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Inner Mongolia Environmental Science Institute

Inner Mongolia Lake Restoration Project
Lake Wuliangsuhai Comprehensive Study Extension

Historical Development of Lake Wuliangsuhai

Norwegian Institute for Water Research

– an institute in the Environmental Research Alliance of Norway

REPORT

Main Office	Regional Office, Sørlandet	Regional Office, Østlandet	Regional Office, Vestlandet	Regional Office Central
Gaustadalléen 21 NO-0349 Oslo, Norway Phone (47) 22 18 51 00 Telefax (47) 22 18 52 00 Internet: www.niva.no	Televeien 3 NO-4879 Grimstad, Norway Phone (47) 22 18 51 00 Telefax (47) 37 04 45 13	Sandvikaveien 41 NO-2312 Ottestad, Norway Phone (47) 22 18 51 00 Telefax (47) 62 57 66 53	P.O.Box 2026 NO-5817 Bergen, Norway Phone (47) 22 18 51 00 Telefax (47) 55 23 24 95	P.O.Box 1266 NO-7462 Trondheim Phone (47) 22 18 51 00 Telefax (47) 73 54 63 87

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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 describes the historical development of Lake Wuliangsuhai based on available sources: interviews with elderly fishermen, documentation from aerial and satellite images, sediment analysis, water quality monitoring and various sources on the Internet.

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Project manager

Strategy Director

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Inner Mongolia Environmental Science Institute

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Inner Mongolia Lake Restoration Project

Sub-Project 4:

Historical Development of Lake Wuliangsuhai

Final Report

Preface

This is one in a series of reports of the: 'Inner Mongolia Lake Restoration Project'. Inner Mongolia Environmental Science Institute (IMESI) has through the Inner Mongolia Science and Technology Committee and the State Science and Technology Commission applied to Sida and NORAD for financial support to carry out a three years' restoration project in Lake Wuliangsuhai in Inner Mongolia, the Peoples Republic of China.

IVL and NIVA are the consultants of the project.

Several parallel analyses of satellite images have been performed; by Prof. Shang Shiyou at the Agricultural University of Hohehot, by the Chinese Mapping Services and by NIVA. Gunnar Severinsen, NIVA performed the Norwegian analysis of satellite images, in co-operation with Tone Joeran Oredalen and Bjoern Faafeng. Comparison of satellite images with aerial photos were carried out by Bjoern Faafeng (NIVA).

Depth measurements were carried out over the 'open water' area of the lake by the staffs from Wulateqianqi Monitoring station, IMESI and NIVA. Anne Bjoerkenes and Robert Abelsen, NIVA together with Tone Joeran Oredalen and Bjoern Faafeng, performed the construction of the depth-contour map based on these measurements.

The National Environmental Research Institute (NERI) in Silkeborg, Denmark is responsible for the analyses of micro-fossils in the lake sediment. The analyses were performed by Liselotte Johansson, Susanne L. Amsinck, Karina Jensen and Erik Jeppesen at NERI (Silkeborg, Denmark) and Emily Bradshaw, The Geological Survey of Greenland and Denmark (Risskov, Denmark).

Interviews of local fishermen was carried out by Mr. Li Zhonghe (secretary of the Communist Party at the Fish Farm), Ms. Tao Li (IMESI), Mr. Liu Zhiguo (Li Yawei's student - Agricultural University), Finn Medboe (NIVA) and Tone Joeran Oredalen (NIVA).

Authors of this report have been:

Bjoern Faafeng[1], Shang Shiyou[2], Liselotte Johansson[3], Susanne L. Amsink[3], Karina Jensen[3], Erik Jeppesen[3], Emily Bradshaw[4], Tao Li[5], Finn Medboe[1], Anne Bjoerkenes[1], Fridtjov Ruden[1], Tone Joeran Oredalen[1] and Jarl Eivind Loevik[1].

1 NIVA
2 Agricultural University of Hohhot
3 NERI
4 The Geological Survey of Greenland and Denmark
5 IMESI

Oslo, 13 April 2005

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CONCLUSIONS

This report describes the historical development of Lake Wuliangsuhai based on available sources: interviews with elderly fishermen, documentation from aerial and satellite images, sediment analysis, water quality monitoring and various sources on the Internet.

On a geological time scale there has also been a lake on the Hetao Plain. The very reason for the Yellow River taking its famous easterly detour (the Great Bend) is tilting and subsidence of the South-eastern corner of the Ordos Plateau. In other words, natural sedimentation and block subsidence has diverted the river and has controlled the presence and size of a lake since the early Pleistocene, some 3 million years ago.

A main picture of the lake's recent history emerges from this information: Since the cut-off from the Yellow River during a major flood at 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.

Analysis of satellite images from 1975 until 2002 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.

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 (ca. 7.000 km^2) with a population of more than a million people, it gradually became a serious source of polluted water to the lake, including run-off from farmland, industrial effluents and sewage from cities.

Today the lake is characterized 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. An analysis of the lake sediment has documented the development from a deeper situation with much 'healthier conditions' with cleaner water and less plant production during the first ca. 100 years of the lake's life-span.

The average concentrations of main ions during the ice-free seasons have increased considerably during the 14 years from 1987-88 to 2001, on both sampling stations in the lake. This is primarily caused by heavy evapo-transpiration in Hetao Irrigation Area. Average concentrations of phosphorus (Tot-P) and nitrogen (Tot-N) also increased strongly from 1987-88 to 2001. The increase in nutrients (43-218%) over this 14 years period illustrates the deteriorating water quality and the severity of the eutrophication problem of Lake Wuliangsuhai. At both lake stations (north and south), large increases in the average concentrations of organic matter (COD_{Mn} and BOD_5) were observed from 1987-88 to 2001. The increase in concentrations of mineral salts, nutrients and organic matter shows that the water quality of Lake Wuliangsuhai has become much worse during the years from 1987-88 to 2001 and that countermeasures to reduce the pollution are imperative to restore good water quality and high biodiversity.

Despite this negative development, the lake is still a large, valuable and rare wetland ecosystem of the dry northern plains in China. Its high value depends both on the production of valuable resources for the local people and its environmental significance; not the least as a bird habitat.

However, the average depth of the ‘open water’ part of the lake is only about 1 m today. It is clear that the lake will inevitably become more shallow at a high speed due to the pollution and its high biological productivity. Unless efficient steps are taken to counteract the present development it is predicted that the lake will be dried out during the next 30-100 years.

1 SYNOPSIS OF THE RECENT LAKE DEVELOPMENT

The birth of Lake Wuliangsuhai

The present Lake Wuliangsuhai was formed in the middle of the nineteenth century, as a result of Huang He – Yellow River changing its course after a large flood. A large turn of the river was left isolated from the river; a so called oxbow lake.

It has not been possible so far to retrieve any detailed documentation on how the lake developed during the last 150 years; its size, depth, surface elevation and supply of water. However this short presentation will give the main points of present knowledge.

On a geological time scale there has also been a lake on the Hetao Plain. The very reason for the Yellow River taking its famous easterly detour (the Great Bend) is tilting and subsidence of the South-eastern corner of the Ordos Plateau. In other words, natural sedimentation and block subsidence has diverted the river and has controlled the presence and size of a lake since the early Pleistocene, some 3 million years ago.

Early settlement in Hetao
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. The climate in the area is however, too dry to allow agriculture other than grassland dependent on rainwater alone.

In 127 BC, during the reign of Emperor Hanwu, about 100,000 people from what is now Hebei, Shandong, Henan and Anhui provinces were summoned to move to the Hetao Plain and areas to the south of the Yellow River (http://www.china.org.cn/english/2002/Aug/38581.htm).

The present Hetao Irrigated Area refers mainly to the area with irrigation canals directing water from the Yellow River and located in Bayanaoer League, Inner Mongolia Autonomous Region. Many structures were built in the Qing Dynasty; 1644AD-1911AD (http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGL/swlwpnr/china/Image_e/129e.htm).

The settling of migrant Han farmers in the Yellow River bend region, or Hetao, began back in the late Qing, but after the extension of the Peking-Suiyuan rail-line to Baotou in 1923 the rate of settlement increased dramatically (http://www.aasianst.org/absts/1997abst/china/c155.htm). The Colonization of the Hetao area of western Inner Mongolia that took place by the end of the nineteenth century resulted in a considerable number of Han settlers and a growing Mongolian resistance despite the official Qing ban on agriculture and Han immigration outside the Great Wall. (Ellen McGill**,** Columbia University, USA, 1996).

Recent lake history
Available information claims that the lake was much larger and considerably deeper during the first half of the 20-ieth century than today. At that time the lake was reported to cover 900 km^2, compared to today's size of ca. 300km^2. About half of the lake area is presently covered by reed and the other half is open water with considerable densities of submerged vegetation, mainly dominated by *Potamogeton pectinatus*. The massive growth of submerged vegetation makes both fishing and boating difficult and affects water quality in different ways.

Utilization of the lake's resources

The lake had in its earlier days a high production of fish, which both employed and fed a considerable human population along the lake's shores. In the 1950ies when people were moved from Hebei Province south of Beijing to Lake Wuliangsuhai, they got improved life conditions as fishermen depending on fish from the lake as their primary food source. These people are now retired, but their descendants are still employed and live primarily of what the lake produces. The name of the unit administrating the harvesting of the lake's resources is still called "The Fish Farm" although now the major source of income from the lake is not fish, but the steadily increasing reed belts with *Phragmites communis* and *Typha* sp. The reed is harvested from the ice in winter and is used as a valuable raw material for three paper-mills in the nearby city Wulateqianqi. Fish production has declined dramatically since the 1960ies.

Development of lake size and depth

Approximately 50 years ago the lake is said to have been considerably bigger and deeper, we do not have exact information on this. Unfortunately the first available satellite images are only from the mid 1970ies, and at that time the lake surface area was not larger than today. This was partly due to the fact that 1975 was an extremely dry year.

Interpretation of the satellite images in combination with interviews with elderly peoples who lived close to the lake in the early 1950ies, give us a fair idea of what has happened to the lake during the last fifty years. Especially along the northern and western shoreline large areas of the original lake are now covered with reed (mainly *Phragmites*), providing income to a great number of families surrounding the lake. But also land has been reclaimed for agricultural purposes, both by decreasing the water level of the lake and by building dykes to protect the reclaimed land from being flooded. Of these measures the lowering of the lake surface is by far the most influential on the lake ecosystem, as this triggered the accelerating expansion of the reed belts. Some areas cultivated for agricultural purposes in the 1970-ies have later been transformed back to reed production areas (ca. 32 km^2).

The lake had probably at least 100 – 200 km^2 larger water surface area in the 1950ies than today, which is now either agricultural land or reed belts. Even more important, from a lake ecosystem perspective, the lake was probably more than 1.0 meters deeper. The retired interviewed fishermen reported about maximum water depth of 4 meters at that time. The deepest point of the lake observed during this investigation was 3.2 m. Satellite images however, reveal that the lake surface has varied through the last half of the past century. Especially in 1975 the water level, and the extension of the lake, was much reduced compared to later years.

The interviews of fishermen living in fishermen's villages around the lake have confirmed that that the lake got its water directly from the Yellow River through several (three or four) irrigation canals of the second or first level prior to 1978. The lake was even fed from the outlet canal back-flowing when the Yellow River was flooding. No water budgets on the lake are available from this period. The water fed the lake by gravity, even though the elevation of the lake surface was higher than today. Information given says that prior to 1978 the surface level was up to1020 meters above sea level. Today the average level is 1018.5 m above sea level, which is the target elevation to be kept in October before ice covers the lake. This water level is considered an optimum for reed cutting in winter and giving the highest yield.

Deteriorating water quality

The reduced water depth provides the fish population with less area and water volumes. Winter ice-cover of the lake combined with heavy pollution with dissolved organic waste from industries and run-off from farmland, lead to consumption of all or most of the dissolved oxygen in the water during winter, and regular massive winter-kills of fish. The salinity in Lake

Wuliangsuhai has almost doubled from 1987/88 until 2001 (from 0,8 to 1,4 o/oo on St. North; Xidatian, and from 1,2 to 2,4 o/oo on St. South; Erdiar). An additional factor has been the loading of plant nutrients (phosphorus and nitrogen) that stimulate the dense growth of submerged vegetation. When decaying under the ice in winter, these plants add to the harmful oxygen depletion of the water. Measurements of oxygen under the ice in year 2001 confirmed anaerobic conditions in the lake water.

Studies of microfossils in the lake sediments indicate major changes in lake biota over time. A shift has occurred from a pelagic to a plant dominated system during the 150 years of existence of the lake. The fish predation risk has decreased in recent years, potentially reflecting a reduction in fish abundance during winter and an increased refuge effect for the larger zooplankton. Moreover, salinity seems to have gradually increased. As interpreted from the density of zooplankton remains, a major increase in lake productivity seems to have occurred from 32.5 cm sediment depth and upwards. Unfortunately, as the core cannot be dated, the timing of changes and the actual changes in lake productivity cannot be determined. Assuming an annual sedimentation rate of 0.5-1.0 cm over the most recent period, this sediment layer corresponds with ca. 30-60 years back in time.

Improvement of the Hetao irrigation system

In the early 1990-ies a large engineering project supported by the World Bank was carried out in the Hetao area to increase the irrigated farmland and to protect from further salination of the soils. One major component in this scheme was the construction of a network of drainage canals deep enough to lower the ground water level in the farmland, because of this the drainage system near the lake was too low to allow gravity flow directly into the lake. In 1978 the first Main Pumping Station was built and put in operation. Its purpose was the pumping of water at the rate of up to 30 m^3/sec into the lake at a lift height of one to two meters.

Expansion of reed and economic utilization of its fibres

At the same time the surface-level of the lake was lowered gradually, the lake surface area was reduced and the reed started to spread over larger areas at an accelerating speed reducing the lake surface further. In areas shallow enough the reed established and grew vigorously in the nutrient rich drainage water.

In the early 1980ies the first big paper factory was built in Wulateqianqi (and later two more), utilising the local reed resource. Until then the reed was used mainly for the construction of fish-traps and equipment, roofing of greenhouses and some export out of the area to more distant paper factories.

A much larger pump-station was put in operation in 1995 next to the first, with a capacity of 100 m^3/s. A third pump station was put in service to lift water from drainage canal no. 9 which most of the time gravity feeds the lake, but at certain higher levels has to be pumped.

The seasonal variations for the lake-elevation can vary up to 70 cm during the summer, while in the late fall the outlet canal construction built in 1984 regulates the level up to 1018.5 m above sea level. Today backflow from the Yellow River is only possible in restricted parts of the year.

Satellite images show that the major increase in reed area took place during the years between 1975 and 1994. The major decrease in open water area took place between 1975 and 1986. Between 1986 and 1994 the expansion of reed took place into former land areas rather than into open lake areas; hence the area of open water in the lake has only diminished slowly after 1986.

Measures to increase the water depth of the lake
Without increasing the depth of the lake in designated areas, it will first develop to a reed marsh and in the end it will dry out. An increasing surface cover of reed will accelerate the evapo-transpiration from the lake and speed up the process. This development will depend heavily of the equally important variables governing the lake development: the amount of water allowed into the lake from the Yellow river and Hetao area, as well as the regulation of the lake's depth.

Increasing the depth of the lake can in principle be achieved in two ways; increasing the elevation of water (with a higher outlet dam) or excavating mud from the bottom of the lake; or a combination of those. Both these measures have been studied during this project, with regard to effects and costs of investment and cost of operation.

Several other factors will affect the future management of the lake:

- What are the costs and consequences of the different measures?
- Will irrigation water be supplied from Yellow River in the same amounts; if not – how much?
- Will more water-conserving irrigation methods be introduced in the farmland?
- Will less water consuming crops be introduced?
- Will the pollution of the lake be reduced?
- Will reed have the same economic value in the future for paper production?
- Will other economic factors, like bird protection or tourism, be more important?

These matters will be discussed in more detail in the Management and Control Plans (MCPs).

Future perspectives
Lake Wuliangsuhai is presently under a concerted attack on many fronts, a combination of several dynamic factors which will require considerable resources to counteract. Without significant and continuous human interventions, the future of Lake Wuliangsuhai will be determined by the following factors:

- Low rate of (geological) basin subsidence
- High rate of natural basin sedimentation
- Induced sedimentation from man-made causes
- Induced organic sedimentation caused by eutrophication
- Reduced artificial replenishment of water from Hetao and Yellow River.

Even when the surface of a shallow lake is kept at a constant level, all lakes tend to fill in and dry out on a long time scale (tens, hundreds or thousands of years). Local people are, however, increasingly aware and worried about the expansion of reed areas since the 1970ies. This is in agreement with the conclusions of the Chinese and Scandinavian experts of this project who warn that the lake at this tempo will have a limited life, estimated to some 30-100 years, if nothing is done to change this pattern of negative impact.

Over time Lake Wuliangsuhai is doomed to end up as dry land unless water is used and managed in a more wise way to 'save the lake as a lake'. Pollution from different sources in the Hetao Area, reduced input of water to the lake, and a lower water level than previously, significantly will decrease the life span of the lake. It has taken only a few decades to bring the lake to the vulnerable - labile state in which the lake is today. To keep the lake alive will take equally strong determination to stop the negative trend, involving the necessary financing of restoration measures. These will be described in more detail in the Management and Control Plans.

2 INTRODUCTION

This is one in a series of reports of the Project: 'Inner Mongolia Lake Restoration Project'. Inner Mongolia Environmental Science Institute (IMESI) has through the Inner Mongolia Science and Technology Committee and the State Science and Technology Commission applied to Sida and NORAD for financial support to carry out a three years' restoration project in Lake Wuliangsuhai in Inner Mongolia, the Peoples Republic of China.

Inner Mongolia Environmental Science Institute (IMESI) is the implementing institution, whereas
IVL Swedish Environmental Research Institute and NIVA (Norwegian Institute for Water Research) are the consultants of the project.

The long-term goal of the project is that the lake Wuliangsuhai shall be kept as a lake, and developed into a productive resource for future sustainable development of the Hetao area.

The purpose is to facilitate the establishment of sustainable water usage in the Hetao area by building a maintainable knowledge base on the natural and societal processes that affect the water quality. Further, the project aims at qualifying the Chinese personnel in relevant topics and skills.

The output of the project is a feasible management and control proposal for addressing the conflicting interests that cause the eutrophication problems of Lake Wuliangsuhai.

2.1 Aim of this subproject

The aim of the sub-project "Historical development of the lake" is to verify the reduction in size of the lake surface and the increase in vegetation cover after the lake was diverted from the Yellow River some 150 years ago.

Maps of lake surface area and propagation of vegetation cover will be produced from available aerial photos and/or satellite images as long back in time as possible until today. Estimates of trophic development of the lake will be made based on sediment accumulation and chemical and biological analysis of the sediment.

3 METHODS

The historical development of the lake has been studied by means of different methods:

- Satellite images covering the period 1975 - 2002
- Aerial photos from 1985
- Sediment cores
- Interviews with old, local fishermen.

A depth contour map of the lake has been constructed.

3.1 Depth Contour Map

The depth measurements were performed through 3 different field studies; May 2001, February and June 2002. Most of the depth measurements were performed from a boat by putting a stick vertically into the lake through the submerged vegetation until it hit the lake bottom. The stick was marked every 10 cm with tape of different colours to facilitate the reading of the depths. Each depth was measured, also simultaneously the geographical co-ordinates of the site were secured by means of a GPS (Garmin model).

During winter (February 2001) the depths were measured through holes in the ice along some straight transects across the lake. The positioning at this time was noted according to available maps and satellite images of the lake.

The lake depths and co-ordinates were stored in a computer spreadsheet where the actual depths were adjusted according to the given lake surface elevation on the respective days of measurement. The corrected data were transferred into a GIS system (Arc-Map) and the measured points were superimposed on a satellite image from that served as a digital map of the lake. Iso-lines, e.g. lines of similar depths for every 0.5 m below the lake surface, were drawn by hand between points of similar depths. From a number of measurements, the average depth at the lake-ward border between reed and open water was set to 1.2 m (according to annual average water level). On the basis of the resulting draft of a depth-contour map more depth measurements were performed to form a final network of sites in the lake sufficiently close to construct a reliable depth contour map. The depth-measurements were superimposed on a satellite image of the lake to include visual clues, especially about the deepest areas in the south. The deepest trench of the lake was positioned according to the satellite image. The final result was checked by different stakeholders of the lake project.

The areas surrounded by each 0,5 m iso-line were calculated in Arc-Map. To present as detailed information as available, we separated between areas of open water, reed and harvested reed.

Water volumes between every 0,5 m is-line was calculated from the area-depth values by a standard method described a.o. by Cole (1983):

$$\mathrm{V}_{\mathrm{z1\text{-}z0}} = 1/3\,(\mathrm{A}_{\mathrm{z0}} + \mathrm{A}_{\mathrm{z1}} + \sqrt{A_{z0} * A_{z1}}) * (z1 - z0)$$

where V_{z1-z0} is the volume of the lake between the lake surface and the first iso-line below the surface ans A_{z0} is the total area of the lake, A_{z1} is the area of the first iso-line below the surface, and so on. Volumes of succeeding depth strata are summarized to give the total lake volume.

3.2 Satellite images

The following is a description of the Norwegian methods.

To quantify the total lake area, the different types of lake areas ('open water' and ‘reed’) and the possible changes in the reed and open water areas, we studied satellite images over the lake area covering the years 1975 - 2002. Landsat images have been used in the analysis. Very few satellite scenes without clouds are available from the 1970'ies. Below some information of the used scenes are listed.

Satellite images have also been provided by prof. Shang at the Agriculture University of Hohehhot. He and his students have also supplied us with information about “farmed reed areas” on reclaimed farmland along the western shore of the lake.

3.2.1 Total lake extension

To estimate the total area of the lake during different years, several satellite scenes were studied: 16 June 1975, 6 August 1978, 9 August 1986, 8 July 1989, 15 August 1994, 20 July 1999, 14 July 2000, 21 July 2001 and 29 August 2002. The sensors of these satellites were different due to the technological development, but we assume that they at least give comparable information of the land/water interface. The 1975 scene is a combination of Multi-Spectral Scanner bands nos. 3, 2 and 1 in Landsat 2. The 1999 scene is a combination of Thematic Mapper bands nos. 3, 2 and 1.

Table 3.1 The water levels during the observations in 1975, 1978, 1994, 1999, 2000, 2001 and 2002.

date	water level (meters above sea level)
16 June 1975	1018.20 (as annual mean)
6. August 1978	1018.70 (as annual mean)
15. August 1994	1018.56
20. July 1999	1018.42
14. July 2000	1018.49
21. July 2001	1018.15
29. August 2002	1018.78

3.2.2. Reed and 'open water' areas

One of the infrared (IR) bands was used to discriminate between water and other areas, since it showed the most evident differences. Digital satellite pixel values from 1 to the digital threshold value given in the table below were classified as 'open water' areas.

Table 3.2. Dates of satellite scenes used for the analysis of different area types. Name of satellites, optical bands used and threshold values for the identifications of 'open water' are given.

Satellite	Date of acquisition	Spacial resolu-sion	Band	Digital threshold value
Landsat 2 Multi-Spectral Scanner	16. June 1975	ca. 70m	4	20
Landsat 5 Thematic Mapper	8. July 1989	ca. 30m	5	35
Landsat 5 Thematic Mapper	20. July 1999	ca. 30m	5	40

3.3 Aerial photos

Aerial photos from summer 1985 were kindly provided by the former director of the “Fish Farm”, mr. Li Aiming during a visit in June 2002. The photos were presented as paper copies, some of which we were allowed to copy by a digital camera. The digital images from some selected areas were compared with the same areas on satellite images from 2002. The intension of this exercise was to confirm the interpretation and accuracy of the satellite images.

3.4. Sediment COREs

3.4.1 Sedimentation rate

Estimating the age of different layers of the sediment cores by C-14 dating was intended, but turned out impossible due to lack of access to methods in Hohehot. Only a rough estimate of the overall average sedimentation rate in the lake has been possible. Inorganic sediments probably originating from the latest fluvial period in the mid 1800ies, before the isolation of the lake, were found at a sediment depth of ca. 70 cm.

3.4.2 Macrofossils

Samples of sediment from different depths were taken from a core at the monitoring station in the southern part of the lake (Erdiar). Sediment samples of 2 cm thickness were taken from the following depths: 0-5 cm, 15-20 cm, 30-35cm, 45-50 cm and 65-70 cm). These samples were sent to The Danish National Environmental Research Institute in Denmark (NERI) for microscopic analysis of macrofossils (diatoms and zooplankton).

Diatoms
Samples were prepared according to Renberg (1990), and slides were analysed using a Leitz Laborlux S microscope (phase contrast, 1000x magnification). Taxonomy classification/determination was made using various keys, including Krammer & Lange-Bertalot (1986-1991). Counts were converted into percentage abundance using the program TRAN (Juggins, 1997).

Zooplankton:
The sediment core was sub-sampled into 5-cm sections in the laboratory. Each section was homogenised, and sub-samples of approximately 5 g (wet weight) sediment were weighed. Five subsamples were used for the analyses of zooplankton remains. These were boiled in 30 ml 10 % KOH for 20 minutes and subsequently kept cold (4 °C) for no longer than 2 weeks until taxonomical analysis was performed. The samples were filtered manually and remains of zooplankton >80 µm were identified using a stereomicroscope (Olympus SZX12) and an inverted light microscope (320x, Leitz Labovert FS). To facilitate counting, the remains were divided into two size fractions: >140 µm and 80-140 µm. The following keys were used for identification: Frey (1959), Margaritora (1985), Hann (1990), Røen (1995) and Flössner (2000).

3.5 Interviews

During the project period, a lot of information has been collected about Lake Wuliangsuhai – about development of the lake, utilisation of the lake and organisation of activities. Lake experiments and monitoring of the lake and Hetao canals are major tasks of this project. In addition, more information is collected from other written sources; the majority has emerged from discussions during the project period.

To help sorting out the partly diverting impressions and information achieved about the lake, we interviewed local elderly fishermen people that live by and from the Lake Wuliangsuhai today about the late history of the lake, and about their knowledge on the development and activities in the lake.

Our interviews were organised at two different times and locations. One interview took place at the Fish Farm with 5 elderly fishermen that had lived by and from the lake since the late nineteen-fifties. The other interview took place with a fisherman's family in Fishermans village no. 15, situated close to the Main Pumping Station. The people to be interviewed were chosen by the director of the Fish Farm, Mr. Li Zhonghe (Secretary of Communist party), and our colleagues from IMESI. Both interviews lasted for about 1 ½ hours, and the majority of the questions were asked at both occasions. The interviews were performed by two project-members from IMESI (Ms. Tao Li and Mr. Liu Zhiguo) – both skilled in English, one from Monitoring Station in Wulateqianqi (Mr. Zhang Fengqing) and two project members from NIVA (Finn Medboe and Tone Joeran Oredalen). The minutes from the interviews are given in Appendix.

4 RESULTS

4.1 Development Of The Lake In A Geological Perspective

The description of the geological context of the Lake Wuliangsuhai is merely intended to contribute a broad perspective of the underlying processes that form the basis of the present lake. It must be kept in mind that these forces are still active, aggravated by a series of man-made processes and the desire to maintain the lake as a lake.

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. A vivid testimony of these recurring processes is seen in the form of parallel 'strath terraces' along the adjoining hillsides[1] and fault escarpments. These features are remnants of ancient and abandoned channel bed deposits.

The sedimentary basin under the lake is several thousand meters deep and constitutes one of China's many prospective oil provinces.

The modern Lake Wuliangsuhai is the recipient of water emanating from the Yellow River as well as from the agricultural sector of the lake's hinterland; in particular from the Hetao plain. This water is rich both in suspension and nutrients, and is pumped into the lake via drainage canals and two large pumping stations. As opposed to earlier historical times water no longer freely gravitates into the lake, but has (to a considerable degree) to be elevated to regain elevation lost by sedimentation and low rates of subsidence in the lake area. The ensuing eutrophication of the lake stimulates aquatic plant growth. The combined effects of suspended particle sedimentation, eolian dust blown into the basin, mineralization of organic material and the accumulation of plant material, result in a steady accretion of an organic/inorganic layer. In other words, the lake becomes increasingly shallow.

While sedimentation takes place within the lake basin, the bottom of the lake literally sinks in. Being part of an ever subsiding geological basin ('Hetao Graben') the geological subsidence has to some extent kept pace with the sedimentation over the millennia. But not always, as demonstrated by the pumping stations that presently keep the lake alive with their 'artificial respiration' in the form of life-supporting replenishment of water. The natural drainage into the modern Lake Wuliangsuhai accounts for less than 10% of the minimum influx required to keep the lake alive.

4.1.1. Environment

The climate of Lake Wuliangsuhai in a geological and historical perspective
The climate of the Ordos Plateau, of which the lake Wuliangsuhai is a NE part, has undergone dramatic changes since Tertiary. With the Pliocene collision of India into the Asian continent,

[1] Shaoping et al, 2002: Strath terraces of Jinshaan Canyon, Yellow River and Quaternary tectonic movements of the Ordos Plateau, North China. Terra Nova, 14, pp.215-224.

the resulting 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)[2]. The trend has continued through Pleistocene and Holocene and explains some of the problems encountered in the lake area today. During late Pleistocene the Ordos Plateau had become extremely cold and with dry, with moving sands covering much of the area.

Archaeological evidence shows that the Ordos Plateu has been inhabited for some 60.000 years[3]. Early written records exist for the last 2.000 years. Whereas climatic changes in the Pleistocene (3 million to 10.000 years before present) can be attributed solely to geological changes, the more recent Holocene shifts can be attributed to human intervention such as grazing, farming practices, etc.

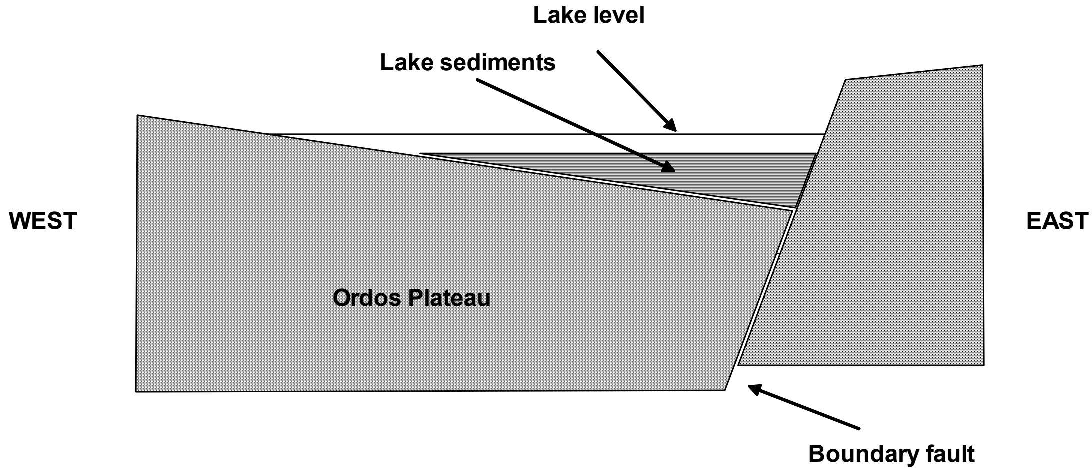


Figure 4.1. Lake Wuliangsuhai is created by a slight tilting of the Ordos block. The lake is dammed against the northern and eastern fault scarps which form the main confinements of the present lake.

Factors controlling water depth and size of Lake Wuliangsuhai

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 South and East by active tectonic escarpments.

The very reason for the Yellow River taking its famous easterly detour (the Great Bend) is due to tilting and subsidence of the SE corner of the Ordos Plateau. In other words, natural sedimentation and block subsidence has diverted the river and has controlled the presence and size of the lake since the early Pleistocene, some 3 million years ago. The lake has expanded and contracted over much of the Hetao area countless times during this period. As a consequence, several thousand meters of alluvial, lacustrine and eolian sediments have accumulated under the present Lake Wuliangsuhai. 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 1000 years has also contributed to less water and more sediments due to eolian transportation of loess, dust and sand.

Also man-made factors are controlling the lake level and depth. The most important factor is presently the artificial replenishment of water which is drained from the intensely irrigated

[2] Li et al, 1990
[3] Shi, 1991

Hetao plain and pumped into the lake. At present, the lake's area is 293 km^2. According to satellite remote sensing analysis the Lake Wuliangsuhai area has decreased about 20 km^2 since 1995. While the lake water level is being controlled by the outlet weir, organic and inorganic sedimentation of the Lake Wuliangsuhai is slowly but steadily filling up the basin, at the expense of the water quality as well as the volume of water stored in the lake. Since the water level is not being adjusted correspondingly upwards to compensate for the increasing elevation of the bottom level, the inevitable consequence of the sedimentation is: less available water, and an increasingly shallow lake.

With increased populations, development, living standards and consequent water demands downstream the pressure on the available water resources of the Yellow River is mounting. The amount of water that eventually will be allowed to replenish Lake Wuliangsuhai will no doubt determine the lake's future.

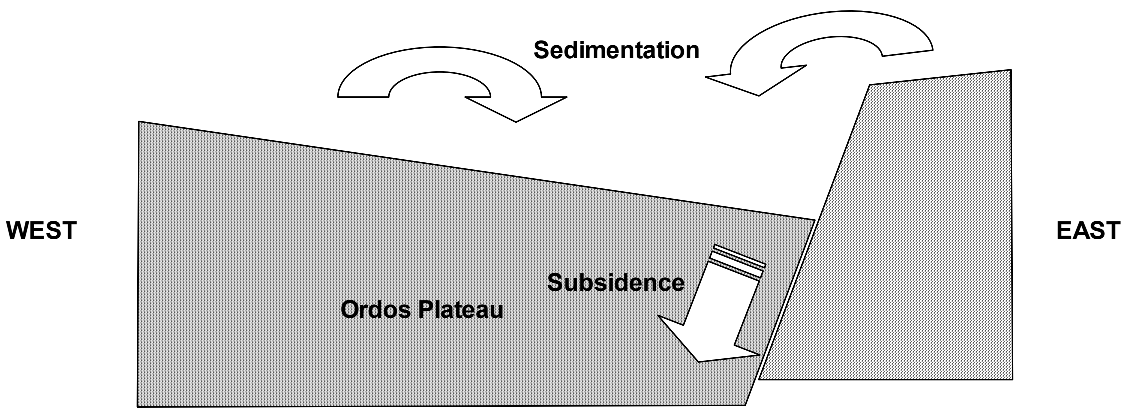


Figure 4.2. Competing rates of sedimentation and subsidence determines the size and depth of Lake Wuliangsuhai at any point in time. The age of the faulting (and the subsidence) is predominantly Pliocene until Recent, i.e. the system is still active.

Lake Wuliangsuhai sediments

The sediment distribution under the lake remains largely unknown. However, several generations of abandoned Yellow River water courses are still visible from the air and have been tentatively traced on satellite image, (see later chapter). Even Still and similar alluvial episodes have left their legacies over most of the lake area. It will be assumed that earlier deposition processes include braided streams, possible covering large areas with fluvial deposits. Alluvial fans are well developed around the lake. Intermittent rivers (wadis) enter the lake from all sides except from the Hetao Plain to the NW. Typical wadi deposits are seen in eroded channels and road cuttings along the lakes perimeter; evidence of earlier flash floods and higher lake levels.

The boundary between fine argillitic lacustrine sediments and the underlying coarser alluvials has not been investigated. The depth of this boundary could be vary and indeed interfere with the projected dredging depths. When dredging the lake, coarse sediments would be costly to remove, mainly on technical grounds. Sand and gravel is highly abrasive and does not readily form the desired suspension or sludge which is a prerequisite for cost-efficient dredging and transportation.

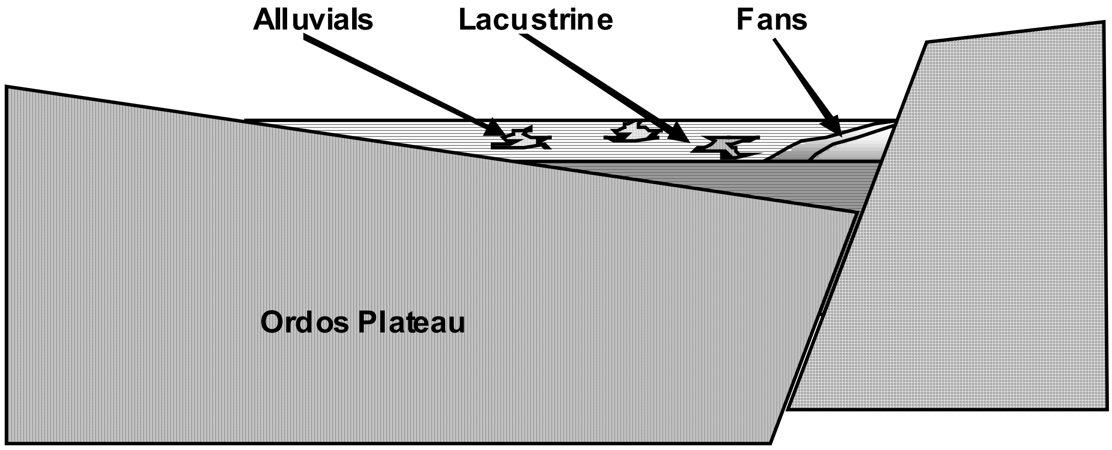


Figure 4.3. Principal sketch of dominant sediment deposition environments of Lake Wuliangsuhai. The area to the West of the present lake is geologically known as the Hetao Graben; a part of the Ordos Plateau.

As a consequence of the collision between the Indian subcontinent and Asia, the rapid uplift[4] of the Tibetan Plateau exerts a lateral force on the adjacent Ordos Block, located to the NE. The Ordos block is considered to be rigid and stable as there are no major earthquakes within the block; such activity is confined to the edges where there is active faulting. The faults describing the SE confinement of the Lake Wuliangsuhai (see illustration above) belong to this category. Satellite imagery (SPOT) investigations by Zhang[5] et al., 1998) indicate a counter-clockwise rotation model for the Ordos block. This oblique faulting and rotation of the Ordos Block is the geological basis for the very existence of the Lake Wuliangsuhai.

4.2 Depth Contour Map

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.

Lake Wuliangsuhai is a very shallow lake. The maximum depth found during the 3 field studies in 2001 and 2002 was 3.3 m situated in the southern part of the lake. 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 northernmost part) due to limited resources, the map probably gives a fairly good framework for most relevant problems to be addressed in this project.

Volumes and areas of 'open water' areas are shown in figures below and in table I Appendix.

4 Zhang, X.; Mooney, W. D.; Li, S.; Duan, Y., 2002: Structure of the Tibetan Plateau and the Ordos Block. In: American Geophysical Union, Fall Meeting 2002, abstract #S51B-1049.
5 Zhang et al., 1998: Zhang, Y.Q., Mercier J.L., and Vergély, P., 1998, Extension in the graben system around the Ordos (China), and its contribution to the extrusion tectonics of south China with respect to Gobi-Mongolia: Tectonophysics, no. 285, pp. 41–75.

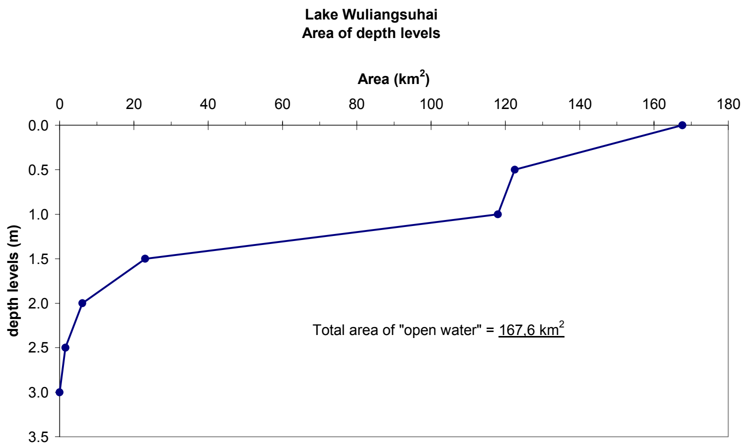


Figure 4,4 Areas of 'open water' calculated from the depth contour map.

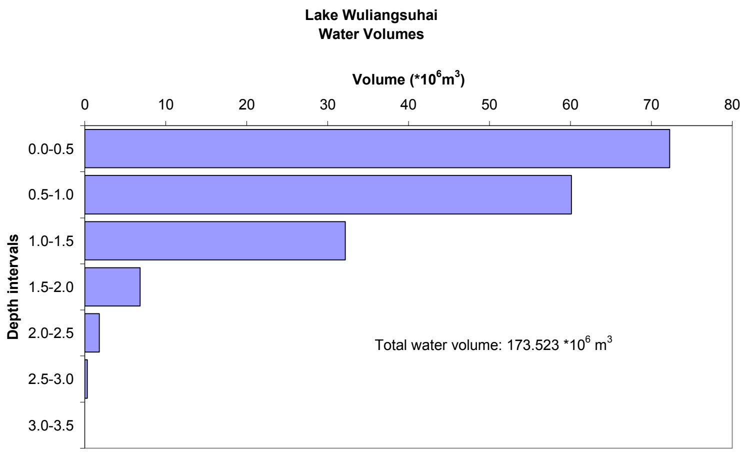


Figure 4.5 Volumes of 0.5 m depth-levels of 'open water' in Lake Wuliangsuhai.

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 and northern parts of the lake.

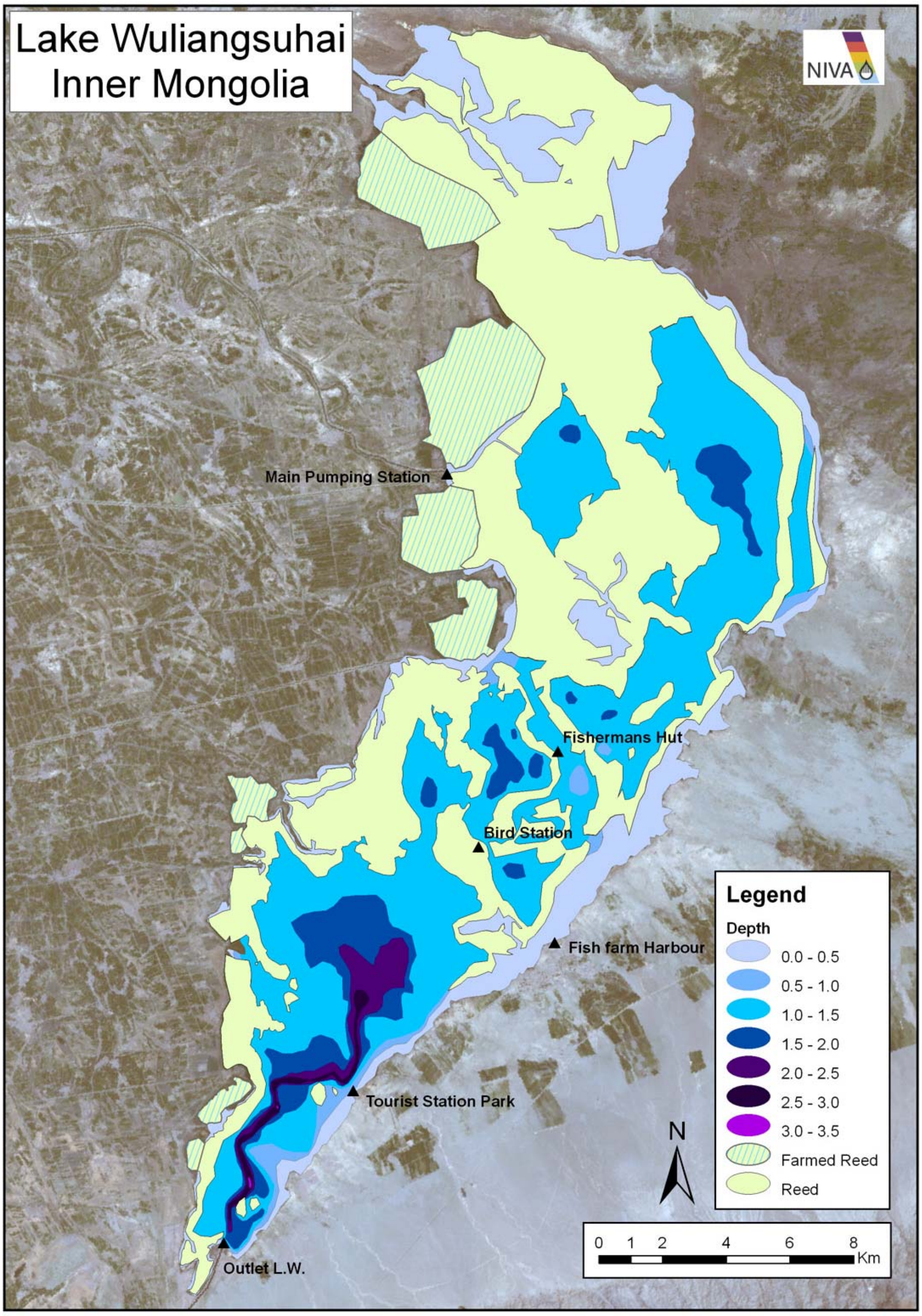


Figure 4.6 Depth contour map of Lake Wuliangsuhai constructed from a large number of depth measurements during this project

4.3 Satellite images

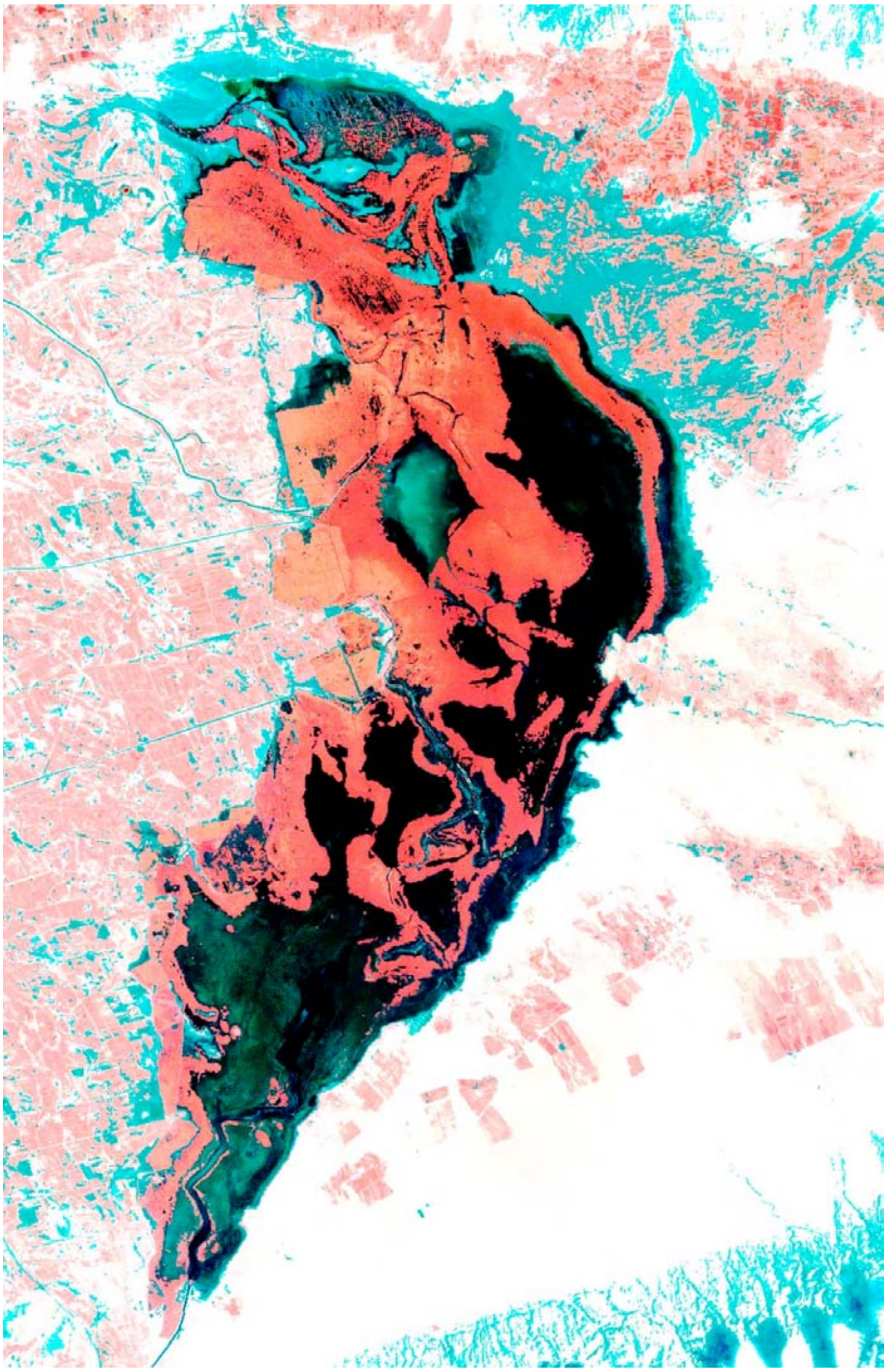


Figure 4.7 Satellite image from 20. July 1999. Red colour is vegetation, the dark red is mainly reed in the lake while lighter red is farmland on terrestrial areas. Close to 50% of the lake surface area is covered with reed today. Shallow areas in the lake and turbid water in Xidatian basin, as well as wet mud on terrestrial areas are green (image interpretation by NIVA).

Although the interpretation of different types of areas is more doubtful in the image from 1975, it is clear that the area of 'open water' has gradually become smaller since 1975. The most pronounced changes took place between 1975 and 1989. After 1989 only minor changes have occurred.

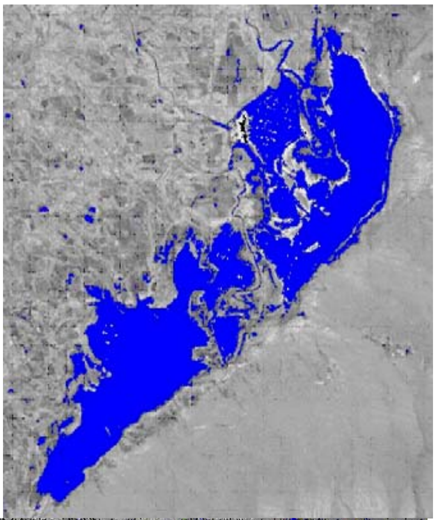


*Figure 4.8 Lake Wuliangsuhai 1975.
Open water areas are coloured blue while grey areas in the lake are reed.
Digital value between 1 and 35 based on Landsat MSS Ch 7 (image interpretation by NIVA).*

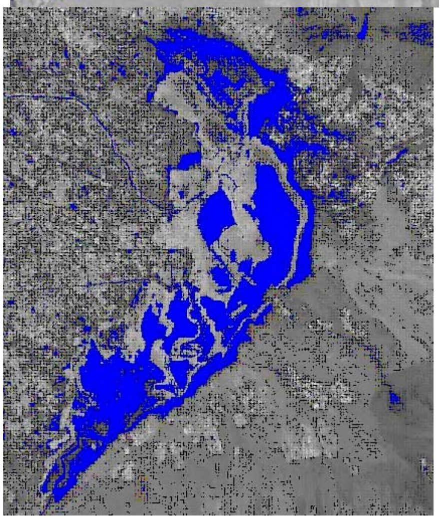


*Figure 4.9 Lake Wuliangsuhai July 1999.
Water area coloured blue. Grey areas in the lake are reed.Water is classified as digital pixel value 1 – 102. Landsat TM Ch 4 (image interpretation by NIVA).*

Figure 4.10 Most areas with 'open water' are covered with the submerged plant Fennel pondweed (UK) or Sago pondweed (US) Potamogeton pectinatus*. This species is distributed world-wide and tolerates high concentrations of salt. The reed belts are visible far away, with mountains in the background.*

Below are presented satellite images from the period 1975 to 2002 analysed by different participants of this project (Agricultural University of Hohehot and NIVA) as well as from the Mapping Services of China. Although these images have been processed in somewhat different ways, the overall conclusion draws from these images are quite clear:

- During the years 1975 and 2002 the area of reed has increased considerably
- The major increase in reed area took place during the years between 1975 and 1994
- The major decrease in open water area took place between 1975 and 1986.
- Between 1986 and 1994 the expansion of reed took place due to crop management into former farmland areas rather than into open lake areas; hence the area of open water in the lake has only diminished slowly after 1986.

The actual expansion rate of reed into lake since 1986 should be studied carefully by estimating the change in open water area during this period.

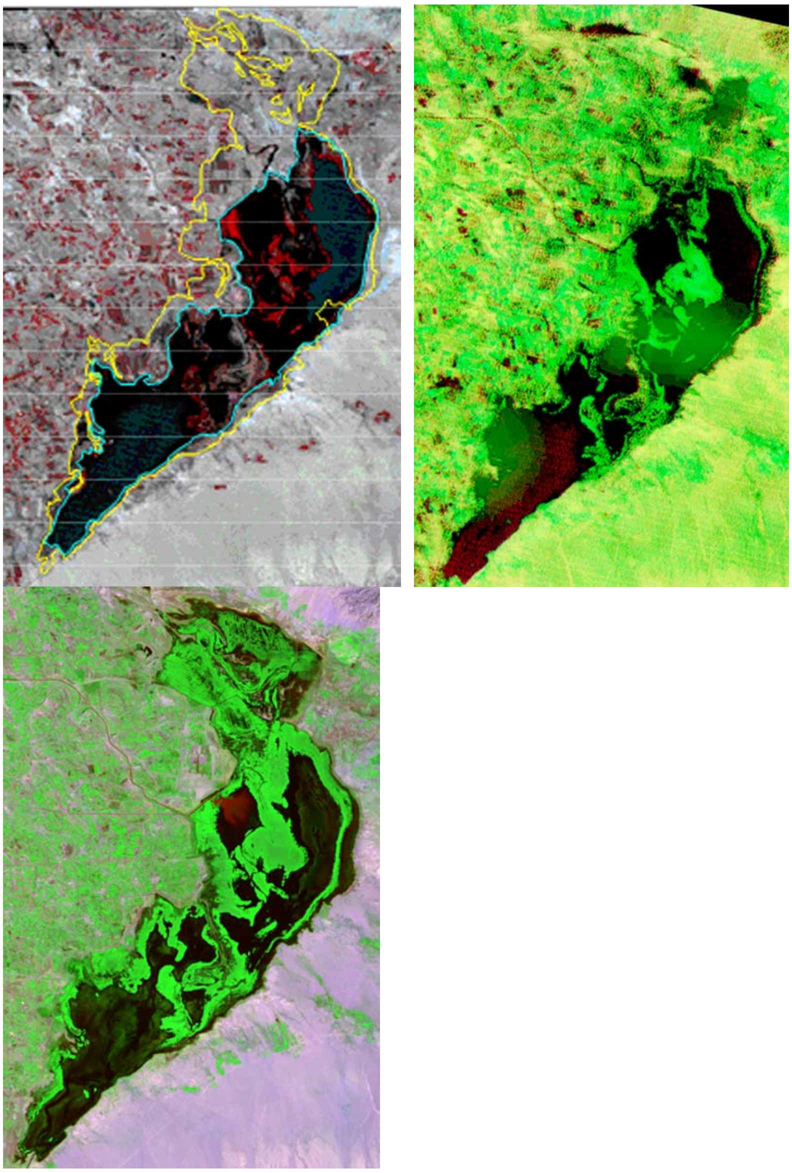


Figure 4.11 Satellite images of Lake Wuliangsuhai from left to right: 1975 (16 June), 1978 (6 August) and 1986 (9 August). These images have been coded in different ways and by different institutions, but do all show open water in black and vegetation in red (left) or green (middle and right). The left image also show the approximate outline of the lake including reed areas in 1975 (light blue) and in 2002 (yellow).

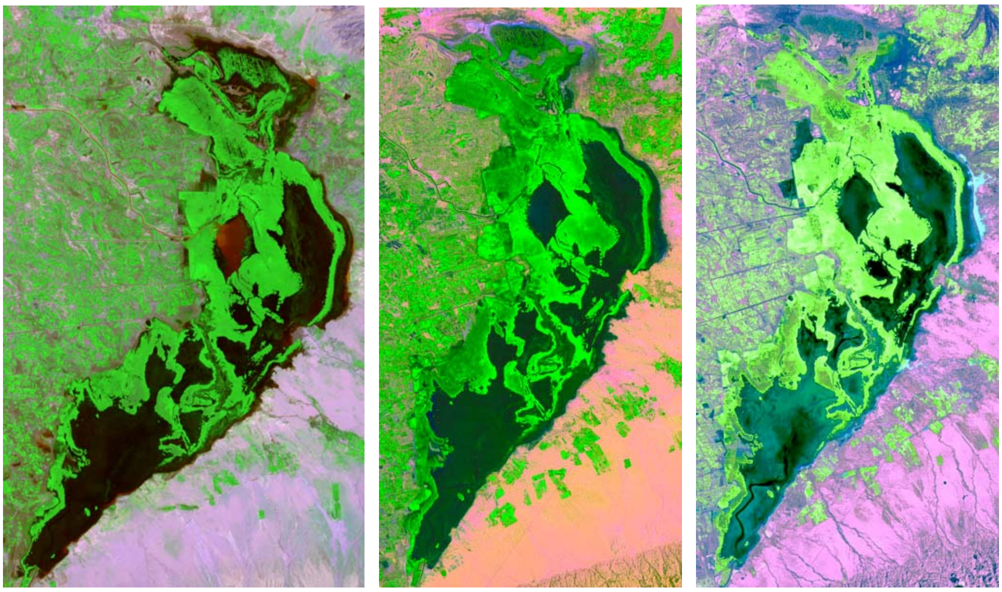


Figure 4.12 Satellite images of Lake Wuliangsuhai from left to right: 1994 (15 August), 2000 (14 July), and 2001 (21 July). These images have been coded in different ways and by different institutions, but do all show open water in black and vegetation in green.

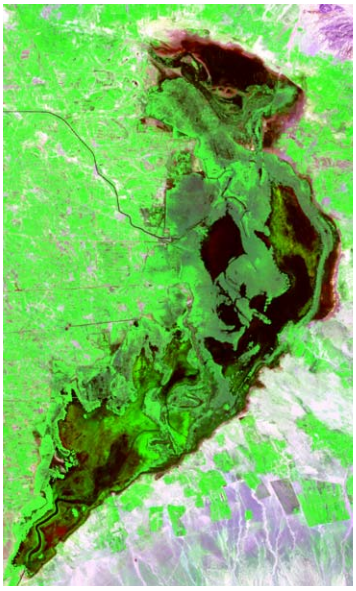


Figure 4.13 Satellite image of Lake Wuliangsuhai from 2002. This image has been coded to show open water in black and vegetation in green.

It seems from the satellite image from 2002 that the submerged vegetation in the "open water areas" has become denser during the last years. However, closer studies show that the reed has not expanded much further into these areas during the last years (compare Figs. 3.6 and 3.8).

A closer study of the development of Lake Wuliangsuhai shows that the expansion of reed area was to a large degree caused by human management. Due to the better price of reed delivered to the paper factories, considerable areas previously used as farmland were planted with reed.

These areas are shown in the next figure below as brownish green areas on the western side of the lake. This increase did not reduce the area of open water in the lake.

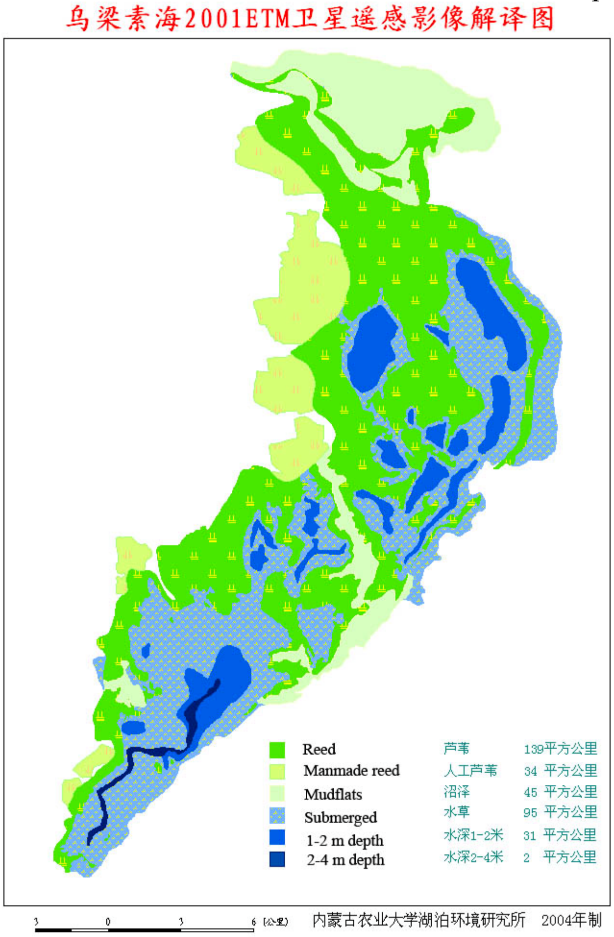
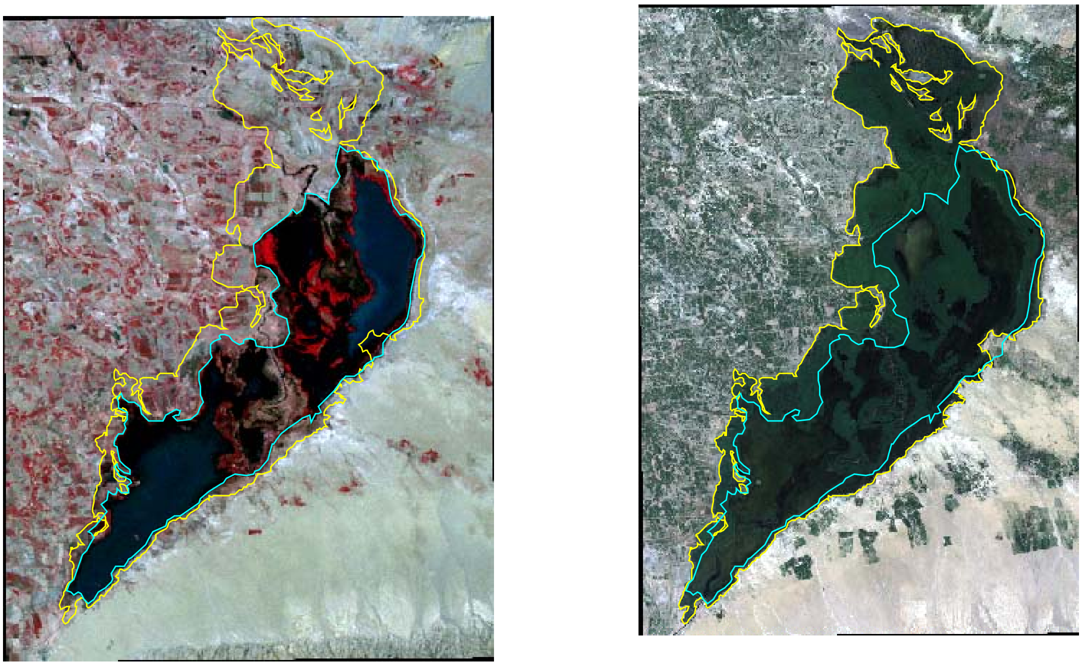


Figure 4.14 Lake Wuliangsuhai 2001 distribution of different types of area according to interpretation of satellite image by Agricultural University of Hohehot (prof. Shang and his students).

4.3.1 Lake extension

Here the extention of the lake is called the sum of open water and reed. Considerable new areas have been added to the lake between 1975 and 1999 by expanding reed into former farmland, especially on the western and northern side of the lake. The main reason for this expansion is the extremely low water level due to drought in 1975.



1975 1999

Figure 4.15 Satellite images showing the situation in 16 June 1975 (left panel) and 20 July 1999 (right panel). The yellow line is the area (348 km^2) defined as reed and 'open water' on 20 July 1999, while the blue line is the extension of the lake on 16 June 1975 (201 km^2). Black areas are considered 'open waters'.

4.4 Aerial photos

We found good accordance between details in the aerial photos from 1985 and satellite images from 1999. Some close-up details are shown below. This supports the use of satellite images for the purpose of distinguishing open water from reed and dry land.

Figure 4.16 Comparison of satellite image (left) with aerial photo (right) of the Xidatian area close to the Main pumping station. Note the good agreement between outline and details in the two images.

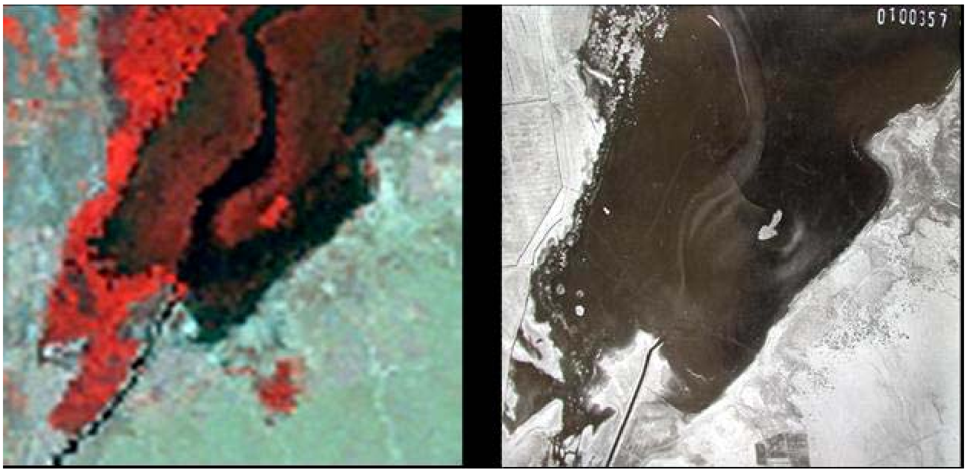


Figure 4.17 Comparison of satellite image (left) with aerial photo (right) of the southern, outlet area of the lake.

4.5 Sediment Cores

4.5.1 Sedimentation rate

Assuming an equal sedimentation rate during the approximately 150 year history of the lake gives a recent sedimentation rate of about 0.5 cm per year in the lake. However, it is fair to assume a lower sedimentation rate during the first 100 years, possibly about 0.3 cm per year. This means 30 cm during this period. Then, if assuming an equal sedimentation rate over the last 50 years (remaining 40 cm) with higher pollution and plant production, the rate would be approximately 0.8 cm per year. If the sedimentation continues at this rate, and the lake water level is not changing significantly, it is reasonable to conclude that major parts of the lake (mean depth 0.7 m) will be 'filled up' with sediments within 80-100 years.

4.5.2 Microfossils

Diatoms
Samples from 10 depths were analysed for diatoms (Fig. 3.1.3). The diatoms were unfortunately very poorly preserved in the sediment and absent from all but 3 levels (0-2.5 cm, 30-32.5 cm and 32.5-35 cm). The diatom flora reflects the shallow water conditions and high salinity, the latter is also the most likely cause of the dissolution of diatom cells (e.g. Ryves et al., 2001). The presence of diatoms in the surface sample may owe to the lack of time for dissolution to occur. Diatom count size was low (ca. 100 valves per sample), probably due to the poor preservation.

The samples between 30 and 35 cm exhibit a relatively high abundance of the planktonic species *Aulacoseira granulata*. Several of the diatom taxa (e.g. *Cyclotella meneghiniana*) are typical of eutrophic lakes, but are also commonly found in saline lakes. The results indicate a shift from a larger proportion of pelagic forms in the middle of the core to dominance by benthic-plant associated forms at the top.

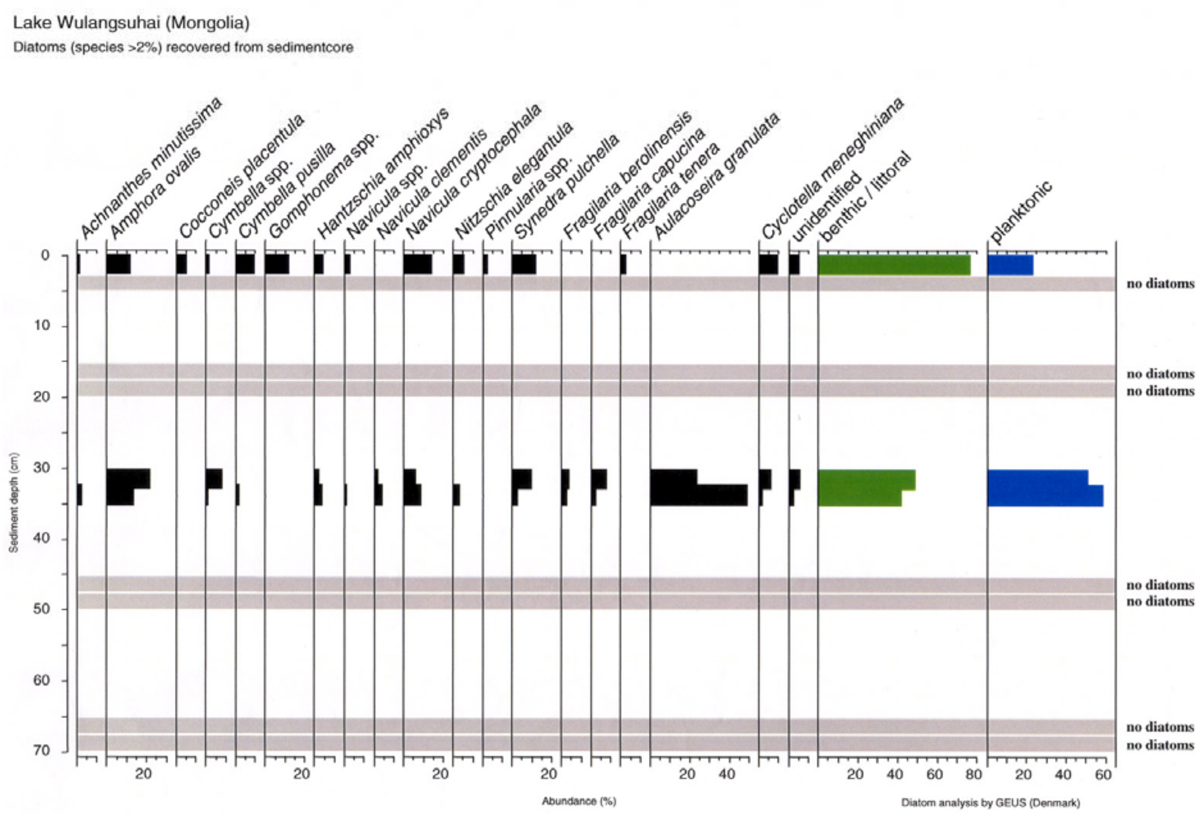


Figure 4.18 Stratigraphic plot of diatom species in the sediment core from Lake Wuliangsuhai. Only species occurring with at least 2% abundance in at least one sample are shown.

Zooplankton
Five samples, at depths corresponding to those of the diatom analyses, were analysed for zooplankton fragments (3.14-3-15). At depths lower than 17.5 cm the number of zooplankton fragments was relatively low.

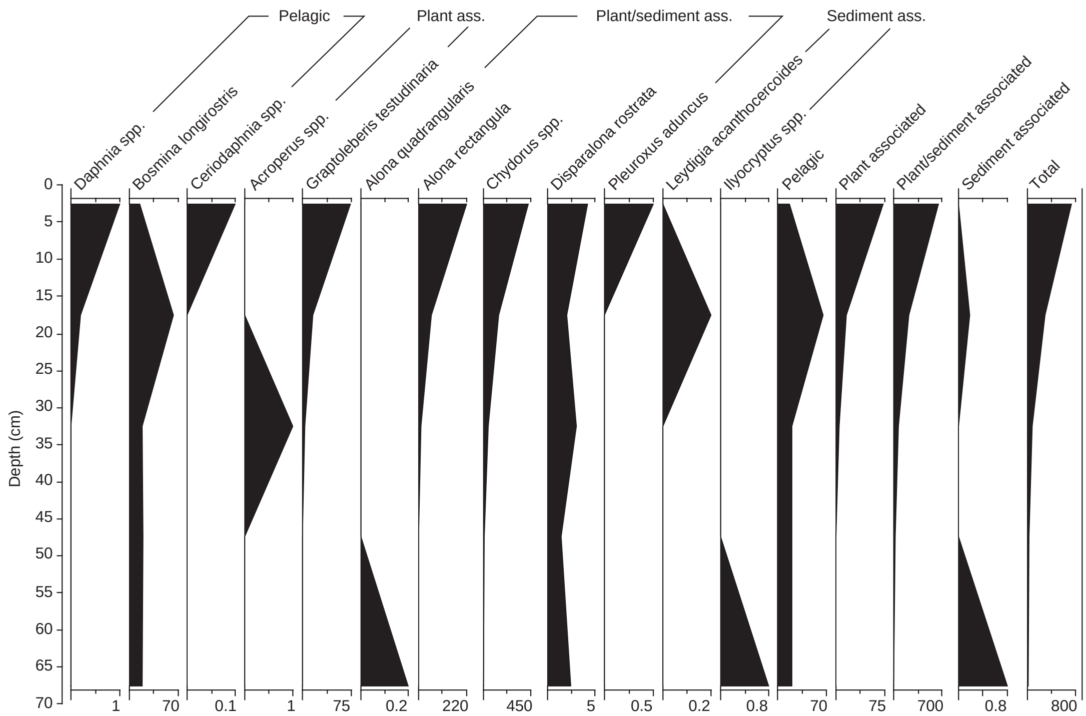


Figure 4.19 Cladoceran concentrations in the sediment of Lake Wuliangsuhai (fragments g wet weight sediment-1). Note the different scale for abundance data. Lake association types are indicated on the right hand side.

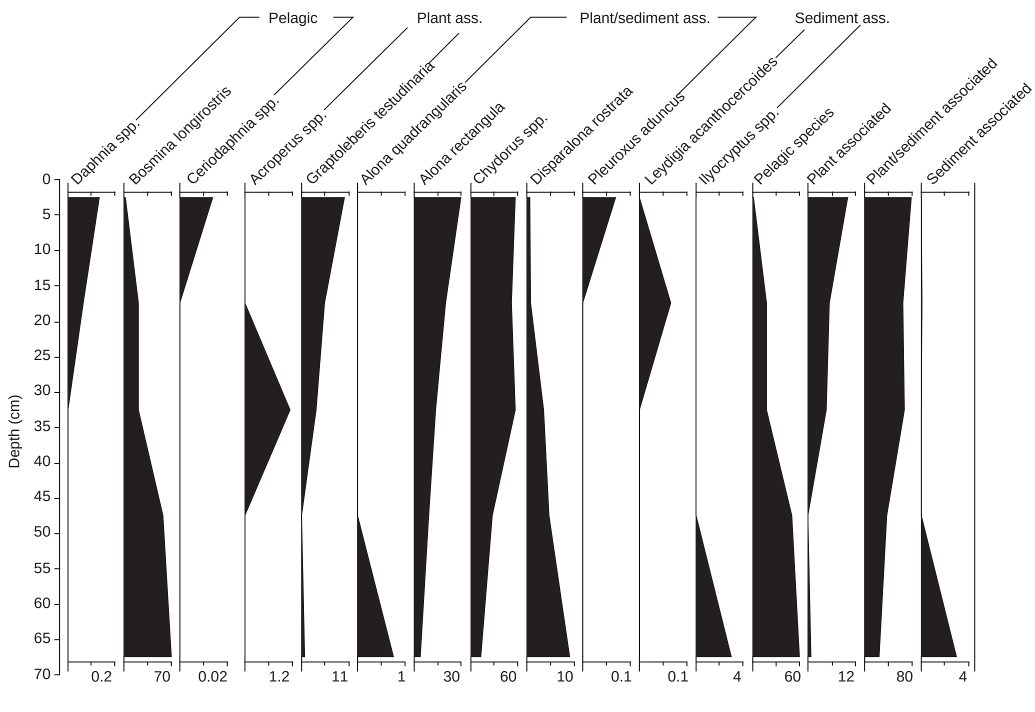


Figure 4.20 Percentage distribution of cladocerans in the Lake Wuliangsuhai sediment.

At the bottom of the core the cladoceran community is dominated by pelagic species, almost exclusively *Bosmina longirostris*. The abundance of this species gradually declines to almost complete absence in the top sediment. Concurrently with this, the abundance of the plant and sediment associated cladocerans (mainly *Chydorus* spp. and *Alona rectangula*), and to a lesser extent the pure plant associated *Graptoleberis testudinaria*, increases. At 32.5 cm *Chydorus* spp. become completely dominant. Other important species are *Disparalona rostrata*, whose abundance gradually decline but which is still found at the top of the core, and *Ilyocryptus* spp. whose share is relatively high at the bottom of the core, but which is absent from 47.5 cm.

Also other zooplankton fragments were found, such as resting eggs from *Brachionus* spp., Bryozoan statoblasts and shells from *Ostracoda* spp. (Fig. 3). The *Brachionus* resting eggs increase in numbers from 47.5 cm and maintain a high level to the top of the sediment, though a reduction is seen from 17.5 cm. The abundance of Bryozoan statoblasts increases gradually from the bottom to 17.5 cm, with no change further up to the top sediment. The numbers of *Ostracoda* shells increase slowly from the bottom to 32.5 cm and then rise markedly towards the top sediment.

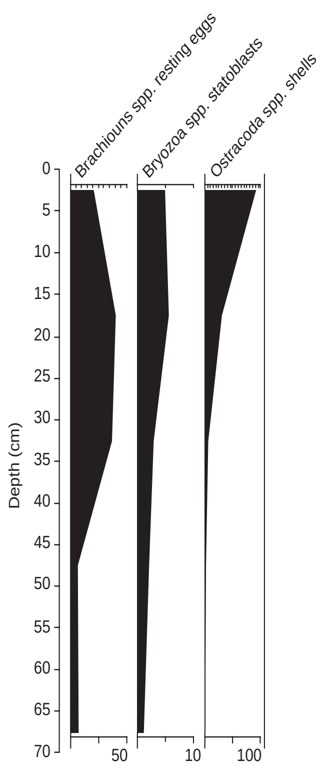


Figure 4.21 Stratigraphy of Brachionus resting eggs, Bryozoan statoblasts and shells from Ostracoda spp. (fragments g wet weight sediment^{-1}).

Changes in fish and plants

Simple and robust indices may be helpful in evaluating the changes in fish predation pressure (Jeppesen et al., 2003) and abundance of plants (Thoms et al., 1999; Jeppesen et al., 2001). As fish prefer large-bodied zooplankton, a high ratio of small Bosmina to large Daphnia is indicative of a high predation pressure from fish, and thus often high fish abundance. Daphnia carapaces are poorly preserved in the sediment, and the carapace ratio is thus not a useful indicator. Instead the ratio of resting eggs was used (Fig. 4). The Daphnia/(Daphnia + Bosmina) ratio increases from zero at the bottom of the core until 32.5 cm after which it increases to 1 at the top, indicating reduced fish predation from 17.5 cm and upwards. If the total phosphorus concentration (TP) is known, the ratio can be used to calculate fish abundance (Jeppesen et al., 2003). Unfortunately, the poor preservation of diatoms TP does not allow TP reconstruction.

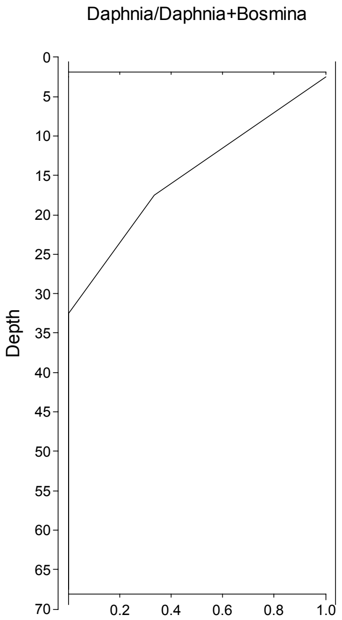


Figure 4.22 Relation of Daphnia to Daphnia+Bosmina resting eggs as a function of depth in the sediment of Lake Wuliangsuhai

The ratio of chydorid carapaces to the sum of *Bosmina* and chydorids has been used as an indicator of plant abundance (*Thoms et al., 1999; Jeppesen et al, 2001, Johansson et al., submitted*), as most chydorids are associated with plants or benthic algae (Frey, 1986) The ratio of *Chydoridae* to *Bosmina* carapaces increases up through the sediment (Fig. 5). It passes 0.5 at a depth of 47.5 cm and reaches 1 at the top. This is a clear evidence of a growing plant cover in the lake, although it cannot be fully excluded that a reduction in water depth may have been a contributory factor.

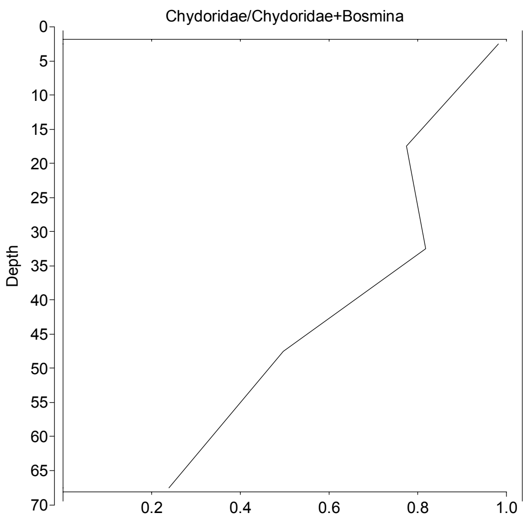


Figure 4.23 Relation of Chydoridae *to* Chydoridae + Bosmina *carapaces as a function of depth in the sediment of Lake Wuliangsuhai.*

We also attempted to reconstruct fish and plant abundance using the transfer function for Danish lakes, but reliable results were unfortunately not obtained (Appendix) .

Discussion and conclusions

Changes in the composition of zooplankton fragments show a gradual shift from a "pelagic community" dominated by *B. longirostris*, reflecting clearwater conditions with high predation pressure, to a more "benthic" community, dominated by plant associated chydorids. This is most likely due to both increasing eutrophication, increasing plant cover and a decreasing water level. The changes in composition of the zooplankton fragments are rather gradual up the core, whereas the total numbers of fragments show the most marked changes from 17.5 cm to present. The gradual increase in *A. rectangula* and *Chydorus* spp. also indicates a growing distribution of plants, but also an increasing nutrient concentration. The increase in total numbers of fragments, which begins at 47.5 cm but is most pronounced from 17.5 (Fig. 2b), is typical sign of enhanced eutrophication. Increasing abundance of Bryozoans in the upper part of the sediment is indicative of increasing plant density as plants are used as substrate for Bryozoans.

Strong dominance of the pelagic *B. longirostris* and the low ratio of *Daphnia* to *Bosmina* ephippia (Fig. 4) at the bottom of the core are indicative of an environment with few plants and a high risk of predation (planktivorous fish preferring the large-sized *Daphnia*). The increase in plant-associated animals from 47.5 cm suggests plant development. Apart from acting as substrate to some of the cladocerans, plants offer refuge to especially *Daphnia*. (Lauridsen et al., 1996). High abundance of Daphnia may explain the reduction in *Bosmina* by competitive exclusion from 32.5 cm. Whether enhanced plant refuges are the only reasons for the reduced predation risk of zooplankton is uncertain. A contributory factor could be enhanced fish kill during winter due to increased oxygen depletion under ice, which, in turn, reflects higher oxygen consumption by the more abundant plant population in the lake. Supporting this view (Jackson, 2003) found much higher oxygen consumption under ice in plant rich systems than in shallow lakes without plants. A reduction in the population of fish may promote an increase in the Daphnia population.

Saline conditions have been observed in the lake and are confirmed by diatom analyses. Impact of salinity is also indicated by the zooplankton record by low species diversity and by the dominance of *Bosmina longirostris*, *Chydorus* spp., and *Alona rectangula*. As mentioned above these species are also indicative of high nutrient values, but they are also known to tolerate moderate to high salinity (Amsinck et al., 2003). The increase in *Brachionus* spp. (despite an increase also of the more efficient competitor, *Daphnia*) suggests increased salinity up through the core. This is supported by the diatom analyses.

In conclusion, the palaeoecological investigation shows major changes in lake biota over time. A shift has occurred from a pelagic to a plant dominated system. The fish predation risk has decreased in recent years, potentially reflecting a reduction in fish abundance during winter and an increased refuge effect for the larger zooplankton. Moreover, salinity seems to have gradually increased.

As judged from the density of zooplankton remains, a major increase in lake productivity seems to have occurred from 32.5 cm and upwards. Assuming an annual sedimentation rate of 0.5-1.0 cm over the most recent period, this sediment layer corresponds with approximately 30-60 years back in time.

4.6 Changes in lake water quality 1987-88 to 2001

To evaluate how the water quality in Lake Wuliangsuhai has changed over time we have compared data on main ions, nutrients and dissolved organic matter from 2001 with similar data from 1987-88. These are the two best data sets available for such a comparison in terms of number of samplings and a relatively long space of time between them. Average values during the ice-free seasons at Lake Station North (Xidatian) and Lake Station South (Erdiar) are shown in the table and figure below.

Mineral salts
The average concentrations of main ions during the ice-free seasons have increased strongly during this 14 years period, on both sampling stations. Nearly all main ions showed marked increases, and for sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) and chloride (Cl) there was a doubling of the concentration, or more, at one or both stations. The salinity in Lake Wuliangsuhai has almost doubled from 1987/88 until 2001 (from 0,8 to 1,4 o/oo on St. N; Xidatian, and from 1,2 to 2,4 o/oo on St. S; Erdiar).

Generally the concentrations of main ions were higher at the Lake Station South than at Lake Station North, both in 1987-88 and in 2001. Conductivity analyses, which are measurements on the total mineral salt content, also show marked increases from the north to the south of the lake (see Sub-project report 3). This is most likely because the majority of the inlet water is entering the lake at the northern part and undergoes high evaporation from the lake surface and through reed vegetation on its way to the outlet of the lake in the south.

Table 4.1. Changes in average concentrations (ice-free seasons) of main ions, nutrients and organic matter in Lake Wuliangsuhai from 1987-88 to 2001.

	Lake st. North				Lake st. South			
	1987-88 mg/L	2001 mg/L	Change mg/L	Change %	1987-88 mg/L	2001 mg/L	Change mg/L	Change %
Na	219,7	353,3	133,6	61	339	664,9	325,9	96
K	5,9	22,2	16,3	276	6,1	33,8	27,7	454
Ca	39,7	117,1	77,4	195	33,4	43,3	9,9	30
Mg	44,4	75,8	31,4	71	79,4	165,7	86,3	109
Cl	243,1	524,3	281,2	116	431,6	997,5	565,9	131
SO_4	236,4	320,3	83,9	35	316,8	538,7	221,9	70
HCO_3 [1]	206,9	209,1	2,2	1	123	221,9	98,9	80
CO_3 [1]	15,4	19,9	4,5	29	77	53,5	-23,5	-31
Tot-P	0,073	0,118	0,045	62	0,08	0,19	0,11	138
Tot-N	1,65	5,25	3,6	218	1,5	3,05	1,55	103
COD_{Mn}	4	8	4	100	7	10	3	43
BOD_5	1	8	7	700	2	7	5	250

[1] Concentrations in microeq/L

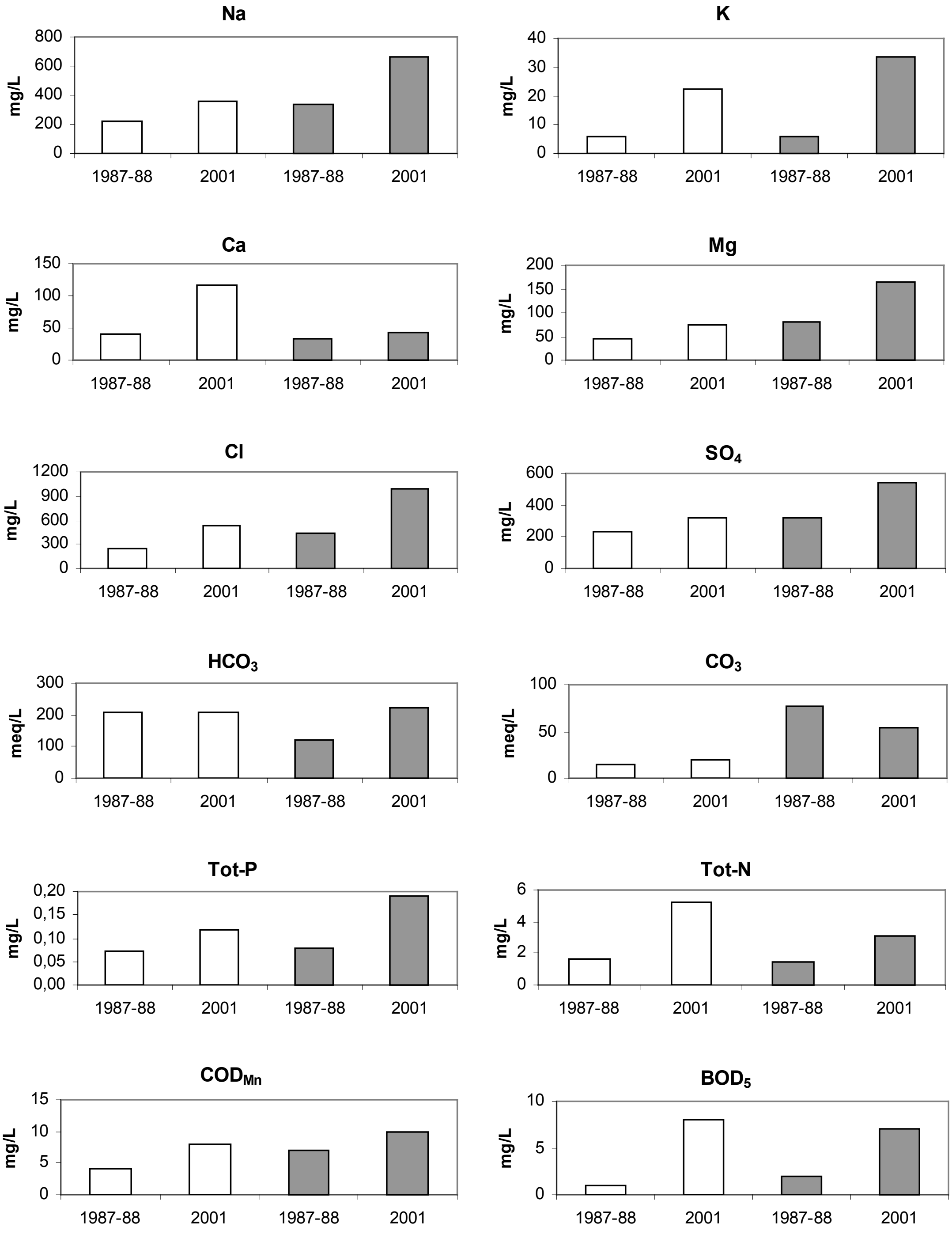


Figure 4.24 Average concentrations (ice-free seasons) of main ions, nutrients (Tot-P and Tot-N) and organic matter (COD_{Mn} and BOD_5) in Lake Wuliangsuhai in 1987-88 and in 2001. Lake station north (Xidatian) in white and lake station south (Erdiar) in grey shading.

In the long run, further increase in salt concentration will be a severe threat to Lake Wuliangsuhai as a freshwater ecosystem. Assuming that the increase during these 14 years is representative, and that the salt concentration continues to increase at the same rate in the future, several of the main ions will reach levels of typical seawater concentrations within approximately 150-450 years (rough estimation for Lake Station South).

Nutrients
Average concentrations of phosphorus (Tot-P) and nitrogen (Tot-N) also increased strongly from 1987-88 to 2001. The increase in nutrients (43-218%) over this 14 years period illustrates the deteriorating water quality and the severity of the eutrophication problem of Lake Wuliangsuhai. The increase in nutrients is caused by inputs of heavily polluted water from the Hetao Irrigation Area originating from discharges from industries, runoff from farmland and municipal wastewater. According to Chinese water quality standards the water quality changed from class IV to class V (the worst class) for Tot-P and from class V to far beyond class V for Tot-N during this period. 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 potentially toxic blue green algae, and it boosts the process of transforming the lake to a marshland.

Organic matter
At both lake stations (north and south), large increases in the average concentrations of organic matter (COD_{Mn} and BOD_5) were observed from 1987-88 to 2001. This is a result of large inputs from the heavily polluted drainage canals, as well as large amounts of detritus (dead organic matter) from the high internal production of aquatic plant material. Water quality classes changed from class I-IV in 1987-88 to IV-V in 2001. The high concentrations of organic matter lead to anoxic conditions and massive fish-kills during winter.

The large increase 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 and that countermeasures to reduce the pollution are imperative to restore good water quality and high biodiversity.

4.7 Interviews

A summary of the interviews are given below.

4.7.1 Development in the lake from the last fifties and the sixties:

Many of the people living by the lake today originally came from the Hebei province (close to Beijing) in the late nineteen-fifties. China was at that time ridden with famines, with the most severe in 1958 when millions starved to death. Some Hebei people were moved to the shores of Lake Wuliangsuhai to make a better living here. At that time it was a lot of fish in the lake, and the amount of big fishes was larger than today. The lake water quality was good, and at that time they also used the lake for drinking water and cooking.

Water level, inlet and outlet of the lake
The lake surface level was up to 1 ½ meter higher 40-50 years ago than today, according to the interviews, and the area of open water was larger. At that time the lake received its water by gravity from the irrigation canals going through the Hetao area. Due to population growth and a higher focus on agriculture in the area through the coming years, gradually more of the water was retained in the Hetao area and less water reached Lake Wuliangsuhai. Therefore the drainage canals were built to collect the run-off from the fields, and the main pumping station was built in 1978 (capacity: 30 m^3/sec) to pump the remaining drainage water up into the lake. (Today the level of the Main Drainage Canal is lower than lake surface level). A new pump station was constructed at the same site in 1995 with a capacity of 100 m^3/sec. A third pump station exists at the drainage canal no 9. This station is reported to work only occasionally when the water level in the lake is at the highest. At other times the water flows by gravity to the lake.

Reed
The areas covered by reed were smaller 30-40 years ago, than today. Most of the reed was cut and used for making mats, fish baskets and fishing gear (fish-traps and "leading"-nets). The rest was sold to paper factories in other cities, mainly Tianjin near Beijing. The first local paper factory was built in 1980, before that there was no paper production in this district. Reed expansion in the lake has accelerated after 1980, and reed production is today the main income from the lake.

Submerged vegetation
In the nineteen-fifties and -sixties the highest growth of the submerged plants occurred during spring and summer, and one of the dominating species at that time had a long, soft stem with floating leaf. This configuration contributed to a better environment for the fishes, than the plants dominating the lake today. One of the earlier submerged species was used for food – both for humans and pigs.

5 References

Amsinck, S.L., E. Jeppesen & D. Ryves (200)3: Cladoceran stratigraphy in two brackish lakes with special focus on changes in salinity, macrophyte abundance and fish predation pressure. J. Paleolimnol. 29: 495-507.

Cole, G.A (1983): Textbook of Limnology. The C.V. Mosby Company, St. Louis. 401 pp.

Frey, D. G. (1959): The taxonomic and phylogenetic significance of the head pores of the *Chydoridae Cladocera*. *Int. Rev. Gesamt. Hydrobiol.* 44: 27-50

Flössner, D. (2000): Die Haplopoda und Cladocera (ohne Bosminidae) Mitteleuropas. Leiden: Backhuys Publishers.

Hann, B.J. (1990): Cladocera. In Warner, B.G., editor, *Methods in Quaternary Ecology*. *Geoscience Canada Reprint Series* 5, 81-91.

Jackson, L.J. (2003): Macrophyte-dominated and turbid states of shallow lakes: evidence from Alberta lakes. *Ecosystems*, 6, 213-223.

Jeppesen, E., E.A. Madsen, J.P. Jensen & N.J. Anderson (1996): Reconstructing the past density of planktivorous fish and trophic structure from sedimentary zooplankton fossils: a surface sediment calibration data set from shallow lakes. *Freshwat. Biol.* 36, 115-127.

Jeppesen, E., P. Leavitt, L. De Meester & J.P. Jensen (2001): Functional ecology in palaeolimnology: using pelagic and cladoceran remains to reconstruct anthropogenic impact. *Trends. Ecol. Evol.* 16: 191-198.

Jeppesen, E., J.P. Jensen, T.L. Lauridsen, S.L. Amsinck, K. Christoffersen & S.F. Mitchell (2003): Sub-fossils in the surface sediment as proxies for community structure and dynamics of zooplankton in lakes: a study of 150 lakes from Denmark, New Zealand, the Faroe Islands and Greenland. *Hydrobiologia* 491: 321-330.

Johansson, L.S., E. Jeppesen & J.P. Jensen (in press): Lake Dallund during 7000 years: Changes in trophic structure based on zooplankton remains in the sediment. Holocene.

Juggins, S. (1997): TRAN (1.8). University College London, UK.

Lauridsen, T.L., L.J. Pedersen, E. Jeppesen & M. Søndergaard (1996): The importance of macrophyte bed size for cladoceran composition and horizontal migration in a shallow lake. J. Plank. Res. 18: 2283-2294.

Krammer K. & H. Lange-Bertalot (1986-1991): Susswasserflora von Mitteleuropa. Bacillariophyceae. Verlag., Stuttgart. Volumes I - IV.

Margaritora, F.G. (1985): Cladocera. Fauna D´Italia Vol. XXIII, Edizioni Calderini Bologna.

Renberg, I. (1990): A procedure for preparing large sets of diatom slides from sediment cores. J. Paleolimnol. 4: 87-90.

McGill, E.1996. Go West, Young Han: Republican Reclamations of Inner Mongolia. FIFTH ANNUAL GRADUATE STUDENT CONFERENCE ON EAST ASIA Held at Columbia

University
Friday February 9 to Sunday February 11, 1996.

Ryves, D.B., S. Juggins, S.C. Fritz & R.W. Battarbee (2001): Experimental diatom dissolution and the quantification of microfossil preservation in sediments. Palaeogeography, Palaeoclimatology, Palaeoecology 172: 99-113.

Røen, U.I. (1995): Danmarks Fauna Bd. 85, Krebsdyr V, Gællefødder *Branchiopoda* og Karpelus *Branchiura*. Dansk Naturhistorisk Forening.

Thoms, M.C., R.W. Ogden & M.A. Reid (1999): Establishing the condition of lowland floodplain rivers: a palaeo-ecological approach. *Freshwat. Biol.* 41: 407-423.

Appendix

Interviews with local fishermen

(1) Visit to the Fish farm and interview with 4 fishermen April 20 2002

From the project:	Ms. Tao Li (IMESI), Mr. Liu (Li Ya Wei's student- Agricultural University), Finn Medboe and Tone Jøran Oredalen (NIVA)
From the Fish-farm:	Mr. Li (secretary of the party of the fish farm)
4 retired fishermen:	1 **Mr. Liu Yue Zhi**, came to Lake Wuliangsuhai in 1955, 66 years old
	2 **Mr. Yang Zhi Ru,** came to the lake in 1955
	3 **Mr. Wong Fu Xiang,** came to the lake in 1956
	4 **Mr. Sun Guo Fu,** came to the lake in 1954. The oldest of the four. Has been leader of the fishermen,74 years old.
	5 Mr. Wang Ging Liang, accompanying the fishermen (younger)

All the fishermen originally came from the Hebei area, south of Beijing. When they came to Lake Wuliangsuhai they were fishing all year through, both summer and winter. At that time there were several more fish species than today, and the amount of larger fish was higher (up to several kilograms). The colour of the fish-skin has changed from then to now: Before the fish was clear yellow, now the colour is black or pale. The water level was also higher in the 1950ies and 60ies, maybe 1-1,5 meter higher than today. The fishermen told that the level of the sediment was about the same as today, but the water surface level was higher. They support this by telling that the lake surface area was also larger in that period. At that time it also happened that during flood periods there came a back-flow of water from the Yellow river into the lake, through the normal outlet (Mr. Li). Today highest water level is 1018,5 meter. The lake is filled up to this level in October before ice cover the water surface. This water level is necessary for the reed harvesting during December-January. If the water level is lower than this, old roots from the reed will follow the harvesting, witch is not preferable. Earlier the water in the lake was clean, and the farmers could use it for drinking and cooking. Due to water pollution that is not possible today.

In the years from the fishermen's arrival up to 1978, the lake received water directly from the Yellow river through irrigation canals. These canals had two main purposes: Irrigation for the Hetao area and water supply into the lake. Due to population growth and higher focus on agriculture in the area, gradually more of the water was retained in the Hetao area and less water reached Lake Wuliangsuhai. Therefore the drainage canals were built to collect the run-off from the fields, and the main pumping station was build in 1978 to pump the remaining drainage water forward into the lake.

The areas covered by reed were much more limited 30-40 years ago, than today. The paper factory was built in 1980, before that there was no paper production in this district. Most of the reed was cut and used for making mats, fish baskets and fishing gear (fish-traps and "leading"-nets). The rest was sold to paper factories in other cities, mainly Tianjing near Beijing. They still use these spiral-looking fish traps, even though the material of the traps has changed into synthetic small-meshed gill nets. The reed is normally cut from the ice in the middle of December to middle of January. The reed expansion in the lake has accelerated after 1980.

There have been big changes in amount and species composition of submerged vegetation the last 50 years. The fishermen told that earlier there were two or three dominant species in the lake, different species than the one dominating today (*Potamogeton pectinatus*). These two or three species covered the whole lake, but had their maximum growth from early spring to July. One of the plant species had a very thin and soft stem with big leaves on the top, a construction that made it possible for the fish to swim easily within the submerged vegetation. The other dominant species produced small yellow flowers in June. (TaoLi: Could you try to find the names of these species?) One of the submerged species was used both for human and pig food.

(2) Visit and interview with fishing family in Fishing village no 15 located near the main pumping station April 21 2002 (Sunday)

Participants :

Mr Shang (Wulate EPB), Ms Tao Li – IMESI, Mr Liu - Student and teacher IM Agricultural university, Tone J Oredalen and Finn Medbo NIVA. The Fisherman and his wife. The fisher has 10 years fishing experience from Lake Wuliangsuhai, but is born elsewhere.
Picture and name(?)

Administration

Fishing village no 15 have 20 families with 70 people. The Schoolchildren must walk or ride a bike to the nearest school. Fishing is organised in teams of 8, who travels 10 to 15 minutes by bike or motorbike to the lake where the boats are. They do not return to home every night, actually we were told they move to the lake for the season, but sleep in the boat at an island in the lake. Most boats are of the punting type –flat bottom but with motor (?) Fish is delivered to nearest road where the buyers with cars take over the fish for transport alive to town.

The fishing rules are administrated by the Fish Farm, which belongs to the Agricultural Bureau in Bayanor League.

Fishing is allowed from May to November. Between ice breaking usually in March and season start in May, the fish is spawning and therefore forbidden to catch.

Generally fishing is performed all over the lake, but some sort of distribution between the teams takes place.

Fish Species:

The volume of fish caught is carp and golden carp. Golden carp is the dominating species. The size of the fishes is small, 46 in a kilo (22g each), which is sold for 1 RMB/kg. Next category fish size (medium) is 6 carps to the kilo, which is sold for 4 RMB/kg. A few times big fish up to 2.5 kg is caught. An average catch, which can last from one to three nights for the team of eight fishermen, is 250 to 300 kg. From this total the big fish constitute about 7-8 kg, the medium sized fish about 20 kg and the rest is small fishes (46 fish /kg).

Age distribution: The fisherman thinks the biggest fish (2.5kg) is ca 7 years old, Carps (ca 175 grams) are ca 4-5 years old, while the small fish are 2-3 years of age.,

Other species

Occasionally ”large” mallets (mud eaters) of 0.5 kg can be caught
Shrimp.
There are considerable amount of shrimps in the lake, which are quite popular. Since two years back these are forbidden to catch. When they were caught they were sold for 5 RMB/kg after being cooked in the home of the fisher. A normal yearly catch could be 2000 kg pr team. The reason for the shrimp-pause is to provide the carp with more food – to increase the fish production. We saw many illegal shrimp-ruses on the way back in drainage canal no 9.

Fishing equipment

As we heard from the older fishermen the day before no nets where used until the eighties. Now ruses of fairly small mesh-widths are used. The ruse has long leading nets. The equipment is sunk down in various densities of submerged vegetation. Depth is probably around one to 1.5 meters.

The carp was reported to feed on *Typha* roots and submerged vegetation from inspection of stomach content.

The fishermen’s evaluation of the conditions now and ten years ago

He was in no doubt that the catch was considerably smaller now than ten years ago, and he thought this was due to especially industrial pollution. However the decrease in catch was compensated with an increase in price, so that the family income was fairly stable- perhaps even increasing.
He further reported the amount of submerged vegetation to have increased considerably. 10 years ago there were three species, now there were two other species dominating. He did not see any connection between increased vegetation and decreased fish, but it was more difficult to catch the fish because it could hide more easily, and submerged vegetation was a hindrance to navigating the boats and putting down the ruses.

Fish death

”Many” dead fish were observed each year ”floating” in the ice in the wintertime. He thought the fish that survived sought out the deeper parts of the lake (2.5m).

Reed cutting

The fisherman and his wife cuts reed during winter normally in December for one month.
The family can cut as much as ten tons of reed and is paid 450 RMB pr ton; that means 4500 RMB for four to six weeks work. From this income they have to pay rent to the Fish-farm and tax to the government, witch leaves about 2500 RMB for the family. The income from reed-cutting constitutes a larger percentage of the total family income than fishing which takes place over a five month period. The rest of the year the fisherman does miscellaneous work adding to the family income.

Pump stations

We also visited the main pump stations which pumps water from the Main drainage canal and drainage canal no 8. The first station was put in 1978 and has a capacity of 30 m3/sec. The newest pump station was constructed at the same site in 1995 and has a capacity of 100 m3/sec. It looked like only the smallest station was operating that day.

We then stopped at the third pump station farther south, pumping water from drainage canal no 9. It was reported that this station only works occasionally when the water level in the lake is at the highest. At other times the water flows by gravity to the lake.

Changes in fish and plants using transfer functions.

Information on past changes in fish abundance and coverage of submerged plants can be obtained from analyses of fragments from taxonomically different zooplankton organisms. The reconstruction of fish is based on a statistical relationship between remains of pelagic zooplankton in surface sediment samples and corresponding contemporary data on planktivorus fish CPUE, caught with gill nets during one night in 38 lakes with contrasting fish densities (Jeppesen et al., 1996). For submerged plant cover similar transfer functions are used. 22 lakes were investigated, including 14 plant-associated taxa (Jeppesen et al., unpublished).

Estimation of changes in fish abundance and plant cover was carried out for Lake Wuliangsuhai, but reliable results were not obtained (Figs A1 & A2). This is partly due to the fact that the model is developed for Danish freshwater lakes and does not take into account the species composition and trophic dynamics of Lake Wuliangsuhai. Obviously, the transfer function for Danish lake abundances is not able to track the changes occurring in Lake Wuliangsuhai. Secondly, only few of the taxa used in the model are found in the samples from the sediment core (for fish reconstruction: three out of six and only at two depths, and for plant cover only 2-3 at most depths).

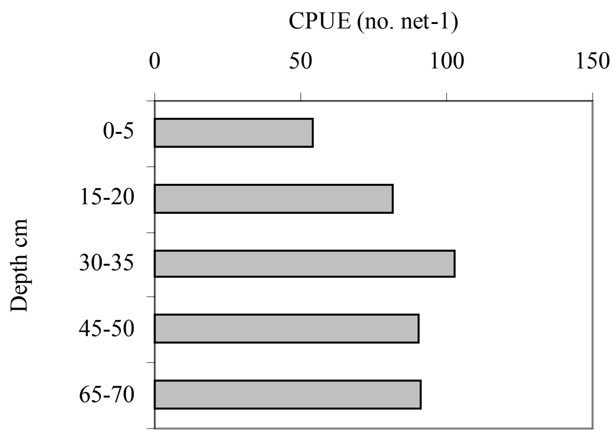


Figure A1. Reconstruction of fish abundance in Lake Wuliangshuai,

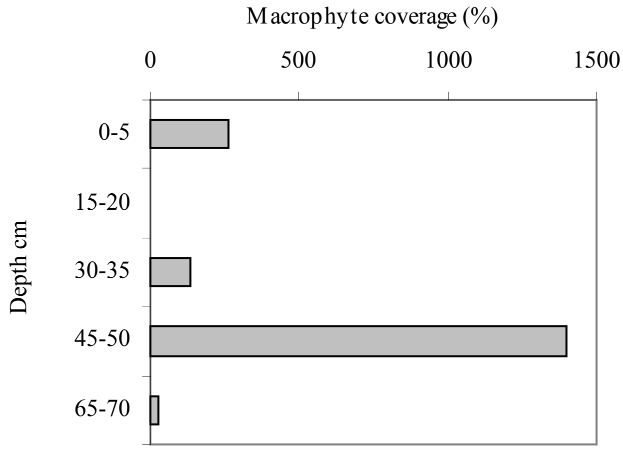


Figure A2. Reconstruction of plant cover in Lake Wuliangsuhai.

Calculated 'open water' areas and volumes

Table Areas and volumes of water in 'open water' areas

Depth level (m below surface)	Area (km^2)
0.0	167.640
0.5	122.547
1.0	117.991
1.5	23.056
2.0	6.114
2.5	1.566
3.0	0.025
Average lake depth (m):	1.035

Depth interval	Volume ($*10^6$ m^3)
0.0-0.5	72
0.5-1.0	60
1.0-1.5	32
1.5-2.0	7
2.0-2.5	2
2.5-3.0	0
3.0-3.5	0
Total volume	174

Norwegian Institute for Water Research

Gaustadalléen 21 • NO-0349 Oslo, Norway
Telephone: +47 22 18 51 00 • Fax: 22 18 52 00
www.niva.no • post@niva.no