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Inner Mongolia Lake Restoration Project
Lake Wuliangsuhai Comprehensive Study Extension

Final Report

Norwegian Institute for Water Research

– an institute in the Environmental Research Alliance of Norway

REPORT

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Abstract

Lake Wuliangsuhai is the 8th largest lake in China and only 170 km^2 of 300 km^2 is at present considered as open waters due to widespread reed vegetation. The massive pollution loads from domestic, industrial and agricultural sources threats the existence of the lake. A collaboration project was implemented to study the lake status, trends and threats and to propose Management and Control Plans to secure the lakes existence as a lake. This report provides an overview and results from one of the sub-projects.

This report provides the most important details of the project implemented and the results making specific findings and recommendations. Ten major actions for the lake restoration are proposed and reviewed. A ranking of actions according to environmental, economic, social and institutional goals and cost-benefit reasoning are presented. The proposed actions sum up to an investment of 0.8 billion RMB (about 1.5 billion RMB annual costs), excluding the investments on agriculture pollution reduction. Implementation of these actions will enable careful management of the living resources of the lake, ensuring maximum public benefit and guaranteeing perpetuation of these resources.

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Inner Mongolia Environmental Science Institute

Inner Mongolia Lake Restoration Project

Final Report

Preface

Lake Wuliangsuhai is the 8^{th} largest lake in China and is the largest freshwater lake in the north-western region. Although it has a total area of about 300 km^2, only 170 km^2 is at present considered as open waters due to widespread reed vegetation. The massive pollution loads from domestic, industrial and agricultural sources as well as increasing vegetation threats the existence of the lake.

A collaboration project with the participation of Chinese, Swedish and Norwegian scientists was initiated to study the lake status, trends and threats and to propose Management and Control Plans to secure the lakes existence as a lake. This is the summarised version of the Management and Action Plans.

Basis for this report was provided by a large number of specialists and stakeholders from the three countries. Actions were identified, analysed and ranked with a broad stakeholder involvement. The final versions of this summarised report as well as the sub-project reports are only consolidated versions of a great number of working documents. The editors wish to acknowledge the valuable contributions by various persons in fulfilling this task. We also greatly appreciate the financial assistance provided by the Governments of China, Sweden and Norway, as well as the contributions from the three lead institutions: Inner Mongolia Environmental Science Institute, Swedish Environmental Research Institute and Norwegian Institute for Water Research.

Abstract

The overall aim of the project is to assist the exploitation, management, protection, and restoration of the natural resources of the Lake Wuliangsuhai, while keeping it as a lake; a functional wetland with high biodiversity. The XIth 5-year plan of the People's Republic of China defines the restoration of the Lake Wuliangsuhai as a priority. The various sub-reports presented in this report pertain to the required activities of the project. The project realises that Lakes' management issues are addressed by many institutions, and is complex.

The Lake Wuliangsuhai serves as a source of income for several local stakeholder groups who have rights to harvest fish, reed and other natural resources. These groups together with local authorities have implemented some management measures to regulate their harvest, restore, and enhance natural resources. Pollution from various sources including agriculture, urban sewerage and industry is a problem. Thus, loading of nutrients (phosphates and nitrogen), dissolved organic matter and mineral salts to the lake is an important issue to be addressed, as it affects a number of different sectors, and have many side- or secondary effects.

Overall, exploitation, management, protection, and restoration of Lake Wuliangsuhai pose unique challenges. One of the challenges is to balance the competing demands of the lakes' resources involving various stakeholders. This involves the need to satisfy the various user interests while at the same time sustain or restore both the water quality and the biodiversity in the lake. Scientific challenges include questions concerning the applicability of site-specific data to understand natural resource problems at the sub-basin, basin, or whole lake levels. Other challenges are the lack of long-term data collection programs and the use and compatibility of data from various sources and time periods to understand ecosystem health trend analyses.

The Lake Wuliangsuhai Lake Restoration Project is a complex programme, and the potential measures were identified during a stakeholder workshop in 2003. These measures were further elaborated and grouped into 10 management and control measures (MCP). These include 1.Urban Sewage Treatment; 2. Industrial Waste Water Treatment; 3. Increasing Depth by Dredging; 4. Harvesting Submerged Vegetation and Utilisation; 5. Reed Bed Control and Utilisation of Mud; 6. Keeping Water Level High; 7.Natural Pre-Treatment and Moving Inlet Pont; 8. Erosion Control; 9. Agricultural Pollution Management; and 10. Improvement of Internal Circulation. These various MCPs simultaneously address the most important issues to better understand and rehabilitate the lake ecosystem.

Most part of the lake has water qualities belonging to the Class IV and V of the Chinese classification system. The intention is to improve the status at least to the Class III. In order to achieve this, reductions of 47 % of organic matter (8,750 t/a), 72 % of phosphorous (76 t/a) and 52 % of nitrogen (873 t/a) are required. The analysis show that the proposed domestic and industrial wastewater treatment plants can reduce the pollution loads to by far to the above required levels. The phosphates need to be reduced further by 13 t/a or 12 % and nitrogen by 254 t/a or 15 %. Both these targets are easily achievable with a well functioning wetland, which is also proposed. The domestic and industrial wastewater treatment requires 310 and 10 million RMB, respectively.

This report provides the most important details of the study undertaken and the results making specific findings and recommendations. A Multi-Criteria Analysis (MCA) has been performed to rank the preference of the stakeholders to prioritise the environmental, economic, social and institutional goals. A ranking of actions according to cost-benefit rations are also suggested.

The fact that the restoration of the lake is proposed as a specific issue in the next 5-year plan is a significant acknowledgement. However, most of these funds need to be secured externally through bi- or multi-lateral loans. Considering the ownership of the action, it is recommended the following financing structure:

- Industries should bear 100% of the investment costs
- Municipal WWTP: 30% from the local government and the enterprises
- Other costs and measures: loan and investments from the Inner Mongolia government and central governments as well as donors

The proposed actions sum up to an investment of 0.8 billion RMB (about 1.5 billion RMB annual costs), excluding the investments on agriculture pollution reduction. For the domestic wastewater treatment plants, the total investment is about 310 million RMB, indicating a need of over 200 million RMB as loans. The industries have a relatively lower investment burden of 10 million RMB, provided the Haojiang paper mill will remain closed. Otherwise, heavy investments will be required.

The ranking of the proposed actions can be carried out using various approaches. A logical approach would be to:

- actions to reduce the pollution loads to the lake
- actions within the lake which reduces pollution
- actions to secure sufficient quantities of water to control vegetation, provide favourable dilution and to improve biodiversity, etc
- actions to sustainable utilisation of the lake's resources

Such an approach is widely utilised by internationally and in China, and are well in agreement among the Chinese, Swedish and Norwegian specialists. The following ranking was identified as rational according to this approach.

1. Industrial wastewater treatment (all)
2. Wuyuan wastewater treatment
2. Linhe wastewater treatment
2. Hanghou wastewater treatment
3. Yellow River water supply and lake level increase
4. Moving of inlet and wetland construction
5. Harvesting submerged vegetation and utilisation
6. Reed bed control
7. Erosion control
8. Agricultural pollution abatement
9. Improvement of internal circulation
10. Dredging (all)

Implementation of study recommendations will enable careful management of the living resources of the lake, ensuring maximum public benefit and guaranteeing perpetuation of these resources. Agreed-upon goals and objectives will be realised as the health of fish resources improves. When viable and productive stocks of native and other desired fish species are available, birds successfully visit the lake and reproduce in high species numbers, chemical and other stress-induced deformities in fish and wildlife are eliminated, fish can be consumed with little or no risk to human health, and growth of reed etc. provide the local communities with employment and income, then restoration goals for the lake will have been met.

Contents

1 INTRODUCTION

1.1 Justification/Rationale

The Government of Inner Mongolia recognises the need for restoration of the lake Wuliangsuhai, the eight largest freshwater lakes in China, whose existence as a lake is now threatened due to various reasons. The restoration of the lake is recommended to be defined as a specific action in the XIth 5-year plan.

Inner Mongolia Environmental Science Institute (IMESI), with the auspicious of Inner Mongolia Science and Technology Committee and the State Science and Technology Commission (SSTC) and the financial contribution of the governments of Sweden (Sida) and Norway (NORAD) has launched a project to scientifically elaborate the status, problem and actions. The project had a financial frame of about 40 million RMB over a 10-year period.

The project is completed in 2005 and the findings are documented in a series of Project Reports, together with various working documents.

Inner Mongolia and the rest of northern China suffers from water scarcity to varying extent, as a result of the rain-shadow behind the Himalayas. It is therefore of great importance to appreciate and protect available water resources.

Lake Wuliangsuhai, situated just north of Yellow River's Great Bend, is the largest lake in the Yellow River basin. As such it is at the same time unique and representative for shallow grassland lakes; there are specific characteristics due to the size of the lake as well as challenges and opportunities common for many of the lakes in northern China. Lakes in dry regions are multifunctional, resulting in competing, possibly conflicting, interests. These must be managed in a rational and sustainable way not to cause extensive environmental damage or hampering necessary social and economical utilisation of resources.

The natural values of Lake Wuliangsuhai are very high and the lake is a remarkably rich bird habitat for both migrating and nesting birds. A large water body like this is also important from a microclimate point of view, facilitating surrounding vegetation and soil conservation. At the same time it functions as a valuable exploitable resource for the people living in the region, supplying them with irrigation water, reed to harvest and fish to eat. Lake Wuliangsuhai is a pollution sink, acting as an important buffer for downstream Yellow River. Without the lake, Yellow River would receive the entire pollution load from the Hetao area. It is from a combination of these different perspectives the rapid changes of the lake over the last decades should be viewed; this set of expectations defines what in the current situation constitutes a problem.

There is a real threat that the lake's ecosystem will collapse within a foreseeable future, with dramatic consequences for the neighbouring communities. This grim scenario is the result of mainly three, interrelated, processes:

- Reed gradually occupies a larger part of the surface area of this shallow lake
- Severe water pollution from agriculture, industry and domestic sources and resulting deterioration of lake water quality
- Salt accumulation due to the combination of the irrigation technique and climatic factors
- Erosion in the local catchment
- Conflicting interests between users of lake resources
- Decreased inflow due to restricted volume of irrigation water to be diverted in the future.

Thus, there is a dire need for actions relieving Lake Wuliangsuhai from the immediate threat as well as long-term commitment of managing this precious resource. This should be done both for the sake of Lake Wuliangsuhai and also for all other grassland lakes that can benefit from the knowledge and experiences gained from this project.

The material presented here is developed by a group of Chinese specialists and stakeholders in collaboration with the Swedish and Norwegian consultants. The basis for the presented material is separately organised as a series of internal working documents, available with IMESI.

1.2 Objective and outputs

The overall aim of the project is to assist the exploitation, management, protection, and restoration of the natural resources of Lake Wuliangsuhai. By achieving this, the lake will develop into a productive resource for future sustainable development of the Hetao area. This has been phrased as the main goal of this project: “keeping the lake as a lake”.

A prerequisite for this aim is to facilitate the establishment of sustainable water usage in the Hetao. This includes many different aspects, not all of which can be concretised. The project has nevertheless stated a set of objectives required for reaching the overall aim:

- The main delivery of the project is a proposed management and control plan (MCP). This addresses how to manage the conflicting interests that affect the eutrophication process of Lake Wuliangsuhai and to suggest actions to keep the lake as a productive resource.
- Lake Wuliangsuhai’s water will reach class III, according to Chinese water quality standards for lakes.
- The project will establish a maintainable knowledge base on the natural and societal processes affecting the water quality and quantity.
- Furthermore, the project will qualify Chinese personnel in relevant topics and skills.

2 CHARACTERISTICS OF LAKE WULIANGSUHAI

2.1 General description

2.1.1 Geography of the catchment

The large and shallow Lake Wuliangsuhai, situated in the Autonomous Province of Inner Mongolia, P.R. of China, is the largest internal lake in the north-west China, and no. 8 in surface area in China. It is an important and unique ecosystem in the vast semiarid grassland region and has multiple functions of climate buffering, bird refuge, irrigation/drainage water adjustment, primary production of harvestable plants, tourism, etc.

Lake Wuliangsuhai is situated in Urad Front Banner of the Bayannaoer Prefecture of Inner Mongolia Autonomous Region. It is linked to Hetao Irrigation Catchment in the west, to Wula Mountains in the east, and located at the east tip of the Hetao Plain. The lake is 35 to 40km long (N-S) and 5 to 10km wide (E-W), with an area of about 293 km^2. Its approximate location is given in Figure 1. The average elevation of the lake over the years is 1018.5m, steered by an outlet dam, and with a capacity of 250 - 300 million m^3. It has a maximum depth of less than 4 m, while the average depth is only about 1.0 m. Annual average temperature in the area is 7.3 °C, annual sunshine 3184.5 h, average annual rainfall 224 mm, potential average annual evaporation 1,502 mm. The lake is normally covered by ice from November to March, and only 152 days per year are frost-free.

Figure 1: Lake Wuliangsuhai is located at the eastern end of the Hetao irrigation system, indicated by the blue lines to the north of the Yellow River's Great Bend. Bayannaoer is a league (administrative unit) in western Inner Mongolia.

Being an isolated wetland in an otherwise arid area, Lake Wuliangsuhai is attracting bird-life both as a breeding area and a stopover on migration to breeding areas further north in the spring and back again in the autumn. The quality of the lake for wetland birds is of great concern that has already been recognised by the authorities.

The lake is fed mainly by water originating from the Yellow River. Large volumes are diverted for irrigation. Runoff and drainage water, together with heavily polluted water from industrial and municipal discharges, is routed to Lake Wuliangsuhai. This has resulted in an increasing eutrophication of the lake. Today 50 % of the lake's surface area is covered with dense reed (mainly *Phragmites australis*), and the remaining 50 % of 'open water' is filled with submerged vegetation (dominated by *Potamogeton pectinatus*). The lake is therefore classified as a slightly salt, 'grass-type' eutrophicated lake. Both reed and submerged vegetation is utilised as resources by the neighbouring communities.

The capitol of Bayannaoer is Linhe, which is the largest city in the catchment area with a population of around 180,000 people. Hanghou and Wuyuan, the two other towns in the catchment have a population of approximately 60,000 people, the same size as Wulateqianqi, the town just down-stream of the lake.

Hetao is mainly a rural region. The majority of the 1,400,000 inhabitants are farmers. There are nevertheless examples of industrial enterprises in the catchment area with a regional and national market, even though they are few. During the last years a number of factories exceeding the environmental emission standards have been forced to close down, among these a few paper factories. Others have changed the production or have installed treatment plants.

2.1.2 Geological background of Hetao area and Lake Wuliangsuhai

This subject is further elaborated in the final report of sub-project 4: Historical Development.

Owing its very existence to the result of a whole series of global geological events, the Lake Wuliangsuhai is a lake of many contrasts. Claims such as 'the lake is of quite recent origin and formed only a century and a half ago' may be true, but are at the same time also false: the lake is actually as old as the very sediments forming the Hetao Graben of the Ordos Pleateau. In other words, the Lake Wuliangsuhai has appeared and disappeared, has been desiccated and refilled, has been backfilled and subsided, again and again in an uneven race since the beginning of Pliocene, more than 6 million years ago. The sedimentary basin under the lake is several thousand meters deep. Depending on one's perspective, the lake is therefore young and old, large and small, shallow and deep, all at the same time.

From a geological perspective, the Lake Wuliangsuhai is situated at the very depocenter of the tectonically active Hetao Fault Basin of the Ordos Plateau. The lake is bounded to the S and E by active tectonic escarpments. The very reason for the Yellow River taking its famous northerly detour (the Great Bend) is due to tilting and subsidence of the SE corner of the Ordos Plateau.

The climate of the Ordos Plateau has undergone dramatic changes since Tertiary. The Pliocene uplift of the Himalayas created a barrier to the monsoon rains, and shifted the climate from humid to arid, from subtropical to cool, and from forest to steppe (and the occasional deserts). As the rate of subsidence has not always kept up with the rate of sedimentation over the past few hundred years, the lake is presently being filled in and is consequently steadily shrinking, essentially from natural causes. The deterioration of the climate (colder and drier) during the past 1,000 years has also contributed to less water and more sediments due to eolian transportation of loess, dust and sand.

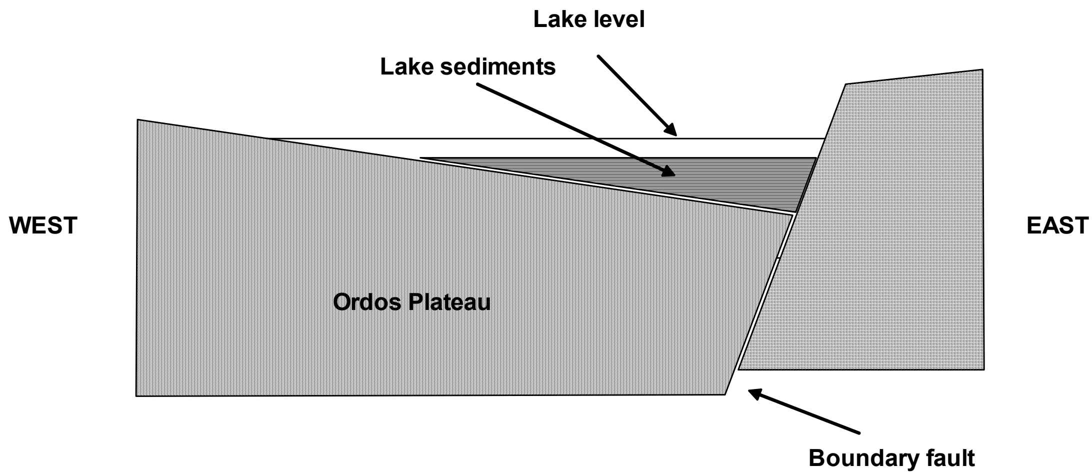

Figure 2. A slight tilting of the Ordos block creates Lake Wuliangsuhai. The lake is dammed against the easterly fault scarp, which forms the eastern confinement of the present lake.

2.1.3 Development of the irrigation and drainage canals system

Already before the cut-off of Lake Wuliangsuhai from Yellow River ca. 1850, some parts of the Hetao plain were important agricultural areas utilising river water for irrigation. After the extension of the Peking-Suiyuan rail-line to Baotou in 1923 the rate of settlement increased dramatically. Since ca. 1850, the main lake basin including dense reed areas has gradually diminished to the present size of ca. 300 km^2 due to a combination of natural processes and the establishment of Hetao Irrigation Area.

The development of increasingly more sophisticated irrigation systems both caused a need for a definition of a boundary delimiting the lake's size to protect the farmland from flooding, but the irrigation also provided a continuous supply of surplus water to the lake. During development of the huge irrigated farmland in Hetao, it gradually became a serious source of polluted water to the lake, including run-off from farmland, industrial effluents and sewage from cities.

In recent decades, the canal system has improved significantly. The most important projects are:

- **Main Drainage Canal 1978:** The drainage system was improved significantly, lowering the ground water level to remedy the salinity problem. The project included construction of the first pump station to raise the drainage water from Hetao into the lake.
- **Main Pump Station 1985:** A new pump station with increased capacity was constructed at Lake Wuliangsuhai.
- **Expansion of the irrigation area 2000:** A large engineering project supported by the World Bank was carried out in the Hetao area to increase the irrigated farmland and to protect it from further salination of the soils.

The irrigation canals are used to distribute water from Yellow River, diverted at Sanshenggong Dam at Dengkou, eastward and northward over the cultivated area. The remaining water is collected in the drainage canals, ending at the Main Pump Station at Lake Wuliangsuhai's western shore. Figure 2 gives an overview of the canal system.

Figure 2: Map over Hetao Irrigation Area. Red lines are irrigation canals and blue dashed lines are drainage canals. Yellow lines are roads and black dashed lines are administrative borders. Along the main drainage canal at the northern border of the area are the numbers of the major drainage canals noted (Bayannaoer City Hydrological Bureau, 1980).

Lake Wuliangsuhai is an important part of Hetao agriculture irrigation and drainage system. Yellow River is the main irrigation water resource of this area. Sanshenggong branch dam is the intake of Yellow River. About 6.0 billion m^3/y water is introduced to Hetao each year. The area of 6,900 km^2 plowland is in the irrigation areas, and it is planed to add to 7,300 km^2. There is a main irrigation channel and a sub-division into about 20,000 branch irrigation channels that composes the irrigation system in Hetao. The drainage system consists of 22,000 branch drainage channels, which head for the main drainage channel together and finally into Lake Wuliangsuhai. The pumping stations lift 0.7-0.9 billion m^3 water from the drainage canals into Lake Wuliangsuhai. Once the surface level of the lake is higher than 1,018 m above sea level, or in the low water period of Yellow River, Lake Wuliangsuhai will be drained to supply Yellow River. The output volume is about 2 billion m^3 every year, with a supply of 20 m^3/s water to the Yellow River. The lake retention time is 160-200 days.

2.1.4 Lake area, coverage and water volume

Lake Wuliangsuhai is a very shallow lake. The maximum depth found during the three field studies in 2001 and 2002 was 3.3 m situated in the southern part of the lake, probably part of an old riverbed. Most parts of the lake have depths less than 1.0 m and the mean depth of open water' is approximately 1.0 m. Other information claim that the deepest point of the lake is somewhat deeper (up to 4 m), but it has not been possible to verify this during the project work.

Despite some inaccuracies (especially in the northern part, north of the crossing road) due to limited resources, the depth contour (Figure 3) probably gives a fairly good framework for most relevant problems to be addressed in this project. The depth contour map below is super-imposed a satellite image from 2002, and shows the lake with reed belts in yellow and open water in different shades of blue and violet depending on depth.

The volumes and areas of open water are estimated from the above map are presented in figures 3 and 4.

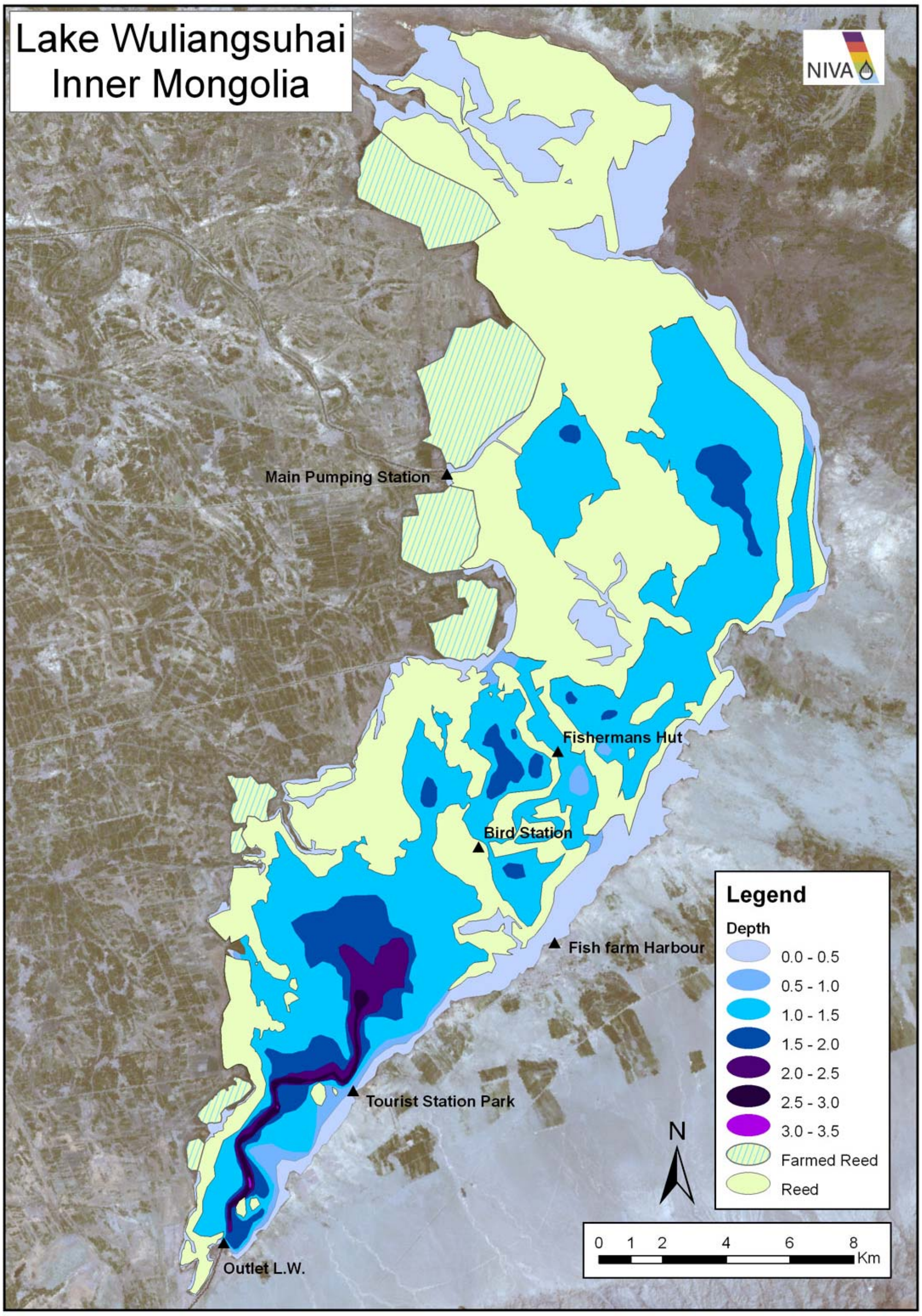

Figure 3. Depth contour map of Lake Wuliangsuhai constructed from a large number of depth measurements during this project.

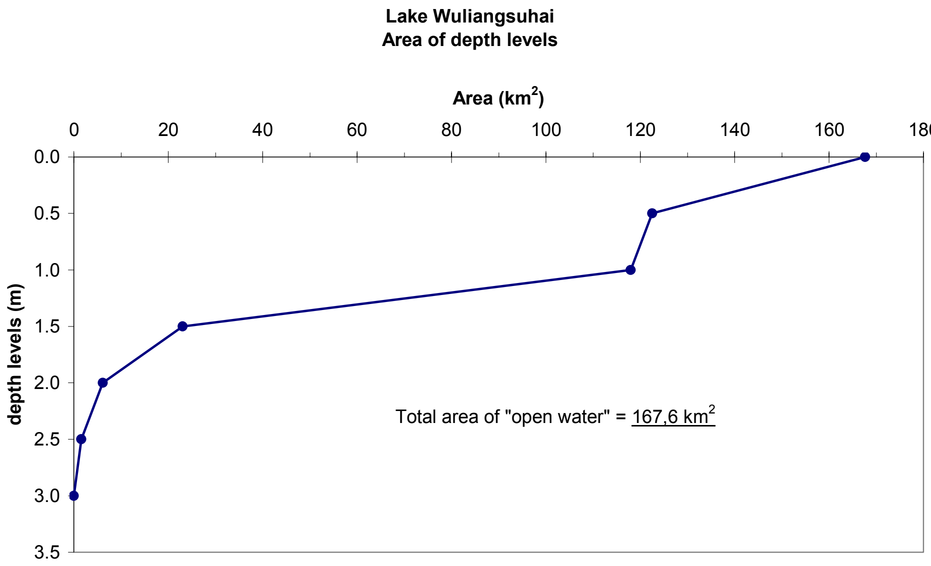

Figure 4. Areas of 'open water' calculated from the depth contour map.

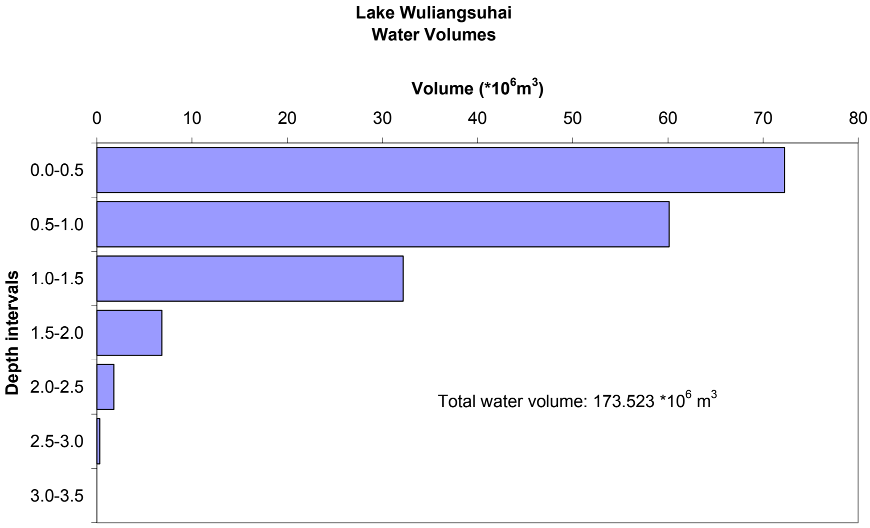

Figure 5. Water volumes of 0.5 m depth-levels of 'open water' in Lake Wuliangsuhai.

As it is shown in the Figure 4, the total area of 'open water (without reed) is calculated from satellite images to be 167 km^2, whereas reed covered an additional 178 km^2. 32 km^2 of the present reed area is defined as 'farmed reed' as it grows on former agriculture land on the western side of the lake. The satellite images as Figure 6 were used to estimate the reed coverage area.

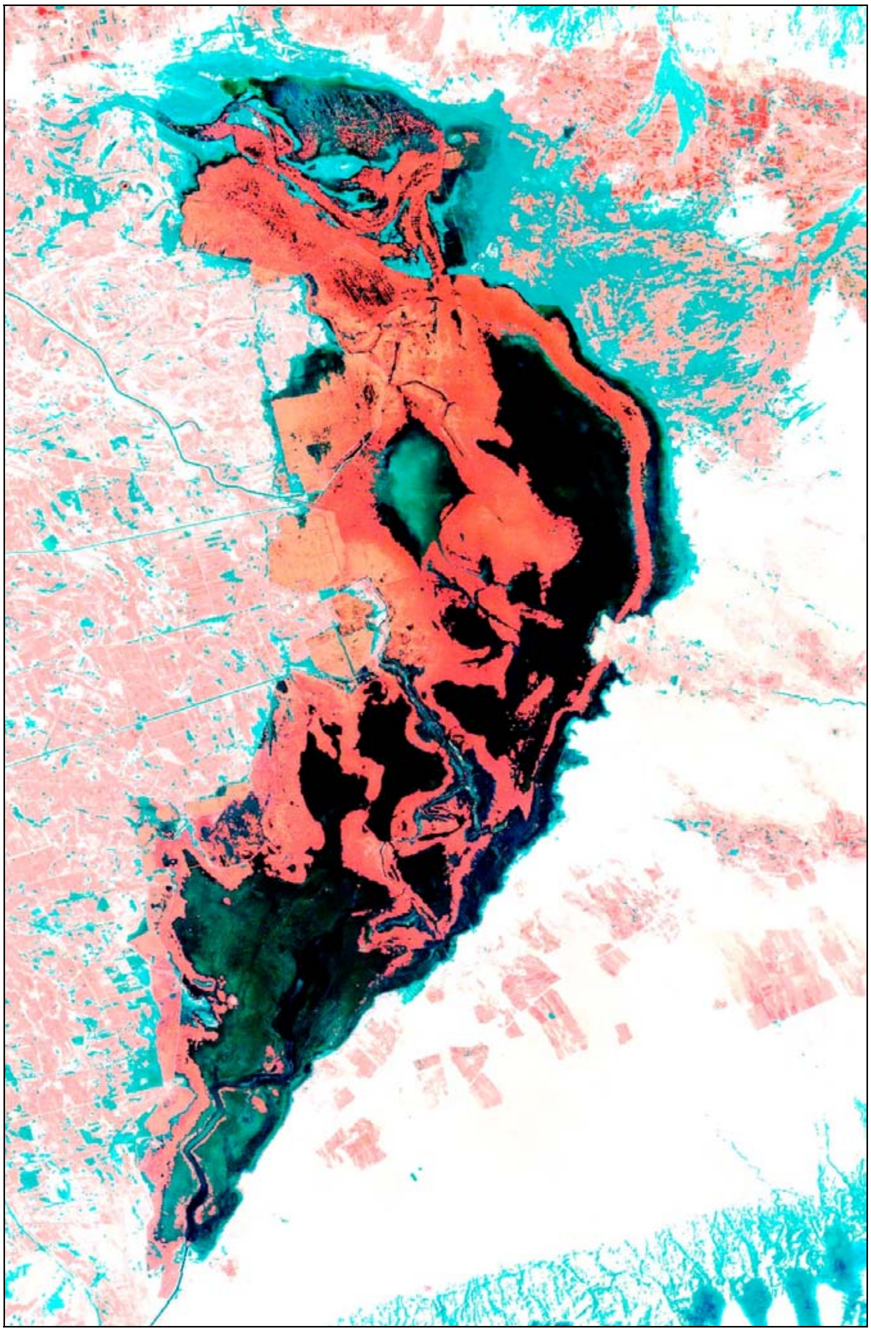

Figure 6. Satellite image from 20 July 1999. Red colour is vegetation, the dark red is mainly reed in the lake while lighter red is farmland on terrestrial areas. Close to 50 % of the lake surface area is covered with reed today. Shallow areas in the lake and turbid water in Xidatian basin, as well as wet mud on terrestrial areas are green.

2.2 Hydrological aspects

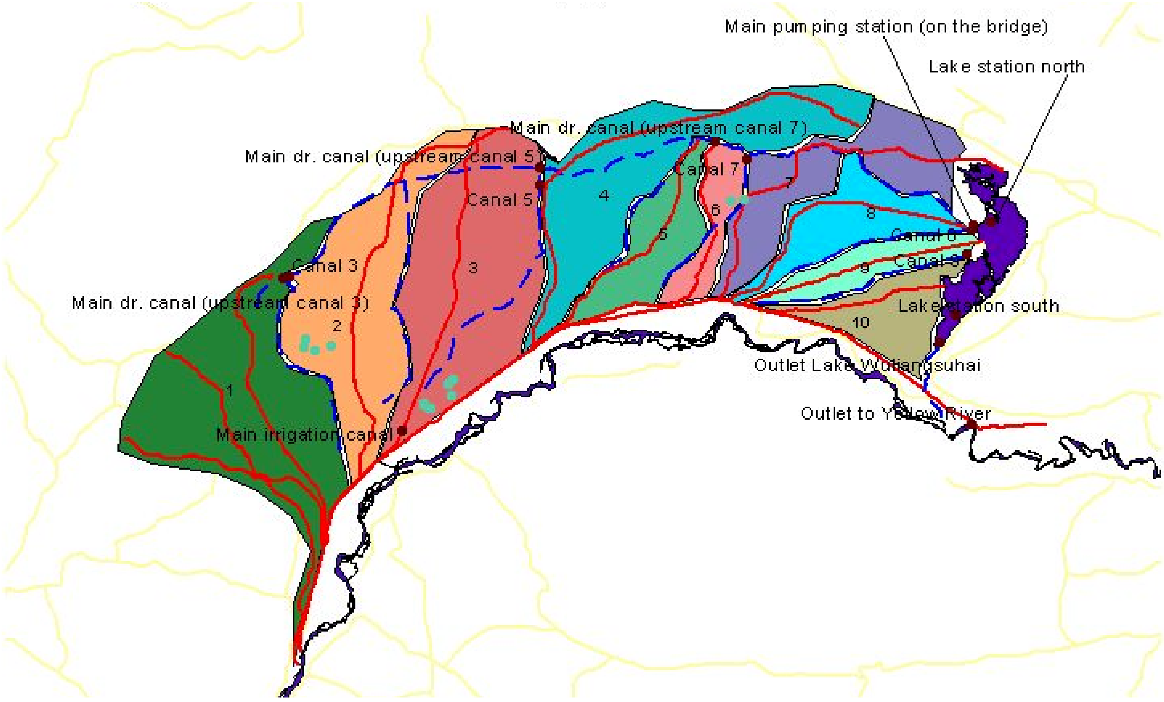

Figure 7. Drainage (red) and irrigation (blue) canals in the Hetao area. Local catchments to irrigation canals nos. 1-10 are presented in different colours.

The Lake Wuliangsuhai receives its water from the Yellow River, via the Main Irrigation Canal (Figure 7). The gate in Yellow River at Sanshenggong is open during the irrigation period, i.e. mid April to late October. During this period, half of the water flow of Yellow River at this point is diverted into Hetao for irrigation purposes.

The total Hetao Irrigation Area uses the irrigation water diverted from the main canal by gravity flow. The canal system of the Hetao Irrigation System consists of seven levels of canals. On the downstream side of the farmland, the drainage canal system also consists of seven levels. After irrigation of the farm fields, the drainage water enters the Main Drainage Canal, which runs parallel to the Main Irrigation canal about 200 km further to the north, and finally into Lake Wuliangsuhai through the Main Pumping Station. Only drainage water from Drainage canals 8 and 9 is pumped directly into the lake via separate pumping stations.

The water in Lake Wuliangsuhai discharges into Yellow River by gravity flow. A dam regulates the water level of Lake Wuliangsuhai according to the need for flood protection, a stable water level through the winter etc. The lake occasionally receives backwash water from Yellow River via the outflow canal. In this way, the lake may serve as a flood protection reservoir for the lower parts of Yellow River.

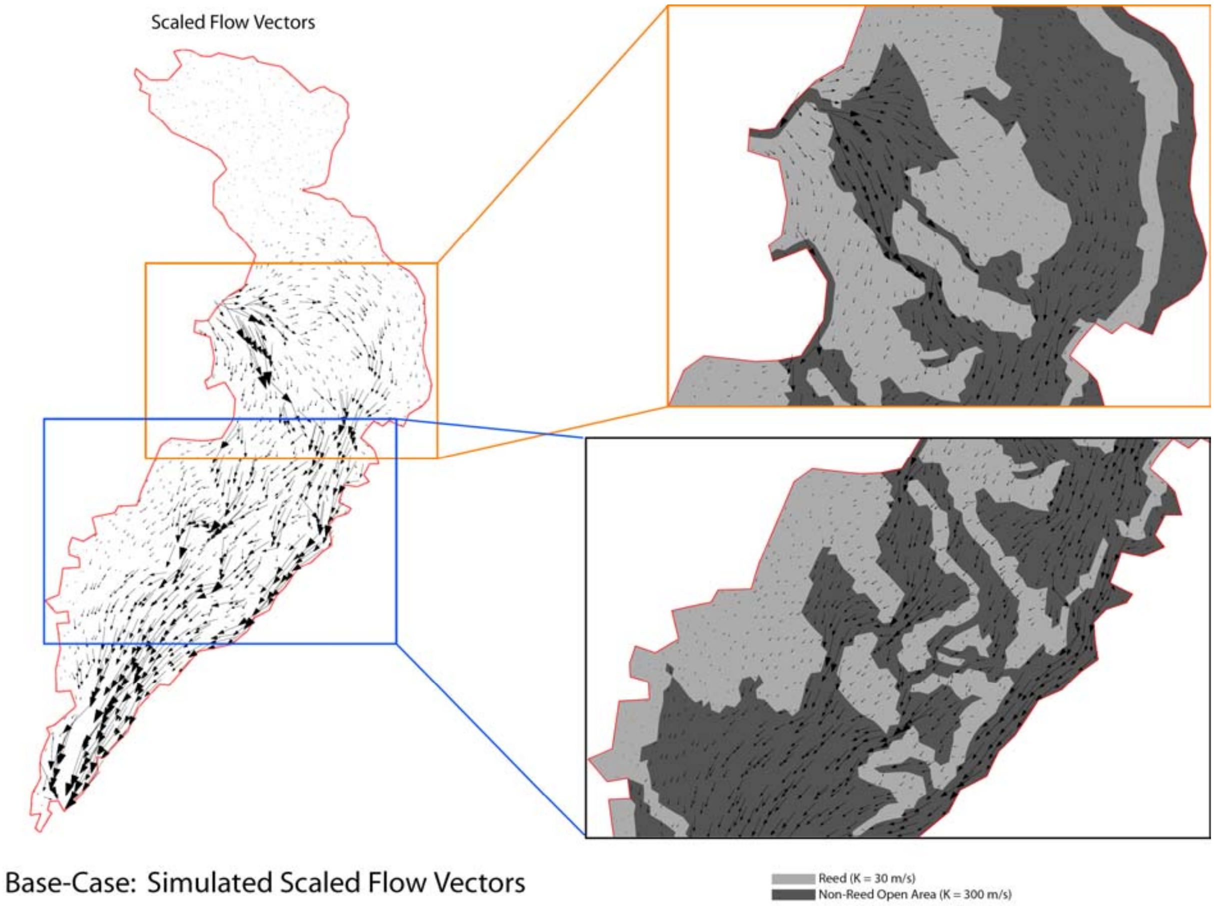

Figure 8. Simulation of hydraulic conditions of the lake. Length and direction of the arrows indicate the hydraulic condition.

A hydrological simulation of the current situation was carried out (see next chapter for details), and the results are depicted in Figure 8. The water enters to the lake from the mid-left and discharged through the southernmost point. It is well evident from the simulations that there is an obvious stagnation of water in the northernmost 1/3 of the lake, as well as many other areas. The reed coverage, entering and discharging points, flows and internal barriers (roads) have created the current hydraulic conditions.

2.3 Pollution situation

This subject is further elaborated in the final report of sub-projects 2: Pollution Sources Inventory and 3: Water Quality Monitoring.

2.3.1 Yearly pollution load on Lake Wuliangsuhai

The yearly pollution load on Lake Wuliangsuhai is (approximately):

- T-P: 100 tonnes
- T-N: 2,000 tonnes
- COD: 20,000 tonnes

These numbers are not exact but will vary from year to year, not least depending on the water volumes used for irrigation and thus drained to the lake. The project has applied both an indirect approach (summing up the loads from the different pollution sources) and a direct approach (using monitoring data for Main Pump Station and drainage canals 8 and 9) to calculate the loads. The results are surprisingly well corresponding. The ranges for studied years, suggesting magnitude of variation and uncertainty of the calculations, are given in Table 1. The loadings are further discriminated into the pollution source classes Cities, Industries and Agriculture, the estimated relative contributions for the pollution classes are presented in Table 2.

2.3.2 Water quality of the lake

Lake Wuliangsuhai's water quality has been monitored at two sites; Lake Station North (Xidatian) and Lake Station South (Erdiar). The water quality is generally much worse in the Xidatian basin close to the outlet of the Main Pump Station, than in other parts of the lake. The dense reed stands surrounding the Xidatian and the *Potamogeton* in the lake reduces the impact of the high pollution loading from Hetao. However, in the non-irrigation period the concentrations of dissolved organic matter were higher in the southern part than in the northern part.

A marked increase (80 %) in conductivity was observed between the Main Pump Station and the outlet of Lake Wuliangsuhai. This is caused by the high evapotranspiration from reed and the lake surface.

Annual average values of pH are in the range 8 – 9 due to the high plant production.

Annual average values for metals, arsenic and cyanide are within classes I – III according to the Chinese Water Quality Standards, for both lake sampling stations. Mercury and chromium were up to class IV some years. There was a marked increase in concentration of several metals between the outlet of the lake and the inlet into Yellow River because of effluents from industries in the Wulateqianqi area. Here the mean values of chromium and arsenic exceeded class V some years.

The discharge of organic matter into Lake Wuliangsuhai from the Hetao area is so large that the concentration of these variables are beyond the classification standard (exceed class V), when measured as BOD_5 and COD. Only in the southern part of Lake Wuliangsuhai, at the central Erdiar station, the organic content is within the limits off class V during summer. For total nitrogen the water quality class is beyond class V at both lake stations, except at Erdiar during winter (class V). A large part of the total nitrogen is present as ammonium. Total phosphorus is in class V the whole year around in the southern basin, while in the northern basin, at Xidatian, it is beyond class V in winter and in classes IV – V during the rest of the year.

The conducted sediment exchange experiments show that the release of phosphate did not increase from sediments to water under anaerobic conditions compared to aerobic ones.

Table 1. Estimated loadings during 1999 – 2002 (sub-project 3)

	Total phosphorus (tonnes/year)	Total nitrogen (tonnes/year)	COD (tonnes/year)	BOD_5 (tonnes/year)
Into the lake	28 – 180	720 – 3,600	10,400 – 25,800	1,000 – 3,700
Out of the lake	0,2 – 38	5 – 590	200 – 12,900	5 – 1,800

Table 2. Relative contribution of total pollution load on Lake Wuliangsuhai, given for the three considered pollution source classes (based on the situation 2004, sub-project 2)

	Total phosphorus	Total nitrogen	COD	Water
Cities	50 %	15 %	10 %	2 %
Industries	15 %	35 %	25 %	2 %
Agriculture	35 %	50 %	65 %	96 %

The discharge of organic matter into the lake from the Hetao area is so large that the water quality for these variables are beyond the classification standard (exceed class V), when measured as BOD_5 and COD. Only in the Erdiar during summer, the organic content is within the limits off class V. For nitrogen, the water quality class is beyond class V at both lake stations, except at Erdiar during winter. A large part of the Total nitrogen was present at ammonium. Total P was in class V the whole year around in the southern basin, while the Xidatian was beyond class V in winter.

The water quality was generally better in the southern part of the lake (Erdiar) than in the northern basin close to the Main Pumping Station (Xidatian), for nitrogen (Total N, NH_4, NO_2 and NO_3), but not for Total P and organic substances (BOD_5 and COD). However, during the non-irrigation period the Total P concentration was also markedly higher at Xidatian than at Erdiar. These evaluations are based on average values for all sampling years (1987-2002).

The water quality tends to be better in the irrigation period compared to the non-irrigation period at both lake stations. The tables below show both the average concentrations (with numbers) and the water quality class (colour according to standard classes to the left on the preceding table).

Water quality data collected during the project has also been compared to monitoring data from a previous study, conducted in 1987 and 1988. The average concentrations of main ions during the ice-free seasons have increased strongly during this 14 years period. Average concentrations of phosphorus (Tot-P) and nitrogen (Tot-N) also increased considerably. Nearly all main ions showed marked increases, as seen in Table 5.

Table 3. The Chinese water quality standard classes for surface water (GB 3838-2002) for the most relevant variables in lakes with upper concentration limits for the different variables

	BOD5 mg/L	COD mg/L	CODmn mg/L	NH4-N mg/L	NO2-N mg/L	NO3-N mg/L	PO4-P mg/L	total N mg/L	total P mg/L
Chinese Standard (Lake)									
class 3	4	20	6	1		10		1	0,05
class 4	6	30	10	1,5				1,5	0,1
class 5	10	40	15	2				2	0,2

Exceed class5

Table 4. Comparison of water quality classes in irrigation and non-irrigation periods. Numbers in this table refer to the average seasonal concentration while the colour is the water quality standard class for surface water

Non-Irrigation Period, Lake	BOD5 mg/L	COD mg/L	CODmn mg/L	NH4-N mg/L	NO2-N mg/L	NO3-N mg/L	PO4-P mg/L	total N mg/L	total P mg/L
Lake station, North	12,83	91,63	11,56	9,47	0,03	0,43		25,15	0,51
Lake station South	16,23	127,23	7,49	0,41	0,01	0,11		1,89	0,15

Irrigation Period, Lake	BOD5 mg/L	COD mg/L	CODmn mg/L	NH4-N mg/L	NO2-N mg/L	NO3-N mg/L	PO4-P mg/L	total N mg/L	total P mg/L
Lake station, North	10,86	50,48	7,55	2,00	0,18	0,28		6,91	0,13
Lake station South	6,69	67,90	10,24	0,32	0,04	0,13		3,13	0,17

Table 5. Changes in average concentrations (ice-free seasons) of main ions, nutrients and organic matter in Lake Wuliangsuhai from 1987-88 to 2001

	St. North (Xidatian)			St. South (Erdiar)			Water quality standard
	1987-88	2001	Change	1987-88	2001	Change	Class III
	mg/L	mg/L	%	mg/L	mg/L	%	mg/L
Na	219.7	353.3	61	339	664.9	96	
K	5.9	22.2	276	6.1	33.8	454	
Ca	39.7	117.1	195	33.4	43.3	30	
Mg	44.4	75.8	71	79.4	165.7	109	
Cl	243.1	524.3	116	431.6	997.5	131	
SO_4	236.4	320.3	35	316.8	538.7	70	
HCO_3	12.6	12.8	1	7.5	13.5	80	
CO_3	0.92	1.19	29	4.62	3.21	-31	
Tot-P	0.073	0.118	62	0.08	0.19	138	0.05
Tot-N	1.65	5.25	218	1.5	3.05	103	1.0
COD_{Mn}	4	8	100	7	10	43	6
BOD_5	1	8	700	2	7	250	4

2.3.3 A description of the pollution sources

The water feeding the lake is mainly originating from agricultural runoff, municipal sewage and industrial wastewater. The water quality from all three sources is characterised by high concentrations of mineral salts, plant nutrients (P and N) and dissolved organic substances. The catchment includes twelve major point sources; three towns and nine industries. Based on conducted samplings it is clear that individual point sources can have a significant impact on the lake. Figure 9 schematically illustrates where they are situated in the catchment. The relative contribution is also given for the most important pollutants.

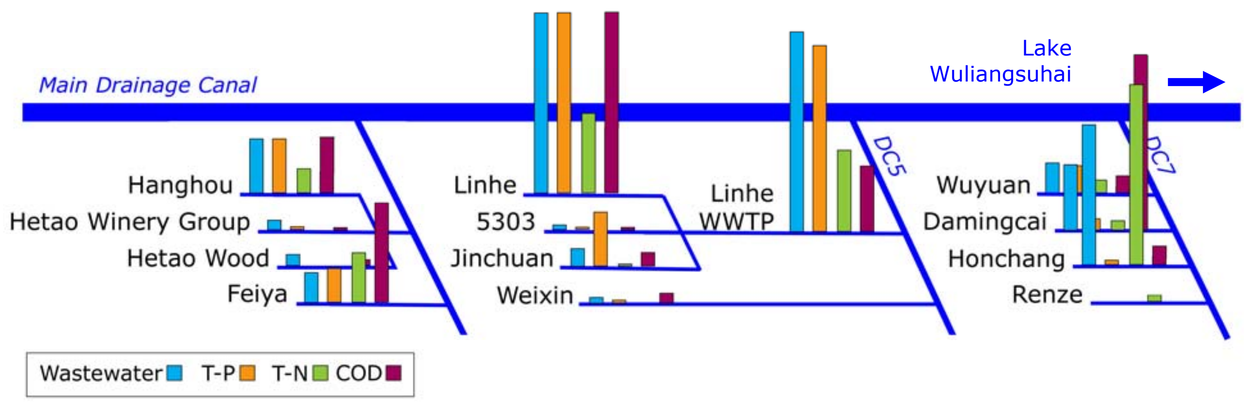

Figure 9. Relative yearly pollution discharge from each point source. Schematic routes to Main Drainage Canal, via drainage canals 3 (DC3), 5 (DC5) and 7 (DC7) are also presented. Note that the effluents from Linhe, 5303 and Jinchuan passes the Linhe wastewater treatment plant, where phosphorus and COD-loads are decreased. Other losses during the transportation to Lake Wuliangsuhai are not illustrated, neither is the contribution from diffuse sources.

Table 6. Agricultural runoff concentrations from Hetao, compared to water quality standard class III

	Hetao mg/L	Water quality standard Class III mg/L
T-P	0.075	0.05
T-N	2.5	1.0
COD	28	6

The project's monitoring programme has continuously measured the water quality in the drainage canals. Concentrations of cadmium, chromium, arsenic and cyanide were low or moderately high (class I – IV) at all canal stations, except for the Main Pumping Station where class V were recorded at a few times. Evaporation causes considerable increase in mineral salt concentration in the Hetao irrigation system. The highest salt concentrations, measured as conductivity, were observed in canals nos. 7, 8 and 9 as well as in the inlet into Yellow River.

The most important pollutants are arguably nutrients (total phosphorus and total nitrogen) and organic matter (COD). For these parameters the water quality is very bad in most drainage canals in Hetao; mainly beyond class V according to Chinese water quality standards. The situation is only slightly better during the irrigation period compared to the non-irrigation period. The highest concentrations of organic matter were observed in Drainage Canal 7, whereas Drainage Canals 3, 5 and 7 had the highest concentrations of nutrients. Remaining canals only discharges agricultural runoff, where the concentrations are much lower. Agricultural drainage water is, however, the most important polluter due to its overwhelming volume. Average concentrations for agricultural runoff, based on available data and neglecting variations over time and space, are presented in Table 6, together with corresponding water quality standard values for class III.

It has been found that losses during transport are insignificant when compared to the uncertainties in pollution load results.

2.4 Approaches for critical pollution loads estimation

2.4.1 Approaches for critical pollution loads estimation

The estimation of the maximum tolerance loading (critical loads) is a complicated task in shallow lakes, which involves nutrient release from the sediments, absorbability and accumulation of various nutrients, chemistry and natural process as well as other activities influencing the accumulation, release and degradation of pollutants. The impact of submerged vegetation on the release, absorbability and accumulation by sediments needs not only lengthy and extensive research, but also relevant technology. On the other hand, harvesting of reed will remove significant amounts of nutrients from the lake, which will affect the conditions.

We can use three approaches to estimate the critical pollution loads to the lake:

1. **Estimation according to standards:** Let us assume that the lake does not degrade and accumulate the pollutants if the lake water quality achieves the Class III of the "State surface water environmental quality standards" GB3838-2002. This refers to the concentrations of T-P = 0.05 mg/l, T-N= 1.0 mg/l and COD= 20 mg/l. Assuming that the annual average water volume in the lake is about 460 million m^3, the critical loading will be: T-P = 23 t/a; T-N = 460 t/a; COD = 9,600t/a.
2. **Estimation by modelling:** The critical loads in the lake according to the Dillon formula estimates to be T-P = 25.83t/a, and T-P = 34.1 t/a according to the R.R. Vollenweider formula (Inner Mongolia Lake Eutrophication Investigation and

Research, May, 1990, 150p). Although these formulas are valid for large deep lakes only, they could be used as conservative figures for a shallow lake like Wuliangsuhai.

3. **Estimation by monitoring:** In 1987, the average T-P concentration in the monitoring points in the centre of the lake was 0.068 mg/l. It was estimated that the total input of T-P from the main drainage channel to the lake to be 55.5 t/a at that time.

The critical load can be estimated as the ratio between the concentrations according to the water quality standards (TP = 0.05, TN = 1, COD = 20mg/l) to the observed water quality, multiplied by the observed loading. This has resulted in critical loads in 1987 as T-P = 41 t/a and T-N = 31 t/a. Following the same concept, the present critical loads can be estimated as given in Table 7, using the monitoring results from 2001.

2.4.2 Estimation of the critical load

With reference to the above estimates, the critical pollution loads to Lake Wuliangsuhai are estimated to be TP = 28-41t/a, TN = 460 – 800 t/a and COD = 4,600 – 9,600 t/a. Considering the assimilation of phosphates by the dense submerged vegetation, it may be assumed that the critical phosphate loading should be higher than 30 t/a. For the purpose of further analysis, we suggest to select TP = 30 t/a, TN = 800 t/a and COD = 10,000 t/a as the recommended maximum loading of nutrients to the lake.

However, this must be considered a low estimate when the ecological functioning of shallow lakes, and the principle of the "two alternate stable states", are taken into consideration. 30 t/a of T-P will ensure a low concentration of phytoplankton in the lake water even if the submerged vegetation should be removed or considerably reduced. If the submerged vegetation is protected from damage and removal, a higher loading of T-P, ca. 50 t/a T-P, could be acceptable. This does not apply to the estimate of T-N loading to the same degree as that of T-P.

2.5 Ecological status

This subject is further elaborated in the final report of sub-project 5: Basic Processes.

Today the lake is characterised by severe plant-type eutrophication including high concentrations of plant-nutrients (P and N), dissolved organic substances and mineral salts, causing a dense growth of reed and submerged vegetation, winter-kills of fish and a markedly reduced biodiversity of many groups of plants and animals.

The total number of bird species ever reported at the lake is now 208 of which 127 species were found during the two surveys. During the two surveys conducted by this project, nineteen bird species, not previously reported from the lake, were identified.

Migrating birds and birds resting and feeding at the lake were surveyed from Sept 11 to Sept 19, 2000 and April 17 to April 28, 2004. In the autumn more than 18,000 birds of 84 different species were counted and in the spring 53,000 birds of 105 species were recorded.

Table 7. Critical loads estimated based on monitoring results

	1987			2001		
	Concentration, mg/l	Load, t/a	Critical load, t/a	Concentration, mg/l	Load, t/a	Critical load, t/a
TP	0.0677	55.5	41	0.187	116	31
TN	1.788	820	459	2.789	2200	789
COD				107.6	25000	4647

Table 8. New bird species identified at Lake Wuliangsuhai during the project's two avifauna inventory missions

September 2000	April 2004
Red-necked grebe (*Podiceps grisegena*)	Bean goose (*Anser fabalis*)
Cattle egret (*Bubulcus ibis*)	Garganey (*Anas querquedula*)
Steppe eagle (*Aquila nipalensis*)	Merlin (*Falco columbarius*)
Avocet (*Recurvirostra avosetta*)	Dunlin (*Calidris alpina*)
Common greenshank (*Tringa nebularia*)	Mew gull (*Larus canus*)
Terek sandpiper (*Xenus cinereus*)	Common swift (*Apus apus*)
Sanderling (*Calidris alba*)	Rosy pipit (*Anthus roseatus*)
Ruddy turnstone (*Arenaria interpres*)	Isabelline shrike (*Lanius isabellinus*)
Far eastern curlew (*Numenius madagascariensis*)	Great grey shrike (*Lanius excubitor*)
Richard's pipit (*Anthus richardi*)	

In the period 1960-1974 there was a dramatic decline in total commercial fish catches in Lake Wuliangsuhai. Catches have varied in the range 300 – 3,600 tonnes per year since 1960. From the late 1970s to the late 1990s the fish catches have varied from low to medium level compared to the early 1960s. After prohibition of fishing in 2000 and 2001, the total catches in 2002 reached a level comparable to that in the early 1960s. However, in 2003 there was a decrease of about 50 % compared to the previous year. In later years the catches have been totally dominated by small sized Golden Carp. Maintenance of the fish population in the lake has been strongly supported by annual introductions of young individuals of different fish species.

Large parts of the shallow areas of Lake Wuliangsuhai are covered with reed, primarily *Phragmites australis* and *Typha spp*. The maximum depth at the lakeward edge of the reed is found to be 1.2 m. It seems that the lake depth is a critical factor for further expansion of the reed.

The by far most dominating species of submerged vegetation is *Potamogeton pectinatus*. Also a number of other species of the genera *Ceratophyllum* and *Chara* are abundant. Only in the deepest areas of 'open water' is the bottom not covered with submerged vegetation. Submerged vegetation covers a major part of the lake bottom between 1.0 and 2.0 m depth. Most observations were without plants below 2.5 meters.

The characteristics of the zooplankton in Lake Wuliangsuhai are the high numbers of *Rotifera* species and the high biomass of *Copepoda*, whereas *Cladocera* is only observed occasionally.

2.6 Development of the lake's vegetation regime

This subject is further elaborated in the final report of sub-project 4: Historic Development.

The Project has used available sources: interviews with elderly fishermen as well as documentation from aerial and satellite images, sediment analysis and from various sources on the Internet to describe the historical development of Lake Wuliangsuhai.

A main picture of the lake's recent history emerges from this information. The lake was cut-off from the Yellow River during a major flood at ca. 1850. Since then the main lake basin including dense reed areas has gradually diminished to the present size of ca. 300 km^2 due to a combination of natural processes and the establishment of Hetao Irrigation Area.

Analysis of satellite images from 1975 until today has shown a considerable increase in the area covered by reed. The most pronounced changes took place between 1975 and 1989. Only minor changes in the area of 'open water' have taken place since 1989. Since then, however, the formerly 'open water' area was gradually overgrown by submerged plants until they today constitute a more or less continuous cover, with exception of the areas deeper than 2.0 – 2.5 m.

Population composition of the lake vegetation is relatively simple, possibly due to the exclusive competitions among species. *Phragmites australis*, *Typha latifolia*, and *Potamogeton pectinatus* were the winner species conquering the lake. Studies on reproductive biology revealed their secrets for success, which lies on their diverse reproductive strategies and strong regenerating/recovery growth. Overgrowth of these macrophytes has a huge primary production capacity, which may be a great potential for removal of nutrients from the lake. On the other hand, vast production of macrophyte biomass posts a threat for the lake's biological filling up.

In order to investigate dredging technologies and the re-colonisation capacity of submerged vegetation a test area was excavated. Measurements performed approximately one year after the dredging showed that the water quality in terms of pH, total phosphorus and total nitrogen was almost the same as before dredging. The submerged vegetation had re-colonised with the same species as before dredging, and the abundance was about the same as before at the 0.5 meter and 1.0 meter test areas, whereas the re-colonisation of the 1.5 meter test areas had been markedly slower.

2.7 Previous studies

Over the last decades a number of studies on Lake Wuliangsuhai and the lake's catchment have been conducted. Among these should the following be recognised:

- Limnological assessments (Li Yawei, 1987)
- Xing, L., Yang, G. S., Li, Y., Guo, L. and Xiao L., 1995, The avifauna of Wuliangsuhai, Inner Mongolia. Inner Mongolia University Press, Hohhot.
- Xing, L., Yang, G., Li, Y., 1993, A study of the conservation and management of breeding and migratory waterfowl in Wuliangsuhai Wetland, China. Orient. Bird Club Bull., 21, 15-16.
- Yang, G., Xing, L., Yan, C., Zhao, Y. and Tian, L., 1999, Birds new records for Wuliangsuhai Wetland. Acta Sci. Nat. Univ. Nei Mongol, 30, 739-740.
- Fishery studies

3 CONDITIONS FOR THE MANAGEMENT AND CONTROL PLAN

3.1 Function Analysis

During a stakeholder workshop (LFA- Logical Framework Approach) in 2002, the following issues were identified and concluded as the main issues.

3.1.1 Functions in the past

- ecosystem function of wetland
- containing irrigation water
- improving water quality before water input to Yellow River
- supplement water to Yellow River in low water periods
- tourism
- fishery
- reed harvesting
- climate adjustment

3.1.2 Functions at present

- ecosystem function of wetland
- containing irrigation water
- improving water quality before water input to Yellow River
- supplement water in low water period
- tourism
- fishery (very limited)
- reed and submerged vegetation harvesting
- climate adjustment

3.1.3 Planning Functions in the future

- ecosystem function of wetland
- utilise of water resource
- containing irrigation water
- improving water quality before water input to Yellow River
- supplement water in low water period
- prevention flood
- tourism
- fishery
- reed and submerged vegetation harvesting
- climate adjustment

3.2 Summary of lake status and goals

Table 9. Status and goals of the Lake Wuliangsuhai

	STATUS	GOALS
Environmental	Poor water quality Problem of pollution loading into lake from various sources Reduced lake area Lake biodiversity under stress Unsustainable use of lakes resources	To improve water quality suitable for various uses To treat and reduce the pollution loads into the lake Increasing lake depth by various measures To sustain or increase the biodiversity in Lake To achieve environmental sustainability
Economic	The lake provides income to various stakeholder groups	To protect lake resources with an objective to sustain the income of the local groups Selection and implementation of the most cost-effective measures for pollution management and control measures Efficient allocation of water between competing uses within the Hetao Basin
Social	Several stakeholder groups have user rights to lake resources Competing demands and conflicts over access to the resources The reduced water quality has an impact on the health of the local people using the lake	Identify key stakeholders and establish an appropriate framework for their participation in the lake restoration and management Balancing the competing demands by rehabilitating the lake resources Assess the social impact of investment projects Conflict resolution Improved health of the local groups

4 PRESENTATION OF THE MANAGEMENT AND CONTROL PLAN MEASURES

This subject is further elaborated in the final report of sub-project 9: Management and Control Plan.

During a stakeholder workshop (LFA- Logical Framework Approach) in 2002, fifteen potential actions were identified. These were further elaborated and integrated to 10 actions as presented in the below table.

Table 10. *Management and Control Measures*

No.	Description of measure	Main purpose
1	Domestic wastewater treatment for cities	Reduction of pollution loads
2	Industrial wastewater treatment	Reduction of pollution loads
3	Increase of water depth in selected areas by dredging	Ensure fish survival during the winter and improve fish production; increase water storage capacity and improve biodiversity
4	Harvesting of submerged vegetation	Increase the open water area
5	Reed bed control	To reduce the potential of the lake becoming a reed marsh land
6	Introduce water from Yellow river and increase water level	Reduction of nutrient concentration, increase water level, improve water circulation
7	Moving of the main inlet and to construct a wetland	Improve water circulation and to reduce nutrient loading
8	Erosion reduction	Reduce water loss and sedimentation
9	Reducing diffuse pollution from agriculture	Reduce pollution load
10	Improvement of internal water circulation	Reduce stagnation and improve self-purification

4.1 Urban sewage treatment

The pollution from inadequately treated domestic wastewater is a significant contributor of nutrients to the lake. The main population centres of the lake catchment are Hanghou, Linhe and Wuyuan, and consist with about 480,000 persons. The wastewater from these cities contribute to over 50% of the total phosphate loads to the lake, which already has exceeded by over 400 % of the recommended phosphate content.

All three population centres also have a number of polluting industries, and their partially pre-treated wastewater will be treated at the proposed municipal treatment plant. The estimated pollution, including pre-treated industrial inputs, and reductions are given below. As seen from the table, this is the action that will achieve the highest reductions in nutrients.

Among the proposed plans, Hanghou and Wuyuan intend to construct WWTPs during 2005-2008, and the local governments have allocated 30% of the investments costs. Balance funding is anticipated from the central government, referring to the 5-year plan recommendations. Only Linhe has a wastewater treatment plant consisting with aerated lagoons. However, the treatment level is not adequate. Thus improvements are required. Since the sewer network in none of these areas is not comprehensive, it is necessary to provide necessary investments.

According to the Chinese standard GB 18918-2002, the effluents with secondary treatment must comply with COD ≤ 100 mg/l, T-P ≤ 3.0 mg/l and T-N ≤ 25.0 mg/l. Considering the sensitive recipient which needs to reduce it's current phosphate levels by 300% or about 70 t/a, it is justified to require a more stringent phosphate levels in the effluent. The objective should be to achieve 0.3 mg/l levels, though 1.0 mg/l could be used as the initial effluent target.

It is anticipated to recover O&M costs through revenue from water supply. A fee of 1.20 RMB/m3 is suggested for this purpose.

Table 11. Total reduction of nutrient loads by municipal WWTPs, excluding pre-treatment effects, and assuming that the effluent discharges meet the requirements

	Input to WWTP, t/a			Output from WWTP, t/a			Pollution reduction, t/a		
	COD	TP	TN	COD	TP	TN	COD	TP	TN
Hanghou WWTP	1,115	22	110	278	3	60	838	19	50
Linhe WWTP	2,935*	39	224	586	6	128	2,349	33	96
Wuyuan WWTP	1,133	9	66	399	3	57	734	6	9
Sum	5,183	70	400	1,263	12	245	3,921	58	155
Improvement							76 %	83 %	39 %

**COD load to Linhe WWTP was reduced by about 1800 in the year 2004 compared with 2002. Thus the COD reduction compared with 2004 at Linhe WWTP is 550 t/a.*

Table 12. Investment and Operational and Maintenance (O&M) costs, RMB millions

	Investment costs			O&M costs
	WWTP	Sewers	Sum	
Hanghou WWTP	57.3	33.6	90.9	4.6
Linhe WWTP*	37.3		37.3	4.9
Wuyuan WWTP	134.0	47.9	181.9	6.1
	228.6	81.5	310.1	15.7

**Only upgrading costs*

4.2 Industrial wastewater treatment

There are a number of industries discharging wastewater containing nutrients and toxic matter to the lake. Most of them have existing and functioning WWTP, through some require investments to improve treatment efficiency or/and increase the capacity.

Below table presents the status and impact of the industrial treatment plants. Very good removals of nutrients are anticipated with the proposed investments at 3 industries. From Lake Wuliangsuhai's perspective, there are two industries that need particular attention: Haojiang Paper and Hongchang Chemical industries.

Haojiang, the paper factory in Linhe, closed down in summer 2004. By doing this, the single largest source of COD disappeared. Depending on what is decided in the future, Haojiang might re-open with or without a new production. If so, it could have consequences for the lake.

Hongchang Chemical in Wuyuan is by far the main source of nitrogen to the lake. Still there is no decision made on local treatment. How this situation develops will have direct effect on the lake's water quality, even though nitrogen is not considered the main reason for eutrophication.

There have been questions on the reliability of the monitoring results and it is recommended that supplementary samplings are taken, since Hongchang's effluents alone can change the nitrogen budget for Lake Wuliangsuhai.

At present, only the "end-of-pipe" actions are considered. However, it is necessary to consider the possibility in recovering both clean water and chemicals for reuse in production. Therefore, the cleaner production approach is much more attractive since pollutants effectively are removed at the same time as the production costs are lowered due to a more effective usage of the natural resources. During specific pre-feasibility studies, this needs to be addressed. The impact and the need for abatement actions regarding other pollutants like heavy metals from Hongchang and Renze should also be addressed during such studies.

Table 13. Industries with nutrient pollution and their loadings before and after treatment /pre-treatment.

	Discharges in 2002. t/a				Discharges after pre-treatment. t/a			
	Volume	COD	T-P	T-N	Volume	COD	T-P	T-N
Weixin Cashmere	90,000	130	0.2	0.6	336,000	67	0.3	1.3
Hongchang Chem.	3,800,000	316	0.70	510.0	4,380,000	131	0.4	6.6
Renze Rare-earth	21,000	4	0.0	16.0	80,000	12	0.0	6.1
Haojiang Paper*	1,460,000	7,400	5.0	63.0	0	0	0.0	0.0
Sum	5,371,000	7,850	5.9	590	4,796,000	210	0.77	14
Total reduction						97 %	87 %	98 %

* *Closed at present.*

Table 14. Investment and Operational and Maintenance (O&M) costs

Industry	Investment, RMB millions	Investment costs, RMB/m^3 ww	O&M costs per year, RMB millions	O&M costs, RMB/m^3 ww
Hongchang	5.4	1.2	0.336	1.0
Renze	1.5	18.8	0.080	1.0
Weixin	3.2	9.6	0.288	3.2
Haojiang	closed	-	closed	-

** O&M costs are estimated based on 1 RMB/m3, a figure justified from existing industrial WWTPs in Wuliangsuhai area.*

4.3 Increasing lake depth by dredging

There are three main objectives to this action:

- Improve water quality and mitigate the process of lake eutrophication (discharge of accumulated nutrients from sediment sludge will decrease with the removal of bottom sludge)
- Secure conditions for fish survival during winter and Meet the demands of fish living through the winter and biological diversity (creation of depths and areas where the water will not freeze will secure this).
- Increase the lake depth to improve the lake capacity and efficiency of water resource usage.

It is suggested to dredge the areas given in the figure. The size of dredging area as following:

- Large areas to keep the water quality in category-III: 12 km^2 with a depth of 1 m
- Six areas for fish breeding: Each site with 1.5 km^2 and 1.5 m depth.
- One site in the protected area of ecological diversity: area of 0.5 km^2 with 1.5 m depth.

The total dredging area will thus be 21.5 km^2, which is approximately 18% of the visible water area of the lake. The dredging volume is about 26.25 million m^3.

4.3.1 Utilising dredged material (mud) for agricultural purposes

Some samples of lake bottom mud contained 165.8 ppm-P, 110.4 ppm NH_3-N and 6.86 ppm NO_3-N (ref. Prof Shang Shiyou). Another study reports 2.5 ppm-N and 0.547 ppm-P (ref. Jiang Xiangcan).

In an analysis conducted by Prof Shang, Inner Mongolia Agricultural University, the fertilisers contained in the lake mud found feasible to be 'extracted' and compared quantitatively and economically with current typical market prices for the same constituents as used by farmers. In such a case, fertiliser can be sold at 500 RMB/t, and with an extraction of 50 000 t/a, and income of 25 million RMB can be anticipated.

However, due to the low concentration of relevant chemical constituents in the lake mud (P, N etc) and other technical difficulties may challenge this concept. Further investigations are recommended before making final estimates.

The real value of the lake mud would probably be found elsewhere: As a soil improvement agent, to recover the soil profile integrity and structure of farmlands, which has been seriously degraded over the past decades. The potential of soil improvement by lake mud application may be considerable and the message should be conveyed to stakeholders and decision-makers.

A main concern will be that soil improvement is a long-term affair. Economic benefits must be seen in a much broader and longer perspective than can be dealt with at this project level. There are no O&M costs anticipated, as the dredging should have a lifetime of about 15-20 years.

Table 15. Investment and Operational and Maintenance (O&M) costs

Name	Quantity	Cost, RMB mill.
Dredge and transport sludge	26.25 mill m^3	262.5
Cofferdam engineering	67,500 m^2	33.8
Establishment and landscaping of sludge disposal facility	1.368 mill m^3	13.7
Total		310

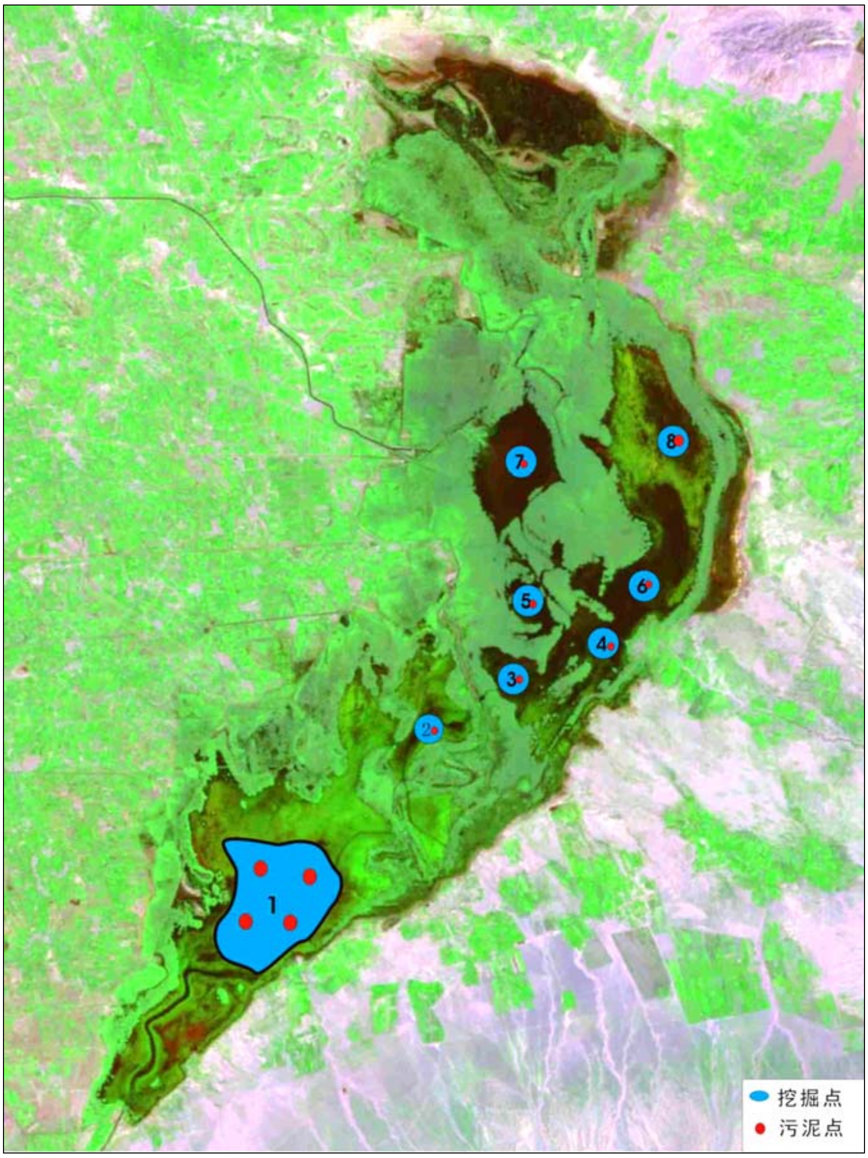

Figure 10. Suggested areas for dredging: 1:improve water quality; 2-7: for fish breeding; 8: for improving biodiversity

4.4 Harvesting of submerged vegetation in lake

The open water areas of Lake Wuliangsuhai is to a large degree covered by the submerged plant Fennelleaf Pondweed, also called Sago Pondweed (*Potamogeton pectinatus*). The total area of submerged vegetation reached, according to interpretation of satellite images, ca. 115 km^2 in 2001.

Most of the submerged plants collapse and decompose every year and cause oxygen depletion under the ice and contribute to accumulation of organic particles in the sediments. The high rates of sedimentation in the lake, about 7-13 mm every year will convert Lake Wuliangsuhai to a continuous reed wetland without open water within 30-50 years, unless actions are taken to increase the water depth and/or reduce the sedimentation rate.

Harvesting of submerged plants from Lake Wuliangsuhai may serve different purposes that are considered beneficial for the lake, as they all satisfy central goals for the management of the lake. It will result in a socio-economical benefit for the local people by establishing a new livelihood by the harvesting and feedstuff production activities. In addition, it will remove nutrients taken up by the plants and over time contribute to a balance between input and output of nutrients in the lake. In this way it is suggested that up to 40,000 tons of dry weight (D.W.) of high proteineous aquatic plants could be harvested each year, which could be utilised further for various economical purposes

A total of 10-20% of the total submerged vegetation in Lake Wuliangsuhai should be harvested annually, according to general agreement between project participants. The outcome of this action would be the balanced benefits of: socio-economic advantages for local people, the production of useful feedstuff and hence increase livestock production, removal of surplus plant nutrients from the lake, and the construction of a more diverse wetland habitat. The total harvested area (16-32 km^2) should be restricted to patches within 60 km^2 of pre-defined 'open water' areas with the smallest possible conflicts with other lake user interests: bird protection, fishing, tourism etc. Additionally, the harvesting should not take place in the most important 'self-purification areas' close to the outlets of the main polluted canals (Main Drainage Canal and Drainage Canals nos. 8 and 9).

According to test results and breeding experiments, the aquatic plants of Lake Wuliangsuhai are rich in nutrient components. The nutrient value of aquatic plant feedstuff is higher than green hay and dahurian wildrye, sunflower head powder, sugar beet leaves etc., and the nutrient index corresponds to the feeding standard of poultry and domestic animals.

At present, grassland degradation is serious in Wulatezhongqi and Wulatehouqi of Bameng. In addition, larger areas suffer from continuous drought. The proposed 40,000 tons hydrophytes powder feedstuff demand exceeds today's supply. In addition, many duckeries and cattle farms in the Beijing area have a high demand for feedstuff. A local sale price of high-density hydrophytes bundling and common hydrophytes powder of 400 RMB/t seems to be feasible compared with other products (Green hay price from Humeng grassland to Beijing is 650 RMB/t, Ningtiao plant powder price of Helin County to Ximeng is 750 RMB/t, and the alfalfa price of Shanxi to Shanghai is 1,300 RMB/t).

It is anticipated that 40 000t of product can be sold at 400 RMB/t generating an income of 16 million RMB/y.

Table 16. Investment and Operational and Maintenance (O&M) costs

Investment costs, RMB millions	O&M costs, RMB millions/year
55.0	6.0

4.5 Reed bed control

The purpose of the MCP on Reed Bed Control is to reduce the speed by which the edge of reed expands into 'open water' areas in Lake Wuliangsuhai;

In 1975 the reed area of Lake Wuliangsuhai was about 17 km^2 while reed production was 23,000 tonnes DW. In 2001 the reed area of Lake Wuliangsuhai was 116 km^2 and reed production was 115,000 tonnes DW. In other words, the lake has experienced a five-fold increase in reed production and a seven-fold increase in reed area in 26 years. Further reed spread and production increases may lead to the lake becoming reed marshland affecting the ecological functions of Lake Wuliangsuhai, as well as the drainage functions of Hetao Irrigation Area to the Yellow River. Because reed for paper making is an important economic activity, maintaining existing reed areas while preventing reed spreading through gardening measures is proposed. This should guarantee both ecological functions, as well as satisfy the sustainable development and utilisation of reed resources.)

A proposed measure to reduce the expansion rate of reed was to cut the reed plants along the edges of the reed beds, preferably under the water surface, during summer. Harvesting the green summer reed was suggested as an efficient method to reduce the vitality of the reed and slow down its ability to expand horizontally into 'open water' areas. Cutting the stems under the water surface will probably give additional negative effect on the *Phragmites* and *Typha* productivity.

Before demonstration tests have been carried out to study the effects of summer harvesting of reed along the edges, no conclusions can be drawn about the feasibility of this measure, as well as accurate investments and running costs.

However, and estimate of possible costs under the assumptions that a 10 m wide part of the reed edge is harvested over 200 km during 2 summer months (total reed area is 178 km^2, while approximated perimeter is 460 km. In this exercise, we assume harvesting 200 km of reed edge) are presented.

Table 17. Investment and Operational and Maintenance (O&M) costs

Cost	Estimate
Investment costs	1,200,000 RMB
Operational and Maintenance costs	120,000 RMB/season

Note: an alternative concept suggests an investment of 7.4 mill RMB investment with 5.25 mill RMB/year operational and maintenance costs, resulting of about 4 mill RMB/y income from the increased amount of reed harvesting (ref. Prof Shang Shiyou)

4.6 Introduce water from Yellow River and raising of lake water level

The general objective of this measure is to provide more water to Lake Wuliangsuhai, and thereby increase the lake surface level. The measure includes widening of canals to support the transport of water directly from the Yellow River. The canals Changji, Tabu, Yihe and Tongji are identified as the means for water transport. The desirable water volume in Wuliangsuhai should be 450 million m^3, taking into consideration of the development of aqua-culture, fishing, reed production, tourism, transportation and the conservation of wetland bird species as well as the depth and extent of the lake and the impact on surrounding environment.

The goal of the project is to increase the lake water level to 1,019.0-1,019.3 m above sea level, which in turn increases the average depth with 0.5-0.8 m. Annually 253 million m^3 should be introduced from the Yellow River through main canals in order to maintain the depth of the lake. This measure can ensure the current lake extent and, more importantly, dilute the water body of the lake, thus improving the water quality. Raising the water level and thereby increasing the average depth of the lake will have positive impacts on the biodiversity in the lake ecosystems, such as possibly stopping the recent decline and even increasing in diversity.

The maximum lake level during the introduction phase will be 1,019.2 m above the sea level, which will occur in March/April during 14 days-period. Later in the annual cycle, (July/August) the level will be approximately 20 cm lower, not considering natural variations due to rain. In the winter, during the reed harvesting period, the level will be at 1019.0 m.

A possible negative effect of the introduction of more water from the Yellow River is that this water may infiltrate along the shorelines at the ends of the canals and may cause the ground water level to rise. The shores lie, however, between wasteland and bulrush fields, so the effect on agriculture and the nearby environment may not be high. The loss of water in the canals has been estimated as 15 %. However, in MCP 3 the loss has been stated as 20 - > 58 %. Therefore, there is a risk that the calculated water volumes are overestimated. The mitigation for this is to tighten the canals or to increase the flow periods.

The investment need for this project considers reconstruction of canals to enlarge and repair the original ditches, which are the ends of the main irrigating ditches. The action includes cleaning and widening the ditches, reconstruction of reserve water gates, straight-mouth water gates, sand—traps, pedestrian and automobile bridges and canals for ferry transport, etc.

During 2004 the water level was constantly kept at 1,018.9 m.a.s.l. which is 0.4 meter higher than normal. Before the lake froze the level was raised further to 1,019.7 metres. No negative effect on reed production was observed during the last season. Additional water was also successfully introduced from Yellow River to improve the water quality of the lake, through existing canals, during 2003, 2004 and early 2005. In 2004 80 million m3 was introduced. A new species of fish has been found in the lake, possibly introduced with the river water.

Table 18. Investment and Operational and Maintenance (O&M) costs, mill RMB

Description	Investment	O&M costs/year
Canal modifications to introduce water	36	
Modifications to raise the water level	5	
Water costs for storage, 0.015 RMB/m3 for 253 mill m3		3.8
Water costs for agriculture, 0.040 RMB/m3 for 253 mill m3		10.0
Maintenance costs of the ditches		0.18
Total	41	13.18

4.7 Moving the lake's inlet and constructing a pre-treatment area

The main objective of this measure is to reduce the eutrophication of the lake through treatment of the water from the Main Drainage Canal using a pre-treatment wetland.

The water is at present entering in the north-east area of the lake, creating a very low on none movement in the water mass in northernmost areas. This is well illustrated in the hydrodynamical simulations presented earlier. Even today, the initial area of the water entrance is functioning as a natural wetland to a certain degree. The proposed action is to move the inlet to a northernmost point, and to reserve an area there as a wetland. The benefits are two folds: an improved nutrient removal due to a new and optimised wetland area; and the improved circulation of water due to the favoured hydrological conditions.

This action involves not only the construction and management of the wetland, but the heavy engineering costs to move the inlet from its current position to a northern point, as well as to construct a new pumping station.

The initial investigations suggests that the new drainage canal should start from about 192 km downstream the Main Drainage Canal, which is located in the Zhaoqitai village of Sudulun countryside of Wulatezhongqi banner. New drainage canal section will be 11.5 km long and shall enter into Lake Wuliangsuhai through Guangyizhan village. This choice will reduce the excavation costs as well as result in least compensation for the farmland to be acquired. The canal shall have a compound cross-section with 2.2 m bottom, and the slope coefficients of 1:5 and 1:3.

The new pumping station will be similar to the one at Hongqibo pumping station, with a design and maximum capacities of 60.0 m^3/s and 100.0 m^3/s, respectively. The design and maximum flow speeds will be 0.65 m^3/s and 0.75 m^3/s, while the pumping heights will be 2.70 m and 3.65 m, respectively.

A conveyance canal with 13 km will be built from the preset depository before lake at the outlet of Hongqibo pumping station, E 108°51′11″, N 40°59′44.5″, to North.

It is estimated that a wetland of 4 km^2 can remove 38 tonnes of phosphorus and 500 tonnes of nitrogen per year.

To gain the maximum benefits from the wetland, a lot of knowledge is required. In fact, the proposed wetland is the essence of what is suggested for the entire lake – reed bed control, improved (note, not necessarily increased) internal circulation, better utilisation of lake resources, periodical dredging etc. Thus, the wetland can also be used as an experimental area where field tests can be conducted before new practices are introduced in full scale in the proper lake.

Table 19. Investment and Operational and Maintenance (O&M) costs, RMB millions

	Investment	O&M costs/year
Wetland construction /Management	10.0	0.550
Canal construction /Management	47.9	0.990
Total	57.9	1.539

4.8 Erosion control

At present, large quantities of mineral particles (sand, gravel) enter the lake through torrential rain, due to the severe water and soil loss in eastern shore of the lake. The average annual volume of floodwater to Lake Wuliangsuhai is 52 million m^3. This adds to the silting up of the lake at a dramatic rate.

According to the analysis of satellite images in 1987 and 1996, the area of Lake Wuliangsuhai had decreased by 20 km^2 in almost 10 years, when bulrush field and marsh areas had increased by 24 km^2. The alluvial area was 1.1 km^2, where floods from Wula Mountain have entered the lake directly through the ditches and deposited large amounts of mud and sand. The deposit was severe, with the average of 40 cm thick, and the thickest of 90 cm.

This action is mainly intended to transform and control XiaoMingSha in the east shore and Wula Mountain in the south-east of Lake Wuliangsuhai, which cause severe loss of water and soil and sediment deposits. The project objectives can be identified as following:

- to control the loss of water and soil. By stabilising drifting sand, recovering plants, building dam systems, the loss of water and soil can be effectively controlled, and the environment can be significantly improved.
- to obstruct floods and reduce the quantities of sand and mud. Through comprehensively controlling the ditches stretching to the lake, when the project exerts its functions completely, 30.8 million tons of sand can be reduced, and 66.8 million m^3 of water will be obstructed and saved.
- to improve the terrestrial environment. By fencing and forbidding livestock grazing, planting and building dam system, the ecological environment of project area can be recovered and rebuilt. The plant coverage rate will reach 78.6 %.
- to protect the wetland itself from receiving large amounts of eroded material. The lake will be made to gradually recover the ecologically self-adjusting abilities, and become a beautiful resort.

According to natural conditions – land-use situations and characteristic of water-and-soil loss – the methods of controlling by fencing and restricted grazing should be carried out to natural grassland with good conditions or stabilised sand pile groups. In areas with severe wind erosion – largely gathered drifting sand and pass by river channel – the system of windproof and sand-stabilising forest could be constructed with two methods in two sides of river channel. One is to set up a wood and sand barrier, an another is to plant trees and grass.

The highland region on the northern side of Wula Mountain can be multi-controlled through small drainage areas as unit. A system of dams should be set up. Some projects should be constructed based on characteristics of channel, such as main dams, middle and small deposit dams, prevention of channel head, etc. The method of planting and forbidding of grazing can be carried out on the slope surface of two sides of channel as well, according to the actual situation.

The basic benefit is mainly the saving of water and reserving soil. Additionally there are direct and indirect positive impacts to the air, soil and biological cycle of the lake.

Table 20. Investment and Operational and Maintenance (O&M) costs, RMB millions

Investment costs	3.974
Operational and Maintenance costs per year	0.359
Economical benefits per year	1.455

4.9 Farmland Surface Pollution Control

The two overall purposes of this intervention is to reduce excess use of fertilisers and irrigation water within the agriculture, thus reducing the eutrophication of Lake Wuliangsuhai.

The fertiliser and the pesticides are identified as the main pollutants from agriculture. The average of fertiliser quantities per acre reached 70 kg, some even surpassed 100 kg, highly beyond the average of 23.5 kg of the whole country. Although the fertiliser quantities have increased rapidly, the fertiliser efficiency grew slower during last 40 years. According to the materials provided by the agricultural bureau of BaMeng City, the effectively utilising rate of nitrogenous fertiliser is 35% in BaMeng City, whereas that of phosphorus fertiliser is only 22.4%. The rest is transferred to the soil and water, creating a massive influx of nutrients to the lake. The quantities of pesticides used in 2002 were 757 tons in Hetao Irrigated Area, an increase by 66.9% compared with that in 1996, which is also partially transferred to the lake.

Based on the test results conducted, it has been estimated that the nitrogenous and phosphorus fertiliser loss into surface water in the whole Hetao Irrigated Area are 938.9 t-N/a and 13.3 t-P/a, calculated as ratio of irrigation and drainage. Calculated by irrigated acreage the amount of nitrogenous fertilisers is 644.47 tons, and phosphorus fertilisers are 10.07 tons.

This action is based on the fact that to control the pollution, both fertiliser and water must be controlled at the same time. The following actions are suggested:

- Establishment of water-saving irrigation: using laying bricks and sticking concrete on sides and bottom of canal, irrigating by groundwater wells and/or canals.
- Developing water-saving agriculture actively: Policy and management measures are required.

The proposed action is divided into two parts, namely extending construction of irrigation system and water-saving system. The whole project is separated to two stages. The first-period engineering began in 2000 and will end in 2005. The main engineering content is to set up a drainage establishment, accessorial buildings and defence measure in Dongfeng sub-canal, YangJiaHe canal, YongJi canal, FengJi canal, YiHe canal, ChangJi canal and SanHuHe canal. It also includes the restoration of main drainage channel and set up accessorial buildings, the construction a demonstration area of 200,000 mu (133 km^2) with highly efficient water saving capacity combining wells with channels.

The second-period engineering is from 2006 to 2015 with the main engineering contents consisting of setting up a drainage establishment, accessorial buildings and defence measures in canal No.1, DaTan sub-canal, WuLaHe River, Nanyizhi sub-canal, QingHui sub-canal, HuangYang sub-canal, HuangJi canal, HeJi sub-canal, Guangze sub-canal, ZaoHuo canal, ShaHe canal, FuXing canal.

Estimates indicate that, the diverted water volume from Yellow River will decrease by 1.2 billion m^3, after the suggested water-saving irrigation engineering measures. This is vital for the downstream Yellow River drainage area, which since the 1970's have suffered from severe droughts. As to Hetao Irrigated Area, salinity input will be decreased by 600,000 solids t/y (considering salinity in water of Yellow River as 0.5 g/L). The input of nitrogen will be decreased by 4,800 t/y (considering nitrogen in water of Yellow River as 4 mg/L).

Estimating drainage water being decreased by 0.2 billion m^3 per year, the nutrient load to the lake will be decreased by over 800 t-N/a and over 10 t-P/a.

It is estimated that 6.121 billion RMB as investment costs for the whole project, of which 3.754 billion RMB for main structure of the whole system, and another 2.367 RMB for construction within farmland (including agriculture comprehensive development).

4.10 Improvement of internal circulation

It has been common knowledge that the present water recycling situation in the northern as well as the north-eastern part of Lake Wuliangsuhai is not satisfactory. The eastern area between Shajianzi and Nanchang is characterised by stagnant water, with reduced biodiversity. It also causes lower self-purification due to short circuiting and lower retention times of the water in the lake. The model simulations presented before seem to confirm this picture.

The purposes of the proposed project include:

- Strengthen the water circulation within the northern part of the lake,
- Improve the circulation in present stagnant areas
- Improve the general water quality of the Lake Wuliangsuhai
- Provide a more uniform distribution of flow in the lake

Both canals and barriers are considered in this task . Compared to canals, the use of levees (barriers) is obviously a more cost-efficient means of deflecting and redirecting water to desired areas, i.e. improve the internal circulation of the lake. Moreover, the construction of levees is less costly and requires simpler technology, for several reasons:

- The transportation of excavated or dredged mud is a only few meters,
- The machines can operate from dry land (on top of the levee) as work progresses.

The resulting excavated strips on the lee (down) side of the levee may double as navigation canals, and will also ensure a minimum of water circulation on the downstream side. An important aspect of canals vs. levees is the fact that the latter can make better use of smaller volumes of water. In the case that additional water from external sources such as the Yellow River becomes problematic, levees will assist in making good use of whatever water there is.

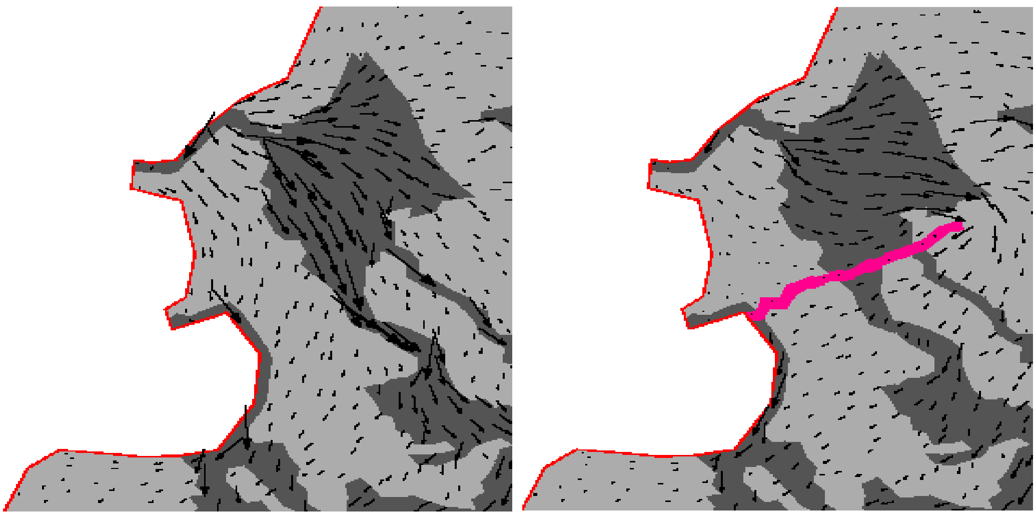

Figure 11. *The effects of establishing levees (barriers): The left image illustrates the present situation; The right image illustrates the effects of a levee (barrier) (red) on water emanating from the Main Pumping Station.*

Table 21. Investment and Operational and Maintenance (O&M) costs, RMB millions

Investment costs	3.660 millions RMB, over 2 years
O&M costs	None.

5 RANKING OF PROPOSED MEASURES

This subject is further elaborated in the final report of sub-project 9: Management and Control Plan.

After identification of potential actions and their benefits, it is necessary to rank them according to the priorities. In a given situation with limited financial resources, it is an important task.

The ranking of the proposed actions can be carried out using various approaches. A logical approach would be to:

1. actions to reduce the pollution loads to the lake
2. actions within the lake which reduces pollution
3. actions to secure sufficient quantities of water to control vegetation, provide favourable dilution and to improve biodiversity, etc
4. actions to sustainable utilisation of the lake's resources

Such an approach is widely utilised by internationally and in China, and are well in agreement among the Chinese, Swedish and Norwegian specialists. The ranking of activities following such an approach is presented in Table 17.

The usage of a more comprehensive approach was demonstrated during the project

As part of the Management and Control Plan for Lake Wuliangsuhai a stakeholder workshop was held in Linhe 23-24 November 2004, with the purpose of carrying out a multi-criteria analysis (MCA) and project ranking session with a group of stakeholder representatives. This chapter is based on a report that discusses the data and assumptions behind the MCA.

A series of scenario analyses for alternative future scenarios for lake water quality ("turbid" and "clear") were conducted, as well as the differences in preferences for different criteria expressed by the stakeholders. It was found that ranking of management and control measures (MCM) are not very sensitive to the choice of scenario or set of preferences.

In a clear water scenario the ranking of MCM is presented in the table below, taking into account both the aggregate benefit calculated across 37 criteria, subcriteria and indicators, as well as cost of the measures. Based exclusively on environmental, social and institutional impacts ("benefits") the erosion control measure (MCM 8) ranks highest.

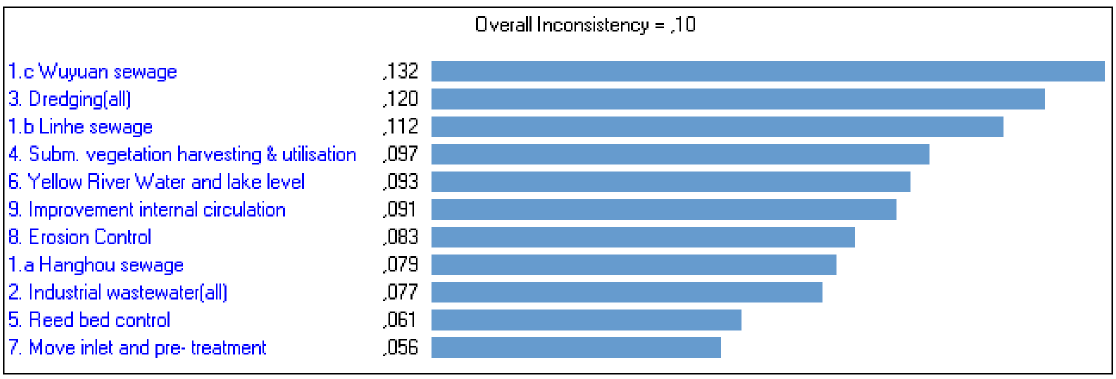

Figure 12. Management and control measures ranked by weighted benefits

Table 22. Ranking of actions according to common approaches. (Recommended)

Rank	No	Description
1	2	Industrial wastewater treatment (all)
2	1.3	Wuyuan wastewater treatment
2	1.2	Linhe wastewater treatment
2	1.1	Hanghou wastewater treatment
3	6	Yellow River water supply and lake level increase
4	7	Moving of inlet and wetland construction
5	4	Harvesting submerged vegetation and utilisation
6	5	Reed bed control
7	8	Erosion control
8	9	Agricultural pollution abatement
9	10	Improvement of internal circulation
10	3	Dredging (all)

If cost of measures is also considered in the form of a cost/benefit ratio, the general conclusion is that the smallest, cheapest measures should be implemented first, starting with reed bed control (MCM 5). The ranking of measures with very different scales of implementation cost leads to this difference in implementation priorities. This is because environmental, social and institutional impacts ("benefits") are largely qualitative in the analysis and cannot capture the difference in the scale of the measures represented so clearly by 2 orders of magnitude difference in the costs of the cheapest and most expensive measures.

Limitations of the analysis include the fact that most of the environmental data used for ranking are based on qualitative expert opinion, rather than modelling. This was due to the fact that the decision to compare and rank measures using a multiple criteria approach was taken quite late in the project, after monitoring data and modelling tasks had been designed and carried out.

Further limitations include the limited experience in adequate budgeting of management and control measures and scaling of the impacts. Most cost and revenue of measures are only based on the MC reports by the Chinese authors. The use of this data is not an endorsement of the valuation methods used in the MC reports as the underlying data were not verified. For some measures revenue estimates play a large part in the high ranking of the measure, particularly: revenues from the sale of fertiliser from dredged mud (MCM 3) and from harvested submerged vegetation (MCM 4). In both cases, revenues are calculated based on existing fertiliser prices without consideration of how the market will evaluate these as substitutes for chemical fertiliser, nor are supply-side effects on local market prices considered. In the case of erosion control (MCM 8) large increases in revenue have been assumed in agriculture and pasturing. In a large number of projects around the world the predicted effectiveness of erosion control has been exaggerated. These assumptions should be revised in a detailed feasibility study.

Table 23. Cumulative costs and benefits of management and control measures

Ranking based on benefits only	Alternative	Individual benefits (normalised)	Individual costs (million Yuan)	Cost/ normalised benefits (million Yuan)	Ranking based on ratio costs/normalised benefits
1	1.3 Wuyuan sewage	1	236 029 934	236 029 934	10
2	3. Dredging(all)	0,914	304 757 590	333 432 812	11
3	1.2 Linhe sewage	0,852	81 376 045	95 511 790	5
4	4. Subm. vegetation harvesting & utilisation	0,738	105 776 571	143 328 687	6
5	6. Yellow River Water and lake level	0,705	159 330 406	226 000 576	9
6	10. Improvement internal circulation	0,691	3 598 918	5 208 275	2
7	8. Erosion Control	0,629	7 213 328	11 467 930	3
8	1.1 Hanghou sewage	0,599	132 093 951	220 524 125	8
9	2. Industrial wastewater(all)	0,582	16 425 647	28 222 761	4
10	5. Reed bed control	0,462	1 249 238	2 703 978	1
11	7. Move inlet and pre- treatment	0,423	71 797 479	169 733 993	7

Table 18 illustrates in the first column the ranking of measures if implementation is based only on environmental, social and institutional criteria (benefits). The last column illustrates the ranking if the cost/normalised benefits ratio is used. The latter illustrates the limitation of the MCA analysis when the cost of measures varies across a large scale, while the qualitative characterisation of impacts does not capture the same variation in scale. Consequently, the ranking based on cost/benefit ratio more or less implies implementing the cheapest measures first (because relatively little information is provided on the scale of benefits). Investments towards establishing sustainable conditions of the Lake Wuliangsuhai should follow this sequence if the budget for implementation is only gradually made available.

Despite the limitations in the underlying data, the ranking exercise itself conducted at the Linhe workshop was considered a success. Stakeholders found the description of the impacts of each MCM understandable and the process of recording their preferences manageable.

Assuming further quality control of the data and analysis in this report by our Chinese counterparts, and periodic updating of preference weights for the different criteria, we are cautiously optimistic that the method illustrated in this report has helped structure decision-making and will provide continued guidance in evaluating additional measures which may be proposed in a programme of measures for Lake Wuliangsuhai.

6 DISCUSSION

6.1 Different perspectives on the lake's function

6.1.1 Exploitable resource, important for the development of the region

Lake Wuliangsuhai serves as a source of income for several local groups who have rights to harvest fish, reed and other natural resources.

Reduced loading of dissolved organic substances and plant nutrients combined with excavation of some deeper areas without submerged vegetation would support the development of a larger standing crop of fish consisting of bigger individuals. When the environmental conditions have been improved introduction of other, more valuable fish species should be considered.

A number of initiatives have been taken to find new ways to utilise the lake. They are all focusing on raising different animals.

In mid-June 2004 50,000 small grass carps (250 g) were introduced to Lake Wuliangsuhai. They were kept in 70,000 m2 net-enclosed area and fed solely on available submerged vegetation. After four months they had grown to 2 kg and were taken out and sold. The Fish Farm is currently investigating the possibilities of breeding the fish instead of re-introducing them each year. Grass carp is a naturally occurring species in the lake.

The Fish Farm also introduces crabs in the western part of the lake. The first reports indicate that they thrive in the lake. It is too early to say if they are expanding. This is not an original species to the lake.

Currently (spring 2005) a factory and breeding area for ducks is being constructed at the north-eastern side of the lake. The ducks will not be allowed into the lake proper, but will be fed harvested submerged vegetation.

6.1.2 Being a crucial focal point for Central Asia's bird life?

The variety in bird species and great numbers of individuals emphasise the importance of the lake for the avifauna. Probably the number of species not previously recorded indicates that the lake is becoming increasingly attractive to birds. Lake Wuliangsuhai is one of few major favourable sites for nesting and migrating birds in the region.

Lake Wuliangsuhai fulfils the criteria to become an internationally protected area according to the RAMSAR convention, and an application to the convention would probably be an important tool to protect the bird life and the habitat diversity of the lake.

6.1.3 Facilitating increased biodiversity

A large part of the lake suffers from very low flow of water leading to stagnant conditions. Observations of dead fish and birds confirm that this is a serious problem due to the high density and wide cover of reed and submerged plants. By introducing levees that direct the water more evenly to distant parts of the lake, a stimulation of self-purification processes and better water circulation will be achieved.

Also dredging of some parts of the lake to extend the 'open water' areas without reed and submerged vegetation is considered an efficient means to create a more diverse wetland habitat. This will result in both some deeper areas where fish and birds can forage and some islands constructed from parts of the dredged material. These islands should be planted with shrubs and trees and protected in the breeding periods. New species can be established and it will be favourable to species that prefer open water without vegetation. The same applies to a limited harvesting of submerged vegetation, although to a smaller extent. It must be kept in mind that both these measures, if carried out to a too large extent, might have a conflicting result; the switch from clear to turbid water. The reason is that too large areas with open water reduce the efficient stripping of nutrients from the water from submerged vegetation. At a certain, and sudden, stage, phytoplankton will take over and produce dense blooms, possibly with toxin-producing species. This turbid stage has a tendency to become stable once it occurs. Therefore, it is recommended that any harvest of submerged vegetation should take place on a mosaic of smaller areas covering totally less than 32 km^2.

Increase of the water level could produce more shallow areas along the shore well fit for wading birds. This is a type of habitat that should be promoted in Lake Wuliangsuhai.

Birds and fish are only two groups of organisms that would benefit from cleaner water and a more diverse habitat. However not so obvious, richer communities of insects, bottom-dwelling animals, submerged plants etc. would add to the ecological values of Lake Wuliangsuhai, also as they provide more diverse food resources for fish and birds.

6.1.4 Unexplored perspectives

Due to the limitations of the projects, a number of other perspectives have been left out. Two of them are mentioned below:

- **Tourism:** Some studies have been conducted as to the lake's current tourism enterprises and estimations on future potential. The project has however not focused on this issue.
- **Microclimate:** As the proposed restoration measures all support the main goal of the project: 'to keep the lake as a lake', they will also in varying degrees protect the lake from drying out. Once we loose this battle, the effects on the local climate will be serious.
- **Lake Wuliangsuhai in a Yellow River-context:** Even though Lake Wuliangsuhai and its immediate surroundings have suffered under the pollution load, Yellow River has benefited. Lake Wuliangsuhai is a sink for nutrients and organic matter and in this way efficiently protects Yellow River from pollution from Hetao Area. A considerable part of the phosphorus, nitrogen and organic matter transported into the lake is retained by adsorption to particles, primary production and sedimentation. Also a substantial part of the nitrogen is lost by sedimentation, assimilation by plants and by the denitrification process.

  During the project the idea of using Lake Wuliangsuhai as a reservoir for regulating the Yellow River has been proposed. By storing excess water in the lake during the early spring flood season, water could be kept inside the lake and returned to the river in the dry summer season when about half the water volume of Yellow River is diverted at Sanshenggong.

6.2 Challenges that must be overcome in order to save the lake

6.2.1 Challenges caused by a dynamic reality

It should be remembered that the pollution situation in Lake Wuliangsuhai's catchment is highly dynamic. China is developing rapidly and this has consequences also in Hetao. Municipal pollution will increase when the sewer systems are expanded. Today a considerable amount of wastewater is disposed locally, especially at the outskirts of the cities. As Bayannaoer modernises new parts of the cities will be connected to the sewer systems. During recent years industries have closed down, changed production and started operation. All these processes will continue in the future. The same is definitely true also for agricultural practices. Changed choice of crop, fertiliser loads, available irrigation water volumes and irrigation technologies will all effect the pollution contribution and thus the development of the lake. This can be regarded as a challenge as well as an opportunity for future pollution abatement plans.

6.2.2 A fragile water balance is threatening to dry out the lake

Arguably the gravest threat to the lake is the fragile water balance. The annual water input from Hetao has decreased steadily over the last years, as a consequence of water-saving actions and more efficient application of the irrigation water. With a constant evaporation there is an increasing risk for decreasing water level. Although the inputs of water into Lake Wuliangsuhai vary considerably between years, the evapotranspiration loss from the lake is relatively constant at ca. 400 million m^3 per year. This implies that the minimum annual water input from canals cannot go below this value without gradually reducing the water level on an annual basis. The situation is aggravated by the fact that the high sedimentation rate because of large inputs of organic matter and particles as well as high internal production of plant material reduces the available storage volume. If this is allowed to continue too far, it will be difficult to restore necessary water volumes even if more water is introduced.

6.2.3 Increasing salinity and pollution concentrations

A secondary effect is the increasing salinity. In the long run, the rapidly increasing salt concentration will be a severe threat to Lake Wuliangsuhai as a freshwater ecosystem. To counteract this process, a yearly surplus flow of 250 million m^3 is needed, in addition to the 400 million m^3 needed to maintain the water balance. Unless necessary actions are taken, it can be feared that the lake will become a marsh wetland within a few decades and dry out within the next 30 – 100 years.

Assuming that the acute hydrological challenge is dealt with, pollution abatement actions will also be required. If comprehensive measures are not taken the water quality will become even worse than today. The high concentrations of organic matter lead to anoxic conditions and massive fish-kills during winter will continue to occur regularly and the biodiversity of fish and zooplankton will be further reduced. If the lake’s effective volume is increased with “clean” water the dilution will postpone the pollution challenge to a certain extent. This will not solve the problem, but buy time for adequate abatement measures.

The high nutrient content supports a large production of reed, submerged vegetation and other organisms in the lake. However, it also increases the risk for heavy blooms of possibly toxic blue green algae, and it speeds up the process of transforming the lake to a marshland. Loss or removal of submerged plants of the lake will facilitate this dramatic transformation. This is described as a switch from a macrophyte dominated (clear water) state to a phytoplankton dominated (turbid water) state.

6.2.4 Introduction of new species

Introduction of new species of plants and animals to an ecosystem, terrestrial, marine or freshwater, has attracted a lot of attention in research and management during the last decades. Such species are called 'alien' or 'invasive' species. It has been an overwhelming documentation of deliberate or uncontrolled introductions that caused large and everlasting damage to ecosystems, by taking over from the native species or causing other unintended damage to the ecosystem. It seems that this problem has not yet been a worry in China. Introduction of species has a long tradition in China primarily to create more food production. Also in Lake Wuliangsuhai, a high number of fish species have been introduced during the last decades (see sub-project report no. 3: Water Quality Monitoring), but also crabs and plants have been introduced to provide new economic crops. Fortunately, the water quality in the lake has been too poor to allow most of the introduced species to survive their first winter in Lake Wuliangsuhai.

Five famous examples of species that has caused formidable damage in their new environments are Chinese Mitten Crab (*Eriocheir sinensis*), Grass Carp (*Ctenopharyngoden idella*), Zebra Mussel (*Dreissena polymorpha*), Red Water Fern (*Azolla filiculoides*) and Water Weed (*Elodea canadensis*). From the website of the International Convention of Biological Diversity (http://www.biodiv.org/programmes/cross-cutting/alien/default.asp) we site: “'The threat to biodiversity due to invasive alien species is considered second only to that of habitat loss. They are thus a serious impediment to conservation and sustainable use of global, regional and local biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems.”

6.3 Opportunities for a prosperous future

6.3.1 Has the negative trend been broken?

Lake Wuliangsuhai’s water quality has deteriorated over the last fifty years. When comparing the sediment analyses with the last decades’ water monitoring it is clear that the negative processes accelerated during the last decades. There is nevertheless reason to believe that the negative trend has been broken, or at least that the deterioration rate has decreased. The main reason for this is the enforcement of environmental standards during the last years. This has resulted in closures of a number of industries and installation of treatment plants in others.

It is still too early to draw definitive conclusions, but the recent changes in the pollution situation is a step in the right direction. This does not mean that Lake Wuliangsuhai is safe. There still is an imminent risk for continued deterioration if the correct measures are not taken.

6.3.2 Explore potential win-win situations

This project has identified a number of potential win-win situations when adopting a comprehensive management plan for the lake. More such opportunities will be revealed as the resource management matures.

The test excavation did not only illustrate the feasibility of mechanically deepening the lake. When analysed, the dredged material proved to be a valuable agricultural resource as soil improvement as well as a possible secondary use as construction material for roads. In addition to these uses it has been suggested to use some of the dredged sediments to create islands inside the lake, thus further increasing the habitat diversity.

Another example of a win-win situation is that submerged vegetation is not only suited for livestock fodder. By raising more livestock, more manure will obviously be produced. This secondary resource can be sold to Hetao, reducing application of synthetic and mineral fertiliser as well as transports.

6.4 Monitoring programme for the lake

The project has put a lot of resources into inventory of pollution sources and monitoring of water quality in the canal system and in the lake. This work should be made permanent to guarantee long time-series of data.

It is also suggested to construct permanent monitoring stations, at the inlet, in the central part and at the outlet of the lake. This station should preferably be equipped with automatic samplers for common chemical and physical parameters.

Fish Farm village is well suited to host a laboratory for special analyses and monitoring of specific activities (reed harvesting, dredging, fish, ducks, etc). This laboratory should not be solely intended for environmental protection, but also to quality control utilisation of resources.

A specific programme to monitoring introduction of new species is strongly recommended. This would give an indication of whether a new species is invasive and needs to be removed from the lake, even though that can be near to impossible.

6.5 Analysis of the value of water in alternative uses

This subject is further elaborated in the final report of sub-project 1: Economic Indicators.

The present study uses available data on

- historical income and operating and capital cost data to reed and *Typha* harvesting,
- lake tourism business and recreational benefit,
- fishing and
- potential for animal feed and fertiliser production

to calculate net annual returns to these lake uses. A similar analysis of net returns to irrigated agriculture in Hetao Basin is undertaken, as well as obtaining published estimates of the returns to downstream uses of water in the Yellow River. Net returns to different crops are compared to total water use by crop in field, including data on losses in irrigation transportation of water. Based on this data we can construct a simplified demand curve for water in irrigated agriculture.

The reader should keep in mind that no effort is made in the report to assign economic values to biodiversity conservation (e.g. birds), nor to the potential value of a 'healthy', optimised fishery in the lake such as had been observed in the 1950s. We have also used conservative assumptions for recreational values based on data collected in the visitor's survey. We have excluded from the analysis potential new businesses based on lake resources, such as production of fertiliser from mud dredging and production of animal feed from harvesting of *Potamogeton*. These were excluded because historical site-specific or reliable secondary data was not available. For all of these reasons lake values we have calculated are conservative.

For drops in lake water level there is a possible trade-off between visitation and reed production if we assume aggressive reed colonisation. Given conservative assumptions the value of additional water to the lake to avoid a 0.5 meter drop in water level (91 million m^3) is about 0,081 Yuan/m^3.

No value is assigned to water stored in Lake Wuliangsuhai and released to the Yellow River during the dry season. In 2001 this was 366,000 m^3. Returns to downstream water uses in the Yellow River were given at 0,3-0,5 Yuan/m^3 in available studies. At these values the current (2001) value of the reservoir services provided by Lake Wuliangsuhai to Yellow River would be small. We have in no way pretended to evaluate the economic potential of such reservoir services given the poor resolution of topographical data from the lake shore. However it would seem to be limited and inferior to economic impacts of large seasonal changes in water level on reed harvesting and especially visitation.

Putting Lake Wuliangsuhai and Hetao Basin in a wider context we make some simple comparisons on the value of water allocation. If irrigation water losses are excluded from calculations (0 % loss) we see that the values of water in irrigated water in Hetao are considerably higher than values with irrigation losses observed in 1989. Increase in the water value of economically marginal crops such as wheat may be as much as 0,5 Yuan/m^3. This is more than our most conservative marginal value of water for lake uses. Based on this logic water savings in wheat should be pursued aggressively assuming that the increased value to wheat production would be greater than the (albeit conservatively) estimated losses to downstream lake uses.

This is however, a theoretical value given that water transportation will always entail some loss before reaching the field. Wheat is a water demanding crop using an estimated 670 million m^3 /year in Hetao, including irrigation loss proportional to its cultivation area. Depending on which year is used as a basis, the average residual value of water to irrigated wheat varies between 0.05 Yuan/m^3 (1999) – 0.39 Yuan/m^3 (2003). Even with the very conservative estimates of the marginal value of lake water uses, the report shows that a good economic case could also be made for reallocating water from the least productive areas under wheat to the maintenance or increase of water level in Lake Wuliangsuhai.

From the perspective of downstream uses in the lower half of Yellow River, even the very conservative estimates of opportunity costs to downstream water uses (0.3 – 0.5 Yuan/m^3) make a good case for reallocating at least some of the water from marginal crops such as wheat (670 million m^3 /year), maize (574 million m^3/year) and interplanting of wheat-maize (2,088 million m^3/year) to downstream uses. Based on the agricultural production data we have available for 1999-2003, this conclusion would also be true even after eliminating all irrigation losses in agriculture. Part of such reallocated water could be passed through Lake Wuliangsuhai in order to achieve a somewhat higher flow back into the Yellow River in the dry season (keeping in mind the limitations of the lake as a reservoir). This would obviously have joint benefits, which further justify such a course of action.

Our analysis does not take into account social costs of reducing agriculture in Hetao Basin, but the differences in financial returns to different uses of water in irrigated agriculture and downstream – even with very conservative assumptions – are so striking that we feel such a conclusion is justified.

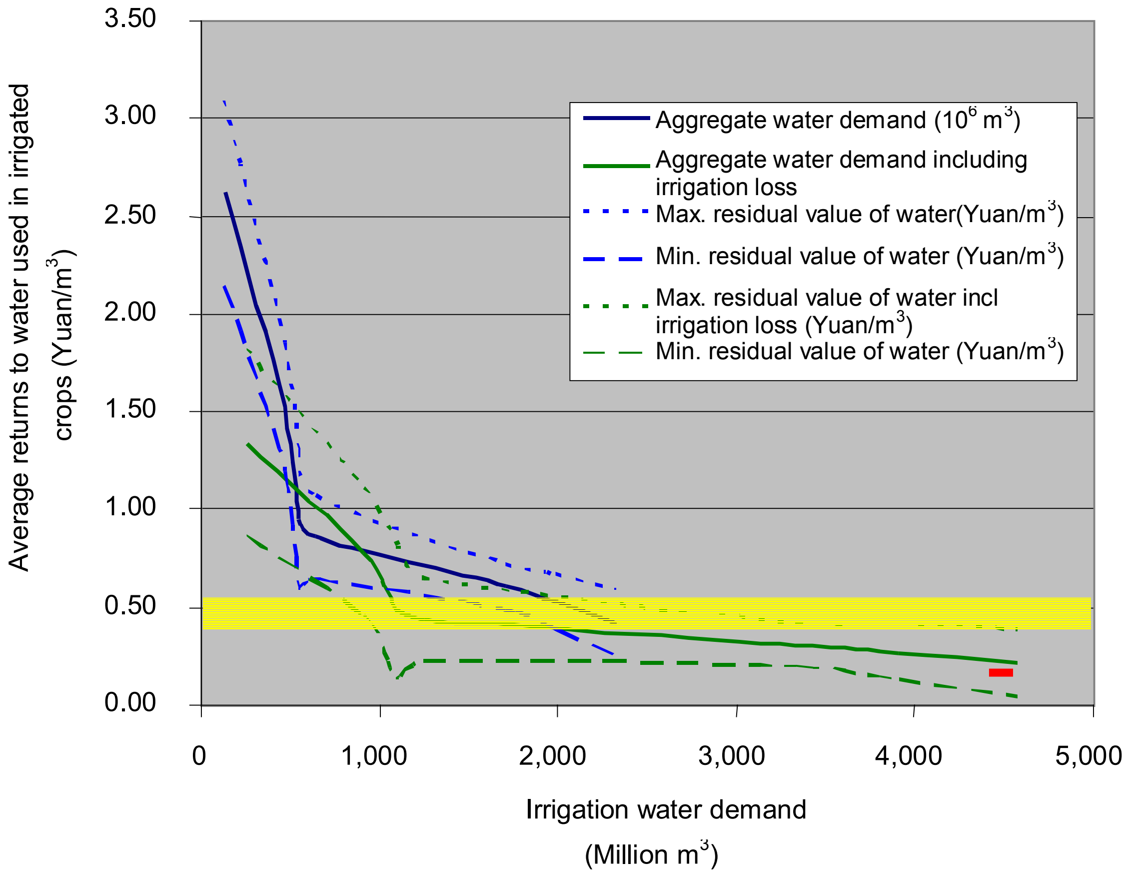

Figure 13. Returns to use of water in agriculture (1999-2003) compared to estimates of average opportunity cost in Yellow River (yellow area), marginal value of 91 million m^3/year relative to 2001 levels for lake water uses (red line; conservative estimate).

7 CONCLUDING REMARKS: ACHIEVEMENT OF RESULTS

7.1 State of the lake

The large increases in concentrations of mineral salts, nutrients and organic matter shows that the water quality of Lake Wuliangsuhai has become much worse during the relatively short period of time from 1987-88 to 2001. If this development is allowed to continue the lake will turn into a marshland within 30 – 100 years.

When comparing the results from the monitoring programme with water quality measurements made 15 – 20 years ago this is clearly the case for most chemical parameters. It can be seen that the lake has developed from a situation with much ‘healthier conditions’ with cleaner water and less plant production during the first ca. 100 years of the lake’s life-span since 1850.

From the satellite images it can be concluded that the decade and a half before 1989 witnessed more dramatic changes regarding expansion of reed than during the years after. During those years a combination of eutrophication and deliberate planting of reed in certain areas around the lake helped establish much of the current situation. Today dense widespread reed banks separate smaller basins of open water. This provides a rich habitat diversity of the lake.

7.2 Development of the Management and Control Plan

The initially identified 15 potential actions were integrated in to 10 actions, which were studied in detail by various groups of specialists. The summary of these results was presented in the previous chapters.

When only limited amounts of resources are available, actions need to be priorities. This process is normally achieved by a combination of scientific and political priorities. It is important to have the participation of stakeholders to secure the ownership of such an action, which will inevitable improve the efficiency, results and the sustainability. The previous chapter has presented a methodology and an example how such a prioritisation can be made jointly with many stakeholder groups.

To achieve the overall goal of the project – to keep the lake as a lake – a series of objectives need to be achieved. Some of these objectives are qualitative, which is difficult to present quantitatively. Some of these objectives are achieved over a long period, thus it is difficult to measure any impact over a short period. However, there are a number of concrete objectives, which can be measured. The reduction of pollution loading is such an objective, which will be analysed further.

7.3 Achievement of pollution reduction

The scientists, to a greater degree, agree about the current pollution loading and the required loading to reduce the eutrophication potential to a minimum and as well as to improve the current water quality status from Class-IV and V to III. These are presented in the below table.

Table 24. Current and required pollution loading to the lake

	Organic matter, COD	Total-Phosphorous	Total Nitrogen
Current loading, t/a	18,750	106	1,673
Required loading, t/a	10,000	30	800
Required reduction, %	47 %	72 %	52 %

Table 25.. Change of pollution loading after wastewater treatment

	COD	TP	TN
Current loading, t/a	18,750	106	1,673
Reduction by domestic WWTP, t/a	3,921	58	155
Reduction by industrial WWTP*, t/a	7,639	5	464
Sum loading after actions, t/a	11,560	63	619
Remaining loads after actions	7,190	43	1,054
Recommended loading, t/a	10,000	30	800
Loads should be reduced by Wetland	0	13	254

**Including the effect of closure of Hongjiang paper mill.*

The domestic and industrial wastewater treatment requires 310 and 10 million RMB, respectively. The wastewater discharges to the sewers from industries and municipal WWTP should comply with the Chinese national effluent standards of GB 18918-2002. The standard for municipal WWTP effluent according to the Class-I B is 1 mg/l of Tot-P, 20 mg/l of Tot-N and 60 mg/l of COD. The above table shows that the proposed domestic and industrial wastewater treatment plants can reduce the pollution loads to by far to the required levels. The phosphates need to be reduced further by 13 t/a or 12% and nitrogen by 254 t/a or 15%. Both these targets are easily achievable with a well functioning wetland, which is proposed.

Alternatively, the phosphorus and nitrogen removal can be achieved by upgrading the domestic treatment plants to more efficient systems. One has to remember that with the proposed improvements in the sewer connections, more pollutants will be transported directly to the lake via a treatment plant, a loading that is probably not fully accounted for in the current figures. On the other hand, the environmental authorities are demanding higher treatment efficiencies than the design capacities of the proposed wastewater treatment plants, which will naturally reduce the loading. With the other actions improving the circulation and even retention within the lake, one can assume improved self-purification levels. However, it is safer to assume that a wetland will be a quite important activity to secure the safe loading levels.

7.4 Securing water quantities

Although the inputs of water into Lake Wuliangsuhai vary considerably between years, the loss by evapotranspiration and percolation to the groundwater from the lake is relatively constant at ca. 400 million m^3/yr. This implies that the minimum annual water input from canals cannot go below this value without gradually reducing the water level on an annual basis. A lower water level than today might cause a rapid expansion of reed further into ‘open water’ areas of the lake. To achieve a replacement of the water volume, as well as to have a sustainable development and utilisation of the lake resources, at least another 200 million m^3 should be supplied to the lake. The proposal is to obtain 253 million m^3/y from the Yellow River.

In addition, timing of the water inputs must be considered together with regulation regime of the outlet dam, not to reduce the water level below accepted levels. The annual mean water level of

Lake Wuliangsuhai has varied in the range 1018.4-1018.9 m with an average of 1018.5 m above sea level in later years. It is proposed to increase the lake water level to 1019.0-1019.3 m above sea level, which in turn increases the average depth with 0.5-0.8 m.

7.5 Improving the internal circulation

The retention of incoming water within the lake and its circulation has voluble functions in the self-purification process. As is demonstrated in a number of simulation figures (as well as observed manually), the retention time of water masses varies quite significantly. Additionally, the vegetation and sedimentation reduces the volume available for this function. Thus, it will be severely beneficial to the lake restoration activity to improve the internal circulation of the lake. It will secure a more even retention and transport of water through the whole lake area. The canals may easily create short-circuiting worsening the current situation. The actions should be preferably verified using hydrological models as done in this study to avoid costly errors.

7.6 Improving biodiversity

Biodiversity will be improved from the results of number of actions. There are actions like dredging and increasing the water level that will directly improve the biodiversity. Other actions while improving the water quality of the lake, may increase the diversity and quantity of species found in the lake water and surroundings. The livelihood activities such as fishing and tourism must be carefully monitored that they will not create a negative impact on the biodiversity.

Restoration activities should specifically address aspects of bird-life, considering the lake’s rare bird qualities. Different actions may affect breeding and migrating birds differently. The protection status needs to be increased and existing protective regulations better enforced. Increasing importance for birds.

7.7 Socio-economical aspects

Although the project’s main objective is to suggest actions “to keep the lake as a lake”, the authors acknowledge the need for sustainable utilisation of lake associated natural resources for direct and indirect benefit of the more than one million of people that lives surrounding it. The suggested actions will definitively have a positive impact on the population on the quality of life by having access to a water body with better water quality and functionality. They will also have an impact on their livelihoods, which will increase their income. The increasingly practised and observed stakeholder participation will secure the ownership and the sustainability of the actions, but attempts should be made to increase the current level of participation in the decision making process – by awareness raising.

Lake Wuliangsuhai has unique qualities that must be preserved for the sake of local communities and future generations. Many of the lake’s wetland functions can not be appreciated in full by mere economic evaluations or even from a societal perspective.

Economical analyses of the current water usage shows that good economic case could be made for reallocating water from the least productive areas under wheat to the maintenance or increase of water level in Lake Wuliangsuhai. Reallocating at least some of the water from marginal crops such as wheat to downstream uses is also found to be economically rational.

7.8 Special restrictions

The role of the submerged vegetation in phosphorous control should not be underestimated. This type of vegetation consumes phosphates that are otherwise available for the alga, thereby limiting the potential for eutrophication. This is a special feature in shallow lakes with reference to the “two stable states”, which is described in other project reports in this series. The removal of organic matter is critically important, as they will otherwise consume the oxygen in the water leading to further oxygen depletion in the lake. That will result in fish kills during winter also in coming years, causing a low survival of fish beyond one or two years' age.

It is extremely important to keep in mind that the Lake Wuliangsuhai is at present in a clear stage due to the phenomena described as the two stable states of lakes. Even a smaller action may convert larger parts of the lake to be turbid in a very short time, and making it a lengthy and difficult process to reverse. Therefore, it is emphasised that all actions within the lake should be verified on pilot scale and observed carefully for any possible indication of loosing the stable state. One potentially dangerous action is the harvesting of submerged vegetation. It is suggested to follow the limitations proposed in this study, which is maximum 16 - 32 km^2. This should be carried out in stripes so only half of the total area is harvested. The maximum harvesting area should be less than 25 % of the total area of submerged vegetation.

Any new activity that may introduce pollutants to the watercourses must be strictly regulated. The environmental authorities must be entrusted with such decisions, and must be given the opportunity to build their knowledge basis.

7.9 Financial issues

The fact that the restoration of the lake is proposed as a specific issue in the next 5-year plan is a significant acknowledgement. However, most of these funds need to be secured externally through bi- or multi lateral loans. Considering the ownership of the action, it is recommended the following financing structure:

- Industries should bear 100% of the investment costs
- Municipal WWTP: 30% from the local government and the enterprises
- Other costs and measures: loan and investments from the Inner Mongolia government central governments as well as donors

The proposed actions sum up to an investment of 0.8 billion RMB (about 1.5 billion RMB annual costs), excluding the investments on agriculture pollution reduction. For the domestic wastewater treatment plants, the total investment is about 310 million RMB, indicating a need of over 200 million RMB as loans. The industries have a relatively lower investment burden of 10 million RMB, provided the Haojiang paper mill will remain closed. Otherwise, heavy investments will be required.

Among the additional actions not studied in detail during the course of the project, the following three could be mentioned:

1. Wulateqianqi wastewater treatment plant (RMB 33,5 mill)
2. Restoration of fish population and fishing (RMB 20 mill)
3. Automated water quality monitoring facility (RMB 10 mill)

Table 26. Summary of investment, O&M costs and annualised costs , RMB

MCP		Investment(I)	O&M	Investment life, years	Present value (O&M)	Present residual value of investment year 30 (R)	Total present value(I+O&M+R)	Income/year	Present value of income
1a	Hanghou WWTP	90 930 000	4 630 000	25	41 770 962	607 011	132 093 951	5 830 000	52 597 129
1b	Linhe WWTP*	37 310 000	4 912 000	25	44 315 111	249 066	81 376 045	20 020 000	180 616 557
1c	Wuyan WWTP	181 850 000	6 140 000	25	55 393 889	1 213 955	236 029 934	28 702 000	258 943 877
1	Sum domestic WWTP	310 090 000	15 682 000	25			449 499 930		
2a	Hongchang	5 417 000	336 000	25					
2b	Renze	1 500 000	80 000	25					
2c	Weixin	3 225 000	288 000	25					
2d	Haojiang paper	closed							
2	Sum industrial WWTP	10 142 000	704 000	25	6 351 351	67 704	16 425 648	2 500 000	22 554 515
3	Dredging	309 930 000	0	20	0	5 172 410	304 757 590	25 000 000	225 545 151
4	Harvesting submerged vegetation	54 980 000	6 037 240	10	54 466 808	3 670 237	105 776 572	16 000 000	144 348 897
5	Reed bed control	200 000	120 000	5	1 082 617	33 378	1 249 239	0	0
6	Introduce yellow river water	40 970 000	13 180 000	50	118 907 404	546 997	159 330 406	0	0
7	Moving of inlet and wetalnd construction	57 912 920	1 539 000	30	13 884 560	0	71 797 480	0	0
8	Erosion control	3 974 500	359 000	30	3 238 828	0	7 213 328	1 454 760	13 124 563
9	Farmland pollution control	ommited - estimate >3 billion RMB							
10	Improvement of water circulation	3 660 000	0	20	0	61 082	3 598 918	0	0
	Sum	**791 859 420**	**37 621 240**		**339 411 530**	**11 621 839**	**1 569 149 041**		

Note: present values calculated using:
Discount rate 0.12
Analysis horizon (years) 30
Residual capital values in year 30 using linear depreciation

7.10 Ranking of the actions

The ranking of the proposed actions can be carried out using various approaches. A logical approach would be to:

- actions to reduce the pollution loads to the lake
- actions within the lake which reduces pollution
- actions to secure sufficient quantities of water to control vegetation, provide favourable dilution and to improve biodiversity, etc
- actions to sustainable utilisation of the lake's resources

Such an approach is widely utilised by internationally and in China, and are well in agreement among the Chinese, Swedish and Norwegian specialists. The ranking of activities following such an approach is presented in Table 27.

The usage of a more comprehensive approach was demonstrated during the project. The performance of each management and control measure (MCM) were studied according to the four main criteria ENVIRONMENT, ECONOMY, SOCIAL and INSTITUTIONAL, and using large number of subcriteria. The major disadvantage in this approach is the need for more detailed information and the difficulty in securing reliable data.

This concept was presented in this report as a tool to be used in future activities.

This exercise has resulted in the in the following ranking of the priorities as presented in Table 27.

Table 27. Ranking of actions according to common approaches. (Recommended)

Rank	No	Description
1	2	Industrial wastewater treatment (all)
2	1.3	Wuyuan wastewater treatment
2	1.2	Linhe wastewater treatment
2	1.1	Hanghou wastewater treatment
3	6	Yellow River water supply and lake level increase
4	7	Moving of inlet and wetland construction
5	4	Harvesting submerged vegetation and utilisation
6	5	Reed bed control
7	8	Erosion control
8	9	Agricultural pollution abatement
9	10	Improvement of internal circulation
10	3	Dredging (all)

Table 28. An example of ranking of measures according to four main criteria: Environment, Economy, Social and Institutional. (subject to the verification of input data)

Rank	No	Description
1	1.3	Wuyuan wastewater treatment
2	3	Dredging (all)
3	1.2	Linhe wastewater treatment
4	4	Harvesting submerged vegetation and utilisation
5	6	Yellow river water supply and lake level increase
6	10	Improvement of internal circulation
7	8	Erosion control
8	1.1	Hanghou wastewater treatment
9	2	Industrial wastewater treatment (all)
10	5	Reed bed control
11	7	Moving of inlet and wetland construction

Table 29. Ranking of the measures according to cost-benefit ratios. (subject to the verification of input data).

Rank	No	Description
1	5	Reed bed control
2	10	Improvement of internal circulation
3	8	Erosion control
4	2	Industrial wastewater treatment (all)
5	1.2	Linhe wastewater treatment
6	4	Harvesting submerged vegetation and utilisation
7	7	Moving of inlet and wetland construction
8	1.1	Hanghou wastewater treatment
9	6	Yellow river water supply and lake level increase
10	1.3	Wuyuan wastewater treatment
11	3	Dredging (all)

Although the costs of the measures need to be verified with detailed pre-feasibility studies, the following ranking is suggested based on the cost-benefit ratios. The need for a revised ranking with more secure cost and revenue measures is emphasised.

Table 28 illustrates the ranking of measures if implementation is based only on environmental, social and institutional criteria (benefits). Table 24 illustrates the ranking if the cost/normalised benefits ratio is used. The latter illustrates the limitation of the MCA analysis when the cost of measures varies across a large scale, while the qualitative characterisation of impacts does not capture the same variation in scale. Consequently, the ranking based on cost/benefit ratio more or less implies implementing the cheapest measures first (because relatively little information is provided on the scale of benefits). Investments towards establishing sustainable conditions of the Lake Wuliangsuhai should follow this sequence if the budget for implementation is only gradually made available.

It is recommended to follow the ranking based on common approaches as presented in Table 27. However, it is suggested to utilise the ranking tools and concepts presented in the previous chapter and in Table 28 and Table 29 with more reliable data for a more precise and logical prioritisation.

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