Pollution point sources in Lake Wuliangsuhai’s catchment area, P. R. of China

Förorenande punktkällor i sjön Wuliangsuhai avrinningsområde, Kina

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Erik Lindblom
Abstract

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Lake Wuliangsuhai in western Inner Mongolia, China, is severely eutrophicated and its surface is rapidly giving way to beds of reed. The lake is important to the arid region and there is an interest to restore the lake.

This study updates the list of major pollution point sources, compiled by IVL Swedish Environmental Research Institute. It also describes the sources both qualitatively and quantitatively. Three cities and seven industries are included in the study. It is evident that agriculture is the dominating source for nutrients reaching the lake. Cities are nevertheless a potentially important contributor of phosphorus while the industries, especially the paper mills discharge large loads of COD.

The total yearly discharges from the point sources are:

- Wastewater: 9 million cubic metres (cities 50 %, industries 50 %)
- Phosphorus: 60 ton (cities 75 %, industries 25 %)
- Nitrogen: 400 ton (cities 54 %, industries 46 %)
- COD: 13,300 ton (cities 17 %, industries 83 %)

Keyword: semi-flow-proportional sampling, grab-sampling, Lake Wuliangsuhai, Hetao, P. R. of China, pollution point sources, wastewater

Referat

Förorenande punktkällor i sjön Wuliangsuhais avrinningsområde, Kina

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Sjön Wuliangsuhai i västra Inre Mongoliet, Kina, är kraftigt övergödd. Under de senaste femtio åren har ungefär halva sjöytan försvunnit på grund av att sjön växer igen. Samtidigt är sjön av stor betydelse i det torra klimatet och det finns ett regionalt intresse att bevara sjön.

Studien uppdaterar den inventering av de punktkällor som IVL Svenska Miljöinstitutet sammanställt. Dessutom beskrivs föroreningskällorna kvalitativt och kvantitativt. Totalt ingår tre städer och sju industri i studien. Det är tydligt att jordbruken är den största källan av näringsämnen till sjön. Städerna är icke desto mindre en potentiellt betydelsefull källa av fosfor och industrierna, särskilt två pappersbruk, släpper ut stora mängder COD.

De årliga utsläppen från punktkällorna uppgår till:

- Avloppsvatten: 9 000 000 kubikmeter (städare 50 %, industri 50 %)
- Fosfor: 60 ton (städare 75 %, industri 25 %)
- Kväve: 400 ton (städare 54 %, industri 46 %)
- COD: 13 300 ton (städare 17 %, industri 83 %)

Nyckelord: semi-flödesproportionell provtagning, stickprov, Wuliangsuhai, Hetao, Kina, punktkällor, avloppsvatten

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Preface

This report is the result of the thesis work “Pollution point sources in Lake Wuliangsuhai’s catchment area, P. R. of China”. The work is a master thesis within the Master of Science Program of Aquatic and Environmental Engineering at Uppsala University. It has been carried out for IVL Swedish Environmental Research Institute as part of the international Inner Mongolia Lake Restoration Project – Lake Wuliangsuhai.

A few notions could be made about the disposition of the report. Chapter two contains the background, regarded as important for the understanding of the report. It should be considered as a resource for the not-so-initiated reader in giving the presented work its appropriate context. A reader familiar with the project may very well proceed to the following chapters directly.

The results are divided into three different chapters, four, five and six. In this way the different aspects are clearly separated. First the different point sources are described qualitatively in order to define which sources are considered in the study as well as to support interpretations of gathered data. Next chapter tries to quantify pollution loads from the different sources. Chapter six, finally, compares grab-sampling versus flow-proportional sampling with focus on the consequences of fluctuating flows and concentrations for municipal and industrial pollution sources.

At a few passages in this report the term “sampling” refers to both the actual sampling and the flow measurement, for example in “sampling site”. This is unfortunate but no better common description has been found. Hopefully there should be no confusion because of this.

The chemical compounds of interest are total phosphorus, total nitrogen and chemical oxygen demand. Throughout the report they are called just phosphorus and nitrogen or by the abbreviations P, N and COD.

The Chinese currency is called Renminbi, meaning “the people’s currency”, and is abbreviated RMB in the text. One RMB is worth approximately 1.1 SEK.

As a result of working in China, all geographical names, names of industries and many personal references are Chinese. According to international standard Chinese characters should be transcribed using pinyin. This has been done by the Chinese counterparts.

In all cases Chinese geographical names have been used instead of English translations, for example Huang He instead of Yellow River. The only exceptions are the names China and Inner Mongolia.

Erik Lindblom
Eksjö, January 2003
1 INTRODUCTION

1.1 Rationale

The study examines how to describe water pollution point sources, both qualitatively and quantitatively. It is applied on Hetao, a large irrigated area in the Autonomous Region of Inner Mongolia, the People’s Republic of China (herein after referred to as Inner Mongolia and China respectively). The main objectives of the study are to identify and describe the pollution point sources and compare methodologies of water pollution measurement, especially to compare the used method of flow-proportional sampling with grab-sampling.

The environmental problem in focus is that the largest lake in the area, Lake Wuliangsuhai, acts as recipient for agricultural drainage water as well as wastewater from three cities and a limited number of industries. Due to severe eutrophication the lake is rapidly giving way to expanding beds of reed, threatening the future existence of the lake. For that reason the study focuses on the pollutants phosphorus, nitrogen and organic matter, being the main contributors to eutrophication. It is known that shallow grassland lakes of Inner Mongolia are particularly vulnerable to eutrophication (Fejes and Palm, 1997). At the same time they are of great importance to the local communities due to water scarcity in the region.

Figure 1: Municipal and industrial wastewater, in many cases untreated, contributes to the eutrophication of Wuliangssuhai. To the left the outlet from the spice factory Fei Ya in Hanghou. To the right reed beds in Lake Wuliangssuhai. Photos Lindblom, 2002.
The rationale for the field study is:

- The Chinese standard for monitoring pollution sources today is based on grab-sampling. Grab-samples are uncertain when there are variations in flow and concentrations. This is usually the case for point sources such as cities and industries.
- The results of the analyses are of great importance since a large number of enterprises have been forced to close down because of exceeded pollution limits. Thus the choice of sampling method may have local economic and social consequences as well as strictly environmental consequences.

During the fieldwork the method of flow-proportional sampling is used, hoping to practically introduce that concept to the local Environmental Protection Bureau (EPB). In the long term these results might contribute to change the national standard by increasing the knowledge of the benefits with flow-proportional sampling.

New knowledge about the pollution situation in the region will be generated through this study as the identified pollution sources have not previously been examined with flow-proportional sampling. The results will be used to describe the total pollution load on Lake Wuliangsuhai in greater detail. Reliable data is of value when addressing any pollution-induced problem and can be used as decision support for planning pollution preventing actions in the future.

1.2 Objectives

The objectives of this study are to

- describe each pollution point source qualitatively and quantitatively. This includes on-site inspections and interviews with local staff, as well as measurement of flow and chemical analyses of wastewater samples.
- discriminate the total load of pollutants on Lake Wuliangsuhai into municipal, industrial and agricultural sources respectively.
- compare and evaluate grab-sampling and flow-proportional sampling as methodologies for determining pollution from cities and industries.

The work aims at getting a better understanding of the pollution point sources in the project area. It will give a more accurate description of the pollution load on Lake Wuliangsuhai. This knowledge will also help tracing historical changes and predicting consequences of future actions.
2 BACKGROUND

2.1 Eutrophication

Eutrophication is a natural process in ageing water bodies. Hedelin (2001) characterise it by accumulation of plant nutrients and increasing primary production. This leads to larger amounts of decomposing organic matter, which increases the oxygen consumption at the bottoms. Decreasing concentration of dissolved oxygen results in slower decomposition. With time the lake is becoming shallower, making new areas available for vegetation. This further increases the primary production and eventually the lake disappears. The rate of the process is often dramatically increased by human activities due to discharge of nutritious wastewater. Important sources are municipal sewage, different industrial enterprises and fertilised agriculture. This is sometimes referred to as cultural eutrophication in contrast to historical eutrophication, being the natural process.

Phosphorus (P) and nitrogen (N) are the most important plant nutrients, with phosphorus usually being the limiting factor in freshwaters. Chemical oxygen demand (COD) describes the total content of organic matter, possibly contributing to the raise of bottom level.

One of the main problems of Lake Wuliangsuhai is macrophyte establishment, which is facilitated by the shallow water. Shallow lakes are also more sensitive to eutrophication, since high water temperature and more light is favourable for photosynthetic production and decomposition as well as chemical reactions promoting phosphorus release from the sediments (Hedelin, 2001).

2.2 Lake Wuliangsuhai’s catchment area

Lake Wuliangsuhai’s condition is to a great extent a consequence of its catchment area and the ongoing activities within it. A catchment area is an area from which all runoff reaches one point, in this case Lake Wuliangsuhai. Since Hetao is extensively irrigated, Lake Wuliangsuhai’s catchment area is well defined by the channel system.

2.2.1 Physical geography

Lake Wuliangsuhai is situated in the northernmost part of China, on the grasslands of western Inner Mongolia. The lake’s catchment area lies within the administrative region of Bayannaore (also known as BaMeng) and consists mainly of the irrigated Hetao area.

Bayannaore is flat, open and arid, 64,000 square kilometres large and with a population of 1,770,000 people. It is divided from east to west by the Yinshan Mountains. North of the mountains there is a plateau and to the south a plain. (Fejes and Palm, 1997) Administratively Bayannaore is divided into seven counties. The capitol is Linhe, which also is the largest city in the catchment area.

Hetao lies on the southern plain of Bayannaore and is confined by Huang He to the south. The area’s total length is 250 kilometres from east to west and 50 kilometres from south to north. It contains northern China’s largest agricultural area, 5,700 square kilometres. The area is an old alluvial flood plain created by Huang He. (Fejes and Palm, 1997)

The geographical outline is given in figure 2.
The Bayannaore area has an arid temperate continental monsoon climate with long, cold winters and short, warm summers. The low precipitation makes agriculture in this area impossible without irrigation. Dust storms are frequent during winter and spring. The annual precipitation in Hetao is between 130 and 200 millimetres increasing from west to east and the annual evapotranspiration is between 2,000 and 2,400 millimetres. The highest temperature in summer is 38 °C and the lowest temperature in winter is –38 °C (GIS Development, 2002).

In order to feed the irrigation system part of Huang He is diverted. The intake is Sanshenggong Diversion Dam at the city Dengkou, in the south-west of Hetao. The water is spread over the cultivated area through a number of irrigation channels. Later the surplus water is collected and transported in seven drainage canals leading to the main drainage canal, ending in Lake Wuliangsuhai, as illustrated in figure 3. About nine tenths of the water is lost by evaporation and plant consumption before reaching the lake. During wintertime there is no need for irrigation, and the intake is therefore closed between 1 November and 19 April (Fejes and Palm, 1997).

In Bayannaore and Hetao there are two main problems identified concerning the use of water; salinisation of the soil and desertification.

Natural streaming water, such as Huang He, contains dissolved salts from the soils and rocks it passes. Even though all irrigation inevitably leads to salinisation, the rate is depending on local irrigation practices. Often excessive use of water combined with poor drainage management is the cause of increased soil salinity (USDA, 2002). Once the salt is accumulated in the soil it can not be removed unless leached by excessive amount of rain or irrigation water (GIS Development, 2002). The salinity problem is recognised by the local authorities and the irrigation scheme is designed to reduce the risks (Guo, personal communication). Nevertheless, white spots of precipitated salt on the soil’s surface, up to tens of square metres, are common in the fall, indicating that the problem is still present. According to a Japanese study half of Hetao’s cultivated area is affected by salinisation (GIS Development, 2002).
Hetao’s vegetation is largely influenced by the irrigation. The surroundings are sparsely vegetated with actual desserts nearby. West of Wuyuan the dessert is spreading into cultivated areas whereas farmers in Dengkou are claiming new areas from the dessert by forestry (Guo).

### 2.2.2 Socio-economic aspects

Bayannaore is an agricultural region with a rural economy. Its gross domestic product (GDP) per capita was 5,788 RMB in 1999 (Sternhufvud, 2000), a mere third of the more industrialised coastal area’s 17,200 RMB in 2000 (Kwan, 2002). There are no numbers available on unemployment but it is generally considered to be over ten percents (CIA, 2002).

Hetao has a population of approximately 1,400,000 inhabitants. A large majority of the population, 1,020,000 people or 230,000 families, is farmers. (Fejes and Palm, 1997) The region is not urbanised. The three major cities in the catchment area, Hanghou, Linhe and Wuyuan have less than 350,000 inhabitants in total, according to staff at BaMeng EPB.

- Linhe: 180,000 ± 20,000 people
- Hanghou: 60,000 ± 10,000 people
- Wuyuan: 60,000 ± 10,000 people

Virtually all human activities result in pollution of surrounding ecosystems. The status of the ecosystems has an impact on the local economy. This is particularly true for rural economies, which are directly dependent of the outcome from their natural resources.

Actions aiming at restoring Lake Wuliangsuhai will include pollution preventing measures to reduce inflow of nutrients to the lake. This will most likely mean restrictions for the businesses in the catchment area, affecting local economy and thereby probably the society.

Agriculture constituted about half of Bayannaore’s GDP during the years 1996 through 1998 (being the most recent data available) (Sternhufvud, 2000). Hetao is in fact one of northern China’s most important producers of agricultural products. Stockbreeding is the second most important source of income, after crop rising, with sheep being the most common livestock. The main crops are grain, sunflower, corn and sugar beet. The yield varies considerably depending on soil salinity. (Fejes and Palm, 1997) Worth mentioning is that agriculture’s share of GDP is slowly decreasing. This decrease is implying that the industrial sector, though smaller, is of increasing importance, which is necessary in order not to fall too far behind the coastal region economically.
The industrial enterprises in the catchment area are mainly small-scale producers on the local market. 1993 a total of 9,212 industries were registered in Bayannaore. Today many of them have been closed as a consequence of efficiency improvements and environmental regulations. (Fejes and Palm, 1997) Two significant closures are the paper mills in Hanghou and Long Shan. They were probably closed due to political reasons. The Chinese Government has decided to close all paper and pulp industries producing less than one thousand ton paper per year. The reason is that environmental impact is considered to be too high in relation to the amount of paper produced (Röttorp, 2002).

The enterprises directly related to Lake Wuliangsuhai are likely to detect any changes in the lake’s condition at an early stage and depending on what actions will be suggested as an outcome of the Lake Restoration Project, they may be the first to gain or lose. Traditionally the lake has been used for fishing and there are still a number of fish farms active around the lake. Probably depending on decreasing oxygen levels the number of species has decreased. More important, and increasingly so, is the harvest of reed. The reed is used for pulp in local paper factories and to a lesser degree for carpets. Experiments are conducted in order to use submerged vegetation as forage. These sectors are however small compared to the total economy in Bayannaore. Some numbers for 1999 on income and number of employees are given in table 1.

Worth mentioning is the fact that the tourism sector is expected to grow considerably in the future if the lake restoration is successful. Being a very important bird refuge the lake has potential to become a popular visit for bird-watchers from around the world. Today there is already a bird exhibition hall, boat rental and a tourist island with a lookout tower and possibilities to stay overnight.

It can be argued that the value of keeping the lake as a lake is significantly larger than just the value of the enterprises profiting on the lake’s resources. For example the quality and availability of drinking water will increase and the microclimate will benefit (Sternhufvud, 2000).

2.2.3 Pollution situation according to Chinese data

The water flowing into Lake Wuliangsuhai is regularly analysed in accordance with Chinese standard. From this information, together with the knowledge about entering volumes, it is possible to calculate pollution load during the previous years. It should be noted that these estimates of load are based on grab-sampling.

The total load on the lake for year 2001 is presented in table 2. The load is based on flow data provided by BaMeng Hydro Survey Department and concentration data collected by NIVA.

<table>
<thead>
<tr>
<th>Income [RMB]</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing</td>
<td>2,200,000</td>
</tr>
<tr>
<td>Reed</td>
<td>9,445,000</td>
</tr>
<tr>
<td>Tourism</td>
<td>Unknown</td>
</tr>
<tr>
<td>Agriculture</td>
<td>279,080,000</td>
</tr>
</tbody>
</table>

Table 1: Income and number of employees 1999 in sectors directly related to Lake Wuliangsuhai. Values for the agricultural sector in Bayannaore are given as a comparison (Sternhufvud 2002)
To get an estimate of the origin of the pollutants, Röttorp (2000) created a preliminary list of pollution point sources in June 2000. This compilation is based on a list of cities and major industries given by the provincial EPB of Inner Mongolia. In the catchment area only the cities Hanghou, Linhe and Wuyuan have operational sewer systems. It is important to remember that the municipal sewage contains the wastewater from the numerous enterprises within the cities.

The list was narrowed down by excluding all industries not discharging their wastewater to Lake Wuliangsuhai and then by only choosing the most important pollution sources. This choice was made by the local EPB in Linhe and the provincial EPB independently from each other. The result is listed in table 3, together with relevant pollution related data.

Agriculture and ineffective use of fertiliser is considered to be the main source of nutrients to Lake Wuliangsuhai. Due to cold and dry winter climate the use of pesticides is on the other hand low. (Fejes and Palm, 1997) Unfortunately there is very little data available on agricultural discharge, because of difficulties in finding representative test fields. The other diffuse sources are background concentrations in the water from Huang He, natural runoff, direct atmospheric downfall and resuspension of nutrients from the sediments in the lake. At least the first two are considered to be insignificant by comparison, even though there is no data available to confirm this.

Table 3: List of cities and industries in Hetao contributing to pollution of Lake Wuliangsuhai, compiled in June 2000 (Röttorp, 2000). Drainage canals are the numbers of the canal transporting the wastewater to the main drainage canal

<table>
<thead>
<tr>
<th>City/company name</th>
<th>Type of production</th>
<th>Estimated flow [x 1,000 m³/year]</th>
<th>COD [ton/year]</th>
<th>Wastewater treatment</th>
<th>Drainage canal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanghou City</td>
<td>City</td>
<td>800</td>
<td>Unknown</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Linhe City</td>
<td>City</td>
<td>4,380</td>
<td>Unknown</td>
<td>No</td>
<td>5</td>
</tr>
<tr>
<td>Wuyuan City</td>
<td>City</td>
<td>630</td>
<td>Unknown</td>
<td>No</td>
<td>7</td>
</tr>
<tr>
<td>5303</td>
<td>Gloves and caps for industrial workers</td>
<td>15</td>
<td>7</td>
<td>Yes</td>
<td>5</td>
</tr>
<tr>
<td>Chen Guan</td>
<td>Paper and pulp</td>
<td>1,000</td>
<td>560</td>
<td>No</td>
<td>5</td>
</tr>
<tr>
<td>Da Ming Chai</td>
<td>Paper and pulp</td>
<td>830</td>
<td>1,936</td>
<td>Yes</td>
<td>7</td>
</tr>
<tr>
<td>Dengkou</td>
<td>Fertiliser</td>
<td>640</td>
<td>199</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Hangzhou</td>
<td>Instant milk products</td>
<td>80</td>
<td>76</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Hanghou</td>
<td>Paper and pulp (will later make chipboard)</td>
<td>750</td>
<td>1,680</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Hetao</td>
<td>Liquor factory</td>
<td>400</td>
<td>801</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Jin Chuan</td>
<td>Beer</td>
<td>210</td>
<td>227</td>
<td>No</td>
<td>5</td>
</tr>
<tr>
<td>Long Shan</td>
<td>Paper and pulp</td>
<td>810</td>
<td>722</td>
<td>No</td>
<td>5</td>
</tr>
<tr>
<td>Wei Xing</td>
<td>Clothes industry: manufacturing both wool and leather clothes</td>
<td>10</td>
<td>8</td>
<td>Yes</td>
<td>5</td>
</tr>
<tr>
<td>Wuyuan Fertiliser</td>
<td>160</td>
<td>38</td>
<td>Yes</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>
The dominating source of water in the catchment area is diverted water from Huang He. Its chemistry is affected by the soils through which it has streamed. The lowest recorded concentrations found fall below 0.02 mg P/l and 0.07 mg N/l respectively (NIVA, 2002). These analyses are complicated by the extremely high concentrations of suspended material, but clearly indicate that background levels of nutrients are insignificant.

Natural runoff and atmospheric downfall contribute with less than 10 % of the total inflow to the lake. The concentrations must be unreasonably high in order to affect the total load.

According to Röttorp (personal communication), resuspension from the sediments is likely to be an important diffuse source of nutrients. Lake Wuliangsuhai has received heavy loads of pollution for a long time. Some of the nutrients has been assimilated by the vegetation or has been discharged to Huang He, but much has settled. These sediments can be thought of as a large environmental debt. Regardless of inflow the eutrophication process will continue for a long time due to this nutrient release.

2.2.4 Lake characteristics

Wuliangsuhai is the largest lake in the Huang He basin in Inner Mongolia and the seventh largest lake in China. It is 35 to 40 kilometres long and 5 to 10 kilometres wide. The average depth is about 1.5 metres. The most conspicuous problem with Lake Wuliangsuhai is that the lake surface is rapidly giving way for reed beds that today cover roughly half of the lake. A closer look reveals typical eutrophication characteristics. Lake Wuliangsuhai’s characteristics and the processes within the lake are typical for all shallow grassland lakes in the region.

The lake was cut off and thus created about 150 years ago when Huang He changed its course. Due to the climate, Lake Wuliangsuhai would probably have dried out today without the Hetao irrigation scheme. Still the surface has been decreasing from approximately 470 square kilometres in the 1950ies to 280 today.

The lake is almost entirely regulated. Approximately 97 % of the incoming water to the lake is drainage water, primarily from agriculture. The rest is natural runoff. The water budget is illustrated in figure 4. The drainage water is pumped from the drainage canals into the lake, whose surface is about two to three metres above the canal. Also the water level in the lake is regulated through the outlet from Lake Wuliangsuhai to Huang He, and is fixed at 1,018.5 metres above sea level.

![Figure 4: Water budget for Lake Wuliangsuhai.](image-url)
Table 4: Some characteristics for central Lake Wuliangsuhai, samples taken 20 September 1997 (Fejes and Palm, 1997)

<table>
<thead>
<tr>
<th>Conductivity [mS/m]</th>
<th>P [µg/l]</th>
<th>N [µg/l]</th>
<th>COD [mg/l]</th>
<th>Cl⁻ [mg/l]</th>
<th>SO₄²⁻ [mg/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>253</td>
<td>13</td>
<td>660</td>
<td>69</td>
<td>530</td>
<td>370</td>
</tr>
</tbody>
</table>

Being a recipient for agricultural, industrial and municipal wastewater, Lake Wuliangsuhai gets heavy loads of nutrients and possibly other pollutants such as pesticides and heavy metals. Presently the sediment grows with 1 centimetre each year (Fejes and Palm, 1997). Hui et al. (2002) suggest that the irrigation water from Huang He has arsenic concentrations four times the environmental standards.

The water quality has been thoroughly examined during the last decades. NIVA characterise the water as slightly salt with regard to Chinese standards after their study in fall 1997. Analyses indicate high concentrations of salt but moderate concentrations of nutrients, possibly due to absorption of dense submerged vegetation (Fejes and Palm, 1997). High turbidity and suspended solids make the transparency less than one metre. The results are presented in table 4.

In this arid area lakes and wetlands are important for biodiversity, for example as nesting places and migration refuges for waterfowl, as well as the local microclimate. Lake Wuliangsuhai is no exception with at least 178 different bird species reported, of which twelve are on the Chinese Red List. Recent inventory indicates that the lake’s importance for migrating birds is increasing (Svensson, 2000).

2.3 Inner Mongolia Lake Restoration Project

The overall purpose with the Inner Mongolia Lake Restoration Project is to transfer knowledge about eutrophication processes and lake management from Scandinavia to China. In order to do this Lake Wuliangsuhai has been chosen as the pilot lake, being a typical eutrophicated shallow grassland lake. Knowledge gained and transferred to Chinese experts during this project will later be applied on other lakes with similar problems.

The long-term goal for the Wuliangsuhai project is to keep the lake as a lake. This will be done by developing a plan for sustainable management of the water and nutrients resources in the lake’s catchment area. The plan must address the conflicting interests of regarding Lake Wuliangsuhai as a recipient for irrigation and sewage water as well as a sustainable source of resources (IVL, 1998).

Fejes and Palm (1997) describes how the project was initiated in 1994. At an early stage it was decided to split the project in two separate parts, the first being a pre-feasibility study. This study was conducted during fall 1997 and spring 1998. In September 1997 the work started with a field trip to Lake Wuliangsuhai and its catchment area in Inner Mongolia. The pre-feasibility study resulted in a Terms of Reference for the second part of the project.

The second part of the project, which started in 1999, will according to plans be finished by the end of 2002 (IVL, 1998). Additional funds have been applied for in order to continue the project through the first half of 2003. This will allow for better evaluations of long-term experiments, such as re-growth of lake vegetation after dredging (Fejes, personal communication).

The entire project has been carried out as a joint project by the Inner Mongolia Environmental Science Institute (IMESI), the Norwegian Institute for Water Research (NIVA) and the Swedish Environmental Research Institute (IVL). IMESI is the client, with consultation service delivered by NIVA and IVL. The consultants are financed by the Norwegian Agency for Development Co-operation (NORAD) and the Swedish International Development Co-operation Agency (Sida) (Fejes and Palm, 1997).
In the Terms of Reference it is stated that the project will have three outputs, including a knowledge base describing the eutrophication problem affecting Lake Wuliangsuhai, tools for decision support and a management and control plan for the lake. These outputs are divided into nine goals, each one being a sub-project in the Lake Restoration Project:

- Data on economical and social information.
- Inventory of major pollution sources.
- A monitoring system that describes water quality and pollution transport in the channel system and in Lake Wuliangsuhai.
- Analysis of the historical development of the lake surface area and the vegetated area.
- Basic properties of and processes in the lake ecosystem.
- Local staff trained in the different links of the management process.
- Quality assurance of the outputs and sub-projects.
- A GIS-based system for environmental management.
- A management and control plan.

2.4 Chinese sampling standard and environmental law

The Environmental Protection Law of the People's Republic of China is the cardinal law for environmental protection in China. It consists of a number of special laws addressing different environmental aspects, such as Law on the Prevention and Control of Water Pollution. The laws emphasise environmental standards for quality, pollution discharge and emission as well as criteria for sampling and methodology (Information Office, 2002).

According to Li (personal communication) municipal and industrial wastewater must be sampled once every year. The sampling methodology to use is grab-sampling. If the quality of the effluent does not meet the emission standards, the enterprise is obligated to treat it. In that case there are two alternatives. Either the enterprise installs a local treatment plant or it buys treatment capacity of an existing treatment plant. The emission standards are based on concentrations and not loads. The emission standards are depending on the type of enterprise, but in all cases the most important parameter is COD compared to phosphorus and nitrogen.

The Chinese Government considers the law enforcement to be as important as the legislation. During the last years environmental problems have attracted more attention than before from media focusing on governmental efforts. Attempts have been made to open channels for the masses of people to report on environmental problems and adopted measures for the media to expose environmental law-breaking activities. At the same time it must be pointed out that much work remains. For instance, some areas still remain uncovered, some contents are yet to be amended or revised and there are problems of not fully observing or enforcing laws (Information Office, 2002).
3 MATERIAL AND METHODS

3.1 Used equipment

To collect data for this report two American Sigma 900 Standard Portable Samplers, three American Sigma Flow Meter Model 920 and two sets of MultiLine F/SET-3 were used. The MultiLine F/SET-3 was used for on-site measurements of pH, dissolved oxygen, conductivity and temperature. The equipment is shown in figure 5.

A Pentax 430 RS digital camera and a handheld Garmin etrex 12 channel GPS were used for documentation. Since they are of no importance for the samplings they are not described further.

3.1.1 American Sigma 900 Standard Portable Sampler

An American Sigma 900 Standard Portable Sampler was used for sampling the wastewater. The sampler consists of two sections: a large round container for the sample bottles in the bottom and on top of that a control section with a pump and front panel. The control section is protected by a top cover. When assembled the sampler is slightly cone-shaped and moveable by one person. Specifications for the sampler used in the field study are presented in table 5.

![Figure 5: The equipment used during the fieldwork. The white instrument is an American Sigma 900 Standard Portable Sampler, the black cylinder an American Sigma Flow Meter Model 920 and the white suitcase a MultiLine F/SET-3. To the right and left are examples of sampling in a pipe and in an open channel respectively. Middle top show the sampler with the control panel, battery and pump intake exposed. Middle bottom is a close-up on the MultiLine. Photos Lindblom, 2002.](image-url)
Table 5: Specifications for Standard Portable Sampler 900 (American Sigma Sampler, 2000)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>50.5 cm diameter x 69.4 cm height.</td>
</tr>
<tr>
<td>Weight</td>
<td>15 kg with empty bottles.</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>0 to 50 °C.</td>
</tr>
<tr>
<td>Power requirements</td>
<td>12 V dc, supplied by A/C power converter or battery.</td>
</tr>
<tr>
<td>Battery</td>
<td>Rechargeable 6 Ah gel lead acid battery.</td>
</tr>
<tr>
<td>Battery life</td>
<td>Two complete sampling cycles.</td>
</tr>
<tr>
<td>Vertical lift</td>
<td>8.23 m maximum, remote pump recommended for lifts over 6.7 m.</td>
</tr>
<tr>
<td>Sample volume</td>
<td>From 10 to 9,999 ml (one ml increment).</td>
</tr>
<tr>
<td>Interval between samples</td>
<td>From 1 to 9,999 minutes (one minute increment).</td>
</tr>
<tr>
<td>Data logging</td>
<td>Records program start time, stores up to 400 sample collections.</td>
</tr>
</tbody>
</table>

The two samplers at hand were equipped with twelve glass bottles each and programmed to take one 500-millilitre sample every second hour.

There are several different versions of sampler configurations available. The number of sample bottles to use range from one to twenty-four. The base section may be insulated and for the pump there is an additional external pump available if high lifts are requested. There are also slightly different tubing and connectors to choose from (American Sigma Sampler, 2000).

When putting the sampler at the sampling site it should preferably be placed on a level surface close to the sampling point. In order to avoid contamination of previous samples the tube should slope downward to the intake, without loops or kinks. The intake itself should be placed in an area of turbulent and well-mixed flow. Depending on the variation in water level during the sample period and the amount of suspended material in the water the depth of the intake should be adjusted to avoid clogging as well as sucking air (American Sigma Sampler, 2000; Röttorp, 2000).

When sampling channels with laminar flow there will be a concentration gradient from the bottom, since heavier particles are settling (Röttorp, personal communication). Thus the sample is not representative for the entire flow. During the fieldwork the sampler intake has been placed close to the bottom, since that is the worst case with concentrations probably higher than the average concentrations in the channel.

3.1.2 American Sigma Flow Meter Model 920 and Submerged Level/Velocity Sensor

To determine the flow an American Sigma Flow Meter Model 920 was used together with a submerged level/velocity sensor. The flow meter is a cylinder-shaped black instrument containing the logger and the devise for programming and data handling. The sensor is contained in a probe, connected to the flow meter with a long cable. Placing the probe in the channel, level and velocity are measured and recorded by the flow meter. The sensor consists of a small pressure transducer, converting measured water pressure to water level. To compensate for the atmospheric pressure there is a reference at the intake (American Sigma, 2002). Some specifications for the flow meter and sensor used are presented in table 6.

Depending on the situation and the user’s requests it is possible to configure the flow meter in a wide variety of ways. For example there are different kinds of probes available, such as an extremely low-profile streamlined probe for use with very low flows. Model 920 can be equipped with two probes simultaneously. It is also possible to change the recording interval, specify units and specify type of channel measured to get the flow calculations correct. If a long time monitoring is conducted it is possible to download the readings via modem connection (American Sigma Flow Meter, 2000).
Table 6: Specifications for Flow Meter Model 920 (American Sigma Flow Meter, 2000)

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Model Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>16.8 cm diameter x 44.7 cm length.</td>
</tr>
<tr>
<td>Weight</td>
<td>7.5 kg with batteries.</td>
</tr>
<tr>
<td>Probe cable length</td>
<td>7.6 m.</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>-18 to 60 °C.</td>
</tr>
<tr>
<td>Power source</td>
<td>Two Energizer EN-529 alkaline 6 v dc batteries.</td>
</tr>
<tr>
<td>Battery life</td>
<td>90 days effective use typical.</td>
</tr>
<tr>
<td>User interface</td>
<td>PC.</td>
</tr>
<tr>
<td>Velocity measurement accuracy</td>
<td>Method: Doppler ultrasonic.</td>
</tr>
<tr>
<td></td>
<td>Minimum depth: 2 cm.</td>
</tr>
<tr>
<td></td>
<td>Range: -1.52 to 6.1 m/s.</td>
</tr>
<tr>
<td></td>
<td>Accuracy: ±2 % of reading.</td>
</tr>
</tbody>
</table>

The flow meter supports flow-proportional sampling if connected to the sampler by a cable. In that case the flow meter sends a signal to the sampler each time a pre-programmed volume of water has passed. By this arrangement the work of manually calculating the flow-proportional sub loads of each time interval is made unnecessary and, more importantly, samples are taken at peak flows, which may be missed with time controlled sampling. To configure the flow-proportional sampling correctly there must be a basic knowledge of the total flow. There is also a prepared program for sampling storm water if connected to a rain gauge (American Sigma Flow Meter, 2000).

In this study semi-flow-proportional sampling was used, as described in chapter 3.2. The cable needed for true flow-proportional sampling was not delivered to Linhe EPB together with the flow meter when the equipment was purchased in 2001 (Röttorp, personal communication).

The flow meter is configured through a PC interface and the InSight Data Analysis Software. This software is also used for downloading the data and creating reports and graphs to present the result. If needed, the data is easily exported to spreadsheet programs or word processors (American Sigma, 1998).

To get as accurate flow readings as possible the selected site should have normalised flow with minimal turbulence. Turbulence is often caused by obstructions, vertical drops and pipe or channel bends. Where these difficulties are encountered the velocity probe should be placed at least ten times the expected level from the obstacle (American Sigma Flow Meter, 2000). Furthermore the probe must be securely mounted to the channel’s bottom. In most cases a steel plate, approximately 30 by 30 centimetres was used to which the probe was taped.

During the study depth and velocity readings were recorded every ten minutes. Having those parameters the flow is easily calculated as long as the cross section area is known.

According to the manual the flow meter should always be placed with the connectors facing downward in order to avoid corrosion and eventual seepage, but this is inconvenient since it will tip over. Instead a plastic bag was used from time to time to protect the connectors.

### 3.1.3 MultiLine F/SET-3

A MultiLine F/SET-3 was used for measuring pH, dissolved oxygen, conductivity and temperature on-site. It is an instrument with three different sensors giving instant readings. The instrument and its sensors are conveniently packed in a plastic suitcase, together with calibrating solutions and empty beakers for water samples. Thus all necessary equipment is always available and in good order, ready to use. The instrument uses a rechargeable battery. During the applied study the sensors were only calibrated the first week and some of the later readings may be affected by instrument drift.
3.2 Flow-proportional sampling

True flow-proportional sampling means that the sampling frequency is depending on variations in flow. Large flows result in frequent sampling, smaller flows in fewer samples. This is based on the simple fact that more water passes the monitoring point during large flow and thus has a potentially greater impact on the recipient than smaller flows. Principally a new sample is made each time a default volume of water has passed the monitoring point.

Due to limitations in available equipment (see chapter 3.1.2) it was not possible to use true flow-proportional sampling during the conducted fieldwork. Instead what might be called semi-flow-proportional sampling was used. Flow readings were recorded during the entire monitoring period (twenty-four hours) with time controlled samplings every second hour. This arrangement makes it possible to calculate the flow-proportional weight of each sample afterwards, which is also described in detail below.

3.2.1 Calculation of flow-proportional sample weight

In order to calculate total loads for the monitored time period information about both flow and concentrations must be used. The challenge is that available data has different time resolution. The flow was recorded once every ten minutes and the samples, giving the concentrations, were taken every other hour.

There are a number of possible ways to determine the flow-proportional weight of each sample. In this work two variants are considered.

In the first method each sample is regarded as valid only for the moment it was taken. This implies that the concentration for each sample is multiplied with the weight factor for the concurrent flow recording with regard to average flow. An average of the weighted concentrations is calculated and multiplied with the total flow, according to equation 1. This combines the principle of flow-proportional sampling and available flow and concentration data in a good way (Almemark, personal communication).

\[
M_p = \frac{\sum_{i=1}^{N} C_{p,T_i} \cdot \frac{q_{T_i}}{q}}{N} \cdot Q
\]

\[\text{Equation 1}\]

Where

- \(M_p\) = mass of pollutant [kg]
- \(N\) = number of samples
- \(C_{p,T_i}\) = concentration of pollutant \(p\) at time \(T_i\) [kg/m\(^3\)]
- \(q_{T_i}\) = flow at time \(T_i\) [m\(^3\)/s]
- \(q\) = average flow [m\(^3\)/s]
- \(Q\) = total flow [m\(^3\)]

Another approach is to assume that the variations in concentrations are not entirely random but mainly depending on trends. Thus each sample is regarded as representative for a symmetric two-hour interval around the sampling time. This is however the same assumption as for grab-sampling, namely that one sample is describing a time interval. In order to be able to compare the sampling methods, this weighting algorithm was avoided.

Mass of pollutant is given by multiplying the concentrations with the volume of water that passed the sampling point during the time interval. This is expressed in equation 2.
\[ M_p = \sum_{i=1}^{n} \left( C_{p,T_i} \cdot \sum_{t=T_i}^{T_i+\Delta t} q_t \cdot \Delta t \right) \]  \hspace{1cm} \text{Equation 2}

Where  
- \( M_p \) = mass of pollutant [kg]
- \( C_{p,T_i} \) = concentration of pollutant p at time \( T_i \) [kg/m\(^3\)]
- \( q_t \) = flow at time \( t \) [m\(^3\)/s]
- \( \Delta t \) = length of time interval [s]

This method was only used for mixing 5303’s combined sample before analysis. In this case only one sample was analysed instead of each sample individually.

### 3.2.2 Flow measuring with the v/h-method

During this work the v/h-method was used and is therefore described in some detail. V/h is short for velocity/height and as the name explains the flow is calculated from the average velocity of the streaming water and the cross section area, according to equation 3.

\[ Q = \bar{v} \cdot A \]  \hspace{1cm} \text{Equation 3}

Where  
- \( Q \) = flow [m\(^3\)/s]
- \( \bar{v} \) = average velocity [m/s]
- \( A = f(h) \) = cross section area [m\(^2\)]

The quality of flow-proportional sampling is heavily relying on the accuracy of the flow measurements. There are a number of different methods available, depending on the physical conditions and the objective of the measurement.

When measuring the velocity it is necessary to consider the variability both across the channel and in the vertical. Because of friction against bottom and walls of the channel the water is retarded at the periphery. This is shown in figure 6. For laminar flow it is possible to calculate the velocity distribution if the cross section is known. In practice the average velocity is determined by measuring the velocities at different points across the cross section simultaneously and summing the contributions according to equation 4 and figure 7. This is done automatically by the flow meter and submerged area/velocity sensor.

**Figure 6: Principal velocity distribution in channels dominated by laminar flow. Channel viewed from the side (left) and from above (right).**
\[ Q = \int_{A} v(A) \cdot dA \Rightarrow Q = \sum_{i} \sum_{j} v_{ij} \cdot a_{ij} \Rightarrow \bar{v} = \frac{\sum_{i} \sum_{j} v_{ij} \cdot a_{ij}}{A_{\text{total}}} \]

Equation 4

Where \( Q \) = total flow [m\(^3\)/s]
\( v(A) \) = velocity as a function of area [m/s]
\( v_{ij} \) = average velocity in area segment \( ij \) [m/s]
\( a_{ij} \) = area of segment \( ij \) [m\(^2\)]
\( \bar{v} \) = average velocity [m/s]
\( A_{\text{total}} \) = total area of cross section [m\(^2\)]

Each time the level is measured the velocity is determined by using ultra-sonic signals. Particles and bubbles in the water reflect the signals and flow velocities at different depths are calculated with the Doppler method, as shown in figure 8, and an average velocity is calculated. There are enough particles in almost all natural waters, especially in municipal and industrial wastewater (American Sigma Flow Meter, 2000).

To calculate the flow from the average velocity the cross section area must be known. As long as the cross section’s geometry is known the area is easily calculated as a function of the depth. The flow meter’s software offers a range of default area functions, such as circular, rectangular and trapezoidal cross sections.

Figure 7: Indexing of equation 4. The grey-coloured segment represents \( a_{54} \) and the bullet indicates where the corresponding velocity, \( v_{54} \), is measured.

Figure 8: Sketch of the probe measuring flow velocity. The particles move in the flow direction. When the ultrasound-signal from the sensor hits the particle in position \( A \) the wavelength shortens as the particle moves towards \( B \). When the signal is reflected back to the sensor, the change in wavelength corresponds to the particles velocity, the Doppler Effect.
3.3 Comments on calculations for specific sites

When the circumstances prevented using the semi-flow-proportional methodology described above the actual measurements had to be completed in different ways, depending on available data. These special cases are presented and commented below.

In the appendix “Performed samplings” all samplings are listed and commented. These notes further explains the conditions for the sites included in this chapter.

3.3.1 Hanghou city: Estimation based on discharge per person

The samples from Hanghou were diluted because of an unfortunate choice of sampling site. Because of that it is necessary to estimate Hanghou’s discharge based on the knowledge of pollution from Linhe and Wuyuan.

To calculate the wastewater and pollutants discharge per person and day, the values from Linhe and Wuyuan are simply divided by the number of residents. In Linhe’s case, the data recorded at the treatment plant must first be corrected in order to describe the households. Thus the wastewater and pollution loads from 5303, Chen Guan, Jin Chuan and Wei Xing are subtracted.

The subtraction is complicated by the fact that some settling occurs in the channels between the industries and the treatment plant. Assuming that the evaporation from the channels is insignificant and that the nutrients are dissolved, only COD loads decrease during the transport to the treatment plant. Chen Guan by itself produces six times the amount of COD detected at the treatment plant’s intake. Because of this all COD originating from the industries is considered to settle before reaching the sampling site. This assumption is only made for this calculation.

Based on daily discharges from Linhe and Wuyuan it is possible to calculate a daily discharge per person in these cities. Under the assumptions that all three cities have similar sewer coverage and enterprise density the discharges from Hanghou are calculated. Linhe is assumed to have 180,000 inhabitants, Hanghou and Wuyuan 60,000 inhabitants each.

3.3.2 Linhe city: Operation time and capacity

In the case of Linhe’s treatment plant no velocity measurements were recorded, due to malfunctioning equipment. From the recorded level, shown in figure 9, it is easy to determine when the sewage water was pumped into the plant from the monitored tank. It is also obvious that the inlet is regulated, since there is practically no raise of level during the night.

![Figure 9: Linhe's municipal treatment plant. Recorded water level in the tank from which the wastewater is pumped into the first settling basin. Intervals with falling water level indicate when the pump was operating.](image)
During the twenty-four hour period studied Linhe produced between 14,000 and 16,000 cubic metres of wastewater. The exact volume is estimated to be 15,000 cubic metres. This is based on the facts that the capacity of the pump is known to be between 1,400 and 1,600 cubic metres per hour and the operation time gathered from the figure is just over eleven hours. Noticing that the water level is higher at the beginning of the period than at the end it is obvious that more water has been pumped from the tank than what has been flowing in. Some of the pumped water comes from the previous day and that volume corresponds to one hour and twenty minutes of pumping. Effective pumping time for the studied day is thus ten hours.

The inlet was closed for approximately eight hours during the morning, confirming the information given by Yu.

A second problem with Linhe is the fact that the sampling site was in fact a tank rather than a channel. Water flowing into the tank is mixed with volumes already sampled, resulting in samples not representing the water flowing in at the sampling moment, but rather some kind of accumulated average concentration. Because of that the average concentrations for the twelve samples are used when calculating the load rather than the individual concentrations.

3.3.3 Different sites: Grab-sample and/or inspection of flow

At four sites too few samples were taken to calculate the load in a flow-proportional manner. This was the result of different reasons, but mainly because of difficult sampling conditions and depleted batteries in the sampler.

Hanghou’s minor sewage outlet and Wei Xing have only been examined with one grab-sample and on-site inspection of flow. Both these sites were considered to be of less importance for the total result due to apparently small flows. In the case of Wei Xing the concentrations in the grab-sample were multiplied with a daily wastewater volume of 300 cubic metres, based on the information that 350 cubic metres are discharged daily at peak production.

Hetao Liquor Factory was never sampled. The only data available is the factory’s information that daily discharge is 1,000 cubic metres combined with the fact that the wastewater is pumped through Hanghou’s minor outlet. Loads given by the grab-sample from that source are presented only for Hetao Liquor. Hanghou minor is thus neglected and all municipal wastewater is accounted for by Hanghou major.

At Jin Chuan the sampler’s battery was depleted after two samples. The pollution loads were calculated from average concentrations of these samples and the total flow recorded. Since flow recording was successful the loads are given with two significant digits, instead of one as for the samplings above.

3.4 Pollution sources in Lake Wuliangsuhai’s catchment area

The inventory and examination of the pollution sources in Lake Wuliangsuhai’s catchment area was conducted from late August until early October 2002. Staff from BaMeng EPB, located in Linhe, assisted with advice and resources during the entire fieldwork.

In order to accurately describe the pollution situation it is of great importance to have reliable knowledge about which the pollution sources are. The first principal classing is done in point sources and diffuse sources. Point sources are characterised by the possibility to relate the total contribution of pollutants to a single point. Diffuse sources on the other hand act over larger areas. These categories can be divided further. In this study three categories have been considered:

- Cities
- Industries
- Agriculture and other diffuse sources
Early in the field study the original list, presented in table 3, had to be updated to reflect the present situation. Liu Wei and Miao (personal communications) compiled a revised list, which was complemented continuously during the fieldwork. The qualitative information was collected through on-site inspections and interviews with employees. Because of difficulties with transcribing and translation most names and titles of informants have been left out.

As a complement, the wastewater has in most cases been analysed on-site regarding pH, conductivity and \( \text{O}_2 \)-saturation.

No analyses of the different diffuse sources were conducted due to limited time. The potential sources considered are, apart from agriculture which dominates the catchment area, background concentration in Huang He, atmospheric downfall, natural runoff and resuspension from the sediments in the lake.

### 3.5 Selection of sampling site

When selecting a suitable sampling site there are a number of conditions that should be fulfilled in the ideal situation:

- The total flow of interest should pass the site. The flow must not be diluted. (Röttorp, personal communication)
- The site should have a well-defined and measurable cross section, in order to give correct flow from level and velocity readings.
- The site should be easily accessible both by transport vehicle carrying the equipment and the person mounting the equipment. Also the velocity probe and the intake tube should be mountable at the selected site. This means avoiding both remote and inaccessible sites as well as hazardous locations and confined spaces where possible.

In reality all these conditions are seldom fulfilled at the same time. Natural and dug open channels are often bending and have irregular cross sections, sometimes further complicated by muddy, undefined bottoms. Pipes, having perfectly defined cross sections, are difficult to enter and mount the equipment in.

To get correct flow readings the flow should be laminar, but for representative samples the flow should be turbulent. Choosing different spots for flow measurement and sampling could at some sites solve this, as long as there are no forks changing the characteristics of the flow. When this is not suitable the most crucial information should govern the choice of site. In this study accurate flow readings were judged to be more important than perfect samples. Thus sites with laminar flow were preferred.

### 3.6 Chemical analyses

All chemical analyses were conducted by the local EPBs. Primarily the laboratory belonging to BaMeng EPB in Linhe was used, but because it was forced to change premises some samples were sent to the laboratory in Wulateqianqi. The methodology is identical between different laboratories, but the instrument’s quality in Wulateqianqi is probably lower.

The only analyses conducted on the sampled wastewater were total phosphorus, total nitrogen and chemical oxygen demand (COD). Chinese methodologies for these analyses are equivalent of the Swedish standard analyses SS 02 81 27-2 for phosphorus, SS 02 81 31 for nitrogen and SS 02 81 42 for COD (Röttorp, personal communication). The COD-analysis used is the precise titration.

Available laboratory equipment is sufficient for all common wastewater analyses, such as phosphorus, nitrogen, heavy metals, COD, BOD and oil analysis (Röttorp, 2000).
3.7 Assumptions

The following assumptions are made:

- The time resolution of one sample every second hour and on flow recording every ten minutes is enough to represent the continuous fluctuations of flow and concentrations.
- The samplings are representative for the activities of the industries visited; if not other information is given by the interviewed staff.
- All used equipment functioned correctly, if nothing else is stated.
- All chemical analyses conducted are done according to standards.
- All major cities or industries contributing to the pollution of Lake Wuliangsuhai are included in the inventory.
- All cities in the study have the same degree of sewer coverage.
- The phosphorus and nitrogen are in dissolved phase.
- There is no groundwater transportation of pollutants into Lake Wuliangsuhai.

3.8 Uncertainties

Both the choices of material and methods as well as the assumptions made are contributing to the total uncertainty. Errors can be divided into three categories:

- Systematic errors (bias) are constant for unchanged conditions, for example a wrongly calibrated instrument. It is often possible to detect systematic errors and correct for them.
- Random errors occur for an infinite number of reasons, such as variations in power supply, changed weather conditions and so on. They can usually not be quantified, but may be reduced by making a larger number of samples.
- Rough errors are due to mistakes, such as mixing up samples or misreading instruments. Samples with rough errors should be excluded if identified.

The uncertainty is the magnitude of all random errors after correcting for bias and excluding rough errors. It is calculated with equation 5. This equation requires that all random errors are expressed in the same way, such as percentage or standard deviation. They must also have the same probability distribution and be independent of each other.

\[
e_t = \sqrt{\sum e_i^2}
\]

*Equation 5*

*Where*  
\( e_t = \text{total error} \)  
\( e_i = \text{specific error i} \)

Each step in determining pollution discharge contributes with potential random errors. They are listed and commented below. In chapter 5.3 the appropriate errors are quantified and the total uncertainty is calculated. Naturally, efforts have been made during the fieldwork to minimise the errors.

- Choice of sampling site is strongly influencing the accuracy of data. Badly defined cross section areas are the main problem. Also concentration gradients in the channel, with heavier particles close to the bottom, are an error source.
- The absence of proper equipment prevents true flow-proportional sampling. Time controlled sampling might miss peak flows even though they are detected by the flow meter. Important changes in concentrations might be missed. Resolution of depth and velocity recordings is a smaller source of uncertainty. Also inaccuracies in the submerged sensor affect the result. Inaccuracies in sampling volume do not affect the analyses, since only part of the volume is used.
- Conservation, handling and transportation of samples might cause errors. The chemical analyses consist of numerous steps conducted by different persons at different laboratories.
• How representative is the sampling day? It is important when estimating loads for longer time periods, including issues such as variations in processes at the enterprise and knowledge about length of working week et cetera.

3.8.1 Magnitudes of variation

The grab-sampling methodology is relying on the assumption that the mass flow of the substance at hand is not varying too much during the period the sample is supposed to represent. There are different ways to express these magnitudes of variation based on the semi-flow-proportional samplings. One way is to use the coefficient of variation ($CV$) for the series, calculated with equation 6.

$$CV = \frac{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2}}{\bar{x}} \cdot \frac{n-1}{n-1}$$  \hspace{1cm} \text{Equation 6}

Where
- $n = \text{number of samples}$
- $x_i = \text{value of grab-sample number } i$
- $\bar{x} = \text{average value}$

Coefficient of variation is simply standard deviation divided by the average value (Chatfield, 1998). Standard deviation expresses the spread of a set of normally distributed data in terms of the interval, within which two thirds of a population lies. When divided with the average value the interval is expressed as percents of average value. The larger the $CV$, the larger the spread and the more inappropriate will grab-sampling be.
4 RESULT: INVENTORY OF POINT SOURCES

4.1 Industrial pollution point sources included in the study

The list of industrial pollution sources, as presented in table 3, was updated during September 2002. The result, with a few comments on production and detected errors in the previous list is presented in figure 10. These industries are the point sources examined in this study.

Figure 10: Flow chart of pollution point sources included in the study. Channels from the sources to Lake Wuliangsuhai are illustrated. Note that the wastewater from most industrial sources in Hanghou and Linhe passes through the municipal sewers. In the map drainage canals three through seven are included.

Apparently no new enterprises have been established since June 2000, but three industries have been removed from the list. They are Hanghou and Long Shan paper mills and Dengkou fertiliser factory. The paper mills are probably closed as a consequence of a political decision (Röttorp, 2000). Liu Xiao at Dengkou EPB testifies that no wastewater from Dengkou reaches Lake Wuliangsuhai. Instead it is used locally, or more commonly discharged into Huang He.

4.2 Municipal wastewater in Lake Wuliangsuhai’s catchment area

Linhe is the central city in Hetao with approximately 200,000 inhabitants. It has a university and railway station, connecting it with Inner Mongolia’s capitol Hohhot and the rest of China. There are more shops, markets, hotels et cetera visible here than in Hanghou and Wuyuan. That said, Linhe is not an industrial city, but the commercial centre of the surrounding farmlands.

The other two cities, Hanghou and Wuyuan, have some 60,000 inhabitants each and are considered to be small by Chinese standards. The buildings are mainly one or two storeys high and both cities give a strong impression of being agricultural. Hanghou is located approximately 20 kilometres north-west of Linhe, Wuyuan lies some 60 kilometres east of Linhe.
Today the sewer systems do not completely cover the cities. Miao (personal communication) estimates that two thirds of the wastewater is discharged through the sewer system, the rest is thrown on the ground or directly in drainage ditches and channels.

### 4.2.1 Linhe’s municipal wastewater treatment plant

Linhe is the only city in the catchment area that has any municipal wastewater treatment. The treatment plant has been fully operational since July 2002. Since it collects the wastewater from both the sewers and the industries 5303, Chen Guan, Jin Chuan and Wei Xing, it is not practically possible to study the sewage from the households specifically.

The local production engineer Yu Zhi Ping (personal communication) gave most of the information about the municipal treatment plant in Linhe at a visit 24 September 2002. The construction work started in 1999 and was finished in July 2002. As early as October 2001 the plant was starting to receive wastewater from Linhe, but to what extent is not known. The layout of the plant is a consecutive row of seven large pools, each one approximately 500 by 500 metres large and three to six metres deep. This gives a total volume of between five and ten million cubic metres.

The huge volume of the pools has the capacity of containing several months of wastewater from Linhe. The retention time is said to be approximately two months, but that is not confirmed. According to other informants (Liu Wei, Miao and Yu, personal communications) no treated water had been discharged up until 24 September 2002. There is a contradiction between the stated retention time and the fact that the plant has been operational since July. If it started to receive wastewater as early as October 2001 all pools should have been flooded well before the following autumn if no water was discharged. No water was, however, discharged during the three visits in September 2002. It is not clear whether the water will be reused as for example irrigation water or discharged into the drainage canal and Lake Wuliangsuhai.

Before entering the pools, the sewage is passed through a sand filter. Next the wastewater is pumped to the first pool from an underground tank. The pump limits the total receiving capacity of the plant. Today the pump rate is 1,400 to 1,600 cubic metres per hour, working sixteen hours per day (Yu, personal communication). In 2005 this capacity will be doubled, making a total of 60,000 cubic metres a day (Guo, personal communication).

The seven pools are identical in function, working as settling basins with natural microbiological decomposing of organic matter into carbon dioxide (CO₂) and water. There is no chemical treatment or any active aeration (Yu, personal communication). According to the plan the efficiency will be 85 % decrease of COD-concentration, although how this can be guaranteed is not known. Apparently no limits on phosphorus or nitrogen are stated (Guo, personal communication).

Another important question is how the plant will function during winter, when the pools will be covered with ice and the natural processes will halt. This had not been answered.

There is confusion about the total cost for the construction work. First it was said to exceed 2,000,000,000 RMB, but later the still highly uncertain but considerably more probable figure of 180,000,000 RMB was given (Miao, personal communication). Previous information, stated in different IVL-reports, estimates the cost to 50,000,000 RMB (Sternhufvud, 2000).

### 4.2.2 Hanghou and Wuyuan

There is no treatment of the water from Hanghou and Wuyuan. According to Liu Wei (personal communication) there is a governmental plan saying that all cities of Hanghou’s and Wuyuan’s size will have treatment plants within three to five years. Probably the treatment plants will be of the same type as the one in Linhe, which is described in chapter 4.2.1 above.
Hanghou’s wastewater is collected through a sewer system in an underground tank, from which it is pumped to drainage canal number three through two ditches. The minor outlet is probably insignificant by comparison since neighbouring children, disliking the smell have clogged it. However the wastewater from Hetao Liquor Factory is discharged through this outlet.

The wastewater from Wuyuan is led through sewers into drainage canal number seven. The outlet is a concrete pipe, fifty centimetres wide with its mouth one and a half metre above the canal’s bottom.

4.3 Major industries in Lake Wuliangsuhai’s catchment area

The number of industries affecting Lake Wuliangsuhai is changing over time due to new regulations and the economic conditions. Seven industries are included in this study: two in Hanghou, four in Linhe and one in Wuyuan. The selection of these is explained in chapters 2.2.3 and 4.1.

It should be remembered that the total number of enterprises in Hetao is much larger. The industries in other cities are excluded since they discharge their wastewater into Huang He and among those remaining only the largest are examined.

4.3.1 5303

Factory 5303 is owned by the People’s Liberation Army. It consists of two building complexes on opposite sides of a street in central Linhe. One of the buildings seems to be the administrative centre; the other one is housing the production. 5303 is a leather factory, preparing hides from sheep and possibly also making other products, such as gloves and caps. The yearly production is confidential, but the factory has 850 employees working 180 days a year.

There is a local treatment plant operational since summer 2002. It has five steps: filtration, settling, flotation, biological treatment in five aerated tanks and post-settling. Part of the sludge from the post-settling is used as nutrition in the biological treatment. The daily capacity is five hundred cubic metres and the outgoing water meets the Chinese emission standard. After treatment the wastewater is currently not reused, but led to Linhe’s municipal treatment plant.

4.3.2 Chen Guan

Chen Guan is one of two remaining paper and pulp factories in Lake Wuliangsuhai’s catchment area (the other being Da Ming Chai in Wuyuan). It is situated on the outskirts of Linhe, close to the factory Wei Xing.

Chen Guan has 260 workers and two paper machines producing 3,000 ton a year. The factory runs three shifts, thus working twenty-four hours per day, seven days per week, three hundred days per year. The pulp is made from straw.

There is no operational wastewater treatment, even though some installations suggest that there has been at least settling and possibly also flotation. According to information from the factory the yearly wastewater production is 1,200,000 cubic metres.

4.3.3 Da Ming Chai

The Wuyuan paper factory, Da Ming Chai, is located close to the Wuyuan municipal wastewater outlet and the closed fertiliser factory. It is a very small paper factory, having only one paper machine. The paper is made of straw (or possibly reed), that is transported to the factory using tractors and stored just outside the main building in large piles.

Da Ming Chai has three hundred employees and they seem to be working seven days a week. The yearly production is approximately 750 ton.
There is no wastewater treatment present besides a small settling tank, through which some but
not all wastewater is passed. The wastewater is led through an open ditch to the nearby drainage
canal. The water is high in suspended material, reddish-brown and virtually deficient of oxygen.

4.3.4 Fei Ya

Fei Ya lies on the outskirts of Hanghou. Formerly it was a sugar factory, but has since then
closed, changed management and reopened. Today the factory is producing spices. Fei Ya is a
large factory, with two main buildings, five and six storeys respectively. At least one is
operational. As with most other buildings in the area, Fei Ya is worn down, having broken
windows and flaking paint.

The annual production is reported to be 10,000 ton. Three hundred employees are working three
shifts, twenty-four hours per day, seven days per week, three hundred days per year. In some
step of the production a considerable amount of sulphuric acid (H2SO4) is used, which is
polluting the wastewater (Guo, personal communication).

There is no wastewater treatment at Fei Ya. From the production process the water is collected
in an underground tank. The water is pumped from the tank into a nearby open ditch and flows
via canal number three to Lake Wuliangsuhai. The outlet consists of three different, parallel
pipes. Apparently different pipes are being used depending on the magnitude of flow.

Being contaminated with sulphuric acid, the wastewater’s pH is extremely low, a value of 2.4
was recorded 2 September 2002. This naturally constitutes a local environmental problem of its
own, prohibiting any higher plant or animal life in the drainage ditch. Also noticeable is the
whitish colour of the water, probably due to some unknown chemical precipitation.

4.3.5 Hetao Liquor Factory

Situated in central Hanghou, Hetao Liquor Factory gives the impression of being a major
industry in the area. The complex spans both sides of the road with production facilities on one
side and administration on the other. The buildings are white and in good condition, the yards
well kept and litter-free all adding to the image of a prosperous enterprise. The factory is known
to be the single largest liquor producer in the area, with 2,300 employees.

The yearly production is 30,000 cubic metres of liquor. The factory is operating twenty-four
hours per day, 320 days per year. The factory produces 300,000 cubic metres of wastewater
every year, which is treated at a local treatment facility. This was unfortunately not inspected.
After leaving the factory the wastewater is transported through the city sewers and discharged
through the minor sewage outlet. The quality of the outgoing wastewater is unknown.

4.3.6 Jin Chuan

Jin Chuan is a beer brewery in central Linhe, producing beer for the local and national market.
Notable is their green-coloured “health beer”. The production manager himself promises that he
used to be very thin, but now he is strong and healthy, thanks to the beer. The brewery washes
reused bottles, produces the beer and bottles it, all in the same establishment.

Each year Jin Chuan produces 37,000 cubic metres of beer. In total Jin Chuan has 500
employees, of which 350 are workers. During approximately five months they work ten hours
day, seven days per week while working four to five days per week the remaining months.

There is no wastewater treatment at the brewery. The water is discharged into canal number five
and reaches Linhe’s municipal treatment plant.
4.3.7 Wei Xing

Wei Xing is located close to Chen Guan in Linhe. The factory produces cashmere sweaters and is thought of as successful and profitable. With 1,400 employees it is a major employer.

The yearly production quota is 200,000 sweaters. The factory is operating 180 days per year, part of the time one shift, part of the time two shifts, seven days per week.

The factory produces 350 cubic metres wastewater per day during peak production. Wei Xing has an internal wastewater treatment plant installed in spring 2002 (Liu, personal communication). The treated wastewater is discharged to Linhe’s municipal treatment plant. The wastewater is transported and discharged through underground pipes and both the pipes and the inspected treatment plant are clearly dimensioned for small flows.

When visiting the treatment plant it was obvious that it had not been used for a while. Possibly this was because of the low production. It was also claimed that there are two treatment plants, or two kinds of wastewater treated differently. This could not be confirmed.
5 RESULT: QUANTIFICATION OF POLLUTION DISCHARGES

5.1 Discharges from examined pollution point sources

Table 7 presents the discharges from the examined pollution point sources in Lake Wuliangsuhai’s catchment area. Note that the results apply to the twenty-four hour period when the samplings and measurements were conducted. They are not necessarily representing a normal day but one specific day in autumn 2002. The actual samplings are listed in the appendix “Performed samplings”.

The values are in most cases calculated with equation 1. In a few cases this has not been possible due to lack of data. Different approaches have then been used, further described in chapter 3.3. The uncertainties of the numbers above are estimated in chapter 5.3.

5.1.1 Extrapolated yearly discharges

It is possible to estimate the yearly discharges based on the data above. This extrapolation is done by simply multiplying daily loads with the number of working days per year. The results are presented in table 8.

Table 7: List of wastewater volumes and pollution loads from examined point sources. Every value is only describing the actual sampling period. Thus the numbers presented in the table are describing one specific twenty-four hour period.

<table>
<thead>
<tr>
<th>Source</th>
<th>Volume [m³]</th>
<th>P [kg]</th>
<th>N [kg]</th>
<th>COD [kg]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanghou (main)</td>
<td>2,400</td>
<td>23</td>
<td>110</td>
<td>1,100</td>
<td>City. Estimation based on municipal discharge from Linhe and Wuyuan, see chapter 3.3.1.</td>
</tr>
<tr>
<td>Hanghou (minor)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>City. Wastewater included in Hanghou (main) or Hetao Liquor. Based on one grab-sample and estimated flow. See chapter 3.3.3.</td>
</tr>
<tr>
<td>Linhe</td>
<td>15,000</td>
<td>110</td>
<td>611</td>
<td>4,170</td>
<td>City, including 5303, Chen Guan, Jin Chuan and Wei Xing. Velocity readings are lacking. Volume and loads are calculated using operational time and capacity. See chapter 3.3.1.</td>
</tr>
<tr>
<td>Wuyuan</td>
<td>2,210</td>
<td>17.3</td>
<td>96.6</td>
<td>827</td>
<td>City.</td>
</tr>
<tr>
<td>5303</td>
<td>620</td>
<td>1.39</td>
<td>2.01</td>
<td>96.0</td>
<td>Hides and leather. Has a local treatment plant.</td>
</tr>
<tr>
<td>Chen Guan</td>
<td>4,870</td>
<td>16.2</td>
<td>205</td>
<td>24,600</td>
<td>Paper and pulp.</td>
</tr>
<tr>
<td>Da Ming Chai</td>
<td>5,970</td>
<td>7.39</td>
<td>81.0</td>
<td>8,670</td>
<td>Paper and pulp.</td>
</tr>
<tr>
<td>Fei Ya</td>
<td>1,490</td>
<td>13.2</td>
<td>266</td>
<td>2,570</td>
<td>Spice.</td>
</tr>
<tr>
<td>Hetao Liquor</td>
<td>1,000</td>
<td>6</td>
<td>40</td>
<td>500</td>
<td>Liquor. Has a local treatment plant. Never sampled. Volume based on information from the factory and grab-sample of Hanghou minor, see chapter 3.3.3.</td>
</tr>
<tr>
<td>Jin Chuan</td>
<td>1,460</td>
<td>3.6</td>
<td>9.5</td>
<td>600</td>
<td>Beer brewery. Pollution loads are based on only two samples.</td>
</tr>
<tr>
<td>Wei Xing</td>
<td>300</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>Cashmere. Has a local treatment plant. Based on one grab-sample and estimated flow. See chapter 3.3.3.</td>
</tr>
</tbody>
</table>
Table 8: Yearly discharges from point sources in Lake Wuliangsuhai’s catchment area. The values are calculated by multiplying daily discharges with the number of working days per year, according to information from the different enterprises

<table>
<thead>
<tr>
<th>Source</th>
<th>Volume [x1,000 m³]</th>
<th>P [ton]</th>
<th>N [ton]</th>
<th>COD [ton]</th>
<th>Number of working days per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanghou</td>
<td>880</td>
<td>8.4</td>
<td>40</td>
<td>400</td>
<td>365</td>
</tr>
<tr>
<td>Linhe</td>
<td>2,830</td>
<td>32</td>
<td>140</td>
<td>1,500</td>
<td>365</td>
</tr>
<tr>
<td>Wuyuan</td>
<td>810</td>
<td>6.3</td>
<td>35</td>
<td>300</td>
<td>365</td>
</tr>
<tr>
<td><strong>Total cities</strong></td>
<td><strong>4,520</strong></td>
<td><strong>46.7</strong></td>
<td><strong>215</strong></td>
<td><strong>2,200</strong></td>
<td></td>
</tr>
<tr>
<td>5303</td>
<td>110</td>
<td>0.3</td>
<td>0.4</td>
<td>17</td>
<td>180</td>
</tr>
<tr>
<td>Chen Guan</td>
<td>1,460</td>
<td>4.9</td>
<td>62</td>
<td>7,400</td>
<td>300</td>
</tr>
<tr>
<td>Da Ming Chai</td>
<td>1,790</td>
<td>2.2</td>
<td>24</td>
<td>2,600</td>
<td>300</td>
</tr>
<tr>
<td>Fei Ya</td>
<td>450</td>
<td>4.0</td>
<td>80</td>
<td>770</td>
<td>300</td>
</tr>
<tr>
<td>Hetao Liquor</td>
<td>300</td>
<td>2.0</td>
<td>13</td>
<td>160</td>
<td>320</td>
</tr>
<tr>
<td>Jin Chuan</td>
<td>370</td>
<td>0.9</td>
<td>2.4</td>
<td>150</td>
<td>250</td>
</tr>
<tr>
<td>Wei Xing</td>
<td>50</td>
<td>0.1</td>
<td>0.4</td>
<td>1.9</td>
<td>180</td>
</tr>
<tr>
<td><strong>Total industries</strong></td>
<td><strong>4,530</strong></td>
<td><strong>14.4</strong></td>
<td><strong>182</strong></td>
<td><strong>11,100</strong></td>
<td></td>
</tr>
</tbody>
</table>

5.2 Discrimination of pollution load on Lake Wuliangsuhai

In order to estimate the significance of the pollution from cities and industries it should be compared to the total pollution load on Lake Wuliangsuhai. It must be stressed that the results in table 8 are the pollution discharged from cities and industries. These represent the maximum contribution to the pollution load on Lake Wuliangsuhai. The true numbers depend on how much of the pollutants that actually reaches the lake. Some is most certainly lost during the transport, due to settling, uptake or decomposing.

In figure 11, the yearly pollution loads on Lake Wuliangsuhai are discriminated into municipal, industrial and agricultural sources. The charts are based on the numbers presented in table 9. Note that the figures for total load are valid for 2001.

![Figure 11: Yearly pollution load on Lake Wuliangsuhai, discriminated into municipal, industrial and agricultural sources, with respect to phosphorus, nitrogen and COD. Note that the charts show maximum municipal and industrial contribution. The charts are based on municipal and industrial discharges, not considering any losses during the transport to the lake.](image-url)
Table 9: The numbers on which figure 11 are based. For cities and industries the discharged volumes and loads are presented. Total represents the total load on Lake Wuliangsuhai. Diffuse sources are calculated as the difference between total load and contribution from point sources

<table>
<thead>
<tr>
<th>Category</th>
<th>Volume [x1,000 m³]</th>
<th>P [ton]</th>
<th>N [ton]</th>
<th>COD [ton]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cities</td>
<td>4,500</td>
<td>46.7</td>
<td>215</td>
<td>2,200</td>
</tr>
<tr>
<td>Industries</td>
<td>4,500</td>
<td>14.4</td>
<td>182.2</td>
<td>11,100</td>
</tr>
<tr>
<td>Diffuse sources</td>
<td>455,000</td>
<td>140</td>
<td>3,000</td>
<td>4,800</td>
</tr>
<tr>
<td>Total</td>
<td>464,000</td>
<td>200</td>
<td>3,400</td>
<td>18,100</td>
</tr>
</tbody>
</table>

5.3 Estimation of uncertainties

Due to few samples and varying site conditions it is not possible to accurately quantify the different identified random errors. Nevertheless it is necessary to know the uncertainties to be able to evaluate the results given above. In order to get a rough estimate of the uncertainties at hand the random errors are listed in table 10, together with their order of magnitude. Only the most important error sources are included. Different special cases, presented in chapter 3.3, are affected by additional specific uncertainties. As an example the calculation of the largest estimated total error for the sampling of an open channel is shown below in detail.

\[ e_i = \sqrt{e_s^2 + e_t^2 + e_e^2 + e_a^2} = \sqrt{0.30^2 + 0.10^2 + 0.05^2 + 0.05^2} \approx 41\% \]

Where
- \( e_s \) = sampling site (10 – 30 %)
- \( e_t \) = intervals (5 – 10 %)
- \( e_e \) = equipment (<5 %)
- \( e_a \) = analyses (<5 %)

The uncertainties for all sources in the study can be calculated in the same way. Since these calculations are only estimates it is only useful to present average errors, valid for all results:

- The daily loads in table 7 have an estimated average uncertainty of 25 %.
- The yearly loads in table 8 have an estimated average uncertainty of 50 %.

Note that these uncertainties apply to the pollutants. For wastewater volumes the uncertainties are approximately ten percentage units lower, because of more frequent velocity recordings and the absence of chemical analyses.

Table 10: List of random errors and their estimated magnitudes

<table>
<thead>
<tr>
<th>Source</th>
<th>Error [%]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross section area of sampling site</td>
<td>10 – 30</td>
<td>Open channels.</td>
</tr>
<tr>
<td></td>
<td>5 – 10</td>
<td>Pipes.</td>
</tr>
<tr>
<td>Sampling and recording interval</td>
<td>5 – 10</td>
<td>Both samplings and flow recordings successful.</td>
</tr>
<tr>
<td></td>
<td>30 – 50</td>
<td>Only flow recordings.</td>
</tr>
<tr>
<td></td>
<td>&gt; 50</td>
<td>Grab-sample and estimation of flow.</td>
</tr>
<tr>
<td>Inaccuracies in velocity and depth readings</td>
<td>&lt; 5</td>
<td></td>
</tr>
<tr>
<td>Chemical analyses</td>
<td>&lt; 5</td>
<td>Only affecting pollution loads</td>
</tr>
<tr>
<td>How representative is the sampling day?</td>
<td>10 – 30</td>
<td>Cities.</td>
</tr>
<tr>
<td></td>
<td>30 – 50</td>
<td>Industries.</td>
</tr>
</tbody>
</table>
6 RESULT: GRAB VS FLOW-PROPORTIONAL SAMPLING

6.1 Grab-sampling characteristics

Grab-sampling is most likely the simplest sampling methodology available. Taken at one time, the grab-sample can only give information about the conditions at that precise moment. For channels with fluctuating flow and/or concentrations the snapshot given by a grab-sample may be very misleading. The advantage is naturally that it is very easy to conduct and require a minimum of equipment and preparations.

The weakness of grab-sampling is clearly illustrated in figure 12, exemplifying municipal and industrial point sources in Lake Wuliangshai’s catchment. Both magnitude of flow and concentration varies over time resulting in very different loads depending on time of grab-sample.

6.2 Variation in pollution loads for sampled point sources

Depending on the sampling time the concentration measured may vary significantly. For the example shown below, Fei Ya, the variation in COD-concentration is almost 60 % from highest to lowest concentration. The concentration is partly, but not only, depending on the flow. This means that the instantaneous pollution loads calculated for each sampling will also vary.

To illustrate the risks of grab-sampling two different sampling times are chosen for Fei Ya, namely the most unfortunate ones, giving maximum and minimum loads. The largest load is 285 % larger than the smallest one. These loads are based on concentration in that particular grab-sample and the corresponding flow recording. The loads are shown in figure 13, together with the wastewater volumes and the result based on flow-proportional sampling. The load for this site could have been anything between the two shown extreme values depending on sampling time if grab-sampling was used.

Figure 12: Examples of variations in flow and concentration. To the left is COD-concentrations for Fei Ya 24/25 July 2002. To the right is P-concentrations for Da Ming Chai (Wuyuan paper factory) 30/31 August 2002.
The reason for choosing Fei Ya’s discharge of COD as an example is that it has the median variation of the sampled point sources. Half of the examined sites are likely to have an even larger span between maximum and minimum loads than the one illustrated above. The spreads are expressed as coefficient of variation and are illustrated in figure 14. The larger the CV, the larger the spread and the more inappropriate grab-sampling will be.

Assuming flow monitoring equipment is used and the total flow for the examined day is calculated correctly the inaccuracy decreases, but not by much. Average CV is 17 % instead of 32 %. Da Ming Chai’s discharge of phosphorus shown in figure 12 has the median CV if daily flow is used. Difference between maximum and minimum loads is still 250 %.

**6.2.1 Yearly discharge of wastewater**

Using the results from table 8 it is possible to evaluate the Chinese pollution data given in table 3. For the Chinese data wastewater volumes are based on discharge licenses rather than actual samplings (Röttorp, personal communication). COD is based on grab-sampling. In table 11, these values are compared with the results from chapter 5.1.1. It should be pointed out that Chinese data is from 2000 while flow-proportional data is from 2002.

![Figure 13: COD-load and wastewater volume from Fei Ya 24/25 July 2002 depending on different sampling times, compared with flow-proportional sampling.](image13.png)

![Figure 14: Coefficients of variation of load for examined point sources based on grab-sample concentrations and instantaneous flow. The coefficients are calculated with equation 6.](image14.png)
Table 11: Comparison of yearly wastewater and COD discharges. Flow-proportional values are the result from this study, as presented in chapter 5.1.1. Grab values are Chinese data from 2000 as presented in chapter 2.2.3

<table>
<thead>
<tr>
<th>Source</th>
<th>Volume [x1,000 m³/year]</th>
<th>COD [ton/year]</th>
<th>Flow-proportional</th>
<th>License</th>
<th>Difference</th>
<th>COD</th>
<th>Flow-proportional</th>
<th>Grab</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanghou</td>
<td>880</td>
<td>800</td>
<td>+ 10 %</td>
<td>Unknown</td>
<td>Unknown</td>
<td>–</td>
<td>Unknown</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Linhe (total)</td>
<td>4,520</td>
<td>4,380</td>
<td>+ 3 %</td>
<td>Unknown</td>
<td>Unknown</td>
<td>–</td>
<td>Unknown</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Linhe (city)</td>
<td>2,830</td>
<td>4,380</td>
<td>- 35 %</td>
<td>Unknown</td>
<td>Unknown</td>
<td>–</td>
<td>Unknown</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Wuyuan</td>
<td>810</td>
<td>630</td>
<td>+ 29 %</td>
<td>300</td>
<td>Unknown</td>
<td>–</td>
<td>Unknown</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5303</td>
<td>110</td>
<td>15</td>
<td>+ 633 %</td>
<td>17</td>
<td>7</td>
<td>+ 143 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chen Guan</td>
<td>1,460</td>
<td>1,000</td>
<td>+ 46 %</td>
<td>7,400</td>
<td>560</td>
<td>+ 1,221 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Da Ming Chai</td>
<td>1,790</td>
<td>830</td>
<td>+ 116 %</td>
<td>2,600</td>
<td>1936</td>
<td>+ 34 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fei Ya</td>
<td>450</td>
<td>Unknown</td>
<td>–</td>
<td>770</td>
<td>Unknown</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hetao Liquor</td>
<td>Unknown</td>
<td>400</td>
<td>–</td>
<td>Unknown</td>
<td>801</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jin Chuan</td>
<td>300</td>
<td>210</td>
<td>+ 43 %</td>
<td>150</td>
<td>227</td>
<td>- 34 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wei Xing</td>
<td>Unknown</td>
<td>10</td>
<td>–</td>
<td>Unknown</td>
<td>8</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The volumes given for Linhe are both total volume, including all industries, and calculated discharge excluding industries. It is worth pointing out, that differences for volumes and loads are not equal for any of the point sources. This means that not only the wastewater volume differ depending on choice of method, but also the concentration used for calculating the load.

### 6.3 Handling the equipment

Only one real problem concerning the equipment was encountered. It was that two of the flow meters’ batteries were depleted. Unlike the sampler’s these batteries are not rechargeable, making the accessibility of replacement batteries crucial. The batteries used are two 6 V dc alkaline batteries. Also the memory batteries in one of the samplers ran low during the fieldwork. In this case two 1.5 V dc alkaline “C” batteries are used, which are sold more or less everywhere in the project area. Apart from this straightforward problem the flow meter is quickly learnt, reliable and easy to use.

The automatic sampler is very easy to use and booth pieces acted reliable throughout the field study. The only remark is that the battery only lasts two sampling cycles before it needs to be recharged for no less than 22 to 24 hours. Due to this only two samplings per working week can be conducted, unless of course spare batteries are available or one upgrades to Nickel-Cadmium batteries which are more rapidly recharged. This was however not possible during this project.

Another experience is that the probe containing the level/velocity sensor is very light and difficult to mount securely in the channel of interest. When measuring channels without flat bottoms or very turbid water there was an uncertainty if the probe was placed on the bottom or rather was elevated. Comparing recorded depth with the depth measured by a ruler could check this. Unless a portable computer can be brought to the sampling site this must however be done afterwards.
7 DISCUSSION

7.1 Comments on the general presumptions for the study

The largest underlying difficulty of the study is without doubt the language barrier. Since all work has been conducted in co-operation with local staff this has affected every step of the process, from the updating of the list of pollution sources to choice of sampling sites. For example Chinese numerals differ from English, making the translations of numbers remarkably difficult.

The Lake Restoration Project states that point sources should be the main priority of the component to which this thesis work belongs. The examined industries are definitely point sources, having one well-defined wastewater outlet. Considering the cities’ incomplete sewer systems it can be argued that the cities are in fact diffuse sources. When focusing on Lake Wuliangsuhai it is however only the sewage transported through the discharge canals that is of importance. It is easy to pinpoint the location where each sewage outlet joins with the canal and thus cities can be treated as point sources, even though they locally may act as diffuse sources. This point of view can also be applied to the irrigated fields covering the catchment area, in spite of agriculture usually being treated as a diffuse pollution source. With accurate maps over the irrigation system an appropriate number of sub-basins can be defined, each one drained by a single channel. This would give a set of agricultural pollution point sources which would make an interesting extension of the present study.

7.2 Results

This study shows that it is possible to describe the pollution point sources in Lake Wuliangsuhai’s catchment area with semi-flow-proportional sampling. Most importantly, the local EPB-staff have sufficient skills and equipment to conduct this kind of study, and the enthusiasm to do so, at least within the Lake Restoration Project. Furthermore, all point sources were visited at least once. These visits proved that the sites are accessible and that the managers at the industries are co-operative when answering questions and when allowing the samplings. In addition to that the sampling and monitoring equipment have been reliable.

The results presented in chapter 5.1, primarily in table 7, are reasonable and should be regarded as sufficiently accurate. They are expected in the sense that the cities discharge more nutrients, especially phosphorus, than the industries and that the paper mills produce large quantities of COD. It can also be seen that the pollution sources with local treatment have cleaner discharges.

The acquired data will be useful when describing the present pollution situation and when developing the action and management plan for Lake Wuliangsuhai. A few ideas about future actions are outlined in chapter 7.6.

Some of the samplings were not conducted according to preferred methodology. This is unfortunate, but not unexpected since the study in many aspects is a pilot study. Even when semi-flow-proportional sampling was not possible, pollution discharges could still be measured or estimated with reasonable accuracy. The uncertainties are further commented in chapter 7.4 below.
7.2.1 Individual pollution point sources
From the results it is obvious that the treatment plant in Linhe is correctly located, since Linhe, and its industries, are the largest polluters in the study. Also the plan to construct treatment plants in Hanghou and Wuyuan is supported by this study. Unfortunately the nutrient reduction is probably inadequate in these treatment plants.

When studying the individual industries, it is noticeable that Chen Guan, Da Ming Chai and Fei Ya are responsible for the greater part of the industrial pollution. Together they produce 77 % of the phosphorus, 91 % of the nitrogen and 97 % of the COD. None of these enterprises have local wastewater treatment.

7.2.2 List of pollution sources
The heavy dominance of three industrial sources out of seven raises the question of which industries to keep monitoring if the project continues. This question can not be fully answered without knowledge of the action plan. At the same time there are a few very small sources; Wei Xing is probably an insignificant source, not only by comparison, but also in absolute numbers.

If more detailed information about the pollution discharged from the households is required, it might be meaningful to increase the list of industrial sources to examine individually. For example in Linhe there is a flour mill and ErLang Shan Goat and Woolfur Group Factory not included in the study. During the travels in the project area at least three brick factories and two unidentified tall chimneys were spotted between Linhe and Wuyuan. In the cases of the mill and the brick factories, they produce virtually no wastewater, but there might be other industries worth studying.

Several factories have been closed recently, which may have changed the pollution situation. Some closures are only temporary or partial. For example the closed fertiliser factory in Wuyuan had smoke coming out of one chimney when Wuyuan was visited and it will be restarted in the near future.

7.3 Pollution load on Lake Wuliangsuhai
In chapter 5.2 an attempt is made to discriminate the load on Lake Wuliangsuhai into municipal, industrial and agricultural wastewater. Regardless of the uncertainties of the total load (and thus the agriculture) it is obvious that agriculture is a large pollution source, if not the largest. This contradicts the Chinese opinion, as expressed by Liu Wei (personal communication). According to Chinese grab-sampled-based estimations, agriculture constitutes only about 20 % of the phosphorus and 60 – 85 % of the nitrogen.

This report does not, however, give any data on municipal and industrial pollution actually reaching Lake Wuliangsuhai. The results presented in chapter five only describe the sources’ outlets. It is still unknown how much of the pollution from the point sources that actually reaches Lake Wuliangsuhai. Such calculations need a quantified description of the transport process as outlined in 7.5.3. Information about discharge from point sources can however be used to tell their maximum contribution, assuming that 100 % of discharged wastewater and pollutants reach the lake.

It can also be mentioned that the groundwater situation in the area is unknown, but according to Li (personal communication) there might be groundwater inflow to Lake Wuliangsuhai during the winter. If that is the case, groundwater can be transporting nitrogen into the lake part of the year. The magnitude of this possible inflow is of course unknown.
7.4 Uncertainties

It is important to remember that all presented results are actually intervals. Unfortunately it has not been possible to calculate the magnitude of these intervals since the uncertainties themselves are estimates. That said, there are three different parts of the results where the uncertainties deserve further comments:

- The actual samplings, presented in table 7. These results are fairly accurate and give a detailed snapshot of the situation at the time of the fieldwork.
- Calculation of yearly values, presented in table 8. When daily values are extrapolated the question of how representative the sampled day is must be answered. This is difficult, especially when based on a single sample.
- Discrimination of load on the lake, illustrated in figure 11. The suggested approach uses the total load to calculate the contribution from diffuse sources. This total load is uncertain and furthermore, the transport processes, governing how much of the municipal and industrial pollution reaching the lake, are not considered.

The uncertainties outlined above are listed in reversed order of magnitude with the most accurate results first.

7.4.1 Individual point sources

The largest error of any individual sampling is introduced when selecting the sampling site. Presuming that a correct site is chosen, meaning that the total flow of interest, and only the flow of interest, is monitored, it is still difficult to determine the cross section area. One way to get more accurate cross section area measurements would be to simply drain the studied channels and make correct measurements, at the same time quantifying the uncertainty of area estimations. Since all channels at hand were of importance to the examined enterprises this was not possible.

With the used method for calculating flow-proportional sampling weights, described by equation 1, it is important that the clock in the sampler and the clock in the flow meter are synchronised. If not, a specific sample may be weighted with a flow recording from a different moment, which may vary significantly. Without the cable connecting the sampler to the flow meter the clocks have to be synchronised manually.

Another question is which sampling and recording frequency that is necessary to correctly describe the flow. It would have been valuable to monitor at least one city and one industry with a time resolution of for example one minute to quantify the this uncertainty.

Since the three cities are the largest polluters and were difficult to sample, it is necessary to comment on their calculations. Wuyuan’s values are the most reliable, being the only one determined through sampling and flow monitoring. The fact that the Linhe’s per capita discharge is of the same order of magnitude as Wuyuan’s is thus an indication that the calculated contribution from Linhe is reasonable. As expected, the more industrialised Linhe have higher per capita values than Wuyuan. In fact Linhe’s values may be even higher. In the calculations outlined in chapter 3.3.2 all nutrients from industries were subtracted before calculating the discharge from Linhe. If a significant amount of the industries’ pollutants settles before reaching the treatment plant the subtraction changes, yielding a larger city discharge.

The significant decrease of COD between Chen Guan and Linhe’s treatment plant indicates that COD settles fast in the slow running channels. There is however another possibility. The sampling at Chen Guan was made two months earlier than the sampling at the treatment plant and even though it is not likely, Chen Guan may have been closed just before the treatment plant was sampled.
7.4.2 Extrapolation to yearly values
The fundamental question when using the sampled twenty-four hour periods for each point source to describe the yearly discharges is how representative the examined day is? Even though the interviews included that question no quantified answers were given. Lacking complementary samplings an overall uncertainty of 50% is estimated. Probably effluent from the cities tend to vary less than from industries, due to a large number of small sources and the levelling of concentrations and flows in the sewer systems. If more samples are taken it might be possible to detect variations due to season and activity. This would answer the question more confidently. The number of days the pollution source actually operates must also be considered. This is, however, a more straightforward question, easily answered by all visited industries.

7.4.3 Total load on Lake Wuliangsuhai
When discriminating the total load on Lake Wuliangsuhai into different classes of pollution sources, the result is heavily relying on the calculated total yearly pollution load. Unfortunately that number is questionable at best.

Because of insufficient data it has not been possible to compare the total load for 2001 with any previous years. This would have been most valuable since 2001 is only described by twelve monthly grab-samples. Remarkably October constitutes 63% of the total inflow of phosphorus. Probably this is a result of relying on grab-sampling, but lacking better data it is nevertheless used. It must be repeated that the charts presented in chapter 5.2 are highly uncertain because of this. Before using the charts as support for an action plan, they must be recalculated using more reliable data for total inflow.

The changed pollution situation mentioned in chapter 7.2.2 may cause older load data to be outdated. As a consequence the load on Lake Wuliangsuhai, based on old data, may be an overstatement compared to the real situation. The maximum municipal and industrial part of the total pollution, presented in chapter 5.2, is in that case larger in reality even though the total load is smaller in absolute numbers.

7.5 Suggestions for additional studies
This report gives an overview of the most important pollution point sources in Lake Wuliangsuhai’s catchment area. Thus the present pollution situation is outlined. There are still numerous possibilities to increase the accuracy and level of details of the study. Assuming that the focus is kept on the pollution sources three main topics are identified.

- Increase the accuracy of the presented discharges from municipal and industrial pollution point sources.
- Identify and describe diffuse sources influencing the status of Lake Wuliangsuhai.
- Determine each source’s load on Lake Wuliangsuhai by describing the transport processes in the drainage canals.

7.5.1 Construction of permanent monitoring and sampling stations
The construction of permanent monitoring and sampling stations at the major sources would definitely facilitate any future work. Firstly the accuracy of the recordings would benefit tremendously from well-defined cross section areas. Secondly it should be possible to fulfil most of the criteria of accessibility et cetera mentioned in chapter 3.5, saving much time. Also the repeatability of the samplings would increase.

It is possible to reduce the need of the flow meter by constructing a determining section at the monitoring station. Using such only depth needs to be measured. Depth is easy to measure with a wide variety of reliable techniques available.

The stations could also include a lockable hut for safe placing of the equipment.
7.5.2 Description of diffuse sources in Lake Wuliangsuhai’s catchment area

Everything indicates that diffuse sources, most likely dominated by agriculture, are contributing with the greater part of the pollution to the lake. The most straightforward approach to estimate the contribution from diffuse pollution sources is to simply subtract the cities’ and industries’ shares from the total. Probably this is what will be done in the Lake Restoration Project and it is also tried in chapter 5.2. Considering the potential errors and uncertainties a more ambitious approach should preferably be used.

Even a rough attempt to quantify pollution discharge from diffuse sources would increase the knowledge about the pollution situation. Comparing such an estimation with the difference between total load on the lake and discharge from point sources will give a hint about the correctness of the results.

The simplest method for estimating diffuse pollution is probably to estimate the discharge from a unit area in the catchment area and extrapolate to the entire area. A more correct method would be to divide the catchment area into a number of sub-basins. In this way agriculture would be described as a set of point sources.

Trying to describe the entire catchment area with a distributed physical model is not feasible because of all data needed.

7.5.3 Study of the transport processes in the drainage canals

For a better understanding of how much pollution that actually reaches the lake the transport processes must be described. To some extent the pollution will settle and decompose on its way from source to recipient. The loss rate is probably depending on a number of variables, such as if the pollutants are dissolved or sorbed, oxygen level and temperature in the water, flow velocity, turbulence et cetera. To correctly describe the physical, chemical and biological processes acting on the pollutants is a comprehensive work. Two different simplified methods are sketched below.

The first method is to state that a constant percentage of sorbed pollutants is lost through settling. This requires more knowledge about how much of the pollutants from the different sources that is sorbed. Required analyses are fairly simple and the settling rate can be estimated through laboratory tests. Decomposing rates and uptake rates can be estimated from literature, as can settling rates if need be.

Another method would be to disregard the actual processes and try to describe the characteristics of the drainage canals empirically. By monitoring each tributary to the examined canal and measure the concentrations and flow at a number of sites it could be possible to determine the loss rate of the pollutants at hand.

These methods can of course be combined for a more reliable result.

7.5.4 Using a modelling tool to evaluate different pollution scenarios

As soon as the description of the pollution situation is validated it can be regarded as a modelling tool. This tool should include a complete description of significant pollution sources and the transport processes. Depending on how detailed the information is the tool can be implemented as a spreadsheet or as a dynamic GIS-system. This tool can be used for studying different pollution scenarios. The two first scenarios to study would be

- the recent past, trying to describe the pollution situation that has been affecting Lake Wuliangsuhai up until today. By doing this the amount of nutrients in the lake’s sediments can at least be more accurately estimated.
- the near future when all three cities have operational treatment plants.
7.6 Future pollution preventing actions

The municipal pollution is likely to increase when the sewer systems are expanded. Today a considerable amount of wastewater is disposed locally, especially at the outskirts of the cities. As Bayannaoere modernises new parts of the cities will be connected to the sewer systems. Miao (personal communication) estimates that approximately one third of Hetao’s municipal wastewater is not discharged through the sewer system. Some of this unaccounted wastewater is thrown directly into the drainage canals but a few tenths may remain to be included.

As long as the right encouragement is provided there is operational wastewater technology available for the industries. The visited treatment plant at 5303 was in very good working order, assured by a competent production engineer. A potential problem is instead the Chinese focus on COD as the pollutant of interest. That is the only pollutant, of the ones considered in this report, having any limits in Chinese emission standards. Unfortunately this results in costly installations on treatment plants not dealing with the nutrients, which are the most important pollutants in the case of Lake Wuliangsuhai. With no limits for phosphorus or nitrogen and only natural aeration the large settling tanks in Linhe are unlikely to significantly reduce nutrient content in the water.

Since the treatment plant is brand new it will most likely be operational for many years to come. Hopefully it will be possible to introduce the concept of nutrient treatment when starting to construct the plants in Hanghou and Wuyuan.

The remarkable COD decrease from Chen Guan’s outlet to Linhe’s treatment plant suggests that settling can be a very efficient treatment method for at least paper factory-produced COD. If this is confirmed to apply to COD in general, construction of settling basins before the inlet to Lake Wuliangsuhai could be a way to treat the ingoing wastewater from COD.

A conspicuous characteristic of the treatment plant in Linhe is its huge surface. In a climate with a yearly net evapotranspiration of some two metres, thousands of cubic metres will be lost through evaporation. As long as the outtake from Huang He is not more restricted this does not need to be a problem.

Severe water scarcity is one of northern China’s most serious problems even if Hetao is not affected. Undoubtedly the outtake from Huang He will be restricted in the near future, forcing Bayannaore’s enterprises and farmers to water-conserving actions. The water lost through evaporation from the treatment plant may then be considered a problem. If new regulations are issued new irrigation policies may have to be introduced. Then there is a good opportunity to revise fertilising practices as well, hopefully enabling a more efficient application resulting in decreased load on Lake Wuliangsuhai. Locally around Linhe the treated wastewater could be used for irrigation, assuming satisfying quality regarding heavy metals et cetera. In that case more water can be conserved and the probably high loads of nutrients in the water will be used as fertiliser. Of course this will decrease the volumes flowing into the lake, but this change is marginal compared to the consequences of altered irrigation practices.

The pollutants are, in other words, governed and affected by a number of interacting processes on their way from source to the lake. The challenge of reaching an optimised pollution load on the Lake Wuliangsuhai will require a wide range of knowledge and concerns. The Chinese counterparts have, during this restoration project, proven that they are open-minded to new influences as well as ready to try different technical solutions. This will be most useful in the upcoming work.
The list of sources has been updated during the initial part of the fieldwork and the final version, together with calculated pollution discharges, is presented in table 12.

<table>
<thead>
<tr>
<th>Source</th>
<th>Volume [m³]</th>
<th>P [kg]</th>
<th>N [kg]</th>
<th>COD [kg]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hangzhou</td>
<td>2,400</td>
<td>23</td>
<td>110</td>
<td>1,100</td>
<td>City</td>
</tr>
<tr>
<td>Linhe</td>
<td>7,750</td>
<td>89</td>
<td>390</td>
<td>4,200</td>
<td>City</td>
</tr>
<tr>
<td>Wuyuan</td>
<td>2,210</td>
<td>17.3</td>
<td>96.6</td>
<td>827</td>
<td>City</td>
</tr>
<tr>
<td>5303</td>
<td>620</td>
<td>1.39</td>
<td>2.01</td>
<td>96.0</td>
<td>Hides and leather. Has a local treatment plant</td>
</tr>
<tr>
<td>Chen Guan</td>
<td>4,870</td>
<td>16.2</td>
<td>205</td>
<td>24,600</td>
<td>Paper and pulp</td>
</tr>
<tr>
<td>Da Ming Chai</td>
<td>5,970</td>
<td>7.39</td>
<td>81.0</td>
<td>8,670</td>
<td>Paper and pulp</td>
</tr>
<tr>
<td>Fei Ya</td>
<td>1,490</td>
<td>13.2</td>
<td>266</td>
<td>2,570</td>
<td>Spice</td>
</tr>
<tr>
<td>Hetao Liquor</td>
<td>1,000</td>
<td>6</td>
<td>40</td>
<td>500</td>
<td>Liquor. Has a local treatment plant.</td>
</tr>
<tr>
<td>Jin Chuan</td>
<td>1,460</td>
<td>3.6</td>
<td>9.5</td>
<td>600</td>
<td>Beer brewery</td>
</tr>
<tr>
<td>Wei Xing</td>
<td>300</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>Cashmere. Has a local treatment plant</td>
</tr>
</tbody>
</table>

Visits and interviews have made it clear that there is an awareness of local environmental problems as well as competence and technology available for at least small-scale wastewater treatment.

The cities discharge approximately three times as much phosphorus as the industries do. Regarding nitrogen, cities and industries are roughly equal in discharge and for COD the paper factories are by far the dominating sources. There are three major industrial pollution sources, namely Da Ming Chai, Chen Guan and Fei Ya, who are responsible for 77% of P, 91% of N and 97% of COD of the total industrial discharges.

It is clear that cities and industries are minor pollution sources compared to diffuse sources, with the possible exception for COD. The most significant nutrient point source is phosphorus from the cities, maximum approximately one fourth of the total inflow of Lake Wuliangsuhai.

Municipal and industrial wastewater has of course much higher pollution concentrations than agricultural. On the other hand it constitutes only 2% of the total volume flowing into Lake Wuliangsuhai.

The largest uncertainties of individual samplings are badly defined cross section areas at the sampling sites and the fact that some sources were not sampled according to methodology.

Large variability in flow and concentration makes grab-sampling unsuitable for this kind of study. When studying the most representative sampling the difference between smallest and largest loads is 285%. Because of this large interval flow-proportional sampling is strongly recommended. During the fieldwork the equipment has proved to be reliable. The local staff is well trained in using it.
APPENDIX: PERFORMED SAMPLINGS

To facilitate interpretation of collected data it is important to know the conditions at the sampling occasion. All samplings were made from 30 August to 9 October 2002, except for two samplings in late July 2002 made by the BaMeng EPB.

In total twelve samplings were made, of which ten were flow-proportional and two complementary grab-samples. Sampling methodology and a general description how the sampling sites were selected is described in chapters 3.2 and 3.5.

Hanghou

- 2002-09-05: A complete sampling was conducted close to drainage canal number three, approximately two kilometres downstream the pump outlet. The second day, when the equipment was to be collected, the water was all white as if polluted by some chemical precipitation. The analyses showed surprisingly low concentrations of COD.
- 2002-09-05: A grab-sample was taken from the minor outlet to compare its chemical quality to the first samples
- 2002-10-09: In order to get more reliable COD-concentrations a second sampling cycle was initiated. At this time the water level was higher, due to a rise in water level in the downstream canal damming the sewage channel. Unfortunately, due to a dented connector pin in the velocity sensor’s cable no velocity readings were recorded.

When leaving the sampling site it was noticed that a second ditch, not coming from the same pump outlet, unfortunately joins the sampled channel. This means that this tributary dilutes the examined wastewater from Hanghou, thus ruining the samples. If this additional water also emanates from the city or from the surrounding fields is not known, but the latter is more likely.

Linhe

- 2002-09-23: The sampling equipment was rigged at the inlet of the treatment plant in order to measure the volume and quality of the wastewater leaving Linhe. This would describe the pollution situation prior to the construction of the treatment plant. The outlet could not be properly sampled since no water was discharged from the plant. A grab-sample was collected from the last basin, close to the outlet, to get an estimation of the quality of the outgoing water.

The flow meter did not record any velocity, only changes in level because of a dented pin in the connector cable between the flow meter and the probe.

Wuyuan

- 2002-09-10: Canal number three was dry due to no drainage of irrigation water at the time. Because of that the sampling had to be conducted inside the sewer outlet pipe. The large flow and high velocity made the instalment complicated. After constructing a rude shovel-shaped tool, the probe and the sampling tube could be firmly placed about one metre inside the pipe. Unfortunately only five of twelve samples were successfully collected. The sewer pump was turned off during night (Miao, personal communication), which is also confirmed by the flow data.

5303

- 2002-09-12: The only easily accessible outlet from 5303’s treatment plant was a square-shaped hole in the last treatment tank. A considerable part of the water did not pass over the
flow meter probe but on its side, since the probe had to be placed a few centimetres from the hole. In spite of these unfavourable conditions the samplings and flow recordings were successful. The recorded flow was approximately twice that of what the local engineer thought the flow should have been. This was the only indoor-sampling conducted.

Chen Guan

- **2002-07-25**: This sampling was conducted solely by the BaMeng EPB. There are no problems reported and the flow readings as well as the sample analyses are reasonable.

Da Ming Chai

- **2002-08-30**: The sampling site was a straight, slowly running part of the ditch with laminar flow. Besides a few garbled flow readings (negative values) the sampling and measurement were successful.

Fei Ya

- **2002-07-24**: The BaMeng EPB conducted the first sampling and flow reading by themselves. The details are not known. Apparently, the flow velocity probe was placed in the wrong direction, according to Ma (personal communication) it was placed upside down. Hence, all velocity readings were negative. This was later corrected for.
- **2002-09-02**: The drainage ditch runs two metres in front of the wastewater outlet, making flow measurements difficult since the water is not running in a defined channel, but through eroded streams. By making a short, rectangular channel using available bricks and mud a sampling site was prepared. This did not work satisfyingly. Probably due to turbulent flow the readings were alternating between negative and positive values.

Hetao Liquor

- **2002-10-09**: Hetao Liquor Factory was never sampled, because of a misunderstanding about the factory’s operating hours. When the factory was visited there was no one available to show us around, because of another, more prominent, visit at the same time.

Jin Chuan

- **2002-09-23**: The wastewater is collected in an underground tank and pumped into Linhe’s sewer system. A manhole on the factory’s yard was selected as sampling site. The conditions were far from ideal with narrow access, extremely turbid water preventing any visual inspection of the probe’s placement and probably turbulent flow due to changing pipe diameter and bends. In addition to those problems the battery of the sampler was not sufficiently charged, only managing to collect two samples out of twelve.

Wei Xing

- **2002-09-24**: A grab-sample was collected at the outlet. This was done in order to save time and due to difficult flow measuring conditions. The small flow and the presence of at least rudimentary treatment suggest that Wei Xing is a small pollution source. The grab-sample was collected to confirm this.
I visited China for the first time in the summer of 1999 and was immediately fascinated by the country. I knew that I was going to go there again.

When I contacted IVL Swedish Environmental Research Institute one year ago I was therefore hoping for, but not expecting, an opportunity to do part of my thesis work in China. (To be honest any thesis work at IVL would probably have been tempting – abroad or not.) To my surprise I was told that there actually was a possibility for me to participate in the ongoing Inner Mongolia Lake Restoration Project – Lake Wuliangsuhai. Not only would I return to China, but I would also combine practical fieldwork with theoretical analyses and evaluations in a project concerning technical, environmental and social aspects. Needless to say I enthusiastically accepted.

At IVL I would like to thank Mr. Jonas Fejes for the swift early arrangements, Ms. Jessica Zachrisson for promptly referring me to the right people when I was interested in working in China and of course my supervisor, Mr. Jonas Röttorp for support and many valuable advices as well as for introducing me to the project on-site in China.

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