Lake Dianchi

Experience and Lessons Learned Brief

*Jin Xiangcan**, Chinese Research Academy of Environmental Sciences, Beijing, China, jinxc@craes.org.cn
Wang Li, Yunnan Environmental Project Office, Kunming, China
He Liping, Yunnan Institute of Environmental Sciences, Kunming, China

* Corresponding author

1. Introduction

Lake Dianchi is an ancient tectonic lake (approximately 3.2 million years old) located in Yunnan Province in southwestern China. It is the 6th largest freshwater lake in China and the largest in Yunnan. The lake and its basin (Figure 1) are located wholly within the jurisdiction of Kunming Municipality, which contains Kunming City, the largest city in Yunnan Province (Figure 2; Section 2.2.1 describes the jurisdictional features. Note that Kunming Municipality is much large than, and contains the urban area called Kunming City). The lake is divided into two parts by an artificial causeway: the northern, inner part is called Caohai and has a surface area of 7.5 km^2 and average depth of 2.5 m; the southern, outer part is called Waihai and has a surface area of 292 km^2 and average depth of 4.4 m. The volume of the Waihai part accounts for 99% of the total lake volume (1.56 billion m^3). The lake is part of the larger Jinsha River drainage basin (an upper stream of the Yangtze River). Water flows out of the lake to the west via the Tanglang River, which in turn joins other rivers in the north before finally heading east until reaching the Pacific Ocean.

The lake has been important throughout history for the development and livelihoods of the people of Kunming and the basin. The lake's age, combined with other favorable factors, meant that until recent decades, the lake contained a large number of endemic species, and an overall high level of biodiversity. The lake is used for various purposes, including industrial and agricultural water supply, water storage regulation, flood control, aquaculture, climate regulation, navigation and tourism and, significantly since 1990, for drinking water, although high pollution levels in the lake have necessitated increased reliance on upstream reservoirs.

Unfortunately, rapid population growth in the basin (3.16 million in 2003, compared to 1.5 million in 1980) and economic development in the drainage basin over the last few decades, combined with changes in land use, especially the lakeshore areas, has placed severe pressures on the lake. For example, the lake's once great biodiversity has been severely damaged. High levels of organic and nutrient loads to the lake have resulted in hypereutrophic conditions, especially in the Caohai part. Lake Dianchi provides a good example of the ecological shift (hysteresis) common in many stressed shallow lakes, from a system dominated by macrophytes to one dominated by plankton. Introduced species also have had negative effects on the lake's ecosystem. Additionally, the region as a whole has limited water resources, so water scarcity is also an issue.

The last ten years or so have seen a comprehensive, integrated response from the national, provincial and municipal levels to reduce the pollutant loads to the lake and restore it to a better condition. These efforts include a large World Bank loan for the

Figure 1. The Lake Dianchi Basin.

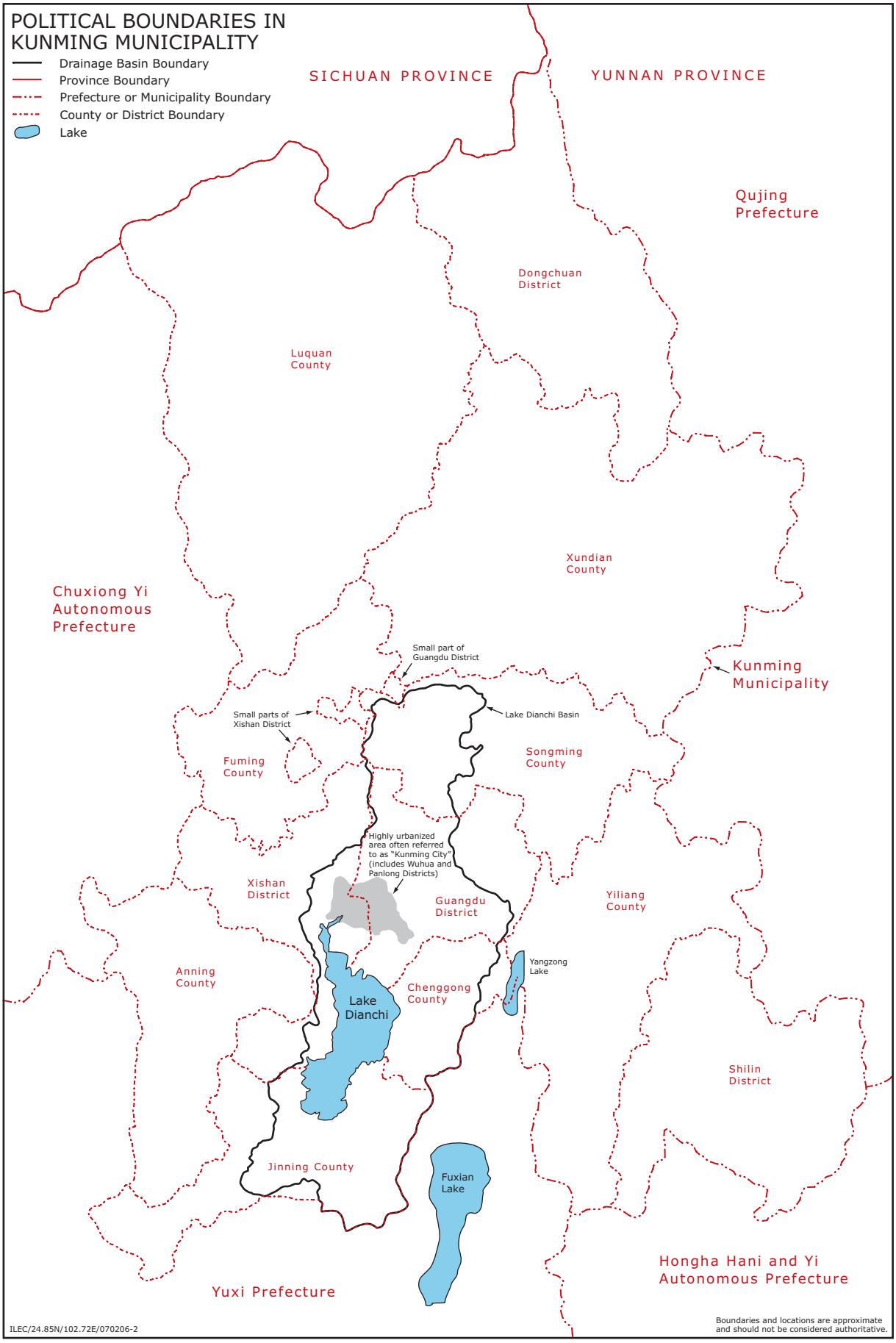


Figure 2. Political Boundaries in Kunming Municipality.

Yunnan Environment Project, and a smaller GEF co-financed project for restoration of biodiversity in a few lakeshore areas. Although early indications are that these comprehensive efforts are having a positive effect on the lake, restoration of the lake to its previous condition will be a long-term challenge.

2. Background

2.1 Biophysical Features

2.1.1 Biophysical, Hydrometeorological and Geophysical Features

The Lake Dianchi drainage basin is situated in the central part of the Yunnan-Guizhou Plateau, along the watershed of the three water systems comprising the Yangtze River, Pearl River and Red River, at 24°29' to 25°28' N and 102°29' to 103°01' E, and an elevation of approximately 1,887 m. To its west are the Hengduan Mountains, to its east lies the East Yunnan Plateau and to its north are the Wumeng and Liangwang Mountains. The landform gradually slopes from the north to the south, where hills, subsided plains and the lake itself have an areal ratio of 7:2:1, respectively. Kunming City is located to the north of the lake. The whole area is typical of a natural plateau landscape.

The land in Lake Dianchi's drainage area is composed mainly of mountains, terraces and dammed river valleys. The total drainage area is 2,920 km^2 (including the lake). The three types of land (mountain, mesa and flat) take up 49.36, 25.48 and 13.62% respectively, of the drainage basin area, while Lake Dianchi's water surface area makes up 10.22% and urban area of Kunming City and land of other various types make up 1.32%.

The drainage 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 North-South-aligned Xiajiang River and Pudu River faults. The drainage area was transformed into a plateau in the early Neozoic epoch 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 drainage area, and the peneplain disintegrated to form parallel North-South-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, with a plane of denudation forming. 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 various grades came into shape. The landforms within the basin varied, to become forms of solution, erosion, denudation and accumulation at different parts with different tectonic structures, stone properties and geologic agents.

There are more than 20 major rivers flowing into Lake Dianchi from the east, south and north, with a cumulative length of about 359 km. The Panlong River is the longest inflowing river (106 km, with a catchment area of 850 km^2). It starts upstream of the Songhuabe Reservoir in the north, flowing through Kunming City to the south before entering the lake. Most of the inflowing rivers flow through farmlands, towns, villages and phosphate mines, bringing water rich in such nutrients as nitrogen and phosphorus to the lake. The lake water flows out of the lake through the Panglang River at Haikou Town, the only natural outlet at the southwest end of the lake, then flows northwards into the Pudu River and finally into the Jinsha River at upstream end of the Yangtze River.

2.1.2 Environmental and Natural Resources Features and Values of the Lake

Climate. The Lake Dianchi drainage area belongs to the wet monsoon climatic belt of the northern sub-tropic zone, controlled alternately mainly by the southwest monsoon and sub-tropic continental air mass. The annual temperature accumulation greater than 10°C is 4,200 to 4,500°C, with an average annual air temperature of 14.7°C. The average annual rainfall is 797 to 1,007 mm, the annual evaporation 1,870 to 2,120 mm, the annual sunshine duration 2,018 to 2,470 h, the annual sunshine rate 47 to 56%, and the relative humidity 73 to 74%. The prevailing wind is from the southwest, with an average wind speed of 2.2 to 3.0 m/s. There are 227 frost-free days in an average year. The climate of the drainage area is typically that of the monsoon region of low latitude and high altitude. Due in part to the thermal regulation provided by the lake, the micro-climate of the region is very pleasant, being warm in the winter and cool in the summer, as described in the well-known saying about the region, "Flowers of various colors do not wither in any season and the temperature is pleasant like spring all the year round."

There is a distinct difference between the dry (winter and spring) and wet seasons (often in summer). Precipitation is the only source of water in the lake's drainage basin (i.e., there is no significant groundwater transfer or artificial canals bringing water into the basin), and the available water resources are limited. The uneven distribution of rainfall leads to uneven surface runoff. The rainy season provides 81% of the total annual water resources, with the rainfall during July, August and September making up 60% of the annual total. 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 Lake Dianchi drainage area ranges between 3.87 to 5.14, with a coefficient of variation of 0.44 to 0.45.

Soil resources. The soil in the drainage basin is complicated due to the topography, the sub-tropic monsoon climate and the local biological conditions. Red soil, paddy soil and purple soil have the widest distribution, although brown earth,

yellow-brown earth, alluvial soil and bog soil also are common. The natural soils of the hills are mountain red soil and purple soil, with places of higher elevation having red-brown and brown soil, and the plains and terraces with cultivated soil, reflecting agricultural land use.

Water resources. The available water resources of the catchment are not only scarce, but vary widely from 242 million m^3/yr (dry year) to over 900 million m^3/yr (wet year). Figure 3 shows the average water balance in the basin in the mid-1990s. The water supply for domestic, industrial and agricultural uses depends heavily on storage in various reservoirs in the basin. The most important reservoir is Songhuabe Reservoir (located on the Panlong River), from which most of Kunming's water supply is abstracted. Lake Dianchi is the second most important "reservoir", providing water supply for domestic use (most importantly in dry years), and industrial and agricultural uses. However, the lake receives sewage, industrial effluents, irrigation return flows and storm runoff for repeated water re-use, with its quality deteriorating well below the national minimum standard for potable water supply (Grade III).

In average years (and particularly dry years), the water supply cannot meet the water demand. The water balance in the drainage basin has to depend heavily on the irrigation return flows and the indirect re-use of domestic sewage. Plans for diversion of water from another river basin into the Lake Dianchi basin are discussed in Section 4.1.

Vegetation resources. The basin's climate makes it suitable for the growth of various plants. The land use in the basin is given in Table 1. Forests occupy almost 1,200 km^2, making up 46% of the total land area. The natural vegetation is dominated by broad-leaved evergreen forests, and the secondary vegetation by burma pine and china armand pine. Artificial farmland vegetation includes rotation of rice, wheat and corn, with two crops often being harvested in a year. Since the mid-1990s, rice fields have been increasingly converted into more profitable cut flowers and vegetable crops.

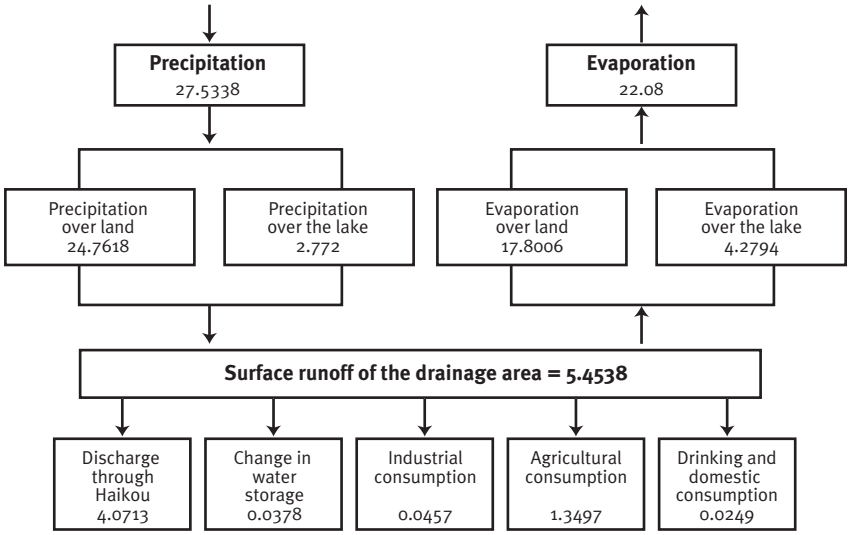


Figure 3. Average Annual Water Balance of Lake Dianchi (expressed as 10^8 m^3; Source: Jin (1995)).

Aquatic resources. Until the 1950s, macrophyte coverage was extensive. It provided both a rich food source and a good fish habitat. Fisheries biologists identified 24 indigenous fish species as originally having been present in the lake, with at least 11 being endemic to Lake Dianchi. In addition, a further 31 exotic species have been stocked into the lake since the late-1950s, for a total of 51 fish species by the late-1950s/early-1960s. However, competition for food and living space, along with increasing fishing efforts and escalating pollution from inflowing river waters that has accompanied development of the Lake Dianchi drainage basin, has resulted in the extinction of many of the endemic and indigenous species.

Table 1. Land Use Changes in the Lake Dianchi Basin.

Land use type	1988		1999	
	Area (km^2)	(%)	Area (km^2)	(%)
Natural landscape				
Forest	1,075.8	42.2	1,196.6	45.7
Bare land	499.0	19.6	135.2	5.2
Garden plot	10.7	0.6	138.5	5.3
Agricultural land				
Wet paddy field	374.5	14.7	405.3	15.5
Non-irrigated farmland	219.2	8.6	359.4	13.7
Residential area	96.5	3.8	117.8	4.5
Transportation area	80.2	3.2	59.9	2.3
Industrial and mining area, etc.	188.6	7.4	208.3	7.9

Source: He and An (2001).

Recent surveys have confirmed 7 of the endemic fish species as extant: *Anabarilius alburnops*, *Pseudobagrus medianalis*, *Sinocyclocheilus grahami*, *Schizothorax grahami*, *Triplophysa grahami*, *Yunnanilus discoloris*, and *Yunnanilus sp.* (GEF 2002). In addition to the decline in fish biodiversity, the fish catches and stocks in Lake Dianchi are also generally on the decline. The catches of six commercially important fish declined from 3,500 tons in 1984 to only 200 tons in 1994. The lake also contains many endemic mollusk and crustacean species including *Caridina nilotica gracilipes* and *Caridina dianchiensis*. Catches of mollusks also have decreased over the same period, from more than 1,000 tons per year in 1984 to 300 tons in 1994.

Up to the 1990s, there were about 2 ha of floating, anchored net cages on the lake, which are used to intensively raise carp. The yield was about 1,800 tons of fish per year. In addition, there was a further 3.5 ha of semi-intensive fenced or caged enclosures, some being located along the western side of the Caohai part of the lake, which were reported to yield a total of 250 tons of fish per year. The caged or semi-caged fish activities have been eliminated since mid-1990s, because the application of artificial foodstuffs to the cages was increasing the nutrient load into the lake water, and this is deemed unfavorable, in view of the efforts to control eutrophication of the lake (see Section 4.1).

Mineral resources. There are 14 kinds of mineral ore within the lake drainage basin, with prospected reserves in 41 localities, of which phosphate ranks first, with a total reserve of 1,477 million tons. A total of 698 million tons out of the total reserve has been prospected at six localities. It is mostly high-grade, easily-extractable ore. There also are many kinds of non-metal ore with considerable reserves.

Tourist resources. Despite the challenging current environmental conditions described above and in the following sections, Lake Dianchi is quite scenic. Mountain cliffs rise steeply from parts of the lake shore, contributing to the lake's nickname, "bright pearl in green mountains". There are 11 designated tourist attractions and scenic resorts of unique landscape around the lake. The Lake Dianchi region has now become a large tourist region, combining scenes of mountains, water, parks, forests, spectacular rocks, caves and amusement parks, in which people can enjoy swimming, navigation, fishing, sightseeing and appreciation of ancient Chinese culture. To the north of Lake Dianchi are the Grand View Park, the Haigeng Holiday 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 the 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 clay statues of the 500 arhats of the Qing Dynasty; and a Hot Spring, which is known as the "Number One Bath in the World" as well as the Caoxi Temple scenic region, in which are well-preserved architecture of the Ming Dynasty.

2.2. Political and Socio-economic Features

2.2.1 Jurisdictional Features

The Lake Dianchi basin is under the jurisdiction of the Municipality of Kunming, Yunnan Province, China. In China, political jurisdictions from the national level down follow the following ranking: nation › province › prefecture/municipality › county/district › township › village › natural village › household. As shown in Figure 2, the Lake Dianchi basin lies wholly within Kunming Municipality, which itself is part of Yunnan Province. Within Kunming Municipality, there are 14 counties/districts, 7 of which cover part of the lake's basin. The highly urbanized area to the north of the lake is called Kunming City. Although not depicted in Figure 2, there are 38 townships in basin. The total registered population in the basin was 2.2 million in 2000 and 3.16 million in 2003, showing the tremendous rate of growth. The population in the area is highly urbanized, with a density of 23,600 persons/km^2 in the urban part, 34 times higher than the province's average.

2.2.2 The Political Significance

Kunming City, the provincial capital and a major industrial center, lies on the "upstream" northern shore of Lake Dianchi. It is by far the largest city, dominating the economy of ethnically-diverse Yunnan Province. The city serves as a gateway to neighboring countries such as Vietnam, Laos and Myanmar. In addition, Kunming City often hosts dialogues between the nations of the Great Mekong Sub-region and ASEAN Meetings, and hosting the Kunming International Commodities Fair once a year. Overall, compared to other places in the Yunnan Province, the Lake Dianchi drainage basin is the area where the population density is highest, where human activity is strongest, and where the economy is the most developed.

As a center for economic development and a gateway to neighboring countries, and in order to follow the national drive to build a prosperous, well-rounded society, the area is undergoing economic restructuring and further urban expansion, while also trying to avoid high-energy consumption and highly-polluting projects. Meanwhile, tourism is encouraged as a precursor for other service industries, accelerating the formation of a more integrated socialist market economy. This initiative will greatly depend on the environmental conditions and water resources available in Kunming Municipality which, in turn, depends on Lake Dianchi, the foundation for maintaining the area's ecological balance and prosperity.

2.2.3 The Past Social and Economic Development History

The economy of the Lake Dianchi basin plays an important part in the economy of the entire province. Its agricultural output value and industrial output value, for example, account for 32.05 and 44.35%, respectively, of the province's total

economic output. Additionally, the output value of large- and medium-sized enterprises of the area accounts for 81.4% of the total output. The total industrial area in Kunming City and its suburbs is 69 km^2, with 168 major industrial enterprises and mines and approximately a dozen newly-built inhabitant quarters. The city now has 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. The area has established its position as one of the production bases for precision machine tools, optical instruments, phosphate chemical products, natural condiments, brand cigarettes, and non-ferrous metal processing in China. The industry of machine building earns more foreign exchange than any other industry, with many products meeting advanced international standards. The electrolytic copper and electrolytic aluminum produced by Kunming and Yunnan Smelters not only rank second in output in the whole country, but are also of high quality. Products of the phosphate industry are exported to many countries in Southeast Asia.

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 Lake Dianchi drainage basin has the largest fresh flower production basin, as well as the largest national "high-class" flower trading market. The basin has 11.24 million ha of farmland and fruit orchards. The area's agricultural structure is now turning to one of comprehensive development of diversified management, with township-run enterprises becoming the new mainstay of the rural economy.

3. Biophysical Environment

Before rapid growth and urbanization in its drainage basin, along with increased modern industrial and agricultural activity, Lake Dianchi was a natural, clean freshwater lake with high biodiversity. In early 1950s, Lake Dianchi was in an oligo- to mesotrophic state, being known as "The Pearl of the Plateau". Bottom sediments of this shallow lake were largely covered by macrophytes, with Charophytes being dominant. The fish community consisted largely of indigenous species, while phytoplankton was dominated by green algae and diatoms. Some blue-green algae also were present. Under these conditions of low to moderate productivity, the zooplankton were apparently successful in suppressing excessive algal growth. Shorelines were sloping, resulting in different ecological zones of littoral macrophyte communities, contributing to a large biodiversity. The lake's biological communities were characterized by high diversity, but low to moderate numbers of individuals of each species.

Although detailed monitoring data on the lake's conditions prior to the 1980s are not available, the general status of the lake can be indirectly derived from records of the classification of its water quality. China uses a system of five classes, ranging from Class I (near pristine) to Class V (suitable for agricultural use, but not fishable or swimmable), to classify lakes. The Caohai part of Lake Dianchi declined from Class II in the 1960s, to worse than Class V in the 1990s. The situation in the Waihai part also has deteriorated from Class II in the 1960s to Class IV in the 1990s.

These changes are documented in the following sub-sections. The discussion focuses on eutrophication, loss of biodiversity, enhanced sedimentation and water scarcity. However, because all these problems are interrelated to varying degrees, this division is somewhat arbitrary.

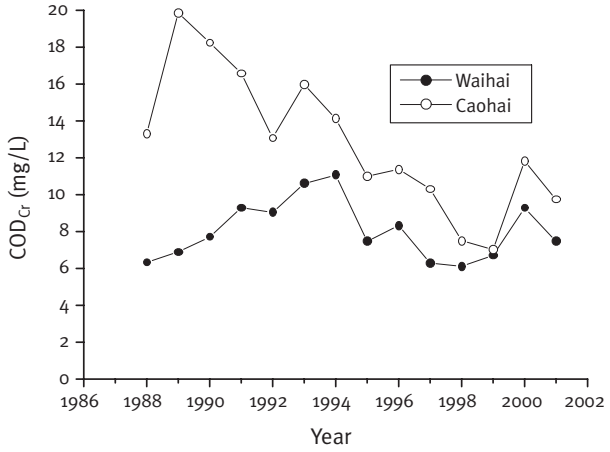
3.1 Eutrophication

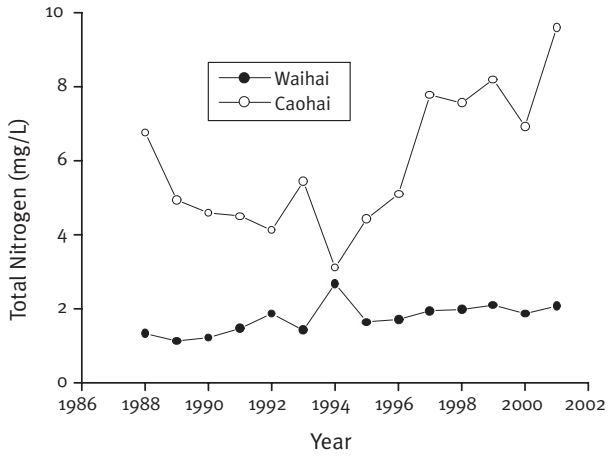
One of the classic indicators of a shift from oligotrophic (low productivity) conditions to eutrophic (high productivity) conditions in a shallow lake such as Lake Dianchi is a shift in the lake's ecosystem from macrophyte dominance to phytoplankton dominance. This shift has occurred dramatically in Lake Dianchi within the last few decades. The water of Lake Dianchi, especially in the Caohai part, has a pea-soup green color, with a water transparency of generally less than 0.5 m over much of the lake. The water transparency in the Caohai part was over 2 m deep in the 1950s, when the water was clean and macrophytes were dominant. Eutrophication of the lake accelerated in the 1960s, with water quality deterioration and greatly decreased water transparency.

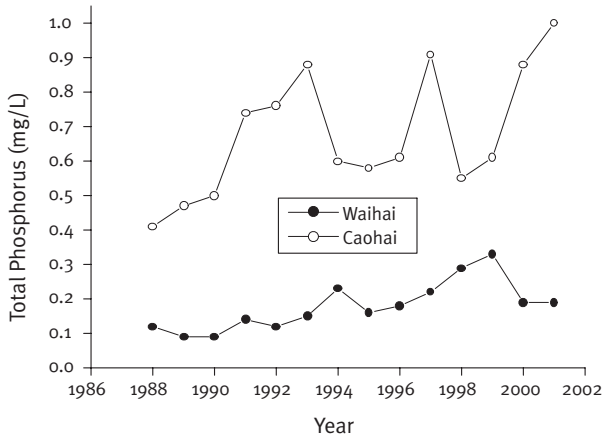
Concentrations of organic matter (COD_{Cr}) and nutrients, such as total phosphorus (TP) and total nitrogen (TN), have been documented since 1988, all showing high values. Figures 4a, 4b and 4c show the COD_{Cr} concentration has somewhat leveled off and even decreased, while concentrations of TN and TP seem to be increasing, at least through 2001. All values are undoubtedly much higher than they were in the 1960s and before.

Estimates of the COD, TN and TP loadings during 1988 to 2000 are given in Table 2. Lake Dianchi received around 240 million m^3 of wastewater in 2000, including about 50 million m^3 of industrial wastewater and 190 million m^3 of domestic wastewater, both deemed point sources. It also receives significant nonpoint source runoff. The proportion of the nonpoint sources of the total pollutant loads is increasing as the point source loads come under greater control. Table 2 illustrates the COD, TN and TP loads to the lake over the 1988-2000 period.

This high nutrient loading has led to hypereutrophic conditions in parts of the lake. As discussed below, chlorophyll-*a* concentration in the Caohai part of Lake Dianchi was up to 320 mg/m^3 in 2000, an extremely high level. This algal growth and the resulting by-products have translated into reduced functioning or difficulties with water treatment operation processes at water treatment plants. The Kunming No. 3 Water Treatment Plant was shut down in the early 1990s, for example, because of this problem.







Figures 4a, 4b and 4c. Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP) Concentrations in Lake Dianchi (Source: He and An (2001))**.**

3.2. Loss of Biodiversity

A number of factors, such as the introduction of exotic species, destruction of natural habitats, and eutrophication of the lake have led to a remarkable decline in the diversity of flora and fauna in the once high biodiversity in this lake. Surveys on species diversity indicate that all taxonomic groups (listed in Table 3) have declined over the last 30-40 years. The decline is most significant in regard to the endemic fish species, since this represents an irreversible loss of genetic material. Some of the specific changes that have occurred are discussed below.

Changes in macrophytes. The coverage area of macrophytes in Lake Dianchi has declined from 90% of the total surface area to only 2% in recent years. The main original macrophytes that have disappeared are *Ottelia acuminata*, *Potamogeton maackianus*, *Myriophyllum verticillatum*, *Phraqmitis communis*, *Ceratophyllum demersum*, and *Limnophylla sessiliflora*. The main macrophytes at present are water hyacinth (*Eichhornia crassipes)*, *Potamogeton pectinatus*, and *Myriophyllum spicatum*.

Changes in phytoplankton. The phytoplankton biomass has greatly increased, although the number of species has decreased. The number of individuals per liter of water increased from a few thousand in the 1950s, to around a hundred million in the 1980s, up to several billion in the 1990s. The chlorophyll-*a* concentration, an indicator of primary production, was reported in 2000 to be 320 mg/m^3 in the Caohai part and 80 mg/m^3 in the Waihai part, highlighting the general eutrophy of the lake and the hypereutrophic condition of the Caohai part. The number of phytoplankton species declined from 186 in the 1950s, to 126 in recent years. Furthermore, the main alga in the 1950s were diatoms, but are now blue-green algae, such as *Microcystis aueruginosa* and *Aphanizmenon flos-aquae*.

Changes in zooplankton. Similar to the phytoplankton changes, the zooplankton biomass has increased dramatically, while the number of species has fallen. Counts of individual zooplankton per liter in the 1950s indicated around 1,800 individuals/L (including rotifera, cladocera, copepoda and protozoa). That number increased to almost 23,000 individuals/L by the 1990s. At the same time, the number of zooplankton species has dropped by about 40%.

Changes in fish communities. The loss of macrophytes, the introduction of exotic species, and the general changes in water quality have had profound effects on the fishes of Lake Dianchi. The general trend is that endemic species are facing extinction/extirpation, and introduced species are developing into dominant ones, with the structure of fish communities becoming more simplified. As noted earlier, only 7 of the endemic species have been confirmed extant (GEF 2002). Since the 1950s, there have been over 30 different species introduced to the lake in the hopes of increasing the output of the lake's fisheries. Some of these introductions have not been successful. Others, however, such as the blue carp

Table 2. Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP) Loads to Lake Dianchi.

			1988	1995	1998	2000
COD (t)	Generated Load	Domestic	12,509	25,364	30,331	32,494
		Industrial	5,928	13,782	9,994	6,944
		Diversion	10,976	17,303	24,275	22,840
		Total	29,413	56,449	64,600	62,278
	Discharged load		29,413	41,674	52,930	43,957
TN (t)	Generated Load	Domestic	2,443	5,255	5,924	9,767
		Industrial	791	955	1,024	566
		Diversion	1,469	2,955	4,101	3,822
		Total	4,703	9,165	11,049	14,155
	Discharged load		4,703	8,981	8,956	10,939
TP (t)	Generated Load	Domestic	175	466	529	803
		Industrial	76	148	180	30
		Diversion	205	417	542	654
		Total	456	1,031	1,251	1,487
	Discharged load		456	1,021	1,133	1,321

Source: Kunming Environmental Protection Bureau and Kunming Institute of Environmental Science (2002).

Table 3. Total Species Numbers of Major Taxa in Lake Dianchi from 1950s to 1996.

Taxon	Year							
	Pre-1957	1958-1966	1977	1981-1984	1989	1992-1993	1994-1995	1996
Phytoplankton		154		175		93		
Zooplankton				157		92		
Crustacea (endemic)	1		1					2
Crustacea (indigenous)	3		2	2		2		2
Crustacea (introduced)	1		3	3		3		3
Macrophytes	34		31	21		19		19
Molluscs	69							29
Fish (endemic)	10	10		1			2	2
Fish (indigenous)	14	15		6			6	7
Fish (introduced)	1	26		24			25	19

Source: Lake Dianchi Aquatic Ecology Study and Survey (1996).
Note: Empty cells in the table indicate lack of survey for a given period.

(*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichithys molitrix*) and big head carp (*Aristichithys nobilis*) became dominant in the 1950s, resulting in a dramatic decline in endemic and native fishes by the 1960s. Other species subsequently introduced, such as the goldfish carp (*Carassius auratus auratus*), the salangid fish *Neosalanx taihuensis* and the minnow (*Cultrichthys erythropterus)* have, in turn, become dominant.

Changes to littoral habitats. A number of activities have had a negative impact on the littoral areas of Lake Dianchi. Examples include construction of a perimeter dyke around the lake, as well as reclamation of lakeside land for various human uses. Additionally, dredging for bivalve mollusks has damaged the macrophyte beds. Overall, the change in the lake's ecoenvironment has impaired or destroyed many of the spawning grounds and habitats for fish. In particular, the region along the east shore of Lake Dianchi has a high human population density, with intensive productive activities bringing much damage to the lakeside vegetation. There are still some areas, such as Huiwan Bay in the west of the Waihai part of Lake Dianchi, where a great number of macrophytes exist. Restoration activities in this area are described in Section 4.1.

3.3 Enhanced Sedimentation

When it was formed around 3 million or so years ago, Lake Dianchi was much larger, with an surface area of about 1,000 km^2 and a depth of more than 50 m. Although natural changes

led to a gradual decrease in area and volume, changes in land use over the last half century have increased the rate of erosion in the basin. Since the 1950s, the total sedimentation in the lake has been more than 50 million m^3, with the storage capacity decreasing by 210 million m^3. The annual loss of erosion materials averages about 0.377 million tons. The soil erosion on the mountains facing the lake directly results in sedimentation and reduction in the water area of the lake. Nitrogen and phosphorus carried by the sediments contributes to eutrophication of the lake.

3.4 Water Scarcity

Water scarcity also is a major issue. The annual per capita water resources in the Lake Dianchi drainage basin have decreased from 900 m^3 in the 1950s, to less than 300 m^3 now. In the basin, the gap between water demand and supply is about 100 million m^3 in average years and 200 million m^3 in dry years. This gap has to be balanced by the use of storm runoff and the reuse of wastewater and return flows from farmland. The current water demand is increasing, due to the expanding urbanization and rapid social and economic development. The rate of development and utilization of water resources has reached 60% in the drainage basin, exceeding the internationally accepted limit of 40%, which is the point at which excess water use is thought to cause destruction of the ecological environment. Decreasing water quality due to increasing pollution inputs also represents a form of water scarcity in the basin, in that the range of potential water uses decreases as the water becomes increasingly polluted, without pre-treatment of the water resources, which is typically time-consuming and expensive.

4. Management Environment

4.1 Lake Management Programs and Process

The severe problems outlined above in Section 3 have drawn much attention from the local, provincial and national governments, as well as from international organizations. At the national level, Lake Dianchi has been selected as one of the "Three Lakes, Three Rivers" targeted for special efforts. With the establishment of the Yunnan Research Institute of Environmental Sciences in 1978, more systematic and comprehensive studies of the lake have been carried out on a regular basis. It has been realized that no single approach or project can help prevent the problems of Lake Dianchi. In a feasibility study conducted in the early 1990s on the comprehensive renovation of Lake Dianchi's water quality, it was recognized that an integrated approach, including legal, administrative, and engineering interventions with increased funds (not only from the government, but also enterprises and all beneficiaries of Lake Dianchi) would be necessary to manage the Lake Dianchi drainage basin as a whole. An outline of this integrated approach is presented in Figure 5.

This integrated approach is a long-term, arduous, and complicated program, which must be implemented in phases. It provides the basis for the World Bank-financed Yunnan Environment Project, which is dominated by Lake Dianchi Basin Management, and incorporated in the Five-Year Plans for Water Pollution Control of the Lake Dianchi Basin.

A discussion on some of the specific programs/projects undertaken up to the present time is presented below. Again,

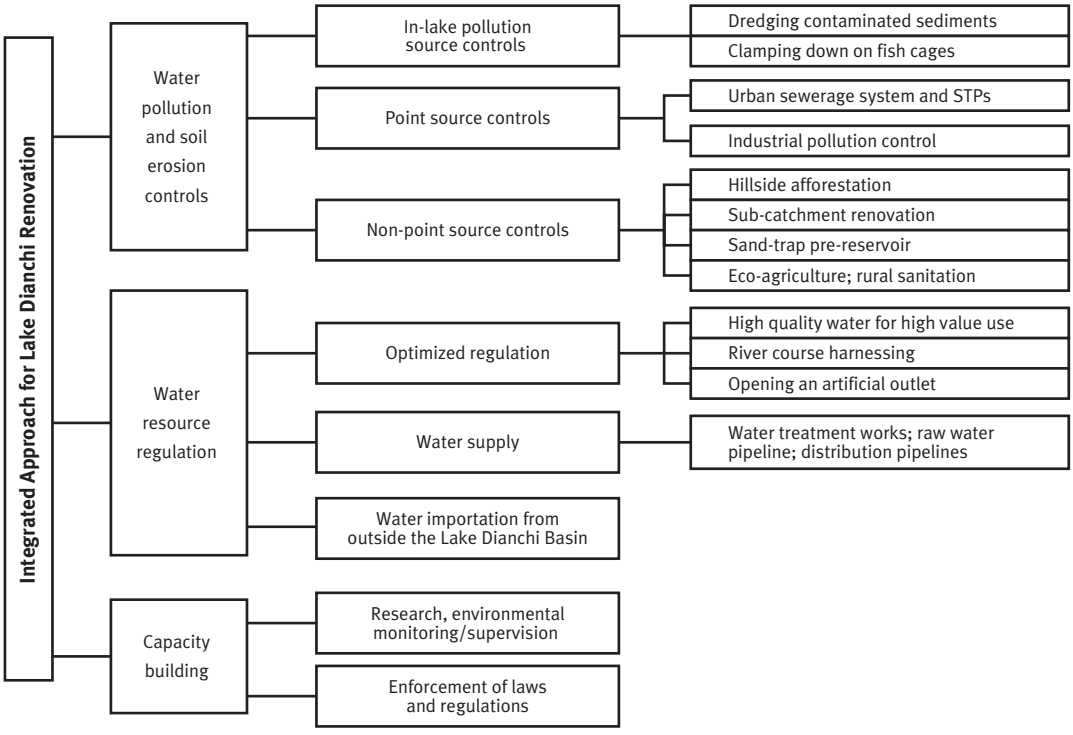


Figure 5. Integrated Approach for Water Pollution Control of Lake Dianchi.

many of the programs/projects detailed below are related to each other, so that the division between the programs given below should not necessarily be considered an indication of a lack of integration.

4.1.1 Local and National Projects

Since the National Government gave its commitment to clean up Lake Dianchi, the lake management has been increasingly strengthened, in terms of administration, enforcement of laws and regulations, and investment. By the end of 2003, a total of 3.536 billion Yuan (including part of the World Bank loan described below) was spent in support of the completion of a series of projects planned for the various five-year plan periods, as described in Table 4.

The implementation of projects described in Table 4 has resulted in the following:

Table 4. Cumulative Investment in Restoring Lake Dianchi (to the end of 2003).

No.	Project Name	Investment (100×10^6 Yuan)
I	**Completed Projects by the End of 2000**	
1	Point sources control and others	
1.1	4 sewage treatment plant (365,000 m^3/d), all secondary treatment process with high efficiency in removing nitrogen and phosphorus	4.2
1.2	Sewage interception along middle section of Panlong River bank and north bank of Lake Dianchi (300,000 m^3/d)	1.105
1.3	Domestic solid waste sanitary landfill (1,500 t/d)	1.2
1.4	Xiyuan tunnel (an artificial outlet)	2.43
1.5	River course diversion	1.5
1.6	"2258"water supply raw water transmission project inside lake basin	2.68
1.7	Interception of sewage along Daguan River and urban section of Panlong River; contaminated sediment dredging of Daguan River	0.3124
1.8	Industrial effluents compliance with discharging standard	1.845
2	Nonpoint source control	
2.1	Hillside afforestation, upland conservation, pilot eco-agriculture project covering 118,000 mu of farmland	3.05
3	Internal source control	
3.1	Harvesting of water hyacinth, removal of fish cages	0.25
3.2	Contaminated sediment dredging in the Caohai part (first phase)	2.5
4	Scientific research	
4.1	Demonstrative projects carried out in the scientific research program during the seventh and eighth five-year phases	0.17
	Sub Total	21.2424
II	**Continuation of Uncompleted Projects Planned for the Ninth-Five-Year Plan Period**	
1	Pollution control	
1.1	Rehabilitation of Kunming central urban area	1.61
1.2	Kunming western suburban sewer system	1.07
1.3	Upgrading and extension of No.1 Kunming sewage treatment plant and its sewers (up to 120,000 m^3/d)	1.00
1.4	Kunming eastern suburban sewage treatment plant and its sewers (50,000 m^3/d)	1.68
1.5	Kunming northern suburban sewage treatment plant and its sewers (75,000 m^3/d)	2.11
1.6	Chenggong small town sewage treatment plant and its sewers (15,000 m^3/d)	0.33
1.7	Jinning small town sewage treatment plant and its sewers (15,000 m^3/d)	0.35
1.8	Kunming domestic solid waste management	0.78
2	Ecological restoration	
2.1	Follow-up dredging of contaminated Caohai sediment	
3	Environmental supervision and management	
3.1	Lake Dianchi basin environmental monitoring system	0.23
4	Research pilot projects	
4.1	Rural sanitation pilot works	0.32
4.2	Technological research on the control of Cyanobacteria in Dianchi Lake and the control of nonpoint pollution sources in Lake Dianchi drainage basin	0.20
	Sub-total	11.01
III	**Implementation of the Project Planned for the Tenth-Five-Year Plan Period**	
1	Pollution control	
1.1	Cailian River diversion	1.78
1.2	Interceptor along upper stream of Panlong River	0.308
1.3	Interceptor along western bank of Dianchi Lake	0.305
2	Ecological restoration	
2.1	Return fish pond to lake body (phase I)	0.098
3	Environmental supervision and management	0.053
4	Survey and studies	0.60
	Sub-total	3.155
I+II+III	Grand Total	35.36

Source: Dianchi Administration Bureau.

- All the industrial polluters in the Lake Dianchi drainage basin have basically complied with the discharging standard;
- Water pollutant discharge licenses were issued to 777 industrial enterprises;
- Eight sewage treatment plants, with treatment capacity of 585,000 m^3/d, have been put into operation;
- A mixed sewerage system in the urban area, comprising trunk/main sewers and connections, has been established to bring the sewage treatment plants into proper functioning;
- The urban sewage treatment ratio in the dry season increased from 60% in 2000 to 80% in 2004;
- A number of the polluted rivers passing through Kunming City into the lake were diverted as sewage delivery systems;
- The interceptor at the north bank of Lake Dianchi can intercept 300,000 m^3/d of polluted river water from the urban area;
- Forest coverage in the drainage basin is up to 50.6%;
- More than 4 million m^3 of contaminated sediment were dredged, removing 8,230 tons of total nitrogen (TN), 1,885 tons of total phosphorus (TP) and 4,431 tons of heavy metals from the lake; and,
- There is a ban on phosphate-containing detergents in the basin.

Fish cages were ban was made in early 1990s by taking the recommendations made by scientists who were conducting research on eutrophication mechanisms of Lake Dianchi and found that fish fodder added to fish cages would release nutrients into the lake and might be one of the causes eutrophication. The ban was made as a Government Decree (Kunming Municipality), and was supervised by the Fishery Administration Division (which is now under Dianchi Management Bureau). At the beginning of the implementation of this ban, no fish cages could be seen, but some operators were still maintaining the cages underneath water surface. It took a certain period of time (about 3-4 years) for the Fishery Administration Division to find and remove all the cages.

The ban on the use of phosphorus detergent was first issued also as a Kunming Government Decree in early 1990s. It was not easy to implement this ban at that time because non-phosphorus detergent product were not available on the market, but the ban influenced domestic detergent manufacturers who started to shift from phosphorus detergent production to non-phosphorus detergent production. By the time that "Dianchi Protection Ordinance" was revised in early 2000s, non-phosphorus detergent products had nearly replaced traditional ones. Therefore, this ban was included as one of the clauses in "Dianchi Protection Ordinance" which was approved by the Standing Committee of the People's Congress of Yunnan Province on 21 January 2002 and was announced to be effective by the Standing Committee of the People's Congress of Kunming Municipality on 8 February 2002. There is a law enforcement team under Kunming's Dianchi Management Bureau who is implementing this ban by inspecting market products.

Until the Xiyuan tunnel project, all the water in Caohai flowed into Waihai via a lock and the water of Waihai flowed out through Haikou the Tanglang River near Haikou. The water quality of Caohai is inferior to that of Waihai, aggravating the pollution of Waihai. At the foot of the Xishan Hill to the southwest of Caohai, the Xiyuan Tunnel was built near the lock to divert some of the flow of Lake Dianchi. The water from Caohai and part of the Waihai water were discharged into the Jinsha River after being treated after passing through the tunnel. The project was completed in 1996. The Xiyuan Tunnel now acts as an additional exit of Lake Dianchi and has improved the flood buffering capacity and has led to better water quality in Waihai.

The "2258" project was conceived due to the deterioration of the water quality of the lake and the corresponding cost and difficulties in purifying water in waterworks which threatened the water quality of production and domestic use in Kunming City. Over 200 million Yuan were invested to channel 50 million m3 of unpolluted water from the Songhuaba Reservoir to provide drinking water for 800,000 people in the east, west and south suburbs of Kunming City. The project was completed in 1998, after which the proportion of drinking water taken from the lake decreased from 30% to 17.5%. This project reduced the supply from Lake Dianchi and alleviated the contradiction of supply and demand of drinking water in Kunming City.

On the basis of these efforts, achievements and lessons learned, the Tenth Five-Year (2001-2005) Plan for Water Pollution Control in Lake Dianchi Basin, approved by the State Council early this year, following the guideline of "pollution control, ecological restoration, optimization of resources allocation, supervisory management and scientific demonstration", established the framework shown in Figure 6. Under this framework, 26 projects with an estimated cost of nearly 8 billion RMB (nearly US$ 1 billion) were identified, aiming at reducing the total pollution load to Lake Dianchi by more than 20% of that entering the lake in 2000. In addition to controlling pollution sources, and other interventions similar to the previous plans, ecological restoration is particularly addressed in this plan, with the goal of returning water ponds, fish ponds and floodplain area to the lake body and restoring the lake shoreline ecosystem and aquatic ecology in parts of the lake water area.

Restoration of the lake's biodiversity is in the beginning stages. The first step will be based on achieving a reduction

in the pollution load to the lake, and then trying to restore the biophysical condition that was previously destroyed, in order to provide a foundation for the future biodiversity restoration. For the Tenth Five-Year Plan for Dianchi water pollution control, it was planned to return fish ponds, floodplains (about 4.5 km^3) and reclaimed farmland (about 15.3 km^3) to the lake, in order to re-establish the natural wetlands and constructed wetlands as a pilot project (for nutrient removal) along the lake shoreline. Other major activities are likely to be included in the Eleventh Five-Year Plan, which is now being developed. The GEF co-financed Lake Dianchi Freshwater Biodiversity Restoration Project (described below) is also contributing to the restoration of biodiversity in certain areas along the shoreline.

Finally, on the local and national level, there have been schemes to import water from external drainage basins into the Lake Dianchi basin. One water diversion scheme to bring water from the Zhangjiuhe River (a tributary of the Jinsha River) is already under construction (begun in 1999; expected completion in 2005/6), financed on the order of 4.0 billion Yuan from the Japanese Bank for International Cooperation (JBIC). Once completed, the project will bring in about 245 million m^3 of water into the basin for drinking water supply. Kunming City will then no longer be dependent on using water directly from the lake. Another plan, larger in scale, to bring in water from the Jinsha River, has had preparatory work incorporated in the Tenth Five-Year Plan to import water from outside the Lake Dianchi basin. Its long-term considerations have two objectives: One is to meet the demand for increased city water supply (particularly if urban development around the lake basin continues as predicted), while the other is to use the diverted clean water as so-called "ecological water" to "flush" the lake.

It is recognized that the second objective must be based on the substantial reduction of pollution abatement. The rationale for the second objective is that more water from outside will be useful in altering the lake water cycling, and shorten the water retention time (which is currently around 1,000 days), to benefit the recovery of the lake's water quality. It is a massive water engineering project, however, and would cost about 30-40 billion Yuan to divert water from 400 km away in the Jinsha River basin across a number of prefectures and river basins within Yunnan Province. Thus, there is some debate among experts regarding the merits of this scheme. Only the preparation activities for this latter scheme are budgeted in the Tenth Five-Year Plan. The Eleventh Five-Year Plan will probably provide a clearer picture on the development of this idea, which has so far eluded a consensus.

4.1.2 World Bank Co-financed Yunnan Environment Project (YEP)

The YEP was begun in March 1997 and concluded in 2004. The total project cost was around US$242 million, with approximately US$175 million for actions estimated to have positive effects related to the lake. The main project objective was "to provide a sustainable environmental framework for the longer-term economic and social development of the Province, while providing a foundation for competitive industrial growth." Specific components of the project included "Lake Dianchi Basin Water Quality Recovery" to improve catchment management by controlling both point and nonpoint pollution (including major investments in water and wastewater treatment infrastructure and solid waste management), "Industrial Pollution Control" with direct investment to abate pollution from the most threatening sources, "Environmental and Water Quality Monitoring" and "Institutional Development, Training and Construction Management". The Yunnan Environment Project Office (YEPO), established under the

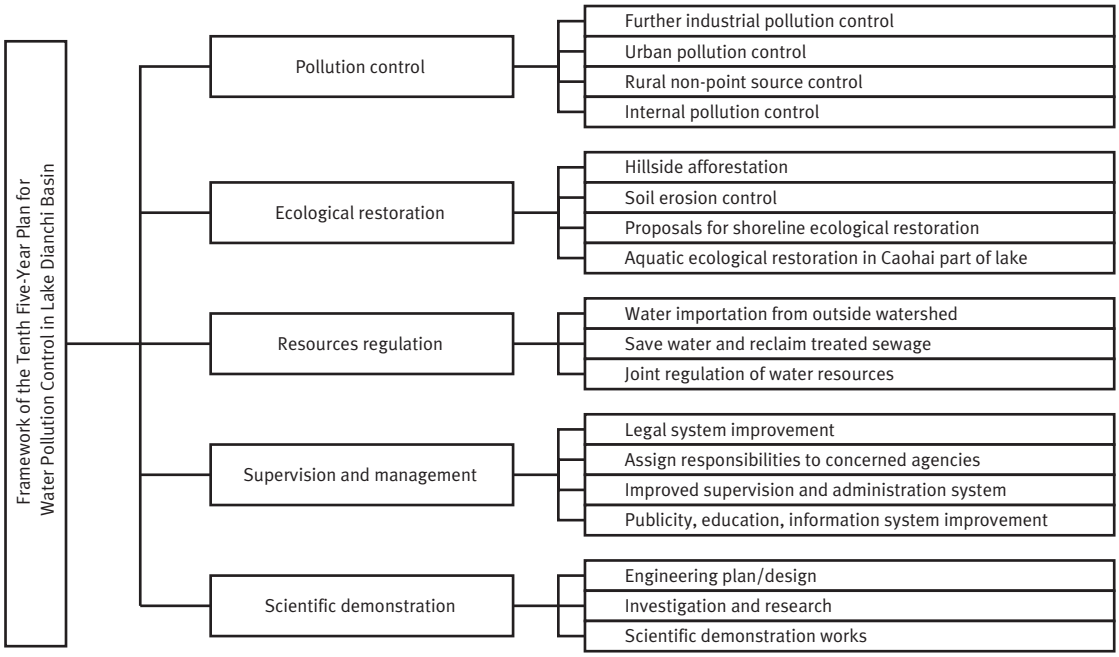


Figure 6. Framework of the Tenth 5-Year Plan.

leadership of a Yunnan Provincial Government Leading Group, coordinated the project. The effects of the YEP on the Waihai part of the lake are depicted in Figure 7.

4.1.3 GEF Co-financed Lake Dianchi Freshwater Biodiversity Restoration Project

Building on the results of the Yunnan Environmental Project, as well as the many other actions being taken in the Lake Dianchi basin, the GEF approved co-financing for the Lake Dianchi Freshwater Biodiversity Restoration Project. Begun in March 2003, this project is expected to last four years. The World Bank serves as the GEF implementing agency and the project is executed by the Kunming Institute of Zoology, which maintains most of the biological collections from the lake. The objective of the GEF project is "to restore and manage habitats around the lake in order to secure the conservation of the remaining endemic species of Lake Dianchi and its immediate tributaries." To achieve this goal, the project has four main components, with the following indicators of success (taken directly from Project's proposal document):

- Component 1. Wetland Management and Restoration: At least three lengths of shoreline remodeled, planted with macrophytes, and re-populated with bivalve mollusks;
- Component 2. Surveys, Monitoring and Species Conservation: Rigorous monitoring protocols established, regular monitoring undertaken, and recovery plans written for selected species;
- Component 3. Capacity Building and Training: Suitable trainees identified and provided with appropriate, wetland management-oriented training in-country and overseas; and,
- Component 4. Public Awareness and Environmental Education: Knowledge, attitudes and behavior surveys undertaken and awareness messages identified and disseminated, and lakeside Visitor Center with displays established.

Given the early stage of this project, it is difficult to speculate about the effects it may have on the lake, although all indications are that it will definitely be positive. One of the key risks for the project is that any benefits related to biodiversity conservation and restoration will be overwhelmed by continued deterioration of Lake Dianchi's environment. The GEF project assumes that the "tide" has been turned for Lake Dianchi (in part because of the major YEP project and other actions described above) and that now is an opportune time to act.

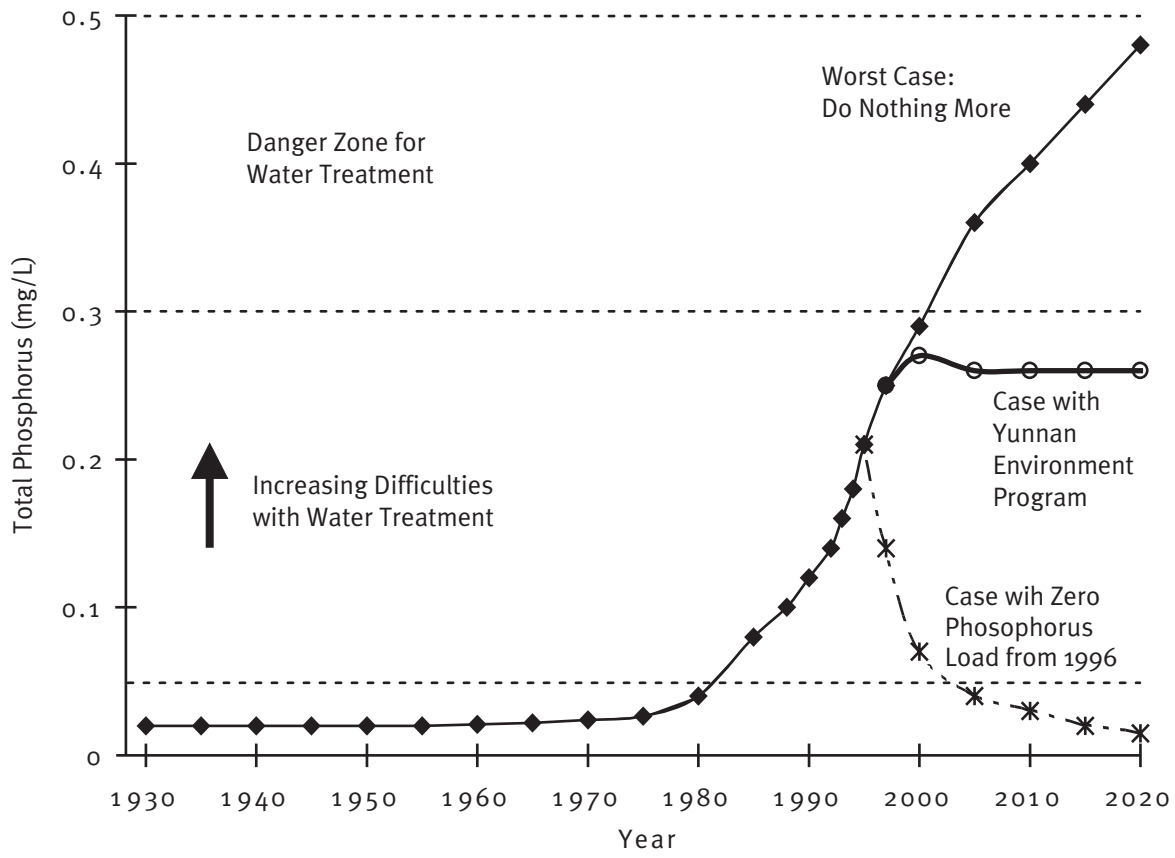


Figure 7. Scenarios for Total Phosphorus in the Waihai Part of Lake Dianchi.

4.2 Reduction of Lake Stresses

Table 2 in Section 3.1 clearly shows the very positive signs of a growing difference between the quantity of COD, TN and TP generated versus the actual pollutant load that makes it to the lake. In 1988, when virtually no pollution control was carried out, all of the generated pollutant load was assumed to make it to the lake. By 2000, approximately 30% of the COD load, 23% of the TN load, and 14% of the TP load were being "captured" before making it into the lake. The fact that over the same period the COD loading to the lake increased by approximately 50%, the TN load by 233% and the TP load by 290% illustrates the tremendous pressure that has developed in recent years. This pressure obviously would have been worse without the actions described in Section 4.1; it also is reasonable to expect that, in the future, the percentage of pollutant load that receives treatment will substantially increase. The future of Lake Dianchi depends on how these factors manifest themselves.

4.3 Environmental Status

Because of the nature of lake ecosystems, it is difficult to observe the effects of management actions over the short term. Given that many of the problems and attempted solutions for Lake Dianchi have been recently addressed, it is not possible to predict the potential effects on the lake with certainty. Figures 4a, 4b and 4c on COD, TN and TP concentrations (up to 2001) indicate that the COD concentration has perhaps been decreasing, but that the TN and TP concentrations are still increasing. This is consistent with the loading data presented in Table 2; however, given the nature of shallow lake ecosystems and the long lag time for lake response, it is not possible to say with certainty whether or not the situation for Lake Dianchi is improving vis-à-vis COD and nutrients.

It can be noted that pollution of the Caohai part from arsenic and heavy metals has been effectively controlled, with the arsenic level improving from its previously "worse than grade V" to "better than grade III". There are also reports that the malodorous condition in the Caohai part of Lake Dianchi has significantly improved.

Water hyacinth used to be a major problem as it covered a large lake water surface area. This supported many flies and mosquitoes, had a seriously impact on the lake landscape, and blocked navigation routes as well as prevented the sunlight from reaching into the water column. Furthermore, water hyacinth it released nutrients into the water column when it died. Since the late 1990s, many efforts have been made to control it including a government-initiated citizen's movement to harvest the hyacinth, and later on, actions under the Dianchi Fishery Administration Division of the Dianchi Administration Bureau to hire local farmers to continuously harvest the plant when it reappears on the lake. Consequently, water hyacinth became less of a problem. There have even been suggestions to plant water hyacinth on the enclosed water area and to regularly harvest this hyacinth in order to use the plant to removal nutrients from the water column; however, this suggestion has not been put into practice because of the final disposal or re-utilization of harvested hyacinth is a problem.

4.4 Enabling Environment

4.4.1 Political Commitment

As urban areas such as Kunming City developed, prospered and are now expanding around Lake Dianchi, their existence, economic development and future are very dependent on the lake. The lake's degradation increasing has become a key constraint for sustainable socio-economic development. Being aware of the importance of the lake, the Government of Yunnan Province, after having a conference and consultation with scientific researchers and experts, made a commitment in 1992 to undertake comprehensive efforts with stronger government financing to renovate the environment of the Lake Dianchi drainage basin. The National Government includes Lake Dianchi as one of the "three targeted lakes" for water pollution control. The preparation of water pollution control plans for the Lake Dianchi drainage basin is required once every five years, and must be approved by the State Council (national level). These have become an important basis for local governments and government sector agencies to take actions to control water pollution in the Lake Dianchi drainage basin.

4.4.2 Institutional Framework

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

- Publicizing the national laws, regulations and enforcement of Dianchi Protection Ordinance, and coordinating, inspecting and urging relevant counties/districts to protect Lake Dianchi legally;
- Organizing the formulation, implementation and supervision of plans, and comprehensive cleaning-up programs for Lake Dianchi protection and utilization;
- Setting up objective responsibility for cleaning up Lake Dianchi and for 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 enforcement of the management;
- Partially officiating administrative punishment of water resources, fishery, navigation, and water environmental protection plan violations; establishing a special administrative team to enforce comprehensively relevant laws and regulations;
- Officiating inspection of the enforcement of laws and regulations related to Lake Dianchi protection;
- Being responsible for initial review of Lake Dianchi pollution clean-up projects and being involved in identification of project clients and supervising implementation of the projects;
- Being involved in reviewing any development projects to be located in the Lake Dianchi drainage basin and developing review comments;
- Being responsible for collecting, managing and utilizing Lake Dianchi clean-up funds; and,
- Undertaking other works assigned by the People's Republic of China and Dianchi Protection Committee.

Special management sub-agencies in counties and urban districts located within the Lake Dianchi basin also are established. Under the unified coordination, direction and supervision of Dianchi Administration Bureau, they will be responsible for the protection, management and enforcement of laws and regulations in their respective administration regions. Figure 8 provides a schematic view of the institutional framework.

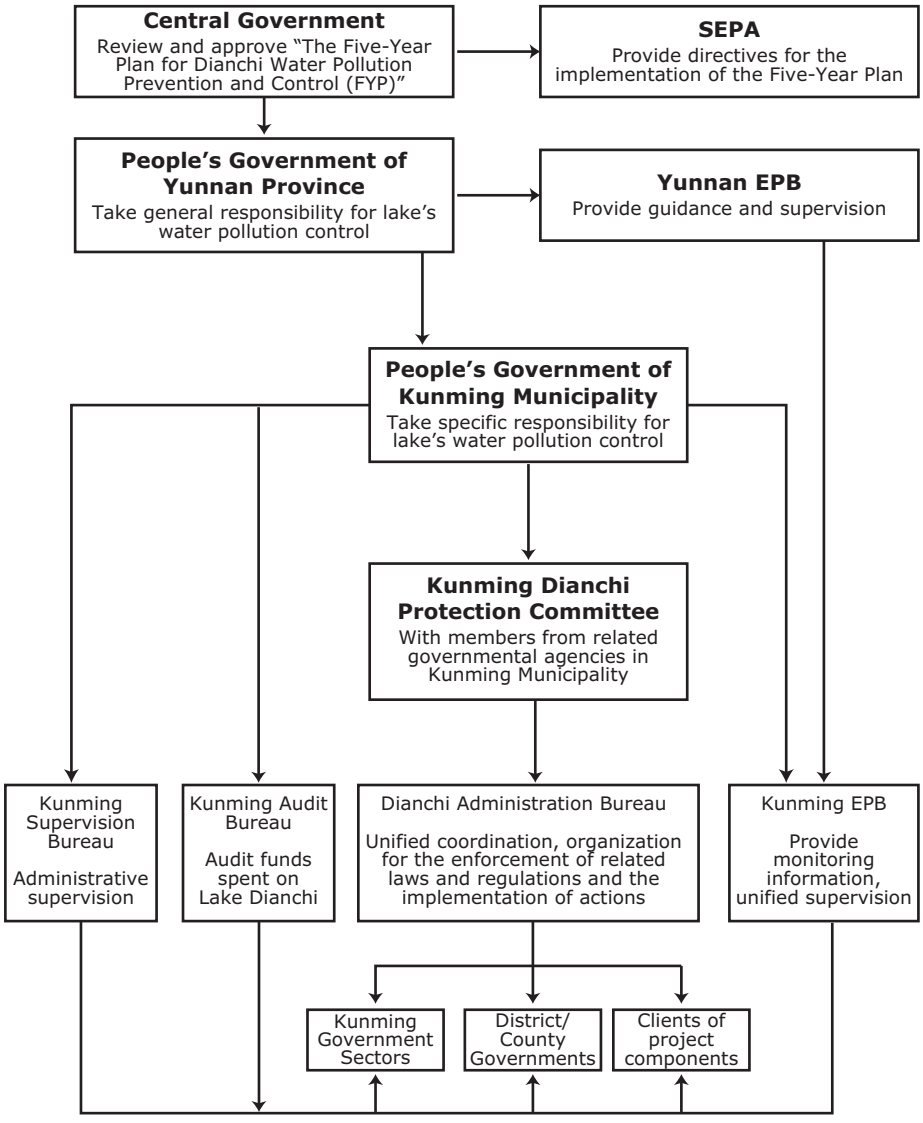


Figure 8. Institutional Framework.

Compared to other lake basins around the world, it may be fair to say that there has not been very much conflict between local, provincial, and national institutions with an interest in Lake Dianchi. One reason may be that the lake basin lies wholly within the jurisdiction of Kunming Municipality, thereby avoiding any debate or conflict over the boundaries (although, of course, there are several counties/districts which share the lake basin). Additionally, at the national level, Lake Dianchi has been selected as one of the "Three Rivers, Three Lakes" program, so all interventions are guided by the Five-Year Plans, which is approved by the State Council. Among local institutions, there naturally has been competition for authority over various management issues, with a reluctance to share responsibility for problems. It is not thought, however, that this "sectoralism" has led to any serious impediments to managing the lake basin.

4.4.3 Legal Framework

Figure 9 provides an overview of the national and local laws and regulations comprising the legal basis for management in the Lake Dianchi drainage basin.

4.4.4 *Involvement of Stakeholders*

Involvement of Citizens. Citizens can easily access a governmental website, on which the monthly water quality monitoring data and daily air quality monitoring data are available. Public dissemination programs and news are often shown on television and radio, as well as being published in newspapers.

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

Before making decisions that may affect local residents' daily lives (e.g., charging/increasing tariff for water, wastewater and/or solid wastes; new ideas for the city master plan), the government will organize a public hearing. When the government banned the use of phosphorus in detergents, for example, informational brochures were widely circulated,

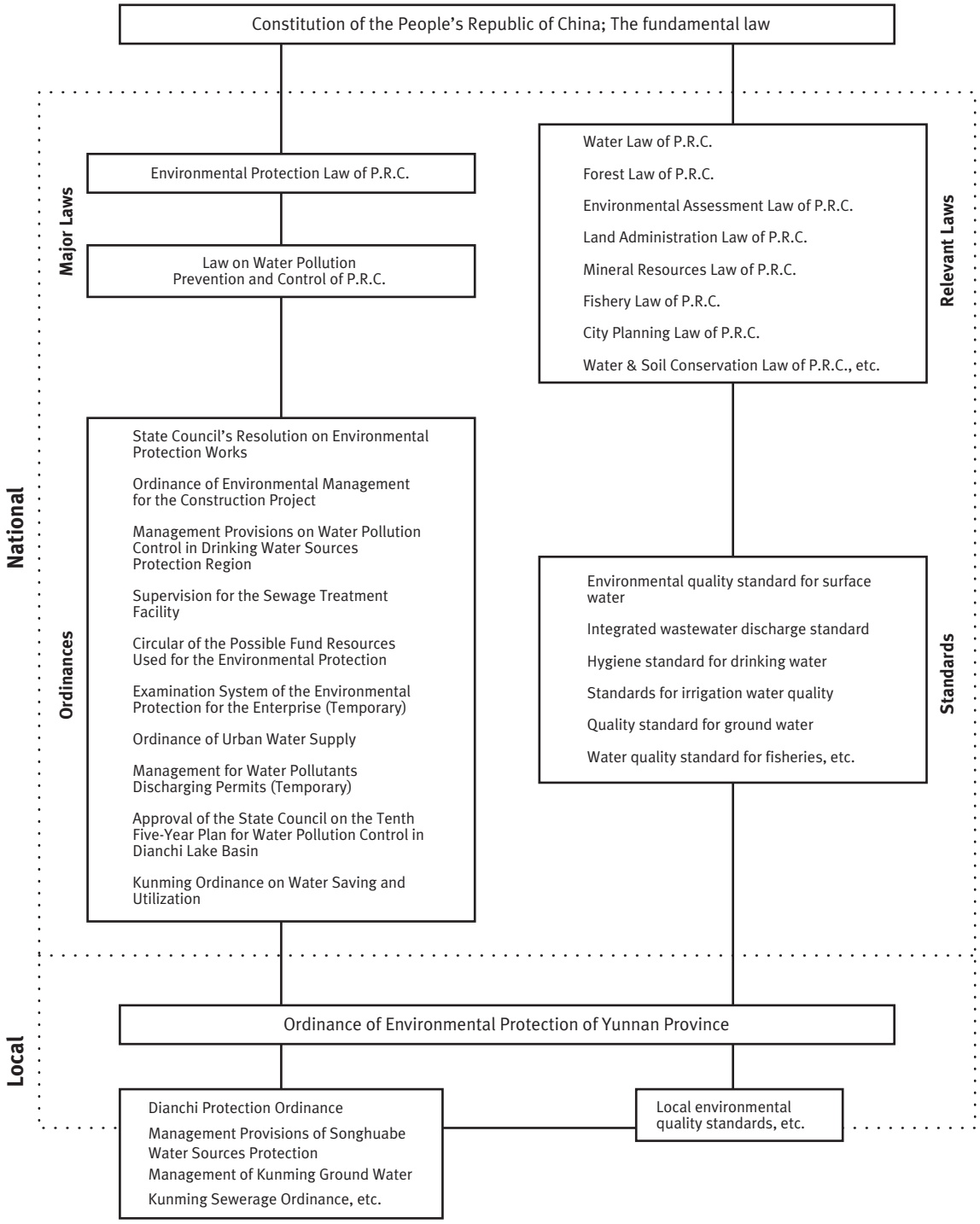


Figure 9. Legal Framework.

and labeling of non-phosphorus detergents products sold in stores was carried out. Gradually, residents voluntarily bought detergents free from phosphorus.

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

Involvement of NGOs. A number of academic and social associations/societies have long been involved in consultations between Government and NGOs. Every year, during the People's Congresses at either the provincial, Kunming Municipal or even urban district levels, many bills and proposals related to Lake Dianchi are proposed, some becoming formal government decisions.

There also are some NGOs (e.g., Green Watershed, Dianchi Research Society) actively engaged in promoting the Dianchi Forum, a discussion between government agencies, scientists and lay citizens.

Involvement of Industries. According to the Dianchi Protection Ordinance promulgated in 1988, no new industries that consume large volumes of water or discharge excess pollutant loads are allowed within the Lake Dianchi basin. Existing industrial polluters are charged a pollution levy if their effluent exceeds 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", the Environmental Protection Departments at the Provincial and Municipal levels jointly carried out a "Zero O'clock Action" to force 253 major polluters located in the Lake Dianchi basin to bring their polluting activities under control before 1 May 1999. In this action, 249 polluters achieved their pollution control requirements under the National Discharging Standard. Four polluters ceased operation by shutting down or relocating. This achievement has provided a solid foundation for all industrial polluters in Kunming Municipality to comply with the National Discharging Standard in 2000. The industries, when taking actions to control discharging pollution, were provided with loans from government generated from the collection of pollution levies, plus governmental special funds for environmental protection. If subsequent evidence proves that industries' actions enabled them to comply with the discharging standard, their loan(s) could became a grant without payment.

5. Lessons Learned

5.1 Lack of Sustainable Development Strategy

For a long period, the eco-environment and economic development of the Lake Dianchi drainage basin were not properly harmonized; development was vigorously pursued, while environmental protection was nearly neglected in the past. In short, economic growth occurred at the cost of environmental quality and sustainability. Thus, the pollution and eutrophication of Lake Dianchi reflects the conflicts between resources, ecology and socio-economic development. To fundamentally solve this pollution problem, there should be more comprehensive mitigation measures, combined with the implementation of plans for urban development, land use, and industrial restructuring on the basis of a sustainable development strategy. Figure 10 shows the interactions between the causes and effects of Lake Dianchi's degradation.

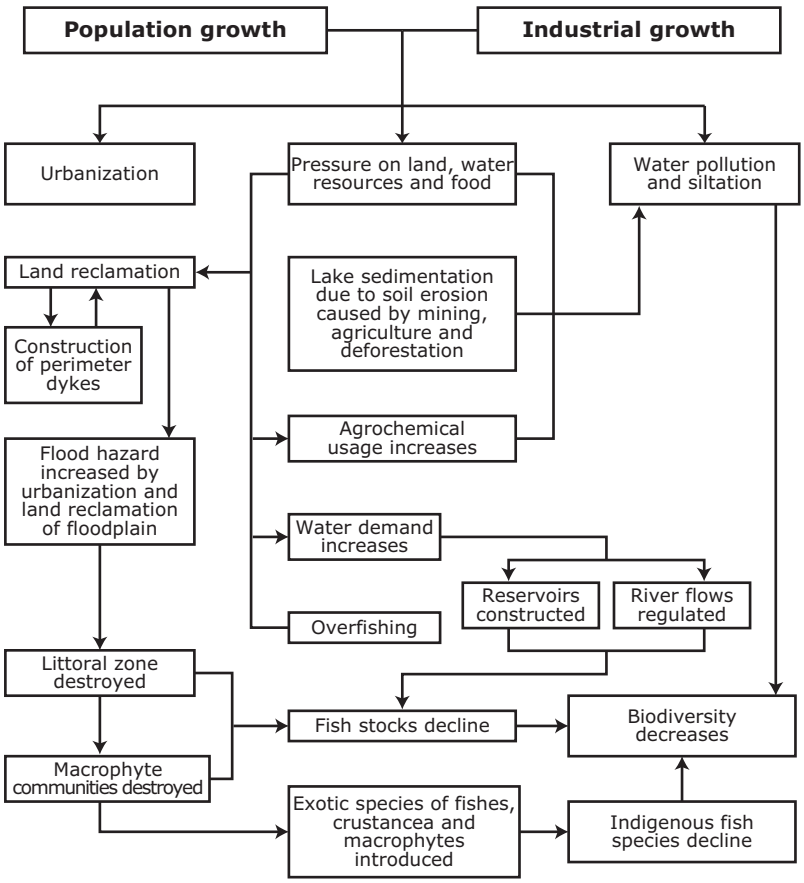


Figure 10. Interactions between Cause and Effect in Lake Dianchi's Degradation.

5.2 Insufficient Awareness of the Long-term, Arduous and Complicated Task

Due to the weakness in such fundamental elements as scientific data, monitoring programs and research, the diagnosis of the environmental issues of Lake Dianchi is insufficient to provide a scientific basis for establishing realistic protection goals. The phased objectives set forth in the Ninth Five-

Year Plan for Water Pollution Control in the Lake Dianchi Basin were too ambitious to achieve. Although the efforts made during 1995-2000 slowed down the tendency to continuous deterioration, the hyper-eutrophication of the lake and the related ecological devastation has not yet been substantially reversed.

5.3 Insufficient Awareness on the Ecological Fragility of Lake Dianchi

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

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

These adverse impacts have resulted mainly from the expansion of the urban population in the drainage basin and ever-increasing human control and intervention in the natural water cycle. These developments in the lake basin have drastically and, in some instances, irreversibly, altered the natural lake ecosystem. Lake Dianchi has become more comparable over time to a man-made regulated reservoir than a natural lake. The loss of wetlands along the shoreline because of intensified economic development activities and over-reclamation of lakeside and floodplain have caused the loss of the lake's natural barrier, resulting in extreme fragility of the lake's ecology.

5.4 Increased Pressure from Population Growth

Domestic sewage is still the major pollution source to Lake Dianchi. While the constructed urban area in Kunming occupies only 5% of the Lake Dianchi drainage basin area, the pollution loads from the city make up half the total load to the lake. Furthermore, the population growth in the city is booming. Without appropriate control measures, the increasing population will impose stronger pollution pressures on Lake Dianchi, even if all the urban sewage were collected and treated (e.g., the total phosphorus concentration of 1.0 mg/L in the treated effluent from secondary sewage treatment plants is much higher than 0.05 mg/L, the standard for grade III, the minimum grade for a drinking water source).

5.5 Delays in Some Key Project Activities

The construction of some key engineering projects, including sewage treatment plants, Kunming central urban sewage rehabilitation, harness of river courses, have been delayed much longer than initially anticipated, further exacerbating the situation whereby pollution controls cannot keep up with pollution generation.

5.6 The Impacts of Resource Development: Mining and Processing were Not Significantly Addressed

Although some efforts were made in afforestation, the newly-established forestlands are covered with small trees with lower shadows. Mining operations, particularly phosphorus ore at the southern end of the lake, done via top-soil stripping and open-cast methods, have caused serious soil erosion. The eroded soil, containing high phosphorus levels, flushed with runoff through inflowing rivers has become a major nonpoint pollutant load to Lake Dianchi. Further, the processing of phosphorus ore by small townships and village enterprises is still not well controlled by government agencies.

5.7 Insufficient Scientific Research

Few data are available on the ecology of Lake Dianchi. Most biological data are from the 1950s and 1988-1989, and focus on macrophytes, plankton, fish and benthos. The spatial and temporal variation of these organisms is usually unknown because most have been summarized only in regard to their quantity. It is also unfortunate that adequate water quality and ecological data from the 1960s and 1970s is lacking. As a result, the historic sequence of events leading to the present poor water quality and degraded ecology of Lake Dianchi cannot be well reconstructed. This is especially unfortunate because this historic perspective could have been helpful in deriving measures for restoration or for assessing the feasibility of these measures. In addition, there is a lack of information-sharing among the concerned agencies/institutes.

5.8 The Financing Mechanism and Subsidies for Management Activities Focusing on Sustainable Lake Use

Co-financing is the most important financing mechanism for cleaning up Lake Dianchi. The sources of funds contributed in the past, and for the future, include:

- Funds allocated from the Chinese Central Government;
- Funds allocated from the Yunnan Provincial Government;

- Funds allocated from the Kunming Municipal Government;
- Funds from World Bank loans/credits;
- Funds from the Global Environment Facility (GEF);
- Funds from bilateral confessional loans;
- Loans from the State Development Bank of China;
- Loans from local commercial banks;
- National treasury bonds;
- Yunnan Government special funds for environmental protection; and,
- Funds raised by companies/enterprises and real estate development firms.

To sustain the operation and maintenance of the environmental infrastructure, and the repayment of debt services incurred from the World Bank and bilateral loans, the Governments of Yunnan Province and Kunming Municipality, under the guidance of the Central Government, have begun to charge a tariff for water resources, centralized water supply, wastewater, and domestic solid waste at a level that could generate revenues to cover at least the operation and maintenance costs and, hopefully, even the loan interest and principal. The utility companies are asked to make financial projections, based on audited financial statements. If the financial projections show any substantial deficit that may threaten the financial viability of management activities, the government will consider adjusting the level of tariff or taking actions to reduce costs.

5.9 Some Recommendations

- There is a need to formulate relevant policies or regulations to harmonize resources, population growth and environmental protection, because the Kunming City has been, and will be, growing without full consideration of the constraints of the Lake Dianchi drainage basin environment (in terms of the carrying capacity of land resources, water resources and pollution load capacity).
- The farmland along the lake's shoreline has been defined as the "fundamental farmland" that should be protected. Returning the farmland to the lake body for the purpose of lake shoreline ecological restoration, however, seems to be in conflict with the policy for the protection of fundamental farmland.
- Water tariffs (including water and wastewater) should be market-oriented to promote the movement of wastewater management business towards the market (the World Bank has promoted this approach in implementing the YEP project).
- There should be incentives to encourage developers to build up ecological residential gardens and ecological residential quarters.
- There is a need to have technical directives to encourage the promotion of clean production, the application of advanced treatment technology, the reuse of treated wastewater, the economic use of water resource, and the replication of ecological restoration technology.
- There is a need to restructure and optimize the industrial sectors in the Lake Dianchi drainage basin.
- There should be some restrictions on the rights to approve and manage phosphorus mining.
- Efforts to recover vegetation on mining sites should be compensated and inspected.

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