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Evaluation of sludge management in Wuhan, China

Utvärdering av slamhanteringen i Wuhan, Kina

Oscar Tottie

Abstract

Evaluation of sludge management in Wuhan, China

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Wuhan is the sixth largest city in China. One of the major environmental problems in Wuhan is the impacts of disposal of sludge from wastewater treatment plants. Today no sustainable method is applied for sludge disposal and the amount is increasing along with the increasing amount of wastewater treatment plants in the area. Sludge is a resource from which products as nutrients and energy can be retrieved. Therefore it is unsustainable to landfill the sludge as the city of Wuhan chooses to do today. This method also leads to a leakage of nutrients, toxins and other pollutants to the environment. China is recommended to follow he example of Sweden, where landfilling sludge is illegal. In Sweden, five common ways for sludge handling are now applied. These ways are as fertilizer, construction soil, and cover material, for energy production by incineration and for biogas production.

The aim of this master thesis was to identify and evaluate the methods in Swedish sludge management and to determine the most sustainable sludge management for Wuhan. Results from a literature study and interviews both in Sweden and Wuhan showed that there are several solutions for sludge disposal and that the least sustainable method is landfill, as the city of Wuhan chooses to do today. The sludge management in Wuhan had no current policy or strategy and was not well coordinated. In addition, the know-how to implement the different methods was lacking. Swedish technology and know-how is welcome to be part of the solution according to stakeholders in Wuhan.

Co-incineration with other municipal wastes was suggested as the best solution for now due to poor sludge quality. Wuhan authorities need to identify and remove sources of pollutants to improve the sludge quality. Only then should the sludge be used as fertilizer, cover material and construction soil. This strategy will generate a better environment as well as economic profit.

Keyword: Sludge, sludge treatment, sludge disposal, wastewater treatment, cover material, construction soil, biogas, incineration, Wuhan, China

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Referat

Utvärdering av slamhanteringen i Wuhan, Kina

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Wuhan är Kinas sjätte största stad. Ett av de största miljöproblemen i Wuhan grundar sig i stadens hantering av slammet från de kommunala reningsverken. Idag tillämpas ingen hållbar metod och mängderna ökar i takt med det ökande antalet reningsverk. Då slam är en resurs som näring och energi kan utvinnas ur är deponering av slam, som Wuhan väljer att göra idag, en ohållbar metod. Detta leder också till läckage av lakvatten med näring, metaller och andra föroreningar. Att deponera slam är olagligt i Sverige och Kina rekommenderas att följa detta exempel. Det finns fem sätt att använda sig av slammet som diskuteras i Sverige. Dessa är som gödsel inom jordbruk eller skogsbruk, som anläggningsjord, som täckmaterial av gamla gruvor och deponier, för energiutvinning genom förbränning och för energiutvinning genom biogasproduktion.

Målet med detta examensarbete var att karlägga svensk slamhantering och att identifiera hållbara lösningar för slamhanteringen i Wuhan. Resultaten av en litteraturstudie, intervjuer och en fältstudie till Wuhan visar att slamhantering har flera lösningar och att den minst hållbara slamhanteringen är deponering. Slamhanteringen i Wuhan är dåligt koordinerad och ansvariga myndigheter har ingen policy eller strategi för slamhantering. Kunskapen om hur mer hållbara alternativ ska genomföras saknas och svensk teknik välkomnas för att fylla detta kunskapsgap.

Då slamkvalitén är relativt dålig i Wuhan är samförbränning med annat avfall den mest hållbara lösningen. För att kunna tillämpa de andra landbaserade användningsområdena måste slamkvalitén förbättras genom att identifiera och hantera föroreningskällorna. Då skulle slammet kunna användas som gödsel, täckmaterial eller anläggningsjord. Denna strategi medför en bättre miljö och ekonomiska besparingar för Wuhan.

Nyckelord: Slam, slambehandling, slamhantering, vattenrening, täckmaterial, anläggningsjord, förbränning, biogas, Wuhan, Kina

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摘 要 (Abstract)

中国武汉市污泥处理的评估

奥斯卡·托蒂 (Oscar Tottie)

武汉市是中国第六大城市。目前武汉市面临的最大的环境问题是如何处理各大污水处理厂产生的污泥。现在武汉市还没有一个有效的方法来解决污泥的处置问题，并且污泥的产生量随着该地区污水处理能力的增加而快速增长。在瑞典，有五种途径来处理污泥：肥料，建筑用土，覆盖材料，焚烧产生能源以及生物气。

鉴于污泥已经被认定为是可回收利用的资源，可以从中得到营养物质和能源，因此仅仅将污泥填埋掉，这一目前武汉地区常用的方式，是不可取的。这种方式也导致了有毒元素以及其他污染物对当地环境的污染。污泥填埋在瑞典是违法的，因此我们推荐中国也可参考这样的例子。

本文显示了处理污泥有多种方式，但填埋是最不可取的方法。目前武汉对于污泥处理并没有一个完整的计划，也没有相应的政策。武汉缺乏不同污泥处理方式的相关技术和知识。武汉欢迎来自瑞典的技术来帮助解决这一问题。

鉴于武汉地区贫瘠的污泥质量，与其他城市垃圾进行联合焚烧是目前最好的处理方式。武汉地区的相关人员需要鉴别并且分离污染物的源头，来提高污泥的质量。只有那样，污泥才能用作肥料，建筑用土和覆盖材料。这种方式将会带来环境效益和经济效益的双赢。

关键词(Keywords)： 污泥 污泥处理 污泥处置 污水处理 污水处理 覆盖材料 建筑用土 生物气 焚烧 中国 武汉

Preface

This master thesis was written for Borlänge Energy and IVL. It is part of the M.Sc. Education in Aquatic and Environmental Engineering at Uppsala University. It covers 30 academic credits. Ronny Arnberg at Borlänge Energy was the supervisor and the subject reviewer was Associate Professor Sara Hallin at the Department of Microbiology at the Swedish University of Agricultural Sciences (SLU).

I would first of all like to thank Borlänge Energy and IVL. To participate in an international project such as this marks the perfect ending to my university studies. I would also like to thank the staff at Wuhan Environmental Protection and Research Institute who helped me to arrange visits, interviews and translate written material. Especially Shaq, Phoebe, Ms Kong, Mr Gong and Mr Zhang.

My dear friends, co-workers and room mates - Annicka, Sofia and Kristina - thank you for all your support and the good times in Wuhan.

Ronny Arnberg, Anna Hagberg, Sara Hallin and Jonas Röttorp – thank you very much for all your help and assistance along the way!

Stockholm, November 2007
Oscar Tottie

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Populärvetenskaplig sammanfattning

Utvärdering av slamhanteringen i Wuhan, Kina

Oscar Tottie

Kina är ett land på frammarsch i världsekonomin. Denna utveckling har pågått utan hänsyn till miljön vilket lett till kraftig miljöförstöring av luft, vatten och mark. Miljöproblemen tros kosta Kina 5-7 % av deras BNP på grund av förlorade arbetsdagar relaterade till sjukdomar som orsakats av miljöförstöring. Ett av de växande miljöproblemen i Kina är vad man ska göra av allt avloppsslam som produceras på de allt fler kommunala avloppsreningsverken. I Sverige finns ingen perfekt lösning på detta problem men flera alternativ finns dock tillgängliga. Man kan antingen göra anläggningsjord för grönytor, täckmaterial för gamla deponier och gruvor, använda det i inom jordbruket som gödsel och jordförbättring eller att utvinna energi från slammet, antingen i förbränningsanläggningar eller biogasanläggningar. Dessa alternativ har blivit allt vanligare sedan 2005 då det blev förbjudet i Sverige att deponera slam.

Wuhan är huvudstaden för Hubeiprovinsen i centrala Kina med 7,3 miljoner invånare. Staden är känd för att vara det finansiella och industriella navet i centrala Kina. Wuhan är inget undantag till Kinas oroväckande utveckling och inte heller till det växande slamproblemet. Idag läggs allt slam på deponi i Wuhan vilket inte är någon hållbar lösning. Det kommunala slammet har blandats med slam från industriell vattenrening och andra sorters avfall. Lakvatten som innehåller tungmetaller och andra giftiga substanser läcker ur dessa deponier och förorenar både luft, grundvatten och mark. Detta är varken ekonomiskt eller miljömässigt hållbart. Detta examensarbete utredde vilka av de svenska alternativen som Wuhan skulle kunna applicera istället. För att välja en hållbar metod för Wuhan utreddes slamkvalitet, lagstiftning, kunskap, teknik och efterfrågan av de olika produkterna som kan utvinnas eller produceras utifrån kommunalt slam i Wuhan. Denna utredning gjordes genom en litteraturstudie men också genom intervjuer och besök hos ansvariga på reningsverk, motsvarande naturvårdsverk och andra experter på området i Wuhan.

För att se vilken av de svenska metoderna som Wuhan bör använda kartlades även dessa grundligt. De svenska användningsområdena utreddes därför med avseende på ekonomi, acceptans, teknikutveckling, miljö och lagstiftning. Resultatet av detta tyder på att det inte finns någon generell lösning för alla städer, då de lokala förutsättningarna styr vilken slamhanteringsstrategi som är optimal. Slam bör anses som en resurs och inte som avfall då det har egenskaper som kan tillämpas inom jordbruk, anläggning och energiutvinning. Den miljömässiga aspekten är svår att ranka emellan de olika alternativen, men samtliga är klart bättre för miljön än deponering. De andra alternativen ersätter nämligen någon annan resurs som samhället slipper utvinna, det gör inte en deponi. Ur en ekonomisk synvinkel är jordbruk, täckmaterial och anläggningsjord de bästa alternativen. Förbränning anses vara dyrt och det är en mycket ovanlig metod i Sverige idag. Askan skulle dock kunna användas till att göra byggmaterial, som komponent i täckmaterial eller vidarebehandlas för utvinning av olika produkter. Tekniken för en sådan behandling är dock inte särskilt etablerad eller pålitlig ännu. Det alternativ som har sämst acceptans i Sverige är inom jordbruket. De flesta producenter och konsumenter välkomnar tanken på att återvinna näringsämnen, men är samtidigt tveksamma till att använda slam inom jordbruket. Samtidigt har Sveriges riksdag satt upp ett miljömål om att 60 % av fosforn ska återvinnas innan 2015. Detta är ett viktigt mål då näringsämnet fosfor är det tionde mest vanliga ämne på jorden men endast en bråkdel är tillgängligt att utvinna i gruvindustrier.

Biogasproduktion är ett allt vanligare användningsområde i Sverige och gasen kan användas som fordonsbränsle eller för utvinning av el och värme. Denna slamhanteringsmetod innebär också att slammet bryts ned, vilket minskar volymen avsevärt samt hygieniserar slammet. Det är tyvärr inte en fullständig lösning då kvarvarande ”rötrest” måste tas om hand. Den kan dock passa utmärkt som komponent i täckmaterial eller andra landbaserade användningsområden.

Resultaten av kartläggningen av svensk slamhanteringen visade att det finns flera alternativ som är mer hållbara än att lägga slammet på deponi, som Wuhan gör idag. I Wuhan är regler och lagar inte lika strikta när det gäller användningsområden av slam. Inga regelbundna analyser av slammet görs och kunskapen om alternativen är relativt låga. Flertalet intervjuer tyder på att det är stora variationer i slamkvalitet och att den inte kan anses som god enligt svenska normer. Därför är förbränning det enda sätt Wuhan bör överväga idag. Det finns både pengar och vilja att investeras i slamhantering i Wuhan. Här bör svensk miljöteknik kunna implementeras vilket det svenska företaget Carl Bro (numera Grontmij) redan gjort. De bidrar till ett biogasprojekt som ännu är under uppbyggnad. Biogasen ska användas som bränsle till bussar och för att producera el till biogasanläggningen. Detta är en slambehandlingsmetod som samtliga reningsverk bör införa på sikt. Att införa en volymminskande behandling, som biogasproduktion behövs då Wuhan med mindre invånarantal än Sverige producerar ca 50 % mer slam. För att komma till bukt med Wuhans allt allvarligare slambekymmer föreslås att koncentrationen av farliga substanser, t ex tungmetaller minimeras. För att uppnå detta måste Wuhan kartlägga var dessa kommer ifrån. Är det ifrån industrier så måste dessa införa intern vattenrening. Dagvattenhanteringen bör även ses över då dagvatten troligtvis är en annan föroreningskälla. Slamkvalitén bör sedan kontrolleras kontinuerligt och delas in i tre klasser:

- Den första klassen ska uppnå kraven instiftade av kinesiska regeringen om användningen av slam i jordbruk. Detta slam bör användas i jordbruket och kan transporteras med tåg till jordbruk ute i Hubeiprovinsen.
- Den andra klassen är det slam som inte når upp till klass ett men som har bättre kvalitet än det slam som bör klassas som farligt avfall. Detta slam kan ingå som komponent i täckmaterial och anläggningsjord.
- Klass tre innebär slam som bör klassas som farligt avfall. Det är slam med för höga halter av farliga substanser. Kompetensen för att sätta dessa gränser bör finnas hos Environmental Protection Bureau i Wuhan. Detta slam ska förbrännas i stadens förbränningsanläggningar tillsammans med stadens övriga avfall. För att uppmuntra en förbättring av slamkvalitén bör höga avgifter sättas på det slam som ska förbrännas.

Resultaten av fältstudien i Wuhan visade att myndigheter och företag i Wuhan saknar kunskap och kompetens för att genomföra dessa åtgärder. Det är därför på lång sikt viktigt att det byggs pilotanläggningar för varje metod. Dessa anläggningar kan då användas för forskning, utveckling och utbildning. Resultaten visade även att svensk teknik är välkommen att delta i utvecklingen av Wuhans slamhantering.

Vocabulary

Anaerobic	Means without air, as opposed to aerobic.
Cation	A positively charged ion
Chemical precipitation	The formation of a solid in a solution during a chemical reaction
Soil conductivity	A soil property that describes the ease with which the soil pores permit water movement
Euthrophication	The increase in nutrients, typically compounds containing nitrogen or phosphorus, in an ecosystem
Digestion	A biological process whereby an organism degrade or oxidize a substance.
DS	Dry Solids. The weight of dry material remaining after drying
Floc	An aggregated structure, e.g. an aggregate of organic material and microorganisms in water,
Pathogens	A biological agent that cause disease or illness
Polymer	A substance composed of molecules with large molecular mass, composed of repeating structural units, or monomers, connected by covalent chemical bonds
Reed	Large grass, native to wetland sites (*Phragmites australis, Phragmites communis*)
Sludge bulking	A sludge settling problem in the biological wastewater treatment caused by certain filamentous bacteria.
Storm water	Water that originates from precipitation events, from snowmelt and runoff water, which enters the storm-water system.

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1. INTRODUCTION

"The environmental situation is catastrophical". This was declared by professor C S Kiang of the Beijing University during a debate at the conference Globe Forum in Stockholm in 2007. The Chinese economy is developing rapidly while China is becoming an increasingly important participant in international economy (Myrsten, 2007). China's rapid industrialisation has substantially increased pollution, which has had many negative affects on both the environment as well as the health of people living in China and around the world. Twenty of the thirty most polluted cities in the world are now situated in China. However, environmental problems are just one of the major problems. Corruption, income gaps and the growing impatience of the unemployed people in the countryside are commonly mentioned factors in debate of the increasing uncertainty in Chinas economic growth. Nevertheless, the biggest challenge seems to be the environmental problems. Air and water pollution cost China 5-7 % of their BNP according to professor Kiang because of millions of work days being lost due to health issues related to pollution.

Wuhan is no exception to the environmental development in China (Hagberg, 2007). Wuhan is the capital of the Hubei province and is situated in the south-east part of China along the great Yangtze and Han River (Figure 1). It is divided into nine districts which are inhabited by 7.3 million people, making Wuhan the sixth largest cities in China. It's considered being the financial, scientific and commercial centre of central China as well as an important transportation hub for railways and waterways in China (Wu et al., 2005). Due to the high temperatures in summer Wuhan is known as one of the four furnaces in China (Wikipedia, 2007). While the great nearby rivers are heavily polluted and the air quality is poor, Wuhan continues to grow. The local and national authorities are now trying to come to terms with the increasing problems described above.

Figure 1. Location of Wuhan (Modified from CBCC, 2007)

One of the major environmental problems in Wuhan is the disposal of sludge from wastewater treatment plants. Today no sustainable method is applied for disposing sludge in Wuhan and the amount of sludge is increasing along with the expanding amount of wastewater treatment plants in the area (Hagberg, 2007). All sludge is disposed on landfills today. This method can lead to leakage of nutrients, toxins and other pollutants to the surrounding environment. The sludge could instead be used in ways that favours Wuhan financially as well as its surrounding environment. Sludge is a resource from which products as nutrients and energy can be retrieved. Therefore it is unsustainable to landfill the sludge as the city of Wuhan chooses to do today.

1.1. PROJECT BACKGROUND

During the last couple of years a co-operation has been founded between Wuhan and Sweden. The partners are Wuhan Environmental Research Science Institute, Wuhan Environmental Protection Bureau, Borlänge Energy and Swedish Environmental Institute (IVL). In 2005, the four partners started a project which aimed to create an environmental centre in Wuhan (Arnberg & Röttorp, 2007). This centre will have several business areas to elaborate, such as to promote sustainable development, encourage matchmaking between Swedish and Chinese organisations and to identify and commence projects. Since the centre will work as a platform on the Chinese market many Swedish companies have shown interest in this centre such as ÅF, Sweco, Kemira and Alfa Laval. One of the environmental problems that the centre has decided to work with is sludge management in Wuhan. This master thesis is the pre-study to the sludge management project.

1.2 AIM

The aim of this master thesis was to:

- Identify and evaluate the methods in Swedish sludge production, treatment and disposal.
- Identify the most sustainable sludge management strategy for Wuhan from an environmental point of view with methods based on Swedish sludge disposal methods.
- Identify business areas and opportunities for Swedish partners in wastewater treatment and sludge management for future cooperation with Wuhan.

1.3. LIMITATIONS

This master thesis focused on sludge from municipal wastewater treatment plants and the solutions for disposal of sludge, based on existing technology that is implemented in modern Swedish sludge management. However, some future sustainable solutions are also discussed. The time span for this master thesis was 20 weeks, of which 12 for literature studies and 8 for a field trip to Wuhan. The clients of this master thesis are Borlänge Energy and IVL.

2. METHOD

The four most influential factors on sludge management is legislation, economic incentives, acceptance and technical developments (Hultman et al., 2002). Sludge management in Sweden and Wuhan was therefore studied and evaluated with focus on those four factors in addition to environmental impact (Figure 2). The results from the investigation of the sludge management in Wuhan and Sweden generated pre-pipe and end-of-pipe solutions. Pre-pipe solutions are defined as solutions that can be implemented before the sludge is produced, such as sludge treatment. End-of-pipe solutions refer to sludge disposal methods. Together, these solutions work as guidelines for a more sustainable sludge management in Wuhan. New business opportunities for the Swedish partners were also identified based on these solutions.

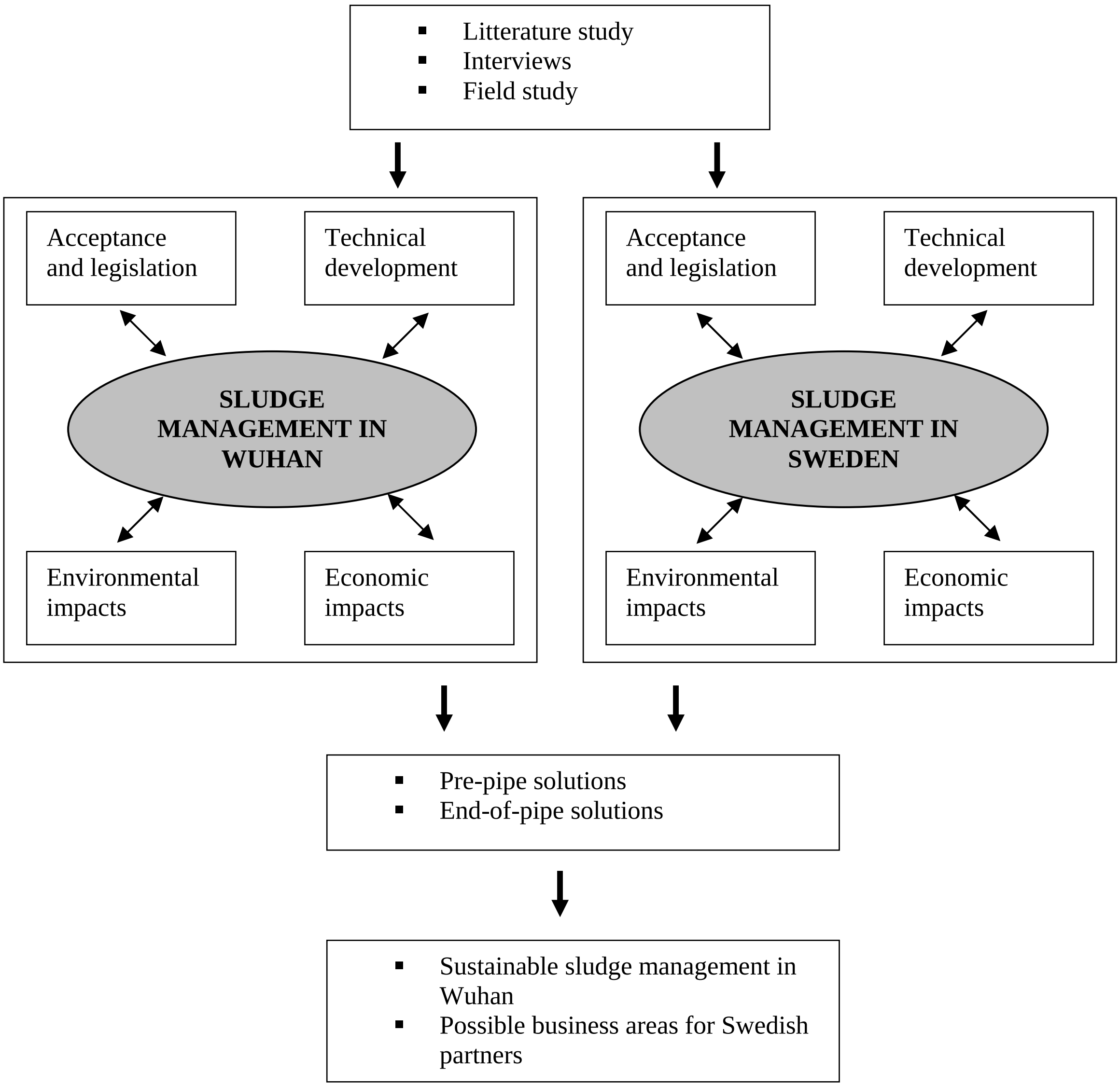


Figure 2. Illustration of inputs and outputs of the master thesis.

2.1. SLUDGE MANAGEMENT IN SWEDEN

The study on Swedish sludge management was primarily based on a literature study and interviews with different stakeholders in Swedish sludge management. These were Anders Tengsved at Ragn Sells, Lars Fritz at Ångpanneföreningen (ÅF) and Bo Von Bar at SP Technical Research Institute of Sweden. It was complemented by a field trip to Käppala wastewater treatment plant in Stockholm. The study on Swedish sludge management revealed how sludge is produced, treated, and disposed in Sweden. It identified the most important stakeholders and regulations in Swedish sludge management. This study also identified suggestions to possible solutions for Wuhan's current unsustainable sludge management. Some examples from the European Union (EU) and especially Great Britain were studied in order to increase the number of possibilities for sustainable solutions for Wuhan. The study was divided into three parts where each step is part of modern sludge management:

1. **Sludge production.** Since sludge is produced in municipal wastewater treatment plants (WWTPs), the treatment processes were mapped.

2. **Sludge treatment**. The different sludge treatments were studied to fully understand the prerequisites and limitations of each sludge route in Sweden. The investigated treatments were stabilization, conditioning, thickening, dewatering, drying and separation techniques.

3. **Sludge disposal.** The benefits, possibilities, risks and downsides to each sludge disposal method were mapped to identify possible solutions to the sludge disposal problem in Wuhan. The investigated methods were landfilling, cover material, construction soil, for energy production by incineration, for biogas production and retrieving products for internal use in WWTPs.

2.2. SLUDGE MANAGEMENT IN WUHAN

The field study in Wuhan involved visits to three WWTPs, an inorganic fertilizer factory, a landfill and two car factories. An investigation of possible sources of pollutants in the sludge was conducted and the car factories were visited for this purpose. The WWTPs were visited to retrieve information on how the sludge was produced, treated and disposed of. The fertilizer factory was visited to inquire into the demand of fertilizer in Wuhan. Experts in the field on sludge management and environmental protection were also interviewed. These were Gong Yuan (Deputy director at of Wuhan Environmental Research Institute), Professor Hou at Wuhan University, Feng Lilin (General engineer of Wuhan Environmental Sanitary Science Research & Design Institute), Yu Xiao (Vice director of Environmental Sanitation Science Research and Design Institute), Chen Lei (Vice director of EPB, Donghihu) and Qiu Wenxin (Chief engineer of Wuhan Water Group Co. Ltd.).

An interpreter translated most interviews from Chinese to English. These interviews and visits where complimented by a literature study on sludge management and wastewater treatment in Wuhan and China. This investigation generated information on Chinese sludge management, sludge management in Wuhan, sludge quality in Wuhan, the possibilities to adapt the Swedish alternatives, sources of sludge pollutants and new possible projects for the Swedish partners.

3. RESULTS - SLUDGE MANAGEMENT IN SWEDEN

Sludge is one of the by-products from wastewater treatment processes. Sludge consists of water, organic and inorganic substances, a wide variety of bacteria and different trace elements such as heavy metals (Svenska Kommunförbundet, 1992). The quality of the sludge is determined by many factors such as dry solid (DS), pH and heavy metals. Almost all the municipal wastewater ends up at the local WWTPs. About 85% of the Swedish population lives in areas which are serviced by municipal WWTPs. The WWTPs also treat storm water and industrial wastewater but larger industries use internal wastewater treatment before discharging water into the municipal sewage system. All these connected households, industries and storm water drains contribute to an annual production of 1 million tons of sludge (Naturvårdsverket, 2007).

Since sludge management affects the environment in many ways it is controlled by Swedish environmental legislation. A sludge management policy was developed in 2005 when the Swedish parliament decided that at least 60% of the phosphorus in Swedish sludge should be recycled by 2015. There is also an EU-directive (86/278/EEG) that Sweden follows which involves governance in agricultural use of sludge. It is now under revision. The Environmental Protection Agency (EPA) governs the necessary permits when the concentrations of pollutants exceed the standards. These laws are the major means of controlling Swedish sludge management (Naturvårdsverket, 2007).

3.1. HOW SLUDGE IS PRODUCED

There are mainly three different kinds of sludge that are produced after the three major steps in municipal WWTPs: primary, secondary (excess sludge or biological sludge) and tertiary sludge (chemical sludge) (Svenska Kommunförbundet, 1992).

There are three commonly used treatments in conventional Swedish WWTPs - mechanical, biological and chemical treatment (Svenska Kommunförbundet, 1992; Figure 3). The first step is primary (mechanical) treatment which involves screening, a grit chamber and a sedimentation tank. Screening removes large objects such as plastic bags and the grit chamber slows down the flow allowing grit to fall out. Solids settle in the sedimentation tank, which is the last step in the mechanical treatment and this is where the primary sludge is produced.

The most widespreadly used biological treatment method is the activated sludge process (ASP) (Carlsson & Hallin, 2003). It is a biological process which can remove both nitrogen and phosphorous apart from organic matter. Part of the active sludge is returned to the aerated tanks to maintain a constant amount of active biomass in the process. Phosphorous is often removed by chemical precipitation followed by biological processes. These processes remove phosphorous by sedimentation of the bacterial floc since it is an essential nutrient for bacterial growth and this is where the secondary sludge is produced. About 30 % of the incoming phosphorous is removed by biological growth. Many different problems in the ASP can decrease the sedimentation ability. Most WWTPs experience problems with filament forming bacteria at some point.

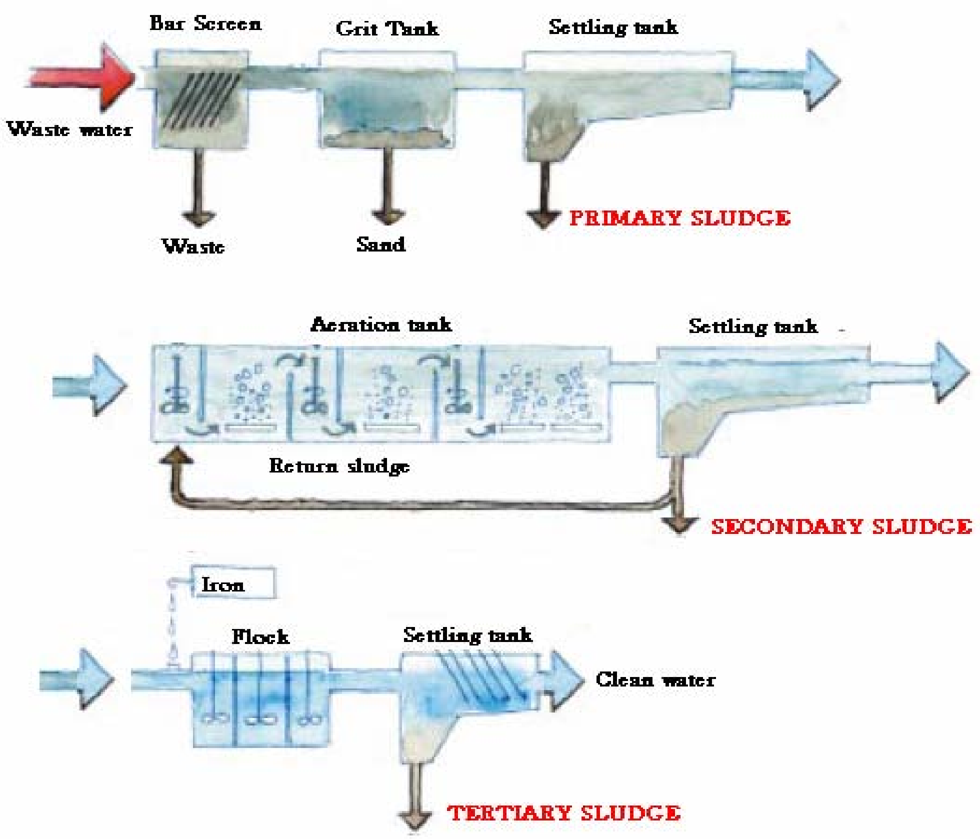


Figure 3. Simplified illustration of municipal wastewater treatment (Modified from Uppsala Kommun, 2007).

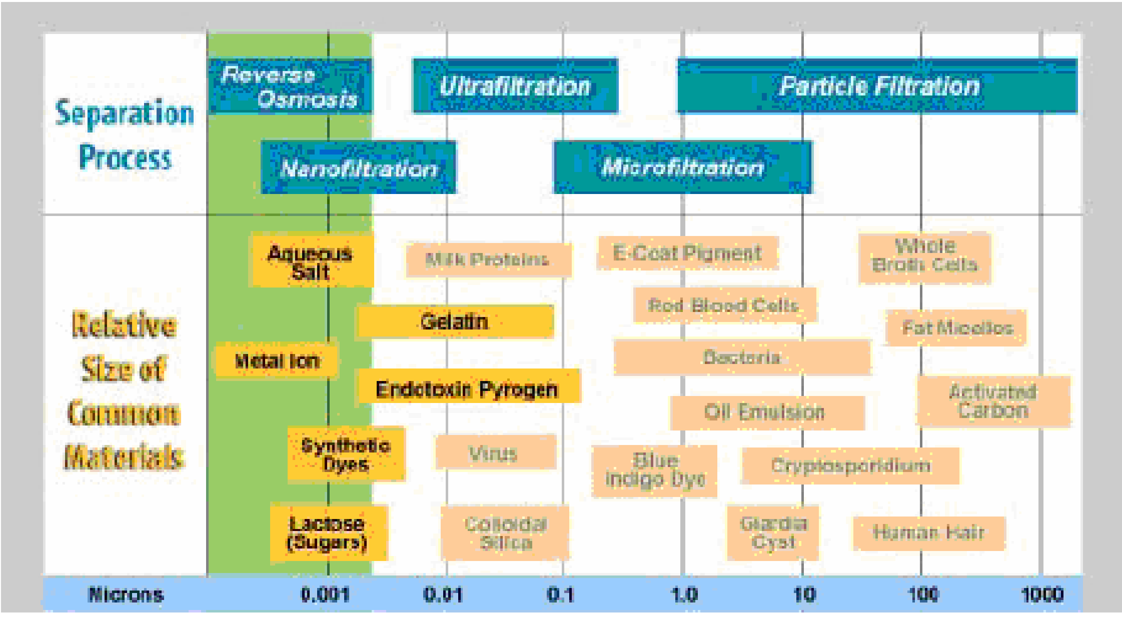
Nitrogen is removed by the bacterial processes nitrification and denitrification. These two processes occur in different compartments of the WWTP since nitrification is an oxygen demanding process and denitrification is not. Nitrification is the sum of two processes by two different kinds of bacteria while denitrification is carried out in several steps in the same bacterial cell.

Nitrification
$NH_4^+ \rightarrow NH_3 \rightarrow NO_2^- \rightarrow NO_3^-$

Denitrification
$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$

The chemical treatment is employed by a growing number of wastewater treatment plants all over the world (Svenska Kommunförbundet 1992). Chemical treatment is sometimes called tertiary treatment. This treatment is used for removal of phosphorous and particles. A precipitation chemical is added that causes the pollutant to flocculate and it is removed by sedimentation. This is where the tertiary sludge is produced in the wastewater treatment process. The chemical treatment can however be implemented simultaneously in the biological treatment or in separate tanks before or after the biological treatment.

To further improve the wastewater treatment membrane technology can be implemented. It was introduced 30 years ago but it’s only in the last 10 years that there has been a radical increased implementation of the technique, especially in drinking water production (Kärrman et al., 2004). Membranes are used as microbiological barrier, separation of particles, pesticides, organic substances, heavy metals and humus. Reversed osmosis and Nano filtration can remove the smallest substances such as metal ions (Figure 4; Blennow, 2005). NF removes double charged ions (Ca^{2+}, Mg^{2+}, SO_4^{2-}) while RO can remove single charged ions (Na^+, Cl^-).



Note: micron = micrometer

Figure 4. Different membrane separation processes (Modified from Koch, 2004).

3.2. SLUDGE TREATMENT

In Sweden, almost all types of sludge are treated to reduce the number of possible pathogens, the quantity of easily degraded organic matter and the water content. Stabilization treatments will decrease the risk of odour and the spread of infectious deceases due to reduction of pathogenic organisms, such as salmonella. The sludge can then be treated by conditioning and thickening to improve the effects of dewatering. Chemical or thermal conditioning are the two most common conditioning techniques and there are four common thickening techniques: gravity thickeners, gravity belt thickeners, dissolved air floatation and drum thickeners (Naturvårdsverket, 2007; Alfa Laval, 2007). Sludge can also be dried instead of dewatered, either by direct or indirect techniques (European Commission, 2001). All these treatments are further discussed in the following sections and are summarized in table 1.

Table 1. Summarised methods and purposes in sludge treatments.

	Methods	**Purpose**
Stabilization	• Anaerobic digestion • Composting • Pasteurisation • Lime stabilization • Bed of reed	• Reduce pathogenic micro organisms • Reduce odour
Conditioning	• Chemical • Thermal	• Preparation for dewatering, thickening and drying.
Thickening	• Gravity thickening • Gravity belt thickening • Dissolved air floatation • Drum thickener	• Reduce water content • Improve density and strength for further dewatering treatment
Dewatering	• Centrifuges • Belt filter press • Recessed-plate filter press • Drying beds • Bed of reed	• Reduce water content
Drying	• Direct • Indirect	• Reduce water content

3.2.1. Stabilization

Stabilization is achieved through anaerobic digestion or composting. Other methods are lime stabilization and stabilising through a bed of reed. When the sludge is stabilised the sludge volume decreases, the amount of pathogenic organisms decreases and the odour diminishes. Therefore, stabilization makes the transport of sludge safer and cheaper (European Commission, 2001).

Anaerobic digestion implies decomposition in an anaerobic environment. This degradation of organic matter causes the sludge volume to decrease, which makes the transport of sludge cheaper (Naturvårdsverket, 2007). Anaerobic digestion is also part of biogas production where there are five major steps that together complete the biogas process, which is further discussed in section 3.2.2. (Schnürer, 1995). Preliminary cost estimate indicates that anaerobic digestion is a fully competitive alternative to the mainly aerobic processes while it achieves the same effluent quality as well (Keller, 2003; Table 2).

Composting is an aerobic decomposition process but includes mixing with for instance sawdust or animal manure. This process produces compost, heat and carbon dioxide. It is carried out using reactor or non-reactor systems. Sludge is composted during a shorter time period using reactors but has high energy costs (European Commission, 2001; Keller & Hartley, 2003). The energy costs are twice as high for aerobic digestions compared to anaerobic digestion. This is because aerobic digestions does not produce any gas from which energy can be retrieved, unlike anaerobic digestions which produces biogas (Kjellén & Andersson, 2002). After 1-2 weeks the product is removed from the reactor and is then piled in long rows (windrows) that are frequently turned to increase the oxygen content for the bacteria, improve the porosity and to decrease moist matter. The treatment is complete after 2-3 months, but varies depending on the climate and weather conditions (De Davila, 1998). The parameters that needs to be monitored in this process is oxygen demand, water content, temperature and pH (Rennerfelt & Ulmgren, 1975).

Lime stabilization is commonly used for stabilising sludge all over the world and the method has many benefits. It stabilises all kinds of sludge, eliminates odours and destroys the pathogenic micro organisms (Andreadakis, 1999).

Another method is using a **bed of reed**. Besides the effect of drainage, the reed (Phragmites australis) consumes a lot of water and therefore raises the DS factor substantially. This technique has been used for about 10 years in Denmark, Germany, France and USA. There are various results from the different facilities but Danish results show that these beds can dewater up to 60kg DS/m^2 (Runeson, 2001).

Table 2. Arguments for and against different stabilization methods.

	Advantages	**Disadvantages**
Anaerobic digestion	• Biogas production	• Investment cost for digestion chamber
Composting	• Simple technique	• High energy costs (reactors) • Time demanding in colder countries • Needs large areas (for windrows) • Produces carbon dioxide (green house gas)
Lime stabilization	• Appropriate for all kinds of sludge	• Cost of chemicals
Bed of reed	• Reduces water content as well	• Variating success rate

3.2.2. Conditioning

Before the sludge is treated to reduce the water content it can be treated chemically or thermally to improve the effect of the water reducing treatments. Many different mineral agents are used for chemical conditioning of sludge such as lime, salts or polymers (European Commission, 2001). An example of a chemical conditioning process is Kemicond. It is currently being tested at Käppala WWTP in Stockholm. Besides the conditioning effect there is also a hygienisation and odour reduction effect. The investment cost are low and treatment for 8000 tonnes DS per year would cost less then 10 million SEK (Kemira Kemi AB, 2005; Table 3). The cost of the chemicals depends on the sludge quality and varies between 350 to 650 SEK / t DS. If the sludge is treated with the Kemicond technology the treated sludge can reach a DS value of 55% after certain dewatering processes (Karlsson, 2006).

When sludge is thermally conditioned it is heated to 150-200 °C for about 45 minutes. This improves the structure in the sludge, which helps the water reduction processes. Thermal conditioning can however cause offensive odours and risk of polluting the water after the water reduction process due to hydrolysed organic matter (European Commission, 2001).

Table 3. Arguments for and against different conditioning methods.

	Advantages	**Disadvantages**
Chemical conditioning	• Improved water reduction effects due to physical changes in the sludge • Can have a stabilising effect and odour reducing effects	• Cost of chemicals
Thermal conditioning	• Improved water reduction effects due to physical changes in the sludge • Suitable for all kinds of sludge	• Energy consumption • Odours • Increased pollution in the recovered water after water reduction processes

3.2.3. Thickening

Thickening is usually a first step to reduce the water content in sludge and is done either by a gravitation thickener, gravity belt thickener, and centrifuge or dissolved-air flotation. All three methods divide the sludge into two phases; a clear water phase and the thickened sludge. Therefore, thickening is a method to increase the content of dry matter (DS) and to decrease the volume of the sludge. A certain polymer can be added to the process to make it more effective (European Commission, 2001). Thickened sludge can be directly used as wet fertilizer if the distance to arable land is short (Naturvårdsverket, 2007).

Gravity thickening is performed in tanks were gravitational forces bring the thickened sludge at the bottom of the tank were it can be extracted. This technique thickens the sludge by 2 to 8 times and the costs are relatively low since only about 5 kWh/t DS (Table 4). It is however not so effective with secondary sludge (European Commission, 2001).

Gravity belt thickening operates in three steps; conditioning, gravity drainage and then compression. The belt is an endless filter on which the thickening takes place. Sludge is placed onto the belt where the water passes through the belt and becomes further thickened when compressed by being turned over. For this process to function properly a polymer is added to the sludge. This method requires about 50 kWh/t DS and water and thickens the sludge to about 5 to 10 % DS, depending on the sludge type. The technique is relatively compact but requires more work force and water compared to the others (European Commission, 2001).

If the solid particles have a low rate of settlement the **air flotation technique** can be applied. The thickened sludge is removed by a scraper since the fine suspended solids' specific gravity is lowered by micro bubbles. If the matter in suspension needs to be reduced, a polymer is sometimes added. This method is more efficient than gravity and gravity belt thickening but has higher energy costs (120 kWh/t DS) (European Commission, 2001).

Drum thickeners are a fourth alternative that works on the principle of conveying sludge through a rotating drum filter. The sludge remains in the drum as the water phase passes through a filter cloth. The sludge is then removed and inserted into the dewatering process. The process usually is combined with the use of a polymer (Alfa Laval, 2007). The drum thickeners have low energy costs and are compact as well (City of Brockville, 2005).

Table 4. Arguments for and against different thickening methods.

	Advantages	**Disadvantages**
Gravity thickening	• Low energy cost • Low investment costs	• Not as effective on secondary sludge.
Gravity belt thickening	• Compact	• Needs work force • Needs water • Needs polymer
Dissolved air floatation	• Easy to perform	• High energy costs
Drum thickener	• Low energy costs • Compact	• Often needs polymer

3.2.4. Dewatering

The step after thickening is often dewatering. There are many ways to dewater the sludge; using centrifuges, filter presses, recessed-plate filter presses, bed of reed or drying beds (European Commission, 2001; Table 5).

Centrifuges are commonly used for secondary sludge (European Commission, 2001). Centrifugal forces separate the sludge into dewatered sludge and the centrifugate. This mechanical process is often compact with high capacity and is relatively simple to operate. It dewaters the sludge up to 15 to 30 % DS but needs significantly large amount of energy (25 to 80 kWh/t DS).

Belt filter presses need a polymer to process the sludge. The process then works the same way as gravity belts but the method is complemented with pressing the sludge between two belts. This process may therefore be combined with gravity belt thickening. This technique increases the DS level by 10 to 20 % depending on the sludge quality and the equipment (European Commission, 2001).

A recessed-plate filter press can increase the DS to between 35 to 45 %. It has high investment costs, but they are also reduced with increasing capacities over time. In this method sludge is dewatered in the filter press when it is injected under pressure between rows of vertical plates. This process demands about 30-40 kWh/t DS and often requires a preliminary conditioning (European Commission, 2001).

Drying beds is one of the simplest techniques for dewatering sludge. The sludge is placed on sand and gravel where it is atmospherically dried. The result depends on the climate and the amount of time that the sludge is treated in the fields. There are risks of contaminating soil, groundwater and air (European Commission, 2001). The use of sand beds has declined with wide scale implementation of mechanical techniques. They are usually used in smaller municipalities and need a considerable amount of land (Al-Muzaini, 2003).

Table 5. Arguments for and against different dewatering methods.

	Advantages	**Disadvantages**
Centrifuges	• Polymer not necessary	• High energy and investment costs • Primarily for secondary sludge
Belt filter presses	• Average investment costs • Easy to operate	• High workload due to continues supervision • Needs cleaning water • Limited DS content can be reached
Recessed-plate filter press	• High DS content can be reached	• High investment costs • Needs conditioner
Drying beds	• Easy to operate • Low operation costs • High DS content can be reached	• Needs large areas • Climate dependant • Risk of odour
Bed of reed	• Also stabilising	• Not established as a reliable technique

3.2.5. Drying

There are two ways of sludge drying where heat can be transferred directly or indirectly to the sludge. This is done either through direct contact with the sludge or through a heat transfer surface. The most widespread dryer is either a revolving drum dryer or the fluidised bed dryer. Using these techniques a DS level can be reached as high as 35 – 90 %. The downside is that the energy costs are much higher than for dewatering when comparing the extracted water volume. A common method is therefore first to dewater the sludge and then to use drying. In order to reduce the energy costs, energy sources on site such as biogas, can be used (European Commission, 2001). Since these two techniques have not been thoroughly investigated in this master thesis, it is not possible to compare them.

3.3. SLUDGE DISPOSAL/RESOURCE MANAGEMENT

Trends in sludge disposal in Stockholm have varied a lot the last 20 years due to changes in legislation, progress in technology and general acceptance of different methods (Thuresson & Haapaniemi, 2005). In 2005 a new law was launched which makes it illegal to landfill sludge unless a certain grant is given by the Swedish EPA (Svenskt Vatten, 2007). Since then there are five common fields of application for sludge that are used in Sweden today: Fertilizer, construction soil, cover material, for energy production by incineration or biogas production. These five solutions are discussed more thoroughly in the next section together with the most common disposal method in Wuhan today, which is landfilling.

3.3.1. Landfill

In 2003 each member state in the EU had to set up a national strategy for reduction of biodegradable waste going to landfills. Landfill is therefore chosen as a last option when the concentrations of contaminants are too high for land based use or if other sludge disposal is not possible for economic or technical reasons. Landfilling sludge can be done in two ways: either in mono-deposits or mixed deposits. Mono-deposits are used for sludge only, where mixed-deposits are used for other waste as well. Besides contaminating soil, water and air there are also other impacts of landfilling such as odour, rats and birds, noise from delivery vehicles and risks of causing fires or explosions (European Commission, 2001; Figure 5). However, there are sanitary landfills where leakage is minimised, such as the landfill Sofielund in Stockholm. It is equipped with leach water treatment, different compartments for different kinds of waste and an artificial geological barrier that will protect the groundwater (SRV, 2007).

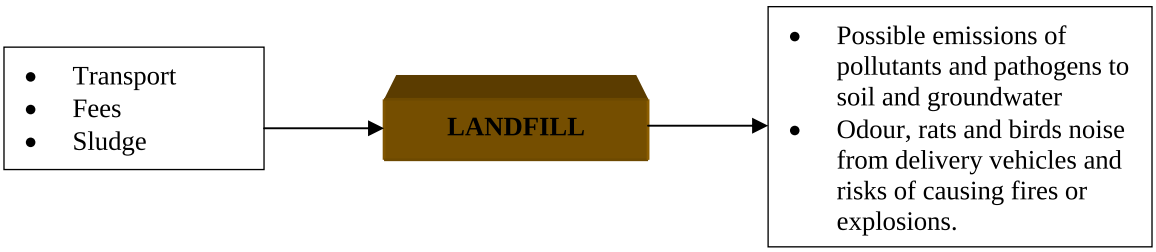


Figure 5. The inputs and outputs of landfilling sludge.

3.3.2. Construction soil and cover material

Golf courses, constructions sites, old landfills and mines are all sectors in the need of both cheap and good construction soil or cover material. The most important sources of metal leakage in Sweden are mines and old landfills (Carling et al., 2007). One way to reduce leaching of hazardous substances is by covering the site. By doing so vegetation can start to grow and thereby decrease the infiltration of rainwater, which minimizes leaching. Sludge is one material that could be used for this purpose since cheap covering material is scarce (Figure 6). Studies show that sludge together with ashes is appropriate as cover material for landfills from an economic, technical and environmental point of view. By sealing mine waste with ashes and sludge, many positive effects could be achieved since cover material decreases leach water and ashes buffers acid leach water. The demand for cover material is growing, which means that currently large amounts of natural material must be used. By using sludge the environmental impact is reduced.

The Swedish regulation 2001:512 defines the cover materials' characteristics. Sludge must be compressed to reach this standard (Carling et al, 2006). Sludge has the required properties of the conductivity but it is not strong enough to function properly as cover material. By mixing sludge with ashes the strength increases. A mix of 50 % ashes and 50% anaerobically digested sludge seem to be a good mix in order to meet these standards (Ribbing & Lind S, 2005).

Construction soil producers who include sludge in their production can apply for a certificate to ensure their customers of the quality. It is certified by the Technical Research Institute of Sweden (SP) (Von Bahr Bo, personal communication, 2007). Gävle Water Company is one of the municipal companies in Sweden that has chosen to produce cover material and construction soil. The sludge is dewatered and transported to a compost facility. Organic waste from parks and gardens is mixed with the sludge and is placed in long windrows. Other components such as sand and lime can also be used to achieve the correct properties (Länsstyrelsen Norrbotten, 2007). Once the compost process has begun, the windrows are turned over every third week to increase the oxygen concentration in the windrows. After about three months this process is complete. The product can then be used as either cover material or construction soil (Svenskt Vatten, 2007).

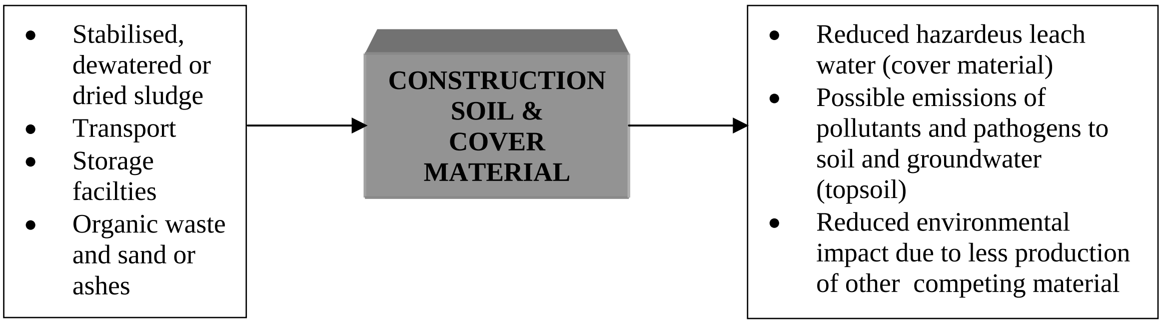


Figure 6. The inputs and outputs of sludge as cover material and construction soil.

3.3.3. Fertilizer for arable land

Sludge consists of about 3% phosphorous and 3.5 % nitrogen which means that sludge can contribute strongly to the euthrophication of our lakes and rivers if it's not properly taken care of. This also means that sludge can be used as a resource in agriculture as fertiliser. Recycling nutrients is a major part of sustainable production. Recycling could reduce euthrophication of lakes and coastal areas and at the same time create a solution for dealing with sludge in a sustainable matter. Sludge from WWTPs is rich in phosphorous compared to most other wastes which is the major reason for using sludge as fertilizer. There are other benefits as well. Using sludge on arable land can lead to increased humus content and therefore increase the water holding capacity, improve the structure and increase the cation exchange capacity of the soil (Johansson, 1999). According to the Swedish bureau of statistics, 13500 tons of inorganic phosphorous fertilizer is used by Swedish farmers annually. Besides leakage and other phosphorous sinks, 12000 tons of phosphorous is bound in the harvest which is then consumed. If all sludge that was produced annually was used as fertilizer it would contribute with 6000 tons annually (SCB, 2007). However, far from all the phosphorus in sludge is available for plants. The amount of plant available phosphorous is much less in sludge then in inorganic fertilizer (Ahnland, 1999).

Although recycling nutrients is very important, there are many problems with the usage of sludge in agriculture (Johansson, 2002; Figure 7). Heavy metals and pathogenic micro organisms are among many substances that have to be removed before using sludge as fertilizer. Due to large concentrations of heavy metals and certain chemicals, the sludge may also be toxic. From an environmental and resource management perspective it is therefore important that sludge is used with precaution (Naturvårdsverket, 2007). Although the quality of the sludge produced in Sweden is good, the use for sludge in agriculture has decreased over the years in Sweden. This is believed to be caused by scepticism towards the quality of the sludge and its impacts on our health and the environment (Thuresson & Happaniemi, 2005). According to Anders Tengsved at Ragn Sells this trend is supposed to be turning towards an increased usage of sludge as fertilizer in Sweden due to the constantly improved quality of sludge and because of international competition. Revaq is a project that was initiated by a number of Swedish WWTPs, LRF and the Swedish Society for Nature Conservation to investigate whether sludge is appropriate as fertilizer for arable land. This project includes investigating if crops fertilised with sludge contain more heavy metals then other crops. The study is not yet completed but the results so far show that no substance has increased in the crops enough to raise awareness (Revaq, 2003).

The Swedish government decided in 2005 that 60 % of the phosphorous in sludge shall be recycled by the year 2015 and 50 % should be used in agriculture (Miljömålsportalen, 2007). Using sludge to produce fertilizer has been the largest field of application in Sweden between 1980-2000 (Naturvårdsverket, 2007). The use of sludge in agriculture, including production of energy crops have varied between 20 to 50 % but has now deteriorated to 10 %. Out of all the produced sludge in Sweden, 60 % meets the standards for agricultural use. The interest for forest fertilizer has increased the last couple of years. Sludge could be used in this purpose to compensate the nutrients that leaches due to acidification and forestry.

If sludge is to be used as fertilizer for arable land, it must be harmless, efficient and cheap. Otherwise neither farmers nor customers will accept it. There are very clear threshold values for heavy metal concentrations in sludge for use in agriculture in both Sweden and the EU today (Table 6). There are currently new propositions which are being processed in both Sweden and in the EU to further increase these standards (European Commission, 2001).

Table 6. Average quality vs. standards for contaminants in sludge used in agriculture (Naturvårdsverket and SCB, 2002).

Contaminants mg/kg DS]	Swedish average in year 2000	EU legislation (Directive 86/278/EEC)	Swedish legislation (1994:944)
Led	33.8	750-1200	100
Cadmium	1.1	20-40	2
Copper	373.4	1000-1750	600
Chrome	31.0	-	100
Mercury	1.0	16-25	2,5
Nickel	16.7	300-400	50
Zinc	549.4	2500-4000	800
AOX	-	500	-
LAS	-	2600	-
DEHP	-	100	-
NPE	-	50	-
PAH	-	6	-
PCB	-	0,8	-
PCDD/F	-	100	-

Besides the legislated standards that must be met when sludge is to be used for agriculture there is an agreement between the federation of Swedish farmers (LRF), Swedish EPA and Swedish Water Company called the *sludge agreement*. This agreement involves work towards improvement of sludge quality and that nutrients should be recycled to arable land. There are also regulations concerning nutrients, organic compounds and dioxins (Table 6) and micro organisms (Naturvårdsverket, 2007).

Rune Andersson at MAT 21 (a Swedish project in sustainable food production) concludes that the debate on the use of sludge in agriculture is based on as much science as feelings. He also claims that most people embrace the idea of recycling but are at the same time doubtful about using sludge in agriculture. This attitude applies to both producers and consumers. (Johansson, 2002). There is also a more fundamental problem with the idea of recycling nutrients. Since food seldom is produced and consumed in the same city, area or even country, recycling nutrients would lead to enormous transport costs (Tengsved Anders, personal communication, 2007). If the sludge is used in agriculture around major cities the nutrients are not recycled but allocated since agricultural products are most commonly produced in other areas then where it is consumed. In order to reduce the transport costs and environmental influence of transport it is therefore necessary to reduce the sludge volume either by stabilization, dewatering, thickening or drying.

Using sludge as fertilizer is important in order to reduce the production of inorganic fertiliser. Phosphorous is considered a limited resource since it only a fraction of the total amount is possible to retrieve by mining. The largest mining regions are North Africa, the United States, Russia, China and South Africa. Imports to Europe come mainly from North Africa and South Africa (Coalition Clean Baltic, 2003). There are also other direct negative environmental impacts with using sludge as fertilizer and soil conditioner. Arable land where sludge has been used instead of inorganic fertilizer can leak more nutrients, which increases euthrophication of lakes and rivers (Torstensson, 2003).

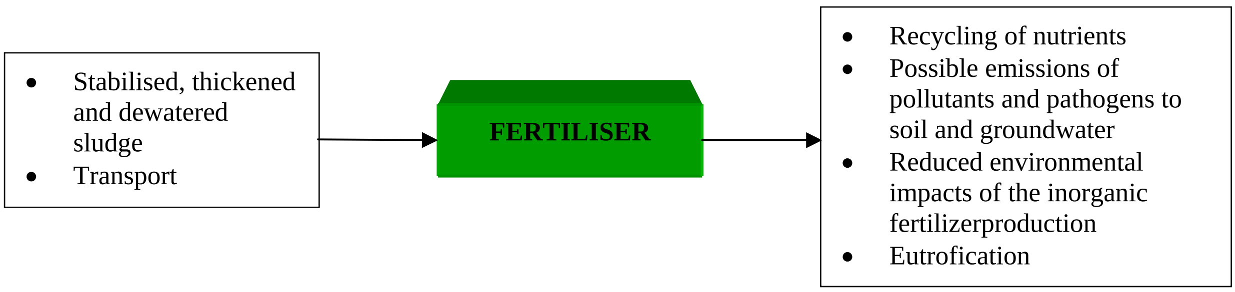


Figure 7. The inputs and outputs of sludge as fertiliser.

3.3.4. Energy production by incineration

Sludge incineration is not a common method of sludge disposal in Sweden since it is difficult to comply incineration with the policy of recycle nutrients (Naturvårdsverket, 2007). However, fluidised bed furnaces or stoke grates designed for co-incineration of waste and bio fuel, are mainly used for sludge incineration (Karlsson, 2005). When sludge is incinerated a complete hygenisation is achieved and sludge volume is decreased (Starberg et al, 1999). The product is energy and ashes which partly contain heavy metals and phosphorus. The recovered energy may be used as heat or electricity. Sludge can be combusted either separately or together with other kinds of wastes. When sludge is co-incinerated it usually contains a mixture of 5-10% sludge. Sludge has an energy value of 12-13 MJ/kg DS and is in that matter equivalent to bio fuels. If the heating value exceed about 3MJ/kg wet sludge it is also possible to generate net energy. 3 MJ/kg is equivalent to a TS value around 50 % (Fritz Lars, personal communication, 2007). Sludge that has previously been anaerobically digested has a lower energy value. Untreated sludge demands 28% DS to be incinerated without support fuel (Svensson, 2000).. Sludge that has been anaerobically digested needs to obtain 45-50% DM to achieve the same effect.

There are examples in Sweden of drying processes where sludge is transformed into pellets. These can then be co-incinerated with other kinds of wastes. Gotland municipality chooses to make pellets out of sludge that is incinerated in the Cementa incineration plant. This solution is applied due to low demand of fertilizer made from sludge (Gotlands Kommun, 2007). Incineration facilities are complicated and expensive and only very large facilities are therefore cost effective (Jönsson et al. 2003).The recovered energy is usually counterbalanced by the energy that is used to reduce the water content in the sludge. If dewatered sludge is incinerated, the generated energy is used to reduce the water content in sludge. If sludge is dried before incineration, the recovered energy will counterbalance the energy used in the drying process (European Commission, 2001).

There are several environmental impacts that need to be avoided. The primary one is emissions to air but there is also risk for noise, odour and visual pollution (European Commission, 2001). However, there are techniques to minimize the air pollution. Successful incineration plants can be found in Germany and Great Britain which operates under national and EU legislation. A good example is Crossness Sewage Treatment Works (STW) in London where the emissions to air are well below the English emission limits. The odour problem is also limited with special sludge transfer systems but is still acknowledged as a problem by Crossness STW (Crossness, 2007).

A problem with sludge incineration is that the interest to improve sludge quality by reducing pollutants in sludge could decrease. Another downside is that valuable nutrients are lost in the ashes (Johansson, 2002; Figure 8).

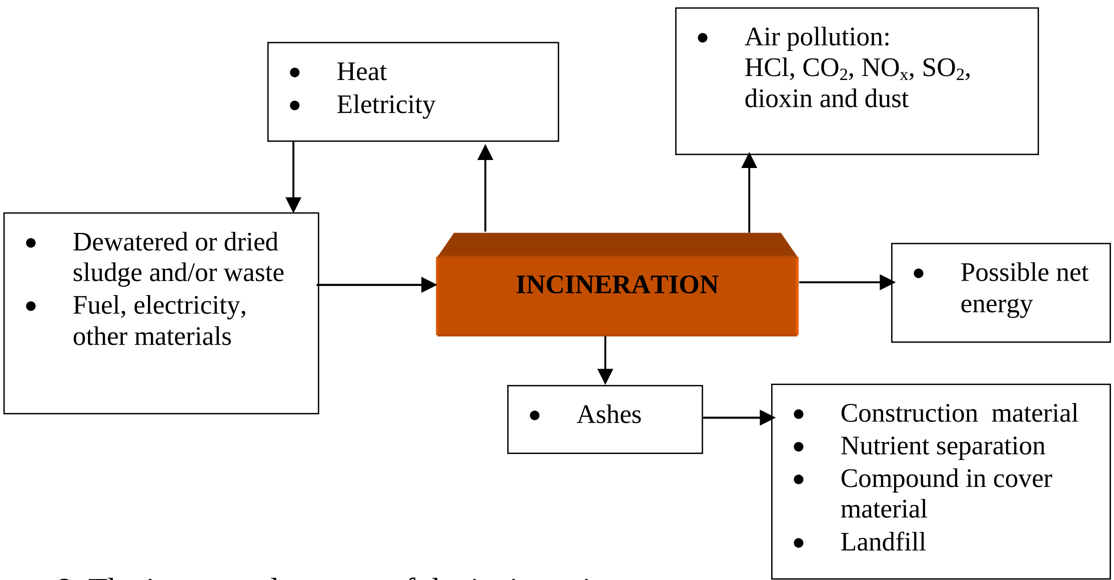


Figure 8. The inputs and outputs of the incineration process.

There are many ways by which ash can come to use in our society. Besides the possibilities of nutrient separation, it can be used as building and construction material or as part of cover material. Brick making, manufacture of cement and use in pavement are examples of where ashes from sludge incineration can be used. However, there is a problem with the acceptance in Europe. Since there are great variations in the sludge quality, it is difficult to establish ashes as a reliable construction material (Babatunde & Zhao, 2007).

3.3.5. Biogas production

Biogas is produced in a biogas reactor where the sludge also is stabilized, as described in section 3.2.1. The major steps in the biogas process are hydrolysis of bio polymers, fermentation of solubilised compounds, anaerobic oxidation of fermentation products, production of acetate from hydrogen and carbon dioxide and conversion of acetate and hydrogen to methane. Biogas consists mainly of methane and carbon dioxide. Since this is a delicate process, biogas may not be the final product if the previous steps are in some way inhibited (Schnürer, 1995). The most important factors that regulate the fermentation process are the composition of the sludge, pH, temperature, the amount of water in the sludge and the absents of substances that inhibit the process, for example heavy metals (Bioenergiportalen, 2007)

The two most commonly used temperature intervals are 25˚ to 40˚ (mesophile) and 50˚ to 60˚ (thermophile). In thermophile fermentation the process is almost twice as fast as in mesophile fermentation (Bioenergiportalen, 2007). This means that the material does not need to be in the biogas reactor as long and that the size of the reactor can be smaller. The process is not as stable at higher temperatures as at lower ones, it is more sensitive to changes in temperature and more sensitive to substances that may inhibit the process. Other kinds of waste can also be included in the process, such as from meat and other foods. Biogas production is a relatively new sludge treatment in Sweden but is an expanding technique all over the country.

Biogas contains different compounds and methane gas is one of them. Besides methane, it also contains water vapour, carbon dioxide, small amounts of sulphur and nitrogen compounds. Unlike natural gas, which also contains methane, biogas is a renewable fuel. This means that it doesn't contribute to emissions of carbon dioxide and which affect global warming. Methane gas is however a green house gas as well, about 20 times more powerful effect. It is therefore of great importance that the production and use of biogas is done with as little leakage as possible to the atmosphere. Biogas it produced locally which decreases the environmental impact (Norrman et al., 2005). Biogas can be used for production of electricity and heat but also fuel for buses and cars (Figure 9). If the biogas is used as fuel for transportation it needs to be further cleaned and upgraded to an acceptable level for engines. 1 m^3 of biogas has approximately the same energy content as 1 l of gasoline. Every litre of gasoline contributes with approximately 2.5 kg of carbon dioxide to the atmosphere. As an example of this one can look at the biogas production of Stockholm Water. They produce 8 million m^3 of biogas every year, which saves the atmosphere from an annual contribution of 20 000 tonnes carbon dioxide (Stockholm Vatten, 2007).

Since fuel for buses is a common field of application for biogas in Sweden it is important to compare the running costs. In order to compare costs, calculations are usually made of fuel, maintenance and investment costs. Since the costs can vary a lot between different regions it is difficult to make such a comparison. However, the numbers in table 8 are taken from examples in Sweden where a comparison has been made between biogas buses (environmental class 1 in the EU) and diesel buses (environmental class 4 in the EU). The calculations are based on 61 000 km per bus and year. The biogas bus is assumed to consume 0.5 m^3 gas / km and the diesel bus 0.45 l / km. The environmental and health effects are based on the emissions from the different buses (Norrman et al., 2005).

Table 8. Comparison of diesel Euro 4 and biogas Euro 1 class.

Cost	Biogas – Euro 1	Diesel – Euro 4
Fuel	225 000	218 000
Maintenance	100 000	80 000
Investment	382 000	328 000
Environment and health	10 000	45 000
Total	870 000	803 000

Biogas production facilities are more advanced than for instance compost facilities. It therefore requires more know-how and staff to operate. However, if the production runs well, large facilities can be very competitive and generate substantial economic profit (Jönsson et al., 2003).

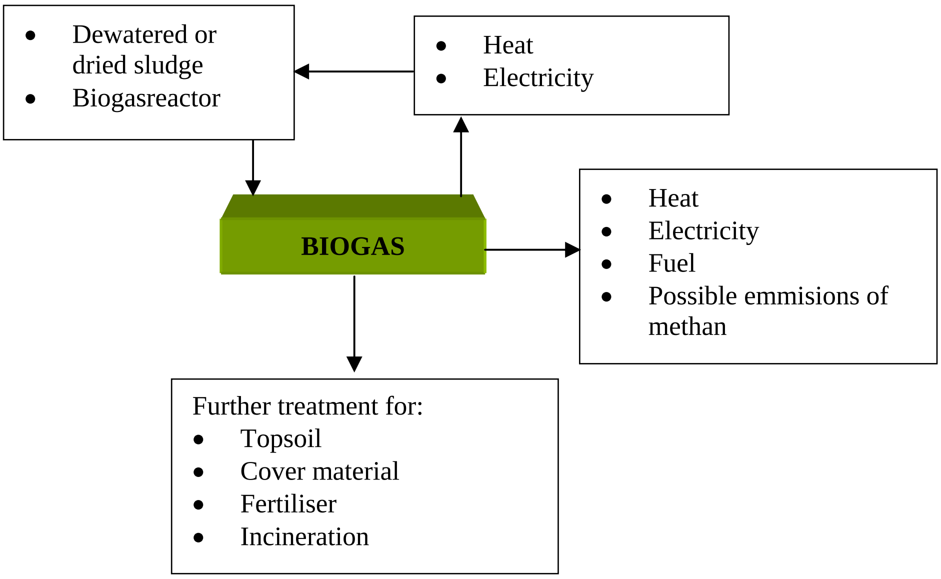


Figure 9. The inputs and outputs of the biogas production process.

3.3.6. Resource recovery

There is a number of techniques that have been evaluated for separation of nutrients, precipitation chemicals and heavy metals in Sweden. Cambi/Krepro and Aqua Reci are two systems which are capable of this with variating success. The possibilities of recovering resources from sludge are very much dependant on the sludge quality (Hultman et al, 2002). The Cambi technique uses heat treatment to dissolve organic material which decreases sludge production and increase the biogas production. This is followed by Krepro (Figure 10) which involves a system of heat, pressure and sulphuric acid to dissolve metals, phosphates and organic compounds (Figure 10). The sludge has a DS value of 45-50% after this treatment and is suitable for combustion. Phosphorous and iron are recovered as ferric phosphate and ferrous iron. Another retrieved substance is the dissolved organic matter which can be used as a carbon source in the denitrification process in the ASP.

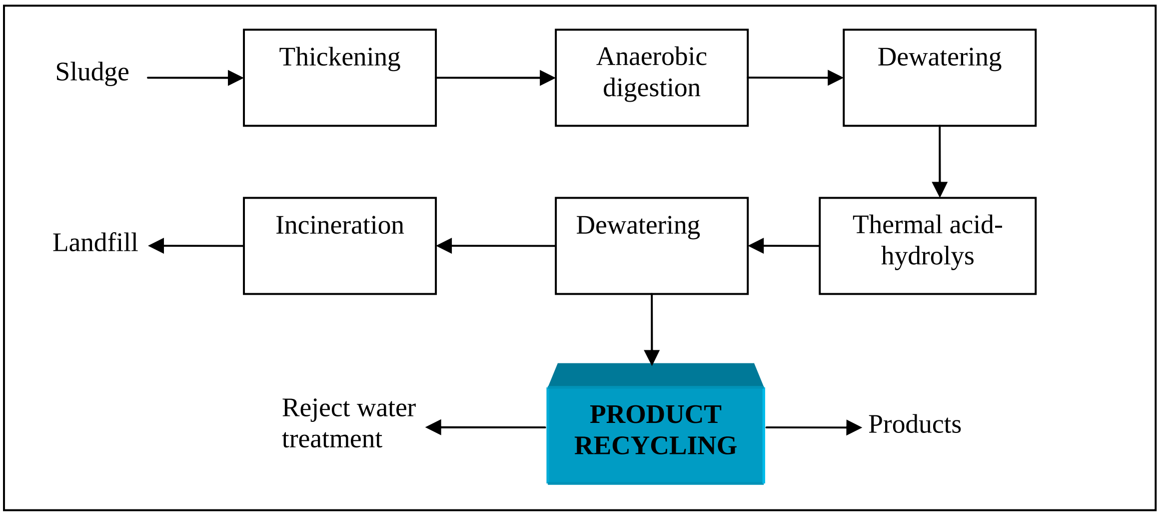


Figure 10. Krepro process (Hultman et al, 2002).

Aqua Reci uses supercritical conditions during which oxygen is added to destroy organic matter. This technique produces clean water containing a fine particulate phase of inorganic material. The inorganic phase is separated from the water phase through thickening or dewatering and is then treated in a subsequent step to recover precipitation chemicals and phosphorous.
(Chematur Engineering, 2007; Figure 11). A great advantage with Aqua Reci is the reduction of the volume of treated sludge. The remaining amount is about 10 % of the initial amount. The process is maintained without external energy since the heat from the oxidation step can be retrieved (Hultman et al., 2002). This technique is supported by Stockholm Water Company for sludge treatment and phosphorus recycling (Köhler, 2002).

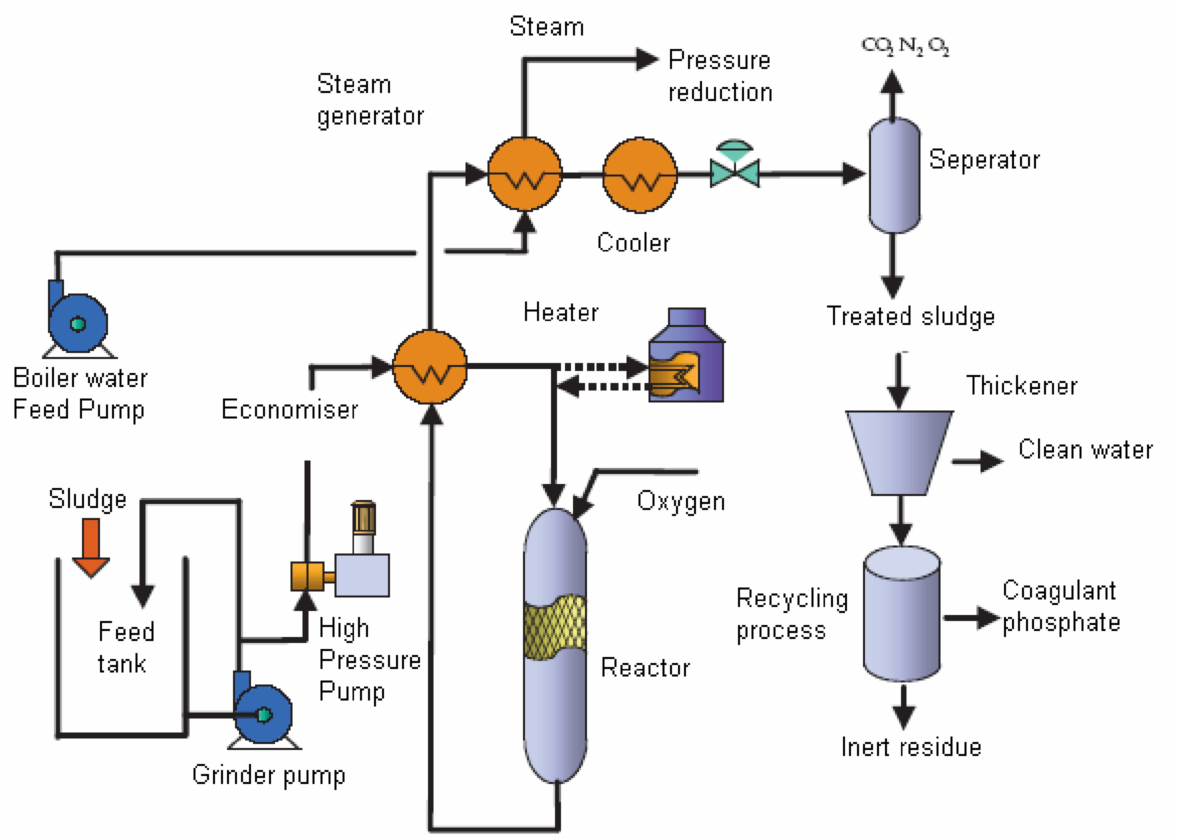


Figure 11. Aqua Reci process (Chemateur Engineering, 2007).

Besides precipitation chemicals, there are many other possible resources in sludge for internal use in WWTPs (Table 9). However, the interaction between WWT and sludge management is a neglected area in research and development with significant potential for cleaner production and savings in running costs (Hultman et al., 2004).

Table 9. Possible resources in sludge for internal use (Hultman et al, 2004).

Resource	**Field of application**
Carbon dioxide (CO_2)	Neutralisation of wastewater with CO_2 that has been produced by anaerobic digestion or incineration
Methane gas	Energy production (heat, electricity)
Pyrolyse gases	Energy production (heat, electricity)
Organic acids	Production of methane gas, improved denitrification and biological phosphorous reduction
Nitrate	Reduction of odour
Metal ions	Precipitation chemicals
Active coal	Adsorption of organic material produced by sludge pyrolyse
Nitrification bacteria	Seeding the nitrification bacteria from a separate step with high influent ammonium concentrations to the ASP.
Sludge with high concentration of inorganic material	Recycle this to the ASP to improve sedimentation properties

3.3.7. Comparison of sludge disposal methods

A summary of the different arguments for and against the described field of application for sludge is illustrated is table 10. The economic factor is one of the most important factors in sludge management (Hultman et al, 2002). In 2004 Gävle Water Company ranked different sludge disposal methods and their costs in Sweden (Weglin, 2004). An overall estimate showed that the most expensive sludge disposal method was landfill (657 SEK/t), followed by incineration (559 SEK/t), followed by topsoil and cover material (239 SEK/t) and the cheapest was as fertilizer (226 SEK/t). The price for incineration was much less if co-incineration was applied (300 SEK/t). Two other studies done by the European Commission and the WRC group in Scotland show differences in exact costs, but draw the same conclusion when ranking the costs in the EU (European commission, 2001; Hall J., 1999). Major changes in Sweden and Europe are predicted due to the development in the major influential factors on sludge management (Figure 12, 13). Incineration will likely become a common method in the EU but not in Sweden. The use of sludge in agriculture will increase and landfilling will decrease. The use of sludge in production in cover material and construction soil will not change significantly.

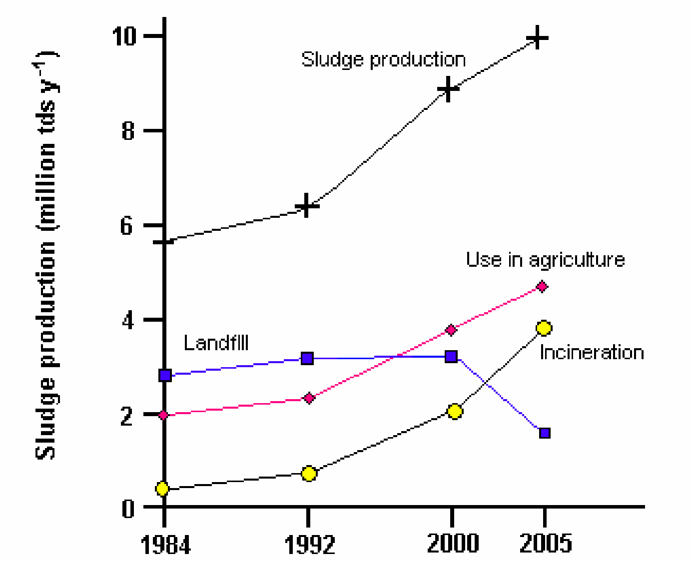


Figure 12. Sludge disposal prediction in 12 EU member countries (EU Commission, 1997).

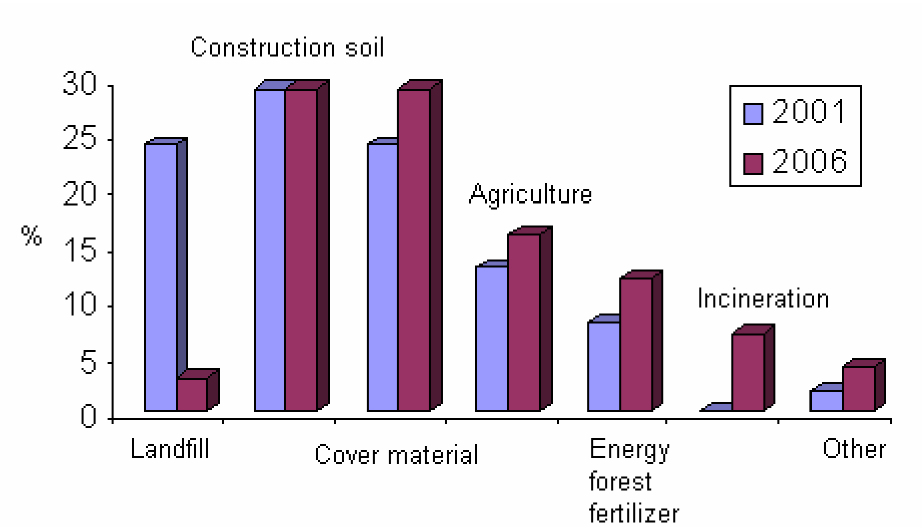


Figure 13. Sludge disposal prediction in 150 municipalities in Sweden (Johansson, 2002).

A life cycle assessment made by Stockholm Water Company ranked the environmental impacts of four different fields of application for sludge (Svanström et al, 2004). The compared routes were Aqua Reci, cover material, construction soil, for agricultural use. The results showed that Aqua Reci had least negative impacts on the environment. A big environmental benefit which was conveyed by all of the compared sludge routes, was the reduced need for inorganic fertilizer. The negative environmental effect they all had in common where transport.

Table 10. Arguments for and against the different sludge disposal methods in Sweden.

Sludge disposal method	Argument for	Argument against	Necessary treatments
Landfill	• Simple (conventional landfill)	• Expensive (due to taxes and fees) • Potential air, water and soil pollution • Noise from delivery vehicles , odour and possible attraction of birds and rats • Transport	None, but dewatering reduces volumes and therefore costs.
Topsoil and cover material	• Topsoil and cover material is normally an expensive and scarce resource • Reduced environmental impacts of other topsoil and cover material production • Reduces certain leakage from dangerous sites (cover material) • Cheap solution	• Transport • Possible water and soil pollution	• Stabilization • Dewatering/drying • A mix with other material such as ashes needs
Fertiliser	• Nutrient recycling • Cheap soil conditioner and fertilizer for farmers • Less need for inorganic fertilizer which causes great environmental damage when produced and transported • Cheap disposal solution	• Transport • Potential water and soil pollution • Euthrophication • Storage facilities	• Stabilization • Dewatering/drying
Incineration	• No transport • Green energy • Possible nutrient recycling • Stabilizes the sludge • Reduces the volume	• Potential air, water and soil pollution • Expensive technology	• Dewatering/drying
Biogas production	• No transport • Green energy and fuel • Stabilizes the sludge for further use. • Reduces the volume	• Possible methane emissions	• Thickening
Separation techniques	• Separate nutrients, precipitations chemicals and heavy metals • The need for transportation is reduced due to reduced volume.	• High investment costs • Not any established techniques	• Thickening

4. RESULTS - SLUDGE MANAGEMENT IN WUHAN

The literature study showed that in the next ten years, there will be more than 1000 operational municipal WWTPs in China. In 2006, 39 % of the Chinese populations was served by municipal WWTPs (Figure 14). Since the year 2000, the collected wastewater in China has increased by 18.2%, while the wastewater treatment capacity has increased by 135%. In the year 2005, 297 cities in China had no WWTPs for treating wastewater. These facts indicate the potential growth of sewage treatment capability and sludge production (He et al., 2006).

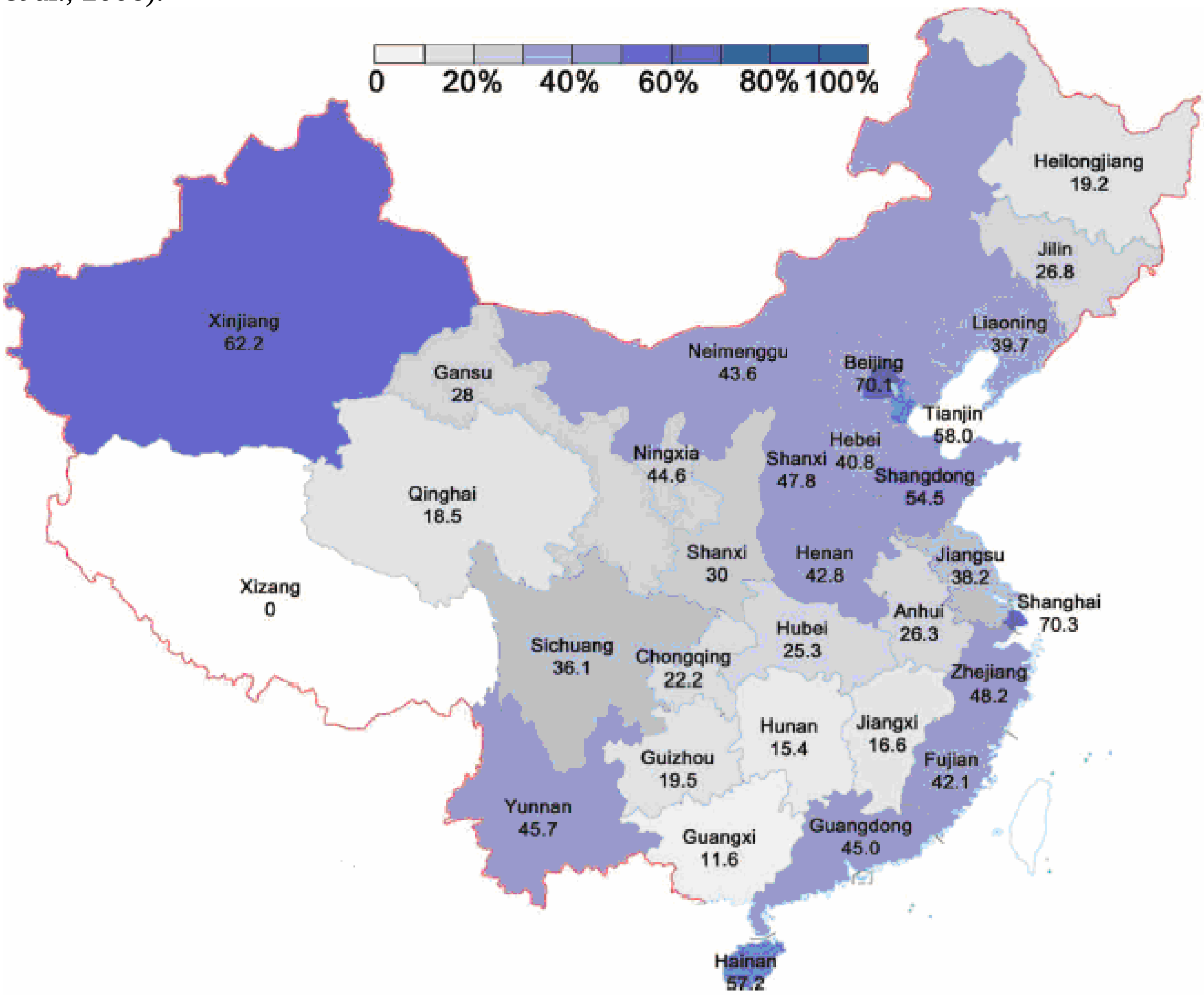


Figure 14. Percentage of population serviced by WWTPs in China 2005 (He et al., 2006).

4.1. CHINESE SLUDGE MANAGEMENT

Results from the literature study showed that although China has begun to pay attention to the problem of sludge disposal, it still remains at the planning stage in many cases (Jun et al., 2004). In 2005, 9 million tons of dewatered sewage sludge was produced with 80% water content, which accounts for 7% of all the solid waste in China (He et al., 2006). The major cities in China apply different sludge treatments and disposal methods (Table 11). China's main disposal methods are fertilizer production (45%) and landfill (31%). Other disposal methods account for 10.5% and no disposal of about 13.7%. In the case of no disposal, the sludge is either randomly discarded in lakes or on land. The Chinese WWTPs investment in sludge treatment and disposal is about 20-50% of their total investments (Wei et al., 2000).

Table 11. Sludge management methods in other Chinese cities (He et al, 2006).

City	Sludge disposal method
Guangzhou	Fertilizer production
Shenzhen	Incineration
Shanghai	Composting for horticulture, landfill and incineration
Tianjin	Anaerobic digestions
Beijing	Land application
Hefei	Incineration
Taiyuan	Compostation to produce fertilizer
Shenyang	Incineration

The main responsibility of municipal sludge treatment and disposal is not clearly established, which is based on three fundamental problems (Jun et al., 2004):

1. WWTPs are not a civil corporate entity and are owned and governed by many institutions. There is no independent instance that bears the responsibility.
2. The expenses for sludge treatment and disposal are not included in the municipal wastewater fees. These fees are not sufficient to cover the charges of sludge management.
3. There is too much focus on sludge as waste or resource rather then on the responsibility to govern a sustainable disposal management strategy.

4.1.1. Chinese sludge quality

The municipal sewage sludge in China contain about 40–50% organic matter which is considered low compared to developed countries (Wei et al, 2000). Other concentrations such as heavy metals vary between different WWTPs (Table 12).

Table 12. Sludge content in 22 WWTP in different Chinese cities vs. Swedish average (Wei et al., 2000; Naturvårdsverket and SCB, 2002).

Control item	Chinese average in 1997	Swedish average in 2000
TN [%]	2.9	-
TF [%]	1.00	-
TK [%]	0.7	-
Ca [%]	7.17	-
Organic matter [%]	39.57	-
As [mg/kg DS]	19.27	-
Cd [mg/kg DS]	2.35	1.1
Cr [mg/kg DS]	403.31	31.0
Cu [mg/kg DS]	393.80	373.4
Hg [mg/kg DS]	4.46	1.0
Ni [mg/kg DS]	125.27	16.7
Pb [mg/kg DS]	168.00	33.8
Zn [mg/kg DS]	2202.78	549.4
B [mg/kg DS]	53.90	-
Benzoa, pyrene [mg/kg DS]	0.17	-

The quality of the sludge from many of China’s WWTPs does not meet the requirement of the regulations. High concentrations of heavy metals and organic pollutants are the main reasons. The quality of sewage sludge in China is also poor since Chinese sludge consists of low fat and high carbohydrates content (Wei et al., 2000).

4.1.2. Chinese legislation

There are three laws in Chinese environmental legislations that contain restrictions on sludge management.

- Control standard for pollutants in sludge for agricultural use, GB4284-84 (promulgated 1984 but never amended).
- Criteria for controlling the discharge of sewage and sludge from municipal wastewater treatment plant, CJ3025-93.
- Criteria for controlling the discharge of pollutants from municipal wastewater treatment plant, GB18918-2002.

GB18918-2002 concludes that all sludge should be stabilized and shall meet the control degradation indexes pathogen concentrations after stabilization (Table 13). The reality is that the construction of WWTPs often is built only to achieve emission standards and not sludge quality standards. Without a stabilization treatment of sludge from high content of organic matter, it is highly corrupt and has a foul smell, especially early sedimentation tank sludge, containing large number bacteria, parasite eggs and viruses and could easily lead to the spread of infectious diseases (Wuhan EPB, 2007).

Table 13. Control indexes of sludge stabilization (GB18918-2002).

Stability Method	Controlled Item	Standard [%]
Anaerobic Digestion	Organic Matter Degradation Rate	＞40
Aerobic Digestion	Organic Matter Degradation Rate	＞40
Aerobic Compost	Moisture content (%)	＜65
	Organic Matter Degradation Rate	＞50
	Helminth (worm) eggs mortality	＞95
	Fecal coliform value	＞0.01

There is also restriction of the water content in dewatered sludge. It must not exceed 80 % water after dewatering. The monitoring and analysis methods that should be used and performed are found in GB18918-2002 as well. GB18918-2002 contains standards for pollutants in sludge for agricultural use (Table 14). GB4284-84 contains many other restrictions for the use of sludge in agriculture. Some examples of these are:

- It is unsuitable to use sludge on crops that are to be harvested the same year.
- It is unsuitable to use sludge on sandy soils and on arable land where the water table is high.
- The use of sludge on arable land should not exceed 30 tonnes dry solids per year and hectare.
- It is not permitted to use raw sludge on arable land.
- Before using sludge on arable land the sludge must be decomposed in high temperature or digested.
- Usage of sludge should be stopped when the growth of crops is negatively influenced or if the hygiene standard of the agricultural product is exceeded.
- The sludge, soil and crops must be monitored for a long time in fixed position by the agriculture and environmental protection department.

Table 14. Standard limits for sludge used in agriculture in China vs. Sweden.

Control item	Chinese legislation (GB18918-2002) [mg/kg DS]		Swedish legislation (1994:944) [mg/kg DS]
	pH<6.5	pH>=6.5	
Total cadmium	5	20	*2*
Total mercury	5	15	*2.5*
Total lead	300	1000	*100*
Total chrome	600	1000	*100*
Total arsenic	75	75	-
Total nickel	100	200	*50*
Total zinc	2000	3000	*800*
Total copper	800	1500	*600*
boron	150	150	-
Petroleum-like	3000	3000	-
Benzo(a)pyrene	3	3	-
Polychlorinated dibenzo-p-dioxins/ Polychlorinated dibenzofurans(PCDD/PCDF [ng toxicity unit/kg dry sludge]	100	100	*100**
Adsorbent organic halide (AOX counted by Cl)	500	500	*500**
Poly chlorinated Biphenyls（PCB）	*0.2*	*0.2*	*0.8**

***EU legislation (**Directive 86/278/EEC)

4.2. SLUDGE MANAGEMENT IN WUHAN

Sludge is a relatively new problem to Wuhan. The production of sludge has increased from 150 000 tons per year to 1.65 million tons per year in only five years (Qiu Wenxin, personal communication, 2007). In 2006, the total amount of sewage discharge was 66 million tons of which 38 % was industry sewage (Wuhan EPB, 2006). Six WWTPs were in operation in Wuhan and another seven were under construction (Appendix 1). When the 13 WWTPs are constructed, Wuhan will have a capacity to serve 4,2 million people (Appendix 1). That implies that when the last WWTP under construction is fully operational, 58% of the population in Wuhan will be connected to the municipal WWTPs. These calculations are based on that the population is constantly 7,3 million.

The amount of treated industrial wastewater varied between the different WWTPs in Wuhan. For instance, Zhuankou WWTP treated 60% industrial wastewater, mainly from the auto mobile industry, while Shaha WWTP treated 20 % industrial wastewater (Hagberg, 2007; Zhang & Wu, 2007). A common problem for the WWTPs in Wuhan was sludge bulking in the ASP. The EPB in Wuhan welcome Swedish expertise to find the solutions to this problem. The sludge quality was poor in general with high water content and varying concentrations of heavy metals which could reach non-acceptable values (Qiu Wenxin, personal communication, 2007). There was no official plan to come to terms with these problems.

4.2.1. Current sludge management in Wuhan

There is no government endorsed strategy for the treatment or disposal of sludge in China (Asian Development Bank, 2006) and Wuhan was without a local sludge disposal policy (Qiu Wenxin, personal communication, 2007). Wuhan Urban Drainage Development Co. Ltd is responsible for the WWTPs in Wuhan. This company belongs to the Water Administration Bureau at EPB. Every district in Wuhan has a sub-division of that department which governs the wastewater treatment and sludge treatment in their district. These sub-divisions have no official strategy or policy for sludge management.

All of the treated sludge was disposed of on landfills which were not far away from the location of WWTPs. The cost was 1 RMB/ton and kilometre transported. Then there was an additional fee about 20-40 RMB/ton. The fee differed depending on which company that runs the landfill. At some landfills, the municipal sludge was not separated from the industrial sludge and solid waste (Chen Lei, personal communication, 2007). There were major problems with polluted leakage from certain landfills since the rather water rich sludge was mixed with solid waste and industrial sludge (Figure 15). Pollutants in the solid waste may therefore be transported with leakage water from the landfill to soil and groundwater (Qiu Wenxin, personal communication, 2007).

Figure 15. Sludge mixed with solid waste on Dan Shan landfill, a branch of the Yangtze River in the background.

There were also plans to use sanitary landfills for the sludge. These landfills will use hydro-geological isolation, where the landfill floor is made of different layers of clay and plastic to reduce leakage. These landfills will also have leach water treatment (Lilin Feng, personal communication, 2007).

4.2.2. Future strategy

There were plans to build eight sludge treatment plants before 2020. The cost for this project is 1 billion RMB. According to the plan, the two largest should be operational before 2010. The construction of one sludge treatment plant was now in progress and will treat the sludge in an anaerobic digestion chamber. The solid residue will be sent to landfills. The specific process of sludge treatment in the other seven plants have not been decided (Yu Xiao, personal communication, 2007).

A 100 million dollar loan has been granted by the Asian Development Bank (ADB) to China to help improve urban environment in Wuhan. The project involves municipal wastewater management, sludge management and storm water management. New WWTP will be built, existing WWTPs will be upgraded and collection networks will be extended. The project's estimated total cost is 266.4 million U.S. dollars. For each new WWTP, a controlled sanitary landfill is selected for the sludge disposal. The sludge that will be produced at these new WWTP is agreed to be handled by the Wuhan Municipal Urban Management Bureau, which is also responsible for garbage disposal. The Wuhan Urban Construction Bureau has agreed to receive the sludge. The Wuhan Municipal Wastewater Company (WMWC) has confirmed this with a signed agreement for the final disposal of sludge in the sanitary landfills. The negative effects from sludge disposal are expected to be minimal. Other options were considered, but were found to be less suitable for technical, financial, and economic reasons (Asian Development Bank, 2002).

Table 15. The WWTP financed by loans from ADB (Asian Development Bank, 2006).

	San Jin Tan WWTP	**Luo Buz Ui WWTP**	**Huangjia Lake WWTP**
Capacity [m3/day]	300 000	120 000	100 000
Service population	820 000	400 000	350 000
Sludge disposal	Sanitary landfill	Sanitary landfill	Sanitary landfill
Industrial wastewater [%]	22.6	17.3	24.1

4.3. RESULTS FROM VISITS TO WWTPs IN WUHAN

Three WWTP were visited in order to confirm the information on Wuhan sludge management and retrieve other information as well. Different members of the staff were asked about sludge quality, sludge treatment, sludge disposal (Table 16), wastewater treatment (Table 17) and other general information about the plant.

Table 16. Sludge quality, treatment and disposal at the visited WWTP vs. national standards.

	San Jin	**Shaha**	**Hanxi**
Construction year	Under construction	1994	2004
Sludge production [tons/day]	100	70	100
WWT Capacity [tons/day]	300 000 (in 2010)	150 000 (20% from industries)	400 000 (20% from industries)
DS [%]	20	24	26
Concentrations of heavy metals	“Low”. No official data	“Low”. No official data	“Low”. No official data
Sludge treatment	Polymer, drum thickeners, centrifuges and anaerobic digestion.	Gravity settling tanks and dewatering filter presses	Polymer, drum thickeners and centrifuges.
Sludge disposal	Future biogas production. Transport to landfill by diesel trucks	Transport to landfill by diesel trucks	Transport to landfill by diesel trucks

Table 17. Emissions from the visited WWTP vs. national standards.

Monitor factor	**San Jin***		**Shaha***		**Xanti***		**Standards***
	Inlet	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	
COD	150	20-40	115	34	170	23	50-120
BOD	50-80	8-20	39,4	11,8	86,6	10	10-60
SS	50-100	10-20	40	10	124	8	10-50
Total N			20	16			20
Total P			2,22	1,49	3,12	1,79	1.5

*Data from the WWTP are based on interviews and standards from GB18918-2002

4.3.1. Results from San Jin Tan WWTP

The construction of this WWTP was not yet finished, but some compartments were operational. The capacity of this WWTP will be 300 000 m^3/day when it is fully operational in 2010. It will treat storm water as well, but no separate control of the inlet was installed. The waste water treatment contains mechanical treatment and biological (anaerobic/aerobic) phosphorous removal (Appendix 2). The system for emission control at San Jin Tan was not fully operational but some estimated values of emissions were established (Table 17). The director was confident of their capability to meet the national standards. The major problem in the wastewater treatment for this WWTP was the energy cost for the aerobic tanks and the pump stations (Li, personal communication, 2007). The sludge was treated in three steps before it was sent to landfill. The company that handled the sludge disposal was confidential but the cost is between 40-80 RMB per ton, which includes transport and fees. The sludge treatment is a three-step process. The first step is adding a polymer, followed by a thickening process with drum thickeners (Figure 16). This process was then followed by dewatering the sludge with centrifuges (Appendix 2). This process produces 100 tons of sludge per day and achieved 20 % DS.

Figure 16. Dewatering centrifuges (left), drum thickener (right) at San Jin Tan WWTP.

A biogas reactor (Figure 17) is under construction but not yet operational. The biogas will be used for energy production for internal use and in the future to produce fuel for buses.

Figure 17. Biogas facilities under construction at San Jin Tan WWTP.

There were not many industries in this specific WWTPs serving area, but it did, however, treat storm water. The director did not see heavy metal concentration in the produced sludge as a problem, but there were no official values to support this claim. The director of San Jin Tan did not prioritize investigating more sustainable methods in sludge treatment or sludge disposal. Although this plant is run by the government, the first priority was wastewater treatment and not sludge management (Li, personal communication, 2007).

4.3.2. Results from Shaha WWTP

The capacity of this WWTP was 150 000 tons per day and it served about 300 000 people. It was constructed in 1993 and was modernised 2002 and 2005 when new dewatering equipment was installed. The wastewater treatment involved mechanical and biological treatment. The sludge treatment consisted of four gravity thickening tanks and three belt filter presses. After the dewatering process, the sludge was transported by diesel trucks to a landfill. About 70 tons (24 % DS) were produced per day and one truck could transport about 5 tons at a time. The price for the sludge disposal was 400-500 RMB per truck, which includes both transport and fees. Mr Zhang, vice director of Shaha WWTP, revealed that Shaha WWTP is interested in investing in more modern technology since the major problems for Shaha is not financial but technical due to large variation in the effluent water quality. However, they were concerned about the high costs for the aeration system to the biological treatment. About 20 % of the treated water came from industries. Shaha WWTP also treated storm water but no control system was installed to monitor the inlet. The concentrations of heavy metals in the sludge were low, but there were no routine controls and no official values were available to support this claim. Such controls were considered difficult and expensive. Other sludge disposal methods have not been considered since Shaha WWTP is owned by the government and the sludge management of Shaha WWTP is not decided by the staff (Zhang, personal communication, 2007).

Figure 18. Finish dewatering filter press at Shaha WWTP (Slamex, 2007).

4.3.3. Results from Hanxi WWTP

Hanxi is one of the newest WWTP in Wuhan. It is run by a Singapore company under a Build, Operate and Transfer (BOT) contract. The contract ends in 25 years and began when Hanxi was constructed in 2004. The plant will reach its full capacity in 2010, but was already serving 150 000 people. The wastewater treatment was followed by the thickening and dewatering of sludge. A polymer was added in the thickening process, which included three drum thickeners followed by three centrifuges. This process produced 100 tons per day (26% DS) which was transported by diesel trucks to landfill. None of the other disposal methods were considered by the management. Hanxi WWTP also treated 20 % wastewater from industries. Storm water was also treated but the inflow of this was not controlled in any way.

The heavy metal concentrations were considered low, but there are no controls made. One control was, however, made during the first day of operation, but no official record of this data was available. Nevertheless, the responsible EPB department for this WWTP did have the results from the analysis of one sample in 2004 (Table 19). This sample indicates that the sludge quality is good enough for agricultural use according to Chinese law.

One of Wuhan's eight planned sludge treatment plants will be built in the Hanxi WWTP. In the future, EPB plan to look for appropriate methods, but nothing has been decided yet. They are interested in applying Swedish technology to this project (Chen Lei, personal communication, 2007).

4.3.4. Summarized results from the three visits

The results from the visits can be summarized by the following:

- The DS value was between 20-26 % and achieved by thickening and dewatering
- The sludge was not stabilized in any of the WWTPs.
- One biogas facility was under construction
- All sludge was landfilled at a cost of 60-100 RMB/ton
- There was only one documented sludge quality sample from the visited WWTPs (Table 18)

Table 18. Hanxi sludge quality vs. limits for sludge used in agriculture (Chen Lei, personal communication, 2007; Naturvårdsverket and SCB, 2002)

Control item [mg/kg DS]	San Jin Tan	Shaha	Hanxi (One sample)	Swedish average in 2000	Chinese legislation (GB18918-2002) [mg/kg DS]	
					pH<6	pH≥6
Total Cadmium	-	-	4.78	1.1	5	20
Total Mercury	-	-	3.05	1.0	5	15
Total Lead	-	-	75.8	33.8	300	1000
Total Chrome	-	-	165	31.0	600	1000
Total Arsenic	-	-	20.3	-	75	75
Total Nickel	-	-	41.8	16.7	100	200
Total Zinc	-	-	458	549.4	2000	3000
Total Copper	-	-	240	373.4	800	1500

The mass balance of the sludge route from the WWTPs was quite simple, since the sludge was only dewatered and dried. It was divided into three steps based on the results from the visits to the WWTPs (Figure 19).

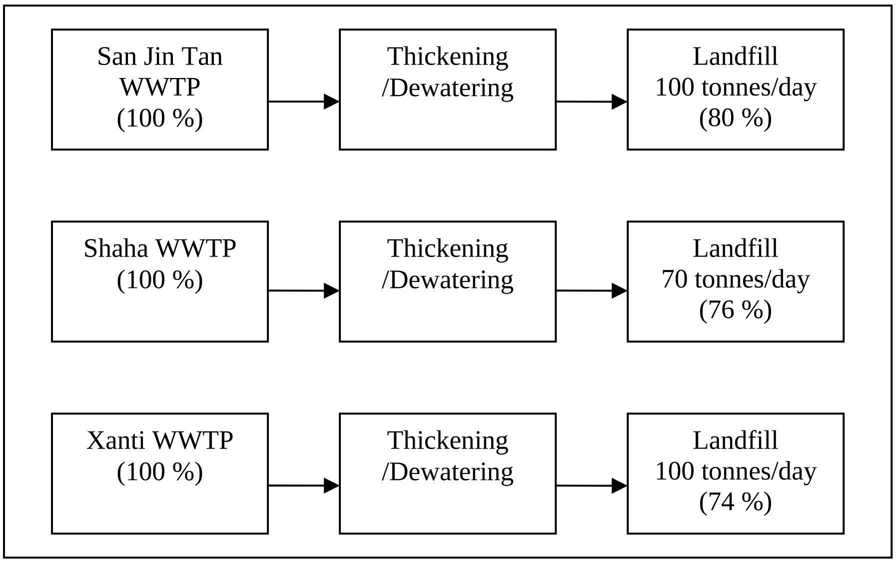


Figure 19. Mass balance of the sludge from the visited WWTPs.

4.4. POSSIBLE SOURCES OF SLUDGE POLLUTANTS

Wuhan is the location for car, plastic, ship-building and textile industries (Gong Yuan, personal communication, 2007) and the major sources of pollutants are industries and storm water (Qiu Wenxin, personal communication, 2007). All major industries operate under strict discharge regulations and have their own wastewater treatment, but there are no control programs to ensure that the effluent water from the industries to the municipal WWTPs meets these standards. However, industries have to pay penalty fees if the emission values are too high (Qiu Wenxin, personal communication 2007). The authorities for municipal WWT are not taking any action to reduce the incoming pollutants from industries, since it is not their responsibility.

4.4.1. Peugeot and Citroen

Dongfeng is a Chinese company that runs car factories in Wuhan in joint venture cooperations. They own 51% of the car factories and therefore operate under Chinese regulations. Two of their factories, Peugeot-Citroen and Honda, were visited to investigate their wastewater treatment. The Peugeot and Citroen factory produce 300 000 cars per year and are soon expanding their capacity to 450 000 per year (Liu Dong Qing, personal communication, 2007). Five m^3 of water is needed to produce one car, which means that 2 250 000 m^3 water will be used every year when the capacity is reached. This industry has operated in Wuhan since 1992 and implemented water treatment in 1997. The sludge is divided into hazardous waste, which include sludge from the painting process, and non hazardous waste, which include the sludge from the pre-treatment. The painting process includes hexavalent chrome, general lead and general nickel. These substances eventually end up in the sludge (Table 19).

Table 19. Discharge concentrations from the painting department in Dongfeng car factory (Peugeot, 2006).

Heavy metals	Standard limit value (mg/l)	Discharge concentration (mg/l)
Chrome (Cr^{6+})	0.5	0.002
Lead (Pb)	1.0	0.03
Nickel (Ni)	1.0	0.02

The pre-treatment involves the use of an iron compound as a precipitation chemical, which ends up in the sludge. There are other possible pollutants as well in the sludge, since the pre-treatment involves many other chemicals. The sludge from the pre-treatment is classified as non-hazardous waste and is put on landfill together with the municipal sludge.

4.4.2. Honda

This factory had their current wastewater treatment installed 2003 and was satisfied with its efficiency (Luo Ning, personal communication, 2007). There was no impartial control of the waste water treatment. The factory was paying a fixed fee of 4000 RMB/month to the EPB, which covered all their emissions to air and water. This fee includes wastewater treatment, noise and other emissions. The Honda factory reused 60 % of the water, which means that only 40 % was treated by the municipal wastewater treatment plants. The treatment for the effluent water was included in the fixed fee to EPB. The monitor factors included pH, SS, COD, BOD_5, petroleum, phosphate, nitrobenzene, volatile phenols, aniline and water effluence. The Honda factory also monitored the heavy metals Cr^{6+}, Pb and Ni after the outlet of phosphate equipment and the outlet of painting equipment. The only heavy metals that are monitored in the total effluent water are however Cr^{6+} and Ni (Table 20).

Table 20. Discharge concentrations from Honda car factory (Honda, 2007).

Heavy metals	Standards [mg/l]	Outlet [mg/l]
	Outlet of phosphate equipment	
Chrome (Cr^{6+})	0.5	0.016
Lead (Pb)	1.0	0.02
Nickel (Ni)	1.0	0.07
	Outlet of painting equipment	
Chrome (Cr^{6+})	0.5	0.002
Lead (Pb)	1.0	0.03
Nickel (Ni)	1.0	0.03
	Total effluent water	
Chrome (Cr^{6+})	0.5	0.002
Nickel (Ni)	1.0	0.03

4.5 OTHER POSSIBLE DISPOSAL METHODS IN WUHAN

Results from the field study in Wuhan showed that today, Wuhan disposes of the sludge on landfills since it is simple, cheap and convenient. Wuhan has recognized the problems of disposing sludge on landfills, since many landfills will close in 3-5 years (Chen Lei., personal communication, 2007). According to Qiu Wenxin, chief engineer of Wuhan Water Group Company Ltd, and Mr Li, the director of San Jin Tan WWTP, the biggest obstacle in finding sustainable fields of application for the sludge in Wuhan is lack of financing. The government in Wuhan does not allocate enough money for the sludge management to develop in Wuhan. The vice president of EPB of Donxihu district, Mrs Chen Lei, has suggested using the sludge for the purpose of construction soil, fertilizer or other use than landfill, but the EPB do not have the know-how. The EPB welcome Swedish companies to assist in this project (Chen Lei, personal communication, 2007).

4.5.1. Construction soil

Results from interviews showed that there are no laws or regulations concerning the use of sludge as construction soil. There is, however, a demand since Wuhan is growing rapidly. The sludge needs to be treated to obtain the properties of good construction soil that the market requires. The EPB was not sure of how to produce this product (Chen Lei, personal communication, 2007).

4.5.2. Cover material

There were five landfills that are not yet sealed, but all five will be sealed before 2017 (Yu Xiao, personal communication, 2007), but there was no plan to use sludge as cover material. For final top cover, sludge does not meet the demand of the standards in the *Technical Code for Municipal Solid Waste Sanitary Landfill.* According to this code, the final top cover can be set up in two ways. One way consists of four layers: Landfill gas (LFG) drainage layer made of gravel or sand, compacted clay layer, water drainage layer made of gravel or sand, top soil layer for growing plants. The second way consists of six layers from the waste to the top. These are LFG drainage layer made of gravel or sand, compacted clay layer, high density polyethylene (HDPE), geotextile protection layer, water drainage layer made of gravel or sand and top soil layer for growing plants. Natural clay is a common alternative as the final top cover and costs 30 RMB/ton (Zhang & Wu, 2005). Thus, there is a potential for substantial economic benefit of using sludge as landfill in Wuhan (Table 21) under certain assumptions:

1) The standard for sanitary landfills (CJJ17-2004) in China defines the conditions of the top layer as no less than 15 cm in both of the two different ways for cover material.
2) Cost of natural clay is 30 RMB/m^3 (Zhang & Wu, 2005).
3) One ton of sludge corresponds to one m^3.
4) Cost of landfilling sludge is 80 RMB/ton (Li, personal communication 2007).
5) Sludge is mixed with 50% ashes to be suitable as top layer (Ribbing & Lind , 2005).
6) There are five landfills that need to be sealed before 2010 (Yu Xiao, personal communication, 2007).

Table 21. Case study of the economic effects of using sludge as cover material.

	Dai Shan (Close in 2007)	**Zi Xia Guan (Close in 2007)**	**Bei Yang Qiau (Close in 2007)**	**Jiang Xia**	**New landfill (Close in 2017)**	**Total**
Area [m^2]	233000	302000	373000	234000	600000	1742000
Volume of necessary top layer [m^3]	34950	45300	55950	35100	90000	261300
Equivalent cost of natural clay [RMB]	1 048500	1 359000	1 678500	1 053000	2 700000	7 839000
Equivalent amount of necessary sludge [tonnes]	17475	22650	27975	17550	45000	130650
Equivalent cost of disposing sludge on landfill [RMB]	1 398000	1 812000	2 238000	1 404000	3 600000	10 452000

4.5.3. Fertiliser

Results from the literature study showed that Hubei province is ranked first place in crop production in China. The production includes rice, cotton, wheat, maize, and edible oil, tea, tobacco and fruit. This implies a high demand for fertilizer (Table 22; IPNI, 2007). The acceptance for using sludge on arable land is high, since China has a long history of using human and animal faeces in agriculture (Qiu Wenxin, personal communication, 2007).

Table 22. Fertilizer demand in Hubei province (IPNI, 2007)

Year	**Total [ton]**	**N fertilizer [ton]**	**P Fertilizer [ton]**	**K fertilizer [ton]**	**Compound fertilizer [ton]**
1999	2 515 000	1 282 000	626 000	168 000	440 000
2000	2 471 000	1 327 000	525 000	162 000	457 000
2001	2 453 000	1 268 000	546 000	175 000	464 000

After the 6th Phosphate and Compound Fertilizer Workshop of China in 2005, hosting more than 1000 fertilizer production companies and 5000 participants, it was established that the consumption of phosphate fertilizer had increased from 8 million tons in 2000 to 11 million tons in 2004 (IPNI, 2005). Due to the increasing demand of this limited resource, it is estimated that in 2010 the Chinese phosphorous industry will not meet the demand of economic development. Another problem is that the quality of Chinese phosphorous is poor and only 6% is established as high standard.

Making fertilizer out of sludge was not seen as a good alternative by chief engineer of Wuhan Water Group Co. Ltd., or the staff from the visited WWTPs, since it is too expensive to meet the standards set by the government. Ms Chen Lui, vice director of EPB Dongxihu, considered it to be a good alternative, but not possible at the moment, since it has not been properly investigated.

A fertilizer factory was visited in Wuhan. The price and demand had seasonal variation, but the factory produced and sold 80 000 tons of industrial fertilizer (phosphorous and calcium) every year for 400 RMB/ton. The price has increased rapidly the last couple of years, but the demand is strong. They sold their product to farmers close to Wuhan and they were the only fertilizer factory in Wuhan (Chen, personal communication , 2007).

4.5.4. Biogas

There was one biogas production facility in Wuhan. It is situated in San Jin WWTP, but it was not yet operational. Many other anaerobic digestion facilities in China have suffered operational problems. Swedish representatives from the Dutch company Grontmij are assisting this biogas project with project management and the delivery and installation of key components. The total cost for this project was estimated to 19 million Euros and this will be the first facility in China that produces biogas for vehicle fuel (Newsdesk, 2007).

4.5.5. Incineration

There were no co-incineration plants for solid waste in Wuhan. However, two new incineration plants were planed to be built for municipal waste incineration (Hou, personal communication, 2007). One will be using fluid bed technology and the other roaster technology. They will both operate under specific contract with municipal waste management bureau, who supplies the waste (Yu Xiao, personal communication, 2007). These contracts define what kind of waste the facilities are supplied with. They were already signed and sludge was not included in any of these contracts. In a feasibility study made prior of the signing of these contracts, sludge incineration was not considered. However, these contracts did not restrict the different incineration plants to use other waste, such as sludge. This implies that the plant has the right to incinerate sludge if emissions meet the national standards. If the plants choose to incinerate sludge, they need specific contracts for this as well. However, there are examples of successful implemented mono-incineration plants in China. The first project of sludge drying and incineration in China started in 2003 in Shanghai (GS environment, 2007). It has a capacity of 213 tons per day (25 % DS) and adapts foreign bed drying technology and domestic incineration technology. The facility will use fluidized bed dryer, fluidized bed incinerator, flue gas and other. The facility will be self-supportive in energy for the sludge drying and incineration process. This facility has been operating since 2004 and has been certified by the Shanghai environmental protection bureau.

5. ANALYSIS AND DISCUSSION

5.1. ANALYSIS - SWEDISH SLUDGE MANAGEMENT

One of the goals in this master thesis was to investigate and evaluate sludge production, treatment and disposal in Sweden. This section discussed the results from that investigation and evaluation.

Results show that the connection between sludge production and sludge disposal is strong since sludge quality is a fundamental aspect when finding a sustainable sludge disposal method. If the sludge would contain high levels of pollutants, it radically reduces the number of fields of application for the specific sludge. The connection is also identified by the many products that can be retrieved from sludge. This knowledge has not yet been widely spread and is an area with great potential in wastewater treatment.

Which sludge treatment that is the best one can not be concluded without knowing the future use of the sludge. However, it is clear that sludge has to be stabilized and that its water content needs to be reduced for several reasons. Conditioning it not necessary but makes further treatment cheaper and easier, where Kemicond seems as a good alternative. Composting does not seem as a good alternative from an environmental perspective since its product is a green house gas, which is not properly taken care of. Anaerobic digestion produces methane which also is a green house gas but can be used as biogas. Therefore, anaerobic digestion (biogas production) seems to be a better choice from an environmental point of view. It is also an important process since it reduces the volume of sludge through decomposition. Among the dewatering processes, drying beds seems like the cheapest technique for reducing water content while also achieving high DS values. However, it requires large areas of land and a warm climate. Since this method does not require energy, besides fuel for the mixing machines, the environmental impact is low. These positive effects may be counterbalanced due to possible leach water and foul odour. Centrifuges and recessed-plate filter press seems as the most effective mechanical dewatering techniques. The success of each method also depends on the level of know-how of operation.

The study has revealed many pros and cons of the different sludge disposal methods in Sweden (Table 10). Disposal of sludge has far from one perfect solution but the least sustainable sludge disposal method is landfill. Every country and city has different possibilities to adapt the various methods based on many aspects such as costs, infrastructure, climate, social conditions, sludge quality and sludge volume. It is also a political debate where neither politicians nor experts and scientists agree on which solution is the best**.** However, a solution for a certain community does not have to include just one disposal method. All five may be combined but each method should be carefully chosen based on objective arguments. The summarised arguments for sludge disposal in the study on Swedish sludge management must be considered with caution. There may be exceptions to these arguments in which the arguments do not apply. To avoid that case of Wuhan is one of these exceptions this has been paid extra attention to.

Based on the five factors; economy, acceptance, technical development, environment impact and legislation, landfill is the worst option in Sweden. An environmental impact rank of the remaining alternatives has not been possible since local conditions must be taken into consideration. The lowest acceptance seems to be towards as fertilizer even though it is encouraged by the government and the fact that sludge quality is good enough according to Swedish legislation. The statistics of the amount of nutrients in sludge and the amount that is needed, indicates that sludge could not single-handedly replace inorganic fertilizer in Sweden. However, it could substantially reduce the usage. Since incineration plants are expensive if large scale is not possible, co-incineration plants seems like the only alternative in Sweden. Incineration also seems as a sustainable field of application since it captures the energy in sludge while the ashes can be further used for producing building material or cover material. A fundamental obstacle in Sweden is that incineration does not comply with the Swedish policy of recycle nutrients. The technology to separate nutrients from ashes is not yet successful in full scale but has enormous potential. Biogas production has proven to be a sustainable sludge treatment as well as a field of application that appeal to the economic, environmental and acceptance aspects in sludge management. It is however not a complete solution and must be complimented by another field of application. Legislation seems to apply to every field of application for sludge. However, the regulations for sludge as a component is construction soil and cover material does not seem as strict as for the other fields of application. The distance to the designated locations and the demand for topsoil, cover material and fertilizer should be the main factors in the decision making when taking these three solutions under consideration.

5.2. ANALYSIS - SLUDGE MANAGEMENT IN WUHAN

The results of this thesis show that about 85 % of Sweden's 9 million inhabitants are serviced by the municipal WWTPs. These produce 1 million tons per year. Wuhan has 7.3 million inhabitants and less then 40 % are serviced. The WWTPs in Wuhan produce more then 1,65 million tons per year. These facts indicate that the sludge treatment needs to be improved in Wuhan.

The results from the visits and interviews with stakeholders in Wuhan show that all sludge is landfilled at different landfills in Wuhan. They also showed that sludge was mixed with solid waste in many cases which causes hazardous leach water. It makes it also very difficult to separate the sludge from the municipal waste if that would be considered in the future. It is not legal to mix sludge with other wastes in Sweden or the EU and this should therefore not be an option for China. However, it is not legal to landfill sludge at all in Sweden and China is recommended to follow this example as well.

Some of the results from the interviews and the literature study show that the fundamental problem in sludge management is the increasing amount of produced sludge and economic issues. Results also show that these two problems are connected in many ways. To reduce the volumes an increase of the DS value is necessary. The volume could also be reduced if anaerobic digestion would be implemented, which also would reduce costs by retrieving energy from the produced biogas. The claim that economic issues are a major problem is contradicted by the fact that seven more sludge treatment plant are planned. Information from Mr Zhang at Shaha WWTP also contradicts this claim. This indicates that the governance in sludge management is weak. The most common internal problems in the WWTP were sludge bulking and high energy costs in the aerated biological treatment. Solutions have not been established by this master thesis but the interviewed staff members at the WWTP are interested in Swedish solutions to these problems.

Many results on sludge management in Wuhan are based on interviews and written communication. An interpreter has translated in many of these cases which may have caused misunderstandings or faulty information. Effort was therefore spent on finding several sources and several interpreters to translate the same information.

5.2.1. Sludge quality in Wuhan

The results of the field study in Wuhan show that only one control of sludge quality from one WWTP has been made. Additional data was not possible to gather since there are no routine controls of sludge. However, it seems that there is a big problem with high concentrations of pollutants. This conclusion can be drawn based on the following facts.

- None of the interviewed staff members at the WWTPs in Wuhan considered producing fertilizer due to the necessary investments needed to reach the standards.
- Second, there were no official data that supported their claims that the concentrations were ”low”.
- Third, the chief engineer of Wuhan Water Group Company Ltd confirmed that heavy metals concentrations were high but varied a lot with time and between the different WWTPs.

This conclusion needs to be confirmed with several sludge quality controls in all of the WWTPs. However, if Wuhan wants to use the sludge in sustainable fields of application, a control program is warranted.

The visits to WWTPs revealed that only one of the plants applied a stabilising technique. Besides the future anaerobic digestion at San Jin WWTP there were no efforts made to reduce the number of pathogens in the sludge. This fact rejects any land use of sludge as a possible field of application. It also emphases the need to revise the law on stabilizing since the law only implies that sludge *should* be stabilized. Since the biogas reactor is not yet operational in San Jin Tan WWTP there is no sludge that is suitable for any land use in Wuhan. The achieved DS values of the sludge were relatively low compared to the potential values of each technique. This indicates that the dewatering processes needs to be optimized. The older WWTP should upgrade their belt filter presses to centrifuges or recessed plate for better results. San Jin WWTP use modern centrifuges and drum thickeners. Another solution could be to invest in better conditioning technology such as Kemikond. However, the investment in more efficient dewatering technology must have a short pay-off time since sludge treatment is a low priority in the WWTPs in Wuhan. Since Wuhan is one of the four furnaces in China, drying beds seem like a cheap and effective alternative of reducing the water content. This method has not been considered by the interviewed stakeholders in the sludge management of Wuhan. The study on Swedish sludge management showed that drying beds are usually implemented in smaller communities. Wuhan should therefore implement several smaller drying bed facilities.

The agricultural sector in the Hubei province is the largest in China and the supply of inorganic fertilizer is decreasing. Wuhan must start to look at sludge as a potential resource and not as a problem. Only then, recycling nutrients and finding appropriate fields of application for sludge will be possible. The only way to reach this level of interest and ambition is by stronger management and economic incentives. An economic profit can be presented as the outcome. Not only must it be more expensive to landfill sludge than the other alternatives, but the benefits of more sustainable solutions, such as recycling nutrients, must be made clear to stakeholders in Wuhan.

5.2.2. Sources of pollutants

There are two major ways of improving sludge quality in Wuhan. The first way is by improving the wastewater treatment in the WWTP with separation technology. The second way is to focus on pre-pipe solutions. This implies that the focus should be on the sources of pollutants. Since the industries are stated to contribute to 37 % of the treated wastewater, one approach is to make a survey over the different industries that are connected to the waste water treatment plants. When these industries are mapped, some of the sources may be located. These industries could then be disconnected from the wastewater treatment plant and a tailor-made wastewater treatment could be designed for the specific industry. One other important aspect is improving the control of storm water since this may also o be a large source for heavy metals in sludge. The local authorities are not up to date in these matters. The investigated industries in this master thesis seem to have their own wastewater treatment but there is not any impartial control. This is not a sustainable situation.

5.2.3. New sludge management

The results from the field study in Wuhan show that there are positive indications of change towards sustainable sludge management in Wuhan. The new biogas facility and the plan to build seven more sludge treatment plants are two examples. Which sludge treatments that should be implemented in the future is not decided, even though the budget is set to 1 billion RMB. This indicate that there are ambitions to change the sludge management even though there is a lack of knowledge. Here is a great challenge and opportunity for Swedish partners to export know-how. The Swedish representatives from the Grontmij in Wuhan indicates that this is possible. One solution to fill this knowledge gap it to construct pilot facilities for each technique. These can be used for research, training and education purposes while ensuring that the know-how will stay in Wuhan.

Biogas production is now implemented in Wuhan in one WWTP. Since biogas can be used for producing heat, electricity and fuel as well as reducing sludge volume it seems like the perfect sludge treatment. Wuhan is therefore recommended to invest in more biogas facilities and implement them in every WWTP.

The supply of inorganic fertilizer is decreasing in China. The rising prices of the products from the fertilizer factory in Wuhan is another indication of this. This is combination with the fact that Hubei province is the top producer of agricultural products in China, leads to the conclusion that recycling nutrients is of great importance for the Hubei province. Producing fertilizer is therefore a sustainable option from an environmental and economic point of view. Since the level of acceptance among farmers and consumers is high, producing fertilizer from sludge seems as the most sustainable solution. The results show that Chinese regulations are less strict then Swedish or EU legislation. The Chinese regulations should therefore be revised. Since the sludge quality can not be proven to be good enough with heavy metal concentrations below Chinese regulation, there is only one sludge disposal method that seems appropriate - incineration. If the ashes can be used as construction material and the nutrients can be recycled, it is also a sustainable solution. The facilities in the new incineration plants in Wuhan comply with the description of which techniques that are appropriate for sludge incineration. If the flue gas condensation is good enough to meet the Chinese standards is still unclear. A contract is needed to grant the incineration plants to co-incinerate sludge. How this could be achieved is beyond the scope of this master thesis. Using Aqua Reci or Cambi/Krepro technology in the incineration process could be a good alternative since it also solves the problem with producing non-hazardous fertilizer for agricultural use. However, none of these techniques is reliable since it not has been tested in full scale yet. Whether there are better techniques to retrieve nutrients is unclear, but the claim that separation technology has huge potential in modern sludge management is certain.

Using sludge as cover material is a quite common method in Sweden but Wuhan has not recognised this as an option. The exact grounds for this low level of acceptance of sludge as cover material have not been established. However, the economic benefits could be substantial. The information on the price of landfilling ranged from 40 to 100 RMB /ton. The assumption of the price of landfilling is set to 80 RMB/ton in this calculation, which means that the calculated economic benefit could be misleading. Since the landfill fees are expected to be substantially increased, so will the benefit of using sludge of cover material. The sludge needs to be compressed to achieve the necessary properties so the economic benefit could be greatly underestimated. The point of this example is however not an exact number but to show that this field of application for sludge could imply major economic benefits and should be recognised as an option by the Chinese stakeholders.

Since there are no regulations or certificates to apply for in the construction soil business an implementation of sludge in this sector could lead to dumping of sludge. The sludge quality must be guaranteed to be good and safe by authorities before it can be used. Stronger management in this matter is therefore needed. However, the demand for construction soil is strong. The other necessary components, as organic park waste and sand, could be mixed with sludge on the existing landfills to produce the final product. The sand that is retrieved in the grit chambers in the WWTP could be used for this purpose.

6. CONCLUSIONS

This section presents solutions for sustainable sludge management for Wuhan in form of pre-pipe and end-of-pipe solutions. New possible projects for the Swedish partners are presented as well.

6.1. PRE-PIPE SOLUTIONS

The sludge quality can be improved by following four basic steps:

1. Coordinate the activities between municipal and industrial wastewater management.
2. Implement sludge quality monitoring systems in the WWTPs.
3. Identify sources of pollutants. Investigate if pollutants derive from industries or storm water.
4. Disconnect the industries from the municipal wastewater system that contribute with contaminants and make improved tailor-made wastewater treatment for these.

The next four recommendations should save money and reduce environmental impact through cleaner production:

1. Use system control optimisation to reduce to energy cost of aeration systems in the ASP in the WWTP
2. Identify appropriate separation technology to retrieve nutrients and products for internal use in the WWTP.
3. Increase the DS value in the produced sludge. Drying fields seems to be a good dewatering method for Wuhan.
4. Implement anaerobic digestion to produce biogas and reduce the sludge volume.

6.2. END OF PIPE SOLUTIONS

The end of pipe solutions probably requires that Wuhan upgrades the incineration plants flue gas treatment. These investments should be covered by the costs of the seven planned sludge treatment plants. Pilot facilities should be constructed for each new technique. A four-step strategy can be summarized as follows:

1. Divide the sludge into three categories. The first category is the sludge that meets the standards in Chinese regulations. Develop standards for a second category which contain such properties that can not meet the standards of category one but still not considered as hazardous waste. These limits should be set by the EPB in Wuhan. The third category represents the sludge that should be classified as dangerous waste. All sludge should then be analysed on a regular basis.

2. The sludge that fits the first category should be used for agricultural use. This is the most sustainable solution since Hubei province is a top producer of agricultural products in China and since the supply of inorganic fertilizer is decreasing rapidly. Use trains to transport the sludge to remote areas since Wuhan is an important railway hub. Even though sludge does not have the properties of a perfectly efficient

phosphorous fertilizer, it still has important positive effects as soil conditioner. It is also appealing from an economic point of view.

3. Category two should be used to produce cover material and construction soil. Treat the sludge in anaerobic digestion chambers to stabilize the sludge and retrieve biogas. Mix the treated sludge with ashes from incineration of municipal waste to retrieve cover material. Produce construction soil by mixing sludge with components such as sand from grit chambers in WWTPs and waste from parks and other green areas. If the market's demand for cover material is saturated, incinerate the remaining sludge in the co-incineration plants, landfill the remaining ashes in sanitary landfills or use it as a component in construction material.

4. The remaining sludge (category three) should be incinerated in the existing co-incineration plants. Retrieve the produced energy and dispose of the ashes in sanitary landfills.

6.3. FUTURE PROJECTS AND CHALLENGES

The analysis of sludge management in Wuhan revealed many challenges that the Swedish partners could elaborate into new projects (The suggested projects are not ranked):

1. Supply Wuhan with the know-how to coordinate the activities between the stakeholders in sludge management.
2. Supply equipment and know-how for testing and monitoring sludge quality.
3. Supply more specific details on how to produce cover material, construction soil and fertilizer for agriculture under the conditions in Wuhan.
4. Implement more efficient water reducing techniques such as Kemikond conditioning or better thickening and dewatering methods.
5. Apply separation technology or membrane technology to reduce concentrations of heavy metals and to retrieve nutrients.
6. Optimise the energy usage in the aeration step in the WWTPs in Wuhan.
7. Solve the most common problem in Wuhan related to WWT in Wuhan - sludge bulking.

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APPENDIX 1

Table A. WWTPs in Wuhan

WWTP	Serving Area	Running Status	Capacity
Huangpu Road waste water treatment plant	7.2 square kilometers; 200,000 persons	Running	100,000 t/d
Shaha waste water treatment plant	21.1 square kilometers; 250,000 persons	Running	150,000 t/d
Long Wang Zui waste water treatment plant	35.7 square kilometers; 363,600 persons	Running	150,000 t/d
Er Lang Miao waste water treatment plant	32.2 square kilometers; 430,000 persons	Running	180,000 t/d
Tangxun Lake waste water treatment plant	20.1 square kilometers; 30,000 persons	Running	50,000 t/d
Hanxi waste water treatment plant	54.67 square kilometers; 714,000 persons	Running	400,000 t/d
Zhuangkou waste water treatment plant	28.6 square kilometers 40 000 persons	Under construction	60,000 t/d
San Jin Tan waste water treatment plant	61.4 square kilometers; 940,000 persons in 2010	Under construction	300,000 t/d
South of Taizi Lake waste water treatment plant	55.0 square kilometers; 260,000 persons	Under construction	200,000 t/d
Luo Bu Zui waste water treatment plant	30.1 square kilometers; 430,000 persons	Under construction	120,000 t/d
Huangjia Lake waste water treatment plant	56.5 square kilometers; 460,000 persons	Under construction	100,000 t/d
North Lake waste water treatment plant	4.0 square kilometers 20 000 persons	Under construction	20,000 t/d
Huang Jia Da Wan waste water treatment plant	7.2 square kilometers 10 000 persons	Under construction	10,000 t/d

APPENDIX 2

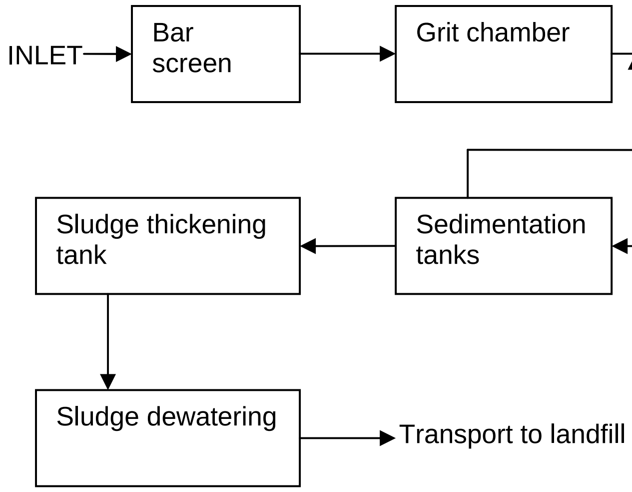

Figure A. Shaha WWTP process chart.

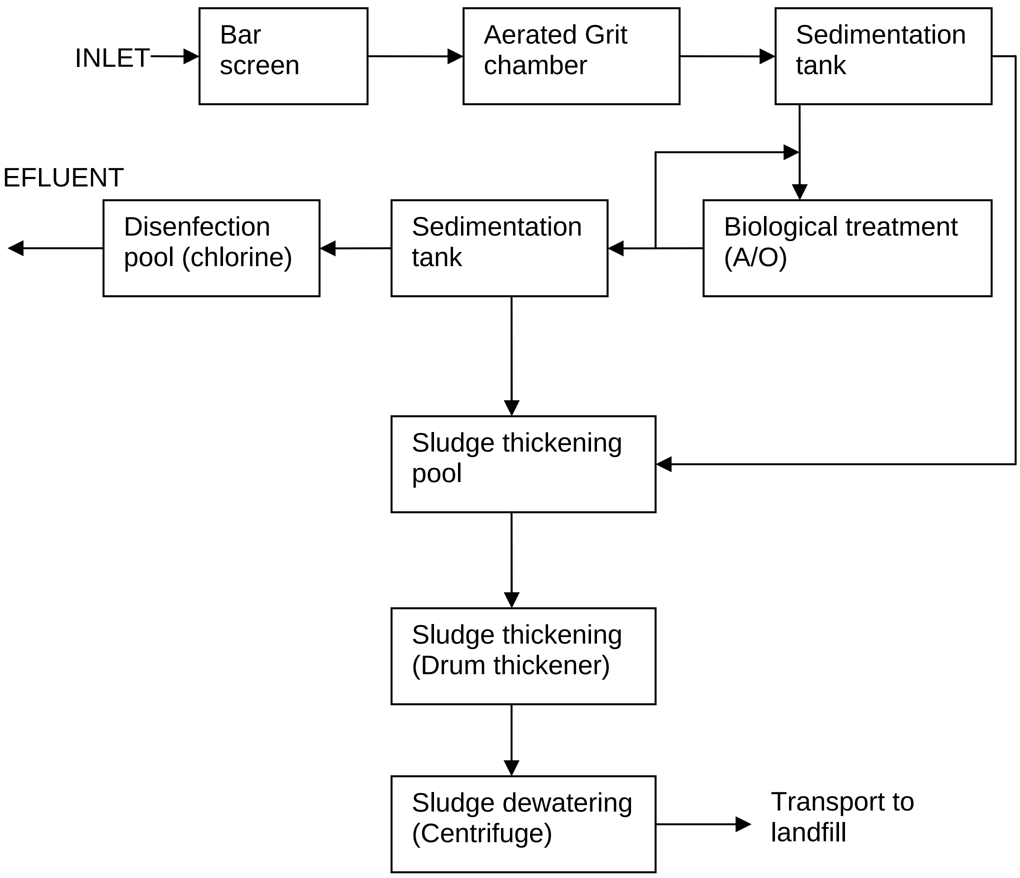

Figure B. Xanti WWTP process chart

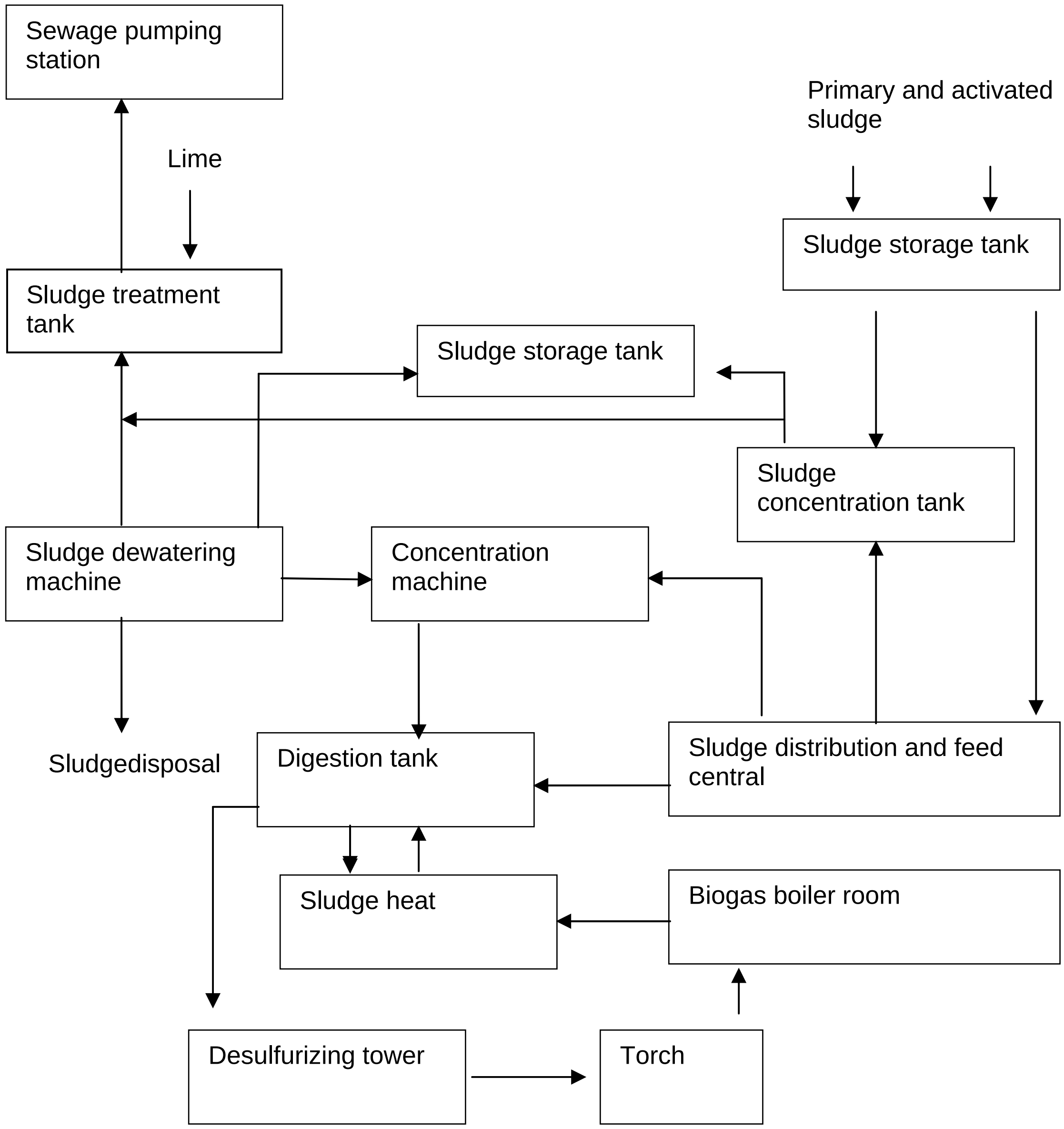

Figure C. San Jin Tan WWTP sludge treatment process chart.

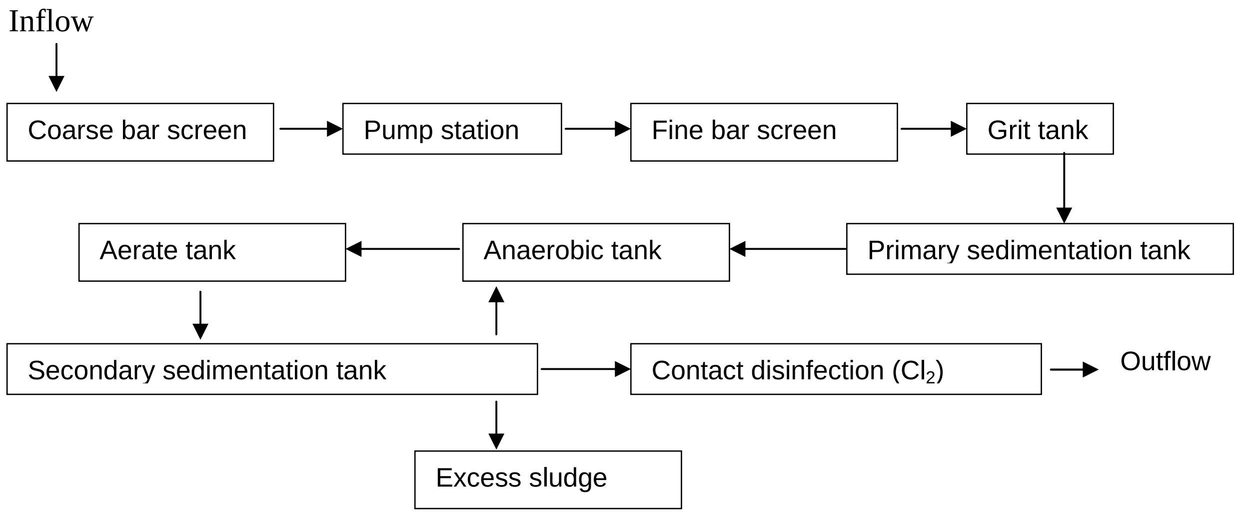

Figure D. San Jin Tan WWTP process chart.