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Experience and Lessons Learned Brief for Lake Dianchi

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Introduction

Lake Dianchi, the sixth largest freshwater lakes in China and the largest lake in Yunnan Province, is the cradle for the evolution and development of the city of Kunming, the capital of the Province. Belonging to Jinsha (the upper stream of Yangtze) River system, the Lake is a tectonic lake formed by fault. It is bow-shaped shallow lake, 40 km long and 12.5 wide with average depth of 5.4m, water surface area of about 309 km2 and total volume of 1.56 billion m3, when water level reaches to 1887.4 m. The Lake was divided by a natural dyke (now an artificial barrier) into two parts: the Inner Lake (called Caohai) covering 3.3% of the entire Lake's surface and the Outer Lake (called Waihai) covering 96.7% of the entire Lake's surface area. The Lake basin hosts about 2.2 million populations. Lake Dianchi is important for the population of the region, because it has multiple functions of water supply, climate regulation, flood regulation, water storage, water purification, aquaculture, tourism, shipping and power generation, and bio-diversity conservation as well.

Lake Dianchi is an important drinking water resource for the city of Kunming, the capital and the most densely populated city of Yunnan Province. It also provides water supply for industrial and agricultural uses in the region.
Due to its regulation, the micro climate of the lake region is very pleasant, warm in winter and cool in summer, described as "flowers of various colors do not wither in any season and the temperature is pleasant like spring all the year round".
Precipitation is the only sources of water in the Basin, available water resources is limited. The sources of the runoff of the rivers in the area are precipitation. As the rainfall is unevenly distributed in the year, so is that of surface runoff. Rainy season provides 81% of the total annual water resources and the rainfall during July, August and September takes up 60% of the annual total, of which August alone contributes 25%, while the driest month April has only 1.2% of the annual total rainfall. The extreme value ratio of the runoff of natural rivers in the drainage area of Lake Dianchi ranges from 3.87 to 5.14, with a variation coefficient of 0.44 to 0.45. This shows the interannual variance of water resources is not remarkable.
The area has a warm climate and sufficient rainfall, suitable for the growth of various terrestrial and aquatic organisms, thus it is of significant in bio-diversity conservation.
Fishery used to have the principal position in the development of aquatic organism resources of Lake Dianchi.
Lake Dianchi is like a bright pearl in green mountains and around the lake are 11 tourist attractions and scenic resorts of unique landscape. Lake Dianchi region now become a large tourist region which combines scenes of mountains and water, parks, forests, spectacular rocks, caves and artificial amusement parks, in which people can enjoy swimming, navigation, fishing, sight seeing and human studies of ancient Chinese culture.

As Kunming City was developed, prospered and extended along the north end of Lake Dianchi. The Lake is also important in maintaining the ecological balance of Kunming City. There would be no Kunming without Lake Dianchi.

Background

Biophysical Features

Biophysical, hydro-meteorological and geo-physical features

Lake Dianchi Basin is situated in the central part of the Yunnan-Guizhou Plateau, along the watershed of the three water systems of the Yangtze River, the Pearl River and the Red River, at 24º29′ to 25º28′N and 102º29′ to 103º01′E. To its west stands the Hengduan Mountains, to its east lies the East Yunnan Plateau and to its north are the Wumeng Mountain and the Liangwang Mountain. The landform gradually declines from the north to the south, where stands hills, subsided plains and water body of the Lake, with ratio of 7:2:1 respectively. The City of Kunming is located at its north end and upper stream in the catchment. The elevation of the City ranges between 1900m to 2550 m. The whole area is of typical natural plateau landscape.

The land in the drainage area of Lake Dianchi is mainly of mountains, terraces and dammed river valleys. The total area of the drainage area is 2920km2 and the three types of land (mountain, mesa and flat) respectively take up 49.36%, 25.48% and 13.62%, while Lake Dianchi water surface area takes up 10.22% and the City of Kunming and land of other usage take up 1.32%.

The area sits on the Kunming platform fold of the west section of the East Yunnan platform fold of the Changjiang peneplatform, between the well-known NS-aligned Xiajiang River fault and Pudu River fault.

The area turned into a plateau in the early Neozoic era and developed into a peneplain in the Mesocene epoch, when red weathering crust developed on the surface. In the late Pliocene epoch, violent faulting and frequent rising and sinking took place in the area and the peneplain disintegrated to form parallel NS-aligned fault valleys and massive swells, entering the process of plateau lake basin formation. Differential faulting intensified in the early and middle Pleistocene epoch, when the northern part of the basin rose and the southern part relatively sank, causing the surface of the lake to recede. The whole landform entered the period of lake and river development and the plane of denudation formed. The lake continued to recede to the south in the late Pleistocene epoch when the riverbeds extended and the whole area entered the period of river valley development. The northern part of the original lake turned into pluvial and alluvial plains. Terraces of Grade I to Grade IV came into shape. Landform within the basin varied to become forms of solution, erosion, denudation and accumulation at different parts with different tectonic structure, stone property and geologic agents.

There are more than 20 major rivers flowing into Lake Dianchi from directions of east, south and north, with total length of about 359 km. Of the inflow rivers, Panlong River, connecting upstream Songhuaba Reservoir at the north flowing through Kunming City to south and then into the lake downstream is the longest one with length of 106 km and river catchment area of 850 km^2. The rivers flow through farmlands, towns, villages and phosphate mines, bringing with their water rich nutrients like N, P and so on (see table 1 below). The lake water flows out of the lake through the Haikou River, the only natural outlet at southwest of the Lake, then flows northwards into the Tanglang River, the Pudu River and finally into the Jingsha River, the upstream of Yangtze River.

See Table 1. Volume of surface runoff from the inflowing rivers.

Environmental and natural resources features and values of the lake

Climate

The drainage area of Lake Dianchi belongs to the wet monsoon climatic belt of the northern sub-tropic zone, mainly controlled alternately by the southwest monsoon and sub-tropic continental air mass. The annual temperature accumulation > 10ºC is 4200 to 4500ºC, with an average annual air temperature of 14.7ºC. The average annual rainfall over the years is 797 to 1007mm, annual evaporation 1870 to 2120mm, annual sunshine duration 2018 to 2470h, annual sunshine rate 47% to 56%, relative humidity 73% to 74%. The prevailing wind in the area is southwest wind, with an average wind speed of 2.2 to 3.0m/s. There are 227 frost-free days in a year. The climate of the area is typically of that of the monsoon region of low latitude and high altitude. There is no chilliness in winter nor sultry summer and all the four seasons are like spring. There is distinct differences between dry seasons (winter and spring) and wet seasons (often in summer). The micro- climate of the lake region is very pleasant, warm in winter and cool in summer, described as "flowers of various colors do not wither in any season and the temperature is pleasant like spring all the year round".

Soil resources

Attributive to the topography, the sub-tropic monsoon climate and local biological conditions, soil in the area is complicated. There distributed 7 types of soil: red soil, purple soil, paddy soil, brown earth, yellow brown earth, alluvial soil and bog soil, of which red soil, paddy soil and purple soil have the widest distribution. The natural soil of the hills is mountain reds soils and purples soil, at places with higher elevation are red brown soil and brown soil and the plains and terraces are mainly of cultivated soil.

Water resources

The available water resources of the catchment are not only scarce but vary widely from 242 million m^3/year (dry year) to over 900 million m3/year. Water supply, for domestic, industrial and agricultural uses, depends heavily on reservoir storage. The most important reservoir is Songhuaba reservoir, from which Kunming City water supply is abstracted. Lake Dianchi is the second most important reservoir and provides water supply for domestic (in the dry years), and industrial and agricultural uses. However, the Lake receives sewage, industrial effluents, irrigation return flows and storm run-off for repeated re-use and the quality has deteriorated well below Grade III, the minimum standard for potable water supply.

See Figure 1. Average Annual Water Balance of Lake Dianchi.

In the average (particularly, in the dry) years, water supply cannot meet the demand. Water balance in the Basin has to heavily depend on the irrigation return flows, re-use of domestic sewage.

Vegetation resources

The area has a warm climate and sufficient rainfall, suitable for the growth of various plants. Forests occupy a total area of 1070km^2, taking up 36.68% of the total area. The natural vegetation is dominated by broad-leaved evergreen forests, and the secondary vegetation is dominated by burma pine and china armand pine. Forest coverage in the basin is 48.9%.

Artificial farmland vegetation includes rotation of rice-rape, rice-wheat, corn-wheat, corn and taro-wheat, corn and green manure, crop-wheat, usually of two crops a year. Since mid 1990s, rice field has been increasingly converted to more profitable cut flowers and vegetable crops.

Aquatic Resources

In 1950s the large coverage of macrophytes provided sound rich foodstuff and good habitat for fishes. Fisheries biologists identified 24 indigenous fish species as having been present in the lake originally, 10 of them being endemic to Lake Dianchi. In addition, a further 31 exotic species have been stocked into the lake since thee late 1950s, making a total of 51 fish species by the late 1950s early 1960s. However, competition for food and living space, along with increasing fishing effort and escalating pollution of inflowing river waters and development of Dianchi Basin, is reported to have resulted in the extinction of many of the endemic and indigenous species. Contrary to the decline in fish biodiversity fish catches and stocks in Lake Dianchi were generally on the decline. There were 6 commercially important fish, catches having declined from 3500 tone in 1984 and only 200 tons in 1994. Catches of molluscs have also fallen over the decade, from more than 1000 tons per year in 1984 to 300 tons in 1994.

Before later 1990s, there were about 2 ha of floating, anchored net cages on the lake in which intensively reared and artificially fed carp yield up to 60 tons of fish per mu or about 1800 tons of fish per year. In addition, there are a further 3.5 ha of semi-intensive fenced caged/enclosures, some of them being located along the western side of the Caohai, which were reported to yield 250 tone of fish per year in total. The caged or semi caged fish activities have been eliminated since mid 1990s, because the application of artificial foodstuff increased nutrients load into the lake water and are unfavorable to control eutrophication of the Lake.

Mineral resources

Within the Lake Basin, there are 14 kinds of mineral ore with prospected reserves in 41 localities, of which phosphate ranks first, with a total reserve of 1.477 billion tons, and 698 million tons out of the total reserve has been prospected at six localities, mostly of high grade and easy to extract. There are also many kinds of non-metal ore with considerable reserves.

Tourist resources

Lake Dianchi is like a bright pearl in green mountains. There are 11 tourist attractions and scenic resorts of unique landscape around the Lake. Lake Dianchi region has now become a large tourist region which combines scenes of mountains and water, parks, forests, spectacular rocks, caves and artificial amusement parks, in which people can enjoy swimming, navigation, fishing, sight seeing and humane studies of ancient Chinese culture. To the north of Lake Dianchi are the Grand View Park, the Haigeng Holidays Village; on the steep mountain peaks to the south of the lake is the Xishan forest Park and to the south of the lake are the provincial and city workers' sanatoriums. The town of Kunyang is the hometown of great Chinese navigator Zheng He. Not far from Lake Dianchi are the Jingdian (golden temple) scenic region, the Heilongtan (black dragon pool) scenic region, which is famous for its Pearl Spring, plum blossom of the Tang Dynasty, cypress of the Song Dynasty and tea of the Ming Dynasty, the Kunming Botanical Garden, the Banboo Temple Park, which is famous for the clay statues of the 500 arhats of the Qing Dynasty and the Hot Spring, which is known as the "Number One Bath in the World" and the Caoxi Temple scenic region, in which are well reserved architecture of the Ming Dynasty.

Political and Socio-economic Features

2.2.1 Jurisdictional features

Located at the north end of Kunming City, Lake Dianchi Basin is under jurisdiction of Kunming Municipality, Yunnan Province, China. In the 2920 km^2 catchment area, there are 4 urban districts and 38 towns/townships with a total registered population of 2.2 million. The population in the area is highly urbanized with a density of 750/km^2 and the density in the urban part is 23600/km^2, 34 times that of the area's average.

2.2.2 The political significance

Kunming is the capital of Yunnan Province, a province of many ethnic groups in southwest China. Yunnan Province is bordered to the south and west by Vietnam, Laos and Myanmar. Kunming, the provincial capital and major industrial center is by far the largest city and dominates the economy of the Province (population 3.5 million and the most of the population are non-ethnic groups), and a gateway towards neighboring countries. In addition, Kunming often hosts dialogs between the nations of Great Mekong Sub-region and ASEAN Meetings and hosts Kunming International Commodities Fair once a year. Dianchi catchment is the area where residents density is highest, human beings activity is strongest and economy are the most developed compared with other places in Yunnan Province.

As a center for economic development and a gateway towards neighboring countries, To follow the whole Chinese Nation's drive to build a well-off society in an all-round way, Kunming is under its economic restructuring and further urban expending while trying to avoid high energy consuming and highly polluting projects. Meanwhile, tourism is encouraged as a precursor for other service industries and accelerates the formation of a more integrated socialist market economy. This initiative will greatly depends on the environment conditions and water resources available in Kunming, which in turn depends on Lake Dianchi, the foundation for maintaining Kunming's ecological balance.

2.2.3 The past social and economic development history

The economy of Kunming plays an important part in the economy of the whole province. Its agricultural output value and industrial output value account respectively for 32.05% and 44.35% of the province's total. And the agricultural output value and industrial output value of the Lake Dianchi catchment, which occupies only 18.7% of the total area of the city, accounting respectively for 79.8% and 82.2% of the city's total. And the output value of large and medium sized enterprises of the area accounts for 81.4% of the city's total.

See Table 2. Economic Output of Kunming City and Yunnan Province

(1) Industry

The industrial output value of Kunming City takes up 96% of the city's total output value of industry and agriculture. The city has now a fairly complete industrial system comprising industries of machine building, metallurgy, textile, food processing, chemicals and building material, whose technical equipment has been improved continuously. Now Kunming has established its position as one of the production bases for precision machine tools, optical instrument, phosphate chemical products, natural condiment, brand cigarettes and nonferrous metal processing in China. The industry of machine building has earned the most foreign exchange in Kunming, with many products meeting advanced international standard. The electrolytic copper and electrolytic aluminum produced by Kunming Smelter and Yunnan Smelter not only rank the second in output in the whole country but are of the best quality. Products of phosphate industry of the city are exported to many countries in Southeast Asia.

The total industrial area in Kunming City and its suburbs reaches 69km2, with 168 major industrial enterprises and mines and around a dozen newly built inhabitant quarters. The main rivers receiving pollution discharge from the city include the Daqing River, the Chuanfang River, the Yunliang River, the Xinhe River, the Panlong River and the Daguan River. Lake Dianchi daily receives 416000t of pollutants.

(2) Agriculture

The rural areas under the jurisdiction of Kunming Municipality have developed agriculture for many crops, such as grain, oil-bearing crops, tobacco, vegetables and fruits. The whole drainage area has 11.24 million ha of farmland and fruit orchards. Now the area's agricultural structure is turning to one of comprehensive development of diversified management and township-run enterprises have become the new mainstay of the rural economy.

Data of investigations show that in normal years, the TN and TP brought into Lake Dianchi by non-point sources--farmland runoff account respectively for 40% and 53% of the total amount entering the lake. In high water years, the amount of TP brought into the lake through land surface runoff accounts for about 50% of the total.

Biophysical Environment

Past and Current Conditions

Around 3 million years ago when Lake Dianchi formed was large (around 1000 km2, and deep more than 50 m) lake. Before the rapid urbanization, the improvement of people’s living standard, rapid growth of population and modern industrial & farming activity, which are the major causes of its deterioration, it used to be a natural, clean freshwater lake with high biodiversity. In early 1950s, Lake Dianchi was an oligo- to mesotrophic clear water lake, known as “The Pearl of the Plateau”. Bottom sediments were largely covered by macrophytes, Charophytes being dominant. The fish community consisted largely of indigenous species, while phytoplankton was dominated by green algae and diatoms. Some bluegreen algae were also present. Under these conditions of low to moderate productivity, zooplankton numbers of about 1,200/L apparently succeeded in suppressing excessive alga growth. Shores were sloping, resulting in different ecological zones of littoral macrophyte communities, contributing to a large biodiversity. The Lake biological communities were characterized by high biodiversity but low to moderate numbers of individuals in each species.

During 1960s and 1970s, important changes took place in the ecology of the lake. Increased human activity led to domestic and industrial pollution, land abuse, erosion processes, land reclamation at shores, over catching of fish and introduction of exotic edible fish species. As a result, the lake ecosystem changed into a turbid water body. By the early 1980s, eutrophic indicator species such as Ceratophyllum demersum and Potamogeton pectinatus became dominant over the Charophytes.

Now Lake Dianchi is facing with 3 major environmental problems:

Water scarity, particularly in terms of quality outstanding imbalance between supply and demand. Annual per capita water resource in Lake Dianchi Basin decreased from 900 m^3 in 1950s to less than 300 m^3 now. In the basin, the water resources gap between demand and supply is about 100 million m^3 in normal year and 200 million m^3 in dry year. The gap has to be balance by storm runoff, reuse of wastewater and returned water from farmland. Now demand for water is increasing due to expanding size of city and fast social and economic development. Now the rate of development and utilization of water resource hits 60% in the basin, exceeding the international rational limit of 40% (the limit causing destruction of ecological environment).

Serious water pollution, eutrophication and increasing deterioration of water quality. The water body of Lake Dianchi is classified as Class II in 1960s and Class III in 1970s. Water quality pollution commenced in the later stage of 1970s, especially after entering 1990s, the speed of pollution accelerated obviously. Now the water quality in Lake Dianchi is classified as less than Class V. Lake Dianchi received around 240 million m^3 of wastewater in 2000, including industrial wastewater of about 50 million m^3 and domestic wastewater of about 190 million m^3, which are deemed as point sources. It also receives non-point sources from rural area, with increased proportion due to the control of point sources effort made in these years.

See Figure 2. Pollution Loads from Various Sources

Degradation of ecological environment, soil erosion, lake siltation and decrease of storage capacity. Human induced development activity weakened ecological function, environmental capacity of the Lake. Lake Dianchi is now too weak to withstand pollution loads from urban domestic sewage, industrial wastewater, agricultural runoff. In the basin, eroded area is up to 964.96 km^2, accounting for 36.8% of total area of basin. Annual loss of erosion materials is 0.377 million tons on the average. Forest cover rate decreased from 37.5% in 1951 to 28.6% in 1996. The soil erosion on mountains facing lake directly results in sedimentation and reducing of water area in the lake. Nitrogen and phosphorus carried by sediment into lake cause water quality pollution in the lake. Since 1950s, total sedimentation in the lake is more than 50 million m^3, and the storage capacity decreased by 210 million m^3.

Present state of eutrophication

The water of Lake Dianchi looks dark yellow green and yellow green, with a transparency (SD) of less than 1.0m and that of the inner lake less than 0.5m. The concentrations of TN and TP are respectively 1 to 3 mg/L and 0.08 to 1.7 mg/L and that of Chlorophyll a being 5 to 25 mg/m^3 (as high as 30 to 50 mg/m^3 in the inner lake). The values of parameters are all above the standard for eutrophication and part of the water body shows the features of extreme eutrophication (Table 3).

See Table 3. Features of Lake Dianchi's Eutrophication

Assessment on the parameters at the sampling points finds the inner lake is already hyper-eutrophic and 39% (1.4% of the whole lake) being extremely eutrophic and the outer lake is eutrophic, with a little part hypereutrophic. 14.7% of the whole of Lake Dianchi is hypereutrophic and 83.9% eutrophic. As a whole, the lake is eutrophic.

See Figure 3. The Spatial Extent of Eutrophic Conditions in Lake Dianchi
See Table 4. Concentrations of major parameters of Lake Dianchi and their assessment
See Table 5. Eutrophication of Lake Dianchi

Composition of species

Surveys on species diversity indicate that of all taxonomic groups (listed in table below) has declined over last 30-40 years. The decline is most significant with regards to the endemic fish species since this represents an irreversible loss of genetic material. Non-endemic indigenous fish species have declined by 50%. Fishery used to have the principal position in the development of aquatic organism resources of Lake Dianchi.

See Table 6. Total Species Numbers of Major Taxa in Lake Dianchi from 1950s to 1996.

Change of number and biomass

The composition of species, number and biomass of zoobenthons differs greatly between the inner lake and the outer lake. Only 5 species of zoobenthons have been found in the inner lake, with the number of 80 to 2974 ind./m^2 and the biomass of 6.29 to 68.2g/m^2, while there are 11 species in the outer lake, with the number of 656 to 13136 ind./m^2 and the biomass of 20.25 to 171.55g/m^2.

Community structure of aquatic vascular bundle plants in Lake Dianchi and their succession

There were 4 species of 28 families of aquatic vascular bundle plants in Lake Dianchi in the 50's, 30 species of 22 families in the 70's, but only 20 species of 12 families were found by the end of the 80's (1988-1989), of which 12 species were submerged plants, 3 fluitantes and 5 emergent plants. Dominant species of the whole lake was Myriophyllum spicatum.

The inner lake was over 2m deep in the 50's, where the water was clean and there was rich water grass on the bottom of the lake and the vegetation of the outer lake had a high coverage and with many types of communities. Eutrophication of the lake quickened in the 60's and the water quality deteriorated and the SD of the water body greatly declined. Most of the water body over 1 to 2m deep, especially in the inner lake, no longer contained submerged plants at all.

The region to the east shore of Lake Dianchi has a high density of population, where intensive productive activities have brought much damage to the lakeside vegetation. There are still some plants in the parts along the southern and western shore. The water bodies near Luziwan, the Dahewei River and Kunyang Farm have a fairly high vegetation coverage and many species of aquatic plants.

By the end of the 80's, the area of aquatic vascular bundle plants in the outer lake was 366ha, with a biomass of 15368.5t (fresh weight, or 941t of dry weight); that of the inner lake was 250ha, with a biomass of 12500t (fresh weight, or 656.25t of dry weight). The total area of high aquatic plants in Lake Dianchi was 616ha, amounting to 2.05% of the total area of the lake. See Fig. 3 and Fig.4 for the change of aquatic plant distribution from the 50' to the end of the 80's.

See Figure 4. Succession of Aquatic Vegetation of Lake Dianchi in the 1950s
See Figure 5. Distribution of Aquatic Plant Communities in Lake Dianchi in the 1980s

Aquatic plant community structure and succession

According to relevant data, aquatic vascular bundle plants in Lake Dianchi in the 1950s could be divided into 14 communities, including the unique community and some associated communities are on the verge of extinction. Now there are 11 aquatic vascular bundle plant communities of different size in Lake Dianchi. The species of the communities have undergone remarkable changes as compared with those in the 1960s and the 1970s. It was reported that the communities of Ceratophyllum demersum and Potamogeton pectinatus had disappeared in the 1970s, but a few scattered communities have been found again.

The succession of aquatic vascular bundle plants in Lake Dianchi shows a regularity and the whole communities have complete succession systems. But the natural process was greatly damaged by artificial factors. Eutrophication of the lake quickened in the 1960s and the water quality deteriorated year by year, when submerged plants began to decline and died in great numbers in the 1970s and not much was left in the early 1980s. The investigation of 1988-1989 found they had disappeared while fluitantes had developed and have become dominant species to spread to the whole of the inner lake.

The succession order of communities along the western shore of the outer lake is: Cyanpphyta; Myriophyllum spicatum community; Potamogeton pectinatus community; Azolla imbricta community; Polygonum amphibium community. The present succession order (at Huiwan) is: Valliisneria spiralis community; Najas marina community; Myriophyllum spicatum community; Azolla imbricta. The order of succession along the eastern shore of the outer lake is: Potamogeton malaianus community and P. pectinatus community; Phragmites communis community.

The change of the aquatic plant communities suggests that some sensitive plant communities have disappeared or are facing extinction as eutrophication of the water body intensifies. the area of aquatic plants has declined and moved towards shallow parts of the lake and the ranges of plant communities is also getting smaller (except that of Myriophyllum spicatum community in Lake Dianchi).

Now the water body at the west bay of Huiwan in the outer lake has a fairly great number of aquatic vascular bundle plants. It is the region where fish spawn. Investigation conducted in 1988 and 1990 found the area of the bay to be about 1km^2, existing aquatic plants there including Myriophyllum spicatum, Vallisneria gigantea, Potamogeton malaianus, P. perfoliatuo, P. maacianus, P. crispus, Azolla imbricta, Ceratophyllum demersum, Hydrilla verticillata, Najas marina and Trapa bispinosa It has a fine biodiversity. Myriophyllum spicatum communities there formed a natural barrier separating it from the outer water surface (see Fig. 5).

See Figure 6. Succession of aquatic vegetation in the outer lake of Lake Dianchi in the 1980s

Change of fish populations

The change in the ecoenvironment of the lake destroyed much of fish spawning ground in Lake Dianchi. Over catching and interactions between different species of fish also caused much change in its species composition. For example, there were 15 original species of fish in the lake in the 50's, accounting for 65.2% of the total number of species of fish. There were only 4 species of original fish left in the 80's, accounting for only 17.4%. The general trend is original species are facing extinction and species introduced in are developing into dominant ones and the structure of fish communities is getting simpler.

History of Lake Degradation

The significant deterioration in water quality of the Lake by two degrees in the last two decades has been caused by increased pollutants and nutrients load to the water body of the Lake. The current classification is worse than grade V, the lowest class of use in the Chinese classification. The high phosphorus, nitrogen levels have stimulated the growth of algae in the Lake. The algae in turn have resulted in reduced function or difficulties with operation of water treatment processes at water treatment plants. Kunming No.3 WTP was shut down in early 1990s because of this problem.

See Figure 7. Chronology of Major Changes in Lake Dianchi Basin
See Table 7. Water Quality of Lake Dianchi in 1988
See Table 8. Changes in Water Quality of Lake Dianchi, 1986-1996

Management Environment

Lake Management Programs and Process

The severe pollution of Lake Dianchi has drawn greater attention from the Central Government. Lake Dianchi was listed as one of the "targeted three rivers and three lakes in China". Since later 1970, more systematic and comprehensive studies of the Lake were carried out. It has been realized that no any single approach or project could help us to save Lake Dianchi. In a feasibility study on the comprehensive renovation of Dianchi water pollution conducted in early 1990s, an integrated approach, including legal, administration, engineering interventions with stronger funds input from Government at all levels, the enterprises, and even every beneficiaries of Lake Dianchi has to be taken to manage Lake Dianchi Basin as a whole was formulated.

See Figure 8. Integrated Approach for Water Pollution Control of Lake Dianchi

This integrated approach is a long-term, arduous, and complicated program, which takes phases to implement. It provide the base for the World Bank-financed Yunnan Environment Project, dominated by Lake Dianchi Basin Management, and are incorporated in the Five-Year Plans for Water Pollution Control of Lake Dianchi Basin further specified the program.

Reduction of Lake Stresses

Since the Government made its commitment to clean up Lake Dianchi, Lake Dianchi management were increasingly strengthened in terms of administration, enforcement of laws and regulations and more investment input. By the end of 2000, a total of 2.124 billion yuan (including part of the World Bank loan) was spent supporting the completion of 17 engineering project.

See Table 9. Completed Engineering Project by End of 2002.

Through the implementation of above project, all the industrial polluters in Lake Dianchi basin have basically complied with discharging standard; 4 sewage treatment plants with treatment capacity of 365,000 m^3/d were put into operation; the interceptor at the north bank of the Lake can intercept 300,000 m^3/d of polluted river water from urban area. Forest coverage in Lake Dianchi Basin is up to 32.9%. More than 4,000 thousand m^3 contaminated sediment was dredge up, removing 8230.45 tons of TN, 1884.54 ton of TP and 4430.72 ton of heavy mental out of the Lake.

Another 13 projects were on-going, including the World Bank loan financed project, of 4 new sewage treatment plants and their sewers, upgrading and extension the existing one sewage treatment plant, rehabilitation of central urban sewerage system, which will increase urban sewage treatment ratio, in the dry season, from 60% in 2000 to 80% in 2004.

Environmental Status

In 2000, compared with mid-1990s, COD_{Mn} in the Caohai and Waihai reduced by 22% and 28% respectively; transparency in Caohai increased from 0.34 m to 0.37 m; pollution of Arsenic and heavy metals to Caohai were effectively controlled with arsenic level improved from previous worse than grade V to better than grade III. Malodorous condition in Caohai was significantly improved. In summary, these efforts basically reversed the water quality deterioration trends Lake Dianchi.

On the basis of the effort, achievement and lessons learned, the Tenth Five-Year (2000-2005) Plan for Water Pollution Control in Lake Dianchi Basin approved by the State Council early this year, set up following framework.

See Figure 9. Framework of the Tenth 5-Year Plan.

Under this framework, 26 project with estimated cost of nearly ￥8 billion RMB (nearly 1 billion USD) was identified, aiming at reducing total pollution load to Lake Dianchi by more than 20% on the basis of that of 2000.

Enabling Environment

Political Commitment

As the City of Kunming was developed, prospered and is now expending around Lake Dianchi, the City's existence, economic development and future are much more dependant on the Lake. The Lake degradation became increasingly the key constrains for Kunming's sustainable socio-economic development. Having been aware of the importance of the Lake, The Government of Yunnan Province, after having a site working conference and consultation with scientific researchers, expert made its commitment in 1992 to take comprehensive efforts with stronger government fund input to renovate Lake Dianchi Basin environment. Central Government includes Lake Dianchi as one the "three targeted Lake" for water pollution control. The preparation of plans for water pollution control in Lake Dianchi Basin are required once in every five years and be approved by the State Council, which become the important basis for local governments and government sector agencies to take actions to control water pollution in Lake Dianchi Basin.

Institutional Framework

Increasingly more attention has been paid on the strengthening of the institutional framework since 1980's. It was not until 1988 when Dianchi Protection Ordinance was promulgated did a watershed management authority, namely Dianchi Protection Committee in Kunming Municipality established. At that time, this committee functioned as a coordinator to coordinate the Municipal authorities (such as bureaus of water resource, forestry, EPB, agriculture, planning, economy & trade, etc.) and be responsible only for the enforcement of Dianchi Protection Ordinance. In 2001, this committee was further strengthened to be the leading agency responsible for decision-making on major issues related to Lake Dianchi protection and treatment, under which, "Dianchi Administration Bureau", a executive administration body, was established. The Bureau has following major responsibilities:

Publicizing the of national laws and regulations and enforcement of Dianchi Protection Ordinance, and coordinating, inspecting urging the county/districts sectors to protect Lake Dianchi legally;

Organizing the formulation, implementation and supervision of plans, comprehensive cleaning up programs of Lake Dianchi protection and utilization;
Setting up objective responsibility for Lake Dianchi cleaning up, inspecting, urging and examining county/district sectors agencies' performance in achieving the targeted objectives;
Organizing the formulation of adjunctive management for Lake Dianchi Protection and urging the enforcement of the management;
Officiating partially administrative punishment of water resources, fishery, navigation, water environmental protection, land, plan; establishing special administrative team to enforce comprehensively relevant laws and regulations;
Officiating the inspection of the enforcement of laws and regulations related to Lake Dianchi Protection;
Being responsible for initial review of Dianchi pollution cleaning up projects and being involved in the identification of project clients and supervising the implementation of the projects;
Being involved in the review of any development projects to be located in the Lake Dianchi catchment and put forward review comments;
Being responsible for collecting, managing and utilizing Dianchi cleaning up funds;
Undertaking other works assigned by the People's Republic of China and Dianchi Protection Committee.

In addition, special management sub-agencies in counties, urban districts located within Lake Dianchi catchment are also established, who, under the unified coordination, directive and supervision of Dianchi Administration Bureau, will be responsible for the protection, management and enforcement of law and regulations in their respective administration regions.

See Figure 10. Institutional Framework

Legal Framework

There are national and local laws and regulations, which are the legal basis for Lake Dianchi Basin Management.

See Figure 11. Legal Framework.

Involvement of Stakeholders

Involvement of Industries

According to Dianchi Protection Ordinance promulgated in 1988, no any new industries which consume high water and discharge heavy pollutants is allowed to be located within the catchment of Lake Dianchi. For those old industrial polluters, they are charged with pollution levy if their effluent exceeded the discharging standard. As required by "The Approval on the 'Ninth-Five-Year Plan and the Tenth-Five-Year Program for Dianchi Basin Water Pollution Prevention and Treatment' by the State Council", Environmental protection department at Provincial and Municipal levels jointly carried out an "Zero O'clock Action" to force 253 major polluters located in the catchment of Lake Dianchi to bring their pollution into control before May 1st, 1999. In this action, 249 polluters achieved their pollution control tasks with emission/effluent complying with National Discharging Standard. Four polluters ceased operation by stopping operating or relocating. This achievement has laid a solid foundation for all industrial polluters in Kunming Municipality to comply with the National Discharging Standard in 2000. According to the statistic data, in 2000, ￥340 million were spent to control industrial pollution sources in Kunming Municipality. Out of the 298 examined industries, 296 of which passed through the examination with treatment facilities accepted. In the particular year of 2000, 483 sets of new treatment plant/facilities were installed. Compared with 1995, industrial wastewater in Kunming Municipality in 2000 reduced by 81.29 million t/a (59.4%) with reduction of COD by 29,500 t/a (79.1%); industrial waste gases emission reduced by 12.142 billion Nm3/a with reduction of soot, dust, SO2 by 25,200 t/a (67.2%), 17,000 t/a (75.0%), 25,000 t/a (32.9%) respectively, resulting significant environmental benefits. The industries, when taking actions to control discharging pollution, were provided with loan from government generated from the collection of pollution levies plus governmental special funds for environmental protection. If evidences proved that industries' action enabled them to comply with the discharging standard, they loan could became grant without payment.

Involvement of Citizens

Citizens are easy to access to Government's web site where the monthly water quality monitoring data, daily air quality monitoring date are available. Public dissemination programs and news are often shown in TV screen and radio voice and newspapers.

According to the provisions Environmental Impact Assessment Law of the People's Republic of China, public participation/consultation are encouraged. When developing the environmental assessment for plans and construction projects, public consultation are practiced.

Before making decisions that may affect local residents' daily life (for instance, charging/increasing tariff for water, wastewater, solid waste, new ideas for the city master plan), the Government will organize public hearing conference. For example, when the government decree on banning the use of phosphorus detergent, throwaways are widely circulated, non-phosphorus detergents products sold in stores or market are marked. Residents gradually voluntarily buy detergents free from phosphorus.

Environmental Protection Bureaus at provincial and municipal levels are now initiating campaign to promote "green schools" in primary and middle schools, where basin environmental knowledge, the importance of Lake Dianchi to the city of Kunming are programmed as teaching curriculum.

Involvement of NGOs

A number of academic and social associations/societies has long been involved in the consultation between Government and NGOs. Every year, when the People's Congress at Provincial, Kunming Municipal or even urban district levels held annual conferences, many bills, proposals related on Lake Dianchi were received and well answered or even become government decisions.

There are also some NGOs, (e.g. green watershed, Dianchi Research Society) actively engaged in promoting Dianchi forum, a discussion between government agencies, scientists and common citizens.

Lessons Learned and Recommended Initiatives

Lack of sustainable development strategy

Eco-environment and economic development was not properly harmonized, development were highly address while environmental protection was nearly neglected or economic growth was at the cost of environmental sacrifice in the past days. Therefore, the pollution and eutrophication of Lake Dianchi is the reflection of the conflicts between resources, ecology and socio-economic development. To solve its pollution problem fundamentally, there should be a more comprehensive mitigation measure combining the implementation of plans for city's development, land use, industrial restructuring, and relevant instrument on the basis of sustainable development strategy.

Insufficient awareness of the long-term, arduous and complicated task

Due to the weakness in such fundamental works as statistic data, monitoring program and research, the diagnosis of the environmental issues of Lake Dianchi is insufficient to lay a scientific basis for setting up realistic goals. The phased objectives set forth in the Ninth Five-Year Plan for Water Pollution Control in Lake Dianchi Basin were too ambitious to achieve. The efforts made during 1995-2000 helped to hold back the continuous deterioration tendency, but the hyper eutrophication of the water body, the ecological devastation has not yet ultimately reversed.

Insufficient awareness on the ecological fragility of Lake Dianchi

The principal socio-economic development are believed to have had the most significant impacts include:

The expansion of urban population and industry in the basin,
The reclamation of lakeside land and floodplain areas for urban and agricultural use,
Construction of the lake perimeter dykes,
the ever increasing human control and intervention in the natural water cycle,
water pollution from industrial, domestic and agricultural sources,
deforestation for fuelling steep production and problems of forestry management control and land allocation,
over-fishing of Lake Dianchi fish stocks
introduction of exotic fish, shrimp and plant species.

These adverse impacts derive mainly from the expansion of urban population in the catchment and the ever increasing human control and intervention in natural water cycle. These developments in the lake basin have drastically, and in some instances, irreversibly, altered the natural lake ecosystem. Lake Dianchi has now become more comparable to a man-made regulated reservoir than a natural lake. The losses of wetland along the shoreline due to intensified economic development activities and over reclamation of lakeside and floodplain mean to the loss of natural barrier of the lake, resulting the lake's ecology extremely fragile.

Increased pressure from the growth of population

Domestic sewage is now still the major pollution source to Lake Dianchi. The constructed urban area in Kunming occupies only 5% of the Lake Dianchi Basin area, the pollution loads from the city takes half of the total. According to the statistic date, during 1995-2000, the registered urban population of Kunming City increased at rate of 2%. Without control, this would impose stronger pressure to Lake Dianchi even if all the urban sewage were collected and treated (the level of TP for example in the treated effluent from secondary STPs 1.0 mg/l, which are much higher than 0.05 mg/l, the standard for grade III, the minimum grade for drinking water source)

Delays of some key projects construction

The construction of some key engineering projects, such as sewage treatment plants, Kunming central urban sewage rehabilitation, harness of river courses, were much delayed than initially planned, which further exacerbated the situation that pollution control pace could not cope with the pollution pace.

The impact of resources mining and processing was not highly addressed.

Although, some efforts were made in afforestation, the newly established forestlands are covered with small trees with lower shadows. The mining of resources, particularly phosphorus resources at the south end of the Lake in a top soil stripping and open casting ways, coursed serious soil erosion. The eroded soil, containing high phosphorus, flushed with runoff through inflow rivers and became non-point pollution loads into Lake Dianchi. The processing of phosphorus ore by small township & village enterprises is still out of the control of government agencies.

Insufficient scientific research

Few data are available on the ecology of Lake Dianchi. Most are biological date from the 1950s and 1988-1989, on macrophyte, plankton, fish and benthos. The spatial and temporal variation of the date is unknown, because most have been summarized only in quantity. Its is also unfortunate that adequate water quality and ecological data from the 1960s and 1970s us is lacking and consequently the historical sequence of events leading to the present poor water quality and degraded ecology of Lake Dianchi cannot be well reconstructed. This is especially regretted because this historical perspective could band been helpful to derive measures for restoration or assess the feasibility of those measures. There is a lack of information sharing among the agencies/institutes concerned. In addition, there is a lack of information sharing among the agencies/institutes concerned.

The financing mechanism and subsidies for management activities focusing on sustainable lake use

Co-financing for the cleaning up of Lake Dianchi is the most important mechanism. The sources of the funds inputted in the past and to be inputted in the future includes:

Funds allocated from China central Government,
Funds allocated from Yunnan Provincial Government,
Funds allocated from Kunming Municipal Government,
Funds from the World Bank loan/credit,
Funds from bilateral confessional loan,
Loan from the State Development Bank of China,
Loan from local commercial banks,
National treasury bonds
Yunnan Government special funds for environmental protection.
Funds raised by company/enterprises, real estate development firms
In the future, BOT, BOO, may be introduced.

In order to sustain the operation and maintenance of environmental infrastructure, and repayment of debt services incurred from the World Bank and bilateral loans, Government of Yunnan Province/Kunming Municipality, under the guidance of the Central Government, started to charge tariff for water resources, centralized water supply, wastewater, and domestic solid waste at the level that could generate revenues to cover at least operation and maintenance cost, and hopefully, even the interest and principals of loan. The utility companies are asked to make financial projections based on the audited financial statements. If the financial projections find any substantial deficit, that may threaten the financial viability, the government are reported to consider adjusting the level of tariff or take actions to reduce cost.

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Report of Pre-reservoir field experiment in Chenggongqianweiying

Projects of environmental dredging in Caohai

Pollution prevention and control techniques of drinking water source in Lake Dianchi

Report of eco-engineering in littoral zone of Lake Dianchi

Technology of macrophyte systemic restoration in Caohai

Water quality monitoring system

Caohai-Dianchi biodiversity conservation plan ore-feasibility study

Xiangcan Jin Lakes in China Research of their environment II China ocean press 1995

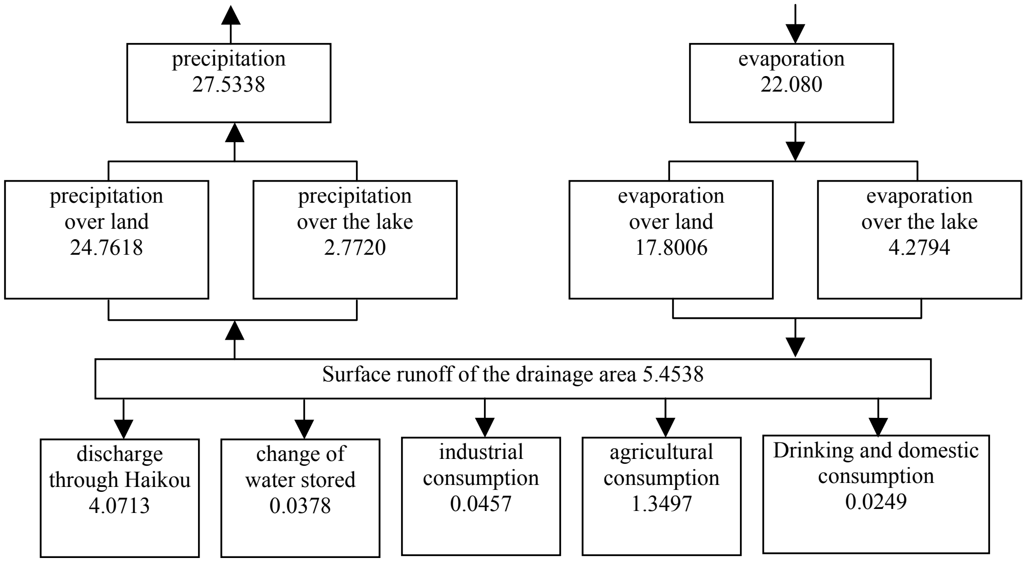

Figure 1. Average Annual Water Balance of Lake Dianchi.

Figure needs to be re-drawn.

Figure 2. Pollution Loads from Various Sources.

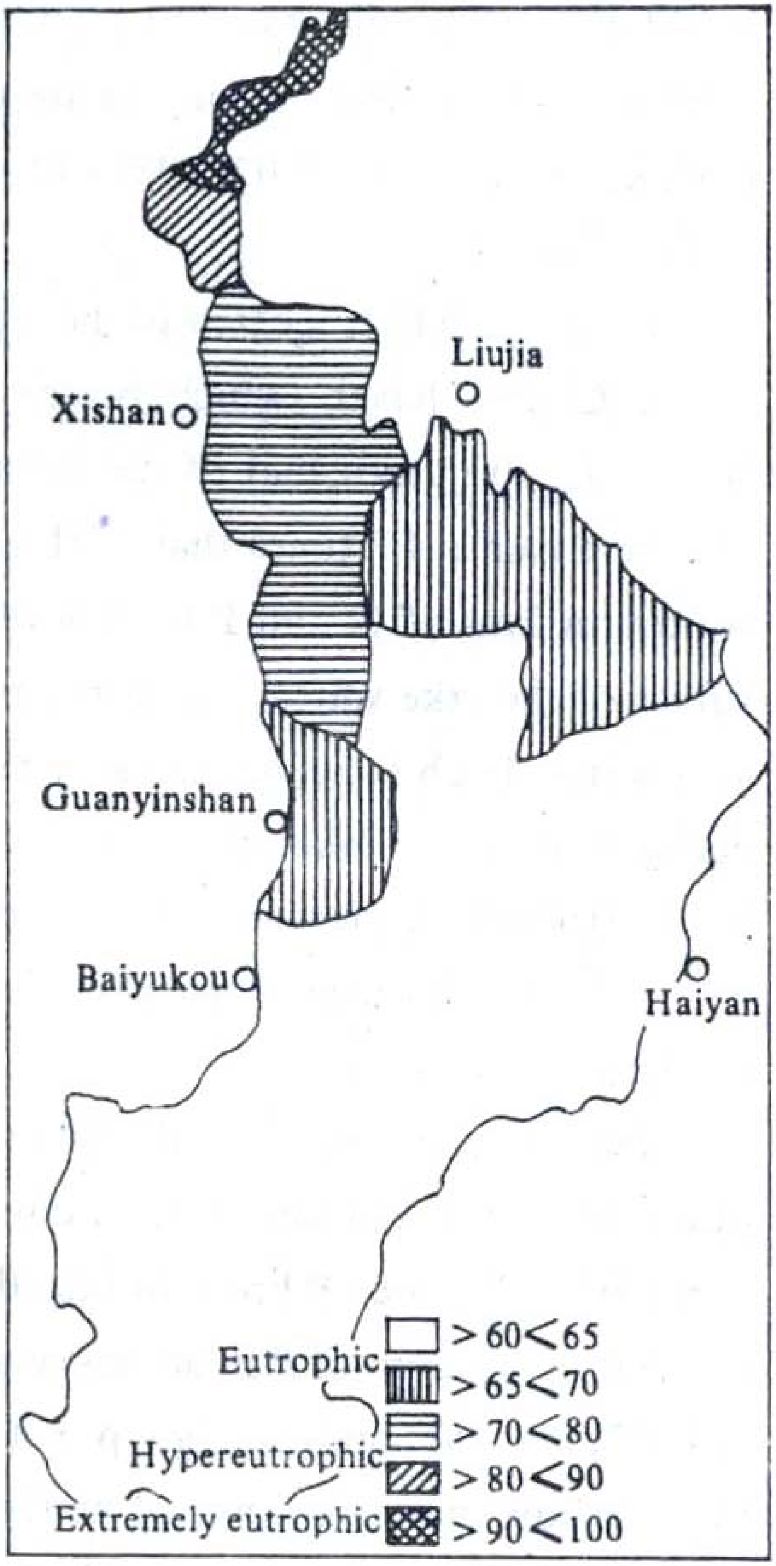

Figure 3. Features of Lake Dianchi's Eutrophication

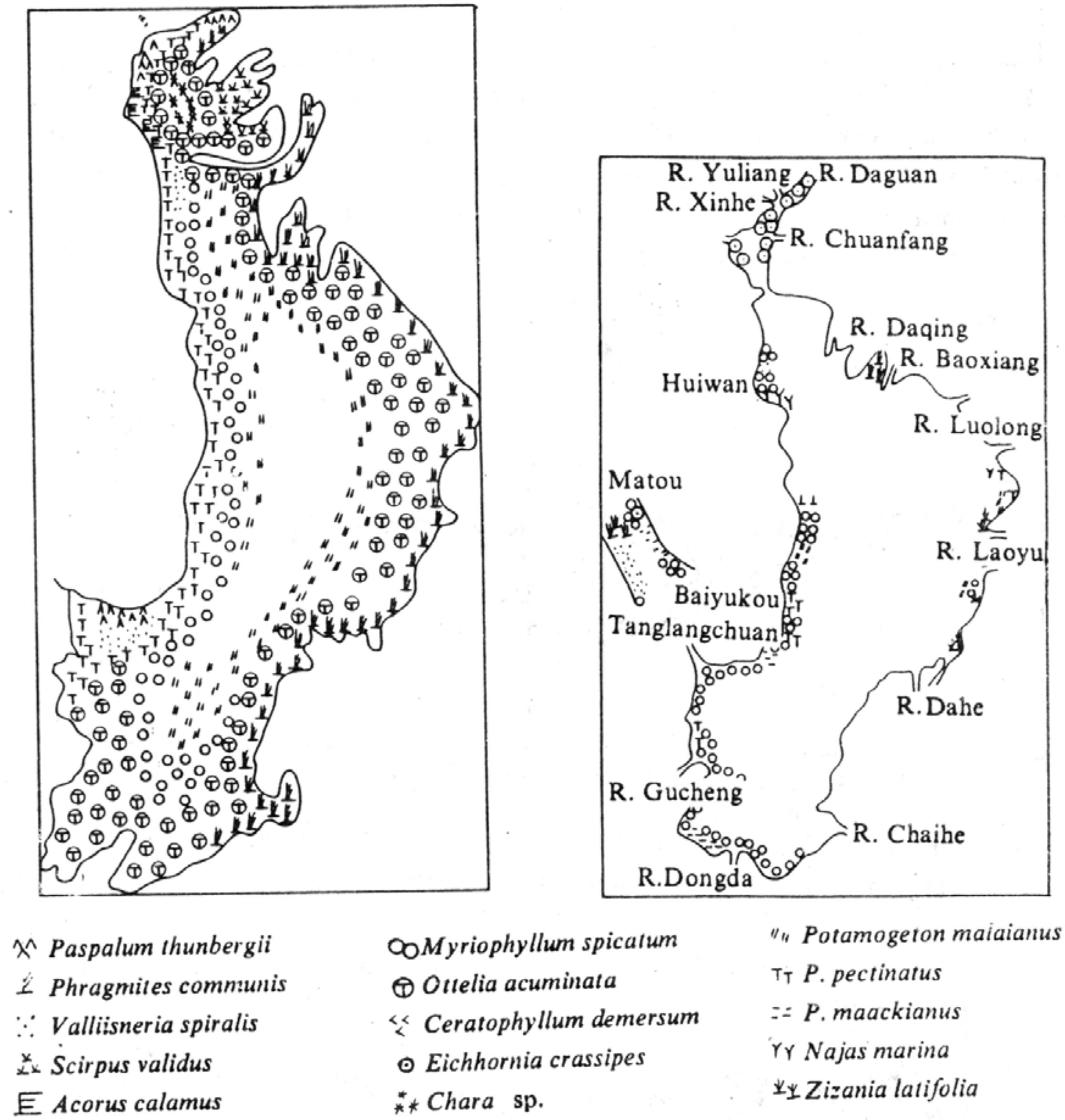

Figure 4. Succession of Aquatic Vegetation of Lake Dianchi in the 1950s
Figure 5. Distribution of Aquatic Plant Communities in Lake Dianchi in the 1980s

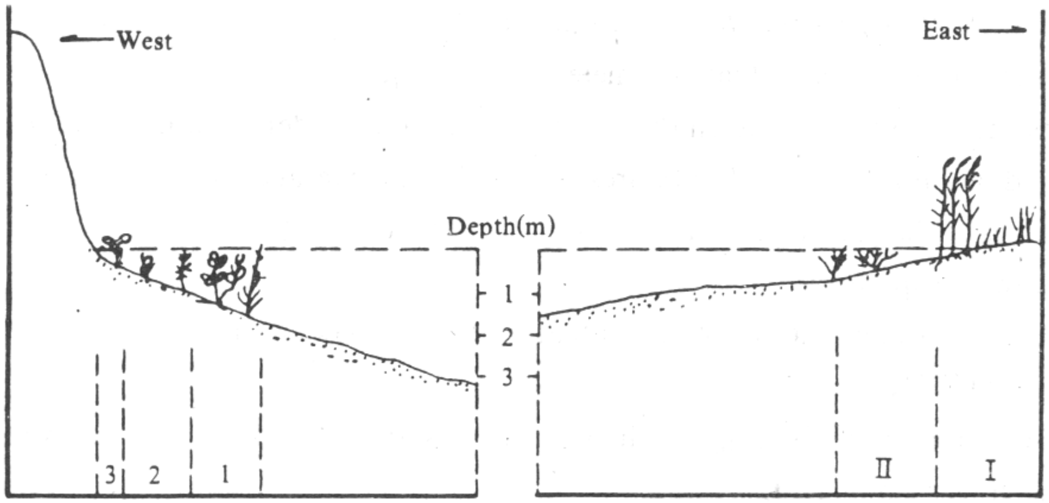

Figure 6. Succession of aquatic vegetation in the outer lake of Lake Dianchi in the 1980s

	Period of Impact				
Event	**1950s**	**1960s**	**1970s**	**1980s**	**1990s**
Dyke construction			↔	↔	
Land reclamation		↔	↔	↔	
Caohai in filling			↔	↔	
Macrophyte decline				↔	↔
Fish introductions		↔			
Loss of endemic fish			↔		
River control	↔	↔	↔	↔	↔
Reservoir construction					
Lake shore irrigation expansion		↔	↔	↔	
Deforestation & soil erosion	✱	↔	↔	✱	
Waihai water clear	↔	↔	↔	↔	
Main water quality deterioration				↔	
Caohai barrage completed					✱
Main period of biodiversity loss			↔		

Figure 7. Chronology of Major Changes in Lake Dianchi Basin.

Figure 8. Integrated Approach for Water Pollution Control of Lake Dianchi

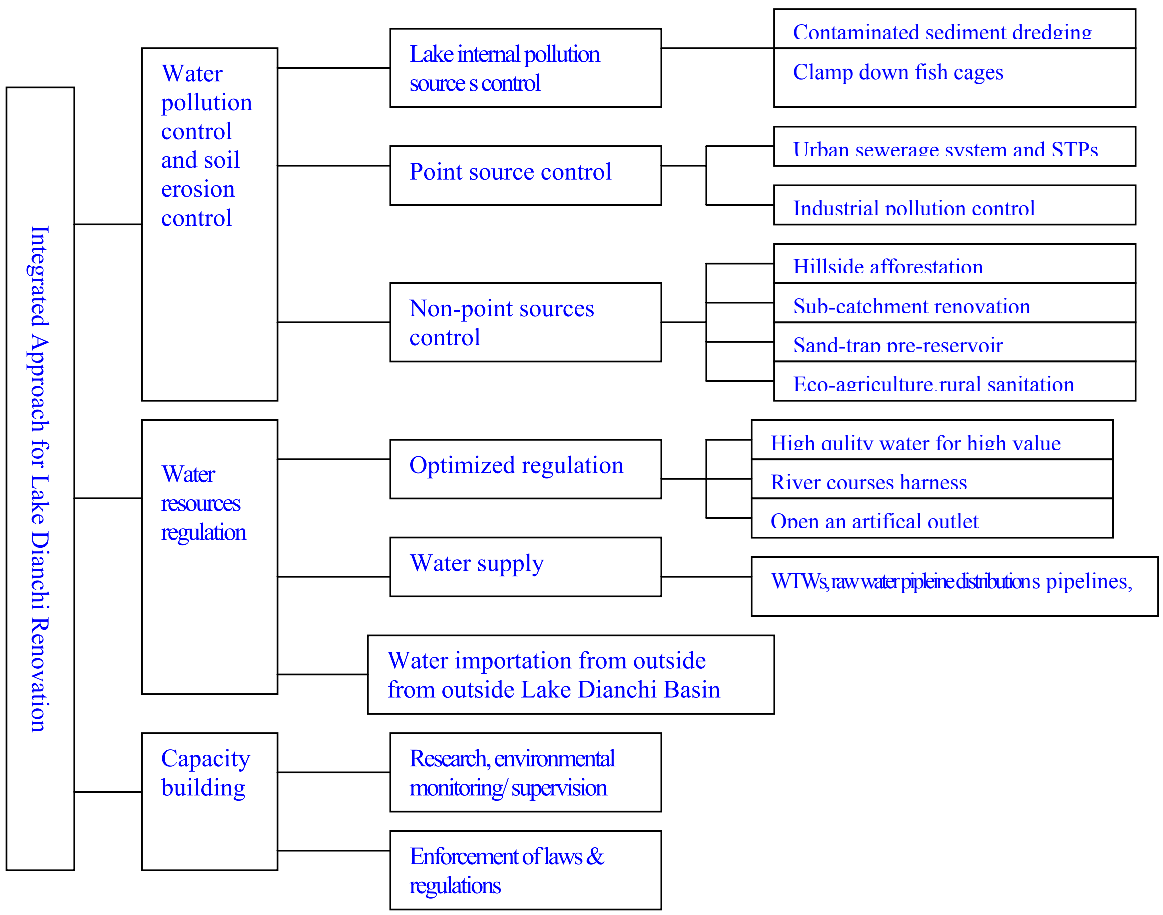

Figure 9. Framework of the Tenth 5-Year Plan.

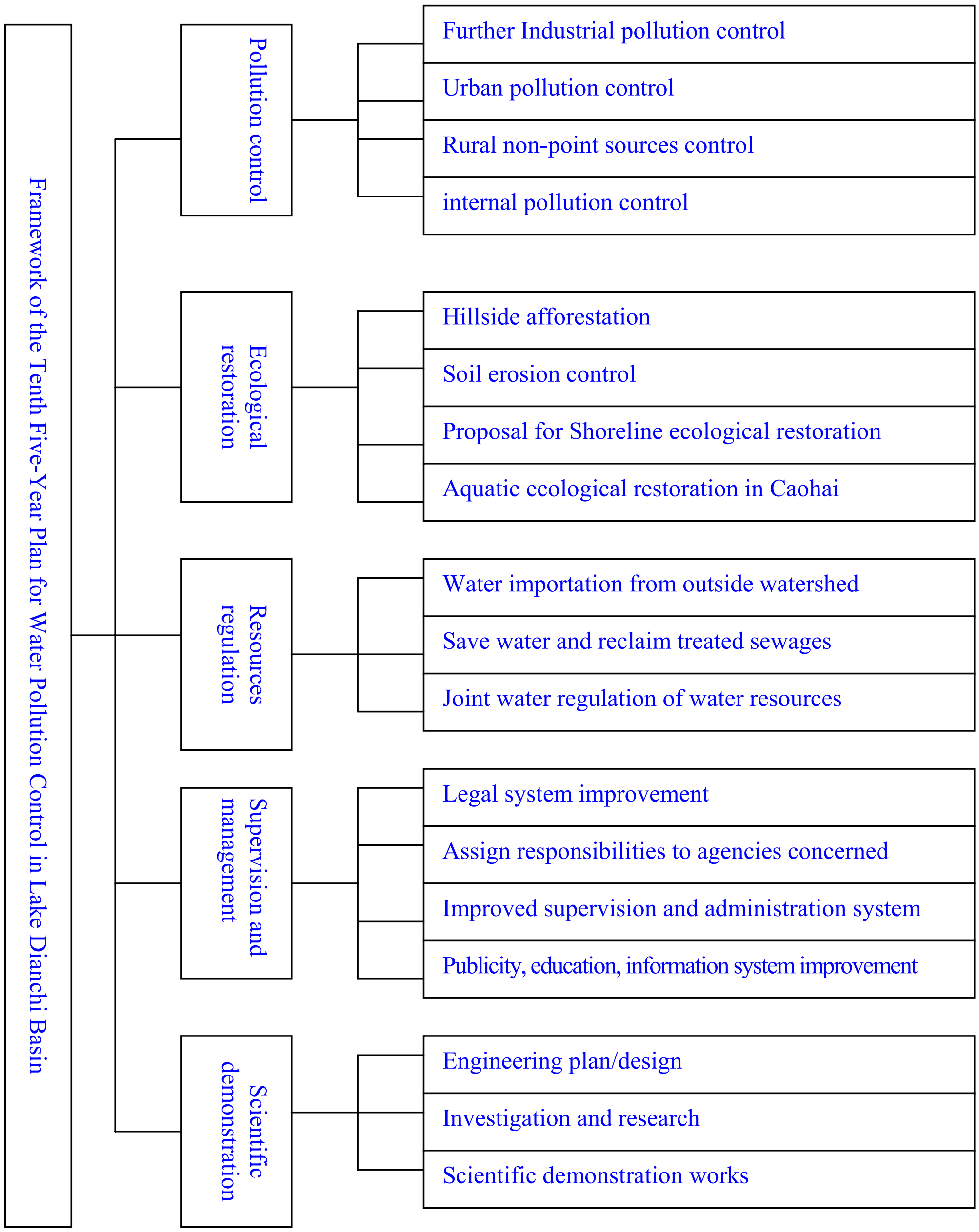

Figure 10. Institutional Framework.

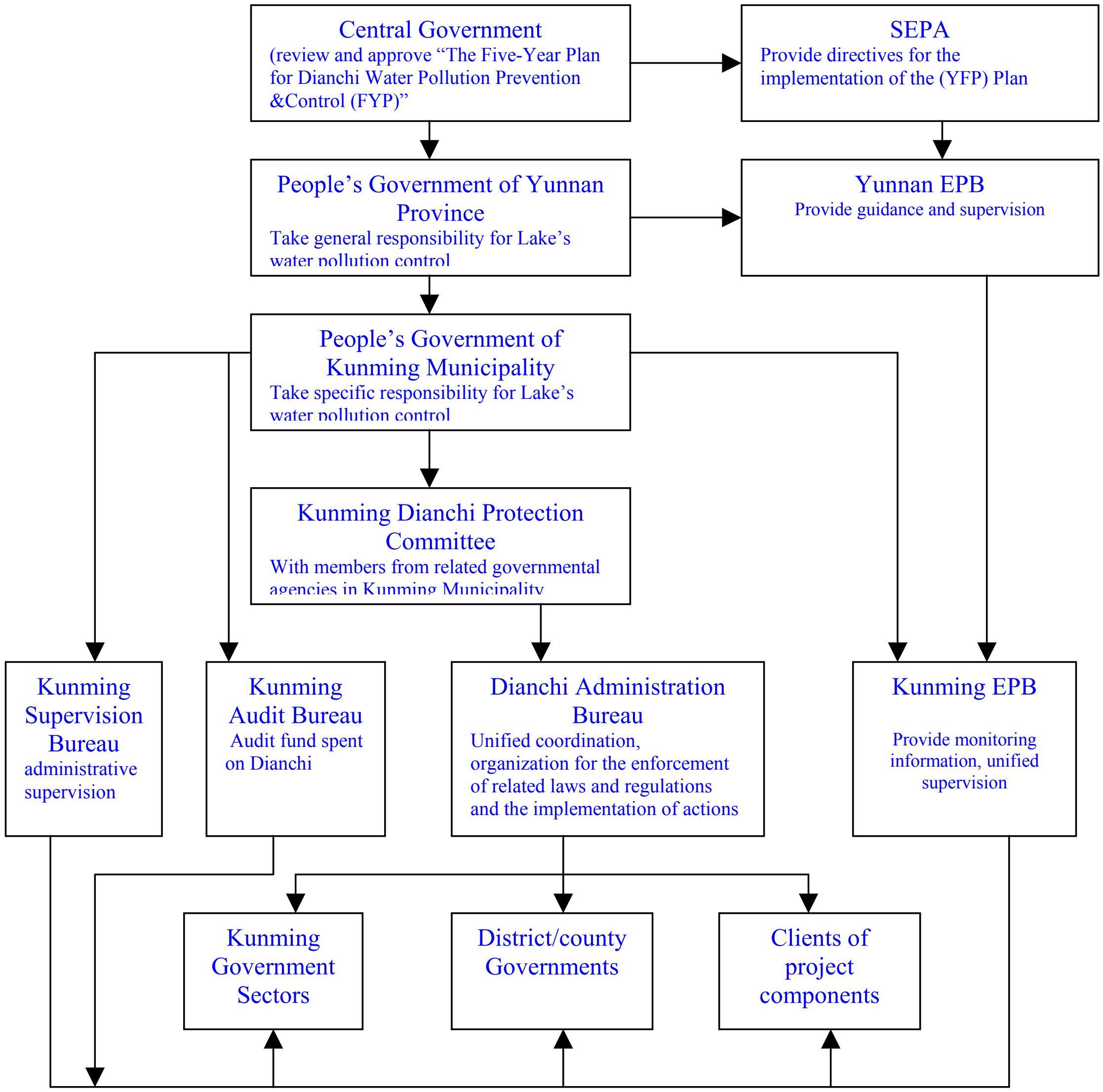

Figure 11. Legal Framework.

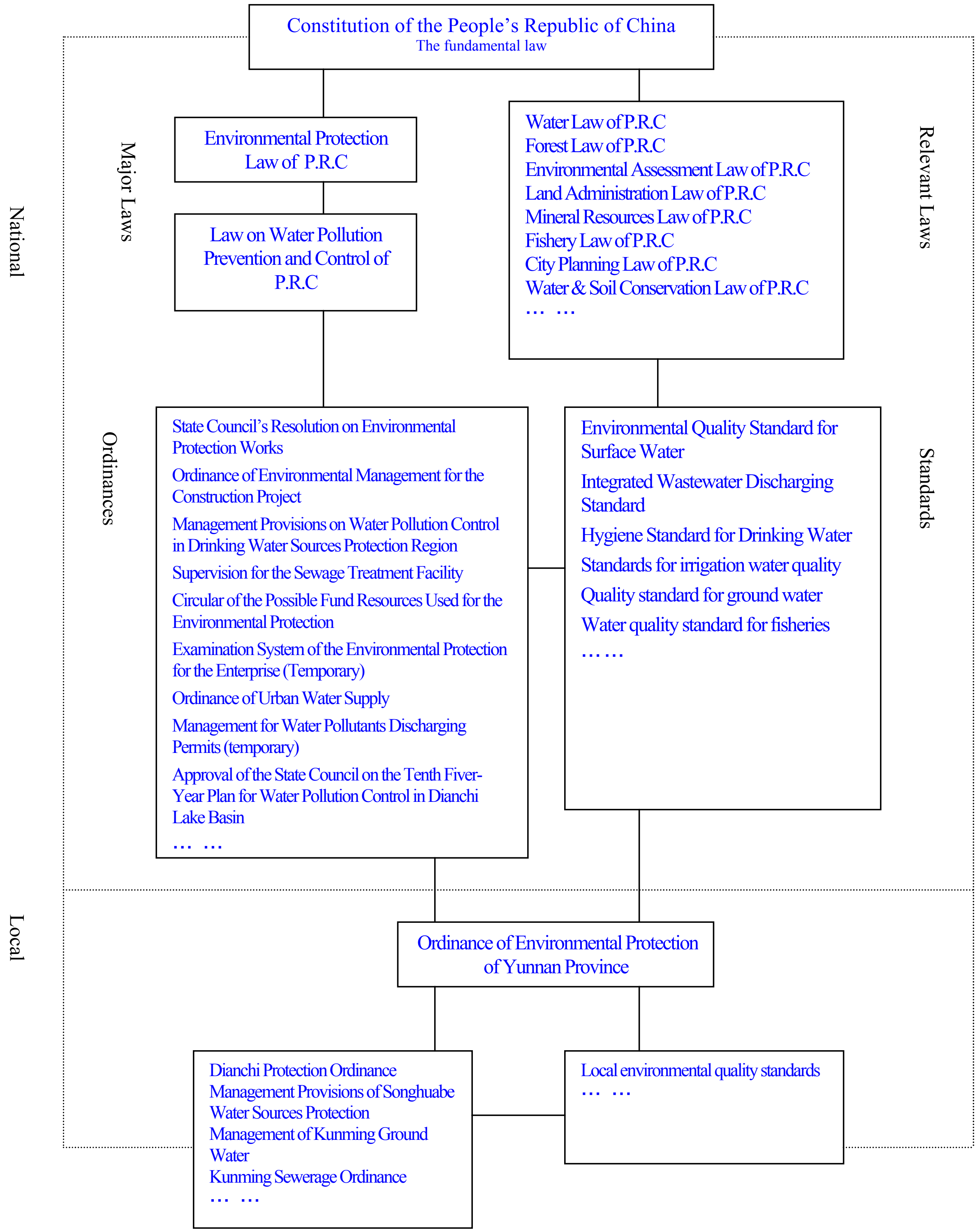

Table 1. Volume of surface runoff from the inflowing rivers.

River(s)	Catchment area (km^2)	Annual surface runoff (million m^3)	Annual surface runoff [$10^3 m^3/(km^2 \cdot a)$]
Xinhe	112.5	45.7	406.2
Yunliang	14.5	5.4	372.4
Baoxiang, Dongbaisha Maliao	463.4	79.0	170.5
Luolong	135.2	18.7	138.3
Laoyu, Liangwang, Nanchong	280.8	47.9	170.6
Daqing	205.2	46.0	224.2
Chaihe, Dahe	256.4	50.5	197.0
Dongda	180.4	42.3	234.5
Panlong	858.6	330.0	384.3
Gucheng	34.1	5.4	158.3
Scattered rivers in the west mountains	78.9	25.2	319.4
(Lake Dianchi)	300		
Total	2920	696.1	

Table 2. Economic Output of Kunming City and Yunnan Province

Main index	Unit	Drainage area	Kunming City	Yunnan Province	(%) of Kunming City	(%) of Yunnan Province
Area	($10^4 km^2$)	0.292	1.56	39.4	18.7	7.4
Total population	($10^4 p$)	180.38	346.87	3594	52	50
Population density	(p/km^2)	689	223	89		
Total output value	(billion yuan)	6.603	8.381	26.147	7.979	0.253
Industrial output value	(billion yuan)	6.342	7.713	17.391	8.22	0.3647
Agricultural output value	(billion yuan)	0.261	0.668	8.756	3.907	0.0298
Total grain output	($10^4 t$)	26.15	75.23	940.72	3.48	2.8
Per capita value	(10^4 yuan)		0.366	0.2416	0.073	
Number of large and medium enterprises	(ind.)	86	104	237	82.7	36.3
Output value of large and medium enterprises	(billion yuan)	3.9	4.79	9.346	8.14	0.417

Table 3. Features of Lake Dianchi’s Eutrophication

Item		Inner lake	Outer lake	Eutrophication features
Basin shape		flat, gradient 1.6%-2.5‰, shallow,3-5m deep, narrow, shaped like a bow, in N-S alignment, 39-41km long about 7.5km wide		shallow, open
Physical Properties	color	dark yellow green	yellow green	green-yellow
	SD (m)	< 0.5	< 1	< 5
Chemical Properties	pH value	8.0-8.5	8.5-9.0	neutral to weakly basic,strongly basic at the top layer in summer
	DO	0 to saturate	saturate or over saturate	saturate or over saturate at top
	chromaticity	< 50	< 20	
	TN(mg/L)	3-16	1-1.6	>0.2
	TP(mg/L)	0.3-1.7	0.08-0.15	>0.02
Biological Features	Chla (mg/m^3)	30-500	5-25	5-140, 20-140
	Number and dominant algae species	20-200 million ind./L *Cyclotella, Chlamydomonas, Micractinium*, *Closterium, Euglena*	10-30 million ind./L Aphanizomenon, Mougeotia	numerous, "water bloom" in summer
	dominant zooplankton species	*Mesocyclops leuckarti, Brachionus Calyciflorus, Daphnia pulex Kerayella cochlearis, Polyarthra trigla, Bosmina longirostris*	numerous, Rotifera increase	Dominant zoobenthon species
	dominant zoobenthons species	*Branchiuta Sowerbyi, ch. plumosus*	*Ch. plumosus*	
Bottom matter features		fertile, with thick sludge, remains of animals and plants, very stinking	Fairly fertile, brown yellow, with faulschlamm	faulschlamm, muck

Table 4. Concentrations of major parameters of Lake Dianchi and their assessment

No.		1	2	3	4	5	6	7	8	9	10
Location		Dahewei	Taishi Village	Niulian Township	Haibao-shan	E. of Haikou	W. of Haikou	C. of Baiyukou	E. of Guan-yingshan	C. of Guan-yingshan	W. of Guan-yingshan
TP	average	0.149	0.079	0.090	0.083	0.082	0.078	0.081	0.088	0.082	0.100
	TSIm	73.94	65.97	67.61	66.59	66.44	65.81	66.29	67.33	66.44	68.93
Chla	average	7.77								18.81	
	TSIm	46.98								56.62	
SD (m)	Average	0.70	0.70	0.78	0.74	0.73	0.70	0.72	0.76	0.68	0.59
	TSIm	70.83	70.83	69.02	69.90	70.13	70.83	70.36	69.45	71.31	73.68
COD_{Mn}	Average	6.25	6.46	6.54	6.06	6.18	6.22	6.29	6.15	6.15	6.06
	TSIm	68.17	68.66	68.84	67.71	68.00	68.10	68.27	67.93	67.93	67.71
TSIm average		64.98								65.58	
Trophic state		eutrophic								eutrophic	

No.		11	12	13	14	15	16	17	18	19	20
Location		Xihuajie	E. of Huiwan	C. of Huiwan	W. of Huiwan	C. of Xishan	Pontoon bridge at Haigeng	Xiyuan	C. of Caohai	Duanqiao	Outlet of R. Daguan
TP	average	0.085	0.098	0.097	0.103	0.127	0.269	0.410	0.504	1.102	1.700
	TSIm	66.89	68.67	68.55	69.30	71.93	81.35	86.64	89.23	99.05	104.49
Chla	average		15.89		24.56				77.41	129.41	74.07
	TSIm		54.78		59.24				72.06	77.68	71.58
SD (m)	average	0.68	0.60	0.64	0.54	0.59	0.45	0.43	0.40	0.31	0.25
	TSIm	71.31	73.40	72.32	75.16	73.68	78.20	78.96	80.17	84.43	88.02
COD_{Mn}	average	6.42	6.68	6.70	7.36	7.93	10.82	11.87	14.74	16.13	17.03
	TSIm	68.57	69.16	69.20	70.60	71.70	76.32	77.69	80.90	82.24	83.05
TSIm average			66.50		68.65				80.59	85.85	86.78
Trophic state			eutrophic		eutrophic				hypereu trophic	extremely eutrophic	extremely eutrophic

Table 5. Eutrophication of Lake Dianchi

Region	TP	SD	Chla	COD_{Mn}	Average TSIm	Trophic state
Inner lake	94.98	81.47	73.66	80.27	82.60	hypereutrophic
Outer lake	68.29	71.31	55.51	68.75	65.97	eutrophic
Lake Dianchi	71.22	71.56	57.07	69.36	67.30	eutrophic

Table 6. Total Species Numbers of Major Taxa in Lake Dianchi from 1950s to 1996

<table>
<tr><td></td><td colspan="8">Year</td></tr>
<tr><th>Taxon</th><th>Pre-1957</th><th>1958-1966</th><th>1977</th><th>1981-1984</th><th>1989</th><th>1992-1993</th><th>1994-1995</th><th>1996</th></tr>
<tr><td>Phytoplankton</td><td></td><td>154</td><td></td><td colspan="2">175</td><td colspan="2">93</td><td></td></tr>
<tr><td>Zooplankton</td><td></td><td></td><td></td><td colspan="2">157</td><td colspan="2">92</td><td></td></tr>
<tr><td>Crustacea-endemic</td><td>1</td><td></td><td>1</td><td colspan="2"></td><td colspan="2"></td><td>2</td></tr>
<tr><td>Crustacea-indigenous</td><td>3</td><td></td><td>2</td><td colspan="2">2</td><td colspan="2">2</td><td>2</td></tr>
<tr><td>Crustacae-introduced</td><td>1</td><td></td><td>3</td><td colspan="2">3</td><td colspan="2">3</td><td>3</td></tr>
<tr><td>Total Crustacea</td><td>5</td><td></td><td>6</td><td colspan="2">5</td><td colspan="2">5</td><td>5</td></tr>
<tr><td>Macrophytes</td><td>34</td><td></td><td>31</td><td colspan="2">21</td><td colspan="2">19</td><td>19</td></tr>
<tr><td>Molluscs</td><td colspan="7">69</td><td>29</td></tr>
<tr><td>Fish-endemic</td><td>10</td><td>10</td><td></td><td>1</td><td></td><td></td><td>2</td><td>2</td></tr>
<tr><td>Fish-indigenous</td><td>14</td><td>15</td><td></td><td>6</td><td></td><td></td><td>6</td><td>7</td></tr>
<tr><td>Fish-introduced</td><td>1</td><td>26</td><td></td><td>24</td><td></td><td></td><td>25</td><td>19</td></tr>
<tr><td>Fish-total</td><td>25</td><td>51</td><td></td><td>31</td><td></td><td></td><td>33</td><td>28</td></tr>
</table>

Table 7. Water Quality of Lake Dianchi in 1988

No.	location Item	SD (m)	pH	TN (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	NH_3-N (mg/L)	TON (mg/L)
1#	Dahewei	0.70	8.76	1.05	0.028	0.004	0.151	0.867
2#	Taishi Village	0.70	8.72	1.03	0.020	0.001	0.108	0.901
3#	Niuxi Township	0.78	8.78	1.10	0.032	0.002	0.124	0.942
4#	Haibaoshan	0.74	8.72	1.09	0.021	0.001	0.146	0.922
5#	east of Haikou	0.73	8.76	1.09	0.020	0.001	0.080	0.989
6#	west of Haikou	0.70	8.74	1.07	0.020	0.001	0.070	0.979
7#	center of Baiyukou	0.72	8.74	1.05	0.020	0.000	0.060	0.970
8#	east of Guanyingshan	0.76	8.70	1.14	0.020	0.001	0.120	0.999
9#	center of Guanyingshan	0.68	8.64	1.08	0.030	0.001	0.090	0.959
10#	west of Guanyingshan	0.59	8.74	1.09	0.030	0.006	0.080	0.938
11#	center of Xihuajie	0.68	8.62	1.20	0.020	0.001	0.110	1.070
12#	east of Huiwan	0.60	8.68	1.10	0.030	0.002	0.110	0.958
13#	center of Huiwan	0.64	8.61	1.19	0.030	0.001	0.090	1.069
14#	west of Huiwan	0.54	8.64	1.44	0.020	0.003	0.120	1.297
15#	center of Xishan	0.59	8.56	1.62	0.040	0.006	0.160	1.414
16#	ponton bridge at Haigeng	0.45	8.28	2.98	0.060	0.020	0.510	2.390
17#	Xiyuan	0.43	8.19	3.90	0.090	0.030	0.730	3.050
18#	center of Caohai	0.40	8.24	4.14	0.090	0.044	0.910	3.096
19#	Duanqiao	0.31	7.96	11.46	0.080	0.055	5.160	6.165
20#	outlet of R. Daguan	0.25	7.66	155.07	0.090	0.019	9.330	5.631
Outer lake average		0.68	8.69	1.16	0.025	0.002	0.108	1.025
Inner lake average		0.37	8.07	7.51	0.082	0.034	3.330	4.064
Average of whole lake		0.67	8.67	1.39	0.027	0.003	0.220	1.140

No.	location Item	TP (mg/L)	PO_4^{3-}P (mg/L)	Fe (mg/L)	DO (mg/L)	COD_{Mn} (mg/L)	BOD_5 (mg/L)	TOC (mg/L)
1#	Dahewei	0.149	0.052	0.26	8.21	6.25	3.15	8.44
2#	Taishi Village	0.079	0.002	0.15	7.41	6.46	3.37	8.05
3#	Niuxi Township	0.090	0.001	0.14	7.79	6.54	3.36	8.15
4#	Haibaoshan	0.083	0.008	0.25	7.53	6.06	2.97	8.17
5#	east of Haikou	0.082	0.002	0.18	7.86	6.18	3.07	8.33
6#	west of Haikou	0.078	0.006	0.24	7.70	6.22	3.36	8.13
7#	center of Baiyukou	0.081	0.004	0.15	7.60	6.29	3.06	8.01
8#	east of Guanyingshan	0.088	0.008	0.23	7.64	6.15	2.85	8.30
9#	center of Guanyingshan	0.082	0.004	0.22	7.50	6.15	2.98	8.23
10#	west of Guanyingshan	0.100	0.005	0.27	7.86	6.06	3.78	8.18
11#	center of Xihuajie	0.085	0.011	0.22	7.65	6.42	2.98	8.94
12#	east of Huiwan	0.098	0.010	0.33	7.33	6.68	2.97	8.30
13#	center of Huiwan	0.097	0.002	0.30	7.82	6.70	3.18	8.55
14#	west of Huiwan	0.103	0.015	0.26	8.11	7.36	3.90	8.24
15#	center of Xishan	0.127	0.011	0.34	7.79	7.93	4.25	8.90
16#	ponton bridge at Haigeng	0.269	0.034	0.52	6.18	1.82	9.56	9.76
17#	Xiyuan	0.410	0.170	0.36	5.69	11.87	11.52	11.54
18#	center of Caohai	0.504	0.150	0.35	6.81	14.74	14.23	10.77
19#	Duanqiao	1.102	0.380	1.12	4.06	16.13	13.56	13.74
20#	outlet of R. Daguan	1.700	0.410	1.84	1.89	17.03	15.27	16.23
Outer lake average		0.095	0.009	0.24	7.72	6.50	3.28	8.33
Inner lake average		0.797	0.229	0.84	4.93	14.12	12.83	12.41
Average of whole lake		0.120	0.017	0.26	7.26	6.77	3.62	8.47

Table 8. Changes in Water Quality of Lake Dianchi, 1986-1996

Item	Sample	Time										
		1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
PH	Center of Caohai	8.61	8.36	8.31	8.22	7.93	8.36	8.55	8.03	8.37	8.07	8.27
	Guanyin Hill	8.59	8.60	8.79	8.56	8.21	8.41	8.71	8.52	8.75	8.54	9.05
	Luo Jiaying					8.25	8.34	8.74	8.65	8.80	8.64	9.08
Transparency	Center of Caohai			0.52	0.35	0.36	0.50	0.43	0.25	0.46	0.39	0.44
	Guanyin Hill			0.70	0.62	0.68	0.39	0.54	0.50	0.41	0.50	0.52
	Luo Jiaying			0.75	0.55	0.49	0.35	0.46	0.45	0.37	0.43	0.45
BOD_5	Center of Caohai	17.99	14.35	10.80	16.05	20.32	12.64	7.94	12.96	10.48	9.50	14.54
	Guanyin Hill	2.35	2.19	2.65	2.22	2.61	3.10	3.70	4.11	4.61	2.73	3.27
	Luo Jiaying					2.69	3.43	3.13	2.79	3.53	3.38	3.60
COD_{Mn}	Center of Caohai	15.47	13.67	13.32	19.86	18.25	16.59	13.08	15.98	14.11	11.00	11.38
	Guanyin Hill	6.35	7.29	6.33	6.90	7.70	9.30	9.04	10.60	11.06	7.47	8.33
	Luo Jiaying					7.51	9.52	7.93	8.73	9.44	5.88	9.28
TN	Center of Caohai			6.77	4.94	4.59	4.51	4.12	5.44	3.11	4.43	5.10
	Guanyin Hill			1.33	1.13	1.22	1.47	1.87	1.42	2.68	1.65	1.71
	Luo Jiaying						1.74	1.67	1.49	1.83	1.52	1.87
TP	Center of Caohai	0.42	0.38	0.41	0.47	0.50	0.74	0.76	0.88	0.60	0.58	0.61
	Guanyin Hill	0.08	0.06	0.12	0.09	0.09	0.14	0.12	0.15	0.23	0.16	0.18
	Luo Jiaying					0.08	0.15	0.13	0.16	0.20	0.19	0.19
Chla	Center of Caohai			98.94	219.22	205.05	194.00	83.08	183.89	70.45	91.10	195.96
	Guanyin Hill			31.46	23.24	22.56	24.73	25.4	15.75	25.94	24.95	41.68
	Luo Jiaying					28.30	36.33	43.82	10.93	32.41	27.69	49.08
Count of Alage	Center of Caohai			5772	12040	4293	5827	2710	2238	1883	4640	1386
	Guanyin Hill			1696	1265	640	1374	1194	1407	2466	2494	971
	Luo Jiaying					625	1060	2127	1429	2324	3948	1147

(unit : mg/L, algae : 10 thousand/L, Chla : mg/m^3)

Table 9. Completed Engineering Project by End of 2002.

No.	Project Name	Investment
I.	Point sources control and others	
1	4 sewage treatment plant (365,000 m^3/d), all secondary treatment process with high efficiency in removing nitrogen and phosphorus	4.2
2	Sewage interception along middle section of Panlong River bank and north bank of Lake Dianchi (300,000 m^3/d)	1.105
3	Domestic solid waste sanitary landfill (1500 t/d)	1.2
4	Xiyuan tunnel (an artificial outlet)	2.43
5	River course harness	1.5
6	"2258" water supply raw water transmission project inside Lake Basin	2.68
7	Interception of sewage along Daguan River and urban section of Panlong river, contaminated sediment dredging of Daguan River	0.3124
8	Industrial effluents compliance with discharging standard	1.845
II	Non-point sources control	
1	Hillside afforestation, upland conservation, pilot eco-agriculture project covering 118000 mu of farmland	3.05
III	Internal sources control	
1	Harvest water hyacinth, clamp down caged fish	0.25
2	Contaminated sediment dredging in Caohai (first phase)	2.5
IV	Scientific research	
1	Demonstrative projects carried out in the scientific research program during the seventh and eighth five-year phases	0.17
	Total	21.2424