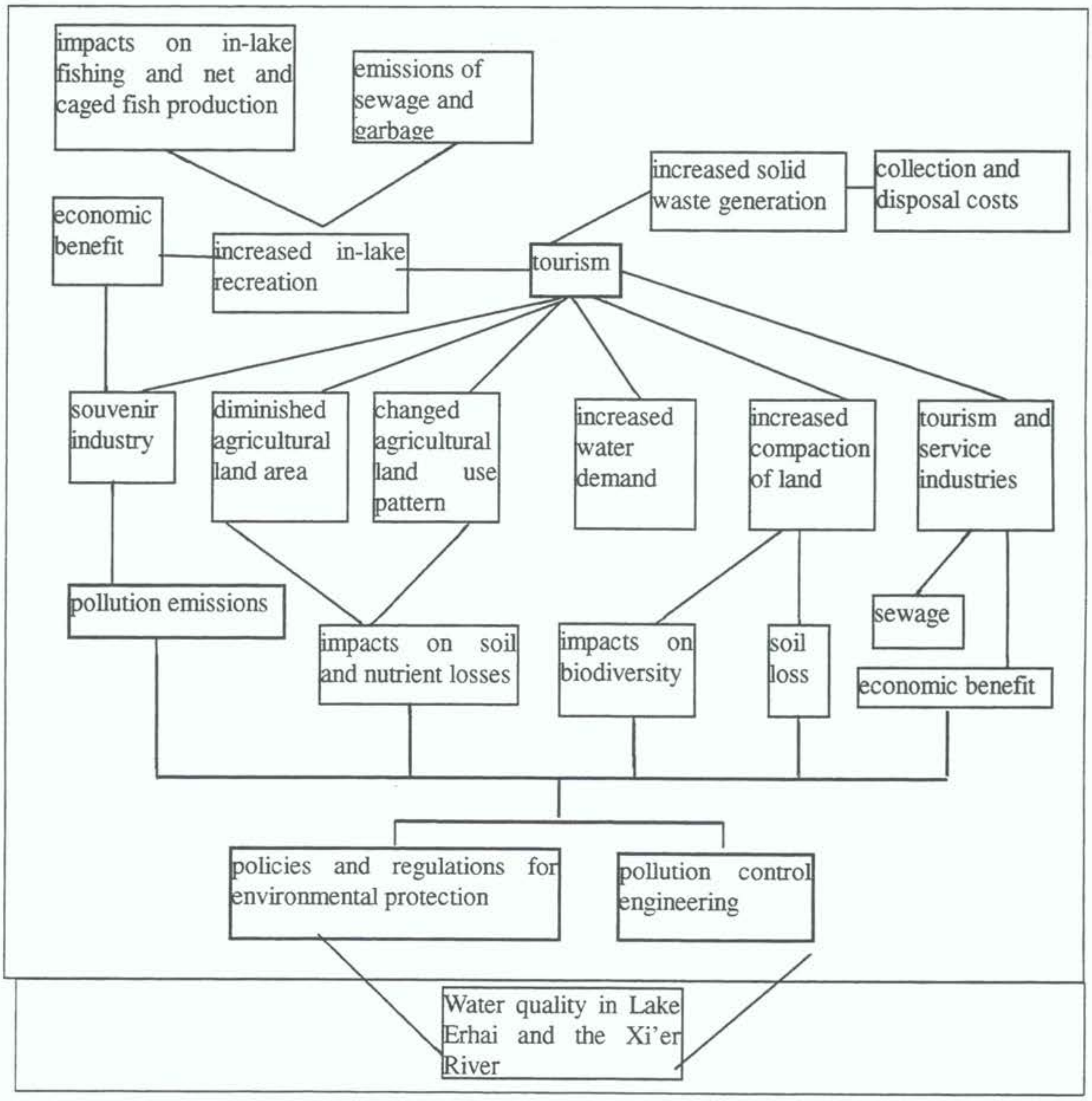

Figure 11. Relationships between tourism industry components.

The major environmental impact of the forestry industry is that of the discharge of organic-rich wastewater to the Xi'er River by the pulp and paper industries. Development of effective pollution control and waste management policies that address this pollution source will be important for water quality protection.

Quarrying

Quarrying is a major economic activity. In the western portions of the basin, along the Cangshan Mountains, the majority of the bedrock is marble which is extracted for use as a decorative and construction material for buildings throughout Asia. In the eastern portions of the basin, the majority of the bedrock is "Haidong Stone" which also is used for construction purposes.

Figure 13 shows the relationships among and between the economic components of quarrying. Stone products contribute significant economic benefits, which extend beyond quarrying operations to related industries, such as construction and production of construction materials. Quarrying also contributes disbenefits or costs related to the exposure of soils to erosive processes and increased soil loss to the lake. It also scars the landscape and can adversely affect tourism by degrading the aesthetics of the quarry area (although the quarries can become secondary tourist destinations if provision is made for viewing of the quarrying operations and sale of locally produced stone goods). Along with the eastern shoreline of the lake, excavations along a number of hillsides have led to damage of the lakeshore landscape that are unlikely to be amenable to landscape restoration activities. Quarrying also competes with agricultural and forestry activities for land, and contributes to increased solid waste generation and emissions of suspended solids (creating both air and water pollution problems).

Conflicts exist between environmental protection, economic development, and resource management objectives within this economic sector. Resolution of these conflicts will require careful analysis of the benefits and costs related to the environmental impacts. Such an analysis will contribute to the development of effective policies and regulations for managing quarrying activities, while protecting the water quality of the lake.

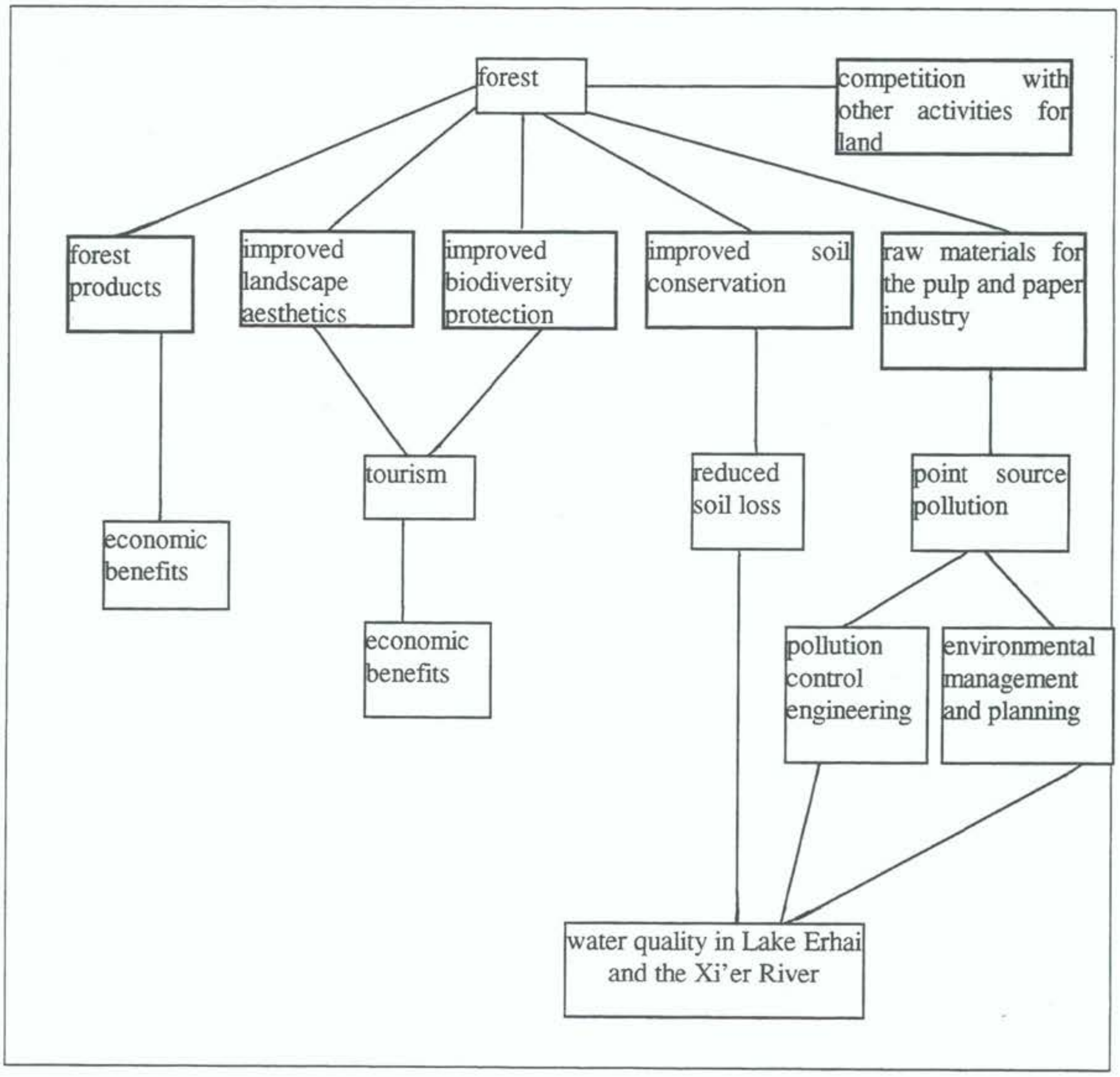

Figure 12. Relationships between forestry components.

Lake Navigation

Figure 14 shows the relationships among and between components of the lake navigation sector. Lake navigation is an important means of transportation having significant economic benefits. Lake navigation also contributes to the generation of income from tourism activities. Costs associated with lake navigation include impacts on the in-lake fishery and net and caged fish culture industry, and increased sewage and garbage discharges and oil spills from vessels. Therefore, from both the economic and environmental points of view, lake navigation activities need to be controlled at a level consistent with the objectives established for the protection of water quality in Lake Erhai.

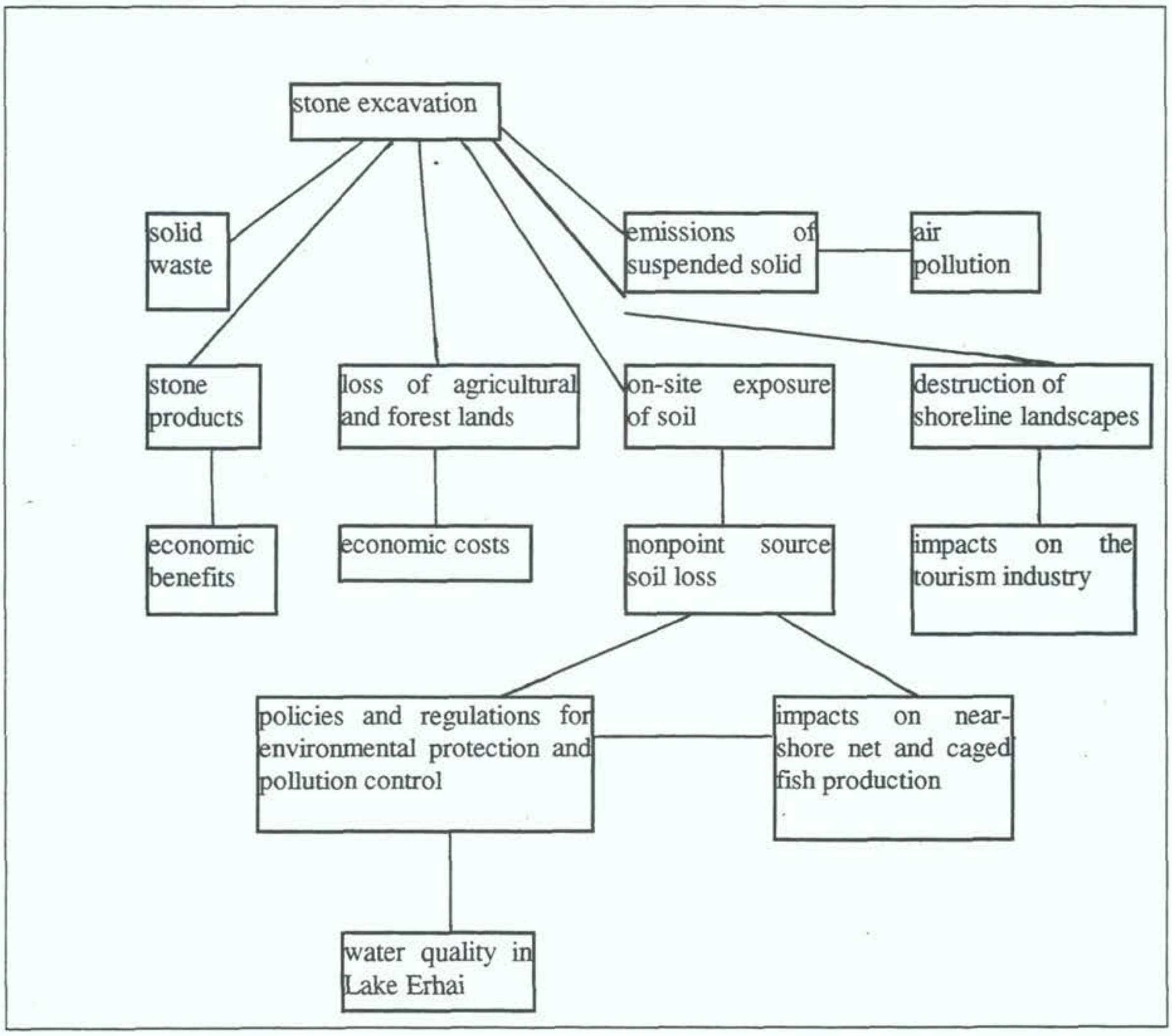

Figure 13. Relationships between excavation and quarrying components.

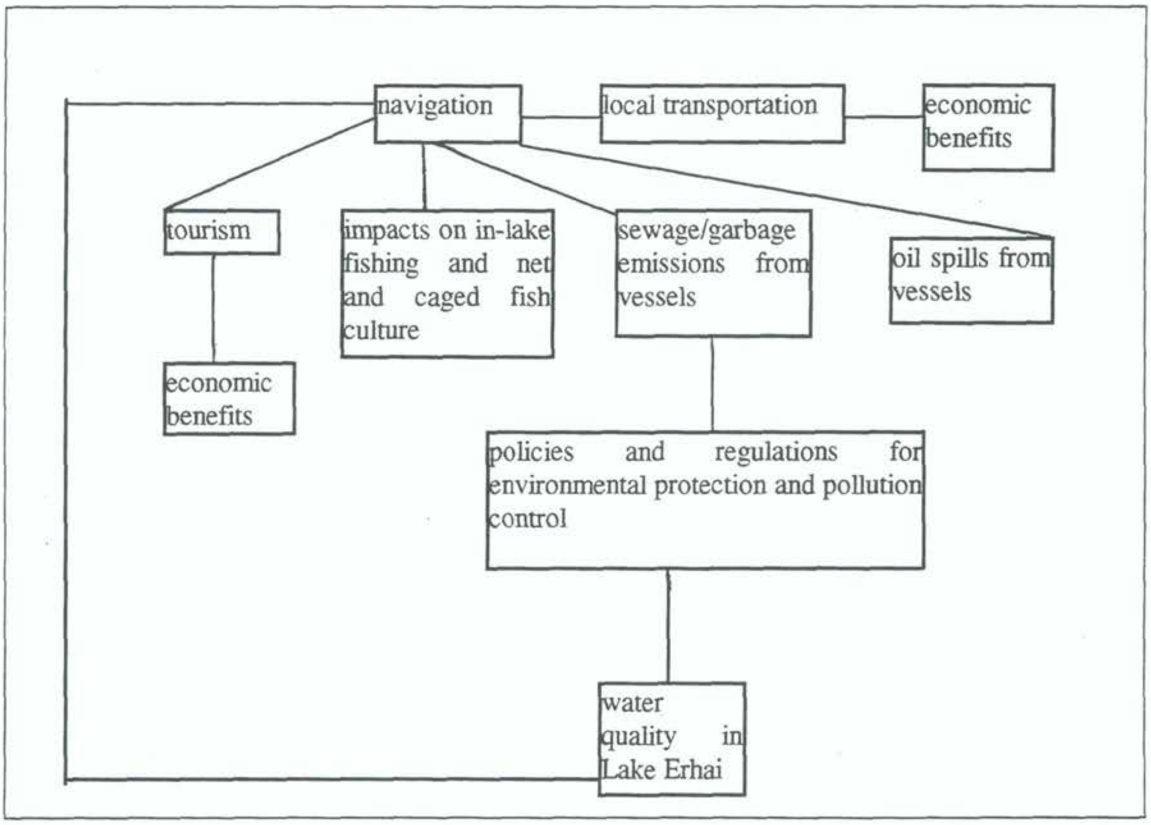

Figure 14. Relationships between lake navigation components.

In-lake Fisheries

Figure 15 shows the relationships among and between in-lake fisheries components. It is indicated that this activity will bring economic benefits through its fish products and the related fish processing industries. The negative effects from this activity include conflict with in-lake tourism activities, impacts on aquatic ecosystem and biodiversity, vessel oil leakage, and wastewater emissions from fish processing industries. These may lead to a series of environmental and economic consequences. Therefore, different aspects of benefits and costs and related environmental and resources concerns need to be comprehensively considered.

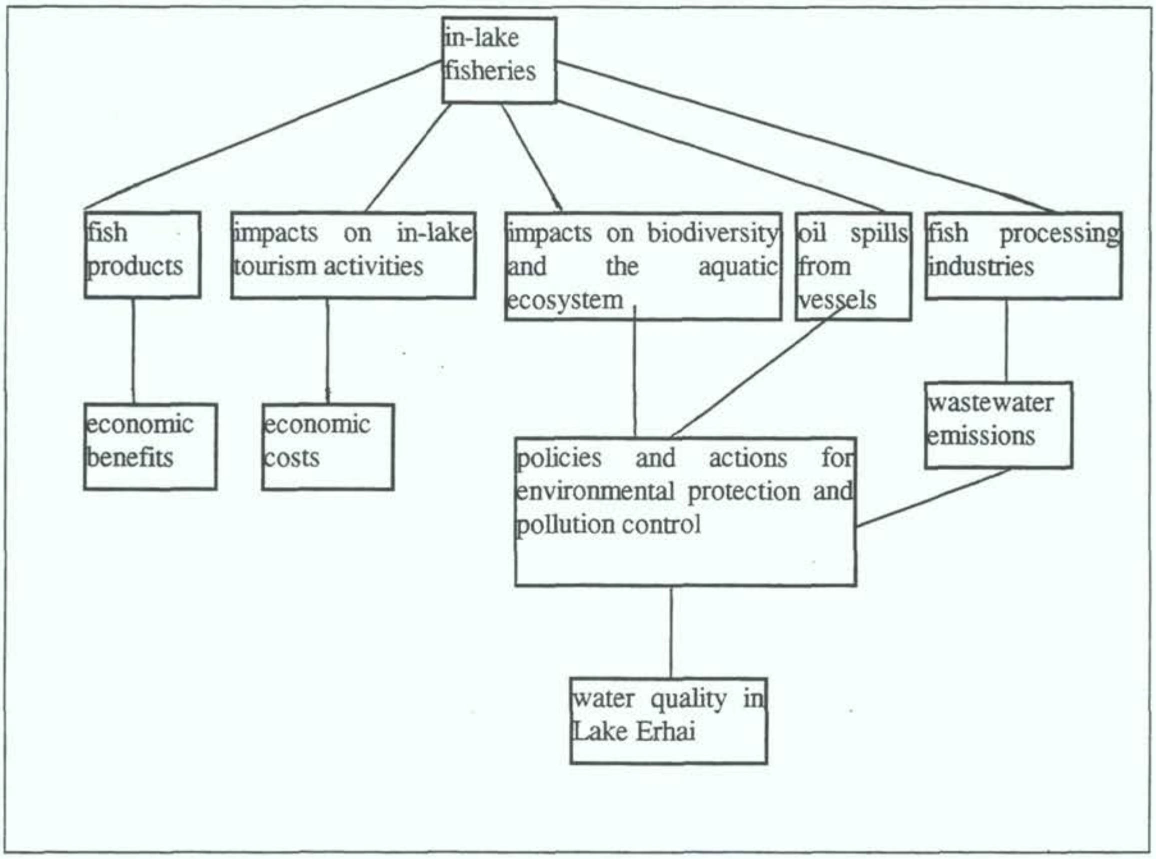

Figure 15. Relationships between in-lake fisheries components.

Lime-kiln/Brick-kiln Operations

Figure 16 shows the relationships among and between economic components of the lime and brick production industry. These activities contribute economic benefits through the sale of lime and brick products. However, there are a number of costs, including the high cost of scarce fuels. The shortage of coal and other energy sources in the study area places a major stress on forests and woodlands as a source of fuel used in the lime and brick production activities. Currently, due to unsustainable forestry practices, this stress contributes significantly to reduced forest cover, increased soil erosion, and decreased biodiversity. In addition, the excavation of specific soils which form the raw materials for lime and brick production exacerbate soil erosion problems. Disposal of lime-kiln and brick-kiln residues on the lands surrounding the production facilities also contributes to land degradation and loss of aesthetic value which affects both the aquatic environment and other regional economic activities (including tourism). Thus, effective policies and regulations for managing lime-kiln and brick-kiln operations must be developed in order to achieve the established water quality objectives in Lake Erhai and the Xi'er River.

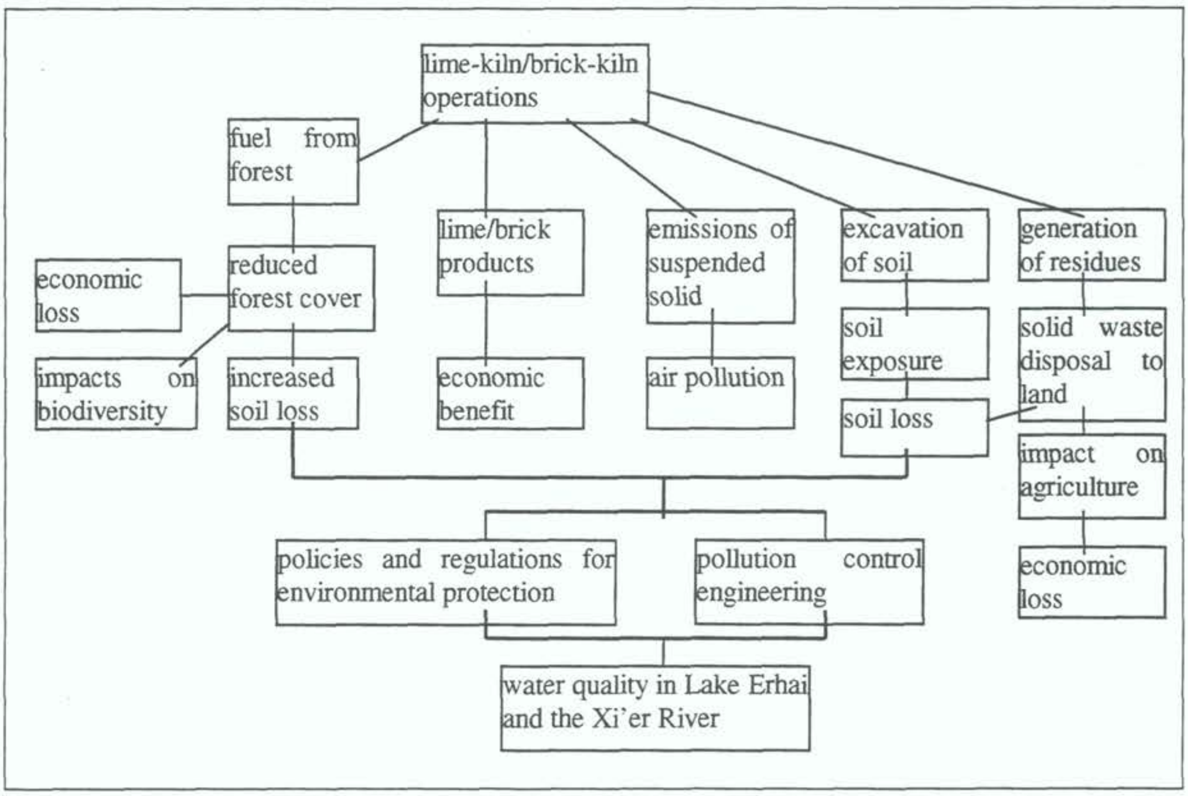

Figure 16. Relationships between lime-kiln/brick-kiln components.

Water Supply

Figure 17 shows the relationships among and between the various water users in the basin. Water use includes two aspects that relate to water supply needs; namely, off-site uses and on-site uses. Off-site uses are agricultural, residential, and industrial in character, and include hydropower generation and outflows for environmental purposes. On-site uses are fish culture, navigation, in-lake fisheries, and in-lake recreation. The major water consumers in the system are agriculture (consuming between 120×10^6 and 140×10^6 m^3/year) and residential/industrial users (consuming about 40×10^6 m^3/year). Of the estimated sustainable yield (about 700×10^6 m^3/year), most of the remaining water is normally used for power generation with some being diverted to external systems as described in Chapter 1.

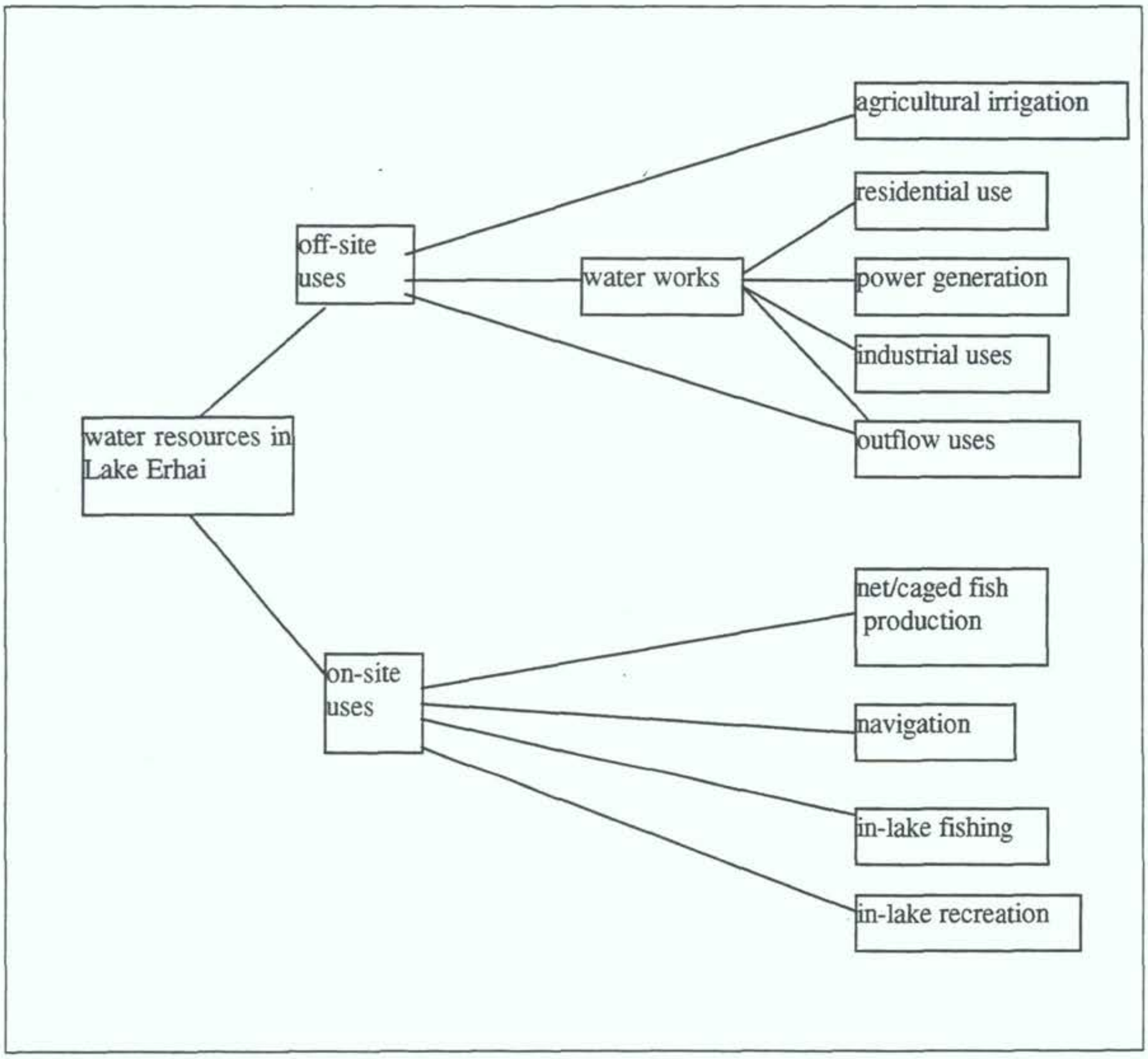

Figure 17. Water users in the study area.

Relationships Between Management Objectives

Figure 18 shows the relationships between environmental protection, resource management, and economic development objectives. While some economic activities contribute to environmental degradation and water pollution in Lake Erhai and the Xi'er River, economic activities also generate the revenues, needed for environmental protection and pollution abatement. On the other hand, there are limited natural resources and pollutant loading capacity in the basin area, which imply necessity for effective use of them. Therefore, environmental planning will help to design/plan a variety of system activities under these limited "allowances" for pollutant emission and resources consumption, in order to realize sustainable socio-economic development with satisfied environmental and resources objectives and maximized global system benefit.

Relationships Between Various Economic Activities

Figure 19 shows the relationships between various economic activities in the study area. Most economic activities are related to each other in some way. Any change in one component may lead to a series of consequences to, and responses from, the other components. Therefore, both economic and environmental planning within such a system must be based upon consideration of the whole system. Consideration of individual components, and even independent consideration of several components, cannot adequately reflect the responses of the overall system. This means that even a good plan based upon an individual economic sector, or even several economic sectors, may not be a good plan for the entire system if some related component was neglected. Therefore, systems analysis methods are essential for an integrated assessment of this complex system. Such methods must form the basis for sound environmental planning leading to the sustainable development of the basin.

Relationships Between Economic Activities and Related Pollution Problems

Figure 20 shows the relationships between economic activities and related pollution problems in the study area. As might be inferred from the relationships between economic activities, most activities are not only related to each other but also to a number of pollution problems. Any change in an economic activity may lead to a series of consequences that affect and effect a number of other activities and related environmental problems. Further, pollution problems are also related to each other.

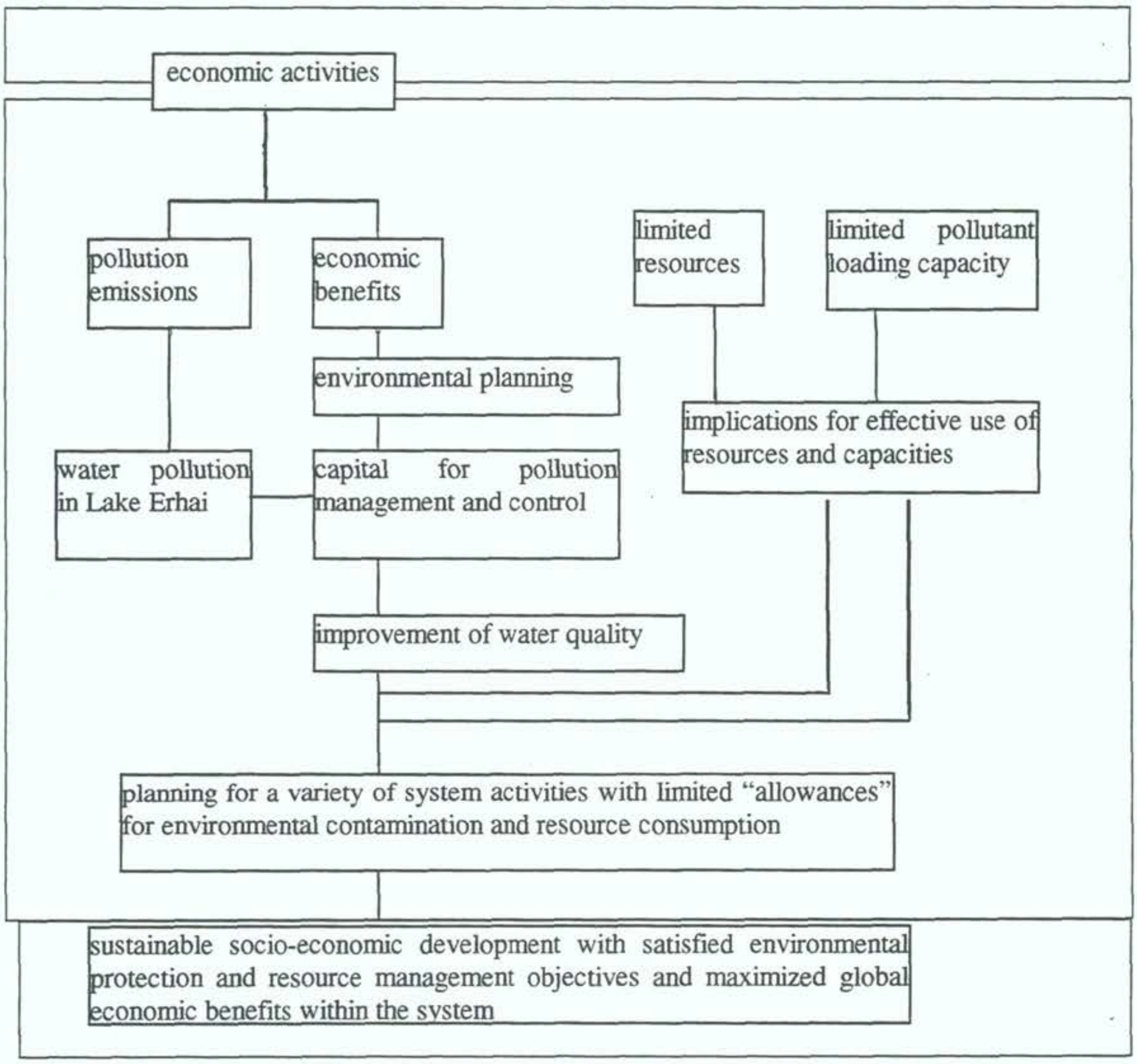

Figure 18. Relationships between environmental protection, resource management, and economic development objectives.

For example, point and nonpoint source pollution may affect biodiversity, while solid and hazardous waste generation may contribute to both point and nonpoint source pollution depending on disposal techniques used. Nevertheless, these relationships among and between activities and related pollution problems provide opportunities to achieve effective levels of pollution control and sustainable resource management while achieving economic growth (e.g., through targeted pollution control engineering projects and environmental management initiatives within regional development activities).

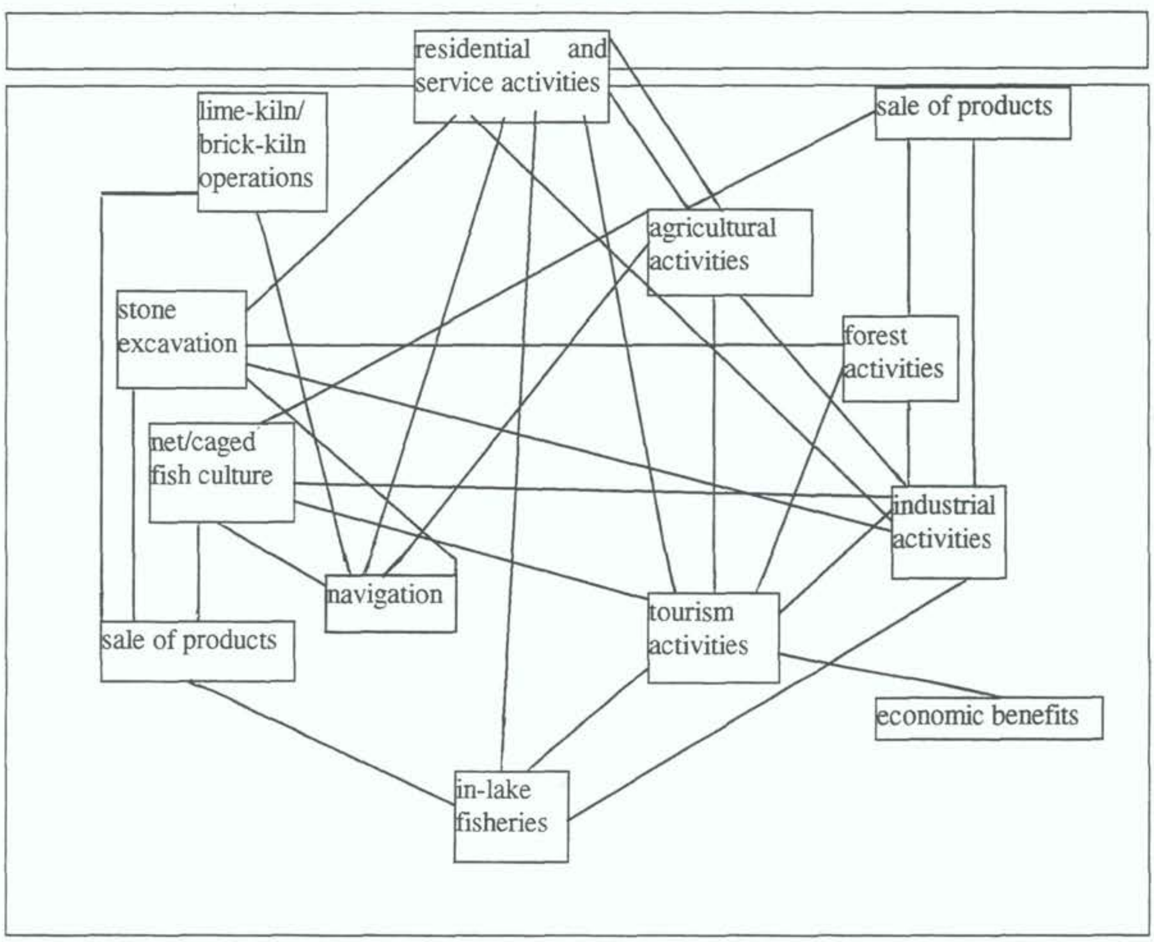

Figure 19. Relationships between various economic activities.

To take full advantage of these potential synergies, economic development decisions must be based upon a careful systems analysis that includes consideration of all related environmental, socio-economic, and resource management objectives. However, due to the complexity of the Lake Erhai and Xi'er River basin system, the systems analysis tool must be interactive and dynamic in order to successfully analyze options under conditions where multiple objectives and an high degree of uncertainty exist. These features are examined in more detail below.

Interactive features. Figures 18 through 20 show the interactive relationships between the various economic activities. As has been noted, any change in one component may lead to a series of consequences to, and responses from, a number of others. Therefore, the systems analysis methods used in environmental planning within the Lake Erhai and Xi'er River basin must be able to integrate a number of characteristics and consequences within this complex system.

Dynamic features. Social, economic, legislative, and resource management conditions will vary with time over the 15-year planning time horizon. Therefore, the systems analysis methods used in environmental planning within the Lake Erhai and Xi'er River basin must be sensitive to such temporal variations in order to generate effective and realistic environmental planning alternatives. Thus, the development of tools for dynamic optimization and inclusion of systems dynamics in analyzing problems is necessary for effective environmental management and planning. Because of the possibility of continual changes in system components with time, this necessity should lead to the development of a "real-time" decision support system. This means that the analytical results should be composed not only of a set of firm decision alternatives (presented as research reports) but also of a controllable management system through which the alternatives can be implemented (presented as computer software packages). Decision-makers can then input information for the future periods and generate updated solutions using the modelling software, allowing "new" planning alternatives to be developed. This "real-time" feature will improve the effectiveness of environmental planning in the basin.

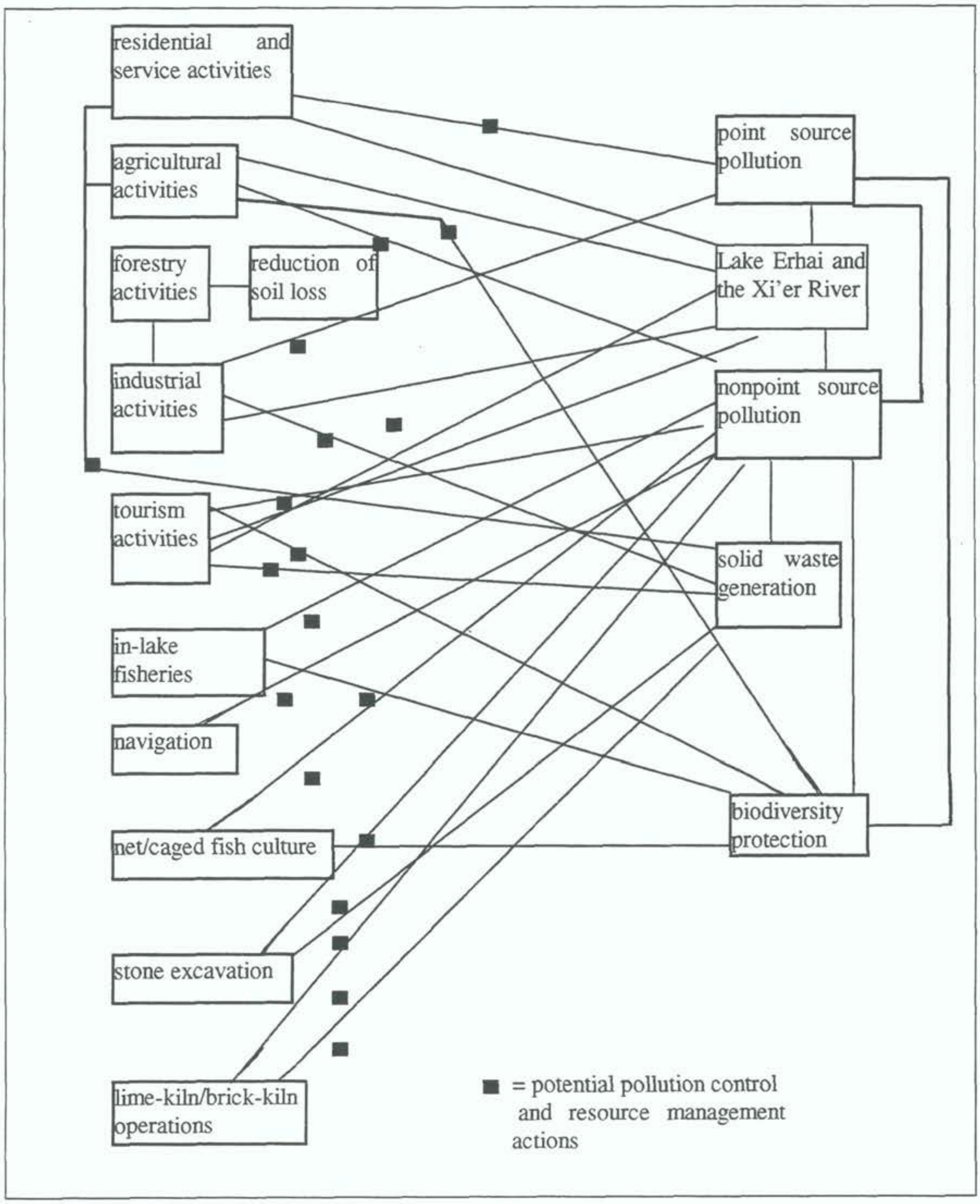

Figure 20. Relationships between economic activities and related pollution problems.

Multi-objective features. In the study area under consideration, many environmental protection, socio-economic development, and resource management objectives exist. Many of these competing objectives are of concern to a number of decision-makers and stakeholders having differing interests. These decision-makers and stakeholder interact with each other in various ways depending on the particular issue being analyzed. All decision-makers and stakeholders within the study area have the potential of limiting or promoting each of the other decision-makers and stakeholders. Thus, the systems analysis methods must be sensitive to tradeoffs and/or compromises between the interests of different stakeholders in order to maximize overall benefits throughout the entire system (i.e., the entire basin during the entire planning time horizon).

Uncertainty features. Many system components and parameters, as well as their inter-relationships, are difficult to identify, analyze and quantify within an analytical framework. From the modelling point of view, such difficulties are analyzed as uncertainties in the study system. Such uncertainties are poorly conveyed using mean or median values to represent uncertain information, leading to loss of information and/or mistakes in the interpretation of the result. In the Lake Erhai and Xi'er River system, many activities are uncertain. For example, it is hard to calculate a deterministic value for the loading capacity of tourists at a specific tourism site. Instead, only some uncertain information can be obtained to represent it. If this information is simply presented as a mean or median value, the reliability of the result used in making planning decisions may be adversely affected. Consequently, development of systems analysis methods that can effectively reflect uncertainties is important for generating reliable and realistic planning alternatives.

Model Selection

Based upon the analysis set forth above, the resolution of the complex relationships identified as existing within the Lake Erhai and Xi'er River basin requires that a nested set of dynamic mathematical models be used to forecast likely outcomes of a given set of proposed actions. Recent advances in programming have resulted in a number of compatible methodologies to be developed. These methodologies include the Inexact Fuzzy Multi-objective Programming model

(IFMOP), the Systems Dynamic model (SD), the Environmental Support Capacity Assessment model (ESCA), and the Object-Oriented Programming model (OOP). The assumptions inherent within these techniques can be applied in combination to guarantee the rationality, applicability, and flexibility demanded when undertaking a task as complex as the environmentally-sound planning of a large watershed. The basic features of these programming methods are highlighted below, and form a methodology for effecting watershed-based, environmental planning decisions in the Lake Erhai basin.

Inexact Multi-objective Optimization (IMOP) and Inexact Fuzzy Multi-objective Optimization (IFMOP) Approaches

The Inexact Multi-objective Programming model (IMOP) is formulated by incorporating the concepts of inexact analysis and multi-objective programming (MOP) within a general framework. The IFMOP is an extended hybrid approach that incorporates fuzzy set theory within the IMOP framework. The merit of the IFMOP model is its efficiency in dealing with the uncertainties of real-world systems. IFMOP allows uncertainties to be directly incorporated within the programming process and resulting solutions. Its inexact solutions can be interpreted for generating decision alternatives and conducting further risk analyses. Generally, the solutions for each decision variable, which are represented as interval numbers, can be interpreted within the intervals according to the practical conditions or the preferences of the decision-makers. This facility allows the generation of management schemes for the human activities in different temporal-spatial units. Because this method produces a range of outcomes, if the decision-makers are not satisfied with a particular set of schemes, modifications of the inexact solutions can be easily undertaken until a more satisfactory set of schemes is determined. In this way, the IFMOP model can not only deal effectively with the multi-objective and uncertain real-world problems, but also can facilitate realization of the applicable planning schemes produced. In short, the IFMOP model incorporates the four features identified in the analysis set forth above.

A general MOP problem with uncertain parameters can be formulated as follows:

$$max\ \{f_k^{\pm}(\mathbf{x}^{\pm})\ |\ \forall k\}, \tag{2.1a}$$

$$s.t.\quad g_i^{\pm}(\mathbf{x}^{\pm}) \le b_i^{\pm}, \qquad \forall i, \tag{2.1b}$$

$$x_j^{\pm} \ge 0\ ,\ x_j^{\pm} \in \mathbf{x}^{\pm}, \qquad \forall j, \tag{2.1c}$$

where $x^{\pm}$ is a vector of the uncertain decision variables; $f^{\pm}_k\ (x^{\pm})$ are uncertain objective functions; and, $g_i^{\pm}(x^{\pm}) \le b_i^{\pm}$ are uncertain constraints.

When all of the parameters in equations (2.1) are known as intervals without distribution information, the solution is an IMOP problem. When some parameters are known as intervals and some parameters can be specified as membership functions, the solution of equations (2.1) becomes a hybrid IFMOP problem. Generally, the hybrid inexact optimization approaches will allow effective identification, quantification, communication, and assessment of different types of uncertainties and their associated risks. They will be more computationally efficient, with the development of interactive algorithms, and can be directly used for generating decision alternatives and providing bases for further tradeoff analysis and risk assessment. The specific model to be used is determined based upon consideration of the problem, data availability, desired solution, approach, and related computational effort.

2.3 The Lake Erhai Model

The environmental planning program for the Lake Erhai basin can be divided into several portions or stages, based upon the locations of specific actions within the lake basin and upon different time intervals within the planning horizon. For purposes of this study, the interactions between the various system components are integrated within a general framework provided by the Lake Erhai-Xi'er River hydrologic system, and occur over a planning horizon from 1997 through 2010. The decision variables represent various activities in different spatial locations throughout this time period, as well as elements reflecting the dynamic nature of the decision-making process surrounding development/expansion decisions (i.e., decisions that are based upon varying environmental, economic, and resource management conditions). The objective is to optimize development activities, including environmental protection and resource management components, in light of the consideration of economic and environmental tradeoffs. Constraints include almost all of the relationships between the decision variables and a variety of system conditions. Thus, an IMOP environmental planning model (or its fuzzy hybrid version) is an ideal choice for forecasting potential outcomes.

Optimization Approach and System Variables

A model for Lake Erhai should be structured to maximize (or minimize) the respective outputs to achieve the optimal:

- economic objective
- forest cover objective
- soil conservation objective
- water quality objectives, including nitrogen loss and phosphorus loss control objectives and a COD discharge objective.

Identified constraints within which the model should operate include:

- land availability constraints
- agricultural production constraints
- forest-related constraints
- industrial constraints
- tourism constraints
- net and caged fish culture constraints
- lime-kiln and brick-kiln production constraints
- water demand and supply constraints
- soil erosion tolerance constraints
- technical constraints.

The decision variables involved in reconciling these objectives and constraints span the fifteen economic sectors, two planning periods (i.e., near term and long term), and seven geographic sub-areas. The economic sectors can be categorized as follows. In terms of primary industries, decision variables relate to the economic activities that occur within the:

- paddy farm area
- dry-land farming area
- vegetable farming or market gardening area.

In terms of secondary industries, decision variables relate to the output value, or value-added, of economic activities within the:

- food industry
- textile industry
- chemical fiber industry
- cigarette industry
- cement industry
- pulp and paper industry
- leather industry.

In terms of tertiary industries, decision variables relate to the volume of economic activities:

- the number or tourists
- the extent of forest coverage
- the mass of net and caged fish produced
- the numbers of bricks produced
- the mass of lime produced.

The outputs of the IFMOP model, based upon the foregoing elements, will provide decision-makers with an answer about "what to do" without elucidating a set of possible outcomes based upon proposed interventions. Resolution of the dynamic "what if we do....?" scenarios requires the use of a system dynamics model. Hence, the integration of the IFMOP outputs into a SD sub-model is proposed to simulate the temporal variations of the system. Such simulations will inform decision-makers regarding the range of potential outcomes associated with implementing IFMOP-generated actions. These simulation results will be used to evaluate the proposed alternatives, and allow decision-makers and administrative personnel to modify alternatives based upon these likely outcomes. Such an approach should provide a reasonable and applicable planning program for the Lake Erhai basin.

Specifically, the analysis of the socio-economic and environmental factors influencing the basin, as well as interactions with local experts, decision-makers, and stakeholders, contributed to the definition of a number of subsystems and modeling variables. These were centered on the key concerns over water quality and water quantity in the lake. Such concerns, in turn, were related to a number of human economic activities having a sectoral base, including population development, industry, agriculture, tourism, and fisheries. The SD sub-model reflected these key concerns, with their related subsystems and variables, and their inter-relationships, eight sub-systems:

- the population subsystem
- the agricultural subsystem (primary industry)
- the industrial subsystem (secondary industry)
- the tourism subsystem (tertiary industry)
- the water resources subsystem
- the pollution control subsystem
- the lake water quality subsystem
- the forestry subsystem.

These variables were identified after consideration of not only the overall planning objectives but also the impacts of the individual subsystems on the resource. Over 600 variables were considered, with 18 of them being principal state variables (see the Appendix).

It is important to note that the SD model assumes a closed system, within which all dynamic activities occur. In contrast, an open system allows frequent communication between internal activities and external systems. Most "real-world" systems are open, which leads to uncertainties and difficulties in determining their boundaries and in quantifying the external systems. To overcome these uncertainties in a practical way when dealing with water resource systems, a watershed approach is adopted. In the case of Lake Erhai, the boundary of the drainage basin, encompassing the 2,565 km^2 watershed, is used as the basis for the model evaluations. By using this area, the Lake Erhai system can be assumed to be a relatively closed system within which a limited but quantifiable number of socio-economic and environment-related activities take place.

Environmental Supporting Capacity

The environmental supporting capacity (ESC) is defined, under a given set of environmental conditions, as a system's ability to tolerate pollutants without damage to human health and minimal damage to the ecosystem. This concept can be used for evaluating the capacity of a regional environment to support planned economic activities. Determination of the environmental supporting capacity is based upon a select set of environmental indicators which is used to develop a quantitative solution.

The selection of suitable indicators is a key step in the ESC analysis. As noted above, the geographic basis for this selection is the watershed. The urban environment provides the geographic basis for social and economic development. Traditionally, some of the surrounding waterbodies would become receptors for industrial and residential sewage. As a consequence, the utility of these waterbodies to support further urban development would be degraded. Thus, factors related to water supply and demand, and to wastewater management and sewage discharge, would play important roles in supporting on-going urban socio-economic development.

The availability of water resources can be quantified in terms of extractable volume, available volume, and volume currently exploited, as well as in terms of the monetary investment required to develop the remaining available water resources. Similarly, water pollution can be quantified as the volume of wastewater discharged, the types and concentrations of specific pollutants, and current water quality, as well as the level of monetary investment required to provide sewage treatment. Using water pollution control as an example, six ESC indicators can be defined.

The value of industrial output per capita of non-agricultural population (PIOT/UP). The PIOT/UP reflects the capacity, efficiency, and development level of industrial activities. It is also related to the system's capability for providing environmental investments.

The value of industrial output per unit of water resources consumed (PIOT/IWU). The PIOT/IWU reflects the efficiencies of industries in using limited water resources. It is related to the level of technological and managerial sophistication of the industries.

The value of industrial output per unit of wastewater generated (PIOT/ISWT). The PIOT/ISWT reflects the efficiencies of industries in using the limited pollutant emission allowances. It is related to the level of technological and managerial sophistication of the industries, the products being produced, and the rate of water recycling by the industries.

The value of industrial output per mass of pollutant generated (PIOT/ICODT). The PIOT/ICODT reflects technological levels of pollution control within the industries.

The area of land irrigated per unit volume of water resources consumed (TAA/AWU). The TAA/AWU reflects the level of technological and managerial sophistication of the irrigation systems.

The wastewater treatment rate (WSWR). The WSWR reflects the investment in sewage treatment technologies and their efficiency in pollutant removal.

Once these indicators have been identified, the developing variables and supporting variables must be defined. Developing variables reflect the impacts of socio-economic development on lake water quality. These variables can be expressed in terms of population numbers, output value, investment, volume of water supplied, or volume of wastewater generated. The set of developing variables can be expressed as:

$$d = (d_1, d_2, \ldots, d_n) \qquad (2.2)$$

Supporting variables are related to the structure of the environmental system and to conditions that support urban economic development. The set of supporting variables can be expressed as:

$$s = (s_1, s_2, \ldots, s_n) \qquad (2.3)$$

Thus, the ESC is an n-dimension vector with each of its elements being determined by indicators related to the developing and supporting variables. For a city or region, the values of the developing and supporting variables vary with alternative economic development strategies. These variations create variations in the ESC value that permit the alternatives to be assessed relative to each other and with respect to specific development objectives.

Since the dimensions of the ESC elements differ, they must be normalized to facilitate comparison. Assuming that there are m alternatives within an urban economic plan, m corresponding environmental supporting capacities can be calculated:

$$E = (E_1, E_2, \ldots, E_n) \qquad (2.4)$$

Each of the m elements is composed of n specific indicators:

$$E_j = (E_{1j}, E_{2j}, \ldots, E_{nj}) \qquad (2.5)$$

Normalizing these values, the value of the ESC can be calculated as:

$$\overline{E}_j = (\overline{E}_{1j}, \overline{E}_{2j}, \ldots, \overline{E}_{nj}) \qquad (2.6)$$

where:

$$\overline{E}_{ij} = \frac{E_{ij}}{\sum_{j=1}^{m} E_{ij}} (i = 1,2,\ldots,n) \qquad (2.7)$$

The environmental supporting capacity for j can be obtained by computation as follows:

$$\left|\overline{E}_j\right| = \sqrt{\sum_{i=1}^{n} (\overline{E}_{ij})^2} \qquad (2.8)$$

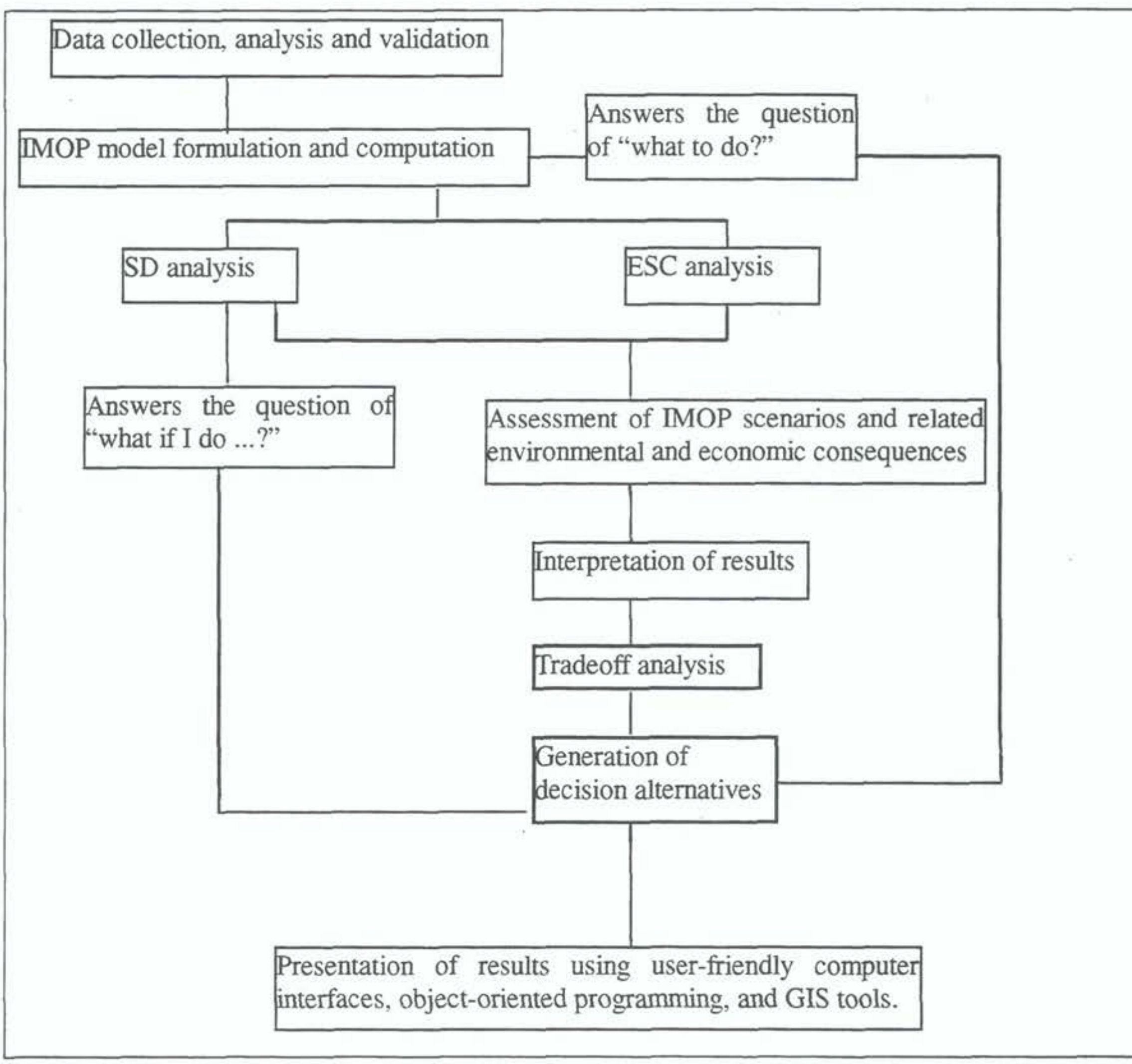

Figure 21. Generalized flow chart of the modelling approach.

Figure 21 presents a generalized flow chart of the modelling approach. This approach synthesizes the five major elements of the study as follows:

- data collection, analysis, and validation through on-site investigation, which is directly related to the reliability of the research
- IMOP model formulation and computation to support integrated environmental management and planning decisions that answer the question of "what to do?" for a variety of human activities in different temporal and/or spatial units
- SD and ESC model evaluations of the IMOP outputs for detailed assessment of the planning scenarios and assessment of related environmental and/or economic consequences
- interpretation and analysis of outputs and potential tradeoffs to generate a realistic and applicable set of alternatives
- presentation of the alternatives using user-friendly computer interfaces, object-oriented programming, and geographical information system technologies.

2.4 Results of the Modelling

As has been noted, the objective of using the IFMOP/SD model package is to harmonize the differing economic and environmental interests that relate to the sustainable development of the Lake Erhai basin. The model allows the preparation of alternative planning scenarios by using various objective function values that represent a range of decisions with differing environmental and/or economic tradeoffs. Without such an objective means of evaluating alternatives, it generally is assumed that planning to ensure that water quality standards are met will result in diminished economic benefits. Using the model-based approach, planning to ensure that water quality standards are met aims toward enhanced economic benefits by achieving water quality objectives through reliably controlling pollution. This means that economic development does not take place at the expense of water pollution. Undoubtedly, the coordination of economic development and environmental protection is the key for the sustainable development of the lake basin, and it is well recognized that the protection and rehabilitation of water quality in Lake Erhai is of the highest priority.

Optimization of the Industrial Sector in the Lake Erhai Basin

The resources of the study area are not being efficiently utilized due to the structure of the industrial sector. Currently, the principal industries within the drainage basin of Lake Erhai are food processing and commerce. These are quite different to the principal industries of a decade ago, when agriculture was the dominant industry. While the agricultural sector retains a dominant position in the local economy, the value of agricultural outputs has been declining in recent years. At the same time, the development of forestry, animal husbandry, fisheries and related industries are falling behind.

Despite the continuous increase in the value of outputs from secondary industries, these industries remain relatively backward in terms of technology and their capacity for applying advanced technologies. Likewise, tertiary industries face the problems of an imperfect free-market and low standards of service (although service has improved rapidly during recent years) which constrain development. Alternatives generated using the IFMOP model aim to optimize this dysfunctional structure and formulate an optimal mix of industries within the basin.

Generally speaking, the strategy for promoting industrial development in the lake basin is to develop high quality, high value-added, and high-tech industries. The IFMOP model suggests that, ideally, the development of primary industries be stabilized and that secondary and tertiary industry development be accelerated and improved. The value of economic outputs from tertiary industries and secondary industries, respectively, is planned to account for about 40 percent and 50 percent of the GNP by the end of this century. Some of this increased revenue will be generated by new industrial development.

One of these new industries is tourism. The basin has abundant tourism resources. Promotion of tourism should be one of the industrial alternatives to be identified and analyzed using IFMOP-generated solutions. The tourism industry has a low pollution potential and high economic efficiency. However, tourist flow, upon which tourism depends, is not only related to human efforts to protect and improve scenic spots and tourist services, but also to a number of external factors. For example, there is an upper limit to the numbers of potential tourists that can physically enter and reside in the study area. Therefore, much attention should be paid to the environmental carrying capacity of the lake basin when promoting the development of the tourism industry. This problem will be further discussed in next chapter.

Other tertiary industries, such as the information industry, the financial services industry, real estate industry, and insurance industry, also could be promoted so as to optimize the economic development of the basin and spur the development of secondary industries in the lake basin.

As to secondary industries, the IFMOP outputs suggest that cigarette and food processing industries be promoted during the planning period. The cigarette industry contributes to the regional economy with relatively low pollution potentials. The food processing industry supports tourism development and contributes to improved living standards. It is worth noting that there are very abundant biological resources in the Lake Erhai basin, so the development of a food industry based upon local sources of supply possesses high potential. However, food processing technologies and product quality can be improved. The pollutants generated by the food processing industry are not difficult to treat.

With regard to other existing industries, careful consideration must be given to their continued existence and development. Questionable industries include the pulp and paper, chemical fiber, leather, textile, and cement processing industries. Although these industries currently contribute significantly to local economy, they are responsible for a significant amount of organic pollution discharged to the lake and river. Among these, the pulp, chemical fiber, and leather production industries currently employ technologies that generate a large amount of organic pollutants (with high COD concentrations). Thus, alternatives generated as IFMOP outputs suggest that the technologies be modified to significantly reduce the mass of pollutants generated, or that the industries be moved to external systems that have higher environmental support capacities. Of the remainder, the textile, paper and cement industries generate fewer pollutants, but the IFMOP solutions suggest that their status be considered questionable in the short-term. Since the development of the study area is predicated upon improved environmental conditions conducive to tourism, a conservative strategy may be desired. The IFMOP solutions for these activities, therefore, would be interpreted at their lower boundaries. Such an interpretation would limiting these industries' further development, while, at the same time, encouraging the development of high-tech industries with low or no pollution potentials. In the long-term, development of these industries would be promoted when improved production and pollution control technologies with high environmental-economic efficiencies are available.

Agriculture is a traditional activity in the basin. While the majority of population in the region is farmers, agricultural activities produce less than 20 percent of total economic return in the lake basin. At the same time, they significantly contribute to nonpoint source water pollution problems. Since management and engineering measures can only partly mitigate these problems, the IFMOP solutions suggest that there is a need for a fundamental adjustment of the structure of the agricultural industry itself. While this adjustment is being made, efforts should continue to popularize agro-ecological engineering technologies and promote good quality and high yield agriculture to build a base for green food production in the lake basin.

Scenario Development

Using the industrial mix identified above, the IFMOP model for the Lake Erhai basin was solved under three scenarios with different environmental-economic conditions:

- Scenario 1 provides for a balance between environmental and economic objectives.
- Scenario 2 provides for an emphasis on industrial development to increase economic returns while accepting increased risks of water pollution problems (this scenario corresponds to a relatively optimistic environmental management strategy).
- Scenario 3 provides for an emphasis on environmental protection through

stringent industrial water pollution control requirement, the cost of which significantly reduces economic returns within the basin (this corresponds to an extremely conservative strategy).

All the three scenarios were based on a common prerequisite; namely, satisfaction of the water quality objectives for Lake Erhai and the Xi'er River.

These scenarios correspond to different objective function values, which represent differing decisions regarding environmental and economic tradeoffs. Generally, planning for lower economic benefits may help to ensure that water quality standards are met (based on the cost of reduced income from economic activities). Planning for higher economic benefits (especially for benefits from industrial activities) subordinates reliability of achieving water quality objectives to the means by which pollution problems are controlled (i.e., the risk of substandard water quality potentially may be increased). In other words, planning for lower economic returns represents a conservative strategy while that for higher returns represents an optimistic strategy. Thus, the inexact IFMOP solutions allow detailed analysis of the tradeoffs between environmental pollution risks and economic objectives. This approach has value not only in planning future system activities, but also in adjusting or justifying the existing activities in the study area.

IFMOP Modelling

The results of the IFMOP modelling were used as inputs for the SD model for further analysis. Variables considered include: the temporal variations in tourist populations; the development of secondary industries (seven sectors) and increased industrial output values; and, variations in cropped area among the primary industries (three types of farm lands, and net and caged fish culture). In the IFMOP model, environmental concerns were reflected not only in the objectives (i.e., maximized environmental efficiencies) but also in the constraints (i.e., water quality in the lake must meet the required water quality standard). The IFMOP solutions reflect variations in system emphases (e.g., on economic or environmental objectives) and the related environmental risks. When the IFMOP results are input into the SD model for further analysis, more detailed interpretation of the scenarios' socio-economic and environmental implications can be obtained. The following parameters are considered in the SD model based on the IFMOP outputs:

- gross value of industrial outputs (PIOT)
- agricultural water consumption (AWU)
- industrial water consumption (IWU)
- nitrogen concentrations in irrigation return flows (NAWUR)
- phosphorus concentrations in irrigation return flows (PAWUR)
- volume of wastewater to be treated (DTSW)
- volume of wastewater actually treated (TTSW)
- total volume of wastewater generated (SWT)
- total volume of industrial wastewater generated (ISWT)
- total mass of COD generated (TCOD)
- total mass of industrial COD generated (ICODT)
- water pollution index (WPI).

The IFMOP solutions for each of the three scenarios (i.e., Scenarios 1 to 3) and the results of the SD modelling for each of the parameters set forth above are shown in Tables 20 through 31. In these tables, E is present conditions; A1 is Scenario 1, balanced environmental and economic objectives; A2 is Scenario 2, increased economic returns while accepting increased risks of water pollution problems; A3: Scenario 3, increased environmental protection through stringent industrial water pollution control requirements.

Table 20. Gross value of industrial output (10^9 Yuan)

YEAR	*PIOT(E)*	*PIOT(A1)*	*PIOT(A2)*	*PIOT(A3)*
1996	1.35	1.57	1.60	1.53
2000	1.94	1.95	2.06	1.86
2004	2.29	2.07	2.15	1.94
2008	2.55	2.19	2.25	2.02
2010	2.66	2.25	2.30	2.06

Table 21. Water pollution index

YEAR	*WPI(E)*	*WPI(A1)*	*WPI(A2)*	*WPI(A3)*
1996	1.03	1.00	1.00	1.00
2000	1.00	0.88	1.07	0.85
2004	1.02	0.87	1.01	0.81
2008	1.07	0.88	0.99	0.78
2010	1.11	0.89	0.99	0.77

Table 22. Amount of wastewater to be treated (10^6 tons)

YEAR	*DTSW(E)*	*DTSW(A1)*	*DTSW(A2)*	*DTSW(A3)*
1996	22.91	24.60	27.31	22.56
2000	30.74	26.12	33.40	20.20
2004	35.02	28.56	34.42	20.21
2008	39.06	31.01	35.45	20.22
2010	41.48	32.24	35.96	20.23

Table 23. Amount of wastewater treated (10^6 tons)

YEAR	*TTSW(E)*	*TTSW(A1)*	*TTSW(A2)*	*TTSW(A3)*
1996	8.21	8.04	8.74	8.01
2000	18.07	16.31	20.04	15.91
2004	20.21	17.25	21.69	15.51
2008	23.40	18.58	22.33	15.68
2010	25.09	19.33	22.60	15.91

Table 24. Agricultural water consumption (10^6 tons)

YEAR	*AWU(E)*	*AWU(A1)*	*AWU(A2)*	*AWU(A3)*
1996	207.09	209.54	208.12	211.04
2000	207.19	213.97	210.12	218.16
2004	207.29	214.31	211.04	218.99
2008	207.39	214.65	211.96	219.84
2010	207.45	214.82	212.42	220.26

Table 25. Industrial water consumption (10^6 tons)

YEAR	*IWU(E)*	*IWU(A1)*	*IWU(A2)*	*IWU(A3)*
1996	28.86	30.02	34.32	27.62
2000	39.51	31.59	43.13	24.55
2004	45.85	34.86	44.18	24.31
2008	52.05	38.13	45.23	24.08
2010	55.75	39.77	45.75	23.97

Table 26. Total amount of wastewater generated(10^6 tons)

YEAR	*SWT(E)*	*SWT(A1)*	*SWT(A2)*	*SWT(A3)*
1996	35.46	37.16	39.87	35.11
2000	44.07	39.47	46.75	33.55
2004	49.17	42.74	48.60	34.38
2008	54.05	46.02	50.45	35.22
2010	56.90	47.67	51.38	35.64

Table 27. Total amount of industrial wastewater generated (10^6 tons)

YEAR	*ISWT(E)*	*ISWT(A1)*	*ISWT(A2)*	*ISWT(A3)*
1996	19.17	20.72	23.44	18.68
2000	26.80	21.80	29.08	15.88
2004	30.88	23.96	29.81	15.60
2008	34.71	26.11	30.55	15.33
2010	37.02	27.19	30.92	15.19

Table 28. N concentration in irrigation return flows (10^6 tons)

YEAR	*NAWUR(E)*	*NAWUR(A1)*	*NAWUR(A2)*	*NAWUR(A3)*
1996	0.58	0.59	0.59	0.60
2000	0.58	0.60	0.59	0.62
2004	0.59	0.60	0.60	0.62
2008	0.59	0.61	0.60	0.62
2010	0.59	0.61	0.60	0.62

Table 29. P concentration in irrigation return flows (10^6 tons)

YEAR	*PAWUR(E)*	*PAWUR(A1)*	*PAWUR(A2)*	*PAWUR(A3)*
1996	0.14	0.14	0.14	0.14
2000	0.14	0.14	0.14	0.14
2004	0.14	0.14	0.14	0.14
2008	0.14	0.14	0.14	0.14
2010	0.14	0.14	0.14	0.14

Table 30. Total mass of COD emissions (10^3 tons)

YEAR	TCOD(E)	TCOD(A1)	TCOD(A2)	TCOD(A3)
1996	58.31	54.97	59.85	54.96
2000	63.64	55.47	68.74	55.17
2004	70.43	58.77	70.82	56.05
2008	79.09	62.08	72.93	56.95
2010	84.53	63.74	73.98	57.41

Table 31. Total mass of industrial COD emissions (10^3 tons)

YEAR	ICODT(E)	ICODT(A1)	ICODT(A2)	ICODT(A3)
1996	26.74	22.27	27.15	22.27
2000	30.99	19.62	32.91	19.32
2004	36.65	21.10	33.19	18.39
2008	44.17	22.58	33.47	17.45
2010	49.03	23.31	33.61	16.99

As could be expected, the results indicate that the gross industrial output value under Scenario 2, increased economic benefits, is the highest, followed by Scenarios 1, balanced economic and environmental benefits, and 3, increased environmental benefits. Scenario 2 is based upon an optimistic estimation of environmental conditions, and, thus, emphasizes the economic return from secondary industries. Similar relationships are indicated in terms of the total amount of industrial wastewater generated, the total amount of wastewater generated, the total amount of industrial COD generated, the total amount of COD generated, and the water pollution index. These results indicate the tradeoff between economic return and environmental risk.

In the agricultural sector, nitrogen and phosphorus concentrations in irrigation return flows are relatively high under Scenario 3, but somewhat lower under Scenarios 1 and 2. This highlights important policy interactions between environmental protection and economic development in this sector. When an economic objective is emphasized, as in Scenario 2, industry would be benefited significantly by increased COD emission levels and concomitant reductions in pollution control requirements. At the same time, agricultural activities are not necessarily benefited since they are not as economically efficient as industries. Thus, an increased economic return through industrial development may not necessarily lead to intensified nonpoint nitrogen and phosphorus pollution. Also, the increased COD emissions may be mitigated by development of effective wastewater treatment systems, the cost of which could be supported (or partially supported) by the increased economic return.

SD Modelling and ESC Determination

Based on the SD analysis of the IFMOP outputs, the environmental supporting capacities for the three scenarios (Scenarios 1 through 3) can be quantitatively determined. Three planning periods, with the base years 2000, 2006, and 2010, were chosen for SD analysis. The results are shown in Tables 32 through 34.

Table 32. Normalized ESC values and synthesized indices for the year 2000

Indicator	1	2	3	4	5	6	Synthesis
Initial	0.25	0.21	0.25	0.21	0.23	0.23	0.56
Scenario 1	0.25	0.26	0.25	0.26	0.26	0.24	0.62
Scenario 2	0.26	0.20	0.25	0.20	0.27	0.23	0.58
Scenario 3	0.24	0.32	0.25	0.33	0.24	0.30	0.70

Table 33. Normalized ESC values and synthesized indices for the year 2006

Indicator	1	2	3	4	5	6	Synthesis
Initial	0.28	0.21	0.25	0.21	0.22	0.23	0.57
Scenario 1	0.24	0.24	0.25	0.24	0.26	0.23	0.60
Scenario 2	0.25	0.21	0.25	0.20	0.27	0.24	0.59
Scenario 3	0.23	0.34	0.25	0.35	0.24	0.30	0.71

Table 34. Normalized ESC values and synthesized indices for the year 2010

Indicator	1	2	3	4	5	6	Synthesis
Initial	0.29	0.20	0.25	0.20	0.20	0.23	0.563
Scenario 1	0.24	0.24	0.25	0.23	0.27	0.23	0.596
Scenario 2	0.25	0.21	0.25	0.20	0.28	0.24	0.587
Scenario 3	0.22	0.36	0.25	0.37	0.25	0.30	0.728

If the existing pattern of economic development remains unchanged through the year 2010, the consequence for the environment will be significant, with the lowest value for the environmental supporting capacity (ESC) index being forecast. By comparison, all three IFMOP scenarios result in higher ESC values. This suggests that any action taken to change the current situation will prove beneficial to the environment of this basin. As anticipated, Scenario 3, management for increased environmental benefit, has the highest value due to its emphasis on environmental protection. Interestingly, the difference between Scenario 2, management for increased economic benefit, and Scenario 3 is not very significant. This is due to the fact that Scenario 2 emphasizes industrial development, with lower priorities being placed on the agricultural activities that generate the major portion of the pollutant loads. Scenario 3 similarly emphasizes industrial development, but with increased pollution controls, and, likewise, de-emphasizes agricultural development (it should be noted that controls on agricultural pollution sources are less stringent than those suggested for application to industrial pollution sources). Since industry is the major contributor to COD pollution to the Xi'er River, and agriculture is the major nonpoint source of nitrogen and phosphorus pollution in Lake Erhai, implementation of either of the two Scenarios will reduce the overall environmental supporting capacity of the lake.

From the temporal point of view, implementation of Scenario 3 will increase the ESC gradually. In comparison, if Scenarios 1 or 2 are implemented, the ESC may either decrease with time or remain stable. Detailed decision alternatives could be generated through analysis of the projected conditions and consideration of the related environmental and economic tradeoffs.

Sustainable Development Planning

The study area can be divided into seven sub-basins to better reflect intra-regional and spatial considerations. Each of the seven sub-basins has different environmental, economic, and resource characteristics, and correspond to distinct ecological, hydrological, and administrative zones. Figure 22 shows these sub-basins. Local decision-makers and administrative personnel within each of these areas have been provided with a software package to facilitate application of the models at the local level. Environmental managers within these planning units can modify the planning schemes by adding new information into the models and generating refined outputs. To illustrate the utility of this approach, the IFMOP model has been applied to four planning and development alternatives, the first of which is presented in detail below.

Alternative 1: Tourism-based Economic Development

Sub-basins 1 through 3. The economic activities in these sub-basins include agriculture, tourism, food processing, net and caged fish culture, and small-scale brick production. Agriculture is the major economic activity in these sub-basins. Currently, agriculture throughout the entire lake basin results in very low economic benefits due to the high costs of cultivation and crop management. Recommended changes to the current patterns of economic and land use development include:

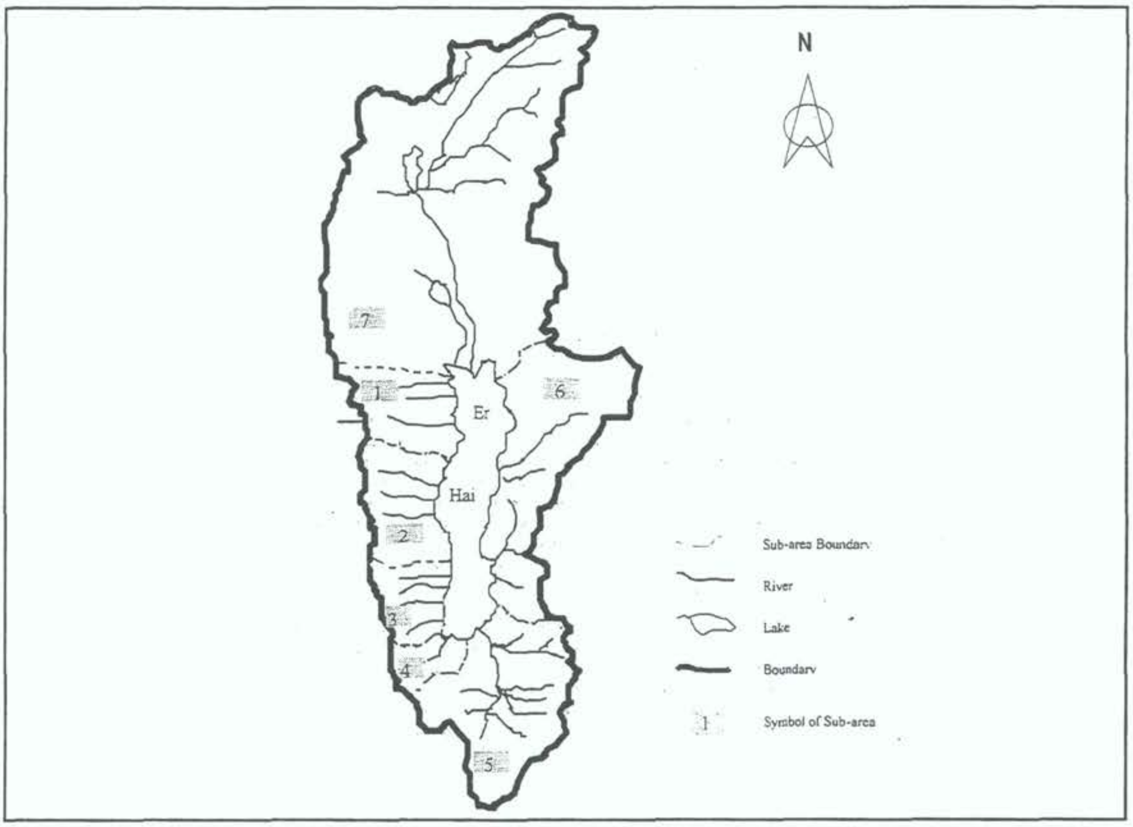

Figure 22. Major sub-basins within the Lake Erhai study area.

- limitation of expansion of paddy farming to minimize the generation of nonpoint source pollutants, regardless of its potential for expansion
- limitation or reduction of dry farming to minimize the generation of nonpoint source pollutants and destruction of forest cover
- expansion of vegetable farming to maximize its economic value and to meet projected demands from tourism
- discontinuation and prohibition of net and caged fish culture activities
- creation of additional lakeside fish culture ponds to meet projected local and tourist demands
- promotion of tourism opportunities provided Butterfly Spring, Zhoucheng, and Xizhou Town

- development of a food processing industry to maximize the economic benefit of the agricultural production and to meet local demands through promotion of town and township enterprises
- prohibition of brick-kiln activities to minimize soil erosion and ecological damage.

In short, to achieve sustainable development in the region, adjustment of the agriculture base and promotion of food and agricultural product processing would complement and support tourism development. The IFMOP outputs for sub-basins 1 through 3 are shown in Tables 35 through 37 for the immediate term, Period 1: 1997—2000, and longer term, Period 2: 2000—2010.

Sub-basin 4. There are non-zero IFMOP solutions, as shown in Table 38, for almost all of the economic sectors analyzed in this sub-basin. This suggests that industrial development in this region is reasonably balanced at present. According to the IFMOP model outputs, secondary industries such as cigarette manufacturing and food processing, and tertiary industries such as tourism development, should be promoted in the future. These industries will bring increased economic benefits with a low pollution potential. Further, these industries are well suited to the prevailing conditions in the study area. The textile and cement industries, while being economically beneficial, have significant water pollution and landscape degradation impacts. Limitations on the further development of these industries are recommended
in the immediate term, but may be reconsidered in the longer term as improved pollution controls, and excavation and production technologies become available. Further development of the chemical fiber and leather processing industries, both of which generate high pollution loads, is recommended to be strictly limited or prohibited unless the effective production and pollution control technologies become available in the future. With respect to agriculture, vegetable farming and some relevant farming sideline products are recommended to be the principal agricultural production activities.

Table 35. IFMOP solutions for sub-basin 1

Period	1		2	
Economic Activity	lower	upper	lower	upper
Paddy farming (km^2)	16.5	21.9	15.4	20.1
Dry farming (km^2)	20.0	20.0	21.1	21.1
Vegetable farming (km^2)	0.11	0.16	0.11	0.20
Textiles (10 000 Yuan/year)				
Chemical fibers (10 000 Yuan/year)				
Paper (10 000 Yuan/year)				
Food processing (10 000 Yuan/year)	284	710	710	710
Cement (10 000 Yuan/year)				
Leather (10 000 Yuan/year)				
Tobacco products (10 000 Yuan/year)				
Net and caged fishery (m^2)	6 250	10 212	5 000	10 528
Tourism (10 000 person-day/year)	128.0	135.0	153.6	162.0
Forest cover (km^2)	110.9	118.5	110.9	119.0
Brick production (10 000 pieces/year)	636.0	795.0	556.0	795.0
Lime production (tons/year)	247.7	247.7	216.7	216.7

Sub-basin 5. Agriculture and construction materials processing are the principal economic activities in this sub-basin. Construction materials processing is especially highly developed. Based upon the IFMOP model outputs (Table 39), it is recommended that paddy farming, vegetable production, and cultivation of other economically valuable plant species be expanded, and dry farming be limited in the future. Of the three types of activities that are classed as construction materials processing, cement production, brick production, and lime production can yield an high economic benefit, but at the cost of serious environmental problems such as forest damage, loss of farmland and displacement of farmers, and source water pollution.

Table 36. IFMOP solutions for sub-basin 2

Period	1		2	
Economic Activity	lower	upper	lower	upper
Paddy farming (km^2)	30.8	30.8	32.5	32.5
Dry farming (km^2)	43.8	54.8	41.6	53.8
Vegetable farming (km^2)	1.6	2.4	1.7	1.7
Textiles (10 000 Yuan/year)	880	1 540	1 760	1 760
Chemical fibers (10 000 Yuan/year)				
Paper (10 000 Yuan/year)				
Food processing (10 000 Yuan/year)	376	940	940	940
Cement (10 000 Yuan/year)				
Leather (10 000 Yuan/year)				
Tobacco products (10 000 Yuan/year)				
Net and caged fishery (m^2)	1 400	1 400	1 120	2 800
Tourism (10 000 person-day/year)	94.8	100.0	113.8	120.0
Forest cover (km^2)	99.2	99.2	99.2	99.2
Brick production (10 000 pieces/year)	67.7	84.6	59.2	84.6
Lime production (tons/year)	15 360	15 360	13 440	13 440

Thus, it is recommended that the small lime-kilns and brick-kilns be closed and that the operations of the larger enterprises be improved so as to meet the environmental objectives for the basin. In the longer term, as advanced technologies for environmental protection become available, this industry could be expanded to become the dominant industry in this sub-basin. As this sub-basin is located on the road linking Kunming and Dali, it is an ideal area for the development of commerce and goods storage. The lack of natural areas of scenic beauty and other tourism resources suggests little potential for developing tourism within this sub-basin; however, the expansion of forest cover to promote soil conservation is recommended.

Table 37. IFMOP solutions for sub-basin 3

Period	1		2	
Economic Activity	lower	upper	lower	upper
Paddy farming (km^2)	8.6	8.6	9.1	9.1
Dry farming (km^2)	18.3	21.5	17.7	20.9
Vegetable farming (km^2)	1.2	1.8	1.3	1.9
Textiles (10 000 Yuan/year)				
Chemical fibers (10 000 Yuan/year)				
Paper (10 000 Yuan/year)				
Food processing (10 000 Yuan/year)	1 160	2 900	2 900	2 900
Cement (10 000 Yuan/year)				
Leather (10 000 Yuan/year)				
Tobacco products (10 000 Yuan/year)				
Net and caged fishery (m^2)	1 875	1 875	1 500	2 217
Tourism (10 000 person-day/year)	56.9	60.0	68.3	72.0
Forest cover (km^2)	42.3	42.3	42.3	42.3
Brick production (10 000 pieces/year)	87.4	109.2	76.4	109.2
Lime production (tons/year)				

Sub-basin 6. Agriculture is the principal economic activity in this sub-basin. Limited, small-scale brick and lime production enterprises also exist, while tourism industry is in its infancy. According to the IFMOP model outputs, shown in Table 40, it is recommended that expansion of farmlands, especially paddy farming, be limited due to the high potential for soil erosion in this sub-basin. Likewise, because the traditional industries of this region, brick and lime production, have seriously damaged the local environment, it is recommended that these activities be restricted. Excavation in the hills along the east Round Lake Road would be prohibited, and further development of these industries would be restricted to specified zones and to the use of technologies that have a low potential for creating environmental damage. In contrast, development of the forest and orchard industry is recommended. For example, significant economic and ecological benefits could be achieved through the cultivation of Snow Pears over a large area of this sub-basin. Tourism also could be developed on an economically beneficial scale throughout this sub-basin.

Table 38. IFMOP solutions for sub-basin 4

Period	1		2	
Economic Activity	lower	upper	lower	upper
Paddy farming (km^2)	3.1	3.9	2.7	2.7
Dry farming (km^2)	6.5	6.5	6.8	7.3
Vegetable farming (km^2)	1.1	1.6	1.1	2.0
Textiles (10 000 Yuan/year)	11 000	19 250	20 515	20 515
Chemical fibers (10 000 Yuan/year)	3 050	3 050	2 440	2 440
Paper (10 000 Yuan/year)	5 600	5 600	11 786	11 786
Food processing (10 000 Yuan/year)	5 668	14 170	14 170	14 170
Cement (10 000 Yuan/year)				
Leather (10 000 Yuan/year)	650	650	520	520
Tobacco products (10 000 Yuan/year)	46 800	117 000	104 820	140 400
Net and caged fishery (m^2)	435	435	348	348
Tourism (10 000 person-day/year)	128.0	135.0	153.6	162.0
Forest cover (km^2)	30.7	34.3	30.7	34.3
Brick production (10 000 pieces/year)	599.0	748.8	524.2	748.8
Lime production (tons/year)				

Sub-basin 7. Agriculture and food processing are highly developed in this sub-basin. The intensive agricultural activities, and net and caged fish culture activities, have contributed large amounts of nonpoint source pollutants to Lake Erhai, and are considered to be responsible for many of the water quality problems experienced in the lake. For this reason, expansion of the area of farmland is not recommended unless nonpoint sources of pollution can be effectively controlled. Net and caged fish culture is recommended to be prohibited without exception. It is further recommended that food processing remain the principal industry in sub-basin 7, with the introduction of new technologies and products, and development of new markets, as opportunities become available. Development of this industry is anticipated to play a role in spurring the further development of primary industry and supporting development of the tourism industry in the region. Given the situation of sub-basin 7 in the upper reaches of the Lake Erhai basin, and the fact that this sub-basin currently contributes more than half of the total nonpoint source pollution loads to the lake, implementation of nonpoint source pollution controls in this sub-basin is strongly recommended. To this end, expansion of the forests and restriction of industrial development in this sub-basin is recommended. Because implementation of this strategy is likely to cause some loss of income within this sub-basin, formulation of appropriate fiscal instruments by the local government to encourage implementation of technological innovations in the future development of animal husbandry and aquaculture is recommended. Table 41 summarizes the relevant IFMOP model outputs.

Table 39. IFMOP solutions for sub-basin 5

Period	1		2	
Economic Activity	lower	upper	lower	upper
Paddy farming (km^2)	24.3	32.5	22.8	30.7
Dry farming (km^2)	29.7	29.7	31.4	31.4
Vegetable farming (km^2)	0.5	0.8	0.6	1.0
Textiles (10 000 Yuan/year)				
Chemical fibers (10 000 Yuan/year)				
Paper (10 000 Yuan/year)				
Food processing (10 000 Yuan/year)	289	717	717	717
Cement (10 000 Yuan/year)	10 000	20 000	23 250	23 250
Leather (10 000 Yuan/year)				
Tobacco products (10 000 Yuan/year)				
Net and caged fishery (m^2)	33.5	33.5	26.8	26.8
Tourism (10 000 person-day/year)				
Forest cover (km^2)	125.9	130.9	125.9	130.9
Brick production (10 000 pieces/year)	8 165	10 206	7 714	10 206
Lime production (tons/year)	38 400	38 400	33 600	33 600

Table 40. IFMOP solutions for sub-basin 6

Period	1		2	
Economic Activity	lower	upper	lower	upper
Paddy farming (km^2)	10.4	10.4	10.3	10.3
Dry farming (km^2)	28.1	28.1	29.6	29.6
Vegetable farming (km^2)	0.7	0.7	0.5	0.5
Textiles (10 000 Yuan/year)				
Chemical fibers (10 000 Yuan/year)				
Paper (10 000 Yuan/year)				
Food processing (10 000 Yuan/year)				
Cement (10 000 Yuan/year)				
Leather (10 000 Yuan/year)				
Tobacco products (10 000 Yuan/year)				
Net and caged fishery (m^2)	668	668	534	534
Tourism (10 000 person-day/year)				
Forest cover (km^2)	59.3	69.5	59.3	69.5
Brick production (10 000 pieces/year)	942.2	993.6	695.5	993.6
Lime production (tons/year)	3 840	3 840	3 360	3 360

Overview

The planning program for promoting the sustainable development of the Lake Erhai basin, based on the IFMOP model results presented above, suggests the development of tourism-based economic activities as the basis for implementing a program of economic development and environmental protection. The situation of sub-basins 1 through 3 within the corridor between the Cangshan Mountains and Lake Erhai provides the scenic resources necessary for tourism development in the basin, while the proximity of productive agricultural lands and supporting food processing operations in nearby sub-basins provides a blend of complementary economic activities necessary to sustain tourism. However, the potential for tourism development is related to not only the presence of scenic areas and a responsive service sector, but also a number of other factors. Effective environmental management measures to protect and rehabilitate degraded scenic areas should be implemented while developing the region's tourism potential. The industrial development in sub-basins 4 and 5, for example, is recommended to be aimed at encouraging industries with low pollution potentials. At the same time, pollution control facilities should be improved and upgraded by constructing a new, separated stormwater and wastewater collection system, and a wastewater plant with suitable capacity. Likewise, in sub-basins 6 and 7 where agricultural activities are the principal generators of nonpoint source pollution to Lake Erhai, limitation of farmlands expansion is recommended, while afforestation is to be promoted. Industrial development is not to be recommended in these sub-basins. Throughout the basin, net and caged fish culture is a direct source of pollutants to the lake, threatening water quality and stimulating growths of aquatic vegetation, and is recommended to be strictly limited or prohibited in all relevant sub-basins.

Table 41. IFMOP solutions for sub-basin 7

Period	1		2	
Economic Activity	lower	upper	lower	upper
Paddy farming (km^2)	86.3	92.4	87.2	95.1
Dry farming (km^2)	205.2	210.2	204.1	206.7
Vegetable farming (km^2)	2.3	3.1	2.2	3.9
Textiles (10 000 Yuan/year)				
Chemical fibers (10 000 Yuan/year)				
Paper (10 000 Yuan/year)				
Food processing (10 000 Yuan/year)	4 560	11 400	8 316	8 316
Cement (10 000 Yuan/year)	600	1200	600	600
Leather (10 000 Yuan/year)				
Tobacco products (10 000 Yuan/year)				
Net and caged fishery (m^2)	38 870	38 870	31 096	31 096
Tourism (10 000 person-day/year)				
Forest cover (km^2)	387.6	442.9	387.6	442.9
Brick production (10 000 pieces/year)	968.2	1 210	847.1	1 210
Lime production (tons/year)	5 590	5 590	4 891	4 891

Water Quantity Management and Water Pollution Controls

Lake Erhai has a number of inflowing streams, but only one outflow, the Xi'er River. Its outflow is controlled by several dams on Xi'er River. Thus, even in dry seasons, water demands created by human activities in the lake basin can be satisfied although water consumption for hydropower generation may have to be reduced accordingly. Thus, water quality becomes important limiting factor in the basin's economic development. To protect and rehabilitate lake water quality, a number of environment-related activities, under various development scenarios, can be considered. The IFMOP model outputs suggest that it is possible to effect such protections and maximize environmental and socio-economic benefits, and the SD model results provide for detailed interpretation and implementation of the IFMOP outputs.

Generally, water consumed for hydropower generation should be subject to the maintenance of desired lake water levels. The lake water level is directly related to lake volume and is closely related to lake water quality in that a larger volume of water volume has a greater dilution potential and greater ability to absorb incoming pollutant loads without detrimental impacts being experienced. Based on local environmental and economic conditions, it is recommended that the lake water level be maintained at 1 971.5 m or higher. After all water demands for sustaining human activities and for maintaining the desired water level are satisfied, the remaining water may be used for hydropower generation. Since precipitation and runoff are closely related to water availability in the lake, three precipitation conditions were considered. Normal, low, and high precipitation conditions were defined based upon multi-year statistical information. Normal conditions correspond to the average precipitation value from the multi-year data set, while the low and high rainfall conditions are based upon the minimum and maximum precipitation values, respectively. The impacts of these precipitation conditions on water quantity (for hydropower generation) and lake water quality were further analyzed using the SD modelling approach. The impacts of agricultural nonpoint source pollution controls, increased forest cover, and the construction of wastewater treatment plants were evaluated. Also, the potential pollutant contributions from external river systems, such as Yangbi and Lanchang Rivers, were considered.

Lake Water Quantity as a Function of Precipitation Conditions

Water entering Lake Erhai as both direct precipitation and surface runoff should be allocated, in terms of priorities, to maintaining the 1,971.5 m lake water level (inclusive of evaporative losses), to satisfying water demands from industrial, agricultural, residential and external water users, and providing water for hydropower generation. Table 42 summarizes the volumes of water for hydropower generation under each of the precipitation regimes.

Water volumes available for hydropower generation range from about 35×10^6 m^3 to about 60×10^6 m^3 under the various precipitation conditions. Under a given precipitation condition, no significant variations in the availability of water for hydropower generation among the three development scenarios were found. Consequently, it was assumed that the level of hydropower generation was dependent solely upon precipitation as moderated by the maintenance of the desired water level.

Table 42. Water availability for power generation under different precipitation conditions (10^6 m^3)

Precipitation Condition	Scenario	1998	2001	2004	2007	2010
Normal	Scenario 1	49.78	49.13	48.76	47.95	47.52
	Scenario 2	49.15	48.33	48.08	47.41	47.10
	Scenario 3	50.06	49.63	49.47	48.89	48.67
Low	Scenario 1	35.70	35.05	34.67	33.87	33.44
	Scenario 2	35.07	34.25	34.00	33.33	33.02
	Scenario 3	35.98	35.55	35.39	34.81	34.59
High	Scenario 1	60.59	59.95	59.57	58.77	58.33
	Scenario 2	59.96	59.14	58.89	58.22	57.92
	Scenario 3	60.87	60.45	60.28	59.70	59.49

Lake Water Quality as a Function of Agricultural Pollution Controls

As noted, lake water quality is primarily related to the discharge of nonpoint source pollutants from various sources. Among these sources, agriculture is the principal contributor of nonpoint source pollutants. Agriculture is also the economic sector that has the highest potential for pollutant emission reduction. Currently, nitrogen and phosphorus inputs from agricultural sources to the lake are about 66 percent and 57 percent, respectively, of the total loading from the basin. Therefore, effective control of pollution from agricultural activities is an important element in lake water quality protection.

Measures to effect nonpoint source pollution controls on agricultural lands include ecological and engineering approaches. Engineering approaches are effective in small areas where serious environmental problems exist. They have immediate effect but may require high levels of economic investment. The major ecological approach is to increase forest cover. This approach is sustainable and effective from the long-term environmental management point of view. In the IFMOP model, forest cover is one of the objectives, but conflicts with agricultural land uses from an economic standpoint. In the SD analysis, a gradual change in the extent of forest cover is assumed in each planning period. This incremental change provides for finer dynamic analysis. Thus, a reduction in nonpoint source pollutant discharges from lands undergoing afforestation can be estimated. The results indicate that nonpoint source pollution contributions from agricultural sources should decrease temporally, as forest cover increases, as shown for Scenario 1 in Tables 43 through 45 for the various precipitation conditions.

Lake Water Quality as a Function of Rainfall

The impact of precipitation on lake water quality was assessed using SD analysis of the outputs generated under the different IFMOP scenarios. The results are shown in Tables 46 through 49. As shown in Table 42, the availability of water (water quantity) is directly related to precipitation, with more water being available under conditions of higher rainfalls. In terms of water quality, higher precipitation results in to more soil erosion, high rates of runoff, and increased in-lake turbulence, which contribute to increased pollutant loadings to the lake. Thus, worse water quality might be expected during the wet season in comparison to that experienced during the dry season.

This relationship between precipitation and pollutant loading notwithstanding, the summer dry season has sufficient sunlight and warm enough water temperatures to support the appearance of eutrophication even if other chemical and biological conditions are unfavorable. For example, during August and September, 1996, a number of pollutant concentrations reached extreme values (when compared with historical data gathered during the preceding 10-year period):

- pH = 8.61 (the highest for the last 10 years)
- suspended solids (SS) = 0.6 mg/l (the lowest for the last 10 years)
- dissolved oxygen (DO) = 7.27 mg/l (the highest for the last 10 years)
- chemical oxygen demand (COD) = 1.48 mg/l (the highest for the last 10 years)

Table 43. Effect of increasing forest cover under normal precipitation conditions based upon Scenario 1

Parameter	1998	2001	2004	2007	2010
Forest coverage (FCR)	0.45	0.50	0.56	0.62	0.68
N from runoff (FNT)	638.1	584.9	531.7	478.5	425.4
Total N from nonpoint sources (TNIL)	967.6	925.2	876.1	837.7	789.8
FNT/TNIL	0.66	0.63	0.61	0.57	0.54
P from runoff (FPT)	48.7	44.1	39.6	35.0	30.4
Total P from nonpoint sources (TNIL)	85.7	83.6	79.9	78.7	75.3
FPT/TPIL	0.57	0.53	0.49	0.44	0.40
N concentration in Lake Erhai (mg/l)	0.307	0.294	0.279	0.267	0.252
P concentration in Lake Erhai (mg/l)	0.027	0.027	0.025	0.025	0.024

Table 44. Effect of increasing forest cover under conditions of low precipitation based upon Scenario 1

Parameter	1998	2001	2004	2007	2010
Forest coverage (FCR)	0.45	0.50	0.56	0.62	0.68
N from runoff (FNT)	547.9	502.2	456.6	410.9	365.2
Total N from nonpoint sources (TNIL)	849.4	814.4	772.8	742.0	701.6
FNT/TNIL	0.65	0.62	0.59	0.55	0.52
P from runoff (FPT)	42.2	38.3	34.3	30.3	26.4
Total P from nonpoint sources (TNIL)	77.8	76.2	73.2	72.6	69.8
FPT/TPIL	0.54	0.50	0.47	0.42	0.38
N concentration in Lake Erhai (mg/l)	0.283	0.272	0.259	0.249	0.236
P concentration in Lake Erhai (mg/l)	0.026	0.026	0.025	0.024	0.024

Table 45. Effect of increasing forest cover under conditions of high precipitation based upon Scenario 1

Parameter	1998	2001	2004	2007	2010
Forest coverage (FCR)	0.45	0.50	0.56	0.62	0.68
N from runoff (FNT)	696.9	638.9	580.8	522.7	464.6
Total N from nonpoint sources (TNIL)	1063.2	1015.9	961.8	918.6	865.8
FNT/TNIL	0.66	0.63	0.6	0.57	0.54
P from runoff (FPT)	52.7	47.8	42.8	37.9	32.9
Total P from nonpoint sources (TNIL)	91.6	89.1	85.1	83.5	79.7
FPT/TPIL	0.58	0.54	0.50	0.45	0.41
N concentration in Lake Erhai (mg/l)	0.324	0.311	0.294	0.282	0.266
P concentration in Lake Erhai (mg/l)	0.028	0.027	0.026	0.026	0.025

- total phosphorus (TP) = 0.21 mg/l (the lowest for the last 10 years)
- total nitrogen (TN) = 0.02 mg/l (the same as for the last 10 years)
- algae = 1.76×10^6 cells/l (the highest for the last 10 years)
- temperature in August = 23.2°C (higher than most of the other years)
- temperature in September = 21.8°C (higher than most of the other years).

High temperatures, low inflows (runoff to the lake during the two months was only about 60 percent of that observed during the same period during the previous year), and low SS concentrations indicated that the lake was extremely stable during this period. The lake had very strong thermal stratification and very weak dispersion capability. These data suggest that eutrophication in Lake Erhai is not solely related to TN and TP concentrations from external sources but also to other, internal factors.

Table 46. Water quality in Lake Erhai under normal precipitation conditions

Scenario	Scenario 1		Scenario 2		Scenario 3	
Concentration (mg/l)	N	P	N	P	N	P
1998	0.307	0.027	0.307	0.027	0.307	0.027
2001	0.294	0.027	0.294	0.027	0.294	0.027
2004	0.279	0.025	0.279	0.025	0.278	0.025
2007	0.267	0.025	0.267	0.025	0.267	0.025
2010	0.252	0.024	0.252	0.024	0.252	0.024

Table 47. Water quality in Lake Erhai under conditions of low precipitation

Scenario	Scenario 1		Scenario 2		Scenario 3	
Concentration (mg/l)	N	P	N	P	N	P
1998	0.283	0.026	0.284	0.026	0.283	0.026
2001	0.272	0.026	0.273	0.026	0.272	0.026
2004	0.259	0.025	0.259	0.025	0.259	0.025
2007	0.249	0.024	0.249	0.024	0.249	0.024
2010	0.236	0.024	0.236	0.024	0.236	0.024

Table 48. Water quality in Lake Erhai under conditions of high precipitation

Scenario	Scenario 1		Scenario 2		Scenario 3	
Concentration (mg/l)	N	P	N	P	N	P
1998	0.324	0.028	0.325	0.028	0.324	0.028
2001	0.311	0.027	0.311	0.027	0.310	0.027
2004	0.293	0.026	0.295	0.026	0.294	0.026
2007	0.282	0.026	0.282	0.026	0.281	0.026
2010	0.266	0.025	0.266	0.025	0.266	0.025

Table 49. Lake water quality and different precipitation conditions (Scenario 1)

Precipitation Condition	Normal		High		Low	
Concentration (mg/l)	N	P	N	P	N	P
1998	0.307	0.027	0.283	0.026	0.324	0.028
2001	0.294	0.027	0.272	0.026	0.311	0.027
2004	0.279	0.025	0.259	0.025	0.294	0.026
2007	0.267	0.025	0.249	0.024	0.282	0.026
2010	0.252	0.024	0.236	0.024	0.266	0.025

River Water Quality as a Function of Lake Water Quality

Socio-economic development in the southern areas of Yunnan Province, especially in the Lake Erhai basin, has already imposed significant impacts on the water quality of the region's rivers. Dali City, riparian to the Xi'er River, is the economic center of southern Yunnan Province. As has been noted, Dali City's paper mills and urban sewage are the major pollution sources in this area. Wastewater from the industrial enterprises in Dali is discharged directly into the Xi'er River without treatment, seriously polluting the river. According to the monitoring results, the water quality of the Xi'er River is worse than Grade V. Because the Xi'er River ultimately discharges into the Mekong River by way of the Heihui River and Lanchang River, it may be anticipated that the Mekong may be polluted if no action is taken to reduce the pollutants generated by economic development in the Lake Erhai basin. Hence, the control of point sources of pollution as well as nonpoint sources in the Lake Erhai and Xi'er River basin takes on transboundary significance, affecting not only western Yunnan Province but also Myanmar, Laos, Thailand, Cambodia, and Vietnam, and the South China Sea.

The Xi'er River is an intermittent river that has no flow when the dams in the upper reaches are closed. The major factors affecting water quality in the river are power generation, governing the flow of water in the system, and COD emissions from industrial and residential sources, which govern the mass of pollutant in the system. The behavior of COD in this system was evaluated using a complete mixing-dilution model without consideration of the decomposition of the pollutants. Tables 50 through 52 show the simulation results and potential effects of wastewater treatment. In the Tables, ECOD represents the mass of COD discharged, MCOD represents the mass of COD mitigated through wastewater treatment, TCOD represents the net mass of the COD discharged and mitigated by wastewater treatment, and TCODP represents the total mass of COD before treatment.

The model output suggests that the mass of COD both discharged and mitigated will increase time. This results implies that pollution control efforts will have to be continuously increased as the regional economy grows and, especially, as industries are developed. The model results have estimated the total mass of COD discharged into the Xi'er River under different planning scenarios. Such estimates provide local decision-makers with a quantitative basis for determining reductions in pollutant discharges necessary to minimize their impacts on water quality of downstream rivers.

The results of the SD analysis further indicate that the COD concentrations in the Xi'er River can be reduced by more than 50 percent by sewage treatment processes. This assessment of treatment efficiency is based upon an investment rate (for wastewater treatment) of between 1.4 percent and 2.0 percent. Tables 53 through 55 show water quality in the Xi'er River under different precipitation conditions based upon the above investment rates. The data also provide comparisons of COD concentrations (before treatment) under the different IFMOP scenarios. If wastewater is discharged directly to the Xi'er River without any treatment, as might be expected under a scenario that maximizes economic benefits, the worst water quality would be experienced. Likewise, if wastewater is treated before discharge to the Xi'er River, as might be expected under a scenario that maximizes environmental benefit, the best water quality would be experienced. Such a result was indeed found. Scenario 2, which maximizes economic benefits, had the worst predicted water quality, followed by Scenario 1, balanced economic and environmental benefits, and Scenario 3, maximized environmental benefits. These results correspond to the results of the earlier ESC analysis.

Table 50. Mass of COD (tons) discharged and removed under different scenarios

Scenario		1998	2001	2004	2007	2010
Scenario 1	ECOD	52780	52340	52510	54720	54810
	MCOD	5171	8856	12460	16090	18750
	TCOD	57950	61200	64970	70810	73560
Scenario 2	ECOD	60970	61790	59360	59830	57760
	MCOD	6740	12370	17660	22120	26030
	TCOD	67710	74160	77020	81950	83790
Scenario 3	ECOD	51940	49560	47380	48160	46260
	MCOD	6007	10730	14870	18140	20970
	TCOD	57950	60290	62250	66290	67230

Table 51. COD removal rates under different scenarios

Scenario	Scenario 1		Scenario 2		Scenario 3	
year	MCOD/ TCODP	MCOD /TCOD	MCOD/ TCODP	MCOD/ TCOD	MCOD/ TCODP	MCOD/ TCOD
1998	0.152	0.089	0.154	0.100	0.177	0.104
2001	0.254	0.145	0.258	0.167	0.315	0.178
2004	0.337	0.192	0.360	0.229	0.434	0.239
2007	0.408	0.227	0.437	0.270	0.520	0.274
2010	0.454	0.255	0.505	0.311	0.600	0.312

Table 52. Mass of COD (tons) discharged and mitigated by wastewater treatment facilities

Scenario	Scenario 1		Scenario 2		Scenario 3	
	TCODP	MCOD	TCODP	MCOD	TCODP	MCOD
1998	33910	5171	43680	6740	33910	6006.7
2001	34910	8856	47890	12370	34000	10730
2004	36960	12460	49040	17660	34240	14870
2007	39420	16090	50600	22120	34900	18140
2010	41260	18750	51550	26030	34940	20970

Table 53. COD concentrations in the Xi'er River before and after wastewater treatment under normal precipitation conditions

Scenario	Scenario 1			Scenario 2			Scenario 3		
COD (mg/l)	before	after	ratio	before	after	ratio	before	after	ratio
1998	73.0	63.1	1.20	91.8	78.9	1.16	73.2	61.7	1.19
2001	76.2	59.2	1.29	101.4	77.5	1.31	74.8	54.1	1.38
2004	81.0	56.9	1.42	104.4	70.2	1.49	76.0	47.2	1.61
2007	87.7	56.2	1.56	109.5	66.2	1.65	79.1	43.6	1.81
2010	91.9	55.1	1.67	112.1	60.9	1.84	79.8	38.6	2.07

Table 54. COD concentrations in the Xi'er River before and after wastewater treatment under conditions of low precipitation

Scenario	Scenario 1			Scenario 2			Scenario 3		
COD (mg/l)	before	after	ratio	before	after	ratio	before	after	ratio
1998	97.2	83.6	1.16	122.9	105.2	1.17	97.5	81.8	1.19
2001	101.6	78.2	1.30	136.1	103.3	1.32	99.7	71.2	1.40
2004	108.0	74.9	1.44	140.3	93.2	1.51	101.3	61.7	1.64
2007	117.2	73.8	1.59	147.4	87.7	1.68	105.5	56.5	1.87
2010	123.1	72.3	1.70	151.0	80.3	1.88	106.4	49.4	2.15

Table 55. COD concentrations in the Xi'er River before and after wastewater treatment under conditions of high precipitation

Scenario	Scenario 1			Scenario 2			Scenario 3		
COD (mg/l)	before	after	ratio	before	after	ratio	before	after	ratio
1998	61.7	53.5	1.15	77.2	66.5	1.16	61.8	52.3	1.18
2001	64.4	50.3	1.28	85.2	65.4	1.30	63.2	46.0	1.37
2004	68.4	48.4	1.41	87.7	59.4	1.48	64.2	40.4	1.59
2007	73.9	47.8	1.54	91.9	56.3	1.64	66.9	37.6	1.78
2010	77.4	47.1	1.64	94.1	51.9	1.81	67.4	33.4	2.02

River Water Quality as a Function of Rainfall

Tables 56 through 58 present the COD concentrations in the Xi'er River for the three IFMOP development scenarios under the various precipitation conditions. When wastewater is discharged directly to the Xi'er River without treatment, the main determinant of river water quality will be the volume of water discharged to the river as a result of hydropower generation. As has been noted in Table 42, the volume of water used for hydropower generation is dependent upon the amount of precipitation and surface runoff as modified by the volume required to maintain the target lake water level. Since the water level should be controlled at 1,971.5 m, the effect of lake level can be removed from consideration, and the amount of precipitation becomes the governing determinant of river water quality. Assuming that the lake water level is maintained at elevations higher than 1,971.5 m, the COD concentration in the Xi'er River will be relatively high under conditions of low precipitation. Even after wastewater treatment, the COD concentrations under these conditions would still be expected to be relatively high (compared with conditions under normal or high levels of precipitation). Consequently, an increased rate of industrial investment in wastewater treatment would be necessary to maintain or improve river water quality. (Note: Under any given precipitation condition, the fluctuations in COD concentrations should be mainly due to variations of COD generated under the different IFMOP development scenarios.)

Table 56. COD concentrations under various precipitation conditions (Scenario 1)

Condition	Before Treatment			After Treatment		
Year	Normal	Low	High	Normal	Low	High
1998	73.0	97.2	61.7	63.1	83.6	53.5
2001	76.2	101.6	64.4	59.2	78.2	50.3
2004	81.0	108.0	68.4	56.9	74.9	48.4
2007	87.7	117.2	73.9	56.2	73.8	47.8
2010	91.9	123.1	77.4	55.1	72.3	47.1

Table 57. COD concentrations under various precipitation conditions (Scenario 2)

Condition	Before Treatment			After Treatment		
Year	Normal	Low	High	Normal	Low	High
1998	91.8	122.9	77.2	78.9	105.2	66.5
2001	101.4	136.1	85.2	77.5	103.3	65.4
2004	104.4	140.3	87.7	70.2	93.2	59.4
2007	109.5	147.4	91.9	66.2	87.7	56.3
2010	112.1	151.0	94.1	60.9	80.3	51.9

Based on the predicted water quality in the Xi'er River, the potential impact on the Heihui River (Yangbi River) can be estimated. Given the average flows of the Heihui River and the Xi'er River as 65.0 m^3/s and 15.2 m^3/s, respectively, and no other significant pollution sources, the present water quality of the Heihui River is Grade II. Based on this present condition and the predicted COD concentrations in the Xi'er River under specific conditions (from Table 53), the predicted COD concentrations at the confluence of the Xi'er and Heihui Rivers can be calculated under the various development scenarios. The results are shown in Table 59. As indicated, the COD concentration at the confluence will become 200% of the present concentration if no treatment is carried out. If development proceeds in accordance with the IFMOP scenarios and the wastewater treatment plant is constructed, the COD concentration in the Heihui River will be reduced to less than 25 mg/l. Further, if Scenario 3 is implemented, the corresponding COD concentration will be reduced to below 20 mg/l. From these results, it is evident that, should the sustainable development strategy for the Lake Erhai basin be carried out, the water quality of the Heihui and Mekong Rivers is unlikely to be significantly impacted.

Table 58. COD concentrations under various precipitation conditions (Scenario 3)

Condition	Before Treatment			After Treatment		
Year	Normal	Low	High	Normal	Low	High
1998	73.2	97.5	61.8	61.7	81.8	52.3
2001	74.8	99.7	63.2	54.1	71.2	46.0
2004	76.0	101.3	64.2	47.2	61.7	40.4
2007	79.1	105.5	66.9	43.6	56.5	37.6
2010	79.8	106.4	67.4	38.6	49.4	33.4

Table 59. COD concentrations in the Heihui River under normal precipitation conditions

Year	Scenario 1	Scenario 2	Scenario 3
1998	24.1	27.1	23.9
2001	23.4	26.8	22.4
2010	22.6	23.7	19.5

2.5 Planning for Water Resources Conservation and Utilization

Water resources in the Lake Erhai basin are not only fundamental for regional economic development but also for the survival of the people living in this area. The availability of water resources is linked with the quality and quantity of water in the lake as well as with the sustainable development of the entire lake basin. For this reason, measures for the sustainable regulation, allocation, and utilization of these resources have been formulated on the basis of the analysis of the principal problems likely to be experienced in the field of water resources development.

One cause of the water quality problems in the lake is related to the over-exploitation of the available water resources. This condition contributes to adverse impacts on the environment. These impacts fall into four areas; namely, those related variations in the inflow regime of the lake, those related to the construction of the Xi'er River Hydropower Station, those related to the deficit between supply and demand for potable and process water, and those related to the degradation in lake water quality.

The long term average annual inflow to Lake Erhai is 0.825 billion m^3 and the average outflow is 0.863 m^3. Over use of water resources has accelerated conflicts between supply and demand. Power generation and agricultural irrigation consume the majority of the lake water abstracted. Up to 0.7 billion m^3 of water are used for power generation and 0.13 billion m^3 for irrigation. The declining lake volume created by the excessive outflows has led to significant conflicts between water supply and demand, which must be addressed if the ecological balance of the region is to be preserved. Strategies and effective regulations for effectively controlling and allocating water among users, including the environment, are a necessary first step in resolving these conflicts.

The construction of the Xi'er River Hydropower Station in 1977 has exacerbated the lake's water deficit, by further altering the natural outflow regime of the lake. The over-utilization of lake water for power generation has accelerated the decline in lake water levels. Over the last ten years, in addition to the large volume of water used for industrial and residential uses, water has been increasingly abstracted for power generation. In 1981, the lake's inflow was 0.3 billion m^3 and its outflow was 0.8 billion m^3. The corresponding figures for 1982 were 0.2 billion m^3 and 0.4 billion m^3; for1989, 0.3 billion m^3 and 0.5 billion m^3; and, for 1995, 11.4 billion m^3 and 9.28 billion m^3, respectively. The continuing over-abstraction, as reflected in the deficit of outflow over inflow, has destroyed the natural water balance of the lake.

As a consequence of these unbalanced inflows and outflows of water, both lake surface area and volume have decreased. Prior to 1976, the lake surface area was 255 km^2 and the lake volume was 29 billion m^3. By 1995, the surface area and volume had decreased to 249 km^2 and 28 billion m^3, respectively. These changes have resulted in related changes in the lake ecology.

One of the immediate consequences of the unbalanced inflows and outflows has been the degradation of lake water quality. Based upon water quality monitoring results, the water quality of Lake Erhai has declined to below Grade II, which is the minimum Grade deemed suitable for drinking water supply purposes. The decline is primarily manifested in the relatively high nutrient levels observed in the lake. In 1996, for example. an algal bloom that occurred in response to the elevated nutrient levels seriously threatened the supply of drinking water. Because the riparian communities depend upon the lake for their water supplies, measures to protect water quality and hygiene also are urgently needed within the scope of the overall water resources development program for this basin.

Basin-Wide Water Resources Management

In response to the concerns enumerated above, the implementation of strategies to preserve and protect both the volume of water available for human use and that available for environmental use are essential. The volume of water available for human use in the basin has been estimated to be about 1.0 billion m^3. This volume suggests a comparative abundance of water in comparison with the existing population and levels of socio-economic development within the basin. Thus, the conflicts between supply and demand that have occurred during the last decade would seem to be due to improper development, allocation, and utilization of these resources. As has been noted above, the problems created by the unbalanced inflows and outflows have been significantly increased by the construction of the Xi'er River Hydropower Station, which has contributed to the decline in lake water levels by discharging large volumes of water from the lake since 1977. Next to this consumptive use of water, agricultural uses consume the most, primarily for irrigated rice production that consumes about 85 percent of the irrigation water in the basin. Paddy farming comprises about 70 percent of the total land area devoted to farm operation. Since paddy farms traditionally keep about 10 cm of standing within the paddy fields, a reduction in this depth to about 5 cm could yield substantial savings in the volume of water consumed, with concomitant benefits in terms of reduced soil erosion and nutrient runoff. These facts suggest that the obvious targets for improved water management in the lake basin are the power generation and irrigated agriculture industries.

Strategies to implement changes in power generation and irrigated agricultural water uses must be based upon sound water resource utilization planning, in both the medium and longer terms, and upon performance monitoring to ensure that the implementation of the management plans is progressing and achieving the desired results. The planning periods considered include the immediate term (1997 through 1998), medium term (1999 through 2000), and longer term (through the year 2010 and beyond). The basis for sound water resource management should be the optimization of water resources allocation and utilization from the viewpoint of the entire basin, while the implementation of the plan should be guided by ecological-economic and systems engineering principles. These actions will promote the socio-economic development of the lake basin without causing a water resources problem. In effect, the end result of the planing process should be directed toward the sustainable development of the entire lake basin.

A first step toward ensuring sustainable utilization of the water resources of the Lake Erhai and Xi'er River basin is set forth in the *Dali Bai Nationality Autonomous Prefecture Regulation for Lake Erhai Management*, which guarantees water supplies for irrigation, industries and other human activities, but which maintains lake water levels at between 1,971.5 m and 1,974.0 m, with an average water level of 1,972.6 m. After the lake level maintenance requirement has been satisfied, the remaining water would be used for human economic purposes, including power generation. Excess water would be stored during the flood season to meet the presumed water demand during the dry season. However, recognizing the sensitivity of the environment to fluctuating water levels, the agreement also suggests that the duration of the period of higher water levels (greater than 1,972 m) be maintained as long as possible.

Planning for Water Resources Management in the Immediate Period

The immediate concerns to be addressed by the management strategy for the Lake Erhai basin are flood control and management of lake water quantity. The peak flood level recorded in the Lake Erhai basin was recorded in 1966, and was estimated to be a 1:50 year flood event. Under such circumstance, the water surface of Lake Erhai rose to a level that was determined to create a hazard to humans. Thus, it was determined that, when lake water levels exceed 1,974 m, water must be discharged from the lake. According to the available inflow and outflow records for Lake Erhai, the months in which the highest inflows occur differ from the months in which the highest outflows occur. Generally, the former is 2 to 3 months earlier than the latter. Thus, there is a minimum of a one-month period during which the flood waters are absorbed in the lake basin, increasing lake levels, and leading to flooding of riparian lands (Table 60). To ensure public safety, flood levels are considered to be the same during each month of the year. Based on these data, spanning a 40-year period, it has been determined that when the lake water level reaches 1,974.76 m, water should begin to be discharged from the lake to minimize flooding. While some houses have been constructed and some crops cultivated below the 1,974.76 m elevation in recent years, primarily in response to the lower lake levels, it is currently anticipated that the risk of flooding in these areas is low. Should flooding occur in these areas, the houses and field would be inundated for a short period, with no serious damage being caused.

Table 60. Frequency of occurrence (%) of flood peaks in Lake Erhai during a given year

Month	1	2	3	4	5	6	7	8	9	10	11	12	total
Inflow					3	6	13	47	19	12			100
Flow						6	6	63	6	19			100
Outflow	17							3	32	31	17		100
Flow	20							10	15	40	15		100

The lowest water levels recorded in Lake Erhai have ranged between 1,970.52 m and 1,971.88 m during the past decade. During this period, four years had levels lower than 1,971.00 m and six years had levels higher than 1,971.00 m. The highest water levels recorded ranged from 1,971.91 m to 1,974.14 m, during the same period. Of these years, eight had peak levels that were lower than 1,974.00 m and two had levels that were higher than 1,974.00 m. Such data show that Lake Erhai has a very limited capacity for multi-year water level adjustments.

Lake Erhai serves many functions, including irrigation and potable water supply, power generation, aquaculture, navigation, tourism, and climate conditioning. Due to the lack of awareness of the negative ecological consequences of a lower water level when the Xi'er River Hydropower Station was designed, some unfavorable impacts have been created by the power station. Given the current assured supply for irrigation purposes as 75 to 85 percent of the yield, the demand for water from the farmlands in the lake basin is expected to exceed the volume of water available to meet demand once in each 4 to 7 year period. For planning purposes, this assured supply level has been established at 85 percent of yield, with 1992 as the base year for comparison. The ratio of the volume of irrigation return flows (to the lake) to the total volume of irrigation water supplied (from the lake) to areas around the lake is estimated to be about 0.25, or about 22.5 to 30.0 million m^3/year. (It should be noted that return flows of water provided to the township industrial enterprises flows into a collection system that discharges below the Tiansheng Bridge to the Xi'er River; hence, this portion of the water being returned to the basin only can be used by the power station.)

Based upon the strategy that water be allocated for power generation only after lake level maintenance and agricultural needs have been satisfied, the foregoing data have been used to compute an assured yield for power generation based upon the five driest years on record (i.e., 1958, 1960, 1977, 1982, and 1988). It has been estimated that 120.2 million m^3/year of water can be allocated for power generation with an assured frequency of 95 percent. About 700 million m^3/year can be allocated with an assured yield calculated with a frequency of 50 percent. Because the water demands of the Xi'er River Hydropower Station are dependent upon the power demands within the southwestern electricity web, and consequently vary significantly from month to month, it is not possible to accurately predict the monthly water demand from the power station. However, the Lake Erhai Management Bureau (ELMB) can determine water allocations on an annual basis, and do so according to the lake level recorded on November 1st of the year preceding that in which the allocation is made, as modified by the predicted volume of inflow anticipated during June of the year in which the allocation is made. Using these forecasts, the ELMB will require the power station to perform in accordance with the stipulated total volume of water available for power generation. Accordingly, the power station must calculate their monthly water demand and submit the result to the ELMB. After review, the ELMB prepares an annual scheme for the utilization of water resources in Lake Erhai and submits the scheme to the Prefecture Government for approval. This ratified scheme is used to manage water utilization during the coming year.

Planning for Water Resources Management in the Medium Term

By the year 2000, it is anticipated that 50 million m^3/year of water will be diverted to Binchuan County from Lake Erhai. It also is anticipated that the capacity of the Haixihai Reservoir, located in the upper reaches of the Lake Erhai basin, will be expanded by 50 million m^3. At the same time, an increased water demand of about 100 million m^3/year is forecast among all economic sectors in the lake basin. Even though the proposed Xiaowan Hydropower Station will not have been completed, the volume of water available for power generation is expected to be reduced by about 100 million m^3. If calculated using an assured yield at the 95 percent level, the water available for power generation will have to be reduced to about 663 million m^3/year.

Planning for Water Resources Management in the Longer Term

After the year 2000, the Xiaowan Hydropower Station is anticipated to have been completed and brought into operation. The diversion of water from Lake Erhai to Binchuan County also is expected to increase to about 125 million m^3 annually. At the same time, water demands from economic activities within the lake basin are expected to approach 365 million m^3/year. These demands are estimated to exceed the available yield at the 95 percent level by some 76 million m^3. Under these circumstances, actions to reduce the supply of water to some economic sectors will be required in order to balance supply and demand. Even so, the assured yield is reduced to 93 percent or lower. In times of plentiful precipitation in a certain year, it is recommended that more water be diverted to Binchuan County, and *vice versa*.

Other Considerations

The allocation of water from Lake Erhai has become the focus of conflict in recent years, especially during dry years. In order to address these water use conflicts, five typical years were modelled. The monthly water demand for water for hydropower generation was determined based upon the water utilization data from 1987 and 1988, summarized in Table 61. This analysis identified some special issues that must be resolved through negotiation between the ELMB and Dianxi Electric Bureau (DEB). In particular, the proposed operating guidelines for integrated water resources management of the Lake Erhai basin would suggest that the annual average capacity for power generation of the Xi'er River Hydropower Station be reduced to 670 million kWh, some 437 million kWh less than the design capacity of 1,107 million kWh. This would provide the "additional" volume needed to meet water demands from agriculture and industry, and to supply the water proposed for diversion to Binchuan County. At the same time, this savings would allow for an increase in the lower threshold water level from 1,969 m to 1,971 m, enhancing the environmental stability of the lake. Notwithstanding, the demand for electricity in Yunnan Province is such that there is a concomitant need to maximize power generation from the Xi'er River Hydropower Station. The competition created by these conflicting demands is estimated to be most acute during May through July and in dry years. Under such circumstances, the demands for water for irrigation and power generation uses may be expected to outstrip the amount of water available, consequently causing some socio-economic and environmental problems, unless provisions are made to manage demand under conditions of water scarcity.

Table 61. Availability of water from Lake Erhai under different development scenarios

Feature	Historic Condition	Scenario 1	Scenario 2	Scenario 3
Maximum storage level (m)	1 973.5	1 974.0	1 975.0	1 974.0
Minimum storage level (m)	1 969.0	1 971.0	1 972.0	1 971.5
Design flow (m^3/s)	28.2	26.1	26.4	26.4
Total water available for industry and agriculture (P = 50%) (10^6 m^3)	--	274.02	274.02	274.02
Water available for diversion to Binchuan County (10^6 m^3)	--	50-135	50-135	50-135
Average electricity generated (10^9 kWh)	1.20	0.67	0.67	0.57

It has already been proven by experience during the past decade that establishing the minimum lake water level at 1,969.0 m, with a maximum range of 4.5 m, was a poor decision. Since the period of record began in 1947, water level records have shown that obvious environmental problems occur when lake water levels drop to below 1,970.52 m, as occurred, for example, during 1983. Scenario 1 in Table 61 corresponds to the current water management pattern with a minimum lake water level of 1,971.0 m and a maximum range of 3.0 m. While this scheme is able to relieve some of the environmental problems experienced in Lake Erhai, it is far from an ideal solution to those problems. In fact, the stipulation of 1,971.0 m as the lower threshold was a compromise between environmental concerns and socio-economic demands. An increase in the lower threshold to 1,971.5 m, with an annual average water level of 1,972.6 m, would establish an equilibrium such that the maximum of water could be supplied to the human activities without significant deterioration in lake water quality and damage to the lake ecology. Scenario 2 reflects these increased lower and upper thresholds of lake water level, and suggests that this increase would continue to satisfy the water demand for power generation and meet the requirements of other sectors.

Because there are large numbers of rural dwellings and about 800 ha of highly productive farmland between 1,974 m and 1,975 m that would be inundated by such an increase in lake level, it is unlikely that this scheme would be implemented. Hence, Scenario 3 is suggested as an intermediate approach. Increasing the lower threshold by 0.5 m without altering the upper threshold would reduce power generation capacity by about 140 million kWh, and reduce income from this source by 8.4 million Yuan. However, this loss could be offset by the economic benefit gained from the sale of water for other purposes. To wit, there currently are three middle-scale reservoirs, eight small (Type I) reservoirs, and 204 very small (Type II) reservoirs, plus some ponds, with total capacity of 153.3 million m^3 in the basin. These works have been constructed at a cost about 36 million Yuan. However, only about 50 million m^3 of water, or only 33 percent of the total capacity of these works, have been stored in these reservoirs and ponds, leaving about 100 million m^3 of available capacity. At the same time, the capacities of the Haixihai Reservoir, Cibi Lake, and Xihu Lake have been expanded by about 79 million m^3. Thus, a total storage capacity of approximately 180 million m^3 remains unutilized. The volume of water represented by this additional storage is equivalent to about 0.7 m depth of water in Lake Erhai. Thus, an increase in the lower threshold of lake water level by 0.5 meter, and storage of the "excess" water in the existing reservoirs and ponds, would retain an equivalent volume of water in the lake basin as would be stored under Scenario 2, but without the inundation of productive lands. The stored water could be used to satisfy the demand for irrigation water from Binchuan County. This 50 million m^3 water would irrigate about 6 000 ha of crops, increasing the annual agricultural yield by about 25 million kg and generating an annual increase in revenue of 39 million Yuan. Further, the loss of power generation capacity suggested under Scenario 3 could be compensated for by power to be produced at the Xiaowan and Xucun Hydropower Stations. For these reasons, implementation of Scenario 3 would optimize the economic benefit to the Dali Prefecture, contribute to the protection of the lake ecosystem, and provide a feasible solution for managing the water resources of the study area in a sustainable manner.

Notwithstanding, the current Lake Erhai Management Regulations (ELMR), while stipulating lower and upper threshold levels for the lake, do not stipulate the designed flood level, the timing and duration of the lower water levels, or the emergency measures to be employed during periods of drought. To overcome these limitations, the ELMR should be amended to include a design flood elevation of 1,974.80 m, a low water level threshold of 1,971.0 m on October 1st (= 1,971.5 m in future should Scenario 3 be adopted), and a drought emergency threshold elevation of 1,971.0 m on July 1st.

Implementation of the Plan

The administrative organization overseeing water resources allocation and utilization within the lake basin is composed of the Yunnan Provincial Economic Committee, the Yunnan Province Electric Bureau, the Dali Prefectural government, the Eryuan County government, the Binchuan County government, and the Dali City government. Prefectural, County and City governments are represented by their Planning Committees, Economic Committees, Urban and Rural Construction and Environmental Protection Bureaus, and Forestry Bureaus. The administrative organization is responsible for coordinating decision-making for the management of Lake Erhai. The Lake Erhai Management Bureau is the executive department that is in charge of the practical management of the lake.

The oversight organization would be responsible for the establishment and implementation of a program of sustainable ecological-economic development within the lake basin. The point of initiation of this program would be the regulation of the present industrial structure. Such regulation would encourage new development in accordance with the Forestry-Food-Animal Husbandry-Water Supply-Tourism model set forth above, and contribute to the achievement of a harmonized interplay between the forest ecosystem, agricultural ecosystem, and tourism, with direct benefit to the lake environment. The direct economic benefit to be achieved through implementing this program would be in excess of 100 million Yuan. It is anticipated that there would be an increase in revenue from the present value of 219.6 million Yuan to 321 million Yuan, while indirect ecological benefits would increase from 694 million Yuan to 1 800 million Yuan. In addition, implementation of this program would rationalize the utilization of water within the basin, effectively increasing the availability of water to all users.

Agriculture is expected to remain the major water consumer in the lake basin. Shifting to new, high efficiency irrigation technologies would save a significant volume of water. While rice production consumes the most of this water, concomitant changes in market dynamics is likely to shift production in the basin toward other food grains with higher economic returns than those of rice. This not only will reduce the volume of agricultural water consumed but also improve the economic condition of the basin. Over time, this should naturally reduce the area devoted to paddy farming and shift production toward less water-intensive cereals within the lake basin.

Some industrial enterprises with an high economic potential and low water consumption potential also should be of high priority for future development. Generally, for all industrial enterprises, water demand should be managed by promoting technologies that include water recycling. In part, this could be effected through the adoption of the Water Utilization Permission System (WUPS). WUPS allocates specified amounts of water to specific enterprises. If an enterprise consumes less water than is allocated, a lower fee is charged, while, in contrast, if an enterprise consumes more water, the additional volume is charged at fee that is 3 to 5 times higher than the normal level. Because of the economic incentive built into WUPS, it is anticipated that WUPS will save a significant amount of water. For example, it is estimated that at least 1.65 million m^3 water can be saved by the Dali Paper Mill, the Yunnan Artificial Fiber Factory, and the Erbin Paper Mill each year. In addition, the reuse for irrigation supply of wastewater discharged by the cement production enterprises and the Dali Brewery could save about 1.0 million m^3/year of water. The likely volume of water saved through the introduction of WUPS, and related industrial sector reuse measures, would provide sufficient water to generate an additional 3 million kWh of electricity.

The quantity of hydropower generated could be further augmented through the implementation of newly developed technologies for power generation and utilization. These technologies incorporate energy storage into power station design, such that, during the daytime hours, water would be discharged to generate electricity to meet the demands from users as usual, while, at night, when much less electricity is required, water would be pumped into the lake to generate electricity during the next day. This type of operation makes more efficient use of available water resources than the traditional once-through generating systems. Two alternatives are proposed to permit such a system to operate on the Xi'er River. The first is to build a downstream reservoir at a suitable place near the confluence of the Xi'er and Yangbi Rivers. The water stored in this lower structure could be pumped from the Yangbi River to the power station in a step-wise manner. The second alternative would be to utilize the three dams that currently comprise the Xi'er River Hydropower Station as the lower ponds and install additional generator units upstream. Under this alternative, the water of the Xi'er River could be pumped upstream into dams and utilized for power generation as well as other purposes. These alternatives are to be preferred over the proposals put forward by some government departments to divert water from the Heihui River to Lake Erhai. Such diversions, proposed since the water resources conflicts were identified in the 1980s, are subject not only to hydrological and geological considerations, but also to ecological considerations. These considerations are much more complex than those typically experienced when constructing inter-basin transfer schemes using artificial reservoirs, and, for this reason, such a scheme is not considered feasible at this time.

The implementation of this water resources management plan is designed to maintain the lake's water balance during most years. Maintenance of the water balance will contribute to the improvement of water quality conditions. However, this does not means that water quality can be guaranteed, or water quality monitoring and control is not necessary. Ongoing monitoring of water quality in each sub-basin is recommended, with special attention to monitoring nutrient concentrations and algal growth in the lake. Such monitoring would provide early warning of the need for additional water quality protection measures. In addition, monitoring drinking water quality should be undertaken to ensure the hygienic quality of the potable water supply.

Integrated Water Resources Management

Although the water resources of the Lake Erhai basin are abundant, the intensification of conflicts between water supply and availability during recent years has exacerbated the uneven spatial distribution of these resources during a period increased water demand associated with the unsustainable development and use of water resources in the socio-economic development of the lake basin. The key to resolving these problems of water resources allocation and utilization requires that consideration be given to the environmental and economic features of water resources utilization. Adoption of a systems engineering approach to this task provides a mechanism to arrange all the water-related activities of the basin in such a way as to optimize the use of the available resources as a whole from the viewpoint of the entire lake basin. None of the currently-constituted water resources management organizations in the basin is competent to accomplish this task. For example, the Lake Erhai Management Bureau does not have responsibility for the management of the reservoirs in the upper reaches of the Lake Erhai drainage basin, despite the fact that these waterbodies can have a significant impact on the volume of water flowing into the lake. Therefore, it is recommended that a new organization be established to have overall charge of the activities affecting water resources development and utilization within the lake basin. This organization also will could have responsibility for the coordination of water consuming activities across all economic sectors and for the establishment of the Water Utilization Permission System, and related oversight and control mechanisms.

2.6 An Environmental Management Information System for the Lake Erhai Basin

As part of this project, analyses of water resources issues affecting the water quality and quantity of Lake Erhai and the Xi'er River have been conducted based upon a computer modelling approach. The approach has been refined into a prototype, user-friendly software package that can be used by water resources managers and decision-makers to evaluate situations likely to occur within the system. The specific features of this software package that contribute to its utility as a management tool are:

- an environmental management database that is directly integrated, by means of a geographical information system (GIS), into the simulation and decision-support models
- an integrated environmental planning package that links IMOP, SD, Vollenweider, and one-dimensional dilution models through the geographical information system to a user-friendly interface
- a user-friendly computer interface that enables the real-time evaluation and revision of water resources planning options that will facilitate future refinements of alternative plans based upon updated information
- an excellent potential for further extensions as new sub-models and information become available.

Although this software is still considered to be developmental, it forms the basis for further study and development. A fully developed Environmental Management Information System (EMIS) for the Lake Erhai and Xi'er River basin is an important tool for effective environmental management and planning in the study area. The following development work remains to be done:

- integration of an advanced environmental management database into the GIS, and the simulation and decision-support models
- addition of environmental engineering, environmental assessment, environmental management, ecological restoration, air pollution control, solid management, and noise abatement modules into the simulation and decision-support models
- improvement of the performance of the geographical information system
- refinement of the computer-user interface in order to achieve a more effective human-model dialogue
- establishment of a decision-support network to promote a more efficient decision-making process.

2.7 Capacity Building to Implement the Environmental Management Plan

To fully utilize the advantages provided by the completion of the Lake Erhai and Xi'er River environmental management plan, it will be necessary to improve the management capacity of various institutions charged with carrying out specific actions associated with sustainable, regional socio-economic development. Basic actions necessary to ensure the institutional and human resource capacity for implementing the environmental management plan include:

- increasing the numbers of environmental management professionals from 5 to 15 at the Prefectural level, from 2 to 5 at the County level in Eryuan County, and from 6 to 20 at the municipal level in Dali City
- extending the jurisdiction of the Prefectural Environmental Protection Bureau to the village level by appointing local coordinators tasked with communicating rural environmental management policies and regulations to farmers in their communities
- establishing an information administration center within the Prefecture Environmental Protection Bureau to collect socio-economic, environmental, resource management, and engineering information from within the basin area, and to provide such information to governmental managers for decision-support purposes
- training of research and administration support staff (Table 62) through a combination of i) formal training programs provided at educational institutions in Kunming, Beijing, and other centers, ii) informal training programs provided through seminars and lectures given invited national and international experts, and iii) practical, hands-on training programs provided through collaborative studies conducted by local staff in association with staff from other institutions.

In addition to staff training to provide the water resources professionals needed to implement the water resources management plan at all levels of government, the local authorities could strengthen their cooperation with both national and international organizations to further improve their environmental management systems. Based upon the foregoing analyses, a number of potential project areas have been identified. A number of these projects could be executed as cooperative studies involving international organizations and other foreign universities and institutes. Indicative projects include:

- development of an integrated environmental and economic Decision Support System for the Lake Erhai Basin
- development of a system of policies and regulations governing the structure of industrial development in the Lake Erhai basin
- assessment of the impacts of development of the Heihui Industrial Corridor on the water quality of Lancang and Mekong Rivers
- assessment of the development and management patterns within of the Mekong River watershed.

Table 62. Training requirements for implementing the environmental management plan for the Lake Erhai basin

Category of trainee	Number of trainees	Training level
Supervisor	20	bachelor
Planner and manager	5	master
Computer specialist	5	master

To support the new staff and the conduct of the abovementioned studies, some institutional strengthening is recommended. Specific elements needed to enhance the ability of basin institutions to execute the environmental management plan measures would include:

- improvement of available transportation and communication facilities
- increased access to computer facilities (including one GIS workstation, two Pentium computers, one color printer, and one duplicator)
- initiation of a Prefecture-wide environmental information network.

Finally, in order to ensure the success of a basin-scale environmental management planning approach, it is considered to be essential to broaden the responsibility for environmental protection from a purely governmental responsibility to one of community responsibility. Enhancing the awareness of all the people living in the lake basin is a necessary step in the effective implementation of any environmental plan. Given suitable conditions, the implementation, revision, and monitoring of the environmental management plan for the basin becomes a community duty, through which each individual working or residing in the basin can contribute to the protection and restoration of the water resources of the system. Through this collective responsibility, community-based actions can be taken to ensure the sustained and sustainable development of the Lake Erhai and Xi'er River watershed.

Chapter 3

Planning for Sustainable Tourism in the Lake Erhai Basin

3.1 Principles of Sustainable Tourism Planning

The key to developing a sustainable tourism industry is to integrate its development into the social economy and environment of a region. To maximise the profitability of tourism activities, effective measures to protect the basis for tourism (e.g., effective for environmental protection measures and rational resource exploitation practices) should be in place within the region. Planning for tourism development, therefore, should include consideration of appropriate resource management measures and practices. The following should be considered:

1. Planning for sustainable tourism development should define basic requirements for coordinating the social economy and environment based upon the comprehensive development goals of the region;
2. Planning for sustainable tourism development should provide for the sustainable use of resources, including natural, social, and cultural tourism resources, to ensure their long term exploitation and utilization;
3. Planning for sustainable tourism development should promote decreased consumption throughout the region in order to minimize the generation of wastes disposed of to the environment and maintain a favorable environment for tourism;
4. Planning for sustainable tourism development should maintain biodiversity;
5. Planning for sustainable tourism development should be comprehensive, taking account of the tourism quotient of urban and rural areas, in order to promote sightseeing in the region that is consistent with the environmental carrying capacity of the region;
6. Planning for sustainable tourism development should support regional economic development and contribute to the development of related economic activities such as the production of handicrafts and related tourism infrastructure (i.e.,

hotels, transportation services and other tourist services operations);

7. Planning for sustainable tourism development should promote the participation of cultural organizations and social societies throughout the community;
8. Planning for sustainable tourism development should recognize market forces and provide for adjustment of tourism infrastructure, routes, and amenities over time, based on changing market capacities and tourist demands;
9. Planning for sustainable tourism development should be consistent with national and local environmental policies and regulations, and incorporate local environmental policies, regulations, and rules into the process of tourism development;
10. Planning for sustainable tourism development should facilitate implementation of basic research on tourism development, including research on tourism policies and markets, geography and landscape ecology, cultural anthropology and religion, etc., to create and enlarge tourism capacities and to improve the quality of tourism;
11. Planning for sustainable tourism development should provide for the training of personnel to improve the quality of the support staff and ensure that international standards of comfort and security are achieved;
12. Planning for sustainable tourism development should include public information and education, and provide for public participation, in order to strengthen regional environmental protection and enhance the environmental consciousness of resource managers and the public, both resident and transient;
13. Planning for sustainable tourism development should include provision of a data collection and management system to classify, store and disseminate timely and relevant data to permit adjustment of infrastructure in response to market and environmental protection requirements;
14. Planning for sustainable tourism development should be computer-based if it is to be dynamic, flexible, and capable of being continuously revised if it is to meet its goals with respect to regional economic development.

3.2 Tourism Resources and Their Development Potentials

The Lake Erhai basin has abundant tourist resources (Figure 23). There are both sites of great natural beauty, such as the scenery provided by the juxtaposition of the Cangshan Mountains and Lake Erhai, as well as sites of cultural interest, such as historic sites and folk customs, that make up a fascinating and wonderful scene.

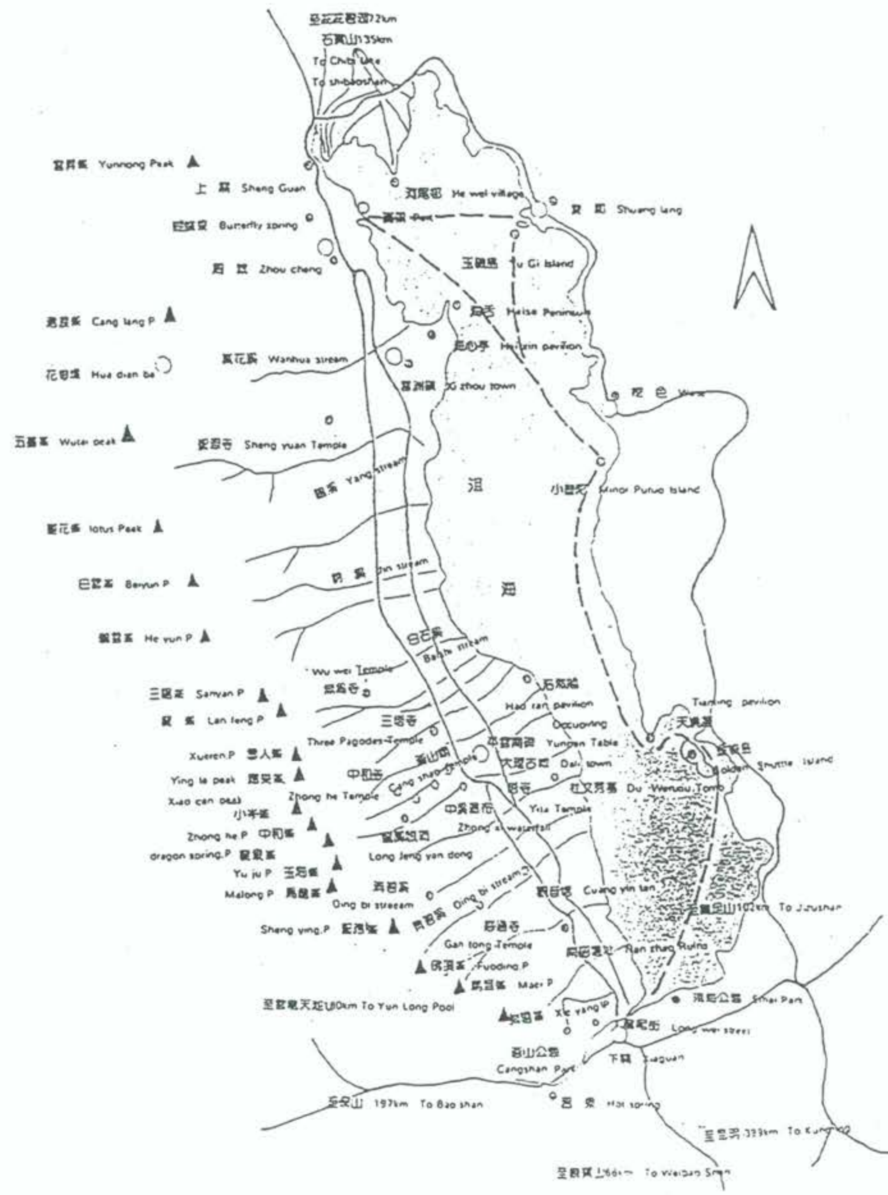

Figure 23. Tourism sites in the vicinity of Lake Erhai.

Landscape Features

The Cangshan Mountains and Lake Erhai form the essence and quintessence of this region. The nineteen peaks of the Cangshan Mountains are beautiful and precipitous. Malong Peak, the highest point in the mountain chain, is 4,122 meters above the sea level. A 10 km ridge, situated above 4,000 m elevation, links Malong Peak to Sanyang Peak. The summits of both peaks are snow-covered year round, in stark contrast to their foothills, which are always covered by green vegetation. The vista provided by this contrast forms the marvelous spectacle known as "Spring Snow in the Cangshan Mountains". Nestled among the foothills is beautiful Lake Erhai whose vast surface area is characterized by broken cliffs, harbors, island, sandbars, and curved stretch of coastline known as "Three Islands, Four Bars, and Nine Turns". Lake Erhai, under bright sunshine and gentle breeze, can be as calm as a mirror, but, when the fierce wind howls, the waves roil the waters, whipping plumes of spray into the air. When the moon rises over the calm lake, the "Lake Erhai Moon" is very beautiful indeed.

In addition to the region's most prominent scenic features, Cibi Lake, the Cangshan's Eighteen Brooks, the deep gorge of the Dragon Pool, and the Xima Pool at the top of Cangshan Mountains, weave a natural scenic spell. The views provided are known as "mountains embracing green water, clear brooks winding down green hills, Dragon Spring coming out from the peak, and mountains rising from the lake". Fantastic natural scenery, together with a moderate, spring-like year round climate and the rich variety of animal- and plant-life, creates the special magic that forms the tourism resources of this region.

Cultural Features

Superimposed upon this dramatic landscape is the region's long history of human settlement, dating back to ancient times. The area contains numerous historical sites and relics. The existing scenic and historical sites dating from the period of the Han Dynasty include more than forty ancient ruins, ten ancient pagodas, thirty temples, eight ancient city sites, five frescoes, and hundreds of steles.

Among these sites are four units listed on the national register for the preservation of key historical relics, and more than ten units listed on the provincial register of key historical sites. Among the nationally-listed sites are the Dali Three Pagoda, the Nanzhao Taihe City ruins, and the Dali Ancient Town site, which are among the most well-known.

The region is not only well endowed with historic sites, but has a rich local culture. Several ethnic groups currently reside in this multi-nationality area. Besides the population of Bai nationality, previously mentioned as the largest population group, the Yi and the Hui nationalities form a significant part of the current population of the basin. In their long histories, these nationalities have jointly created a special Lake Erhai culture. The nationalities not only wear colorful folk dress, but also are distinguished by individual folk customs. For example, there are bustling and complicated wedding and funeral rites, and the "Three Courses Tea" ceremony incorporating both song and dance, that are practiced by people of the Bai nationality. The folk festivals that are most attractive for the visitor include the "Around Three Spirits" Festival, the Butterflies Fair, the March Fair, the Torch Festival, the "Enjoy Sea" Assembly, and the Benzhu Festival of people of the Bai nationality; and, the annual February 8th Assembly of people of the Yi nationality.

The religions of the Dali area likewise reflect the multi-cultural character of the region. Prominent belief systems have included the Wu or Multi-Deities Religion, Buddhism, Taoism, and Islam. Among these, the Wu Religion, Taoism, and Buddhism lasted the longest and had the deepest influence. As the time passed, the Wu Religion in the Dali area gradually evolved into the pattern such that every village had its own god and its own shrine. Eventually, the Wu Religion evolved into a local variant known as the Benzhu Religion. Buddhism and Taoism were spread to the region early in its history, and came to their prime during the Ming (14th through 17th Centuries) and Qing Dynasties (17th through 20th Centuries). The present Buddhist shrine on Jizu Hill and the famous Taoist shrine on Weibao Hill were built during this time. In addition, there are numerous temples in the region. The most well-known include the Three Pagodas Temple, the One Pagoda Temple, the Wuwei Temple, the Shengyuan Temple, the Luoquan Temple, the Small Putuo Temple, the

Wenbi Temple, the Segu Temple, the Guanyin Temple, the Gantong Temple, the Cangshan Mountains Temple, and the Zhonghe Temple. These temples contain artifacts rich in religious and cultural significance. Such sites and customs, when combined with the beauty of the surrounding natural scenery, become more beautiful and attractive.

Tourism Development Potential

The scenic areas of the Dali region currently form the basis for a tourist industry with both national and international significance (Figure 24). The creation of a national park in Dali was initiated in 1982 when the Provincial Government nominated Dali as a National Park for environmental conservation purposes, and the area was duly opened in 1984 to foreign visitors. The overall plan for the development of scenic areas in Dali was prepared between 1985 and 1987 in conjunction with planning for the National Park, which was completed in 1987.

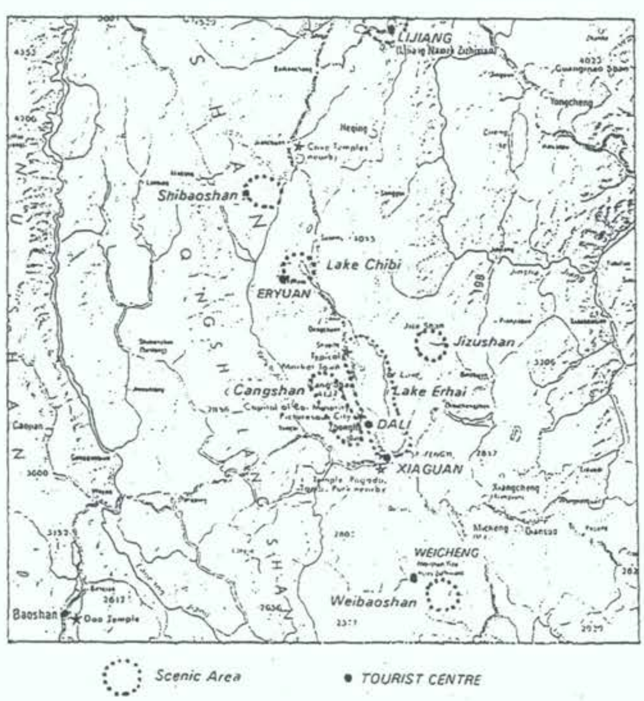

Figure 24. Major tourist sites within the Lake Erhai basin.

However, there are many other sites within the Lake Erhai basin that can be tapped for tourism development. Within the area defined by Lake Erhai, the Cangshan Mountains and Lake Cibi are numerous cultural and historical assets, including religious shrines of great importance; scenic areas; and, ethnic and folk arts, architecture, and handicrafts (see Figure 24). Tourism zones in this area can be categorised into eleven zones; namely, Dali Old Town, Huadianba, Xizhou, Butterfly Spring, Shuanglang, the Lake Erhai Islands, Xiaguan, Guanyintang, the middle and lower elevations of the Cangshan Mountains, the peaks of the Cangshan Mountains, and the Lake Cibi area:

- Dali Old Town includes seven scenic areas, including Dali Old Town itself and the Three Pagodas, One Pagoda, and Wuwei Temples. The zone as a whole is characterised by its historical assets
- The Xizhou zone includes four scenic areas; namely, Xizhou Town, the Shengyuan Temple, the Haixin Pavilion, and the Luosha Pavilion. The attractions in this zone are its historical assets, and ethnic and folk arts
- The Butterfly Spring zone includes three scenic areas; namely, Butterfly Spring, Zhoucheng Village, and Shangguan. The characteristics of this zone are its natural scenery, and ethnic and folk arts
- The Shuanglang zone includes three scenic areas; namely, Jinsuo Island, Shuanglang Village, and Hewei Village. The attractions in this zone are its natural scenery and ethnic fishery
- The Island of the Sea zone includes six scenic areas; namely, the Island of the Sea, the Tianjing Pavilion, the Luoquan Temple, Minor Putuo Island, the Wenbi Pagoda, and Wase Village. Natural scenery, historical assets, and ethnic and folk arts are the major attractions in this zone
- The Xiaguan zone includes seven scenic areas, including the Taihecheng ruins, the Snake-bone Pagoda, Long Wei Street, and Erhai Park. The characteristics of this zone are its natural scenery and historical assets
- The Guanyin zone includes four scenic areas; namely, Guanyintang, Shenglu Park, the Gantong Temple, and Qingbi Stream. The attractions of this zone are the temple and the stream
- The middle and lower elevations of the Cangshan Mountains includes four scenic

areas; namely, the Cangshan Temple, the Zhonghe Temple, Longfengyantong, and the Zhongxi Waterfall. The attractions of this zone are the temples, a stream, and the mountains

- The Huadianba zone is being planned as an area for the cultivation of camellias and Dujuan flowers. The attraction of this zone is its natural scenery
- The Cangshan Mountain peaks zone is being planned as an area for mountaineering, and the cultivation and exhibition of azalea flowers. The attraction of this zone is its natural scenery
- The Lake Cibi zone is being planned as a vacation area. The attraction of this zone is its natural scenery.

The tourist resources of the Lake Erhai basin have an excellent prospect for development as a result of an ideal location relative to population centers and neighboring scenic attractions. The Lake Erhai basin stands in the middle of western Yunnan Province, in close proximity to the Kunming Dianchi, Lijiang Snow Mountain, Three Rivers, and Tengchong Geothermal scenic areas, and astride the tourist corridor linking these western Yunnan Province attractions. Along with the rapid development of the national economy and the steady improvement of Yunnan's economy, the Lake Erhai region, together with the Kunming and Xishuangbanna regions, has become one of the principle focal points in a developing circular tour of Yunnan Province. Further development of tourism resources in this region can optimize the economic benefits to be gained through tourism, but is predicated upon strengthening the tourism infrastructure of the region, including protection and rehabilitation of the resource base upon which tourism is developed.

After many years of exploitation, the natural scenery of the basin is becoming stressed. Both the terrestrial and aquatic ecosystems are showing signs of deterioration. This deterioration is manifested in the eutrophication of Lake Erhai and the decline in biodiversity in Cangshan Mountains. To minimize such stress in future, tourism planning should emphasize environmental protection through careful analysis and selection of tourist routings and tourism content. The present tourist route is concentrated almost exclusively on the Cangshan Mountains and Lake Erhai, and does not take advantage of the region's other attractions. In particular, compared with the natural scenery, the exploitation of the cultural resources of the region is minimal. Folk customs and culture, in particular, is underdeveloped as a tourism feature. To fully develop the tourism potential inherent in the cultural features of the region, specialists are needed to identify those aspects of folk custom and culture that are most attractive to visitors, and commercialize them without diminishing their cultural or religious significance. Especially in the case of religious beliefs, care is required to preserve the fundamental significance of the customs and to respect the freedoms of individuals to practice their religious beliefs.

3.3 Overview of Current Tourism Activities

As has been mentioned, there has been some effort devoted to creating a tourism industry in the Lake Erhai basin. In this regard, three attractions have long been recognized in the Lake Erhai area. Dali is nationally known for its history and culture; Lake Erhai and the Cangshan Mountains are nationally known as scenic areas; and, the Cangshan Mountains are nationally known as a protected natural area. As a consequence of the 1984 National Reform and Opening Policy, and the steady improvement of people's living standards, the local governments have fostered tourism as a major industry, and, after many years of effort, tourism in the area has gradually developed.

Tourist Infrastructure

A major element of the emphasis on tourism development is an improved transportation infrastructure. The Dali Airport has been upgraded and brought into commercial service. The 2,600-m runway is rated as Grade 4C under the national standards, and can accommodate Boeing 737-300, Yak 42, and similar, middle-sized passenger aircraft. There currently are ten flights per week to Kunming, with one of these flights continuing to Beijing, Tianjin, and Changsha. In the future, inter-provincial airline service is planned, and a customs post has already been established in Dali. In addition, the railway will have been extended from Guangtong to Xiaguan by the end of 1998, strengthening the role of Dali as the western gateway between Yunnan and Myanmar. The planned annual capacity of this passenger and freight line is 1.4 million persons and 3.0 million tons of freight, respectively. Four major roadways also serve the region. National Road 320 goes east to Kunming and west to Baoshan. National Road 214 goes north to Jianchuan and Lijiang. Another road begins about 50 km east of Xiaguan, and travels south from National Road 320 to Xishuangbanna. Regional roads include the Lake Erhai Ring Road, the Jizu Hill Highway, the Shibao Hill Highway, and the Cangshan Mountain Cableway.

At the end of 1996, 118 accommodation units were directly engaged in serving tourists in Dali City. These establishments provide more than 21,000 beds and 2,075 standard rooms. Among these accommodation units are 32 hotels, 14 of which are graded as international hotels: six as two-star hotels and three as one-star hotels. Between 1984 and 1989, the number of hotels and hostels which serve overseas guests increased from four establishments providing 595 beds in 1984 to 11 establishments providing 2,682 beds in 1989. There are 23 travel agencies, including one first class and four second class agencies, and nine transportation companies operating travel busses and ships. The transportation companies operate nine tour boats for foreign guests with a total carrying capacity of 2,175 passengers, and 216 tour busses with 6,580 seats.

About 19,200 individuals are engaged in supporting tourist transportation throughout the Dali Bai Nationality Autonomous Prefecture (DBNAP). The total number of the persons engaged in tourism-related businesses, catering, and tourism services increased from about 10,000 in 1980 to about 35,000 in 1988. Between 1984 and 1989, the total annual tourism income in Dali City increased from 1.4 million Yuan to 2.9 million Yuan, the income of travel agencies amounted to more than 10 million Yuan, and the total income from domestic tourism was about 150 million Yuan. The annual value of foreign exchange earned from tourism increased from US $ 298,6000 in 1984 to US $ 670,300 in 1989. In those six years, the total foreign exchange earnings amounted to US $ 2.3 million.

Tourism and Tourist Destinations

The actual number of tourists visiting the region is not well known. However, for purposes of this study, it has been estimated that about 800,000 tourists visited the Dali region (DBNAP) during 1995, including 40,000 visitors from abroad. The data presented in Table 63 indicate a rapid growth in the numbers of visitors. Table 64 presents information on the countries of origin of visitors from abroad during 1994. Nearly one-half of the visitors originated from countries in the Asia-Pacific region.

Table 63. Tourism in the Dali Municipality

	1985	1990	1994	1995 (estimated)
Foreign Tourists	5,000	10,200	34,579	40,000
Total number of beds	9,700	11,000	10,400*	10,400*
Beds for Foreign Tourists	230	2,800	2,900*	2,900*
Tourism Revenues: Direct, ¥ million		12.4		70
Tourism Revenues: Indirect, ¥ million		50		620

*Data from 1993 for the 13 hotels catering to foreign visitors.

During the period of the eighth five-year Plan, Dali's tourism industry set out "to grasp the opportunity, to propel the Reform, to improve the Opening, [and] to promote the exploitation and development of resources". Tourism was envisioned as a means of "making the people and the prefecture prosperous". Based upon statistics for 1995, the tourism development program was a success. Throughout the province, during that year, tourism accounted for a total of about 2.8 million person-days. There were 40,000 foreign tourists and 2,760,000 domestic tourists. Tourism contributed direct income to the value of 70 million Yuan, and indirect or social income to the value of 620 million Yuan. The latest statistical data, for 1996, indicate that tourism accounted for 3.2 million person-days, and that foreign tourism increased to 45,319 foreign tourists. The direct income from tourism was 93.22 million Yuan, while the social income totaled 810 million Yuan. Tourism made up

18 percent of the Prefecture's GDP, confirming a shift from general industry to tourism as the mainstay industry in the Prefecture.

Table 64. Principal Countries of Origin of Foreign Visitors to the Dali Prefecture, 1994.

Country/Region	Number of Tourists	Percent of Total	Country/Region	Number of Tourists	Percent of Total
Singapore	4435	12.8	Switzerland	497	1.4
Hongkong, Macau	4132	11.9	New Zealand	394	1.1
Japan	3584	10.4	Other Asia	314	0.9
United States	2837	8.2	Sweden	309	0.9
Taiwan	2274	6.6	South Korea	144	0.4
United Kingdom	1824	5.3	Spain	129	0.4
France	1817	5.2	Other America	84	0.2
Netherlands	1544	4.5	Overseas Chinese	61	0.2
Germany	1494	4.3	Indonesia	58	0.2
Malaysia	1369	3.9	Russia	17	0.1
Thailand	1063	3.9	Other Atlantic	8	0.1
Australia	973	2.8	Africa	6	0.1
Italy	669	1.9	Philippines	5	0.1
Canada	644	1.9	Other Countries/Regions	3885	10.3

Table 65. The Golden Tour of Dali Bai Nationality Prefecture

Golden Tour	Duration	Trip Route	Tourism Activities in Main Scenic Spots
Itinerary	three days	view the scenery of Dali Cangshan mountains	The first day Board the tour boat at the Erhai Wharf in Dali City to go sight-seeing on Lake Erhai; visit Lake Erhai Park and view Bai Minority singing and dancing of "Three Courses Tea", visit Guanyintang, Jinsuo Island, and Small Putuo; go ashore at Taoyuan Wharf, have a traditional Zhoucheng Bai Minority lunch, visit the Shangguan Flower Park and Tianlong Cavern; visit the Zhoucheng Bai Minority Village, view and purchase embroidery using traditional dye techniques of Bai Minority, stay at Butterfly Spring Hotel, and go to the Zhoucheng night market.
		experience Dali's national culture	The second day Go to Xizhou Town by bus, taste Xizhou Cake and visit residential buildings; go to the Xizhou morning market; visit the Three Pagodas in Chongsheng Temple; see cormorants in a Lake Erhai fishing village; have a traditional lunch at the Dali Residential Courtyard Hotel; travel to Dali March Street (Guanyin City) by bus; view the stele of Ping Yunnan; go to the Cangshan Mountains tourism cable-way by cart and tour Zhonghe Peak by cable-way, looking down at the rural scenery of Dali; visit Longyan Cavern, Fengyan Cavern, and Qilonglu Pool, return by cable-way, and continue to the Dali Old Town by bus; visit the market of national handicrafts and Yuer Garden; stay at Dali Old Town; have a traditional dinner along Dali Foreigners Street; and visit the night market on Foreigners Street.
		view the scenery of Dali Lake Erhai	The third day Go to the South Gate of Dali Old Town by bus along South Gate Dali Marble Street; visit the market for the special dyes, the City Museum (the mansion of Marshal Du Wenxiu), the Marble Exhibition Hall, the Forest of Tablets, and Guanyin Pond; view the Dehua Tablet in the Prefecture Museum; visit the Prefecture Entertainment Center of Folk Custom and experience Bai Minority culture; stay in Dali City.

Based upon the successes to date, the government of Dali Bai Nationality Autonomous Prefecture has acted to put into place policies to continue to develop tourism in the region. In support of these policies, the Prefectural government has allocated annually about 70 million Yuan for construction of the airport, highways, railways, and telecommunication facilities; 80 million Yuan for hotels and restaurants; 8 million Yuan for ships; and, 2 million Yuan for special projects. The total investment on tourism to date is about 510 million Yuan.

At present, tourists visiting the region partake in a one-day sightseeing tour of the principal amenities. A typical tour would include Lake Erhai Park-Minor Putuo-Guanyin Garret-Zhoucheng-Butterfly Spring-Three Pagodas-Dali Old Town-Xiaguan. Such a route provides the tourists with too little time to explore the rich tourist resources of Dali, and provides a somewhat unflattering impression of the quality of the environment and tourism amenities of the region. Should this situation be continued, the economic benefits to be derived from tourism will be diminished, and the favorable impression of Dali's scenery damaged. This would be harmful to the sustainable development of tourism. In recognition of this, the local government has undertaken measures of increasing the numbers of tourist routes and tourist amenities. Fifteen new tourist routes were defined and the additional tour options brought into service on April 1st, 1997. The most important tour is a three-day journey called the "Dali Bai Nationality Prefecture Golden Tour". This tour, detailed in Table 65, includes the Dali Cangshan Mountains, events related to Dali's cultures, and the Dali Lake Erhai. The tour provides a rich, colorful, and varied experience and exposure to the region that combines the natural scenery with the cultural setting. In this way, the tour seeks to exhibit the rich and special tourist resources in this region, and provides the tourist with an introduction eating, living, traveling, visiting, purchasing, and playing in this unique area of China.

Tourist Carrying Capacity Analysis

Sustainable development is based on the balanced development of ecology and economy, such that the level of development does not exhaust the natural and cultural resources of a region nor decrease environmental quality. This concept has been widely accepted by all developmental sectors, including tourism development. Successful and sustainable tourism relies on clean natural conditions, protected environments, and the participation of the local community. Planning to protect both the local environment and local culture will not only promote tourism but also create a means to sustain the environment and culture. Beautiful scenery, good vegetation cover, well preserved flora and fauna, and clean air and water are valuable resources that attract tourists. Thus, the long-term and steady development of tourism in the region cannot ignore environment protection. In other words, for tourism to be economically viable, it must be environmentally sustainable.

Sustainable tourism can be modelled using economic development models. The main economic purposes of tourism are to improve the living standards of local residents, to provide an high quality service to tourists, and to protect the environment for local residents and tourists. To fully achieve these purposes, sustainable tourism development should be combined with environmental protection. This combination takes an holistic approach that recognizes the fact that improvement of environmental quality will, in turn, promote the development of tourism. However, such a dynamic suggests that there is an environmental carrying capacity beyond which tourism will overwhelm the natural resource base and cause or contribute to environmental degradation. Thus, from the modelling point of view, it is necessary to identify the break-even point between tourism development and environmental protection that will maximize economic return but minimize environmental damage.

Carrying capacity, when applied to the tourism industry, quantifies this break-even point. As noted, carrying capacity refers to the number of tourists that an ecosystem can support indefinitely without degrading the natural resource base. Ideally, the tourist carrying capacity should be assessed in three ways:

- as environmental carrying capacity, which refers to the maximum number of tourists that can be accommodated within a given physical and/or cultural environment in such a way so as not to (1) exhaust the tourist resources, (2) decrease the level of satisfaction among the tourists, or (3) result in a negative impact on social and economic conditions, taking into account seasonal and annual variations
- as cultural and social carrying capacity, which refers to the level beyond which tourism developments and visitor numbers adversely affect local communities and their ways of life to the extent that their local identity is altered or lost

- as psychological carrying capacity, which refers to the level of tourism development or number of visitors that is compatible with the type of cultural or natural experience that the visitors are seeking at a particular destination, as conditioned by the type of tourism activity, and the expectations and actual experiences that they have.

While attempts have been made to calculate these carrying capacities for specific sites, such analyses appear to require extensive data and detailed local knowledge. Given the paucity of such information, the development of indicators and models to quantify carrying capacities for different sites is in its infancy, or conceptual development stage. Nevertheless, the concepts involved are rooted in the practical experiences at tourist sites. The essence of such experiences can help to guide the political choices being made by policy makers concerned with the environmental impacts of tourism and leisure.

Each tourist site has its own environmental characteristics that need to be carefully analyzed and to determine the limiting factors that will induce environmental degradation. The administrative office of the Cangshan and Lake Erhai national natural reserve has developed guidelines for the environmental carrying capacity of the natural reserve. The guidelines are based upon the length of each tourist route. The total length of Cangshan Mountains tour is 37 km, 22 km of which is bus route used for purposes in addition to tourism. The remaining 15 km is comprised of footways that are used exclusively for tourism. Assuming that each tourist requires 60 m of footway, the carrying capacity would be 250 persons/day. As the tourism season is approximately 300 days in length each year, the annual carrying capacity would be 75,000 individuals. Similarly, the administrative office has determined comparable carrying capacities for other routes:

- the 20 km Cangshan Mountains Yudai Road has a carrying capacity of about 670 persons/day, based upon a standard trail length of 30 m/person. Given the length of the tourist season of 300 days/year, the annual carrying capacity of this route is 200,000 individuals
- the 30 km Cangshan Huadianba route has a carrying capacity of 1,000 persons/day, based upon a standard trail length of 30 m/persons. Given a 300-day

tourism season, the annual carrying capacity is about 300,000 individuals

- the Lake Erhai tourism route, based upon experience in tourism development over many years, has an annual carrying capacity of about 300,000 individuals.

Thus, the total annual tourist carrying capacity of the Cangshan and Lake Erhai national natural area has been determined to be about 875,000 individuals. This tourist carrying capacity appears to be sound from the point of view of environmental protection, but somewhat conservative from the point of view of tourism development, especially with regard to Lake Erhai.

The tourist carrying capacity of Lake Erhai, determined by the administrative office of the Cangshan and Lake Erhai natural reserve, was based upon the continuation of net and caged fish culture in the lake basin. Because net and caged fish culture has been abolished, and the mechanical systems of fishing boats modified and upgraded, activities that had greatly affected the water quality of Lake Erhai have changed. Moreover, limits on the number of tour boats, and controls on the discharge of wastewater and solid wastes from such vessels, have been implemented. As a result, the tourist carrying capacity can be re-calculated. Under current conditions, the limiting factor becomes the number of available tour boats. At present, there are nine boats, with a combined passenger capacity of 4,350 persons/day. Based upon the annual tourism season of 300 days, the annual tourist carrying capacity of Lake Erhai can be increased to 1,305,000 individuals. This four-fold increase in carrying capacity clearly shows the link between environmental quality and tourism development in this case.

In addition to the Cangshan Mountains and Lake Erhai, the most famous scenic sites in the region are the Butterfly Spring, the Three Pagodas Temple, and Dali Old Town. Because visitors to the region are sure to visit these sites, an estimate of their carrying capacities added to the carrying capacities determined above for the Cangshan Mountains and Lake Erhai will provide an approximate tourist carrying capacity for the lake basin. It can be seen from Table 66 that the number of tourists visiting these sites has changed little between 1990 and 1995. Although these data are limited, it may be assumed that these sites are nearly saturated. If conditions do not change, tourist carrying capacities of these three sites can be estimated as the maximum number of tourists visiting each scenic spot. Thus, the annual tourist carrying capacities of these sites are 350,000, 240,000, and 1,000,000 individuals, respectively. Adding these tourist capacities to those of the Cangshan Mountains and Lake Erhai, as determined above, results is an annual tourist carrying capacity of about 3,480,000 individuals. (Notwithstanding, since this capacity is based only on the main scenic spots, it remains an underestimate. If the carrying capacities of the additional scenic spots identified in Table 65 are taken into account, the total tourist carrying capacity of the Lake Erhai region can be increased by 10 to 20 percent about 4,000,000 individuals.)

Table 66. Numbers of Tourists Visiting the Major Scenic Sites of the Lake Erhai Basin (1,000 persons/year)

Scenic Spot	1990	1991	1992	1993	1994	1995
Butterfly Spring	300	300	300	350	350	350
Three Pagodas Temple	230	230	250	240	240	240
Dali Old Town	300	300	420	420	1000	1000

As has been intimated in the discussion of the carrying capacity of Lake Erhai, one potentially limiting factor to tourism development in the Lake Erhai basin is the capacities of the transportation system. Current capacities (one way) may be estimated at 22,000 persons/year by air, and 900,000 persons/year by road (based on 80 busses/day, each with 30 passengers). Given the current levels of investment in transportation infrastructure, Table 67 presents the annual (one way) passenger capacities of the projected transportation system. This system could convey about 100,000 by air, 700,000 by rail, and 3,600,000 by road, or approximately 4.4 million passengers/year. It should be noted, however, that this capacity is shared between tourists, other visitors (related to government and business), and the resident population. Also, while the passenger capacities set forth in Table 67 can be increased, such increases will require additional investment in infrastructure, equipment, rolling stock, etc. The level of this additional investment, given the numbers of persons, large distances, and topography involved, is likely to be substantial, even with the significant investments currently being made by the Prefectural government in road and rail facilities (and in addition to the investment in air transportation already made).

Table 67. Projected Transportation System Capacities: Kunming-Dali (One-way)

Transport Mode	Travel Time	Trips/day	Passengers/trip	Passengers/day	Passengers/year
Air	0.30 h	2 aircraft	150/aircraft	300	100,000
Rail	7.00 h	4 trains	500/train	2,000	700,000
Road	5.00 h	200 busses	50bus	10,000	3,600,000

Although not explicitly accounted for in the foregoing assessment, it should also be noted that the tourist carrying capacity may change with season, time, the behavior patterns of tourists, infrastructure, environmental conditions and awareness, and management. Nevertheless, tourist carrying capacities provide a measure through which these many criteria can be integrated in such a way as to ensure, insofar as possible, good environmental quality and tourist satisfaction.

3.4 Tourism Development Planning in the Dali Bai Nationality Autonomous Prefecture: 1995-2010

Tourism development planning in the Dali Bai Nationality Autonomous Prefecture was initiated at the end of 1980, and resulted in the publication of the first plan for tourism development in 1990. The current tourism development plan for the DBNAP, 1995 through 2010, updates and elaborates this plan. The plans are based upon a policy that recognizes the importance of tourism in the development of the region. This policy has been given effect by government-supported investments in the development of tourism in the Prefecture. Yunnan Province, of which the Dali region is an important part, is among the ten most important tourist areas in China in terms of number of visitors attracted from abroad. The reasons for this popularity are manifold and include the abundance of both natural and cultural resources, including the mountain and lake scenery, abundant animal and plant resources, and a benign climate (temperatures range between 10°C and 20°C on more than 300 days/year). Cultural resources include religious relics and buildings, traditional ethnic architecture, colorful ethnic traditions and festivals, and a variety of traditional handicrafts. All of these amenities are conveniently located in proximity to each other and regional transportation facilities.

Tourism development policies have included investments in infrastructure development. In recent years, investments have been made in the airport, roads, railways, and telecommunications. In addition, investments in scenic areas (70 million Yuan), hotels and restaurants (80 million Yuan), boats (8 million Yuan), and special projects (2 million Yuan) are made annually, with an accumulated investment in tourism infrastructure estimated at 510 million Yuan since 1984. The numbers of facilities, including travel agencies, hotels and restaurants, busses and boats, and shops, also have increased to serve both domestic and foreign visitors. The numbers of domestic visitors have more than doubled between 1984 and 1995, while the numbers of foreign visitors have increased by eight-fold. Direct revenue from tourism was estimated at 70 million Yuan in 1995, and total revenues at 620 million Yuan. Currently, more than 10,000 staff are directly employed in the tourism sector. Additional projects are underway. Projects planned or under construction include the Asia Star Hotel outside Dali Old Town, being completed at an investment of 260 million Yuan, a golf course, a cabin lift, a holiday center and a recreation center on the beach of Lake Erhai. Table 68 shows the main objectives for tourism development between 1995 and 2010. During this period, 28 million tourists, including 200 thousand foreign tourists, are expected to visit the area to minority folk customs, holiday tours for relaxation and health, sightseeing, religious celebrations, and scientific investigations, exploration, hunting and fishing. Notwithstanding, inadequate infrastructure, poor management and provision of services, and lack of investment in certain types of facilities are among the problems still facing tourism development in the DBNAP.

Table 68. Objectives for Tourism Development in the DBNAP: 1995-2010 (expressed as a percentage increase per five-year period).

Objective	1995—2000	2000—2005	2005—2010
Growth rate for tourism	78	68	25
Growth rate for foreign tourism	150	50	33
Growth rate of direct tourism income	114	66	60
Growth rate of total tourism income	61	50	33

Future development of tourism in the region will focus on the near Asian markets. These markets are deemed to provide opportunities for the rapid development of the tourism industry, and spur further growth. It is envisioned that Dali Municipality will remain the main tourist center, with visits to Weishan, the Lake Cibi area, the Cangshan Mountains, and the caves at Shibaoshan undertaken from this center. For this reason, Dali's role as a tourist center is pivotal in the development of a (geographically) diversified network of multi-functional tourism facilities. This network is expected to include six scenic sites in the Lake Erhai basin; namely, the Cangshan Mountains, the Buddhist Holy Land at Jizu Hill, the Zhoucheng Bai Minority Mountain Villa, a tour center and vacation area on a Lake Erhai island, the Lake Erhai aquatic recreation area, and Cibi Lake. In addition, further protection and development of Dali Old Town, to make it a tourism center for the study of the culture and history of the region, is foreseen. Continued development of the road network that connects these scenic spots will be required in order to promote visits between scenic spots in the area, and optimize tourism among dispersed sites. Finally, the development of tourist routes from Kunming to Dali and the northwest, to Lijiang and Rili, make Dali an ideal tourist distribution center in western Yunnan Province (Figure 25).

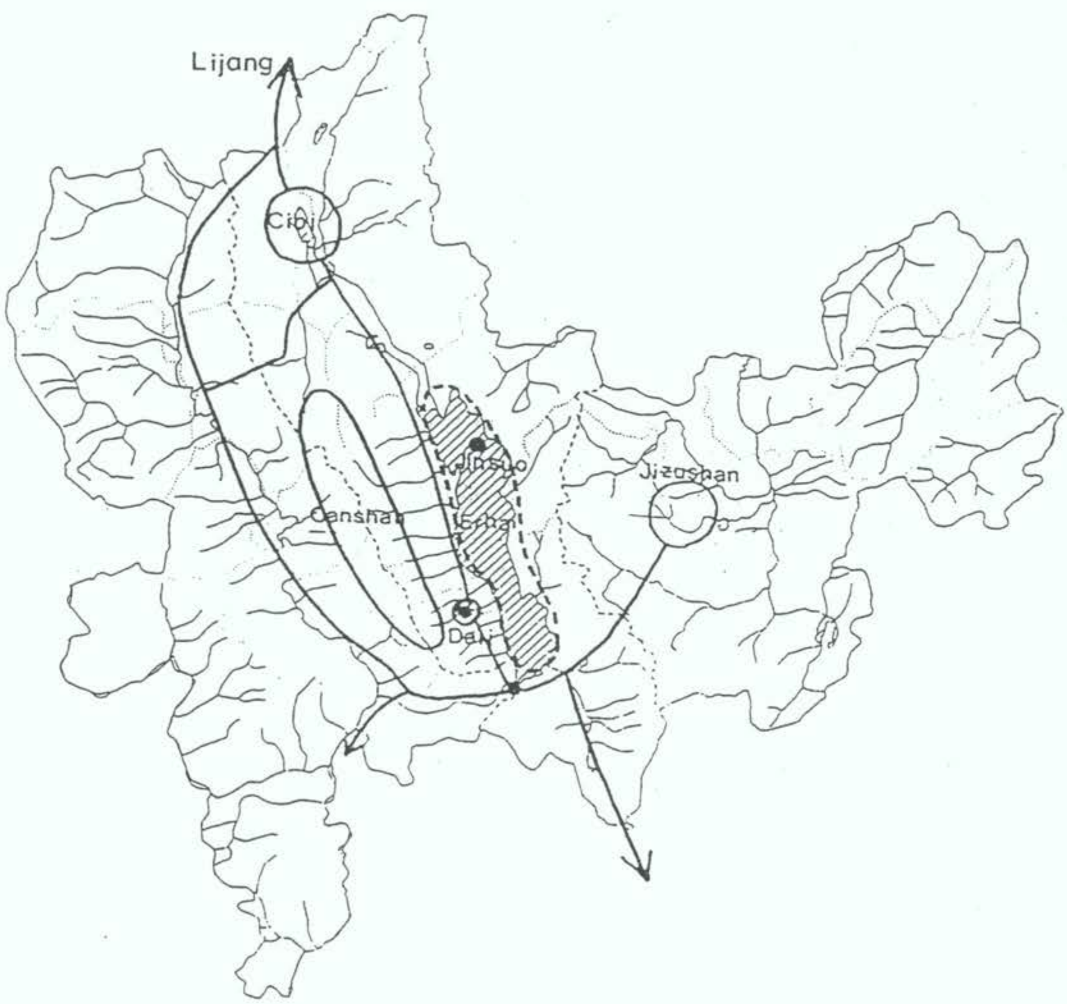

Figure 25. Dali – Lake Erhai area tourism development axes.

Development of Tourist Infrastructure

As noted above, the Prefectural government is undertaking a program of substantial investment in tourism infrastructure, with an emphasis on Dali City. Infrastructural improvements foreseen in the vicinity of Dali City include a cableway providing access to the Cangshan Mountains, highway improvements, a wharf, an hotel, and various tourist facilities.

Cableway

A cableway is proposed to be built in the Cangshan Mountains to the west of Dali Old Town. The cableway will be divided into an upper and lower section, the lower section of which is already built and operating. This existing section of cableway has a vertical elevation of 456 m, terminating to the north of the Zhonghe Temple at an altitude of 2,595 masl. The cableway traverses an horizontal distance of 1,730 m, and can carry 192 seated passengers. To date, the total investment in this system has been 8 million Yuan. The upper section of the cableway extends from the Zhonghe Temple to the peak of Cangshan Mountain, over an horizontal distance of 4,300 m.

Tourist Highway and Wharf

To enhance the accessibility, construction of the first-class Chuda highway has been speeded up, and construction of the second-class highway from Dali to Lijiang, and upgrading of the pavement of the Dali section of National Road 320 between Dali to Rili, is proposed. Construction of these highways will facilitate tourist access to scenic spots in Lijiang, Dali, Dehong, and Baoshan (Figure 26). In addition, to improve accessibility between scenic spots, the following roads and docks will be built:

- construction of a tourist route linking Butterfly Spring-Jiangwei-Shuanglang-Jizu Hill
- construction of a tourist road around Lake Erhai
- reconstruction to third-class standards of the road from Dali City to Weishan Ancient City

- construction of a first-class road from Dali Airport to Butterfly Spring
- reconstruction of the road from Dali Old Town to the Cangshan Mountains Shrine
- construction of recreational facilities and holiday areas in Dali City and Yunnan Province
- provision of tour boat docks at Taoyuan, Shuanglang, Wase, Lake Erhai Park, Jinsuo Island, Minor Putuo, and Luoquan Temple.

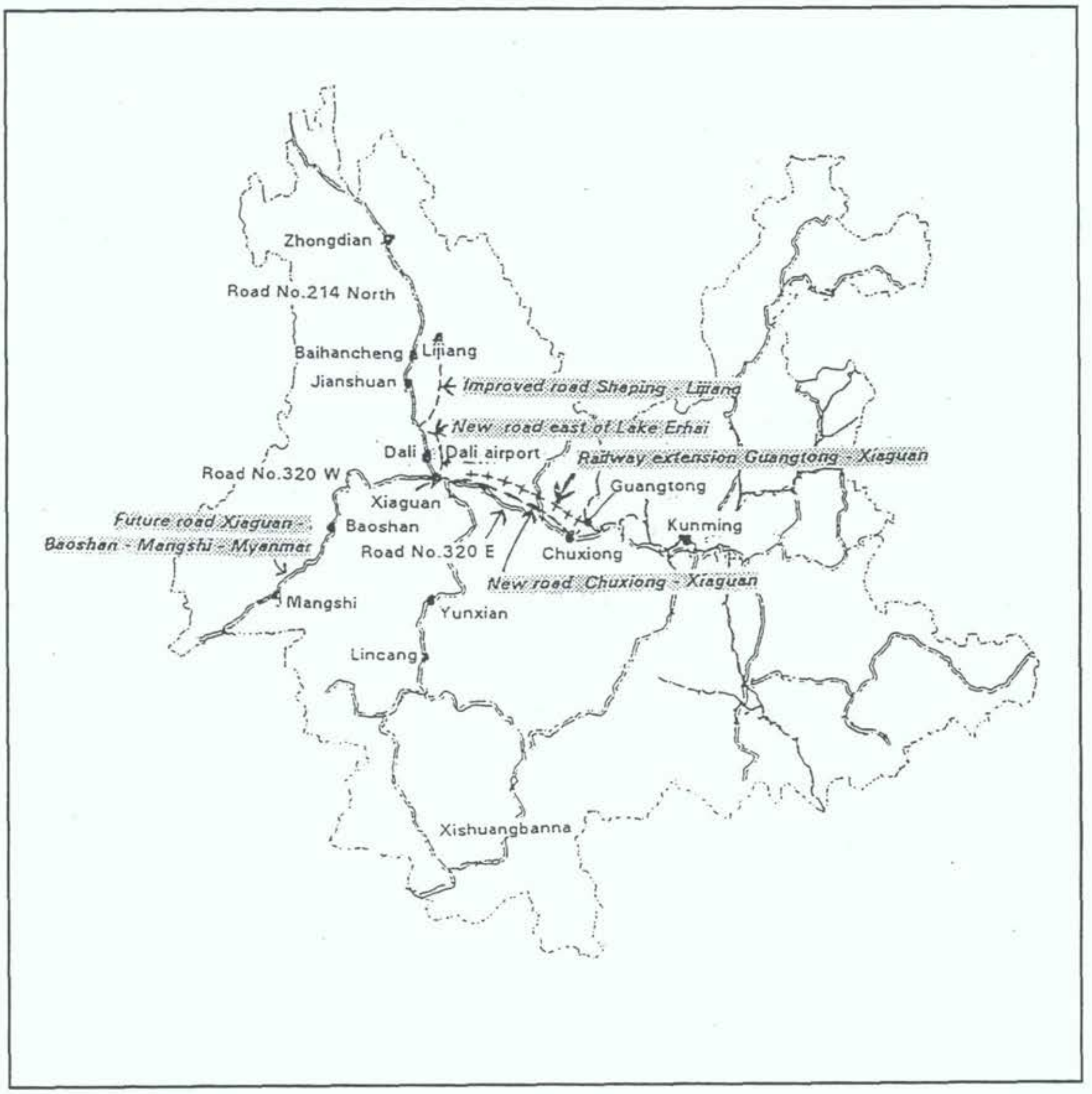

Figure 26. Transportation infrastructure improvements proposed in the vicinity of Dali.

Table 68. Travel Agencies Planned for the Lake Erhai Basin: 2010.

Categories of Travel Agency	Number of Agencies Planned
International, Grade One	1
International, Grade Two	8
Domestic, Grade Two	27

Table 69. Hotels and Restaurants Planned for the Lake Erhai Basin: 2010.

Facility	Number of beds	Grade	Notes
Lake Erhai Hotel	420	Star	Extension
Cangshan Mountains Hotel		Star	Extension
Yaxing Hotel	848	Star	New
Nanzhao Hotel	600	Star	New
Xiaguan Restaurant	900	Star	Extension
Dali Hotel	400	Star	Extension
Hongshancha Hotel	350	Star	Extension
Xiaguan Hotel	450	Star	Extension
Xizhou Hotel	200	Star	Extension
Jinhua Hotel	230	Star	New
Jinpeng Hotel	450	Star	New
Xilong Hotel	400	Star	Extension
Jiuqita Vacation Hotel	100	Star	New
Xihu Hotel	50	Open to foreign visitors	New
Longma Hotel	100	Open to foreign visitors	New
Nanzhao Custom Hotel	150	Star	New

Hotels and Travel Agencies

As reception and service facilities, hotels, and travel agencies are an integral part of tourism, a number of hotels and travel agencies must be constructed to meet the needs of domestic and foreign tourists, as shown in Tables 68 through 70.

Table 70. Planned Capacities of Large, Government-owned Hotels in the DBNAP: 2010.

Area	Number of beds	Grade
Dali Municipality	5,915	Stars
Eryuan County	210	Stars/Open to foreign visitors
Jianchuan County	100	Open to foreign visitors
Binchuan County	280	Stars/Open to foreign visitors
Weishan County	250	Stars/Open to foreign visitors
Midu County	120	Open to foreign visitors

Tourist Facilities

The construction of tourist facilities is proposed to be undertaken in three phases during the immediate term, medium term, and longer-term periods. During the immediate term (1995 through 2000), emphasis will be placed on the development of scenic spots in the Cangshan Mountains and around Lake Erhai. During this period also, construction of the Cibi Lake holiday resort and its related facilities is expected to be initiated. In the medium term (2000 through 2005), emphasis will be placed on the development of surrounding scenic spots, including the Xiangyun Qinghua Cavern and Shuimu Hill, Yunlong Tianchi, and nearby sites at Yangbi, Midu, Heqing, Nanjian, etc. In the longer-term (2005 through 2010 year), it is anticipated that all outstanding construction projects will be completed. Development of these facilities, summarized in Table 71, will result in multi-functional scenic area with adequate and appropriate tourist capacity, which will benefit the peoples of the basin.

Table 71. Scenic Areas in Dali Bai Nationality Autonomous Prefecture.

<u>Central Areas</u>

a. Dali provincial level tourist and holiday zone, including a service zone, recreational zone at the foot of the mountain, a golf course, a beachfront recreational area, an apartment zone, a tree plantation, a local style street, and a cable car to the top of the mountain
b. Dali tourist and recreation center and training facility for ethnic groups
c. Dali Old Town protection and preservation
d. Chongsheng Temple with Three Pagodas reconstruction
e. Enlargement of Butterfly Spring
f. Enlargement and refurbishment of the Erhai and Cangshan Hotels
g. Huadian camping and holiday village
h. Jinsuo Island summer resort

<u>Surrounding Areas</u>

a. Jiuqitai Spring holiday village (¥2.8M investment, 100 beds, physical therapy area, pool)
b. Cibi recreation center
c. Cibi Lake plum plantation and orchidean mountain villa
d. Xihu Lake natural park (six villages, seven islands, accommodation)
e. Niao Diao Mountain (bird watching, hunting, etc.)
f. Shuang Lang natural park
g. Shibao scenic areas
h. Jizhushan scenic areas
j. Weibao mountain scenic areas
k. Preservation and restoration of Weishan Old Town
l. Construction of Nanzhao museum

<u>Auxiliary Areas</u>

a. Qinghuadong scenic area in Xianyun County
b. Shimengguang scenic area in Yiangbi County
c. Scenic areas in Yunlong County
d. Jinguan Temple in Yunping County
e. Tientsupan area in Yunlong County
f. Scenic areas in Heqing County

Dali Old Town

The Dali Old Town development plan, prepared in 1993, anticipated that the population of Dali Old Town would grow from about 13,000 in 1991 to 15,000 in 2000. In addition, three new facilities, with an area of about 200 ha, are proposed to be constructed outside of the Old Town. Half of the land in this area will be used for tourist facilities (hotels and vacation villages) and the rest for commercial and public functions. The total development will include 8 hotels with 2,000 beds and is expected to attract an additional 10,000 permanent residents to the area. The first of the tourist facilities, in the Central Area, to the south of the South Gate, is already under construction, and a highway and sub-star grade hotel to serve this facility will be completed soon. The second facility will be a holiday village at the foot of the mountain, and a holiday village and other facilities are also planned for the beach east of Dali Old Town.

The tourism plan for Dali Old Town incorporates provisions to preserve the historic character of the town within an urban environment. The old city wall, with its gates and the towers, will be restored as an early part of this development program. The Fuxian Road, the high street of the town, is proposed to become a pedestrian street. The two waterbodies, one to the north and the other to the south in the eastern part of the town, also are proposed to be developed for tourism. Service facilities in Dali Old Town are to be improved and developed into a commercial center for tourist products. The techniques and experiences gained from the restoration of Lijiang Old Town are recommended to be employed in the restoration of Dali Old Town.

Cibi Lake

The Cibi Lake area is famous for its hot springs, historical sites, traditional minority nationality culture, and beautiful scenery, incorporating both lakes and mountains. This area is planned to be primarily used as a sanatorium for international and domestic tourists. The major tourism facility development projects planned for this scenic spot are shown on Figure 27, and include:

- Jiuqitai Travel and Vacation Village, built in 1996, which features hot springs and facilities for administering traditional Chinese medicine within a convalescent hospital setting
- Liyuan Garden Vacation Village will be a traditional lakeside village of the region, featuring natural scenery and traditional culture
- Eryuan Town features a hot water spa and is the center of Eryuan County serving both tourists as well as permanent inhabitants of the region
- The outer lake tourism region will feature an aquatic recreation center
- The Cibi Park, middle tourism region, situated between the inner and outer lakes, will feature cultural recreation and relaxation, and will be characterised by a quiet, restful environment
- The inner lake region will feature water sports and picnic sites for vacation tourists, and local residents. Traditional activities around the Dragon Temple also are featured.

Tourism Routes

Tourism requires a specific type of transportation to link between scenic spots, in order to fully develop the tourism market. As noted, provision of an increased number of tourist routes will be based upon the development of the market and the rational exploitation of tourist sites, all predicated upon proper planning. Based upon the current plan, development of a number of additional tour routes is proposed:

- Dali—Butterfly Spring—Shuanglang—Jizu Hill—Wase—Lake Erhai Park
- "Tian Long Ba Bu" tour
- Dali—Eryuan West Lake, Niaotiao Hill, and Cibi Lake
- Drifting tour in Yangbi River
- Jiuqitai relaxing vacation
- Dali-Weibao Hill
- Dali-Jian Chuan Shibao Hill.

These routes include aquatic and terrestrial hiking routes as well as automobile tour routes for the Dali Prefecture. In the context of Yunnan Province as a whole, Dali is the transportation pivot serving western Yunnan, and the only way to access Lijiang, Rili, and other scenic spots in western Yunnan Province. Given that the railway and highway to Dali is soon to be finished, development of the tourist routes is timely, and will contribute to the goal of establishing a tourism market in this region.

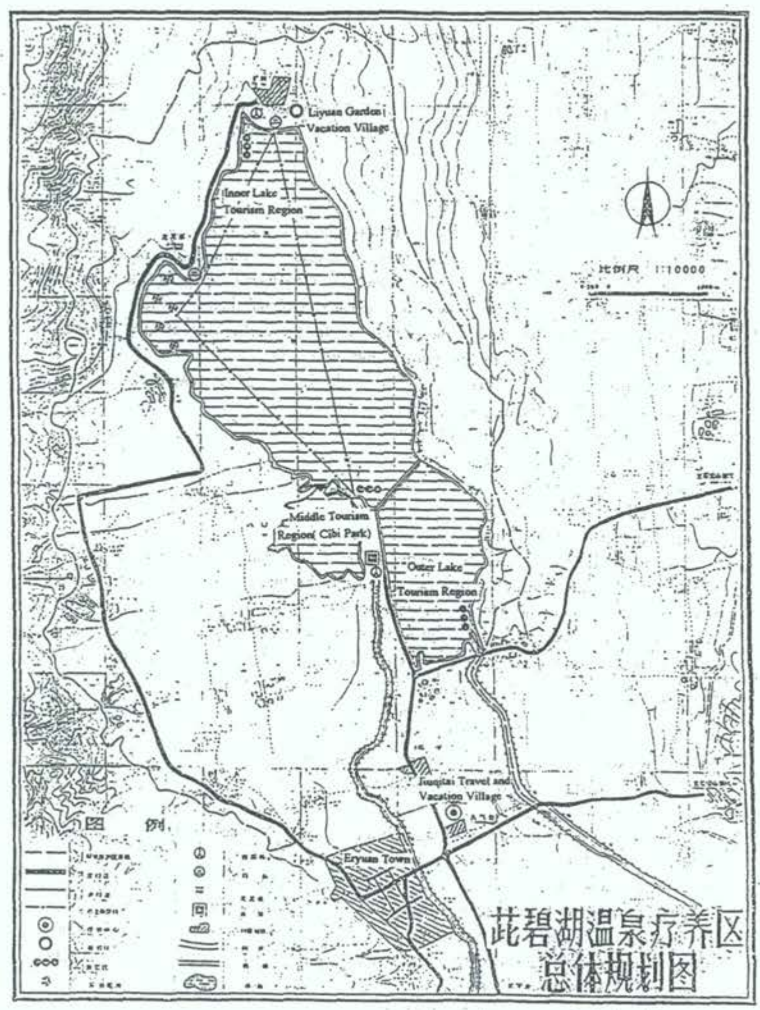

Figure 27. Tourism development plan for the Cibi Lake area.

3.5 Environmental Impacts of Tourism Development

As has been noted above, the development of a sustainable tourism industry is based upon achieving and maintaining a balance between the actions needed to maximize tourist revenues and minimize environment damage. Currently, many scenic areas are in a poor state of maintenance, and seem to be overused in relation to their current carrying capacities. Pathways were generally in poor condition, and visitors were walking on lawns and other adjacent open areas as appeared convenient. Waste receptacles were few and far between. Tourist facilities were non-existent. Informational signage, toilets, and information for the non-Chinese visitor were all lacking. Buildings were generally in poor repair and in obvious need of renovation to restore their former grandeur. These problems combine to create a general impression among visitors to these areas that, although the scenery and the old buildings themselves are quite interesting, the poor conditions of the facilities and the lack of proper maintenance detracts significantly from what could have been quite interesting under other conditions. In their present conditions, it would not be advisable to increase the number of visitors to these scenic areas. Any increase in the number of visitors to these areas would seriously jeopardize their amenity value and contribute to environmental problems. Increased usage would also risk further degradation of both the buildings and the sites.

The Minor Putuo Island gives a good example of this concern. The Island has a small temple on a rock in the lake. The temple has been subjected to disturbance by boats and tourists who make use of a temporary landing, which has been arranged from rocks and gravel placed in the lake adjacent to the island. This disturbance considerably detracts from the experience. Further, the island is much too small to receive so many boats and visitors, and plans have been prepared to construct proper landing facilities in the nearby village. Restoration of Minor Putuo Island is also proposed in this plan.

Natural Areas

A boat trip on Lake Erhai forms an important part of the sightseeing tour to the Dali region. Embarkation and disembarkation facilities at most landings seem to be temporary arrangements, lacking proper facilities. A new harbor is soon to be completed in Xiaguan, but proper landings continue to be required at other sites. In addition, facilities for the handling of sewerage and solid waste onboard the boats, and procedures for containing and cleaning oil spills are required. The boats on Lake Erhai should be provided with sewage holding tanks, and proper facilities for the collection of solid waste on board. These tanks and containers should be emptied in a proper fashion on land. Pumping facilities to receive liquid wastes and discharge them to municipal wastewater treatment plants, and receptacles for solid waste, should be incorporated into the proposed pier and harbor facilities. Special requirements should be established to eliminate oil spills from the boats, and regular inspections to this effect should be instituted.

Lake Cibi is much smaller than Lake Erhai, and has an altogether different character. At present, there are no facilities developed around this lake, although a road is being constructed to Cibi Park. Nevertheless, it is important that measures be taken from the outset to ensure that environmental degradation as a consequence of recreational use does not occur on Cibi Lake. Specifically, the issues of sewerage and solid waste disposal should be fully controlled from the outset.

The Cangshan Mountains are generally accessible only on foot, with the exception of a few mountain roads. One of these roads reaches an elevation of 3,200 m in the vicinity of the highest peak, 4,122 m Zhonghe. The road from the main highway west of Dali Old Town suffers from erosion along its slopes and excavations, while environmental damage from past borrow activities can be seen in many places. Any further road construction on the higher slopes and peaks should be a matter of deep concern from an environmental point of view. Any such construction must be severely restricted and circumscribed by conditions if further degradation of the mountain is to be avoided. From the point of view of tourism, enhanced access to the mountains is likely to be counterproductive, as mountaineers prefer nature to be as intact as possible.

The Villages

Visits to the villages of the region are probably the best way to appreciate the special character and culture of the region. Some villages are already well established along the tour circuits. The villages are still mostly characterized by their own patterns of daily life; tourism seems to have had little impact on most villages. In part, this is likely to be due to the concentration of tourist activities close to Dali Old Town. Thus, there currently are no particular environmental concerns related to tourism in the villages, as there are relatively few visitors. However, as the total number of visitors to the Dali region increases, and especially as the numbers of foreign visitors increase, some impacts may be foreseen.

Dali Old Town. Concern about the conservation and preservation of the unique aspects of this old town is reflected in the town building regulations that are strictly enforced. These regulations, as well as the plans for the improvement and restoration of Dali Old Town, reflect the desire to preserve the heritage of the town while revitalizing the town as the regional center for tourism-related activities. Construction activities in the areas outside of the historic town are an indication of the vitality of local economy.

The traditional buildings of Dali Old Town are mostly two storeys high, with windows and panels made of wood and clay tile roofs. These buildings produce a unique urban environment along the streets. However, residents in these buildings have to cope with often sub-standard installations. It therefore seems reasonable that some kind of support be given for the preservation of the exteriors of these buildings while modernizing the structures internally to better meet modern standards of comfort and convenience. Repairs and updating of mechanical, electrical and sanitary facilities could be made internally, while the building exteriors are retained intact. Unfortunately, many newer buildings in the town have been constructed in a manner that is not particularly sympathetic to the historical environment in which they have been erected. This probably reflects a lack of understanding of the historic nature of the town by those involved in new building construction, rather than difficulties in construction. New buildings can be made to scales, and with forms and materials, that are harmonious with, and reflect an understanding of, the historic environment of the town. The incentive for preserving the historic town lies in attracting tourists to its unique environment. Replacement of historic structures with modern buildings, without regard to the particular character that distinguishes the Old Town from other small towns, will degrade the character of the town and discourage tourism to Dali Old Town. The consequences to the economy, in a region that is counting on tourism to be the largest sector of the economy in the future, could be catastrophic.

There are a number of additional issues that also need to be addressed in Dali Old Town. Traffic is an important concern in all old towns, including Dali Old Town. During the high season, traffic, in the form of cars, busses, horse drawn carriages, bicycles, etc., compete for space along the narrow streets. Thus, strict enforcement of the traffic regulations established for Dali Old Town is recommended. With the anticipated growth in the number of tourists, traffic will become an even greater problem. Traffic concerns center not only on the issue of crowding, but also on the issues of air pollution, traffic safety, and the general amenity value of the town.

To address the foregoing concerns, the area of the Old Town can be divided into three zones with different degrees of regulation, depending on environmental sensitivity and appearance. The Totally Protected Zone (Zone I) should be applied around the most important relics. Any construction activities that might affect the appearance and integrity of historical sites and relics are to be prohibited. Likewise, changes to damaged sites or relics must be planned in detail and approved by the Construction Administration to ensure that such buildings are in, or are restored to, harmony with the historical character of the traditional buildings. Some modern style buildings, three to five storeys in height, harm the appearance of the town, and should be remodeled to better fit into the historical environment of the town. The Strictly Controlled Zone (Zone II) should be applied to lands and buildings within 200 m of certain streets (e.g., Fuxin, Renmin, Xinmin, and Wenxian Streets, and the street from the North Gate to the area of the Three Pagodas, and along these streets). Within this zone, the height of buildings should be limited to 8 m, the building area maximized at 320 m^2, and the frontage limited to less than 25 m. The building regulations should be applied to the area within 16 m of these streets. The Harmonious Environmental Zone (Zone III) should include the entire historical town, including the Three Pagodas. This zone includes the western part of the Old Town.

In this zone, height of buildings should be limited to 11 m, and the building area maximized at 600 m^2. Use of traditional architectural styles and materials within this zone is mandatory. In the area between the Three Pagodas and Hongshengshi Pagoda, the height of buildings should be limited to 8 m (with a maximum height by special permit not to exceed 11 m). Likewise, strict regulations should be applied to all historical buildings, including the pagodas and temples. The main objective of these regulations, as applied to the Old Town, would be to safeguard the unique character of the Old Town as a whole.

In addition to the regulations applicable to individual buildings, the layout of the whole town should be protected. As the intent is to develop the whole town into a tourist center, a pedestrian precinct should be established, and the infrastructure improved. As part of the overall strategy, also the outskirts of the town and surrounding areas should be integrated in the improvement works.

Proposals have been advanced for the rebuilding of the wall around the town, and for the reconstruction of the gate towers. It has been suggested that the existing parts of the old wall be retained, and that replacement parts be built according to the original construction methods. It is also proposed that the East and West Gate towers be rebuilt, the latter in the beginning of Yuer Road, and that the Jinshan Daihai tower in the center of the town, at the intersection of Yuer Road and Fuxing Road, also be rebuilt.

Xiaguan. The largest town in the region, and its administrative center, lies on both sides of the Xi'er River flowing out of Lake Erhai. The town itself is a mixture of higher buildings, of up to ten storeys, and traditional lower buildings. The town is also the location of many of the larger hotels available in the region. Therefore, Xiaguan forms an important part of the currently available tourist resources. Presently, it is the terminus for the long distance busses that connect the Dali region with Kunming. When the railway is opened, a new bus terminal will be located adjacent to the railway station, to allow for the efficient transfer between road and rail transport. Given the fact that this town in the transportation hub for the region, some form of beautification scheme should be adopted to improve the appearance of the town, and to make it a more attractive place for pedestrians. Investments in parks and other appropriate facilities to improve the civic spaces in the town will be required to further promote the development of tourism in the town.

Roads and Terminals

The environmental issues related to road traffic are manifold, including noise pollution, air pollution, land and water pollution, public safety, unbalanced energy consumption, and loss of amenity value. While these impacts are most readily perceived in developed areas, and to an increasing degree as economic development progresses, the problems occur throughout a region, although they may assume a different character in different environments. In this case, issues specific to the Lake Erhai basin are addressed.

The Lake Erhai area is served by two main roadways. Road No.320 runs from Kunming to Xiaguan (continuing to Baoshan and Mangshi to the west). Road No.214 runs northward from Xiaguan along the western shore of Lake Erhai to Baihanchang via Jianshuan with a connection to Lijiang. Even with the current low rate of car ownership among households, the volume of vehicular traffic along these roads is substantial. Traffic is mixed, consisting of busses and trucks, minibuses and sedans, tractors and mini-tractors, hand-drawn carts, bicycles, pedestrians, and cattle. They are considered to be inadequate to cope with the amount and mixture of traffic. Average speeds are low, and sometimes very low, while the traffic flow is erratic and sometimes more or less disrupted. This volume and composition, together with a poor standard of maintenance among the majority of vehicles contributes to very high levels of air pollution. This most certainly affects land and water quality along the roads adversely. In many places, the distance between the road and buildings is small, and this results in considerable disturbance to the occupants. Noise and air pollution diminish the amenity value in these locations, while the closeness of the road to the settlements also increases the risk of traffic accidents. This is exacerbated by the erratic driving habits of some drivers, which are less than disciplined.

Against this background, an increase in traffic volumes is likely to be experienced as a consequence of economic growth. An increase in the numbers of visitors will contribute to an increase in road traffic and possibly alter the mix of traffic types and the character of traffic flow, leading to increased congestion. To resolve these problems, measures to reduce the numbers of, or eliminate, certain types of vehicles, and to create a separation between different types of traffic, should be considered. The most natural solution would be to build a completely new, two-lane road reserved for vehicular traffic travelling at normal highway speeds (i.e., excluding tractors and the like). This is the plan for the new road, currently being built, connecting Xiaguan with Kunming. Completion of this road, north from Xiaguan, the eastern side of Lake Erhai, is not expected to materially change the traffic situation on Road No.214, west of Lake Erhai. To significantly improve traffic conditions along the western side of the Lake between Xiaguan - Dali – Dengshuan, a new road reserved for vehicular traffic should be constructed, leaving the current road for local traffic, slow-moving vehicles, bicycles, and pedestrians. In view of the obvious difficulties in implementing such a project, construction in stages would be preferable, with priority given to the southern part from Xiaguan to Dali Old Town. The standard of this road could be relatively modest in geometric terms, as it would not be designed for speed, but for an uninterrupted traffic flow. This would facilitate adaptation of the road alignment to buildings and other obstructions in the heavily settled area. In addition to these roadway improvements, improvements in vehicle designs, and especially in vehicles designed for the tourist trade, can be anticipated. Such improvements, using state-of-the-art technologies, would minimize air pollution, energy consumption, and noise, compared to other types of transportation.

Completion of the railroad to Xiaguan will provide an opportunity to offer an attractive alternative to road transport, assuming that air transport, in any case, will continue to attract certain categories of travellers. It is anticipated that the railway will become the principle means of local transport in the basin. Assuming that the coaches and trucks are reasonably modern, the absolute volume of rail transportation should not be a matter of special concern. However, the terminus of the railroad is the natural location for a bus terminal, thereby providing a convenient transfer between rail and bus transportation. In this connection, the opportunities to set up a modern bus operation, using state-of-the-art vehicles and modern communications and operations systems, will both increase efficiency of operation and considerably reduce environmental impacts associated with such traffic.

Lake Erhai Basin

The physical impacts of tourism on Lake Erhai are relatively limited. For example, when fully occupied, the hotels would have approximately 10,000 guests compared with a population of more than 700,000 in the study area. As the hotels usually are better served with sewerage and solid waste disposal facilities than the average residences, and even if the visitors consume more water and energy, and travel more along the roads than the average inhabitant, the resulting environmental loads are still marginal in comparison with other loads. Likewise, while impacts from construction and traffic are generally experienced in the region, tourism contributes only marginally to these problems. Exceptions do occur locally, however. For example, in Dali Old Town, tourist traffic may constitute the larger part of total traffic volume.

In the same vein, the socio-economic impacts of tourism are unlikely to constitute a matter of special concern. The tourism sector in Dali employs some 10,000 employees, in comparison to an estimated workforce of 400,000 in the basin (estimated as 57 percent of 691,000 inhabitants in the basin). Conversely, the contribution of tourism to the basin economy is substantial (estimated to be between 10 percent and 15 percent, or even higher) as a result of the greater value-added per employee within the tourism sector. Comparing the environmental impacts of an additional job in the tourism industry with the impacts of an additional job in manufacturing, it is most likely that the impact will be less for the additional job in the tourism industry.

With regard to cultural impacts, as tourism currently caters mainly to Chinese visitors and only marginally to foreigners (see Table 64), there are likely to be few cultural difficulties encountered. Most visitors will share a common language and culture, although people from different parts of China may differ ethnically from the populace within the Lake Erhai basin. The major impact of tourism is most likely to be related to the general increase in economic activity in the region than to tourism activities in particular. Tourism, however, can generate revenues that can be used for investment in a better environment, which will, in turn, continue to attract tourists and their monies. This is a basis for development of environmental sustainability, a constructive symbiosis between tourism development and the environment in general.

Environmental Impact Assessment Related to the Construction of Tourist Infrastructure

<u>Harbors and Shipping</u>

There are currently 23 docks and berthing places around Lake Erhai, but only one real wharf, the Xiaguan passenger wharf in Dali City. This wharf is being extended to serve both passengers and freight. The wharf is located at a site north of Tai'an Bridge on the Xi'er River and south of the museum. The structure is about 750 m long, with the area of 0.1 km^2, and provides 15 berths. The handling capacity of the passenger wharf is expected to increase from about one million passengers per year, when the current extension is completed, to almost two million passengers per year in the year 2010. At that time, a number of other wharves are expected to have been built. These include the Daguanyi Building Material Wharf (handling up to 300,000 tons of freight per year) and Manjiang Stony-Material Wharf (handling up to 750,000 tons of freight per year). The increase in the number of wharves enhances the number of berthing sites for boats, and can be beneficial for the environment. Benefits include:

- a decrease in random mooring and concomitant pollution through provision disposal of pollutants from watercraft
- the centralization of building materials transfer activities that will permit more efficient management and a reduction in pollution
- an increase in access to tourism scenic spots, extending the tourist carrying capacity of the lake.

Disbenefits include:

- an increase in the number of street peddlers and passengers who could generate additional solid waste loads that might cause ecological damage
- an increase in waste loads from massed shipping if supporting facilities for pollution control are not installed.

The impact on the water environment from shipping is obvious. Discharge of domestic garbage and wastewater, and leakage from ship systems, are the main causes of water pollution by ships. As the numbers of boats increase, it can be imagined that pollution loads also will increase. The Prefectural navigation management station reported that, during 1995, there were 5,488 watercraft of all sizes, including 2,625 motor boats, which discharged 133 tons of oil into the water. If one drop of oil can pollute 1 m^2 of water, the total polluted area impacted by 133 tons of oil can be imagined. Similarly, during 1995, domestic garbage produced by tourists and discharged into the Lake Erhai included 151.65 tons of solid waste, 521.32 tons of excreta and 52,131 m^3 of wastewater. Although some of these pollutants could be decomposed, the net effect of such discharges is to accelerate the eutrophication process. Further, the discharge of toxic materials may result in bioaccumulation of these materials in living organisms and ultimately impact human health. To reduce the risk of human and environmental health problems in Lake Erhai, the local government already has taken the measure known as "double abolishment". This includes the abolition of net and caged fish culture and the use of power installations on motorized fishing boats, and the prohibition of pollutant discharges from boats. The number of tour boats has also been limited. While these measures have contributed to the protection of water quality in Lake Erhai, attention to the following issues is still required:

- strict management and monitoring of tourist operations in order to prevent a resurgence of pollution from tour boats
- mandated recovery systems for wastewater and solid wastes generated from tour boats; limitation of the numbers of motorboats and other small motor-driven boats, at least for the present.

Cableways

The Cangshan Mountains Cableway is more than 6,000 m long, and has been constructed at a cost of about 100 million Yuan. The system has a total annual carrying capacity of 2.3 million persons. The cableway consists of two sections. The lower section, from Sanyuejie (March Street) to the Zhonghe Temple, is about 1,700 m long, and is currently operating. The upper section, from Zhonghe Temple to the summit of the Cangshan Mountains, is about 4,300 m long. Construction of this section was begun in June 1996, and is now completed. The construction of this cableway attracts more tourists, and is favorable to the development of tourism and increased economic benefit to the community. Operating in a confined area of the mountain, the impact of this system on the mountain, and its vegetation, scenery, and landform should be minor, since the vegetation was restored at the time the project was finished. Other potential impacts are few, but include:

- increased numbers of tourists having access to the mountain habitats that not only increases the time that tourists can stay on the mountain, but can contribute to increased solid waste pollution if tourist installations are insufficient and tourist information on environmental sanitation is lacking
- increased predation upon plants and wildlife, and especially upon rare orchids, by tourists who may be attracted to pick flowers, hunt animals, or collect soil
- increased risk of forest fire, if tourist information on routes, protected areas, and rules and regulations in the tourism region are lacking
- increased water pollution from the drainage of sanitary equipment, which currently introduces 240 m^3/day of wastewater into Lake Erhai via Tao Brook
- increased ecological stress on the summit if tourist installations are lacking, unless the numbers of tourists who go to the summit on the cableway are limited.

Power and Water Supply

Dali Prefecture has planned several hydropower projects, including the 72 MW Xucun Hydropower Station, to meet a projected power shortage in the region. The total investment in this latter station is estimated to be about 180 million Yuan. While the water resources available to Dali City and Eryuan County are relatively abundant, the consumption of water by the Xi'er River Power Station and Binchuan

County river diversion project has placed a significant stress on the aquatic ecosystem. If environmental management measures are not implemented, water quality will deteriorate and the availability of usable water resources may become a limiting factor in this region's economic development. To avoid this end, water resource management capacities must be strengthened, and water-saving agricultural and pollution control measures actively implemented. Further, to ensure a sustainable water supply, the available water resources of the basin must be rationally allocated.

Increased numbers of tourists will increase water demand. Generally, a foreign tourist will consume about 1 m^3/day on average, while a domestic tourist will consume about 0.5 m^3/day. Assuming an average 3 days stay, the Dali Bai Nationality Autonomous Prefecture Tourism Development Program has calculated a water demand by tourists in the year of 2000 of 7.5 million m^3. This figure is less than one percent of the total quantity of water in the Lake Erhai basin (estimated to be 1.1 billion m^3). This volume becomes insignificant in comparison to the water consumption of the Xi'er River Power Station (estimated to be between 500 and 700 million m^3) and agricultural irrigation (estimated to be 130 million m^3). Notwithstanding this minimal overall impact, the water supply available at tourist sites is severely restricted, and currently tourism at some sites. Water supply at tourism sites should be significantly increased, both with respect to the extension of existing water supply systems and the construction of new ones, and the construction of sanitation facilities. Water supplies for landscape and revegetation activities should also be increased to support the environmental restoration goals upon which tourism development is predicated.

Wastewater and Solid Waste Management

Along with the development of tourism, the associated hotels, catering and service trades will be greatly increase the quantities of wastewater and solid wastes. If these wastes are not disposed properly and promptly, the resulting environmental degradation will adversely affect the sustainable development of the region's tourist industry. Mitigation measures have been formulated within the *Feasibility Study Report of Dali Municipal Wastewater Management Project* and *Pre-feasibility Study on Municipal Solid Wastes Management in the Lake Erhai Basin*, which propose a collection and treatment system for wastes from the densely populated Xiaguan and Dali Old Town where most tourists will stay and quarter. The wastewater treatment system is proposed to be built in Dayutian, while the solid waste disposal system is proposed to be built in Dafengba. It is estimated that, under the current program of economic development, the volume of urban solid wastes will increase from 65,000 tons in 1996 to about 200,000 tons in 2010. The accumulated volume of solid waste to be accommodated in landfills is expected to 2.9 million m^3 in 2010 and 6.7 million m^3 in 2020. Based upon this estimate, the life of the proposed landfill site will be at least 20 years and might be as long as 40 years. The construction projects associated with this infrastructure development include:

- reconstruction of the combined sewerage system as a segregated collection system in Xiaguan and its surrounding area
- reconstruction and improvement of the drainage system in Dali Old Town based upon a segregated system to collect urban sewage
- construction of a stormwater drainage system in Dali Old Town, discharging to Lake Erhai
- construction of new wastewater main pipe from Dali to Xiaguan and Dayutian sewage treatment plant
- construction of a new sewerage pipe to urban sewage to the Dayutian sewage treatment plant
- construction of a new sewage treatment plant in Dayutian to treat a part of the industrial wastewater and all of the domestic wastewater in the urban areas of the basin prior to discharge to Xi'er River [effluent standards to be met are: BOD = 30 mg/l and SS = 30 mg/l]
- construction of a sanitary landfill in Dafengba to serve as the general disposal site for the whole Erhai basin.

The *Feasibility Study on the Non-point Pollution Control of Erhai* has identified tour boats and tourism as main pollutant sources to the lake. A treatment scheme has been proposed based upon the following elements:

- abolition of power installations on more than 2,000 fishing boats in order to decrease oil pollution

- installation on larger passenger vessels of oil and water separators to reduce oil pollution; promulgation of vessel regulation rules setting strict controls on the numbers of boats, prohibiting new boats, standardizing dockyards and setting up an office for comprehensively regulating vessels in Erhai
- prohibition of dumping of wastes into Lake Erhai and requiring larger vessels must be fitted with dustbins and waste containers for storage and proper disposal in land disposal site.

The pollution disposal facilities are proposed to be concentrated around Xiaguan, Dali Old Town and the lake. While pollution treatment at other scenic sites has not been proposed in the above mentioned reports, provision of waste facilities at Butterfly Spring, Xizhou, and Zhouchen, and in the Cibihu and Eryuan County town scenic area, is recommended. These two areas have similar characteristics; i.e., relatively concentrated sites, great development potential, and a rural situation. Using oxidation ponds to treat domestic wastewater at these sites provides a low cost, low energy consumption method to minimize environmental impacts on the surface waters of the Lake Erhai basin. In addition, this technology produces an effluent of consistently good quality, with a BOD = 30 mg/l and SS = 60 mg/l, that can be used for irrigation or fish culture. The construction and operation costs of an oxidation pond system are between 20 and 50 percent of the costs associated with conventional secondary treatment plants.

3.6 Capability Building for Tourism Management

Tourism is flourishing in the region, and, in recognition of this fact, the government of the Dali Prefecture has identified tourism as the leading industry in the future. During the next several years, tourism is expected to develop at an exceptionally high rate. This will not only benefit economic development in the Prefecture, but may also contribute to serious environmental problems. Notwithstanding, environmental maintenance must be a key element of tourism promotion. Thus, while the economy is developing, environmental protection must be strengthened. One way in which to accomplish these dual goals is through strengthening of the tour companies and institutions dealing with economic development and environmental protection in the basin.

Tour companies deal directly with tourists. Hence, their behavior will directly affect the behavior of their clients. Some tour companies are concerned only for their economic benefit, and do not care much for environmental benefits. Their behaviors are harmful not only to the environment, but also to the sustainable development of this region. Inducing such companies to recognize the direct linkages between their economic well being and that of the environment through capacity building within the tour organizations is a major step toward sustainable tourism development. Measures to be considered in this regard include:

- promulgation of tour management standards through government regulation and industry-based standards to encourage tourism enterprises to become more aware of their role preserving environmental quality as the basis for maintaining conditions favorable to the sustainable development of tourism in the region
- adoption of the practice of environmental responsibility within tourism (and other) companies by implementing the "polluter pays" principle through a system of cash pledges, or performance bonding, and pollution licensing to encourage adoption of environmentally-friendly modes of service delivery
- training of tour guides and operators, to international standard, with regard to the rich culture resources of the Lake Erhai basin, beyond the recounting of local legends, and the scientific value and ecological significance of the beautiful natural scenery
- improving the quality of all trades through personnel training and education in tourism management, and increasing the quality of supporting services, through the development of a Prefectural tourism training center which would provide both long term and short term training opportunities plus on-the-job training
- establishing a technical secondary school specializing in the tourism industry in the Prefecture to promote specialized, regularized, and standardized staff training and education (Table 72 suggests training and education targets for the tourism industry in Dali Prefecture).

This capacity building will not only improve the management of tourism in the

Lake Erhai region, but also provide the means of instilling in the industry the following principles:

- ecology and environment as the basis for tourism
- the unique culture of the region as the spirit of tourism
- regionally sustainable development as the goal of tourism development.

Table 72. Education and Training Targets for the Tourism Industry in Dali Prefecture.

Occupation	Education level	Nos. of staff to be trained by the year 2010
Managers	Technician	640
Professional instructors	Technician	100
Tourism product technicians	Technician	1100
Tourist guides	High school or higher	1800
Engineers and technicians	High school or higher	1400
Accountants	Technician	280
Hotel waiters	Professional school or higher	4550
Drivers	Technique school or higher	350
Corks	High school or higher	600
Scenic spot servants	High school or higher	1400
Shop assistants	High school or higher	1500
Actors and actresses	High school or higher	300
		Total: 14120

In addition to the measures recommended for strengthening the tourism sector, measures should be implemented to improve and better integrate transportation services, especially among mass-transit modes of transportation. The upgrading of Dali Airport has been completed and the numbers of international and provincial scheduled flights are being increased. Similarly, the completion of the Guangta Railway through Dali City during 1998 will greatly increase the carrying capacity of passengers and freight. In addition, the Chuda Highway has been resurfaced as of the end of 1997, and the provincial sections of the four National Roads are in the process of renovation. These actions make Dali City the logical hub of intermodal transportation in western Yunnan and should underpin Dali's status as the economic center of the Province. Using this fact, specific measures to promote regional integration based upon the Dali hub to be considered include:

- developing a tourism network centered on Dali-Cangshan-Erhai that will intra-regional tourism and encourage tourists to stay longer in the Dali Prefecture
- developing service trades such as catering, travel agencies, recreational centers, motor fitting, etc., to support the transportation network in order to attract long-distance freight transporters and others who are likely to stay overnight in Dali City
- developing and upgrading the materials storage facilities to create a distribution center for petrochemicals, building materials, lumber and forest products, and foodstuffs.

3.7 Recommendations for Tourism Development

Tourism development planning may be undertaken in various ways. The following elements are normally included in tourism development plans:

- studies and analyses of the existing situation and its historic antecedents, including the establishment of an appropriate and up-to-date statistical base
- identification of existing and potential tourism products and analysis of the existing and potential tourism market to develop projections of tourist profiles, by type, origin, composition, season, spending levels, etc.
- analysis of current and planned transportation facilities by type and capacity
- elaboration of tourism development policies (a cyclical process) and a flexible implementation strategy, including a prioritized timetable for implementation
- determination of facilities requirements by types of accommodation and other facilities
- determination of infrastructure requirements
- preparation of implementation plans, including costs and financing requirements
- development of tourism promotion and marketing outlets and programs in the

source markets

- development and conduct of training and awareness programmes
- analysis of support activities including development of programs of product development in supporting sectors (e.g., food production and preparation, handicraft production, etc.)
- identification of mechanisms for coordination and cooperation between different governmental authorities
- elaboration of mechanisms to enhance cooperation with and between private sector organisations and companies
- establishment of tourism development organisations, both public and private.

With regard to the development of a tourism policy, consideration should be given to the adoption of the following policy statements as a basis for sustainable tourism development in the Lake Erhai basin:

- tourism development shall be undertaken with a view to creating equitable economic rewards for all inhabitants and economic units in the region
- an high level of visitor satisfaction shall be assured in order to encourage visitors to extend their stay in the region
- provision of visitor facilities shall be based on comprehensive market research in the source markets to identify a range of tourist profiles as a prerequisite for increasing the total number of visitors to the region
- natural and cultural resources shall be developed and utilized on a sustainable basis
- quality of life shall be enhanced through the integration of tourism into social structure and economic activity of the community
- development of tourism facilities shall be balanced and integrated with both their host communities and the surrounding environment, both in terms of their physical design and their ongoing operation

- development of visitor facilities, in scenic and nature areas as well as in villages and towns, shall be based upon demand with due consideration given to the carrying capacities of the local sites
- tourism facilities shall be developed in a manner consistent with the preservation of historic and cultural buildings and environments, as these are vitally important elements of the tourism product
- village-based tourism shall be encouraged and supported
- development of tourism opportunities shall be undertaken on the basis of practical and practicable enabling strategies, with provision for the dynamic adaptation of opportunities in response to actual events and experiences.

Such basic policies and principles will contribute to the preservation of a genuine and characteristic environment within this unique region. Such policies and principles also will form a sound basis for the process of successfully enhancing the economy and improving the quality of life in the Lake Erhai basin, while preserving its unique character and environment.

Chapter 4

Strengthening the Environmental Technology and Administration Organizations in the Lake Erhai Basin

4.1 Environmental Technology and Administration

Sustainable development refers to development that not only satisfies the needs of the present generation but also preserves the structure and function of the resource for later generations. At present, the occurrence of environmental problems in the Lake Erhai basin indicates that development in the basin is currently unsustainable. To achieve the goal of sustainable development, the basis for economic production and, perhaps, the life style of the population must be changed, and pollution controls implemented, in order to minimize environmental degradation. Thus, the application of modern environmental science and technology is needed urgently in the basin to address important pollution sources and problems such as eutrophication of the lake, soil loss in the drainage area, and over-exploitation of natural resources on the land and in the lake.

Environmental Technologies, Regulation, and Monitoring

Water Resources Regulation

Conflicts between water supply and the demand for water in the basin are acute due to the irrational exploitation of the water resources of the basin in recent years. Shortages of water may be an important constraint on the sustainable development of the basin. Therefore, water resources management and regulation are required to maintain or enhance water levels, and allocate water optimally between different users, in order to promote harmonious economic development in the basin.

Eutrophication Control Technologies

Lake Erhai is undergoing a period of eutrophication. Eutrophication and organic pollution are the principal environmental problems faced by Lake Erhai in the coming decade. While the introduction of pollution control technologies can help to reduce the loading of nutrients and oxygen demanding substances to the lake, such technologies should be implemented under an holistic program of pollution control and resource protection. Pollution and eutrophication control technologies selected should address both point sources and nonpoint sources of pollution, including in-lake source control and lake ecosystem restoration.

Biodiversity Conservation

The Cangshan-Erhai region contains abundant biological resources. From an ecological point of view, Cangshan-Erhai region is a unique area where the protection of the ecosystem provides benefits to the local population as well as the entire globe. Nevertheless, over-exploitation of forest resources, and unsustainable farming operations, has seriously degraded the biodiversity of the region. Thus, the introduction of measures to protect biotopes, and to regenerate degraded ecosystems, in the Lake Erhai basin are needed.

Water Quantity and Quality Monitoring

River monitoring stations were constructed on the inflowing streams to Lake Erhai during 1976. At the same time a lake-environment monitoring program was instituted on the lake. While these programs have provided useful data for conducting this diagnostic study, it is doubtful if the present monitoring system can meet the information needs for managing the transition to sustainable development in the basin. For example, the modelling procedures used in this study require the type of real-time information that can be generated by Global Position Systems (GPS) and Remote Sensing technologies (RS), and utilized by Geographical Information Systems (GIS). Incorporation of these technologies into a water resources information system will contribute to the establishment a new water qualify monitoring system, the improvement of monitoring programs, and the dissemination of data for purposes of scientific research. All of these factors will combine to facilitate the provision of technical support to administrators for the scientific management of the resource.

Cleaner Production Methodologies

Modern environmental science theory suggests that pollution control should be shifted from its traditional application as a “terminal treatment” to a fully integrated application as a "source control". This means that pollution control measures are fully part of the production process, with reductions in the amount of pollution generated being achieved throughout the course of the production process. These cleaner production technologies are being applied extensively in developed countries. In the Lake Erhai basin, industrial enterprises cause environmental pollution through their wastewater discharges. Altering production methods through the introduction of cleaner production technologies will decrease pollution discharges, not only by reducing the levels of pollutants in the discharges but also by encouraging water reuse within the industrial process. Cleaner production technologies to be applied in the Lake Erhai basin should be considered a priority for the pulp and paper industry, the food processing industry, and the chemical industry, which industries generate the largest volume of pollutants reaching Lake Erhai and the Xi'er River. Notwithstanding, the application of cleaner production technologies in the basin will require significant investments by these industries in capital equipment and trained operating personnel. While few funds and trained personnel to implement such technologies currently exist, any investment in cleaner production technologies will help to strengthen the industrial foundations of the region.

Administration and Human Resources

Environmental management is an important element of sustainable development. Successful environmental management, and consequently successful implementation of sustainable development policies, requires effective administrative organizations. The current administrative organizations in the basin are ill-equipped to implement the measures necessary to achieve sustainable development in the Lake Erhai basin. In part, their inability to implement sustainable development policies is due to poorly-defined function relationships among institutions and the absence of specific environmental management functions from their terms of reference. The serious nonpoint pollution arising from township enterprises requires implementation of environmental protection measures at the township and village administrative levels. Rational allocation of water resources in the basin requires implementation of controls at the Provincial or Prefectural level across a range of institutions in both the public and private sectors. In both cases, organizations to give effect to local level pollution control actions and regional level water allocations are lacking capacity and/or a mandate to give effect to these measures.

Specifically, a number of administrative aspects require strengthening in order to implement sustainable development policies in the basin. These aspects include:

- implementing appropriate laws, regulations and environmental policies;
- instituting environmental monitoring and scientific research activities;
- reviewing scientific and technological progress in relevant areas of economic development;
- providing environmental and technological training to enhance the professional abilities of technical and managerial staff;
- constructing environmental management hardware;
- publicizing the importance of environmental protection in order to enhance public awareness of, and participation in the resolution of, environmental problems and issues.

4.2 Current Situation in the Lake Erhai and Xi'er River Basin

Environmental Regulations, Technologies, and Monitoring

Water Resources Regulations

The recent water shortage in the Lake Erhai basin has caused the government of the Dali Prefecture to pay greater attention to the issues of water resources management and water pollution control. Actions subsequently implemented by the government have alleviated to a degree some of the causes of environmental pollution in Lake Erhai. Water resources management and pollution control technologies that have been employed in the basin include:

- strengthening of the ability of government to strictly control the water level of Lake Erhai through the promulgation of regulations which establish lake water levels between a minimum elevation of 1,971 m and a maximum elevation of 1,974 m
- regulating water flows based upon simulation modelling and a recognition of the environmental use of water as an economic use of the resource

- implementing sewage interception to protect the water quality of Lake Erhai through the construction of a 6.8 km interceptor sewer main along the Xi'er River to minimize the discharge of untreated industrial and domestic wastewaters to the Xi'er River.

Eutrophication Control Technologies

Control of environmental pollution in the Lake Erhai basin has been effectively addressed through actions implemented under the eighth five-year plan. Measures implemented to date include point and nonpoint source controls. Point source controls include completion, during 1990, of the 10 million Yuan interceptor main to convey industrial wastewater to municipal sewage treatment plants. Implementation of this system has resulted in the treatment of 46.6 percent of industrial pollutants, and the improvement of water quality in the Xi'er River to Grade III of the national standard. Three other pollution control projects had been completed during this same period, including two projects to provide wastewater treatment at local hospitals. Implementation of further point source pollution controls, however, is hampered by lack of funds. Nonpoint source control efforts were concentrated on the Mizu River and the 18 Cangshan brooks, which were implemented at a cost of 5.35 million Yuan and 4.1 million Yuan, respectively. The works implemented in the Miju River watershed protect some 100,000 mu (= 6,700 ha) of farmland along the river.

In addition to the point and nonpoint source controls, other water pollution control measures have been implemented during the period of the eighth five-year plan. A forest belt, 75 km long and from 7 m to 30 m wide, has been constructed around the lake. More than one million trees have been planted within this forest belt. Between 1991 and 1995, almost 375,000 mu (= 25,000 ha) of woodland has been restored, contributing to a reduction in the rate of surface water runoff and resultant soil erosion. Further, the Dali Prefectural government has banned caged fish farming in Lake Erhai before April 1st of each year, and motor boating in the lake prior to June 30th of each year. Caged fish farming and motor boating have been banned in Lake Xihu. Measures also have been taken to strengthen the management of tour boat operations and to treat excrement and garbage generated from this source. A detergent phosphorus ban has also been promulgated for the lake basin with effect from January 1st, 1998.

Biodiversity Conservation

The government of the Dali Prefecture has recognized the importance of biodiversity conservation for the sustainable development of the Lake Erhai basin. To give effect to the conservation of biodiversity in the lake basin, the government has delineated three nature reserves within the basin during the period of the eighth five-year plan. These reserves are the Cangshan-Erhai Nature Reserve, the Niaodiao Hill Nature Reserve in Eryuan County, and the Lake Cibi Nature Reserve also in Eryuan County. Flora and fauna are protected in-situ within these nature reserves.

Water Quantity and Quality Monitoring

Fourteen environmental monitoring stations were established in the basin during 1995. The environmental monitoring station in the Dali Prefecture; those in Dali municipality, and in Binchuan, Eryuan, and Yunlong Counties; and the Geological Environmental Monitoring Station are six of these independent monitoring stations. The environmental monitoring system includes 7,500 m^2 of staff housing, nine motor vehicles, and 165 pieces of laboratory instrumentation valued at over 1,000 Yuan. While the system has proven to be a valuable source of environmental data, the monitoring network continues to suffer from inadequate levels of staffing, resources, and funding. Specific concerns include:

- the practical, logistical, and technical difficulties of establishing and maintaining a monitoring network in a large drainage basin that includes the watersheds of the Lancangjiang, Jinsha-Yangtze, and Yuanjiang Rivers
- too few monitoring data, and especially continuous records of water quality, flow and weather conditions, to adequately describe the water resources of this basin in time and space
- outdated equipment, underdeveloped monitoring technologies, and incomplete laboratory instrumentation that hinder effective water resources monitoring in the basin.

Administration and Human Resources

The environmental administration organization within the basin is shown in Figure 28, and staffing levels are summarized in Table 73. There are 73 environmental protection personnel in the basin, excluding monitoring staff at the prefectural level and higher. Agency staff include 6 senior engineers, 38 engineers, and 14 assistant engineers. Sixty percent of these staff is classified as middle or senior management. Thus, despite the presence of highly qualified staff, it is anticipated that a shortage of skilled workers may impede the implementation of environmental management works and limit their applications in the future.

The environmental protection sections of the Prefectural and municipal governments are tasked with preparing and implementing annual plans for environmental protection within their jurisdictions. These agencies also prepare middle- and long-term plans for environmental protection that guide the preparation and implementation of the annual plans. They are responsible for supervising the implementation of national laws, regulations, and policies related to environmental protection, and participate in the preparation of environmental impact assessments (EIAs) for some projects. At the Prefectural and county levels, environmental supervision and management institutes review the implementation of environmental laws and regulations in enterprises and by individuals as provided for in the rules. They are responsible for setting and collecting waste disposal fees and conduct important industrial waste source examinations.

Environmental monitoring is carried out at both the Prefectural level and municipal level. The environmental monitoring station of the Prefecture carries out monitoring tasks assigned by the countries, the province, or the prefecture, monitoring pollution sources and pollution incidents. They are also responsible for the conduct of scientific research into environmental issues and for developing EIAs for some projects. The environmental monitoring stations of the municipalities carry out monitoring tasks assigned by the province and the prefecture. These agencies collect, analyze, interpret, and report monitoring data, and conduct scientific research into environmental issues. The municipal monitoring stations are also in charge of pollution source monitoring in urban areas.

The management section of the nature reserves is tasked with the protection of the natural environment at the Prefectural level. In carrying out this charge, the agency is responsible for managing the level of exploitation and utilization of the nature reserves. It is their duty to prepare management plans for the nature reserves, and to develop and report on the progress of works within newly developed nature reserves.

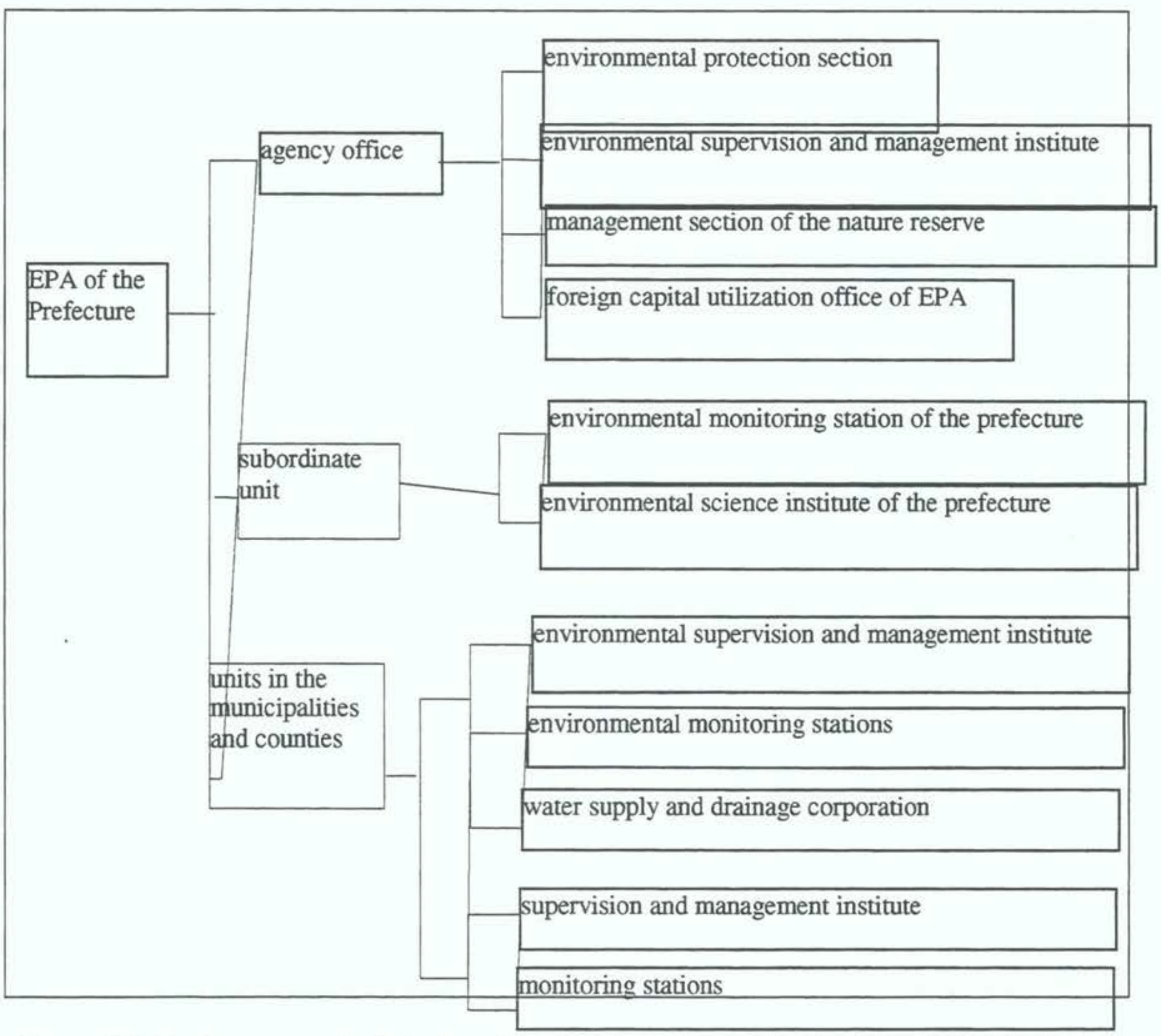

Figure 28. Environmental administrative organizations within the Lake Erhai basin.

Legal Framework for Environmental Protection in the Lake Erhai Basin

The principle laws and regulations, rules, and policies governing environmental protection in the Lake Erhai basin are those issued by the State. These include:

- Environmental Protection Act of the Peoples' Republic of China
- Water Pollution Prevention and Treatment Act of the Peoples' Republic of China
- Enforcement Bylaw for Water Pollution Prevention and Treatment of the Peoples' Republic of China
- Atmosphere Pollution Prevention and Treatment Act of the Peoples' Republic of China
- Enforcement Bylaw for Atmosphere Pollution Prevention and Treatment of the Peoples' Republic of China

Table 73. Environmental Staff in the Lake Erhai Basin

Agency	Title				
	Total Staff	Senior Engineer	Engineer	Assistant Engineer	Other
Environmental Protection Section of the Prefecture	4	1	3		
Environmental Supervision and Management Institute of the Prefecture	4	1	2		1
Management Office of the Nature Reserve	5	1	2	2	
Environmental Monitoring Station of the Prefecture	33	3	18	7	5
Environmental Protection Office of the Municipality	5		3	1	1
Environment Supervision and Management Station of the Municipality	4		2		2
Environment Monitoring Station of the Municipality	14		8	2	4
Environment Protection Section and Monitoring Station of Eryuan County	4			2	2
Total	73	6	38	14	15

- Management Regulation Relative to Drinking Water Source Area Pollution Prevention and Treatment Management Methods Relative to Environmental Protection Construction Items, and Notice for Construction Items to Strictly Implement "Do Three Thing at the Same Time" issued jointly by the State Planning Commission, the State Construction Commission, and the State Commission for Restructuring
- Economy and Environmental Protection issued by the Leading Group of the State Council
- Interim Method for Levies on Pollution Discharge issued by the State Council
- Rules for Nature Reserve Areas of the Peoples' Republic of China.

In addition to national rules, regulations and policies, local environmental laws, regulations, rules, and policies also govern environmental protection within the Lake Erhai basin. The principle local legislation includes:

- Yunnan Provincial Environmental Protection Rules, adopted at the 27th meeting of Standing Committee of the 7th Yunnan Provincial Congress on November 25, 1992
- Yunnan Provincial Environmental Protection Management Measures for Urban and Rural Collective and Individual Enterprises issued by the Yunnan Provincial government on November 20, 1991
- Yunnan Provincial Management Measures for Levying Pollutant Discharge Fees issued by the Yunnan Provincial government on January 4, 1993
- Lake Erhai Administrative Regulation, Yunnan Dali Bay Nationality Autonomous Prefecture, adopted at the 3rd meeting of Standing Committee of the 7th Yunnan Provincial Congress on December 1, 1998
- Administration Regulation for Dali Scenic Spots and Historical Sites, Yunnan Dali Bai Nationality Autonomous Prefecture, adopted at the 29th meeting of Standing Committee of the 7th Yunnan Provincial Congress on April 7, 1993
- Notice about "Management Methods for Lake Erhai Protection in Dali Bai Nationality Autonomous Prefecture" issued by the Dali Bai Nationality Autonomous Prefecture People's government in March, 1991
- Enforcement Methods of Fishery Management in Lake Erhai issued by the Dali Bai Nationality Autonomous Prefecture on August 5, 1991

- "Announcement about Protecting Water Fowl and Young Fish", issued by the Dali Bai Nationality Autonomous Prefecture People's government on February 6, 1987.

As noted, the Dali Bai Nationality Autonomous Prefecture has promulgated administrative rules for the protection of Lake Erhai. The most important and fundamental administrative rules to protect Lake Erhai were implemented from April 1, 1989. Some specific stipulations in these administrative rules that are crucial to water quality protection in Lake Erhai include:

- identification of maximum and minimum water level for Lake Erhai of, respectively, 1,974 m and 1,971 m
- establishment of a water level based lake protection zone to construction and the conduct of farming activities inside the lake boundary markers
- prohibition against establishing new factories, mines, and other enterprises on or around Lake Erhai that might pollute or damage the lake ecosystem or nearby water resources
- promulgation of pollution discharge standards and abatement practice requirements for existing factories that require such enterprises to meet the standards within a specified period or be closed or relocated
- implementation of fishery and aquaculture licensing requirements
- collection of water resources and fisheries resource protection fees from enterprises and individuals, and dock usage and pollution discharge fees from vessels using the lake, with the funds raised through these fees being used for the protection and rehabilitation of Lake Erhai
- promulgation of rules and [seven] standardized supporting documents, for the basis for the lawful management of Lake Erhai
- stipulation of the Lake Erhai Administrative Agency as the governmental organization responsible for the management of Lake Erhai, the Forestry Department as the agency responsible for reforestation in the basin, the Hydrological Department as the governmental unit responsible for managing inflows to and outflows from the lake, and the Environmental Protection, Transportation, and Tourism Departments as the units responsible for water pollution control.

A key element of the foregoing is the establishment of water quality goals for the lake. Achieving these goals will be a function of controlling waste discharges in the watershed, proposed to be accomplished through the implementation of already established water quality discharge standards in various portions of the watershed. These standards provide for strict control of pollutant discharges upstream of the lake, slightly less strict control in middle portions of the basin, and less strict controls in the downstream sections of the basin. Within the upstream areas, discharges are to be strictly controlled to maintain a Grade II water quality in those streams draining to Lake Erhai. In the middle portions of the basin, encompassing the southern region of Lake Erhai and the Xi'er River outlet and including the major population centers and factories, discharges are to be treated to maintain a Grade III water quality. In the downstream areas of the Xi'er River, where water is used primarily for electricity generation, a lower water quality can be tolerated. In the immediate term, discharges are to be treated to maintain a Grade II water quality, although, in the longer term, discharges are to be treated to maintain a Grade III water quality. Pollution reductions to meet these goals have been determined according to the status of the six largest polluters and the feasibility of successfully treating their effluents, and are shown in Table 74.

An additional element supporting the rehabilitation of water quality in Lake Erhai was the adoption by the Prefectural government of the "Dali Bai Nationality Autonomous Prefecture People's Government Resolution about Rescinding Motive Power Installations on Motor Fishing Boats and Net-chambers for Fish Culture in Lake Erhai". This resolution, adopted following a severe blue green algal bloom in September 1996, prohibited the use of mechanized fishing methods and motorized fishing boats in fisheries and net and caged fish culture on Lake Erhai and Lake Xihu. On November 4th, 1996, the Prefecture Committee and Prefectural government further amplified this resolution by promulgating the following measures for the rehabilitation of Lake Erhai:

- prohibiting net and caged fish culture in the lake after March 2, 1997
- encouraging off-lake fish production through fish price supports and support of pond-based fish culture
- protecting aquatic plants

- strengthening controls on this disposal of excrement and garbage from pleasure craft
- prohibiting the sale of phosphorus-containing detergents in Dali City and Eryuan County
- advancing the reconstruction of the drainage pipeline in Dali City and the Dali economic zone;
- strictly controlling the utilization of the lands below and elevation of 1,974 m
- planting reeds and water grasses in Jiangwei
- accelerating the construction of the highway around the lake
- initiating studies of supplementary sources of water in the Lake Erhai basin in order to expeditiously resolve the problem of insufficient water storage volume in the basin.

Table 74. Pollution Reduction Quotas (tons/day) of the Six Largest Polluters.

Enterprise	**Reduction requirement**		Allowable discharge	
	Wastewater	COD	Wastewater	COD
Erbin Paper Mill	978	4.35	10,000	4.72
Dali Paper Mill	449	as set forth in the seventh five-year plan	1,000	5.20
Dali Brewery	0	0.35	1,054	0.36
Dali Pharmaceutical Factory	86	2.44	200	2.44
Dianxi Textile and Dyeing Factory	0	0.70	3,500	0.82
Yunnan Artificial Fiber Factory	2,300	17.10	14,000	12.90
Total	6,513	32.39	35,754	26.44

4.3 Environmental Technologies for Sustainable Development

Science and technology have kept pace with socio-economic development in recent years, with humankind's understanding of the causes and consequences of environmental pollution also improving during this period. For example, controls on point sources of water pollution in the United States have been enhanced since the early 1970s by significantly increasing the level of investment in wastewater treatment works. These investments have increased from US $ 85 billion in 1988 to more than US $ 100 billion in 1991, and, during the 1980s, amounted to about one percent of the GNP. Investments in water pollution controls accounted for 40 to 50 percent of the total investment in environmental pollution controls. Since the 1970s, water pollution control technologies also have changed greatly, from scattered primary treatment plants to regional secondary and tertiary treatment facilities serving over 80 percent of the total population. In China, the recent development and modernization of the national economy also has led to increased volumes of wastewater discharge from cities and factories. The consequent gradual deterioration of the aquatic environment has led to the recognition of the need for secondary wastewater treatment and strengthened implementation of laws and regulation on environmental protection. To meet this need, the seventh five-year plan and eighth five-year plan emphasized application of natural purification technologies having low costs and low energy requirements, wastewater reuse technologies, and technologies for the treatment of organic-rich effluents from paper mills and textile factories. Stabilization ponds and land treatment technologies have been developed and implemented in response to these five-year plan initiatives.

To address environmental pollution arising from industrial development, cleaner production technologies have been widely in industry since the 1990s. Cleaner production technologies minimize environmental pollution throughout the production process, from raw material production and processing through to the despatch of the finished products. In their most comprehensive form, cleaner production technologies have been applied to raw material extraction through to the post-consumer disposal of the product. This approach generally has resulted not only in improved technical and managerial efficiencies, but also to reductions in environmental pollution, production costs, and energy consumption. Cleaner production is implemented through improved management of processes, and modification and improvement of equipment, that, in terms of water, means adopting production processes that require no water, or processes that use a closed water recycling system. China established the National Cleaner Production Center in 1994, and has implemented cleaner production technologies in several hundred enterprises, including beer production, electroplating, printing and dyeing, and paper making operations. As the initial step, the most economical and favorable way to implement cleaner production on a large scale is to reduce the volume of wastewater discharged from current industrial systems.

As point sources of water pollution have been controlled worldwide, nonpoint or diffuse source pollution of waters has become more obvious, and research into effective measures to control nonpoint source pollution began in the 1970s. In the United States, "best management practices" or BMPs are employed to address nonpoint source pollution of aquatic systems. The specific measures employed are selected in terms of the pollutants to be controlled, land uses, and local conditions, but include, in rural situations:

- agricultural measures to manage farming and planting operations and minimize pollution due to soil loss, chemical fertilizers, and other agrochemicals
- engineering measures to protect waterways through construction of buffer zones, placement of sod, and management of water movement
- measures to manage animal wastes.

Nevertheless, increasing levels of investment are likely to be required to achieve the goal of "zero discharge" of pollutants to the environment. In China, during the period of the eighth five-year plan, research on farmland runoff control technologies, watershed ecological engineering technologies, and eutrophication management technologies, including relevant demonstration projects in the vicinity of Lake Dianchi, was completed by the Chinese Research Academy of Environmental Science and other institutions. The results of these studies are currently being implemented, and appropriate best management practices are proposed for implementation in the Lake Erhai basin.

Environmental Technologies for the Lake Erhai Basin

The Lake Erhai basin is facing a period of industrialization with a concomitant need for increased environment protection. This creates an urgent need for advanced environmental technologies that will facilitate sustainable development in the basin. Appropriate environmental technologies should have the following attributes:

- practicality, which encompasses not only effective pollution control, but also ability of the technology to be used effectively in the basin; i.e., appropriate environmental technologies should (1) be cost effective, (2) be readily available and serviceable at the community level, (3) require low levels of capital investment, and (4) be energy efficient so as to be in harmony with the current level of economic development in the basin

- practicability, which encompasses both management techniques and engineering techniques, which facilitates the application of the appropriate technologies for water pollution control, including not only the use of particular technologies but also the creation of the skills base and financial base that will contribute to the successful use of the technologies for environmental protection
- adaptability, which encompasses the ability of selected technologies to be upgraded and expanded as development continues in the basin, while respecting local and national customs, requirements, and technical capabilities
- suitability, which encompasses the ability of selected technologies to be implemented in stages according to the requirements of the environmental technologies and prevailing economic and technological conditions in the basin, particularly in the areas of (1) water level control, (2) lake pollution controls, (3) biodiversity conservation, (4) automated water quality monitoring, and (5) ecologically-sustainable agriculture.

Water Resources Regulation

Water resources regulation is one means of controlling lake pollution and protecting the lake environment through the rational utilization of the water resources of the basin. Conflicts between the supply of, and demand for, water in Lake Erhai basin are acute, with demand exceeding supply by an average 40 million m^3/year. Increasing demands for water for domestic and industrial uses (60 million m^3/year), irrigation (1,330 m^3/year), hydroelectric power generation (600 to 700 m^3/year), and extra-basin diversion (50 m^3/year) far exceed the annual average inflow. As a result, the water level in the lake and the groundwater level in the surrounding area is steadily declining, reducing the surface area of the lake, degrading water quality, and accelerating erosion of the riverbeds. As used in this section, water resources regulation has two components; namely, provision of sewerage services to minimize lake pollution by intercepting (primarily) industrial pollutants that are currently discharged to the lake, and water level maintenance by controlling the outflow of water from the lake.

Sewerage Services and Wastewater Treatment. Sewerage services include sewage collection and provision of sewage treatment. The priority areas for the construction of public sewerage systems are the most populated areas, along the southwestern shoreline of Lake Erhai including the Xiaguan urban area, Dali Old Town and the industrial area of Manjiang. Currently, all of the wastewater produced within this portion of the basin is discharged directly into Lake Erhai or into its inflowing rivers and streams. The only exception is that portion of the urban industrial wastewater flow that is intercepted by a 6.75 km long sewer main and discharged into the Xi'er River downstream of the lake. Most of the existing sewerage system is a combined system conveying both wastewater and stormwater. The following actions are needed to achieve an effective sewerage collection system in the basin:

- separation of the existing combined sewerage system into a separated sewerage system, with most of the pipes of the existing sewerage system being used for the conveyance of stormwater to the lake, and with new pipes being laid alongside the stormwater pipes for the collection of wastewater
- construction of a new sewerage main to collect wastewater from Dali City and the principle villages and factories between Dali and Xiaguan for conveyance to the sewage treatment plant.

To avoid sedimentation of solids within the sewer prior to the sewage reaching the sewage treatment plant, especially during the hours of low flows, a mean velocity of 0.3 m/sec should be maintained in the system. The system should be adequately ventilated. In the upper reaches of the system, where flow velocities are too low to flush waste material through the system, a 1 m^3 underground balancing tank should be built into the system to help flush sediments out of the pipe. The treated sewage is to be discharged to the Xi'er River.

Wastewater collected from the industrial and urban areas around Lake Erhai by the sewer system is intended to be conveyed to sewage treatment plants, where the wastewater will be treated using a tertiary wastewater treatment process. The typical stages of a tertiary wastewater treatment are illustrated in Figure 29. This system provides reliable levels of wastewater treatment through primary sedimentation, even when power failures or other problems interfere with the more extensive biological treatment. Primary sedimentation alone achieves at least a 27 percent BOD removal. In addition, this technology is easy to maintain, has a low operating cost, and does not require high-level or intensive training. Thus, it can easily be adapted to the skill levels of local workers.

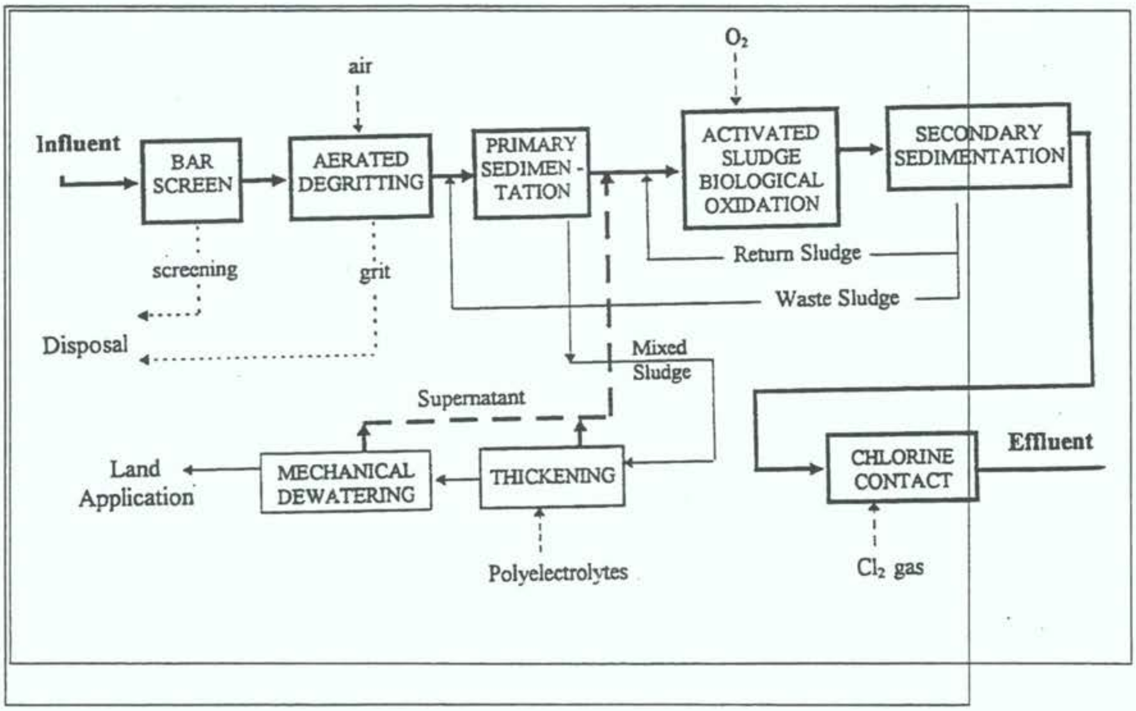

Figure 29. Wastewater treatment schematic

Lake Level Controls. As has been noted, changes in lake level result directly in changes in the aquatic environment. Maintenance of an appropriate lake water level will benefit the lake environment, and contribute positively to the rational and effective use of the water resources of the lake. The many pumping stations and sluice gates that currently exist within the Lake Erhai drainage basin, and in the upper reaches of the Xi'er River, provide the means to coordinate the inflows to, and outflows from, Lake Erhai, and thereby regulate the water level of the lake. Modelling the hydraulic functioning of the lake to optimize the volumes of water to achieve water supply, flood control, and environmental management objectives could not only address conventional water supply and flood control needs but also contribute to the improvement of water quality in the lake. Equation 4.1 presents a dynamic optimization model that would allow determination of an appropriate water level for Lake Erhai:

$$F = \min \sum_{1}^{n} a(C^{n} - b) \sum_{1}^{n} Q_{m}^{n} \bullet \Delta T^{n} - \sum_{1}^{k} Q_{k}^{n} \bullet \Delta T = \left[V\left(Z^{n}\right) - V\left(Z^{n-1}\right)\right] \tag{4.1}$$

where Zmin < Zn < Zmax

$Qmin < Q_{m}^{n}$

$Q_{k}^{n} < Qmax$

$\sum_{1}^{n} Q_{m}^{n} \bullet \Delta T^{n}$ = total volume of inflows during n period of time

$\sum_{1}^{k} Q_{k}^{n} \bullet \Delta T^{n}$ = total volume of outflows during n period of time

K = number of outflowing rivers

m = number of inflowing rivers

a, b = constants.

The hydraulic engineering regulation cycle, T, and the period of time necessary to achieve regulation, n, are identified in terms of the lake volume and lake water residence time of Lake Erhai. Solving this equation with respect to specific lake functions or environmental problems and in such a way as to minimize the time period, n, results in the identification of the optimal regulation regime. Water level, Zn; outflow volume, Qkn; and, inflow volume, Qmn, are the decision variables.

Eutrophication Control Technologies

Lake pollution and eutrophication control technologies encompass a range of lake pollution control technologies, including systems designed for point source control, systems designed for nonpoint source control, systems designed for in-lake source control, and programs designed for in-lake ecosystem restoration, etc. These latter elements encompass the full range of pollution sources contributing to the decline in water quality in Lake Erhai. To optimize the application of eutrophication control technologies, and to allocate elements of the total pollution control effort among contributing pollutant types, an assessment of the lake system as a whole must be undertaken. Such an assessment includes:

- collection of data on the physical geography, economy, and environmental quality of the lake and its basin
- delineation of water quality protection zones based on relevant water quality criteria
- identification of the pollutant loading capacity of the lake and calculation of the loading capacities of the various water quality protection zones
- calculation of the total quantity of pollution reduction required to meet water quality objectives in the lake.

Lake Erhai is required to be a Grade II water in the long run. Based upon the environmental data set forth in Chapter 1, it is clear that Lake Erhai does not currently meet this standard. Thus, a pollution load reduction will be required for the lake to meet the Grade II standard. The Grade II standard is based upon the in-lake phosphorus and nitrogen concentrations of 0.025 mg/l total phosphorus and 0.4 mg/l total nitrogen set forth in the Vollenweider trophic state models. Therefore, the environmental capacity of the lake, or the point at which the lake may be considered to be eutrophic, can be calculated as:

$$[P] = L_P (1 - R)/Q = P_1 (1 - R) \quad (4.2)$$

$$[N] = L_N (1 - R)/Q = N_1 (1 - R) \quad (4.3)$$

where L_P = the inflowing load of total phosphorus (mg);

L_N = the inflowing load of total nitrogen (mg);

P_1 = the total phosphorus concentration in the inflow (mg/m^3);

N_1 = the total nitrogen concentration in the inflow (mg/m^3);

Q = the inflowing volume of water (m^3/year) = 0.615 x 109 m^3/year;

R = the retention coefficient = $V/(v + Q)$ (years);

V = the volume of the lake (m^3);

v = the settling rate of nitrogen and phosphorus in the lake (m/year) = 10 m/year and 15 m/year, respectively.

Solving equations 4.2 and 4.3 for L results in a determination of the allowable loads of total phosphorus and total nitrogen to the lake. The allowable total phosphorus load is estimated to be 111 tons/year, and the allowable total nitrogen load is estimated to be 1,230 tons/year.

Likewise, a determination can be made of the allowable pollutant load within the Xi'er River in order to maintain a Grade III water in the longer term. Equation 4.4 can be used to calculate the allowable pollutant discharge mass in the riverine environment:

$$M_{COD} = C_0 \bullet Q_n = (C_0/C_0') \bullet M_{COD}' \qquad (4.4)$$

where M_{COD} = the allowable COD load (tons/day);

M_{COD}' = the present pollutant load at a specific level of uncertainty (tons/day);

C_0 = the water quality standard concentration;

C_0' = the present concentration;

Q_n = the flow rate of the Xi'er River at a specific level of uncertainty.

The present pollutant load of COD is 66.3 tons/day at an uncertainty level of 50 percent and 43.0 tons/day at an uncertainty level of 75 percent. In order to maintain the Xi'er River as a Grade III water in longer term, the allowable pollutant loads should be reduced to 37 tons/day of COD at an uncertainty level of 50 percent, or 24 tons/day at an uncertainty level of 75 percent. The latter load can be expressed as about 8,750 tons/year.

In achieving pollutant load reductions to meet the water quality objectives set forth above, the pollution control strategies set forth in Chapters 2 and 3 indicate that point source loads must first be reduced to the extent possible based on technology and economics. There are six principle industrial polluters in the basin; namely, the Yunnan Artificial Fiber Factory, the Erbin Paper Mill, the Dianxi Textile and Dyeing Factory, the Dali Brewery, and the Dali Pharmaceutical Factory. The total quantity of COD discharged from these six factories is 52 tons/day, or more than 95 percent of the total allowable COD discharge in the basin. For this reason, pollution reduction requirements should be allocated primarily among these six factories. An integral part of controlling the discharge of COD from these enterprises will be the implementation of centralized wastewater treatment.

Notwithstanding, the total pollutant load is comprised not only of point source discharges, but also of nonpoint sources. The same total quantity allocation method applied to the point sources above can be used to calculate nonpoint source load reductions. Using a method of regionally weighted pollutant load allocations, which divides the basin into several sub-regions or control units, reduction quotas can be allocated proportionately to each region of the basin. The nonpoint source control program is applied mainly to farmlands, with other emphases on stabilization of open lands in the watershed, construction of a pre-treatment reservoir upstream of Lake Erhai, and provision of improved sanitation in the cities and towns. Adoption of ecologically-sustainable agricultural methods are an important element of the farmland program, while lakeshore stabilization and reforestation are important elements of the watershed stabilization program. Priority actions already implemented include determination of an optimal fertilizer application regime, prohibition of caged fish-farming operations, and utilization of phosphorus-free detergents.

Sewage System Design for Industrial Point Source Pollution Control. Point source pollution can normally be divided in two categories: domestic sewage and industrial wastewater. As has been mentioned before, most of the industrial wastewater in the basin and all of the domestic sewage produced in urban areas will be conveyed to sewage works for treatment. Of the six industries identified herein as the principal polluters of the Lake Erhai and Xi'er River systems, the Dali Paper Mill, the Erbin Paper Mill, and the Yunnan Artificial Fiber Factory are the largest. These three factories focus on pulping, paper making, and rayon production, respectively. They discharge more than 70 percent of the total pollutant load in the basin, accounting for 86 percent of the COD load and 93 percent of the BOD load from industrial sources. These enterprises also discharge high concentrations of such harmful substances as acids, alkalis, and cellulose. For this reason, some degree of preliminary treatment is likely to be needed prior to such wastes being discharged into the sewerage system. In the first instance, these enterprises should upgrade and improve their production processes to minimize the mass of pollutants generated, and, in the second instance, these enterprises may need to set up sewage works in the factories.

Outdated equipment and production processes in these factories lead to high levels of raw material consumption and serious pollution. Introduction of more modern production processes and advanced environmental engineering technologies is needed in order for the industries to expand production capacity, improve production quality, and rehabilitate production facilities. Increased production of non-bleached, sulfate fiberboard can be achieved without increasing pulping capacity. However, investments in new equipment, such as a paperboard machine and other machines used for rinsing and sifting, will be required. Expanding production capacity in such a manner will help to promote advanced production processes and wastewater minimization and treatment. At present, the only waste minimization employed in the paper making industry is the alkali recovery process used in the Dali Paper Mill, which currently has a chemical recovery rate of about 55 percent. The process uses a caustic combustion to enhance alkali recovery. Dilute black liquor from the digester plant is concentrated from about 15 percent solids to between 60 and 65 percent solids in five efficient evaporator workshops. The concentrated black liquor is burned in a low-odor recovery boiler, and dissolved in a weak white liquor recycled from the caustic plant to produce a green liquor. The green liquor is then clarified and combined with burnt lime to form the white liquor that is recycled. Lime mud is separated from the clarified white liquor, and, used in landfill operations. Greater use of this process is projected to increase profitability by almost 20 million Yuan and reduce alkali consumption by 127,000 tons of alkali. This action alone is expected to reduce the total BOD and COD loads within the discharged sewage by 85 to 90 percent.

At present, the three factories discharge wastewater directly into Lake Erhai without treatment. A biological treatment plant, the characteristics of which are shown in Figure 30, is being established at the Dali Paper Mill. Bio-filtration and two-stage sedimentation is included in the process, and, while the quality of the effluent (BOD < 60 mg/l, COD < 300 mg/l, SS < 50 mg/l) does not meet the standard for direct discharge, the process water can be accepted by the nearby sewage main for further treatment.

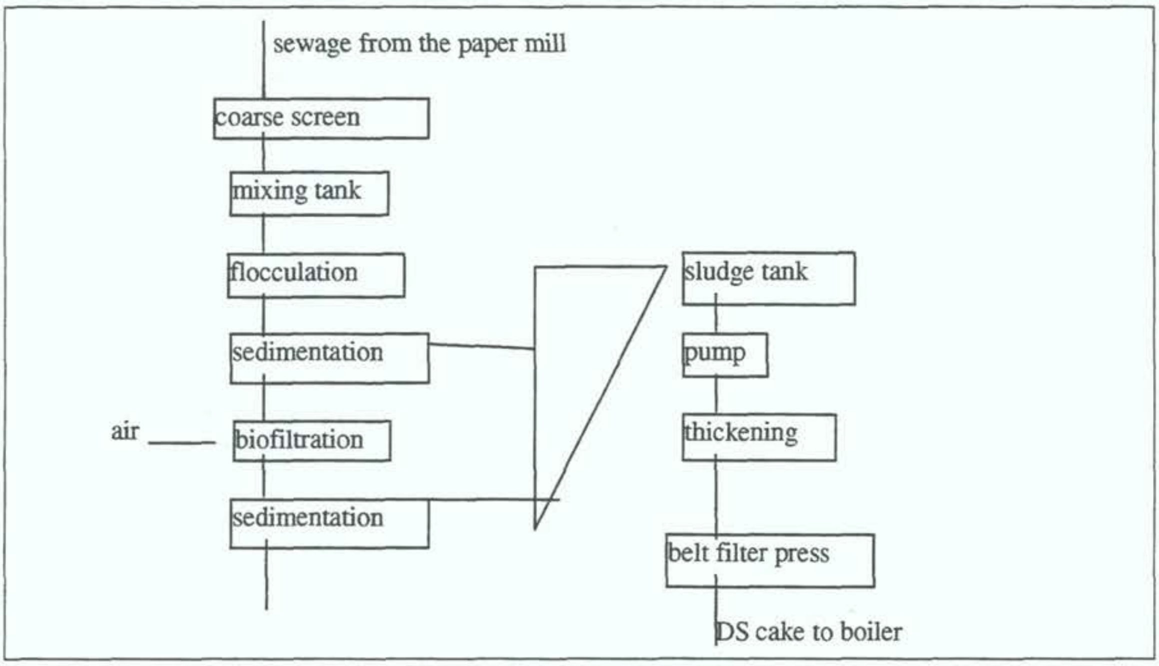

Figure 30. Schematic of the proposed sewage works.

Notwithstanding, the Yunnan Artificial Fiber Factory and Erbin Paper Mill lack the resources and physical space required to adopt this type of technology. Therefore alternative means of reducing pollutant loads from these enterprises must be identified. One option would be to relocate the operations on new, larger sites in the future. Some residual capacity could be maintained in the original areas of operation so as not to cause severe economic hardship and dislocation of the regional economy. The following actions could be considered with respect to the Erbin Paper Mill:

- construction of a new pulp and paperboard mill with a production capacity of 1,000,000 tons/year in a new area, with the excess pulp production being used to supply other paper mills in the basin
- adoption of the "enzyme pulping" or "green pulping" method such as that used by the Jilin Paper Mill in Heilongjiang Province, which separates fiber from xylem using enzymes, not machines, reducing pollution, costs, and maintenance requirements
- utilization of the timber resources of Dali in such a way as to meet the needs for white board, paper production, and packaging paper in Yunnan Province.

The following actions could be considered with respect to the Yunnan Artificial Fiber Factory:

- construction of a new pulp mill with a production capacity of 20,000 tons/year in a new area, while expanding rayon production to 20,000 tons/year at the present plant site
- introduction of the advanced rayon production technologies such as those used by the Dandong Artificial Fiber Corporation
- utilization of advanced wastewater treatment technologies such as those used by the Dandong Artificial Fiber Corporation
- rehabilitation of environmental quality around the original plants.

In addition to these actions, construction of new sewage works in the new areas to which the plants are relocated will be required to treat discharged wastewater from the relocated factories. An aerobic fermentation method is recommended, as shown in Figure 31.

Sewage System Design for Urban Point Source Pollution Control. Other than the three factories, wastewater also is generated from towns and cities within the watershed, including Fengyi, Zhoucheng, and Xizhou. Because of the small amount of pollution and large land area over which the settlements are distributed, construction of centralized sewage treatment plants is considered to be uneconomical. Therefore, small wastewater treatment plants are needed in these areas to meet the requirements of the wastewater discharge standards. These standards are such that tertiary treatment of effluents being discharged directly to Lake Erhai is required, particularly for controlling BOD_5, N, and P loads to the lake. A biological treatment plant, designed to meet these strict standards, is shown in Figure 32.

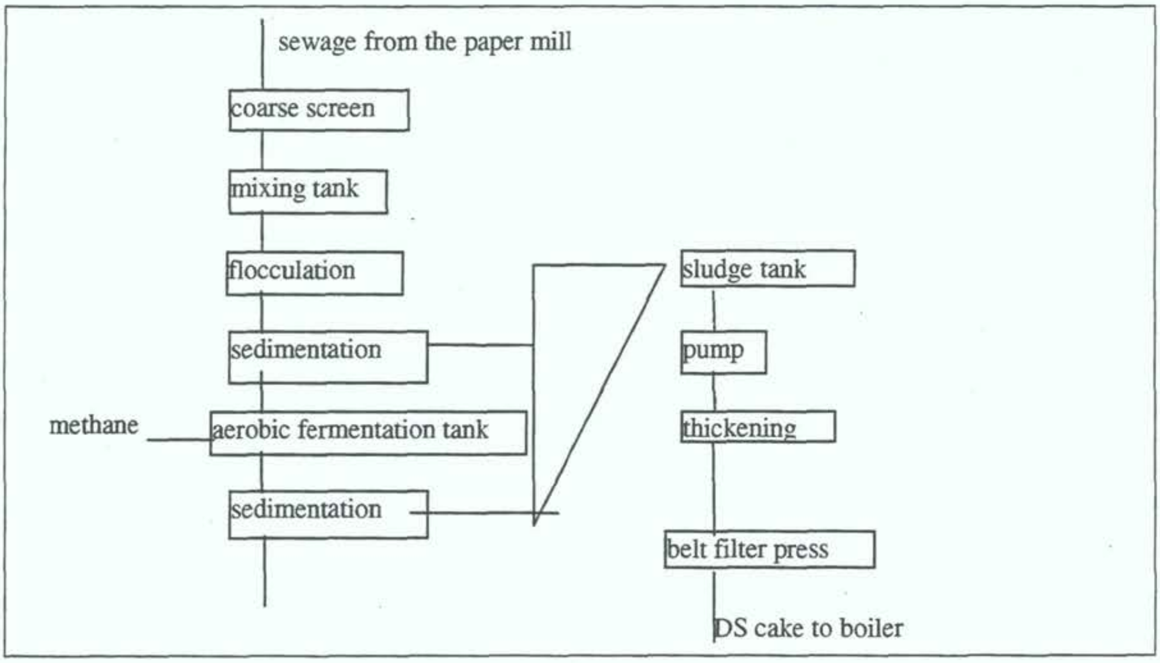

Figure 31. Schematic representation of the aerobic fermentation sewage treatment method.

System Design for Urban Nonpoint Source Pollution Control. Nonpoint pollution in Lake Erhai can be divided into four types: (1) village wastewater and solid waste, (2) farmland runoff, (3) livestock farming pollution, and (4) soil erosion. To address these sources, nonpoint source pollution controls may include the treatment of wastewater and solid waste in villages and towns, introduction of optimal farming systems with more efficient utilization of fertilizers, reforestation, and control of surface water runoff and soil erosion.

Wastewater from villages and towns consists of water used for domestic and industrial purposes in the township enterprises, and stormwater runoff. The main pollutants are organic substances, nitrogen, phosphorus, and suspended solids. Appropriate means to treat these wastes include:

- secondary treatment utilizing both aerobic and anaerobic digestion and composting of resultant solids

- activated sludge treatment
- stabilization pond treatment utilizing algal cultures and agricultural irrigation
- pond-based primary treatment followed by agricultural irrigation
- wetland treatment followed by agricultural irrigation.

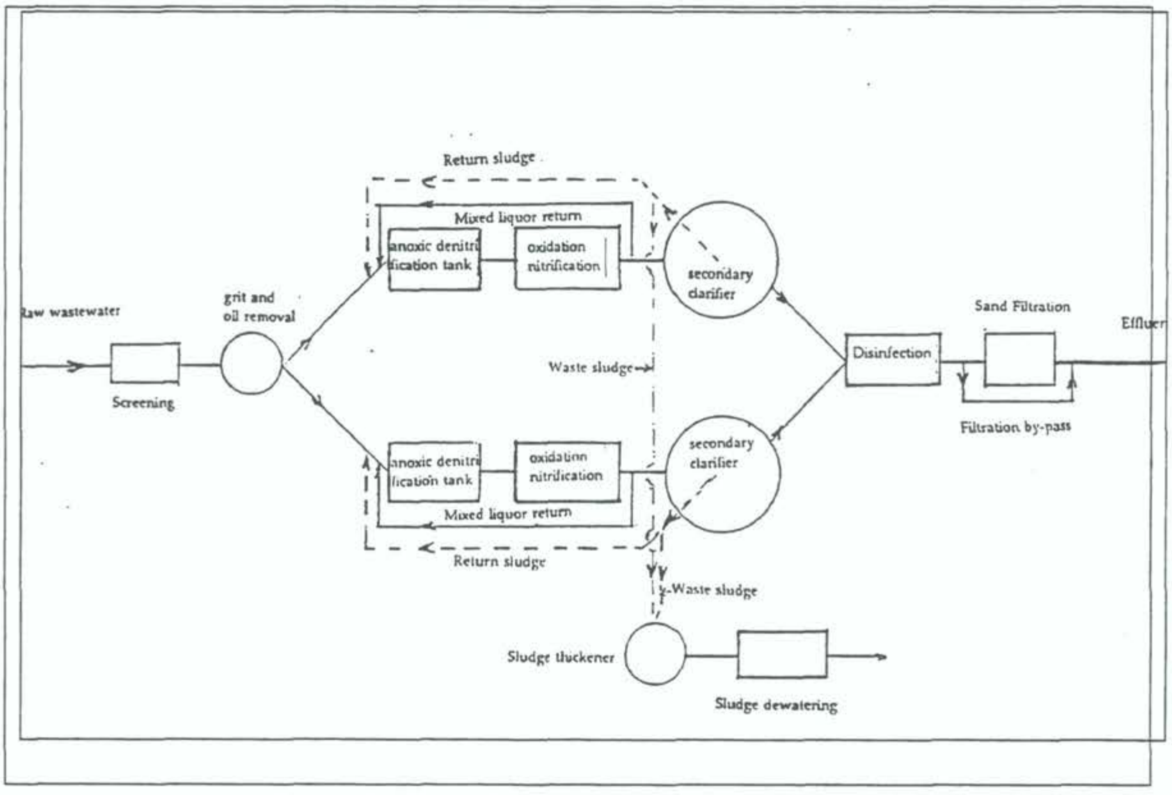

Figure 32. Schematic of a biological wastewater treatment plant.

Secondary treatment can remove nitrogen and phosphorus from the wastewaters in an effective manner. Secondary treatment plants can be constructed in relatively confined areas and are well-suited for use in large towns such as Dali, Zhoucheng, and Xizhou that have high population densities. Such areas are largely built up, and generate large volumes of wastewater. Likewise, the activated sludge treatment method can remove suspended solids, biological oxygen demand, nitrogen and phosphorus very effectively, especially when applied to waste streams generated from cities and towns. In contrast, the stabilization pond method (AIPS) employs a natural purification process to remove organic substances, nitrogen, and phosphorus using biological means. This method requires a lesser level investment, has a low operating cost, and is easy to manage. Even without a balancing pond, this method has the ability to effectively treat wastewater under very high water-loading regimes as may be experienced with combined sewer systems during rainfall events. This method is recommended for villages with sewage flows in excess of 1,000 m^3/day or for economically developed villages. However, in smaller, less economically developed villages, the recommended treatment method is primary treatment method employing agricultural irrigation. Maintenance and operating expenses are low in comparison with the other treatment methods. Wetland treatment is a viable alternative treatment method that is also applicable to smaller, less economically developed villages. Both methods are relatively simple and insensitive to loading rate.

City garbage and solid waste in Dali municipality has not yet been appropriately managed, although a sanitary landfill is proposed. Notwithstanding, solid waste management in the countryside presents certain logistical constraints on the collection and transportation of domestic garbage. Solid wastes in these rural areas consists primarily of organic substances that can be easily treated by composting which not only eliminates pollution but also produces organic manure for agriculture. Both short term composting and conventional composting methods can be used. Short term composting uses a waste-separation and an high-temperature fermentation process to speed the organic decomposition process. The short term composting method can produce large quantities of organic material to supplement the availability of chemical fertilizers in peri-urban areas. It is a centralized treatment process that generally requires a low level of investment, consumes a moderate amount of land, and produces few impacts on neighboring residents. Conventional composting can be accomplished through either a one- or two-stage aerobic fermentation process carried out at ambient temperatures. The one-stage process can produce organic material that is suitable for vegetable production. The two-stage process, in which additional fertilizer is added to the compost during the second stage fermentation, can produce an enriched compost that can be used in large-scale agricultural operations that require large amounts of compost to meet seasonal demands.

In urban areas, disposal of solid wastes in sanitary landfills can protect ground and surface waters from pollution. Currently, solid waste from Dali municipality is dumped or landfilled in conventional landfill sites. The management of these sites is very poor, and the sites are often situated next to waterways. Where landfills exist, they rarely meet international environmental standards for the collection and treatment of leachates, placement of landfill liners, etc. Upgrading these municipal solid waste disposal sites to incorporate specific measures for the protection of water quality is recommended. Further, a new landfill site is recommended to be located downstream of Lake Erhai. Placement of a landfill in this location means that the disposal site is closer to the sources of the solid wastes in Xiaguan and Dali Old Town than at present. In this regard, Dafengba, located to the south of Xiaguan along the Guanwei Highway, is an appropriate site. Dafengba is underlain by a thick clay stratum that makes it ideal as the site for a sanitary landfill, although other lining materials, such as bentonite or geo-fabrics, could be used for additional protection of water resources as necessary as the site is developed. To meet current and projected demands for landfill capacity, based upon municipal solid waste volumes generated from Dali City and Eryuan County, a 10 to 15 million m^3 landfill is required. This facility could be constructed in two stages. The first stage would have a capacity of 3 to 6 million m^3, on a site of 10 to 15 hectares in areal extent. The second stage provides an additional 6 to 9 million m^3 of capacity on a similar-sized site.

System Design for Rural Nonpoint Source Pollution Control. Nonpoint source pollution in rural areas of the Lake Erhai basin arises primarily from the application of agricultural fertilizers. Excessive and irrational fertilizer applications result in the availability of excessive quantities of nutrients on the land surface which are carried to the lake in farmland runoff. The means to control the loss of agricultural fertilizers from the land surface is through a program of rational and optimal fertilization (integrated nutrient and pest management programs) that reduces the rate of fertilizer application and increases its effectiveness in enhancing crop production. In this way, improved fertilizer management will help to control agricultural nonpoint source pollution, and promote sustainable development in the Lake Erhai basin. Application of these methodologies can not only reduce the losses of nitrogen, phosphorus, and organic substances from the land surface, but also decrease the agricultural production costs. The initial step in implementing an improved agricultural production system would be to convert sloped land with a gradient of less than between 8^o and 25^o into terraced land; sloped lands with gradient of more than 25^o should be placed into forestry use. The optimal width of the terraces should be between 3.8 m and 7.0 m, with the berm height being at least 1.2 m, as shown in Table 75. Use of terraced lands permits the more effective and efficient use of pesticides and fertilizers, and contributed to a reduction in the mass of agro-chemicals applied to the land surface.

Table 75. Guidelines converting steeply-sloped land into terraced land.

Conversion of sloped landing terraced land:
Soil depth>60cm
Plow depth>15cm
Land dyke height <2m
Land width>3m
Soil fertility degree: level 1-2

A second major cause of land degradation in the Lake Erhai basin is soil erosion. This problem is exacerbated by the lack of forest cover as a result of human activities. Such activities contribute a large amount of debris to Lake Erhai, resulting in excessive deposition of silt in the lake basin. Coincident with this siltation is nutrient enrichment and deposition of debris in the lake basin. Techniques to minimize the inflow of debris, silt, and other contaminants include biological protections, construction of check dams and diversion tunnels, provision of structural protections on steeply sloping hillsides, and the location of sedimentation basins in strategic locations within the drainage way. Sedimentation basins not only physically retain sediments being transported by inflowing streams, but also provide wetland habitat in which plants utilize the nutrients and provide shelter for fishes that, in turn, can provide a degree of control on the extent of the vegetation cover. Both the plants and fishes can be harvested for other purposes. Thus, these basins not only provide for a 40 to 60 percent removal of plant nutrients, but, at the same time, also contribute certain economic benefits to the community.

In addition to the direct benefits provided by the sedimentation basins, further improvements can be achieved through reforestation projects. An efficient way in which to reforest barren hillsides, around the lake and its inflowing rivers, is by aerial sowing. This method has been proven suitable for large scale planting of Yunnan pine, being fast and requiring little labor, but it is not suitable for all kinds of trees. In some areas, manual planting and planting of saplings remains the most effective way in which to ensure the survival of the planted trees. Nevertheless, in such reforestation projects, the selection of appropriate plant species is important for soil conservation and for the creation of an healthy environment. The recommended mix of grasses and trees for use in the Lake Erhai basin is set forth in Table 76. A mixed system of *Quercus* and Yunnan pine forest is recommended. In addition, a mixture of fruit trees and other trees can also be grown, based on different land and water supply conditions. Experience in the management of a small drainage basin tributary to Lake Dianchi also suggests that the planting of a *Vetiveria* buffer strip can further reduce soil erosion by up to 70 percent. The importance of soil and water conservation as a restoration measure in mountainous areas, and as a water quality protection measure, is illustrated by the number of on-going projects in this area. These projects include the field agronomy, terraced land, and reforestation and grading projects described in Table 77.

In extreme situations, where reforestation and onsite erosion control using sedimentation basins is not feasible or is inadequate, the construction of pre-treatment reservoirs, or pre-impoundments, provides one further way in which suspended soils and other contaminants can be intercepted prior to entering the lake. They are designed to minimize soil erosion, even during periods of storm-related runoff. Pre-treatment reservoirs are constructed along the contour of the land above agricultural lands. The design length of these structures ranges up to 227 km, and their construction involves the excavation of up to 0.13×106 m^3 of soil. In addition, the construction of pre-impoundments includes the construction of a drainage system to convey the stormwater runoff to water storage structures, forest areas, or grasslands once the sediment load has settled out of suspension. Small pre-treatment reservoirs need less investment than larger reservoirs, and cascades of small reservoirs are capable of moderating soil loss and nonpoint source pollution. Such cascades are recommended for large agricultural areas within the basin. Large pre-treatment reservoirs are actually upstream impoundments that operate as natural lake and reservoir systems. Lake Cibi is an example of a large upstream waterbody that provides water quality benefits to downstream lakes and streams. Other such waterbodies exist in the northern portion of the Lake Erhai basin, including Lakes Haixihai and Xihu. These lakes are the main water sources to Lake Erhai. These three lakes have large water surface areas and established aquatic plant communities that could be managed to provide water quality benefit to downstream Lake Erhai by the removal of silt, nitrogen, phosphorus, and other pollutants.

Table 76. Environmental Benefits of Mixed Grass and Forest Systems.

Sample Plot	Soil Characteristics	Soil Permeability		Nutrient Removal	
		Water application rate:180 ml/hr	Water application rate:30 ml/hr	N	P
Quercus variabilis woodland	loose, some roots	25 drops ~75 ml	flow from bottom	3,844	4
Yunnan pine woodland	hard, few roots	36 drops ~10.8 ml	flow from bottom	5,605	19

System Design for Shipboard Pollution Control. There are four in-lake pollution sources: aquaculture, tourism, shipping, and the lake bottom sediments. Of these, aquaculture and motorized fishing boats were banned from Lake Erhai during September 1996. Consequently, the current in-lake pollution sources consist primarily of tourism and transport ships. Pollution from tourism arises mainly as a result of the discharge of wastewater generated by tourists, while pollution from shipping arises mainly as a result of solid waste discharges and oil spills from transport ships. To manage these sources of pollution, it is necessary to establish a system of collection, storage, transportation, and processing. The collection system should be designed to make full use of the existing equipment. The collection facilities (such as pipes) and wastewater containers also should be designed according to the requirements of each specific vessel. Wastewater collected in this way should be stored in hermetically sealed tanks until such time as it can be disposed of at pierhead facilities. At a pierhead facility, the wastewater is pumped into transport vehicles for conveyance to a treatment plant or into the municipal pipe system. Treatment should vary according to the properties of the wastes, but should be at least

Table 77. Overview of Soil Conservation and Reforestation Projects.

Project	Field Agronomy Project	Terraced Land Project	Reforestation and Land Grading Project
Project Overview	This project, also called the water and soil conservation farming project, promotes farming methods that protect slopes and reduce rates of runoff from the land surface.	This project promotes the regrading of slopes, terracing, and the construction of berms along the edges of fields to retain water.	This project promotes reforestation and the regrading of slopes.
Project Content	The farming methods used in this project are contour farming and contour furrow farming.	The farming methods used in this project are horizontal terracing and slope terracing.	The farming methods used in this project are terracing lands with slopes of up to 35°, furrowing, use of pits (e.g., fish scale pits), and furrow front protection.
Application Range	Contour farming methods suit fields with slopes of 2° to 20°, and are suitable for production of grains such as corn, Chinese sorghum, and potatoes.	Terracing suits fields with slopes of 7° to 20°.	Terracing is suitable for fields with slopes of <35°, and is suitable for planting trees when the slopes are >25°; terracing is suitable for planting fruit trees then the slopes are <40°. Furrowing is suitable for fields with slopes of <35°, and is suitable for areas lacking rainfall but subject to strong storms. Pits are suitable for slopes of 35° to 45°, and work well for fragmented slopes and grasslands. Pits are suitable for planting new trees. Furrow front protection is suitable for fields with slopes of 35° to 45°.
Benefits	Benefits include a 71% reduction in annual runoff volumes, an 84% reduction in the annual volume of soil wash off, and a 10% increase in annual outputs.	Benefits include a 90% reduction in annual runoff volumes, and a 50% to 100% reduction in the annual volume of soil wash off.	Benefits include a 100% reduction in annual volume of soil wash off. Reductions in annual runoff volumes vary with individual projects

to the standard provided using oxidation ponds. At some sites, tourist wastes could be conveyed to the nearest municipal sewerage main. Collection, storage, conveyance, and treatment of solid wastes should follow a similar procedure, with solid wastes being collected in garbage bags and containers, stored in either a compacted or uncompacted form in hermetically sealed chambers, and discharged at the pierhead. The waste would be transported from the pierhead to the landfill by vehicle, where it would be processed with other urban garbage. In addition to such pollution control measures, there is a need to improve the supervisory and administrative functions relating to lake-focused tourism. Such improvements in tourism resource planning, including implementation of user charges and limitations on the numbers of tourist boats on the lake, would contribute to the establishment of appropriate regulations and standards for the tourism industry.

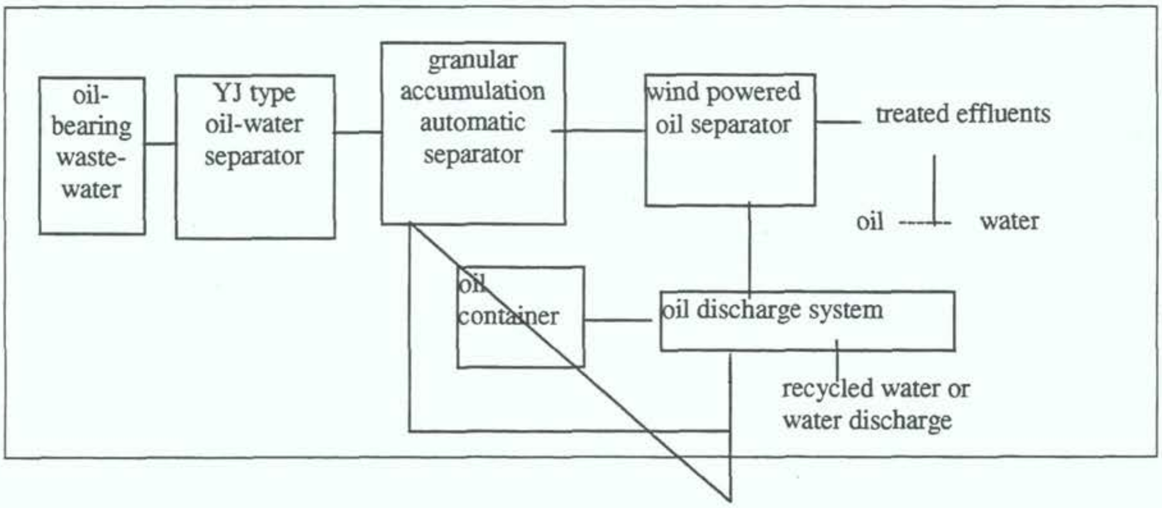

Figure 33. Schematic of an oil-bearing wastewater treatment process.

Shipping pollution refers to pollution from vessels other than those engaged in the tourist trade. Control of pollution from this source includes the same elements as identified above; namely, collection, storage and processing of garbage, and collection, storage and processing of wastewater. These elements can be incorporated into the systems designed to tourist wastes. In addition, shipping pollution control must limit oil-bearing pollutants from entering the lake, both directly and indirectly. The control of oily wastes requires the collection of such wastes and the separation of the oil from the wastewater, as shown in Figure 33. As in the tourism industry, the management of pollution from shipping could also benefit from improved supervisory and administrative procedures, including implementation of user fees, prohibitions against wastewater discharges and dumping of solid wastes into the lake, improved cargo handling to minimize the risk of cargo dropping into the lake, installation of oil-water separators in engine rooms and cargo areas, and strengthened education and training of shipboard workers.

System Design for In-lake Ecosystem Restoration. Lake pollution, or eutrophication, damages in-lake ecosystems. Restoration and optimization of the structure and functioning of the lake ecosystem are important aspects of in-lake pollution control. In Lake Erhai, during recent years, human activities have altered the aquatic communities such that aquatic plant communities are dominant by pollution-tolerant species, while clean water species are threatened or extinct. The community structure tends to become simplified as the ecosystem is degraded. While the degradation of Lake Erhai is attributed to the degradation of the lake's watershed, which is being restored in accordance with the programs already identified above, specific in-lake actions are required to restore the in-lake ecosystem. Such actions are aimed at the restoration of aquatic plant communities of Lake Erhai and its shorelands.

Restoration of the in-lake aquatic plant communities involves not only the control of external nutrient sources to limit phytoplankton growth, but also the artificial restoration of selected species to augment natural regeneration and reduce the time required for full restoration. While the particular plant species selected for use in lake rehabilitation must be based upon local conditions, the list of historically dominant species in Lake Erhai provides some guidance. Pollution-resistant species as *Hydrilla verticillate*, *Myriophyllum humide*, and *Potamogeton malaianus* may be selected as pioneering species during the early period of restoration, to be replaced as plant communities are restored and water quality is improved with such species as *Vallisneria* sp., *Potamogeton crispus*, and *Potamogeton maackianus*. In addition to the submerged macrophytes, some floating-leaved plants such as *Eichhornia crassipes* may be considered. During the second phase, restoration of submerged plant communities, including species such as *Trapa incise* or *Trapa* spp., would be appropriate in the bays. The recommended restoration technique is natural restoration combined with artificial cultivation using plastic liners that contain clean substrate for growing submerged macrophytes, artificial floating islands upon floating aquatic plants are cultivated, and coastal zone restoration and establishment of shoreland buffer zones to limit impacts on the lake from the surrounding land surface. This latter technique forms a protection zone around the lake.

Creation of shoreland buffer zones is accomplished by engineering a shelter-forest and grass-forest complex. Hedges are introduced to minimize the influx of pollutants by interception and absorption. Hedges also can contribute to the control of surface runoff and soil erosion in the area. This technology is adaptive to all regions around Lake Erhai, including those areas adjacent to the inflowing streams. In addition, the construction of natural embankments may further decrease coastal erosion and accelerate the restoration of the aquatic ecosystem, especially in the western and eastern regions and bays. In some areas, however, the introduction of artificial media such as coagulants, potsherds, and/or porous concrete near the embankments will be required to decrease bank erosion, especially in the western and northern regions of Lake Erhai. These artificial media provide habitats for microorganisms and benthic organisms. These techniques will enhance the creation of artificial wetland systems to intercept and purify wastewater and stormwater, while encouraging the regrowth of natural wetland systems that provide habitats for fish spawning and bird nesting. Wetland restoration is recommended in the northern areas of the watershed.

Biodiversity Conservation

Cangshan-Erhai is a key region for biodiversity conservation, having an high species density, rich in endemic species and frequently supporting the appearance of new species. For this reason, the area is important to global biodiversity conservation. In the recent decades, conservation of the biodiversity of the Cangshan-Erhai region has been threatened by excessive exploitation leading to environmental deterioration. The ecological balance of the area below 3,000 m in elevation has been severely damaged, requiring that specific measures be taken to protect the biodiversity of the basin. Two complementary strategies are recommended; namely, prevention of further ecosystem and environmental deterioration and species losses, and intensification of the effective administration of the natural reserves.

Table 78. Equipment Needs in the Natural Reserves

Category	Equipment	Function
Reserve boundary delineation	·Surveying equipment ·Global positioning system ·Bench marks	·Field surveys ·Set bench marks ·Define the reserve boundary
Fire protection capability	·Off-road vehicles (4) ·Fire fighting equipment (4)	· Provide mobility for the prevention and fighting of fires ·Prevention of forest fire inside the reserve
Fire hazard early warning system	·Elevated observation towers (4)	·Monitor fire hazards ·Provide early warning of potential or small fires

The natural reserve is the basic unit for managing the biological resources in approximately 550 km^2 of the Cangshan Mountains and 250 km^2 of Lake Erhai. The staff of these reserves are responsible for developing a comprehensive management plan, establishing a monitoring system, preparing biological resource and habitat protection plans, and creating an emergency response plan. These staff require an administrative center, a laboratory, field offices, housing, office and laboratory equipment, data management systems, archival systems for documents and specimens, and vehicles. In addition, in order to effectively manage the natural reserves under their jurisdiction, there is a need to survey and erect permanent bench and boundary markers, and create an early warning system and fire fighting capability. To accomplish these tasks, the staff require some basic equipment as shown in Table 78. In addition, because the natural reserves cover a large area and staff are scattered in several locations, transportation and communication facilities are essential for the effective management of these areas. Staff also need to be equipped to record images of field conditions, to make image files, and to produce public education and public relations materials. Table 79 sets forth the equipment needs in the areas of communication and transportation.

A key component of the prevention of further degradation of the natural reserves is ecological monitoring that provides information on the structure and formation, development tendency, and dynamic changes of the ecosystems and related plant and animal communities. It also provides information that can be used to infer the relationship between communities and their distribution. Ecological monitoring needs in the Lake Erhai basin include aquatic system monitoring including monitoring of phytoplankton, zooplankton, benthic, aquatic vascular plant, and fish communities, and chlorophyll-a, and monitoring of Cangshan plants. Such monitoring programs should be composed of field observations and sampling, laboratory analysis, instrumentation for remote sensing information and image processing, and data processing equipment. The relationships between these elements of a monitoring program are shown in Figures 34 and 35.

In addition to monitoring and record-keeping, actions are needed to protect and regenerate threatened and endangered species. Arboretums are places where plants are grown for the purposes of aesthetic viewing, scientific studies and collection, and, as such, are ideally suited to playing an important role in biological conservation by protecting plants that might be otherwise destroyed in their natural habitats. The arboretum being created in the Cangshan-Erhai region has seven principle areas, incorporating these functions. The rare and endangered species protection area is designed for the ex-situ protection of rare and endangered plants. These plants will be planted in populations and under conditions similar to those of their natural habitat to enhance their survivability. These plantings will be the bases for propagating plants to be re-introduced into their natural habitats. In this area, rare and endangered plants in other parts of the country also can be introduced for study. The nursery area for young plants is designed for cultivation of young plants of rare and endangered species, and endemic species. The endemic plant area is designed to embody the characteristics of the local flora as well as provide a location for endemic plant research. The ornamental plant area is designed to attract tourists, highlight indigenous ornamental plants, and house species collected from surrounding areas. At the same time, fine varieties of plants may be introduced to enrich this collection. The production area is designed to produce rare flowers for sale. The income generated from the sale of such flowers will be used to support the operation and further development of the arboretum, and to repay the capital investment. The greenhouse area is designed to provide an additional venue for scientific studies of tropical rare and endangered plant species. An office and staff housing area is also being provided.

While arboretums provide a source of plant material for revegetating degraded areas, actions are also required to rehabilitate such areas prior to the reintroduction of native plants and animals. The rural areas in the Lake Erhai Basin have been decimated by the felling of forests, clearing of steep slopes for agricultural production, and depletion of organic matter in agricultural soils as a result of intensive cultivation. The resulting soil erosion has been the single most important cause of water quality deterioration in Lake Erhai, and is a serious threat to the biodiversity of Lake Erhai and the Cangshan Mountains. To overcome such extensive degradation of the watershed, an eco-agricultural approach has been conceived. Eco-agriculture consists of an integrated, household-based agricultural management unit that reuses and recycles plant and animal wastes into the agricultural production process, as shown in Figure 36.

Table 79. Transportation and Communications Equipment Requirements

Category	Equipment	**Function**
Transportation	·Four-wheel drive vehicles (3) ·Passenger van ·6-passenger sedan	·Transporting staff on official business · Receiving visitors ·Field trips
Communications	·Office telephone connections (20) with intercom systems (8) ·Mobile telephones (8) ·Telephone pagers (30)	·Maintain office-to-office and office-to-field communications ·Conduct official business with other agencies
Public Information	·Video camera and playback device ·Still camera ·Projectors and screens	·Record field conditions inside the reserve ·Produce public information materials ·Conduct public education programs

In the Erhai Lake basin, eco-agricultural household project is to be phased in, with the first 50 households being selected during the period through the year 2000.

After this, it is anticipated that the concept will be extended through the whole basin during the period 2001 to 2010. A large methane-generating pit will be set up in each village so as to accelerate the implementation of the eco-agricultural village concept. The eco-agricultural village, or eco-village, project includes those farmlands at moderate to low elevations that should be terraced, irrigated, or brought into an integrated nutrient and pest management program, as well as other farmlands. This project uses ducks, raised within the paddy fields, not only to eliminate many destructive pests such as rice borers, rice leave rollers, and locusts, but also to eliminate weeds and improve the ventilation of the rice fields. Duck excrement also provides a good organic fertilizer that contributes to increasing rice yields.

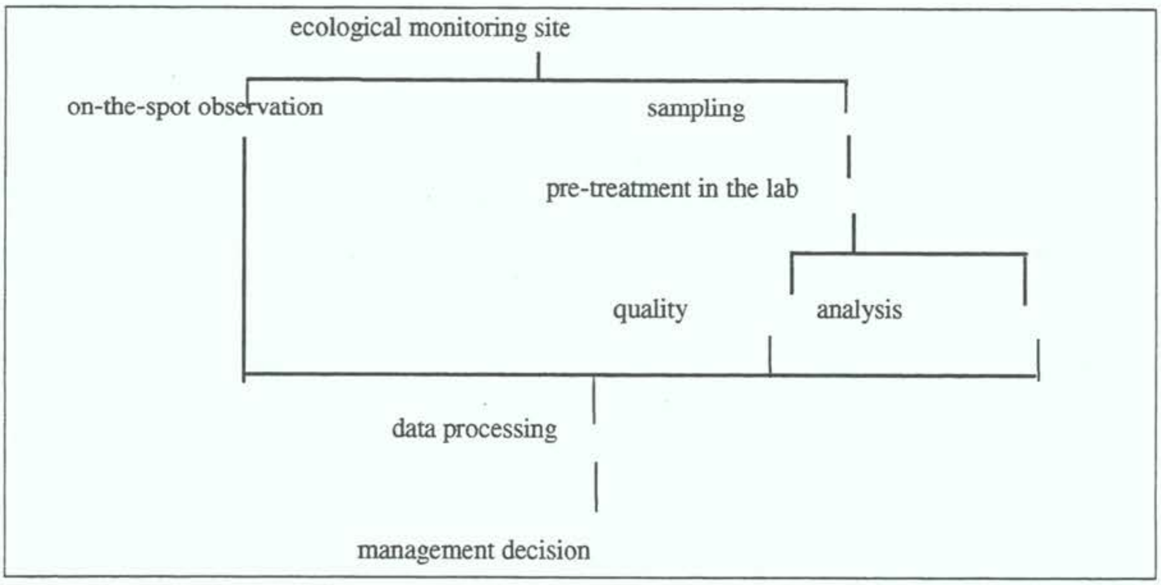

Figure 34. The process of ecological monitoring.

One element of the integrated nutrient and pest management program is the use of microorganisms as an important part of a biological pest control program. Microorganisms such as bacteria, fungi, viruses, and protozoans can be used for this purpose. Varieties of bacteria are currently used in China for the control of insects in fruit trees, tea trees, tobacco plants, and garden trees, and are 70 to 90 percent effective against most insect pests. Likewise, other fauna can be used for the biological control of pests. Frogs can eat 70 to 80 insects daily, and a woodpecker can eat up to 300 insects each day. Both frogs and woodpeckers play important role in ecological agriculture. For this reason, the protection of the beneficial insects, amphibians, and birds is a central feature of eco-agriculture. Not only does this promote their function in pest control but, at the same time, also benefits biodiversity within the agricultural ecosystem.

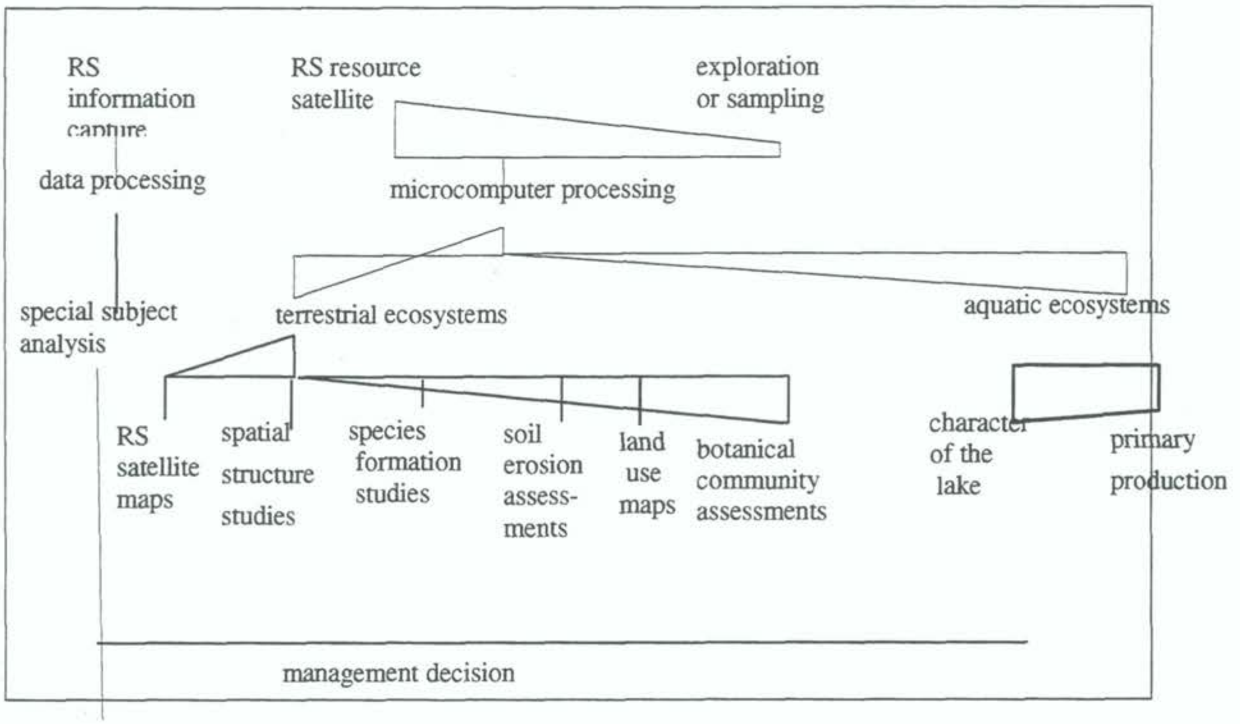

Figure 35. The use of RS-GIS systems in ecological monitoring.

A further element of the integrated nutrient and pest management program is the use of microorganisms to augment organic fertilizer production. Organic wastes, such as excrement, straw, and domestic garbage, are sorted, ground, and sifted to select for a well-blended compost. These materials are rapidly converted into compost through the addition of biologically active substances and microbial starter cultures. The microbial action is enhanced by a fermentation process. The resultant compost can increase the yield and quality of crops by enhancing the survival of microorganism in the soil, improving soil structure, and alleviating some sources of pollution, providing increased environmental protection. A factory with a capacity of

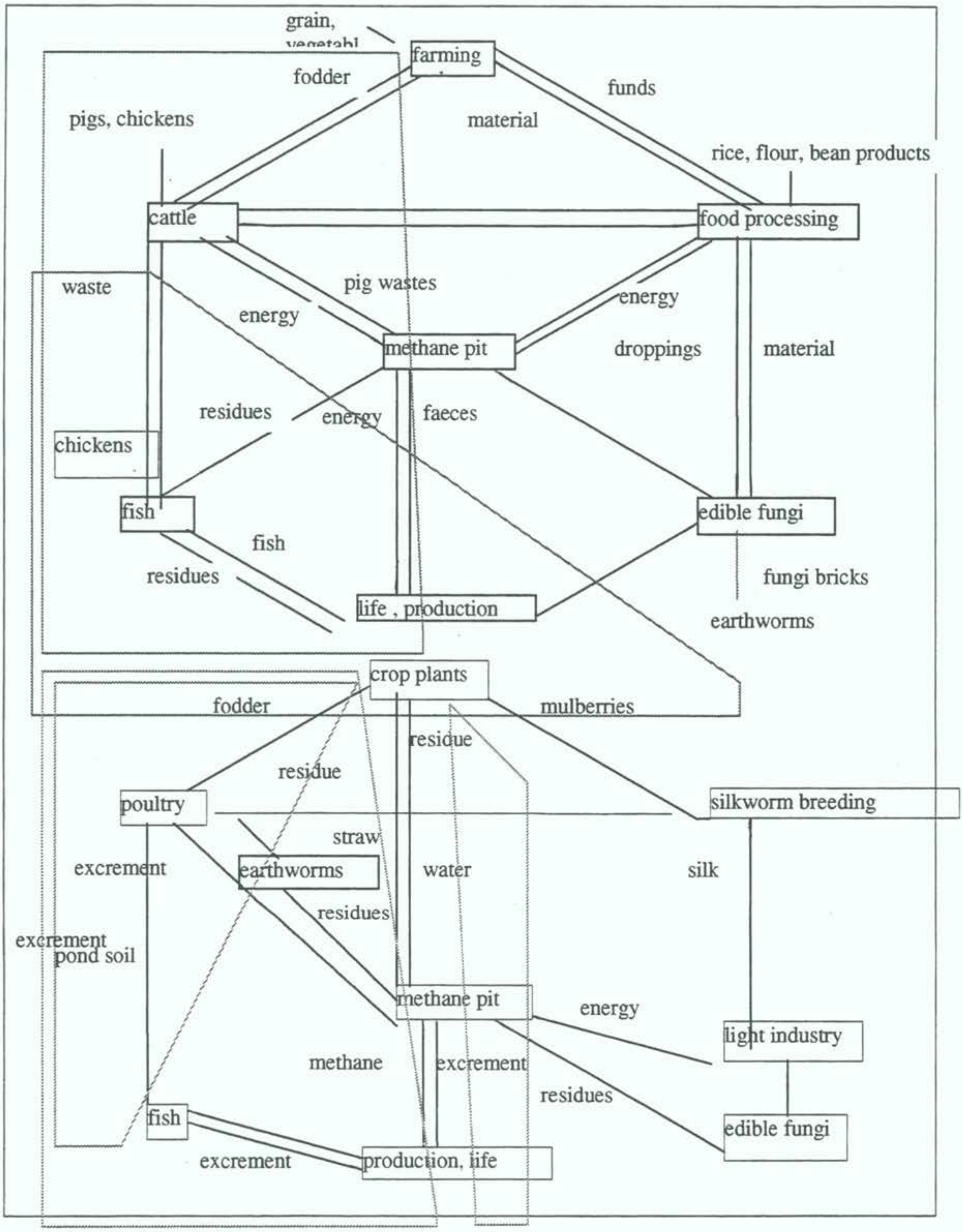

Figure 36. Energy flow in an eco-agricultural household.

1,000 tons/year can provide sufficient compost fertilizer for 667 ha farmland, with a total investment of approximately 4,000 Yuan. In addition, the techniques employed in the production of compost-based fertilizers are compatible with local technical capabilities. The fertilizers themselves have low production costs but a potential to yield high profits within the Lake Erhai basin.

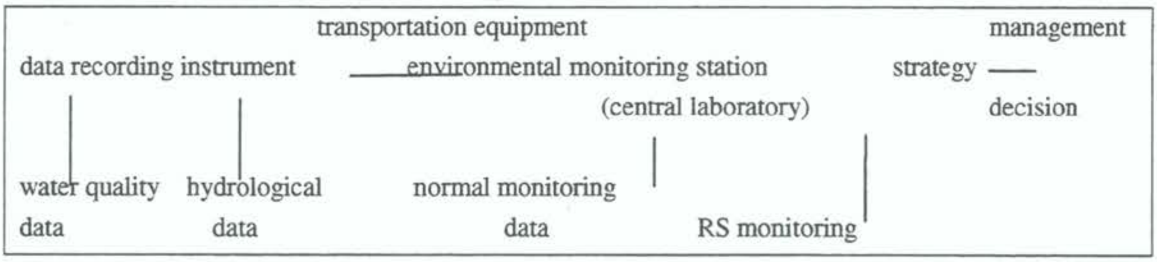

Figure 37. Schematic of an automated environmental monitoring system.

Water Quantity and Quality Monitoring

Lake Erhai is the main source of water within the Dali Nationality Autonomous Prefecture. Lake Erhai is also the center of the fishery and tourism industries. Therefore, the lake plays an important role in Dali Prefecture's economic and social development, and steps are necessary to protect the natural resource base of the lake. One such step is the strengthening of lake environmental monitoring and water pollution control efforts in the basin. The water quality monitoring system is proposed to be automated, with hydrological data and environmental samples being collected throughout the basin and water resources data compiled at a central laboratory as shown in Figure 37. Routine monitoring data to be collected include information on hydrology, lake water quality, sediment quality and transport, aquatic ecosystem integrity, and stream water quality. Collection of such routine monitoring information can help the government to evaluate the present situation of the watershed, plan and implement effective water pollution control measures, and evaluate their success in protecting the lake. The use of water resources data in this manner is shown schematically in Figure 38. This information can also provide input data for the RS-GIS system previously described. Combined with satellite data, environmental monitoring information can contribute to monitoring economic development in the Dali Prefecture, and ensure that such development proceeds in an orderly fashion compatible with the ability of the resource base to sustain such development.

As previously noted, the development of the Lake Erhai basin is predicated upon the introduction and adoption of eco-agricultural economics as the basis for the effective utilization of the abundant natural resources of the region, and for the preservation and protection of the basin's ecosystem. Eco-agriculture is an integral part of the overall development of agricultural production in the region, focussing on the comprehensive use of renewable energy linked to agriculture, forestry, animal husbandry, agro-industrial production, fisheries, and related manufacturing efforts. Under this development scheme, lands above an elevation of 2,300 m would be reforested, while lands between 2,100 m and 2,300 m elevation would be used primarily for forestry or orchards. Lands below 2,000 m elevation would continue to be used for rice and melon cultivation as well as fish farming in the paddy fields. A portion of the produce would continue to be used by the farmers for family purposes, while the waste products would be used for community methane production that will meet a portion of the energy demands within their villages. This eco-agricultural model is recommended for use in the eastern and southeastern regions of Lake Erhai basin. In the western portion of the basin, eco-agricultural activities below 2,300 m would encompass not only the planting of fruit trees, but also the planting of cereals, herbs, tea trees, and woody cover plants, while eco-agricultural activities below 2,000 m would also include the planting of mulberry trees and fodder plants.

Environmental Impact Analysis

Environmental Impact Analysis (EIA), in the context of sustainable development, is an important planning tool, which has essential role in minimizing harmful environmental impacts. In this context, "environmental impact" means the direct and indirect effects of development on (1) human health and living conditions, (2) soil, water, air, climate, flora, and fauna, (3) infrastructure, buildings, landscape aesthetics, and cultural heritage, and (4) natural resources. While the major environmental impacts that currently exist or are foreseen within the Lake Erhai basin have been described elsewhere in this document, there are other, limited-term impacts associated with the transition from current methods of economic development to more sustainable forms of economic development. Some of these impacts are summarized below, as they relate to the implementation of municipal sewerage systems, the relocation of industries, and the construction of pre-treatment reservoirs.

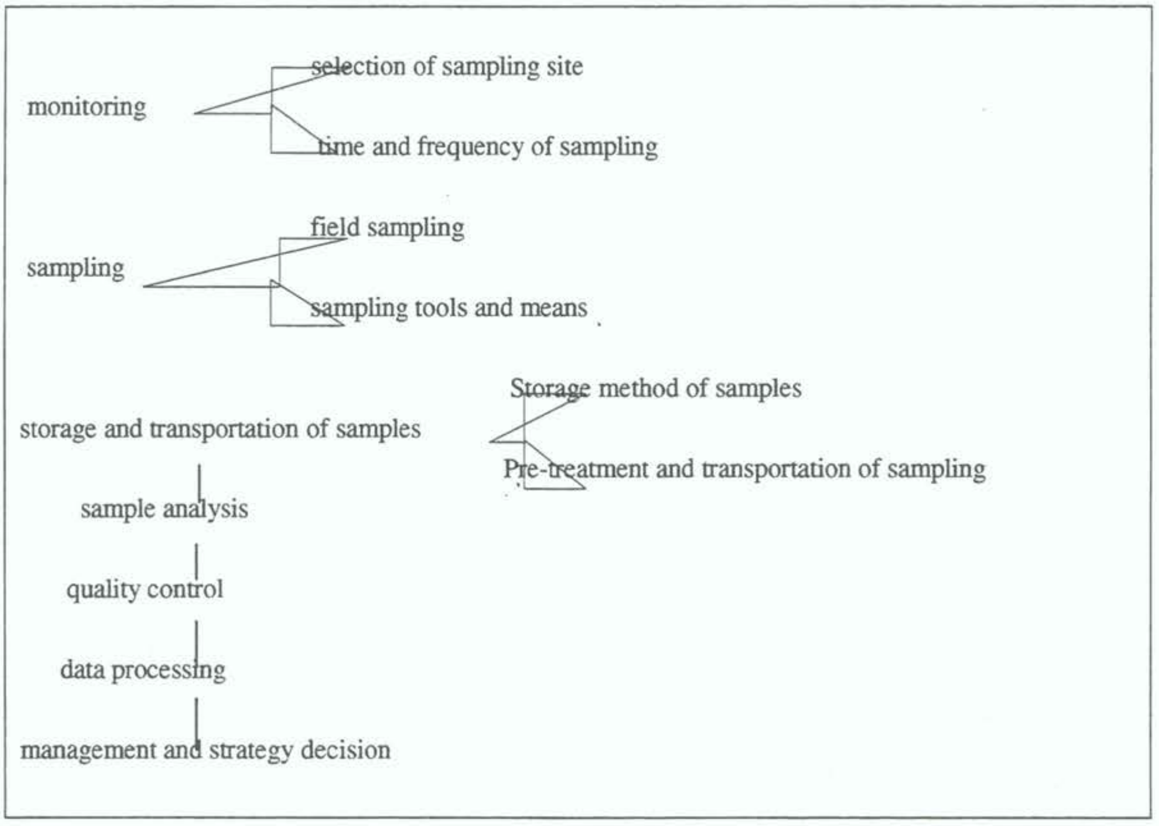

Figure 38. The use of environmental monitoring information in lake and watershed management.

The implementation of municipal sewerage systems will create short-tem impacts on the environment, as summarized in Table 80. These impacts include transit and traffic (noise and air) impacts associated with the movements of construction workers, soil impacts associated with excavation for pipeline and facility construction, and ecological impacts associated with the consumption of raw materials and the occupation of some agricultural lands. While some of these impacts, such as noise from pump and equipment operation, will continue during the operational phase of the project, the net result will be improvements in water quality, sanitation, and the public health. In particular, the treatment of industrial wastewater will eliminate the direct discharge of process liquors into Lake Erhai, reduce COD and BOD loads reaching the Xi'er and Lancang Rivers by 85 percent to 90 percent, and minimize the release of sulphides and other noxious gases within neighboring communities, especially Xiaguan.

The relocation of some industries may result in additional long-term and short-term environmental impacts, especially in the vicinity Machang where many of these relocated developments are proposed to be sited. During the construction period, transportation-related impacts may be expected to increase significantly, especially those impacts associated with road building activities. In the longer term, the local climatic factors (sunny and windy) and topography (mountain terrain) are less than favorable for atmospheric diffusion of stack emissions, and some controls will be needed to minimize atmospheric impacts. Likewise, since the water supply for the Machang area is anticipated to be from the Heihui River, some problems with maintaining an adequate water supply for industry during the dry season also may be anticipated given the low water flow (4 m^3/sec) in the river at these times. Relocation of the Yunnan Artificial Fiber Factory and Erbin Paper Mill will result in effluent discharges to the Heihui River, which, due to limited funds available for the installation and operation of water pollution control equipment, could degrade water quality in the Heihui River - Lancangjiang River system. Notwithstanding, the direct environmental benefits of the projected relocation of these industries include the less intrusive disposal of solid wastes, improved pollution control of wastewaters, and reduced soil erosion. Potential environmental benefits include the improvement of environmental quality, agriculture, soils, and environmental awareness among communities. The direct environmental benefits are shown in Table 81.

Table 80. Environmental impacts of public sewerage systems.

Water	Atmosphere	Noise	Sanitation	Ecology	Soils
Construction Period					
+ / (=)*	+ / (=)*	+ / (=)*	+ / (=)*	+ / (=)*	+ / (=)*
Operational Period					
(+)	(+)	(=)	(+)	(+)	(+)

+ = environmental impact likely
= = minimal environmental impact likely
( ) = environmental impact possible
* = environmental impact following implementation of best management practices

The construction of pre-treatment reservoirs may also result in environmental impacts associated with engineering activities, the movement of personnel and machinery, increased traffic, disturbance of the land surface, consumption of materials, and occupation of lands. These activities will create soil erosion, air pollution, and landscape impacts, most of which are anticipated to be temporary and limited in scope. It is anticipated that significant, longer-term environmental benefits will be achieved during the period of operation of these structures, improving environmental quality in the project areas. Notwithstanding, there is a significant potential for environmental harm to arise, especially where poorly-managed, large pre-treatment reservoir projects change biological communities or harm tourism development. Therefore special administrative arrangements must be established for the operational management of large nonpoint source pollution control projects. Good administration of such projects will result in the successful implementation of nonpoint source pollution controls.

Table 81. Environmental benefits of pollution control measures.

Pollution source	Index	Percentage
control area of runoff (km2)	2,565	100
amount of silt removed (tons/year)	147.7	70
amount of nitrogen removed (tons/year)	2,400	40
amount of phosphorus removed (tons/year)	2,500	50
Amount of garbage disposed (tons/year)	441,000	
Reforestation area (km2)	800	

Environmental protection technologies introduced to the Lake Erhai basin, should be sequenced based upon their urgency and likelihood of funding. A proposed implementation sequence is shown in Table 82.

4.4 Environmental Management and Capacity Building of the Basin

Environmental management has achieved great success in the Lake Erhai Basin. However, if such success is to continue into the future, it will be essential to strengthen the environmental management organization, enhance the capabilities of environmental management institutions to address complex tasks, and provide adequate levels of funding for environmental projects in the basin. In the first instance, it will be necessary to create adequately staffed supervision and management organizations in order to extend environmental management mandates to the village level. Village-level environmental administrators would become the instruments for policy propagation and project implementation. For village-level project management to be successful, however, there is a need for adequate environmental information.

Table 82. Sequencing of project implementation.

Priority	Project
High Priority	1. provision of municipal sewerage systems
	2. total maximum pollutant loading allocation for lake quality protection
	3. optimization of water resource utilization
	4. control of in-lake pollution sources
	5. construction of the water quality monitoring system
	6. implementation of pre-treatment reservoirs
	7. protection of inflowing rivers
Medium Priority	8. implementation of wastewater processing in the pulp and paper industry
	9. construction of urban wastewater treatment plants
	10. implementation of environmental protection projects in towns and cities
	11. adoption of agricultural nonpoint source pollution controls
	12. ecological and biodiversity conservation in the watershed
Lower Priority	13. reforestation
	14. lake shoreland protection
	15. aquatic plant restoration
	16. implementation of eco-agriculture

Establishment of an environmental management information center in the Environmental Protection Bureau of the Prefecture is a necessary step toward achieving local level environmental management. This center would be responsible for the collection, processing, and dissemination of economic, social, resource, environmental, and engineering information to governmental decision-makers. While this center can be a link between governmental units, a formal coordination mechanism between the various organizations and the resource management departments will be required. To this end, it would be desirable to establish a comprehensive administrative organization for the basin. From the viewpoint of the basin as a whole, water resources regulation and utilization is a systematic engineering project requiring the coordination of many departments and regions. Thus, a comprehensive administrative organization is needed to ensure proper consideration of water resources exploitation, distribution, and regulation concerns; to solve water use conflicts between different departments; and, to create and maintain a licensing system for water use in the basin. At present, these functions are performed by a special committee set up under the Environmental Protection Committee of the Prefecture.

In addition to organizational issues, there also is a need to develop, implement and strengthen environmental management policies to regulate the industrial structure of the basin. Priority consideration is to be given to policies relating to the development of tourism and supporting service trades. This will require accelerated construction of transportation and communications infrastructure. Consideration also is to be given to policies relating to the development of tobacco production and food processing industries that use farm products as raw materials. Further, adoption of policies relating to the development of environmentally-friendly chemical fiber production, hide processing, and textile production technologies is required to minimize the generation of industrial pollutants. These same technologies will support policies favoring development of energy-saving products and production methods.

While the relocation of industries is proposed to minimize impacts upon Lake Erhai and the Xi'er River, policies are urgently needed to properly control new pollution sources resulting from such relocations. Currently, it is forbidden to construct projects that cause serious pollution and damage ecosystems. Thus, specific pollution control policies are relating to industrial enterprises generating large quantities of wastewater in the industrial areas of the Xi'er River and Heihui River valleys. Mechanisms for implementing such policies include (1) creation of a pollution discharge licensing system, (2) creation of a total pollutant discharge quantity control program, and (3) establishment of a system of water rates that recognizes the value of water resources and encourages water savings in agriculture and industry.

The development of technically sound and publicly supported environmental protection policies requires clearly identified administrative agencies with discrete responsibilities. Such agencies collectively should have comprehensive authority for the management of Lake Erhai, and be supported scientific and technology consultants. These professionals would be tasked with providing regular and timely reports, technical advice, and other environmental information to government in implementing investment and lake protection projects in the Lake Erhai basin. The agencies also should amplify and enforce the regulatory system, participate in public awareness and informational programming, and conduct pertinent research to protect and enhance the water resources of the Lake Erhai basin. In particular, the agencies should make and implement regulations for Dali-Cangshan-Erhai Natural Reserve, revise the Dali Bai Nationality Autonomous Prefecture Erhai Lake Administrative Regulation, and enforce related laws and regulations that prohibit destruction or degradation of the terrestrial ecology and water environment in the Natural Reserve. Effective results can be achieved through the step by step implementation of cohesive and coherent environmental policies.

As has been noted, effective agencies are not only supported by an appropriate policy framework, but also by environmental monitoring and scientific research. Consequently it is necessary to upgrade the environmental monitoring network and instrumentation within the basin. In this respect, there is a need for awareness of the opportunities provided international technical cooperation. A further outcome of such international cooperation is the strengthening of environmental training and environmental management staff capabilities. Staff trained in this manner can share their knowledge and experience with local staff through seminars regularly held in Kunming and Beijing, and encourage colleagues to pursue higher education so as to increase their knowledge and skill levels. Staffing needs identified during this planning program include senior staff capable of providing leadership in the county and municipal level environmental protection departments, environmental management and monitoring staff in municipal scientific research departments, and environmental management and monitoring staff in industrial enterprises and counties. Senior staff should facilitate participation in international or domestic seminars on environmental management, that should be held annually or biannually.

All staff should have higher educational qualifications. Staff training should be an important component of environment education in the basin.

It should also be noted that trained staff require appropriate facilities in which to apply their knowledge and skills. Such facilities must adequate transportation facilities, especially monitoring vehicles, and reliable communications facilities. The need for an environmental management information system as a support tool for environmental professionals has been noted. However, to gain maximum benefit from such a system, environmental professionals will require access to computer work stations, equipped with a personal computer, color printer, and relevant software. There is also a need for appropriate analytical instruments and water quality monitoring system components, including servers, fiber optic cable linkages, computer terminals, software, and other equipment. While these facilities assist in the acquisition and storage of information, it is equally important that the facilities be used for information processing and dissemination. In this regard, a public information element is a critical element in the identification, implementation, and supervision of plans and policies. The participation of the public will alter the pure governmental behavior to the whole people's consciousness and thus accelerate implementation of the programs and policies that will benefit the entire Lake Erhai and Xi'er River region.

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