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Treatment and Disposal Methods for Wastewater Sludge in the Area of Beijing, China

Minor Field Study
Master's Thesis number:
2005-04

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March 2005

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Sverige

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Behandlings- och Hanteringsmetoder för Avloppsslam i Pekingområdet, Kina

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Summary

This study has been carried out in accordance with the Swedish International Development Cooperation Agency's Minor Field Study programme and constitutes the Master's Thesis of two students at the Environmental Engineering programme at Lund Institute of Technology. The title of the study is *"Treatment and Disposal Methods for Wastewater Sludge in the Area of Beijing, China"*. The topic is very broad and focus is laid upon the possibilities of using sludge as a fertiliser in agriculture. The study includes a field study where the present and future sewage sludge treatment and disposal methods in the area of Beijing, China, are investigated. Also important legislation for sludge handling is collected. A literature study is included regarding general knowledge about sludge content, treatment and disposal methods but also information on how sludge is handled in Sweden, EU and USA and their legislation concerning usage of sludge as a fertiliser in agriculture. This enables a comparison of Chinese conditions with the conditions in these regions.

Wastewater sludge is produced when wastewater from households, and industry is treated at wastewater treatment plants. Some plants also recives stormwater. The sludge contains organic material and nutrients that have an agricultural value but also some pollutants in the form of heavy metals, organic contaminants and pathogens. The raw sludge, generated from different steps in the wastewater treatment process, is unstable and contains high amounts of water. Further treatment is needed to reduce the water content and there are different thickening and dewatering technologies available. In order to stabilise the sludge anaerobic digestion, composting or thermal drying can be used, to mention three common methods used today. This is also important in order to reduce the content of pathogens that may constitute a risk when disposing sludge. The sludge may be disposed in several ways but this study focuses on the usage of sludge as a fertiliser in agriculture. This method creates a recycling of nutrients such as phosphorus and nitrogen and this is of major importance in a sustainable society. If nutrients are recycled the withdrawal of for example phosphorus could be reduced, which is important since this is not an endless resource. Sludge is also less expensive compared to artificial fertilisers. There are some potential negative risks with the usage of sludge as a fertiliser such as the spreading of organic pollutants, heavy metals and pathogens. However, these risks may be minimised by for example, the choice of suitable crop, methods of spreading and by regulating the time between fertilise and harvest.

About 40% of the population in Beijing is connected to the sewer network system and there are nine different wastewater treatment plants in the area. All the plants use a combination of mechanical and biological treatment. Only a small proportion of the wastewater undergoes advanced treatment with chemicals and is reused as for example irrigation water. About 1 000 tonnes of sludge cake with water content less than 80% is produced every day in the area. The sludge is thickened and dewatered, mostly by a combination of a thickening tank and a filter belt but there are also centrifuges at two plants. At the largest plant, Gaobeidian Sewage Treatment Plant, a part of the sludge is anaerobically digested and the energy from the produced biogas is utilised at the plant. Today, about 40% of the sludge in Beijing is composted at Daxing Sludge Disposal Plant. Half of the remaining sludge is deposited at different landfills and the rest is disposed by contractors but this sludge is often also deposited at landfills. At Daxing, the sludge is composted for 25 days in windrows. The sludge is not mixed with another material but the piles are harrowed and regularly turned over and the water content is reduced to about 20%. After composting, the sludge is pelletized and mainly used as fertiliser on agricultural land or as a soil improver on sandy soils to increase the content of organic matter.

China has legislation concerning the usage of sludge as a fertiliser in agriculture. There are quality demands regarding nine metals and five organic compounds. The quality of the sludge in regards of metals, organic pollutants, nutrients and pathogens are measured four times a year at the wastewater treatment plants at different steps in the treatment process. The water content, pH and the organic content is measured daily. When analysing the quality from three different wastewater treatment plants in Beijing, it is seen that the sludge almost meet the quality demands. However, the concentrations of mercury are often too high in the sludge and research is being performed to investigate the sources. It is important to monitor the quality and investigate pollutant sources and implement control strategies. It would be helpful to measure the quality of the sludge more often in order to evaluate trends and this applies to many countries in the world. China has already set discharge standards for the industry and another approach to improving the sludge quality will be made in the future when larger industries are moved outside the city.

100% of the population in Beijing, excluding the suburbs, is planned to be connected to the sewer network system by year 2010. It is estimated that this will generate about 2 500 tonnes of sludge cake with water content around 80% each day. Composting will stand for about 60% of the sludge, 30% will be treated with thermal drying and 10% will be incinerated or deposited at landfills. Thermal drying will demand less area than composting and this is an important factor in a large and expanding city like Beijing. After composting or thermal drying, the sludge may be used as fertiliser or soil improver. Thus, the ambition is to recycle a large amount of the nutrients in sludge. It is also investigated whether it is possible to use some of the sludge as constructing material. The general opinion in China is that it is very important to recycle the nutrients in the sludge. An advantage when sludge is composted or treated with thermal drying is that the end product looks more “clean and treated” and this increases the public acceptance for sludge as a fertiliser. When sludge is dried and pelletized, an advantage is that it is easier to handle and transport. Pelletized sludge also has the advantage that the same techniques used for the spreading of artificial fertiliser can be used. Beijing is located close to the Yellow Plain which is an extensive agricultural area. It has been described as the bread basket of China and there is a need for fertiliser in order to produce sufficient amounts of crops. The pH is around 7.5-8.5 and this makes it suitable to fertilising with sludge since heavy metals are less mobile at higher pH.

Keywords: wastewater, sludge, treatment, disposal, fertiliser, nutrients

Sammanfattning

Denna studie har utförts i överensstämmelse med The Swedish International Development Cooperation Agency's Minor Field Study-program och utgör två studenters examensarbete på civilingenjörsutbildningen i Ekosystemteknik på Lunds Tekniska Högskola. Studien bär titeln"*Treatment and Disposal Methods for Wastewater Sludge in the Area of Beijing, China*". Ämnet är mycket brett och fokus är lagt på möjligheterna att använda slam som gödningsmedel i jordbruk. Studien inkluderar en fältstudie där nuvarande och framtida behandling och hantering av avloppsslam undersöks. Viktig lagstiftning för slamhantering samlas också in. En litteraturstudie inkluderas gällande allmän kunskap om slamsammansättning, behandlings- och hanteringsmetoder men också information om hur slam hanteras i Sverige, EU och USA samt deras lagstiftning angående användningen av slam som gödningsmedel i jordbruk. Detta möjliggör en jämförelse av kinesiska förhållanden med förhållandena i dessa regioner.

Avloppsslam produceras när avloppsvatten från hushåll och industri behandlas på reningsverk. En del reningsverk behandlar även dagvatten. Slammet innehåller organiskt material och näringsämnen som har ett agronomiskt värde men också föroreningar i form av tungmetaller, organiska föroreningar och patogener. Råslammet som genererats från olika steg i reningsprocessen av avloppsvattnet är instabilt och innehåller en stor mängd vatten. Ytterligare behandling behövs för att reducera vatteninnehållet och det finns olika förtjocknings- och avvattningstekniker tillgängliga. För att stabilisera slammet kan rötning, kompostering eller termisk torkning användas för att nämna tre vanliga metoder. Detta är också viktigt för att reducera mängden patogener som kan utgöra en risk när slammet hanteras i efterkommande steg. Slammet kan hanteras på flera olika sätt men denna studie fokuserar på användningen av slam som gödningsmedel i jordbruk. Denna användningsmetod skapar ett kretslopp av näringsämnen som fosfor och kväve och detta är mycket viktigt i ett miljömedvetet och hållbart samhälle. Om näringsämnen återanvänds kan till exempel det jungfruliga uttaget av fosfor minskas vilket är viktigt eftersom detta är en ändlig resurs. Slam kostar också mindre i jämförelse med konstgödning. Det finns vissa potentiella negativa risker med användningen av slam som gödningsmedel så som spridningen av organiska föroreningar, tungmetaller och patogener. Dessa risker kan emellertid minimeras genom till exempel valet av lämplig gröda, spridningsmetod och reglering av tiden mellan spridning av gödning och skörd av grödan.

Ungefär 40% av befolkningen i Beijing är ansluten till avloppsnätet och det finns nio olika reningsverk i området. Alla reningsverken använder en kombination av mekanisk och biologisk rening av avloppsvattnet. Endast en liten del av avloppsvattnet behandlas med kemikalier och återanvänds exempelvis till bevattning. Ungefär 1 000 ton avvattnat slam med en vattenhalt på mindre än 80% produceras dagligen i detta område. Slammet förtjockas och avvattnas, mestadels genom en kombination av en förtjockningstank och ett så kallad filterbälte men också genom centrifugering som används på två reningsverk. På det största reningsverket, Gaobeidian Sewage Treatment Plant, rötas en del av slammet och energin från den producerade biogasen används på reningsverket. Idag komposteras ungefär 40% av slammet i Beijing på Daxing Sludge Disposal Plant. Hälften av det resterande slammet deponeras på olika deponier och resterande omhändertas av entreprenörer, oftast deponeras även detta slam. På Daxing komposteras slammet i långsträckta rader under 25 dagar. Slammet blandas inte med ett annat material men högarna harvas och vänds regelbundet och vattenhalten reduceras till ungefär 20%. Efter kompostering pelleteras slammet och används framför allt som gödningsmedel i jordbruk eller som jordförbättringsmedel på sandiga jordar för att öka andelen organiskt material.

Kina har lagstiftning beträffande användning av slam som gödningsmedel i jordbruk. Det finns kvalitetskrav gällande nio metaller och fem organiska föreningar. Slammets kvalitet med avseende på metaller, organiska föroreningar, näringsämnen och patogener mäts fyra gånger per år vid de olika stegen i behandlingsprocessen på reningsverken. Vatteninnehåll, pH och den organiska halten mäts dagligen. När slamkvaliteten från tre olika reningsverk i Beijing analyseras framkommer det att slammet nästan uppfyller kvalitetskraven. Koncentrationen av kvicksilver i slammet är dock ofta för hög men undersökningar pågår för att kartlägga källorna. Det är viktigt att övervaka kvaliteten och utreda källorna till föroreningar och att implementera kontrollstrategier. Det skulle vara till stor hjälp om kvaliteten mättes oftare så att trender kan utvärderas men detta gäller för många länder i världen. Kina har redan utsläppskrav på industrin och en annan ansats till att förbättra kvaliteten är att större industrier planeras att flyttas utanför staden.

100% av befolkningen i Beijing exklusive förorterna planeras att vara anslutna till avloppssystemet till år 2010. Det beräknas att ungefär 2 500 ton avvattnat slam med en vattenhalt på 80% kommer att produceras dagligen. Kompostering kommer att behandla ungefär 60% av slammet, 30% kommer att behandlas med termisk torkning och 10% kommer att förbrännas eller att deponeras. Termisk torkning kommer att kräva mindre yta än kompostering och detta är en viktig faktor i en stor och expanderande stad som Beijing. Efter kompostering eller termisk torkning kan slammet användas som gödningsmedel eller jordförbättringsmedel. Sålunda är ambitionen att återanvända en stor andel av näringsämnena i slammet. Det undersöks också om det är möjligt att använda en del av slammet som byggnadsmaterial. Den allmänna åsikten i Kina är att det är mycket viktigt att återanvända näringsämnena i slammet. En fördel med att kompostera eller termiskt torka slammet är att slutprodukten ser mer ”ren och behandlad” ut och detta ökar acceptansen för slam som gödningsmedel. När slam torkas och pelleteras ges fördelen att det är lättare att hantera och transportera det. En annan fördel är att pelleterat slam kan spridas med samma utrustning som konstgödning. Beijing ligger nära Gula Planet som är ett vidsträckt jordbruksområde. Det har beskrivits som Kinas brödkorg och det finns ett behov av gödningsmedel för att tillräckliga mängder mat skall kunna produceras. pH är omkring 7.5-8.5 och detta gör marken lämplig för slamgödsling eftersom tungmetaller är mindre mobila vid högre pH.

Nyckelord: wastewater, sludge, treatment, disposal, fertiliser, nutrients

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The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work in a developing country resulting in a graduation thesis work, a Master's dissertation or a similar in-depth study. These studies are primarily conducted within subject areas that are important from an international development perspective and in a country supported by Swedish international development assistance.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of developing countries and their problems. An MFS should provide the student with initial experience of conditions in such a country. A further purpose is to widen the human resource base for recruitment into international co-operation. Further information can be reached at the following internet address: http://www.tg.lth.se/mfs

The responsibility for the accuracy of the information presented in this MFS report rests entirely with the authors and their supervisors.

Gerhard Barmen

Gerhard Barmen
Local MFS Programme Officer

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1 Introduction

In order to create a sustainable society it is important to create a circulation of different materials and one aspect is to recirculate the valuable nutrients that wastewater from households contains. Large quantities of sludge are created when wastewater is treated and a large amount of the nutrients accumulate in the sludge. Using the sludge as a fertiliser on agricultural land would be one way to bring back the nutrients to where they once were utilised. This would decrease the withdrawal of phosphorus, which is a valuable and not an endless resource in the world, but also other nutrients. Another aspect is that this could be a cheaper alternative to artificial fertilisers and partly solve the problem on how the large amounts of sludge should be disposed of.

Beijing is a city in change, rapidly growing and developing. Sewer networks and wastewater treatment plants *(WWTP)* are being extended and built, and this leads to increasing amounts of sludge. This study will look into how sludge is treated and disposed in the area of Beijing today and what could be possible solutions for the future. Focus is laid on the possibilities and limitations of using sludge as a fertiliser in agriculture. Except for the field study in the area of interest, a literature study has been conducted in order to compare Chinese conditions with sludge handling and legislation in Sweden, EU and USA. As stated, focus of this rather broad subject is on whether sludge can be used as a fertiliser in agriculture since this creates a recycling of valuable nutrients. However, there are other side-effects such as the potential spread of pathogens and accumulation of pollutants in the soil. Therefore, pollution sources and control strategies for the area of Beijing is also of interest.

This study has been carried out in accordance with the Swedish International Development Cooperation Agency's *(Sida)* Minor Field Study programme. The field study was enabled by Beijing Drainage Group Co. Ltd which established cooperation with Sida in 1997 and with Lund University in 2004.

2 Problem statement

This study investigates the present sludge handling in Beijing, China. The Chinese legislation is further compared to legislation in Sweden, EU and USA. Focus is on whether sludge can be used as a fertiliser in agriculture.

2.1 Objectives

The objective of this study is to evaluate possible sludge treatment and disposal methods, suitable for Chinese conditions. To achieve this, the present sludge treatment, disposal methods and present and estimated future sludge quantities and quality is looked into. It is also necessary to consider and evaluate the regional infrastructure for the different methods in order to obtain unitary proposals.

The quality of the sludge is of major importance for the usage so therefore the sources for pollutants and sludge quality demands are investigated. Possibilities of having strategies for pollution control are explored, since these are needed in order to improve the quality of the sludge.

Different alternatives for sludge treatment such as composting and different disposal methods such as incineration are evaluated.

This study includes Chinese legislation concerning the usage of sludge. As a comparison the legislation and the usage of sludge in Sweden, EU and USA are also examined. This involves sludge quality demands and specifically the demands for use of sludge in agriculture. The situation in Sweden is more extensively discussed.

In order to obtain better knowledge about sewage sludge regarding its origin, composition, treatment and disposal methods, a literature study is performed and included in this report.

2.2 Focus

The objectives presented above are very broad and the study focuses on the possibilities of using the sludge as a fertiliser in agriculture. This disposal method is chosen because the usage of sludge in agriculture creates a recycling of nutrients. The usage of sludge as a fertiliser would be a complement to artificial fertilisers, which cost both money and resources to develop. Also the problem with how to dispose the sludge would be solved.

The pollutants in sludge reflect all the substances that are circulating in society. Of interest for this project are pollutants that exceed the quality demands for the sludge issued by State Environmental Protection Administration of China and pollutants of special interest for agriculture. The quality demands are evaluated and compared with quality demands for Sweden, EU and USA. Also, if there is any legislation concerning limitations of the amount of sludge to be used in agriculture, this is compared.

2.3 Limitations

Wastewater sludge can originate from both wastewater treatment plants for urban areas and from small individual settlements in rural areas. In individual settlements the sludge is aggregated in a three-compartment tank. Sludge will also be generated when potable water is being processed at waterworks. Sludge in this study refers only to wastewater sludge from wastewater treatment plants in urban areas. Industries normally load wastewater treatment plants but this study does not take sludge from pure industry plants into consideration.

There are different alternatives to the pipe network system present today in our society. In the future it could be possible to use for example urine separating toilets but this alternative would demand the construction of a new pipe network. This would be very costly so alternative including reconstruction of the overall pipe network will not be further looked into in this study.

This study will not include the financial and welfare economics consequences for different systems. These consequences will have a great impact on the selection of treatment and disposal methods of sludge. Neither regulation concerning the work environment for the employees is included in this study.

The study of pollution sources and control strategies include a general discussion of legislation and other means of control in order to minimise pollution in the influent water to the wastewater treatment plants. The study will not include a complete survey of specific substances from specific industries.

China is a very large country containing even two different climate zones. This will of course have an impact on the agriculture in terms of choice of crops etc. In a large country such as China, there are also culture and economical differences. This leads to differences in infrastructure and usage of technology. A limitation in this study will therefore be that the discussion and conclusions are valid only for the area of Beijing.

3 Methodology

The work of this study is divided into three phases. Phase one is a literature study, which is performed to get better knowledge about legislation and sludge handling in Sweden, EU and USA. The field studies, phase two, is conducted in the area of Beijing and the present and predicted situation concerning sludge treatment and disposal methods within the area is examined. Phase three is conducted in Sweden and includes interpretation of received data, further literature studies about conditions in different countries and report writing.

3.1 Literature study

A literature study is performed in order to obtain a good base of knowledge about different treatment and disposal methods for sludge. These different methods are briefly discussed and the purpose is to obtain a better orientation in the subject.

The content of the sludge is studied in order to understand some of the problems and possibilities related to sludge. Pollutants in sludge may be a problem when disposing the sludge so therefore these and their sources is mentioned. On the other hand, it is possible to use sludge as a fertiliser since it contains a large number of nutrients.

One of the objectives is to compare Chinese legislation concerning the handling of sludge to the legislation in Sweden, EU and USA. The literature study therefore includes information about this legislation in these regions. The situation in Sweden is more extensively discussed.

The focus of this study lays on the possibilities to use sludge as a fertiliser due to its content of nutrients. Different aspects of the usage of sludge in agriculture as a fertiliser are discussed in order to be able to evaluate if this usage of sludge is a sustainable method for the future.

3.2 Field study

This project is conducted in cooperation with Beijing Drainage Co. Ltd located in Beijing, China. The company established cooperation with the Swedish International Development Cooperation Agency *(Sida)* in 1997 when Sida decided to support the foundation of a training centre at the Gaobeidian Sewage Treatment Plant in Beijing.

The field study includes visits to different wastewater treatment plants with sludge treatment facilities in order to investigate which different methods are in use. Data regarding present sludge production qualities and quantities is collected. This gives an overall picture of the present situation. A general investigation of pollutants i.e. sources and control strategies is conducted when visiting sludge treatment plants and during interviews. Also sludge disposal sites are visited in order to collect the necessary information. Interviews with experts in the agricultural field give some information about infrastructure and the possibility of using sludge as a fertiliser.

In order to compare the Chinese legislation with the legislation in Sweden, EU and USA sludge quality demands and other legislation concerning sludge handling are collected.

All visits are conducted with valuable help from Ms Gan Yiping and her assistants Mr Wang Jiawei and Dr Zhou Jun. Interviews related to the fields study are also arranged with their assistance. All the interviews are conducted as open interviews.

The public opinion and also experts' opinions about using wastewater sludge as a fertiliser in agriculture is collected throughout the whole visit in Beijing. These are not planned interviews in large scale but a few questions asked to people whenever there is an opportunity.

4 Literature study

This literature study is performed in order to obtain a base of knowledge about different treatment and disposal methods for sludge. Legislation for the usage of sludge in Sweden, EU and USA is also included in the study so these could be compared with the legislation in China. Different aspects of the usage of sludge in agriculture as a fertiliser are discussed. Pollutants in sludge may be a problem when disposing the sludge so therefore these and their sources are mentioned.

4.1 Sewage sludge

Sludge originates from different stages at the wastewater treatment process and has a various content of inorganic and organic substances in both a liquid phase and a solid phase. It is a complex material and it is a mix of both useful and useless components. The useful components may be used in different ways but the sludge must first undergo treatment of various natures.

4.1.1 Origin of the sludge

The treatment of the large amounts of wastewater produced in the society of today generates large quantities of sludge. The wastewater is treated in such a way that undesirable substances are separated from the water. The first treatment is often mechanical and it removes the bigger particles from the wastewater. Substances can also be removed biologically which is often the case in for example nitrogen and carbon, which is measured in biological oxygen demand *(BOD)*. Chemical treatment is sometimes used and it encourages small particles and dissolved substances to form larger particles which facilitate separation. This is called chemical precipitation. Sludge is formed when these larger particles clump together during suitable separation methods. (Casey, 1997) All the sludge that is separated during these treatment methods (mechanical, biological and chemical) are referred to as raw sludge, which has to undergo varies kinds of further treatment.

Sludge is generated and removed at different stages in the wastewater treatment process and can therefore be known as *primary sludge* from the mechanical treatment, *secondary sludge or biological surplus sludge* from the biological treatment stage or in some cases also *tertiary sludge or chemical sludge* from the post-precipitation stage. (European Commission, 2001) Post-precipitation is when chemicals are used after the biological treatment in order to precipitate for example phosphorus. A schematic illustration of a wastewater treatment plant with no chemical treatment is shown in Figure 1. The volume of the produced sludge is around 1% of the volume of the influent wastewater to a treatment plant (Lindquist, 2003).

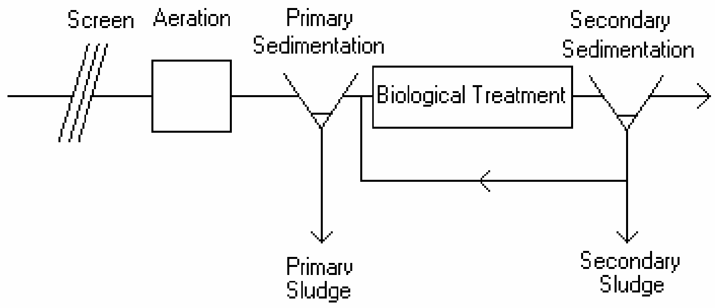

Figure 1 Wastewater treatment plant with mechanical and biological treatment.

4.1.2 Sludge composition

Most often, the wastewater from households is not treated at separate plants but together with wastewater from industries. Most of these treatment plants also receive stormwater. This means that there are large amounts of pollutants in the influent wastewater and hence in the sludge. (Lindquist, 2003)

The contents of the sludge reflect all the substances that are used in the community, which means that there is a vast variation of substances. Apart from the substances that enters the treatment plant, of which some will sediment directly in the mechanical treatment, the sludge will also contain micro organisms produced in the biological treatment step and added chemicals used in the chemical treatment step. Remainders from pharmaceuticals such as antibiotics and hormones in the influent wastewater are other substances that also eventually will end up in the sludge. (Naturvårdsverket 5214, 2002) Thus, metals, living organisms, organic substances and nutrients are all mixed together.

The sludge has two main components; liquid and solids. The liquid phase of course contains water but also dissolved substances. These may be organic substances in the form of carbohydrates and fatty acids, and inorganic salts such as ammonium. The solid phase contains organic and inorganic matter. Living organisms, their decomposition products and other organic compounds that have been broken down to varying degrees constitute the organic matter while metals and nutrients are regarded as inorganic matter. (Lindquist, 2003) Table 1 shows concentrations of phosphorus, nitrogen, metals and organic indicator substances in sludge from municipal wastewater treatment plants in Sweden year 2002 (Naturvårdsverket, Statistiska Central Byrån, 2002). The concentrations are measured in mg per kg dry solids *(DS)*. Concentrations are often measured related to the dry solid content of the sludge since the water content varies. Dry solids are the matter that remains as residue after evaporation and drying.

Table 1 Concentrations of phosphorus, nitrogen, metals and organic indicator substances in sludge from municipal wastewater treatment plants in Sweden year 2002 (Naturvårdsverket, Statistiska Central Byrån, 2002).

Compound	Weighted Mean in mg/kg DS
Phosphorus	27171
Nitrogen	37864
Lead	30.7
Cadmium	1.3
Copper	370.3
Chromium	29.7
Mercury	0.9
Nickel	17.1
Zinc	548.6
Nonylphenol	17.2
Toluene	3.8
PAH[A]	1
PCB[B]	0.1

[A] *Polycyclic aromatic hydrocarbon*
[B] *Polychlorinated biphenyl*

The content of sludge varies depending on local circumstances but also on the choice of treatment method and where in the process the measurements are made. Table 2 shows the general composition of sewage sludge from primary sludge and secondary sludge in the EU (European Commission, 2001). A few other compounds and also the dry solids, volatile solids, calorific value and pH are shown in this table. Volatile solids are the mass of the dry solids that is burned off at high temperatures.

Table 2 Composition of primary and secondary sludge (European Commission, 2001).

		Primary Sludge	Secondary Sludge
Dry Solids (DS)	g/L	12	9
Volatile Solids (VS)	%DS	65	67
pH		6	7
Carbon	%VS	51.5	52.5
Hydrogen	%VS	7	6
Oxygen	%VS	35.5	33
Nitrogen	%VS	4.5	7.5
Sulphur	%VS	1.5	1
Carbon/Nitrogen	-	11.4	7
Phosphorus	%DS	2	2
Chlorine	%DS	0.8	0.8
Potassium	%DS	0.3	0.3
Aluminium	%DS	0.2	0.2
Calcium	%DS	10	10
Iron	%DS	2	2
Magnesium	%DS	0.6	0.6
Fat	%DS	18	8
Protein	%DS	24	36
Fibres	%DS	16	7
Calorific value	kWh/t DS	4200	4100

4.1.2.1 Water content

The water content in sludge exists in several different forms. This liquid does not have the same chemical and physical properties as normal water and separating liquid from solids in sludge is not done easily. (Lindquist, 2003)

The water content can be divided into *external liquid* which includes internal capillary liquid and cellular water, and *internal liquid* which includes absorption liquid, adhesion liquid, contact liquid, capillary liquid and pore liquid. (Lindquist, 2003)

Mechanical dewatering will remove capillary liquid, contact liquid and adhesion liquid, while pore water can be separated by thickening. The internal liquid is difficult to remove mechanically. First, the liquid has to be released by destroying the cell walls. This can be done by different techniques, for example aerobic or anaerobic stabilisation, heating or freezing. (Lindquist, 2003) The desired degree of dewatering depends on the selected final disposal.

4.1.2.2 Metals

The most important metal pollutants in sludge are zinc *(Zn)*, copper *(Cu)*, led *(Pb)*, chromium *(Cr)*, nickel *(Ni)*, mercury *(Hg)*, cadmium *(Cd)*, silver *(Ag)*, gold *(Au)* and tin *(Sn)*. There are also other metals in the sludge such as iron *(Fe)* and aluminium *(Al)*. These exist in the influent wastewater and originate from the raw water used for production of potable water, households, storm water and industries. (Naturvårdsverket 5214, 2002) However, some metals are valuable as plant nutrition in small quantities and a soil with copper deficiency may benefit from sludge fertilising (European Commission, 2001).

Cadmium, which is a harmful heavy metal in sludge, has many different sources. Examples are storm water, discharge water from car wash and laundry facilities. However, diffuse sources are probably exceeding the point sources. Mercury is another harmful heavy metal and one origin is in the amalgam used at dental practices. (Naturvårdsverket 5214, 2002)

In Sweden a lot of work has been conducted in order to reduce the amount of metals in the influent wastewater. The content of metals has been subsiding during the last decades. The metals that are regulated in the Swedish legislation (Pb, Cd, Cu, Cr, Hg, Ni and Zn) were reduced with 50 to 90% during the years of 1969 and 1998. The reduction is mostly a result of decreasing number of point sources. There are not that many point sources left to reduce and the reduction trends of different metals have therefore levelled out during the recent years. Today, most of the metals in the influent wastewater are probably coming from diffuse discharges in the society, which are much harder to trace and regulate. A significant source is metals in the influent stormwater and the content of metals in the sludge could be reduced if the stormwater was treated separately instead of at the municipal wastewater treatment plant. (Naturvårdsverket 5214, 2002) However, the cost for this would be very high due to that this would demand reconstruction of the existing pipe network in Sweden.

Iron and aluminium are metals, which both exist in the influent wastewater and are also sometimes added in the treatment process, in order to precipitate phosphorus and separate it. This leads to the fact that the amount of sludge increases and also the concentration of metals within it. If biological phosphorus reduction ought to be used instead, the amount of added chemical is strongly reduced since no metals are then needed for the reduction of phosphorus. (Naturvårdsverket 5221, 2002)

4.1.2.3 Organic substances

Usually, more than 50% of the dry solids in sludge are organic but the amount depends on how the sludge has been treated. (European Commission, 2001) The organic substances can be organic pollutants broken down to varying degrees, micro organisms and their metabolic products. (Lindquist, 2003) Most of the organic matter is soluble compounds such as amino-acids, lipids, hydrocarbons or small proteins. (European Commission, 2001)

Unlike metals, organic substances are degradable but their toxicity and degradability varies. There are polycyclic aromatic hydrocarbons *(PAHs)*, polychlorated biphenyls *(PCBs)*, linear alkylbenzene sulphonates *(LAS)*, phthalates as di-2-(ethylhexyl) phthalate *(DEHP)*, nonylphenol *(NP)*, and polychlorinated dibenzo-p-dioxins and – furans *(PCDD/PCDF)* just to mention commonly discussed compounds. (Naturvårdsverket 5214, 2002) Most of the easily degradable organic substances are degraded in the biological treatment step of wastewater. The compounds that are more resistant to biodegradation can accumulate in the sludge. (Naturvårdsverket 5217, 2003)

Organic substances can be grouped in several different ways. Common organic substances are grouped in Table 3 according to their different characteristics, degradability and relative concentration in sludge. (Naturvårdsverket 5217, 2003)

Table 3 Grouping of organic contaminants (Naturvårdsverket 5217, 2003).

Parameter	**Quality**	**Concentration in sludge**	
		High	**Low**
Degradation in aerobic soil	Rapid-fair	LAS, DEHP, NP, low weight PAHs	None
	Slow-none	None	PCBs, PCDD/PCDFs, benzo(a)pyrene a.o. high weight PAHs
Sorption (lipophilicity)	Low-medium	LAS, NP, low weight PAHs	None
	High	DEHP	PCBs, PCDD/PCDFs, benzo(a)pyrene a.o. high weight PAHs
Bioaccumulation	Low	LAS, DEHP, NP, low weight PAHs	None
	High	None	PCBs, PCDD/PCDFs, benzo(a)pyrene a.o. high weight PAHs

LAS - linear alkyl benzene sulphonates
DEHP - di-2-(ethylhexyl) phthalate
NP – nonylphenol
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
PCDD/PCDF – polychlorinated dibenzo-p-dioxins and –furans.

Several projects aiming to investigate different characteristics for organic substances and how they may effect the environment have been conducted. The substances identified as being of concern by one or more of these assessments belong to one of the following two groups (Naturvårdsverket 5217, 2003):

- Biodegradable, not bio accumulative substances, which are found in high concentrations in sludge.

- Persistent and bio accumulative substances, which are generally found in low concentrations in sludge.

PAHs form an exception to this rule since its properties vary with the size of the molecule and thus can be placed in both the above groups (Naturvårdsverket 5217, 2003).

There are many sources to organic substances of which several are diffuse. Problems related to organic substances in sludge have recently been given attention. Therefore it is hard to show any long-term development in the reduction of these substances. However, a decreasing trend has been noticed for several substances in Sweden during the 1990s. For example, the content of nonylphenol has decreased with 69% from 1993 to 1998. The occurrence of PCBs in sludge has been unchanged while PAHs have decreased between 1995 and 2000. Several substances have been mapped out quite recently in Sweden. For example phthalates, dioxins, chlorinated benzene, organic tin compounds, chlorinated phenols, PAHs, nonylphenol/octylphenol, chlorinated paraffin, LAS, triclosan, fluorinated carbons and ethylene diamine tetra-acetic acid *(EDTA)* from 19 different treatment plants in the province of the western part of Götaland in Sweden had been analysed during 2001. Another substance that has been given a lot of attention in Sweden is brominated flame retardants, which have been analysed at 50 different treatment plants during 2000. (Naturvårdsverket 5214, 2002)

Apart from the substances already existing in the influent wastewater, some organic compounds are added during the wastewater treatment and can be found in the sludge. Polymers are added in order to dewater the sludge. They are also used as flocculation compounds in order to facilitate the separation of precipitated substances. (Naturvårdsverket 5221, 2002)

4.1.2.4 Nutrients

Sludge also contains a number of different nutrients. It contains about 3% phosphorus (Naturvårdsverket 5221, 2002) and about 4% nitrogen measured by DS content (Naturvårdsverket, Statistiska Central Byrån, 2002). That is why sludge constitutes such a valuable resource since these are very important for growing crops. There are macronutrients in the form of nitrogen *(N)*, phosphorus *(P)*, sulphur *(S)*, potassium *(K)*, calcium *(Ca)* and magnesium *(Mg)* that growing plants need in larger amounts. The sludge contains low amounts of nitrogen and potassium compared to the needs of different crops. Normally, if sludge is used as a fertiliser, complementing artificial nitrogen and potassium fertilisers have to be used. On the contrary, micronutrients such as chlorine, iron, manganese, zinc, copper, nickel, boron and molybdenum exist in sufficient amounts to meet the need of different crops. There is even a surplus of iron, nickel and sometimes copper. (Naturvårdsverket 5214, 2002)

The four most important nutrients in sludge are phosphorus, nitrogen, potassium and sulphur, which are all essential elements (Naturvårdsverket 5221, 2002). Nitrogen is a part of proteins and nuclei acids and is therefore vital to all life forms (NE[1], 2004). It is also the nutrient that the majority of crops need the most and mainly consist of (Naturvårdsverket 5221, 2002). Potassium is essential to all organisms and exists as ions, mainly in the cells (NE[2], 2004). Phosphorus is part of the cell's DNA and plays a central role in the metabolism. It is essential to photosynthesis and respiration for example (NE[3], 2004). Some amino acids contain sulphur as well as iron-sulphur proteins and thiamine (vitamin B) (NE[4], 2004).

Phosphorus found in sludge originates mainly from urine, faeces and washing detergent containing phosphates (Naturvårdsverket 5214, 2002). About 90% of the nitrogen in the influent household wastewater comes from blackwater, i.e. faeces and urine. The figures are 70% and 90% for phosphorus and potassium respectively. (Naturvårdsverket 4425, 1995)

4.1.2.5 Biological community

Sludge contains several different kinds of micro organisms and some of these cause diseases, so called pathogens. Pathogens are secreted by humans and animals through the faeces. The concentration is reflected of the incidence of pathogens in the influent water and this varies according to the health of the connected population. Faeces originate from wastewater from households but also from stormwater, which can contain faeces from birds, cats, dogs, etc. (Naturvårdsverket 5215, 2003)

The treatment of the sludge at the wastewater treatment plant is also crucial for the concentrations of pathogens. Some treatment methods will sanitise the sludge and therefore reduce the concentration of micro organisms. These methods are often dependent of an increase in temperature to levels that will inactivate the micro organisms. (Naturvårdsverket 5215, 2003)

Micro organisms can be divided into different groups such as, bacteria, protozoa, worms and virus (Naturvårdsverket 5215, 2003). Which species that is present and in what quantity can vary considerable with time and between different plants. Table 4 shows typical concentrations of some micro organisms in untreated sludge per g wet weight (European Commission DG Environment, 2001).

Table 4 Typical concentrations of micro organisms in untreated sludge per g wet weight (European Commission DG Environment, 2001).

Organism	Species	Amount per g wet weight
Bacteria	E. coli Salmonella	10^6 10^2-10^3
Virus	Enterovirus	10^2-10^4
Protozoa	Giardia	10^2-10^3
Worms	Ascaris Toxocara Taenia	10^2-10^3 10^1-10^2 5

Salmonella, Campylobacter and EHEC constitute the largest risks among the bacteria and all of these are zoonotic agents (can be transmitted between humans and animals). Giardia and Cryptosporidium are protozoa and they are often persistent with a long survival in the environment. These protozoa are also zoonotic agents. Parasitic worms, Helminths, are associated with bad sanitary conditions. Enteric viruses (intestine viruses) are probably the most common cause of intestine- and stomach infections in the western world. But viruses are hard to detect and therefore have their occurrence and survival in sludge not been further investigated. (Naturvårdsverket 5215, 2003)

There are no documented outbreaks of diseases due to the usage of sludge. The lack of evidence between the spreading of sludge and the spreading of diseases do not necessary mean that the spreading of sludge does not involve any risks. (Naturvårdsverket 5215, 2003)

4.2 Treatment and disposal methods

The large amounts of generated sludge from the wastewater treatment plants have to be taken care of. It may be treated and disposed of in different ways. It is often hard to make a total distinction between treatment and disposal methods, some methods are a combination of both.

4.2.1 Treatment methods

Sludge must undergo various types of processing for economic and hygienic reasons. The purpose of all types of sludge processing is to reduce the volume, stabilise the sludge, remove water and kill pathogenic organisms. It is processed in stages that comprise a sequence of treatments such as conditioning, thickening, dewatering and stabilisation. (European Commission, 2001)

The process of killing pathogenic organisms is termed hygienisation or sanitation where the sludge may be subjected either to high temperature or a high pH. This has the largest effect on reducing pathogens. The competing micro flora that exists when composting and digesting the sludge may also play an important role of the hygienisation process. There are also a number of substances that can accumulate in the sludge and be toxic to micro organisms. Hygienisation is achieved through a number of treatment methods such as anaerobic digestion, pasteurisation, composting, and lime stabilisation.

4.2.1.1Conditioning

Conditioning of the sludge involves modification of the sludge structure so that more water can be separated. This will improve further treatments such as thickening or dewatering and it may also restrict the fine particle content of the reject water. There is *chemical conditioning* using mineral agents such as lime or salts or an organic compound which is different kinds of polymers. Another way is *thermal conditioning* where sludge is heated to 150-200ºC in 30 to 60 minutes. Heating to 40ºC or 50ºC is also possible and will give a partial thermal conditioning. (European Commission, 2001)

4.2.1.2 Sludge thickening

The sludge produced at the wastewater treatment plant contains a lot of water and it has to be thickened in order to reduce the volume and cost for the following treatments. The thickening methods vary with the nature of the sludge and the purpose is to remove some of its free water. *Flotation* may be a suitable method for chemical and biological sludge while primary sludge is best thickened by various *sedimentation processes*. C*entrifugation* can be used either for thickening or dewatering purposes. (European Commission, 2001)

4.2.1.3 Dewatering

Dewatering means that the volume of the sludge is greatly reduced by separating water. Raw sludge contains high amounts of water, usually more than 95% by weight (Casey, 1997). It is only possible to remove a certain proportion of free, adhered and capillary water with the technology available today (Lindquist, 2003). Different dewatering processes are *drying beds, centrifuging, filter belt* and *filter press*. All processes except drying beds requires the addition of a chemical conditioning agent.

The water content of the sludge after dewatering depends on the treatment and can reach about 30%. (European Commission, 2001)

4.2.1.4 Stabilisation

Raw sludge is biologically active since it contains biodegradable compounds. The decomposition rate has to be increased in order to avoid problems such as odour due to anaerobic degradation etc. Stabilisation is of importance in regard to hygienisation since the odours are reduced and therefore do not attract vectors via smell. This can prohibit re-infection and re-growth of pathogens. After stabilisation, the volume has decreased, hygienisation has occurred and the sludge is no longer regarded as active. (Naturvårdsverket 5215, 2003)

Anaerobic digestion is a stabilisation method that will reduce the volume and stabilise the sludge. It will also give a partial hygienisation. The total quantity of the sludge is reduced by about 35%. (European Commission, 2001) The decomposition process in a digester has several stages. Carbohydrates, fats and proteins are broken down in different steps and finally converted into methane gas and carbon dioxide. (Nilsson, 2002) The produced biogas may be utilised as electricity on the plant or used elsewhere. The temperature is normally kept around 35°C and the retention time should be more than 20 days in order to receive a good stabilisation and hygienisation but other retention times and temperatures also exists. Pathogens are reduced during digestion and to which extent depends on the temperature and retention times used. (European Commission, 2001)

Aerobic digestion is a process where the sludge is placed in an aerated vessel. The decomposition is performed by aerobic micro organisms and this generates heat. If the process is working adequately, more than 70°C can be reached. Usually the sludge is subjected to 50 to 65°C for 5 to 6 days and most of the harmful organisms are destroyed. One drawback is that the energy costs are 5 to 10 times higher than for anaerobic digestion. (European Commission, 2001)

Lime stabilisation takes advantage of the fact that all biological activity is effectively terminated when the pH rises above 12. Enough lime, about 30% of the dry solid content, has to be added in order to ensure that no fermentation takes place in the long run. Pathogenic micro organisms are killed effectively during liming, the content of dry solids increases and the handling of the sludge become easier. (European Commission, 2001) Also, the lime binds phosphates and heavy metals very securely. When quicklime is added after dewatering, a sharp temperature rise occurs and the high temperature pasteurises the sludge. If quicklime instead is added before dewatering it results in a sludge that is odourless and has much better dewatering characteristics. (Lindquist, 2003)

Pressurised sludge is subjected to high temperature in processes known as *thermal sludge processing.* During this treatment, the sludge is stabilised and pathogens are killed. The scientists are not entirely sure of what happens when sludge is thermally processed. The dewatering characteristics are definitely improved for a number of reasons. Fats and oils are dissolved, cell walls of organic particles and organisms are ruptured and thereby releasing their cellular water and finally, extra cellular polysaccharides that bind water are also broken down. Four such processes are *pasteurisation, composting, thermal drying* and *pyrolysis*. (Lindquist, 2003)

Incineration is also a form of thermal sludge processing but it may be more regarded as a final disposal method due to the enormous decrease in volume. The ashes however, need to be taken care of.

Pasteurisation is a method where the sludge is heated to a temperature of 70°C to 80°C for a short period of time (about 30 minutes). This must be done in many countries before the sludge can be spread or deposited in a landfill. The amount of pathogens is reduced during pasteurisation (European Commission, 2001) but afterwards the sludge must undergo a secondary process in order to stabilise the sludge. The sludge is sensitive to re-infection directly after pasteurisation. (Naturvårdsverket 5215, 2003)

Micro organisms can be used in order to *compost* the sludge and this involves biological thermal oxidation. Stabilisation, hygienisation and weight reduction occur during composting and this creates a humus-like end product with high agricultural value. This process is an aerobic process and the micro organisms are mainly mesophilic bacteria (growing at 25-45°C) and thermophilic bacteria (growing at temperatures above 45°C). There are two phases during composting; active composting and curing. During the first phase the decomposition rate is rather high and the more easily degradable compounds such as carbohydrates are degraded. The temperature is raised due to an extensive microbial growth and pathogens are destroyed. Optimum is 50 to 60°C for 2 to 3 weeks in order to obtain hygienisation. The decomposition rate is slow during the curing phase and the temperature decreases. Fats, cellulose and other more complex organic compounds are broken down during this phase. (Nilsson, 2002) The process takes several weeks and the end product is stable with reduced odours and the water content may be less than 40%. The sludge should be mixed with a biodegradable material such as sawdust or animal manure and it is very important to keep the compost aerated. (European Commission, 2001) The moisture content in the compost should be around 50 to 60% in order to keep the microbial activity at its optimum. Water is evaporated but also released through microbial activity. Too much water may result in anaerobic conditions and a lot of air is needed to remove water (usually up to 10 times more than the air needed for microbial activity). It is also important to have the right ratio between carbon and nitrogen. It is the part of the total carbon that is available to micro organisms that is of interest. The optimum ratio is about 25-30:1 (C:N) and will gradually decrease to 10-15:1 during the process when most of the organic carbon is converted to carbon dioxide. (Nilsson, 2002)

There are three types of methods (European Commission, 2001):

- Windrows: The sludge-mix is laid in the form of elongated, unenclosed piles, so called windrows, and is mechanically turned on a regular basis. This is done in order to mix the material and rebuild porosity, prevent excessive temperatures but also to introduce air and remove water vapour and carbon dioxide. A large land area is needed for this method.

- Static piles: In this system the compost material is not turned mechanically. The oxygen is instead supplied through perforated pipes or the material is laid on a floor through which air is blown.

- Vessel: The compost material is injected at the top of a vessel, where it is harrowed. Air is supplied at the lower section and the product can be extracted at the bottom.

Thermal drying of the sludge will result in the elimination of interstitial water and reduction of the volume. The process also allows stabilisation and hygienisation when the dry solids content exceeds 90%. Heat is transferred directly or indirectly to the sludge. At direct transfer, hot gas is used and two important methods are the rotating drum dryer and the fluidised bed dryer. At indirect transfer, a heat transfer surface is used and the heat is transferred via heat conduction. (European Commission, 2001) The drying takes place at different temperatures and if higher temperatures are used (above 300°C) it is important to control that no dioxins or furan compounds have been formed. A dry matter content of 35 to 90% is reached and re-growth of pathogens is inhibited mainly due to the reduced water content. (European Commission, 2001) The reduction of pathogens also takes place due to the high temperature (Naturvårdsverket 5215, 2003).

Another thermal processing method is *pyrolysis*, which results in solids containing mineral matter and carbon, and different gaseous compounds. The solids can be regarded as a low-quality coal. In the process, the sludge is heated to 300 to 900°C in absence of oxygen. This is considered to be a treatment method since the end products has a calorific value and further handling of the solids and gases are needed. (European Commission, 2001)

There are also other treatment methods that could be used in order to sanitise the sludge. The sludge can be exposed to *beta- or gamma radiation* or *treatment with acid* so the sludge reaches a pH around 1.5. (Naturvårdsverket 5215, 2003)

4.2.1.5 Storage - air drying

Storage is a method used in order to keep the sludge in one place until it is possible to spread it or use it elsewhere. During storage an increase in dry matter and a reduction of organic matter occur (European Commission, 2001). Also, there is a decrease of pathogens due to storage. During storage or spreading of sludge the micro organisms are affected by natural conditions regulated by the climate. Sunlight or UV-radiation, increases in temperature and drying are all factors that speed up the killing of pathogens. (Naturvårdsverket 5215, 2003) How efficient the hygienisation is depends on the climate (cold climates do not generate sufficient hygienisation) and on the duration of the storage. The amount of bacteria and viruses are reduced during storage but it has been reported that the infectious potential of parasites is not affected. The agricultural value may be reduced since a reduction of nitrogen occurs. Nitrogen is converted into ammonium and ammoniac in a gaseous form and thus released. (European Commission, 2001) *Storage with freezing/thawing* is a storage method used in order to dewater the sludge and thereby obtain a decrease in volume. (Naturvårdsverket 5215, 2003)

4.2.1.6 Bed of reed

A form of temporary deposition or long term storage of the sludge is a *bed of reed*. The sludge lies in a basin for 8-12 years and is dewatered, mineralised and decomposed. During this time the DS content increases from a few percent up to 40-60% without the adding of polymers. The odour is insignificant and does rarely cause any problems. (Naturvårdsverket, SLU, Urban Water, 2002) The biological degradation is speeded up by the increased oxygen transportation due to the root system of the reed and the long retention time leads to sanitation to a certain extent. (Naturvårdsverket 5215, 2003) Figure 2 shows a schematic illustration of a bed of reed (Naturvårdsverket, SLU, Urban Water, 2002).

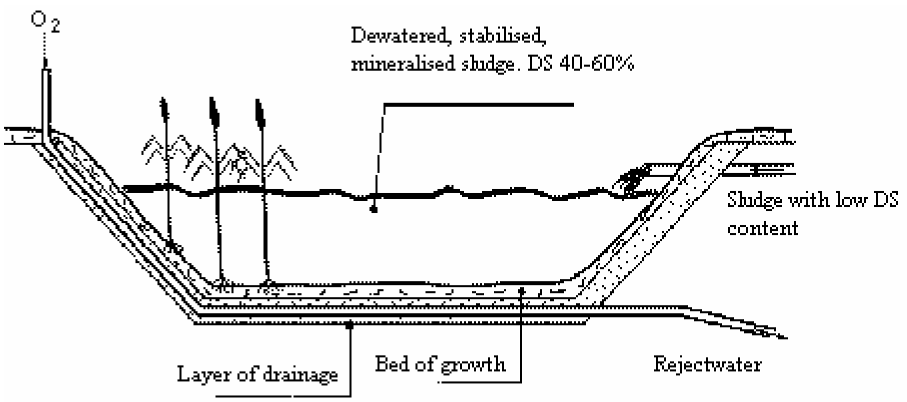

Figure 2 Schematic illustration of a bed of reed (Naturvårdsverket, SLU, Urban Water, 2002).

4.2.1.7 Sludge hydrolysis

Sludge contains hydrocarbons that could be useful as a carbon source to micro organisms. Sometimes when wastewater is being processed at the treatment plant, a carbon source is needed in the biological nitrogen reduction step. The carbon source must exist in an easily accessible form so it can be utilised by the denitrifying bacteria, which are converting nitrate into nitrogen gas. This carbon course can be obtained by hydrolysing the sludge. This can be done biologically using enzymes, thermally or chemically. Both raw sludge and digested sludge will yield high concentrations of dissolved organic substances. (Lindquist, 2003) Sludge hydrolysis is not a treatment method with the purpose to stabilise or dewater the sludge but instead a way to make use of the organic material in the sludge.

4.2.2 Disposal methods

There are several different disposal methods for sewage sludge. In Sweden and EU sludge is classified as waste (Naturvårdsverket 5221, 2002) and therefore the choice of disposal method should follow the waste hierarchy. The first choice should be that the sludge is handled in such a way that the nutrients are recycled. If that is not possible the energy or material should be made use of. The last choice is to get rid of the sludge without making use of nutrients, energy or material. (Naturvårdsverket 5214, 2002)

4.2.2.1 Deposition

Deposition means that the treated sludge is transported to a landfill where it is deposited. The waste is then covered with landmasses. In some countries there are no restrictions of the design of the landfill. Other countries have restrictions in the design, for example stating that the leakage from the landfill should be minimised. The leakage from landfills is hazardous and can often contain heavy metals and other pollution. There are landfill gases emitted to the air mainly consisting of methane and carbon dioxide. This gas is collected at some landfills and the energy content is utilised. There is also a risk for spreading of pathogens when depositing the sludge if the sludge is not sanitised in previous treatment. When depositing sludge, the sludge is disposed without making use of nutrients, energy or material. (European Commission, 2001)

Deposition can also be classified as a temporary storage for sludge before it is decided how to handle the sludge. Then it is important that the sludge is deposited without mixing with other waste that could contaminate the sludge. In order to not pollute the environment the leakage from the landfill should be minimised. A bed of reed is an example of temporary storage where the sludge is also treated as mentioned before.

4.2.2.2 Incineration

The sludge must be treated and dewatered before incineration of the sludge is possible. To incinerate the sludge without auxiliary fuel the DS content must be around 40%. Dewatered sludge normally has a DS of 25%. (Lindquist, 2003)

The calorific value of sludge is around 10-20 MJ/kg DS. (Lindquist, 2003) When sludge is incinerated, it is possible to make use of the energy in the sludge. This energy is in the form of heated water or air and this can be made use of when for example heating houses or swimming pools.

There are several pollutants that may be emitted to the air when incinerating sludge and it is important to treat the flue gases in order to reduce these. Examples of pollutants are particulates and fly ash, nitrogen oxides, carbon dioxide, organic compounds and heavy metals bound to particles, heavy metals in gaseous form, dioxins, acid gases and volatile organic compounds. (European Commission, 2001) During incineration the temperature and the supply of air is monitored to ensure complete combustion of the sludge. Odour problems and emissions of pollution such as oxides of nitrogen can arise if the combustion is incomplete. (Lindquist, 2003)

The aches still remain after the incineration, which need to be taken care of. This aches contains nutrients but also pollutants as different metals (Naturvårdsverket

5214, 2002). Pathogens and unwanted organic substances are destroyed in the process and the aches constitute therefore no sanitary risk (Naturvårdsverket 5221, 2002). The most common way of getting rid of these aches in Europe today is to deposit it in a landfill (Naturvårdsverket 5214, 2002). Incineration of the sludge reduces the amount that needs to be deposited and the aches are sanitised. However a new technique is developing called BioCon where phosphorus is recycled from the aches. This technique is further described below.

4.2.2.3 Use of sludge in agriculture and other land use

Dewatered, stabilised and sanitised sludge can be used as a fertiliser in agriculture. The sludge is often stored temporary before it can be transported away for use in agricultural areas or other land use. It is important that the storage do not lead to any re-growth of pathogens or pollution of different substances. (Naturvårdsverket 5221, 2002) The use of sludge as a fertiliser is only possible during certain times of the year, due to legislation and practise in agriculture, but the sludge is produced continuously so the design of the temporary storage can be of great importance.

Transportation of sludge is almost always needed due to the fact that the wastewater treatment plants are situated in urban areas and the sludge is spread in rural areas. In Sweden for example trucks perform most of the transportation of sludge. The sludge is transported in open containers and the loading is performed by loading trucks or from silo. (Naturvårdsverket, SLU, Urban Water, 2002) The transport as well as the handling and storage should be performed in such a way that the risks for personnel handling the sludge are minimised (Naturvårdsverket 5221, 2002).

The usage of sludge as a fertiliser enables the recycling of all the nutrients in the sludge. There are several potential negative consequences of the spreading of sewage sludge at agricultural land, for example the risk of spreading pathogens, organic pollutants and metals. There are also other compounds in the sludge that need to be more investigated as for example hormones and pharmaceutical substances. The risk can be minimised by the choice of suitable crop, methods of spreading and by regulating the time between fertilise and harvest. (Naturvårdsverket 5221, 2002)

Sludge can also be used as a fertiliser at existing forests and this would increase growth which would enable a higher withdraw of raw material in the future. Energy forest is another option for the usage of sludge as a fertiliser. It has been shown in experiments in Sweden that Salix accumulate more metals than is provided in the sludge. Only 2% of the cadmium that is accumulated in the plant comes from the sludge and the rest from the land. The land is then consequently cleaner from cadmium after the growth of Salix. (Naturvårdsverket, SLU, Urban Water, 2002)

The water content of the sludge is reduced to one third if the sludge is dried and pelletized. These pellets can then be used in agriculture or in forest industry. (Naturvårdsverket 5221, 2002) Energy forest can also be irrigated with sludge directly trough a pipe system. The cultivation is then a part of the treatment plant. (Naturvårdsverket, SLU, Urban Water, 2002)

Sludge from wastewater treatment plants is used mainly as a fertiliser of agricultural land but it can also be used as raw material in traffic noise barriers, golf courses, parks, land fillings, reclamation sites etc. (Naturvårdsverket 5221, 2002)

Existing technique for spreading of stable manure can be used when spreading sludge. (Naturvårdsverket 5221, 2002) Buoyant manure is spread with a slurry tanker and firm manure is spread with a spreader. It is the DS content of the sludge which decides which method is to be used. The DS content is regulated by the treatment method used on the sludge. The tilling down after spreading reduces the amount of leakage of ammonia. This can normally be done with a separate machine but a tilling down aggregate can also be used with a slurry tanker. The spreader spreads the manure or sludge from above but the slurry tanker is normally equipped with tubes that let the manure flow out on the ground. This reduces the amount of manure on the crop and this technique can therefore be used on growing crop. (Mr Kenneth Skog, 2004)

4.2.2.4 The extraction of phosphorus

There are several techniques under development aiming at extracting phosphorus from either sewage sludge or incinerated sludge. The phosphorus is then separated from the bulk and can be recycled in society. These methods are not disposal methods but methods to extract phosphorus.

KREPRO is a newly developed technique where phosphorus is extracted from sewage sludge by acidification and thermal hydrolysis. Phosphorus can then be precipitated as ferric phosphate and separated. (Naturvårdsverket 5221, 2002)

BioCon is a new technique where phosphorus is extracted from the aches after incineration of sludge. The aches are dissolved by sulphuric acid and phosphorus is separated by an ion exchanger. (Naturvårdsverket 5221, 2002)

4.3 Different aspects of the usage of sludge as a fertiliser

Sludge contains different components as mentioned above, which have effects when using it as a fertiliser in agriculture and other land use. It contains nutrients, which is essential for plants but also hazardous metals and organic substances. Sludge can also contain pathogens and pharmaceutical substances and hormones. The content of the sludge has different consequences when using the sludge.

4.3.1 Why circulation of nutrients?

To obtain a sustainable society it is important that material and energy is recycled as far as possible. By recycling for example nutrients the withdrawal of raw material could decrease. (Naturvårdsverket 5222, 2002)

An element such as phosphorus cannot disappear from the earth but it can be spread in an uncontrolled manner or contaminated. Hence it would be a scarce resource because it would be too expensive to accumulate it or purify it from pollutants. This applies for most elements but phosphorus is the substance that is most likely to become scarce first. (Lindquist, 2003) Most of the phosphorus today is extracted from phosphate rich ore and it is estimated to last between 150 and 300 years (Naturvårdsverket 5222, 2002).

Crops are cultivated to give food to human but also energy. In order to obtain larger harvests most crops needs to be fertilised. Sludge contains for example phosphorus, nitrogen, potassium and sulphur, which are all important for plants. If the availability of these nutrients were restricted it would mean that considerably less food could be produced at current costs. (Lindquist, 2003)

Another advantage of recycling nutrients is that it would decrease eutrophication, which is a major problem in for example Sweden. If the nutrients are utilised, instead of being directly or indirectly emitted through deposition and the washing out, this would lead to a decrease of the discharge from land to watersheds. (Naturvårdsverket 5222, 2002)

4.3.2 Sludge as fertiliser

Today most crops are fertilised with either artificial fertiliser or manure from animals. The agricultural land is producing food, which is harvested and sold to people in urban areas. The nutrients are taken from the fields as crops and spread in the whole society and there is no recycling. The only true circulation of different nutrients would be if these were brought back to the fields. Sludge contains nutrients, which are needed on the fields and by bringing it back to the fields a circulation would occur. When using sludge at golf courses, parks etc there is a large eutrophication due to that phosphor is added in too extensive amounts so most of it is not being used. (Naturvårdsverket 5221, 2002)

Sludge is regarded primary as a phosphor fertiliser but it contains other nutrients as well, as mentioned in previous chapters. It contains low concentrations of nitrogen and potassium compared to manure from stables and the need of most plants. The need for different nutrients of plant species varies. When fertilising with sludge a complementary fertiliser with nitrogen and potassium needs to be used. Sludge contains micronutrients such as Cl, Fe, Mn, Zn, Cu, Ni and Mo in sufficient amount and sometimes there is a surplus of Fe, Ni and Cu. Sludge also contains high concentration of sulphur. (Naturvårdsverket 5214, 2002)

A prolonged fertilising with sludge decreases pH in the land more then artificial fertiliser, manure from stables and green fertiliser. This concerns sludge precipitated with iron and not potassium. There are a lot of different processes, which are involved in the acidification of land. The main process is the washing out of sulphate, which brings with cat ions. Sludge contains high concentrations of sulphur, which is not made use of but is washed out. This leads to acidification of the land. (Naturvårdsverket, SLU, Urban Water, 2002)

Sludge contains rather stable organic compounds after being treated and this contribute to the build up of humus in the land. There are tests that show that sludge increases the carbon content the most and give rise to the highest build up of humus in comparison with other organic fertilisers added in the same quantity of fertilising carbon. This has positive effects for the cultivating characteristics of the land due to increased pore volume and aggregate stability and (Naturvårdsverket 5214, 2002) this leads to a porous and fine structure of the land (Naturvårdsverket, SLU, Urban Water, 2002). Another positive effect is that a higher content of organic material will improve the retention capacity of minerals and water. This will reduce the potential for water erosion and surface runoff. (European Commission, 2001)

There can be losses when spreading the sludge, for example 25% of the total nitrogen is lost which corresponds to the percentage of nitrogen that occurs as ammonia (Naturvårdsverket 5221, 2002). This is due to evaporation of ammonia and therefore the losses can be reduced by fast tilling the sludge into the soil. The losses increase if the climate is warm and windy. (Jordbruksverket 2003:22, 2003) There is no loss of phosphorus due to storage or spreading (Naturvårdsverket 5221, 2002).

The availability of nutrients for plants depends on in which form they occur. Most nitrogen is in the form of organic nitrogen while most phosphorus in sludge is present under mineral forms. Naturally, there will be a higher amount of phosphorus in the sludge if the wastewater treatment plant carries out a tertiary treatment for phosphorus removal, either biological or chemical. (European Commission, 2001)

Different treatment methods of the sludge can have effects on the value of the sludge as a fertiliser. The decrease is highest when the sludge is treated thermally. (Naturvårdsverket 5221, 2002) Plants can only absorb mineral nitrogen, thus the availability of nitrogen to plants depends on how much of the organic nitrogen that can be mineralised in the soil. Between 4 and 60% of the nitrogen in sludge is available to plant uptake. The nitrogen availability will vary with the treatment of the sludge as follows: composted sludge<anaerobic digested sludge<aerobic digested sludge. (European Commission, 2001)

There are several different tests in Sweden where sludge fertilising has been performed. It is hard to draw any conclusion about the uptake of phosphorus by plants when comparing sludge and artificial fertiliser. However, it has been demonstrated that it has a lower immediate availability to plants compared to artificial fertilisers. These differences are probably not very significant in a longer time perspective since added phosphorus will bind to the soil in different chemical processes. About 70% of the phosphorus in sludge has been estimated to be available to plants. (Naturvårdsverket 5221, 2002)

In Sweden phosphorus is precipitated with aluminium or iron as mentioned before. This leads to that the phosphorus is less immediate available to plants compared to artificial fertiliser. If the phosphorus was reduced biologically this effect would disappear and the phosphorus in the sludge would be more available to plants. (Naturvårdsverket 5221, 2002)

4.3.3 Accumulation of metals in soil

One problem with sludge is that it contains metals, as mentioned previous. If sludge is spread on agricultural land there is a possibility that some of these metals can accumulate in the land. That could destroy the land though high concentrations of certain metals are poisonous for the biota. (Naturvårdsverket 5222, 2002) There must be a balance between the input and the output of metals to the agricultural land so no accumulation occurs (Naturvårdsverket 5220, 2003). Of course, there are also other sources of metals at agricultural land, for example atmospheric deposition, manure from stables, and artificial fertiliser (Naturvårdsverket 5222, 2002). In Sweden the largest supply of cadmium to agricultural land is by atmospheric deposition (Naturvårdsverket 5214, 2002).

Farmers can be afraid of using sludge because they do not know if this will harm their land, which would make it impossible to use the land in the future (Naturvårdsverket, SLU, Urban Water, 2002). The world's population is growing and the society cannot afford to destroy agricultural land. Pollutants might also accumulate in crops, which will have affects on human health but also, animal health.

Manure from stables also contains metals and the concentrations are higher than the concentration in human urine and faeces. For zinc and copper the concentrations in stable manure can be higher than the concentrations in sewage sludge. This is due to that these metals are added to animal food. There are metals in artificial fertilisers as well and these have been proven to contain large variations in concentrations. (Naturvårdsverket 5221, 2002)

By reduced atmospheric deposition, the exchange to more environmental friendly material (for example copper pipes), and by measures from control authorities the quality of the sludge could be improved. The quality of the sludge can be further improved if wastewater from industries and stormwater is disconnected or if their pre-treatment is improved. (Naturvårdsverket 5221, 2002)

In Sweden investigations has been performed in order to evaluate the usage of sludge as a fertiliser. These indicate that the usage of sludge so far, has not resulted in any negative eco-toxically effects to speak of because of provided elements. The risks for negative effects on plants and humans and animals, which consume plants, normally arise at considerable higher concentrations compared to those concentrations which have negative effects on micro organisms. In general, metals are harder bound to soil particles in soils with high content of clay and high pH. The metals will then exist to a less extent in a form that would affect micro- or soil organisms. Thereby the risk for plant uptake is likely to be reduced as well. (Naturvårdsverket 5214, 2002)

4.3.4 The spread of diseases - need for sanitation

The concentration of micro organisms in Sweden is 10 - 1 000 times higher in the sludge compared to influent water to wastewater treatment plants. (Naturvårdsverket 5221, 2002) The usage of unhygienisated sludge can mean that pathogens are spread further in the environment. That means that it could spread to humans and animals. (Naturvårdsverket 5214, 2002)

Humans can be directly exposed when handling the sludge or by non-deliberate contact. This is when handling the sludge at the wastewater treatment plant, transports and storage or at the spreading of sludge. (Naturvårdsverket 5215, 2003) Animals can be exposed to pathogens in the sludge during treatment (for example storage) or after it has been spread on land. Animals can be infected or spread the infection elsewhere. Surface runoff from land to surface water or groundwater makes it possible for exposure via baths or other water activities and trough the drinking water. Pathogens can also follow the crop when harvesting. (Naturvårdsverket 5214, 2002)

The hygienic risk associated with sludge, when used as a fertiliser on agricultural land, is principally dependent on the treatment method of the sludge. As mentioned before there are several ways of hygienisation based on the rise of temperature or pH. (Naturvårdsverket 5221, 2002) The tilling into the soil further reduces the exposure to animals and humans but also to surface runoff. Sludge is a quite firm material so it is not likely to involve any risks for contamination of the groundwater but the risk for contamination increases during heavy rain. The risk for exposure via the crop can be minimised by prohibition against the usage of sludge on crops that is being consumed raw. (Naturvårdsverket 5214, 2002) The fertilising can also take place before sowing. (Naturvårdsverket 5215, 2003)

Stabilised sludge does not attract animals and organisms due to odour and prevent the re-infection and re-growth of pathogenic bacteria (Naturvårdsverket 5215, 2003). Re-growth of bacteria is possible in all organic material. It is therefore important that the sludge is stored and handled so that these risks are minimised. (Naturvårdsverket 5214, 2002)

There are no documented outbreaks of diseases due to the usage of sludge. The lack of evidence between the spreading of sludge and the spreading of diseases do not necessary mean that the spreading of sludge does not involve any risks. (Naturvårdsverket 5215, 2003)

4.3.5 Organic pollutants, hormones and pharmaceutical substances

Sludge can contain organic substances, which are either (Naturvårdsverket 5217, 2003):

- Biodegradable and not very bio accumulative which are found in high concentrations in sludge in some countries.

- Persistent and bio accumulative substances found in low concentrations in sludge.

Toxic properties of substances that cause danger to humans or the environment or their ability to bio accumulate and persist in the environment are reasons for concern. (Naturvårdsverket 5217, 2003)

Persistent compounds such as PCBs, PCDD/PCDFs and PAHs are generally not transferred from soil to crops, meat and milk, there is however a potential problem that the compounds could accumulate in the soil. Substances, which are present in relatively high levels in sludge such as phthalates and nonylphenol, need to be investigated though little is known about the uptake. (Naturvårdsverket 5217, 2003)

It appears when considering present knowledge about organic substances in sewage sludge that (Naturvårdsverket 5217, 2003):

- Transfer to water is low.
- Micro organisms adapt to changing conditions in soil.
- Numerous organic compounds are rapidly degradable in soil.
- Transfer to crops does not occur for most organic compounds. There is normally no uptake of organic compounds by the roots (Naturvårdsverket 5214, 2002).

Hygienisation of sludge also contribute to higher degradation of organic substance and thus less organic substances will be applied to the land. The risks of organic compounds in sludge need to be investigated and monitored but present knowledge indicates that these substances do not constitute any risks at short-term level. On a long-term basis however, accumulation might occur but possible risks might be harder to evaluate. (Naturvårdsverket 5214, 2002)

If the organic content in land increases, there is also an increase in the ability of the land to bind and degrade organic substances. Sludge contains rather stable organic material as mentioned before and these increases the humus content in the land. So by adding sludge to the land the negative risks with hazardous organic substances are decreasing. (Naturvårdsverket 5214, 2002)

Sludge can also contain hormones and pharmaceutical substances. These are secreted by urine or faeces from human but also from animals. Antibacterial pharmaceutical substances could possibly constitute a risk of influencing the micro flora of the land, risks with spreading of diseases and antibiotics resistance. (Naturvårdsverket 5221, 2002) The Swedish Medical Products Agency has conducted a survey of possible effects that medicines, cosmetics and hygiene products might have on the environment. They concluded that these different products might constitute a risk for the environment but that very few damaging effects have been shown. It is also pointed out that further knowledge about the possible effects of these products is needed in order to avoid future damage. (Läkemedelsverket, 2005)

4.3.6 The society's point of view

Crops are cultivated in order to supply food to people all over the world. Confidence for a brand or a product is important when consumers chose what they want to buy. A brand stands for a certain communication towards the customer and it is costfull to build the confidence but easy to demolish. There is an engagement to recycling issues within the provision industry in Sweden but they regard that the efforts against recycling are never allowed to hazard the quality of the products or the public confidence. (Naturvårdsverket, SLU, Urban Water, 2002) As mentioned before there are problems with metals, organic substances and pathogens that might hazard the public confidence for agricultural land fertilised with sludge and therefore also the products harvested. (Naturvårdsverket 5214, 2002)

If sludge is used as a fertiliser on land there is always an ambition to increase the quality of the sludge. This can be done by creating more pure flows to the wastewater treatment plant and thus from the whole society. The content of sludge reflects the society where there are many diffuse sources of pollutants. By using methods, such as KREPRO, BioCon etc, where only phosphorus is recycled the driving force to create an clean environment disappears and also the ability to recycle other nutrients such as potassium, sulphur and nitrogen. (Naturvårdsverket, SLU, Urban Water, 2002)

Sludge is normally stored at the wastewater treatment plant in cities, which is often expanding. The storage demands space and creates odour but also noise when sludge is to be transported away. This can create problems in the future for expanding cities. (Naturvårdsverket, SLU, Urban Water, 2002)

4.4 Swedish conditions

Sweden has a long history where sludge has been used as a fertiliser on agricultural land and this began in the 1940s and the first recommendations from the Swedish Environmental Agency, *"Naturvårdsverket"*, came in the 1970s. However, discussions concerning the more hazardous content in sludge have intensified during the last decades. Today new regulations are about to be set, which will make the usage of sludge safer. This would satisfy the different actors in the discussion and hopefully increase the recycling of nutrients.

4.4.1 Background

Different choices when constructing wastewater systems in the past has led to that blackwater and greywater from the households are treated at the same facility together with wastewater from the industry and sometimes also stormwater. However, larger industries normally have their own treatment plants. A large amount of sludge, containing many different substances used in the society, is generated today since we have central treatment instead of separated systems. The question on how to handle the sludge has been subjected to discussions for a long time in Sweden (Naturvårdsverket 5220, 2003).

The former College of Agriculture started to examine the value of using sludge in agriculture in the 1940s at different locations in Sweden. The problems with sludge regarding hygiene were then given attention. The National Board of Health and Welfare published the first instructions for the usage of sludge in agriculture in 1973. The hygienic aspects dominated these instructions but it also included the first recommendations regarding metals. The Swedish Environmental Protection Agency also published advice and guidelines for the management of sludge in the end of the 1970s. The attitude towards sludge was then characterised of all the obstacles and risks associated with sludge handling. (Naturvårdsverket 5220, 2003)

Discussions regarding different hazardous compounds in sludge became intense during the 1980s and it was common for purchaser of grains, potatoes, oil plants etc to include bans regarding use of sludge as fertiliser in the contracts with the farmers. The Swedish Environmental Protection Agency published general advice concerning handling and usage of sludge in 1987 and a new set of advice replaced these in 1990. This was due to that the environmental organisation, Greenpeace had analysed concentrations of organic substances such as toluene, xylen, benzene and phenols in the autumn of 1987 at Ryaverket WWTP in Gothenburg. This led to the first so called *"sludge stop"* ("the stop for usage of sludge in agriculture") in 1987 meaning that farmers were recommended by the Federation of Swedish Farmers *(LRF)* not to use sludge as plant nutrition. The advice from 1990 also included recommendations to analyse the concentrations of nonylphenol, PCB, PAH and toluene but no guidance values were established. (Naturvårdsverket 5220, 2003)

The Swedish Environmental Protection Agency was commissioned by the Government in 1990 to establish proposals to programs for the phase out of some environmentally harmful organic substances and action plans for sludge from municipal wastewater treatment plants. This was done in consultation with the Swedish Board of Agriculture, the National Food Administration and the National Chemicals Inspectorate. The mission resulted in a report in 1993 where one conclusion was that using sludge in agriculture does not involve any influences on or risks for the environment from a scientific point of view. (Naturvårdsverket 5220, 2003)

In 1994 Sweden was requested to implement the sludge directive from European Community *(EC)* in Swedish legislation. The Swedish Environmental Protection Agency was then commissioned to formulate regulations instead of the general advice. However, LRF could not accept the proposed regulations since they believed that the threshold values for the supply of metals to agriculture land were too high and they also requested limit values for organic compounds. The Swedish Environmental Protection Agency did not include these since the sludge directive from EC did not include threshold values concerning organic compounds. The solution was instead a voluntarily agreement on quality assurance when sludge is used in agriculture between LRF, the Swedish Environmental Protection Agency and the Swedish Water- and Wastewater Treatment Plant Association *(VAV)* and it was signed in 1994. National consultation groups were, as well as local and regional, then formed in order to keep the agreement alive and controlling that the sludge quality demands were obeyed. The published regulation was called *"Regulations regarding protection for the environment, especially the soil, when sewage sludge is used in agriculture, SNFS 1994:2"* and is still in use today. LRF recommended a second *"sludge stop"* in 1999. They believed that the concentrations of brominated flame retardants in sludge might have increased which was a violation against the agreement. (Naturvårdsverket 5220, 2003)

4.4.2 Present regulations

The regulations in Sweden concerning sludge handling only deal with the usage of sludge in agriculture. The questions on when, where and how to use the sludge on agriculture soil is regulated (Naturvårdsverket 5214, 2002). There are sludge quality demands regarding sludge that is to be used in agriculture. These were legislated in 1998 by the *"Regulation on prohibition in certain cases regarding handling, import and export of chemical substances, SFS 1998:944"*. Table 5 shows the seven metals that have limit values according to this regulation (SFS 1998:944, 20§).

Table 5 Limit values for concentrations of heavy metals in sludge intended for agricultural use (SFS 1998:944, 20§).

Metal	Limit value (mg/kg DS)
Lead, Pb	100
Cadmium, Cd	2
Copper, Cu	600
Chromium, Cr	100
Mercury, Hg	2.5
Nickel, Ni	50
Zinc, Zn	800

No organic compounds are regulated in the Swedish legislation but the sludge agreement from 1994 includes guidance values on nonylphenol, toluene, the sum of seven PCBs and six PAHs. These guidance values are shown in Table 6. (Naturvårdsverket 4418, 1995)

Table 6 Guidance values for organic compounds in sewage sludge, which will be used as a fertiliser in agriculture according to the sludge agreement from 1994 (Naturvårdsverket 4418, 1995).

Compound	Guidance value (mg/kg DS) 1997-present
Nonylphenol	50
Toluene	5
PAH[A]	3
PCB[B]	0.4 (mean annual)

[A] *Sum of six polycyclic aromatic hydrocarbons.*
[B] *Sum of seven polychlorinated biphenyls.*

However, the last "*sludge stop*" from 1999 has not yet been lifted by the LRF. Today, the sludge agreement is a thing of the past according to LRF except for when sludge is used in cultivation of Salix. (Naturvårdsverket 5223, 2003)

The "*Regulations regarding protection for the environment, especially the soil, when sewage sludge is used in agriculture*", SNFS 1994:2 is based on the EC directive 86/278/EEG as mentioned previously. The purpose of this legislation is to regulate the usage of sewage sludge in agriculture in such a way that damaging effects on the soil, animals, vegetation and humans are avoided at the same time as a proper usage of sewage sludge is encouraged (SNFS 1994:2, 1§). It says that sludge has to be treated before it is used in agriculture. Untreated sludge may still be used if it is tilled into the soil within one day from spreading and not causes any inconveniences for people living close by. (SNFS 1994:2, 6§)

Further on it prescribes that sewage sludge shall not be used (SNFS 1994:2, 7§):

- On pasture land.
- On arable land which shall be used for pasture or if pasture crops is to be harvest within ten months from the event of spreading.
- On land with cultivation of berries, potatoes, root vegetables, vegetables or fruit (fruit trees not included).
- On land designated to future cultivation of berries, potatoes, root vegetables or those vegetables which are in contact with the soil and shall be eaten raw, within ten months before harvest.

There are limit values on how much phosphorus and nitrogen that may be distributed to the soil with sludge (SNFS 1994:2, Appendix A). These values can be seen in Tables 7 and 8. The law subscribes that the sludge shall be used with consideration to the limit values in order to not worsen the quality of the soil and surface and groundwater (SNFS 1994:2, 5§).

Table 7 Maximum amount of total phosphorus that can be supplied to soil with sludge (SNFS 1994:2, Appendix A).

Phosphorus classification of the soil (mg/100 g DS)[A]	**Kg tot-P/ha and year (mean annual value)**	**Kg tot-P/ha and spreading occasion**
I <2	35	245
II 2.0-4.0	35	245
III 4.1 – 8.0	22	154
IV 8.1 – 16.0	22	154
V >16	22	154

[A] *Easily dissolvable phosphorus.*

Table 8 Maximum amount of ammonium nitrogen that can be supplied to soil with sludge (SNFS 1994:2, Appendix A).

Kg NH_4^+-N/ha and year	**Kg NH_4^+-N/ha and spreading occasion**
150	150

The sludge may not be used if the concentration of one or more metals in the arable land exceeds the limit values seen in Table 9 (SNFS 1994:2, Appendix B). There are also regulations for the greatest amount of metals allowed to be supplied to soil with sludge (SNFS 1994:2, Appendix C). These limit values can be seen in Table 10.

Table 9 Limit values for the concentrations of metals in agricultural land intended for fertilisation with sludge (SNFS 1994:2, Appendix B).

Metal	Limit value (mg/kg DS)
Lead, Pb	40
Cadmium, Cd	0.4
Copper, Cu	40
Chromium, Cr	60
Mercury, Hg	0.3
Nickel, Ni	30
Zinc[A], Zn	100

[A] A concentration of 150 mg zinc per kg DS in soils is allowed in the counties of Jämtland, Stockholm, Södermanland, Uppsala, Västernorrland and Västmanland.

Table 10 Limit values for the maximum annual amount of metals that can be supplied to soil with sludge. The limit values are average values calculated for a period of seven years (SNFS 1994:2, Appendix C).

Metal	Supplied amount (g/ha and year)
Lead, Pb	25
Cadmium, Cd	0.75
Copper, Cu	300[A]
Chromium, Cr	40
Mercury, Hg	1.5
Nickel, Ni	25
Zinc, Zn	600

[A] Larger amounts of Cu may be accepted if it can be proved that the land in question needs additional Cu.

The sludge shall be analysed regarding the content of the seven regulated metals. At larger plants these measurements should be performed more frequently and it varies between 1 and 12 times a year. (SNFS 1994:2, 11§)

The Swedish Board of Agriculture also has regulations when and where organic fertilisers are allowed to be spread on agricultural land. These were legislated in 1999 and can be found in *"The Swedish Board of Agriculture's regulations on respects for the environment in agriculture, SJVFS 1999:79"*. Organic fertiliser is prohibited to be spread between the 1st of January and the 15th of February with some exceptions (SJVFS 1999:79, 6§5). It must be tilled into the soil within the same day during the period 1st of December – 28th of February. In areas more sensitive to eutrophication the tilling down should be performed within 4 hours. (SJVFS 1999:79, 7§)

Other options, such as using the sludge when constructing green areas and other building constructions, are regulated from case to case by supervisory authority (Mr Ola Palm, 2004). The Swedish Environmental Protection Agency has published general advises regarding methods for professional storage, digestion and composting of waste, which can be found in NFS 2003:15. These advise concern the location, design and management of the methods. There are also general advises concerning the usage of sludge as a final covering material on landfills. These can be found in Handbook 2004:2 which contain general advices about the regulations concerning landfills. These handbooks provide useful general advices when dealing with sewage sludge but are not legally binding.

4.4.3 Present sludge handling

About 1.2 million tonnes of sludge with a mean dry solid concentration of 20% is generated every year in Sweden (Naturvårdsverket 5221, 2002). Table 11 shows how sludge was used in Sweden the year 2000 (Naturvårdsverket, Statistiska Central Byrån, 2002).

Table 11 Disposal of sewage sludge in Sweden the year 2000 (Naturvårdsverket, Statistiska Central Byrån, 2002).

Disposal method	**Disposal percentage** (%)
Agricultural use	21
Other land application	32
Intermediate storage	8
Deposition at landfill	34
Not presented disposal	5

In Sweden the most common procedure is to treat thickened sludge with mesophilic digestion followed by dewatering where a conditioning agent has been added. Mesophilic digestion is used at the majority of the larger wastewater treatment plants in Sweden and the digestion is processed at a temperature of around 35ºC. (Naturvårdsverket 5214, 2002) But the sludge also undergoes other stabilisation treatment methods such as thermal drying or composting (European Commission, 2001).

The results of the sludge agreement were examined in 1996 and it showed that the proportion of sludge used in agriculture had increased. It also showed that the proportion of sludge that could meet the quality standards had increased significantly. It was less than one third of the sludge before the agreement and about two-thirds during 1995. The *"sludge stop"* in 1999 has contributed to a substantial decrease of the amount of sludge used in agriculture. Incineration of sludge is a disposal method that has not been used in Sweden so far, other than at experimental level. A few permissions for incineration has been granted during recent years and several of them have time limits implemented or demands on that the phosphorus has to be made use of during a certain period of time. The proportion incinerated sludge is expected to rise to almost 10% in the year of 2006 according to the municipalities' own estimations. (Naturvårdsverket 5214, 2002)

There are several projects working on sludge handling today. One is ReVAQ, which stands for *"pure plant nutrition from sewage"* and is an experimental work investigating if waterborne sewage systems may be sustainable in the aspect of returning pure plant nutrition. The food industry has a positive attitude towards ReVAQ. Voluntarily agreements could be the fruit from these projects and that would increase the usage of sludge in agriculture. (Naturvårdsverket, SLU, Urban Water, 2002) Another path taken is the possibility to have different certification systems such as one that the Swedish National Testing and Research Institute has initiated regarding manufacturing of soil where sludge could be a possible component (SP Sveriges Provnings och Forsknings Institut, 2005).

4.4.4 Future strategy

Today Sweden is heading for a new set of regulation concerning sludge handling. The recycling of phosphorus is of major importance in the future and several ways of achieving this has been investigated. The new regulation will have more strict sludge quality demands and will also specify demands on hygienisation. Instead of just regulating the usage of sludge as a fertiliser on agricultural land, the usage of sludge on all types of land will be regulated in the new legislation.

4.4.4.1 Background to the "Action plan for the recycling of phosphorus from sewage"

Most people responsible for the water and sewage sector in Swedish cities today, do not consider sludge as a problem that just has to be taken care of, but are instead eager to utilise the useful substances in the sludge. There are in principal three ways of doing so. First, make the sludge as clean as possible so that all parties will accept the usage of the sludge in agriculture or on other soils. Second, extract pure nutrients or other nutrient rich products from the sludge and third, rebuild the sewage system in order to keep useful fractions separated from hazardous ones. (Naturvårdsverket, SLU, Urban Water, 2002) There are in general two opposing wills in Sweden today. The water and sewage industry wants the sludge to be used in food production and thus recycling nutrients, while the representatives for the food sector and consumer organisations requests the nutrients to be separated from other substances in the wastewater before it is used. (Naturvårdsverket 5223, 2003)

The Swedish parliament set up 15 *"Environmental quality objectives"* in 2000, which have the aim to be achieved within one generation. Two of these objectives are (Naturvårdsverket 5217, 2003):

- *"Re-circulation"*: A considerable part of the phosphorus from waste and sewage should be returned to agricultural soil by the year of 2010.

- *"A poison free environment"*: The environment must be free from substances and metals, which have been created in or extracted from the society and which can threaten human health or biological diversity.

The first objective above implies that sludge should be used in agriculture, provided that phosphorus is not extracted and purified first. However, if sludge is applied on agricultural soil, chemicals, which are present in the sludge, will also be applied to the soil. Many of these are known to be able to *"threaten human health or biological diversity"* which must be avoided according to the second mentioned objective. Therefore, there is an immediate conflict between these two environmental quality objectives. (Naturvårdsverket 5217, 2003) The Swedish Environmental Protection Agency was commissioned by the Government in 2001 to investigate the questions concerning environmental and health protection demands for sewage sludge and its usage, and the recycling of phosphorus. The results were presented in a report called *"Action plan for the recycling of phosphorus from sewage - report 5214"* in December of 2002.

4.4.4.2 The Action plan for the recycling of phosphorus from sewage

The Action plan is an extensive report and about ten projects were initiated in order to produce the report. The ideas are based on a vision of the future with sustainable development and where all the environmental quality objectives have been fulfilled. Many of the ideas and requirements presented in the Action plan are connected to the realisation of the environmental quality objectives. These have a time limit of one generation and that is why the objectives in the Action plan have the same time limit. During the project it has been concluded that also other nutrients may be as important to recycle, depending on their scarcity or the resources consumed when they are produced. It is mainly sulphur, nitrogen and potassium but also the content of humus and other essential elements in the sewage should be given attention in the long run. (Naturvårdsverket 5214, 2002) The long-term objectives are formulated as follows (Naturvårdsverket 5214, 2002):

"Nutrients in wastewater are returned to the soil, where they are needed and without jeopardising health and the environment.
This means, for example, that:

- *Wastewater fractions are of such a quality, as regards their degree of purity, that they can be returned to the soil without jeopardising health and the environment,*
- *Nutrients in wastewater fractions can be returned both to arable soil and to other land where they are needed,*
- *Usage of other fertilisers will be replaced."*

An intermediate goal has also been formulated (Naturvårdsverket 5214, 2002):

"At least 60% of the phosphorus in wastewater shall be restored to productive soil, of which half should be returned to arable land by 2015"

In order to achieve the long-term objectives, three alignments have been specified as crucial to the possibility to achieve the objectives. The measures that are implemented shall aim at:

1. "Increase the recovery of phosphorus and other nutrients from wastewater" (Naturvårdsverket 5214, 2002).

One conclusion in the Action plan is that usage of sludge in agriculture is an alternative on a short-term basis as long as the current threshold values for the quality of the sludge are reached. Using the sludge on agriculture soil could also be a long-term system as long as the quality of the sludge is not jeopardising the environment. The achievement of a non-polluted sludge would mean that the environmental quality objective *"A poison free environment"* is fulfilled or that more polluted sewage streams have been separated from less polluted ones. This way of recycling nutrients is the most desirable one but as long as the sludge is not clean enough different alternative systems have to be used. The Action plan also evaluated different system solutions for the recovery of phosphorus. These are the processes described above; KREPRO, BioCon, Phostrip, usage of sludge in agriculture and incineration but also separating systems with the blackwater separated from the greywater and industrial wastewater. All the systems have their advantages and disadvantages and none of them are an obvious solution to the problem. A combination of systems could be used in the future depending on local circumstances, in order to achieve the goal. The Swedish Environmental Protection Agency points out the need for specific “sewage plans” for individual municipalities, which shall include how nutrients will be returned. Deposition of organic waste is prohibited starting from January 2005 and deposition of sludge is therefore not an alternative for the future. The Swedish Environmental Protection Agency suggests that permission for incineration without utilisation of at least phosphorus should be time limited. (Naturvårdsverket 5214, 2002)

2. “Reduce the amount of hazardous substances discharged to arable land and wastewater (To be compatible with the long-term objective, the goal should be to extend this point so that it covers not just arable soil but all land)” (Naturvårdsverket 5214, 2002).

A new regulation with stricter demands concerning the usage of sludge on agriculture soil has been proposed. The threshold values on concentrations are more stringent and two new metals are also regulated as can be seen in Table 12. (Naturvårdsverket 5214, 2002)

Table 12 Proposed limit values for the concentrations of metals in sludge, limit values for the maximum annual amount of metals that can be supplied to the soil with sludge, limit values for the concentrations of metals in the agricultural land (Naturvårdsverket 5214, 2002).

Metal	Limit values in sludge (mg/kg DS)[A]	Limit values in sludge (mg/kg P)[A]	Limit values for supply to agricultural land (g/ha and year)[B]	Limit values in agricultural land (mg/kg DS)
Lead, Pb	100	3600	40	25
Cadmium, Cd	1.7	61	0.75 0.55 (2010)[C] 0.45 (2015)[C] 0.35 (2020)[C]	0.4
Copper, Cu	600	21000	300[D]	40
Chromium, Cr	100	3600	40	60
Mercury, Hg	1.8	64	1	0.3
Nickel, Ni	50	1800	25	30
Zinc, Zn	800	29000	600	100[E]
Silver, Ag	15	540	8	-
Tin, Tn	35	1200	-	-

[A] The demands will be regarded as fulfilled if the limit values in either of these columns are not exceeded.
[B] Average values calculated for a period of seven years.
[C] The limit value will come into force on the 1st of January of the given year.
[D] A maximum of 600 g per ha and year is allowed in soils with a concentration of copper less than 7 mg per kg DS.
[E] A concentration of 150 mg zinc per kg DS is allowed in soils in the counties of Jämtland, Stockholm, Södermanland, Uppsala, Västernorrland and Västmanland

As seen in Table 12, the proposed regulations include the option to regulate the concentrations of the metals in relation to the content of phosphorus, instead of as before where the concentrations were only regulated in relation to the amount of dry solids (Naturvårdsverket 5214, 2002).

No organic pollutants have limit values in the new regulations. The Swedish Environmental Protection Agency suggests that new substances are mapped out, studied and supervised regarding their occurrence, accumulation in the soil and risks in the environment. More knowledge on already known organic substances and potential organic pollutants in the future is needed in order to achieve this. Regulation of known substances such as NP, LAS and DEHP is regarded as not needed. These concentrations are decreasing in sewage sludge in Sweden and the concentrations are far below any threshold values that constitute known risks. However, it is important to keep monitoring these substances to make sure that levels are not increasing. (Naturvårdsverket 5214, 2002) The levels of PAHs seem to be decreasing in Swedish sludge. The concentrations of PCBs and PCDD/PCDFs, as well as PAHs, are quite low. They do not give rise to any concern with respect to risks of toxic effects on man or the environment. They are however persistent or not readily biodegradable which could cause accumulation in the soil. (Naturvårdsverket 5217, 2003) The more stringent demands on hygienisation described below will also give the effect of a reduced discharge of organic compounds (Naturvårdsverket 5214, 2002). More about how to reduce the discharges to wastewater is further described in chapter *"4.7 Pollution sources and control strategies"*.

3. "Reduced risk of the spread of infection" (Naturvårdsverket 5214, 2002).

The importance of strongly decreasing the amount of pathogens in the sludge is vital, the process which is called hygienisation. The regulations of today states that sludge shall be treated before it is used in agriculture and that untreated sludge also may be used if it is tilled into the soil within one day. Treated sludge is defined as *"sewage sludge which has been treated biologically, chemically or thermally, stored during a long period of time or treated in another way to, amongst other things, substantially reduce the health risks in connection with the usage of the sludge"* (SNFS 1994:2, 4§3). Since the demands on hygienisation are not specified, no reduction of importance is necessarily made. In practice, these regulations have not resulted in hygienisation of sludge apart from exceptional cases. (Naturvårdsverket 5214, 2002)

The new regulations mentioned previously include demands on treatment regarding hygienisation of the sludge and these demands concern the usage of sludge on all types of land. The regulations are based on treatment demands in combination with restrictions in the usage of the sludge. The treatment methods have been divided into three different Classes; A, B and C. These have different demands of the parameters temperature, pH and exposure time and Class A has the most stringent demand and so forth. It has been chosen to define parameters of the different treatments, instead of defining what the methods should achieve. It is easier to control and analyse different process parameters than concentrations of certain pathogens. (Naturvårdsverket 5214, 2002)

Restriction in the usage of the sludge is another barrier against exposure to pathogens. The crops that are not to be fertilised with sludge in the proposed legislation are only slightly revised from the one in the current legislation. However, different land usage has demands that the sludge is treated according to the classification system mentioned above. Sludge is not to be used on for example pastureland and Class B or C should not be used in forestry. (Naturvårdsverket 5214, 2002) These regulations can be found in the report *"Action plan for the recycling of phosphorus from sewage - report 5214"* Appendix 2 §8 from the Swedish Environmental Protection Agency.

The Government has not yet made decisions regarding the proposed regulations that have been briefly described above. A decision will be made during the spring 2005. (Mr Simon Lundeberg, 2004) However, there is an ongoing work in the EU with new regulations regarding the usage of sludge. Some say that it might be better to wait for these since they will come in the form of a directive which has to be implemented in Swedish legislation, than having to redefine the new regulations after just a short period of time. (Mr Ola Palm, 2004)

4.5 EU conditions

EU regards sludge as a suitable fertiliser or organic soil improver because of its content of nutrients and organic material. At community level, 40% of the overall sludge production is reused according to the Environment Directorate General of the European Commission. (EU[1], 2005)

4.5.1 Present regulations

The usage of sludge is regulated in the EU by the Council Directive 86/278/EEC from 1986 "*on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture*". The objective of this Directive is to regulate the use of sewage sludge in agriculture in such a way as to prevent harmful effects on soil, vegetation, animals and man, and thereby encouraging the correct use of sewage sludge (86/278/EEC, Article 1). The date of entry into force was on the 18th of June 1986 and the deadline for implementation of the legislation in the Member States was on the 18th of June 1989.

The Directive requires that sludge is used in such a way that the different nutrients requirements of plants are considered and that the quality of the soil and of the surface and groundwater are not impaired (86/278/EEC, Article 8).

The negative effects that heavy metals might have on the soil have been given attention in the past and these are regulated in three different ways when sludge is being used as a fertiliser in agriculture. There are limit values for concentrations of heavy metals in soil to which sludge is applied and concentrations of heavy metals in sludge. Maximum annual quantities of such heavy metals, which may be introduced into soil intended for agriculture, are also regulated. Those limit values are average values calculated for a period of ten years. (86/278/EEC, Article 4) The different values are shown in Tables 13, 14, and 15 (86/278/EEC, Annexes 1A, 1B, 1C). The limit values are expressed as intervals and Member States may also implement more stringent demands.

Table 13 Limit values for concentrations of heavy metals in the soil. Mg/kg DS of a representative sample of soil with a pH of 6 to 7 (86/278/EEC, Annex 1A).

Metal	Limit value (mg/kg DS)
Cadmium, Cd	1 – 3
Copper, Cu	50 – 140
Nickel, Ni	10 – 75
Lead, Pb	50 – 300
Zinc, Zn	150 – 300
Mercury, Hg	1 – 1.5
Chromium, Cr	No value has been established

Table 14 Limit values for concentrations of heavy metals in sludge intended for agricultural use (86/278/EEC, Annex 1B).

Metal	Limit value (mg/kg DS)
Cadmium, Cd	20 – 40
Copper, Cu	1000 – 1750
Nickel, Ni	300 – 400
Lead, Pb	750 – 1200
Zinc, Zn	2500 – 4000
Mercury, Hg	16 – 25
Chromium, Cr	No value has been established

Table 15 Limit values for the maximum annual amount of metals that can be supplied to agricultural land with sludge. The limit values are average values calculated for a period of ten years (86/278/EEC, Annex 1C).

Metal	Limit value (kg/ha and year)
Cadmium, Cd	0.15
Copper, Cu	12
Nickel, Ni	3
Lead, Pb	15
Zinc, Zn	30
Mercury, Hg	0.1
Chromium, Cr	No value has been established

The Directive does not regulate any of the organic substances that are present in sewage sludge.

It is subscribed that sludge shall be treated before being used in agriculture. Untreated sludge may be used if it is injected or tilled into the soil. Every Member State would decide if this usage should be allowed. (86/278/EEC, Article 6a) With treated sludge means: sludge which has undergone biological, chemical or heat treatment, long-term storage or any other appropriate process so as significantly to reduce its ferment ability and the health hazards resulting from its use (86/278/EEC, Article 2b).

Member States shall prohibit the use of sludge or the supply of sludge for use on (86/278/EEC, Article 7):

- Grassland or forage crops if the grassland is to be grazed or the forage crops to be harvested before a certain period has elapsed. This period, which shall be set by the Member States taking particular account of their geographical and climatic situation, shall under no circumstances be less than three weeks.

- Soil in, which fruit and vegetable crops are growing, with the exception of fruit trees.

- Ground intended for the cultivation of fruit and vegetable crops which are normally in direct contact with the soil and normally eaten raw, for a period of 10 months preceding the harvest of the crops and during the harvest itself.

In short, the Directive also includes regulations stating that the Member States must keep records registering the following (EU[2], 2004):

- The quantities of sludge produced and the amount supplied for use in agriculture.

- The composition and properties of the sludge.

- The type of treatment carried out.

- The names and addresses of the recipients of the sludge and the places where the sludge is to be used.

The Directives states that Member States may take more stringent measures than accounted for here if certain conditions exist in that country (86/278/EEC, Article 12).

4.5.2 Present sludge handling

The member states are heading towards an annual production of sewage sludge of nearly 9 million tonnes of dry solids by the end of 2005. There is a constant increase in the number of households connected to sewer systems within the EU, which of course leads to an increase in the sludge production every year. In 1992 the annual sludge production was only some 5.5 million tonnes of dry solids. (EU[1], 2005)

The treatment methods used within EU varies greatly. In for example the United Kingdom mesophilic anaerobe digestion, composting, lime stabilisation, liquid storage, dewatering and thermal drying are the most commonly methods used. In France the sludge is subject to prolonged aeration, aerobic or anaerobic stabilisation, lime conditioning, thermal drying or composting. (European Commission, 2001)

There are no statistics of sewage sludge disposal from the member states of immediate interest but there is some available data from the years 1990 to 2001. Some of the member states are presenting more current data than others, for example Italy and Greece have information from 1990. No information at all was found for Portugal. (EU[3], 2005) Table 16 shows a compilation of information from the available data of the sludge disposal from countries that are members of EU year 2005. The table shows the percentage of sludge disposed in each disposal method but these numbers only give an indication of the situation today. A more detailed table of the disposal from the different member states can be found in Appendix I.

Table 16 Disposal of sewage sludge in EU in percentage (EU[3], 2005).

Disposal method	**Disposal percentage** (%)
Agricultural use	34
Compost and other land application	12
Deposition at landfill	18
Incineration	12
Others	12
Not presented disposal	12

Deposition and incineration are the most widely used disposal methods in some countries despite their environmental drawbacks. (EU[1], 2005) France, United Kingdom, Luxembourg, Germany, and the Netherlands for example plan to further develop incineration. There are however some countries that are planning to increase their agricultural use, for example Finland, Portugal, Ireland and the United Kingdom. (European Commission, 2001)

4.5.3 Future strategy

The Commission is working on a new Directive regarding the usage of sludge since 1999 (Naturvårdsverket 5214, 2002). The latest working document is the third draft from the 27 of April 2000 which is a working document elaborated by the Environment Directorate-General in the European Commission. The ambition is to regulate all types of land application of sewage sludge, septic tank sludge and industrial sludge. Previously, only sludge used as a fertiliser in agriculture has been regulated and the scope is now broadening to include management of sludge on green areas, in silviculture and on reclaimed land (drastically disturbed land that is reclaimed using sludge). (Environment DG, 2000)

It is suggested that sludge should be used when there is an agronomic interest for the crops or when the soil might be improved. It is not allowed to use sludge in forest with the exception of plantations, such as short-rotation plantations or plantations for energy crops, and for re-afforestation purposes. (Environment DG, 2000)

The limit values for heavy metals in soil are shown in Table 17 (Environment DG, 2000).

Table 17 Limit values for concentrations of heavy metals in soil (Environment DG, 2000).

Metal	Limit value (kg/ha and year)		
	5≤pH<6	6≤pH<7	pH≥7
Cadmium, Cd	0.5	1	1.5
Copper, Cu	20	50	100
Nickel, Ni	15	50	70
Lead, Pb	70	70	100
Zinc, Zn	60	150	200
Mercury, Hg	0.1	0.5	1

The table shows that the Commission is suggesting that the soil should be divided into different classes depending on the pH. The pH will thereafter decide which limit values for concentrations of heavy metals in the soil that must be followed. If the concentration of an element is higher in a soil than the set threshold values, use of sludge may still be allowed by a competent authority based on a certain evaluation. (Environment DG, 2000)

The limit values for heavy metals in sludge intended for land use and maximum annual quantities of heavy metals that may be added to the soil as a result of sludge use are shown in Tables 18 and 19 respectively (Environment DG, 2000).

Table 18 Limit values for the concentrations of metals in sludge intended for land use (Environment DG, 2000).

Metal	Limit value (mg/kg DS)	Limit value (mg/kg P)
Cadmium, Cd	10	250
Copper, Cu	1000	25000
Nickel, Ni	300	7500
Lead, Pb	750	18750
Zinc, Zn	2500	62500
Mercury, Hg	10	250
Chromium, Cr	1000	25000

As can be seen in Table 18, there are two different limit values for the heavy metal content of the sludge. The sludge producer may choose to follow either the dry matter related or the phosphorus related limit values. (Environment DG, 2000)

Table 19 Limit values for amounts of heavy metals, which may be added annually to soil, based on a ten years average (Environment DG, 2000).

Metal	**Limit value (g/ha and year)**
Cadmium, Cd	30
Copper, Cu	3000
Nickel, Ni	900
Lead, Pb	2250
Zinc, Zn	7500
Mercury, Hg	30
Chromium, Cr	3000

The limit values for heavy metal that may be added annually to the soil are based on a 10 years average. A competent authority may decide to allow higher values of zinc and copper if it can be shown that the soil are deficit in these substances or that there is a specific agronomic need for the crops. (Environment DG, 2000)

Regulation of organic compounds and dioxins are considered in this working document. The considered substances are the following: halogenated organic compounds *(AOX)*, nonylphenol and nonylphenolethoxylates *(NPE)*, LAS, DEHP, PCB, PAH, and PCDD/PCDF. The limit values for concentrations of these in sludge for land use can be seen in Table 20. (Environment DG, 2000)

Table 20 Limit values for the concentration of organic compounds and dioxins in sludge intended for land use (Environment DG, 2000).

Organic compound	**Limit value (mg/kg DS)**
AOX[A]	500
LAS[B]	2600
DEHP[C]	100
NPE[D]	50
PAH[E]	6
PCB[F]	0.8
Dioxin	**Limit value (ng TE/kg DS)**
PCDD/PCDF[G]	100

[A] Sum of halogenated organic compounds.
[B] Linear alkylbenzene sulphonates.
[C] Di(2-ethylhexyl)phthalate.
[D] It comprises the substances nonylphenol and nonylphenolethoxylates with 1 or 2 ethoxy groups.
[E] Sum of the following polycyclic aromatic hydrocarbons: acenapthene, phenanthrene, fluorene, flouranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1, 2, 3-c, d)pyrene.
[F] Sum of the polychlorinated biphenyls components number 28, 52, 101, 118, 138, 153, 180.
[G] Polychlorinated dibenzodioxins/ dibenzofuranes.

The usage of sludge on land is restricted. It is not allowed to apply sludge on frozen, water-saturated, flooded, snow-covered land or on soil with a pH less than 5. The quantity of nutrients that is introduced should be adapted to the needs of the crops or the soil according to best practices. (Environment DG, 2000)

The working document specifies what kind of treatment of the sludge that is required for different land use. There are two classes: Advanced treatment and Conventional treatment and the different processes needed are clearly defined. It is further listed how these two classes of sludge may be used on agricultural land, parks and reclamation sites. (Environment DG, 2000)

There is a larger producer’s responsibility and certification in the third draft. Producers shall guarantee the suitability of sludge for use and they are responsible for the quality of the sludge. It will be required that producers implement a quality assurance system. (Environment DG, 2000)

There is also a chapter dealing with pollution prevention and goals for 2015 and 2025 are set up regarding the content of heavy metals in the sludge. The objective is to reduce hazardous compounds in the sewer system in order to receive sludge with high quality. (Environment DG, 2000)

It is expected that the European Commission will propose a new Directive in June 2005. (Mr Simon Lundeberg, 2004)

4.6 US conditions

In USA the local government decides whether the sludge is to be used as a fertiliser, incinerated or buried in a landfill. Once the sludge is treated it is referred to as biosolids. Only biosolids that meet the most stringent standards spelled out in the Federal and State rules can be approved for use as a fertiliser. (EPA[1], 2004) The 40 CFR Part 503 regulates the usage and the disposal of sewage sludge in the USA.

4.6.1 Present regulations

The federal biosolids rule is contained in *“40 CFR Part 503 Standards for the use or disposal of sewage sludge”* and this rule became effective on the 22nd of March, 1993. This rule establishes requirements for the final use or disposal of biosolids when biosolids are (EPA[2], 2004):

- Applied to land to condition the soil or fertilise crops or other vegetation grown in the soil.
- Placed on a surface disposal site for final disposal.
- Fired in a biosolids incinerator.

The part 503 rule governing the use and disposal of biosolids contain numerical limits, for pathogen reduction standards, metals in biosolids and demands for vector attraction reduction. (EPA[3], 2004) The different disposal methods mentioned above are also regulated by the part 503 rule concerning general requirements and management practices. Further, there are also demands for the frequency of monitoring, record keeping and reporting for all the different disposal methods.

In USA there are two classes of biosolids with respect to pathogen reduction and these are classified as Class A or Class B. Class A biosolids contain no detectable levels of pathogens and has low levels of metal content according to United States Environmental Protection Agency *(EPA)*. Biosolids of this class has been further treated with respect of pathogens compared to the Class B biosolids. The part 503 specifies the requirements of treatment of the sludge in order for it to be classified as Class A or Class B biosolids in §503.32. Class B biosolids are treated sludge but it still contains detectable levels of pathogens and therefore the regulations of usage are stricter compared to the regulations for Class A biosolids. Buffer requirements, public access and crop harvesting restrictions exist for all forms of Class B biosolids. For Class A biosolids only a permit to ensure that the standards have been met is necessary. When Class A biosolids are used in bulk there are however buffer requirements. (EPA[3], 2004)

There are also regulations for the reduction of vector attraction and these are specified in §503.33. Depending on chosen disposal method, different requirements need to be met.

The application of biosolids to land is regulated in subpart B §503.10-18. Biosolids can be applied to land either to condition the soil or to fertilise crops or other vegetation grown in the soil. Agricultural land, forests and reclamation sites are regarded as non public contact sites and public parks, plant nurseries, roadsides, golf courses, lawns and home gardens are regarded as public contact sites. (EPA[2], 2004)

The application of biosolids to land in regards of pathogens is regulated in §503.15. The Class A pathogens requirements shall be met when sewage sludge is sold or given away in a bag or other container for application to land or when bulk sewage sludge is applied to lawns or home gardens. When bulk sewage sludge is applied to agricultural land, forest, public contact sites or reclamation sites, the pathogen requirements for Class A must be met. But Class B biosolids can also be used for these applications as long as site restrictions in § 503.32 is followed. These site restrictions regulate the time between the application of biosolids and the harvest. It also regulates the time between application and the grazing of animals and the public access to the land. For all application of biosolids to land there are also requirements for vector attraction reduction (40 CFR Part 503, §503.15).

There are also control quality demands in respect to metals when sludge is applied to land. The ceiling concentration for the metals is not to be exceeded for either bulk sewage or sewage sludge sold or given away in containers. The ceiling concentrations can be seen in Table 21. (40 CFR Part 503, §503.13)

Table 21 Ceiling concentrations for heavy metals in sludge (40 CFR Part 503, §503.13).

Metal	Ceiling concentration (mg/kg DS)
Arsenic, As	75
Cadmium, Cd	85
Copper, Cu	4300
Lead, Pb	840
Mercury, Hg	57
Molybdenum, Mb	75
Nickel, Ni	420
Selenium, Se	100

If bulk sewage sludge is applied to agricultural land, forest, a public contact site, or a reclamation site there are further pollutant limits. Either, the cumulative loading rate for each pollutant (Table 22) should not be exceeded or the concentration of each pollutant in the sewage sludge should not be exceeded (Table 23). Table 23 is also applied when bulk sewage sludge is applied to a lawn or a home garden. If sewage sludge is sold or given away in a bag or other container for application to the land there are also pollution limits. Either, Table 23 is applied or the product of the concentration of each pollutant in the sewage sludge and the annual whole sludge application rate for the sewage sludge should not exceed the annual pollutant loading rate for the pollutant in Table 24. (40 CFR Part 503, §503.13)

Table 22 Cumulative loading rate for heavy metals in sludge (40 CFR Part 503, §503.13).

Metal	Cumulative pollutant loading rate (kg/ha)
Arsenic, As	41
Cadmium, Cd	39
Copper, Cu	1500
Lead, Pb	300
Mercury, Hg	17
Nickel, Ni	420
Selenium, Se	100
Zinc, Zn	2800

Table 23 Monthly average concentrations of heavy metals in sludge (40 CFR Part 503, §503.13).

Metal	Monthly average concentration (mg/kg DS)
Arsenic, As	41
Cadmium, Cd	39
Copper, Cu	1500
Lead, Pb	300
Mercury, Hg	17
Nickel, Ni	420
Selenium, Se	100
Zinc, Zn	2800

Table 24 Annual pollutant loading rate of heavy metals in sludge (40 CFR Part 503, §503.13).

Metal	Annual pollutant loading rate (kg/ha and 365 day period)
Arsenic, As	2.0
Cadmium, Cd	1.9
Copper, Cu	75
Lead, Pb	15
Mercury, Hg	0.85
Nickel, Ni	21
Selenium, Se	5.0
Zinc, Zn	140

General requirements in §503.12 state that the person who prepares sewage sludge should provide the user with notice and necessary information so that the regulations in part 503 can be followed. There are also management practises in §503.14. Here it is stated that it is not allowed to apply bulk sewage sludge if it is likely to adversely affect a threatened or endangered species or its designated critical habitat. It is not prohibited to apply sewage sludge to frozen, flooded, or snow-covered land but the user must ensure that the biosolids do not enter surface waters or wetlands. It is not allowed to supply bulk sewage sludge to agricultural land, forest, or reclamation sites that is 10 meters or less from waters. When bulk sewage sludge is applied to agricultural land, forest, a public contact site, or a reclamation site, the whole sludge application rate must equal or be less than the agronomic rate. The agronomic rate is the designed amount of nitrogen that crops or vegetation needs in order to attain a desirable yield while at the same time prohibiting the contamination of groundwater.

The part 503 also regulates the sewage sludge when it is deposited (40 CFR Part 503, §503.20-28). These regulations concern the design of the landfill and location of the site with respect to geology and groundwater. There are pollution limits for some metals and these limits vary according to the distance to the property line if the landfill is designed without a linear and leakage collecting system. (§503.23) Sewage sludge that is deposited must also meet demands for vector attraction reduction unless the sludge is classified as Class A or Class B biosolids (40 CFR Part 503, §503.25).

Incineration of sewage sludge is regulated in §503.40-48. There are also here regulations concerning the design of the facility. Pollution limits values exist for some metals.

4.6.2 Present sludge handling

Sewage sludge is treated so it can be classified either as Class A or Class B biosolids as mentioned before. Today there are several different methods of treating the sludge and common methods used for the treatment of sludge to a Class A biosolid is composting, thermal drying, advanced alkaline stabilisation and thermophilic digestion. Common treatment methods that meet Class B standard are anaerobic digestion, aerobic digestion and lime stabilisation. (Mr Jeffrey E Howard, 2004) The percentage of Class A biosolids in year 2000 was 30 % of the total amount of the treated sludge (Dr Thomas E Wilson, 2004).

The current use and disposal of sludge/biosolids in the USA is mainly land application, deposition and incineration. The percentage of different disposal methods used is shown in Table 25. These numbers are from the year 2000 and the table shows both the percentage of total facilities and the percentage of the total amount of disposed biosolids. (Dr Thomas E Wilson, 2004)

Table 25 Disposal of biosolids in USA year 2000 (Dr Thomas E Wilson, 2004).

Disposal method	% of total facilities	% of total amount
Land application Class B	61	42
Land application Class A	7	18
Deposition at landfill	21	17
Incineration	6	20
Other	5	3

The most common way to use biosolids is by land application and the biosolids is applied as stabilised liquid, stabilised sludge cake or as pellets. Sludge that is disposed at landfills has usually been digested but in some cases the deposited sludge is raw sludge cake. There are only a few incineration facilities but they are normally very large so the percentage of the total amount is high. (Dr Thomas E Wilson, 2004)

Land application of biosolids takes place in all 50 states in the US. There are different land applications such as to promote the growth of agricultural crops, fertilise gardens and parks and reclaim mining sites. About 50% of all biosolids are being recycled to land according to EPA. The large amount of biosolids that is applied to land can be partly explained by the fact that land application is regarded as safe in the USA. The National Academy of Sciences has reviewed current practices, public health concerns and regulator standards, and they has concluded that; *"the use of these materials in the production of crops for human consumption when practised in accordance with existing federal guidelines and regulations, presents negligible risk to the consumer, to crop production and to the environment"*. (EPA[3], 2004)

4.6.3 Future strategy

The treatment methods of sludge are predicted to change in the future. More biosolids classified as Class A will be produced. The thermophilic digestion is predicted to increase due to this fact. Heat drying/pelletization are another treatment method, which produces a Class A biosolid, and this treatment will become more common in the larger cities. (Dr Thomas E Wilson, 2004)

Pre-treatment of the sludge before digestion in the form of thermal, mechanical or biological hydrolysis will increase in order to obtain higher solids reduction. This reduction will lead to an increase of produced biogas. (Dr Thomas E Wilson, 2004)

In the future the part of the biosolids that is beneficially reused is predicted to increase. This will not only include land application but also incineration where energy is recovered. EPA has predicted a scenario for the year 2010 and the percentages of different disposal methods is shown in Table 26. (Dr Thomas E Wilson, 2004)

Table 26 Percentages of various disposal alternatives predicted by the EPA for year 2010 (Dr Thomas E Wilson, 2004).

Method	**% of total amount of biosolids**
Land application and Reuse	70
Deposition at landfill	5
Thermal oxidation (Incineration)	20
Other	5

Dr Thomas E Wilson, president of earth Tech TYCO International Ltd Co, thinks however that the percentage of thermal oxidation (incineration) will be higher than 20%.

In regard of legislation the standards have been proposed recently to include requirements that limit the concentration of dioxin and dioxin like compounds. (EPA[3], 2004) In July 2002 the independent National Research Council examined the part 503 and concluded that additional scientific work is needed in order to reduce uncertainty and public health concerns. These include new risk assessments for both pathogens and chemical limits. EPA is now in the process of implementing the required studies. (Mr Jeffrey E Howard, 2004)

4.7 Pollution sources and control strategies

As mentioned in previous chapters there are both point- and diffuse sources for pollutants in the sludge. Point sources are often easier to trace and regulate compared to diffuse pollutant sources.

4.7.1 Point sources

In Sweden the municipalities has put a lot of effort into reducing the influent flows of pollutants. It has mainly been put on reducing different point sources in the system. (Naturvårdsverket 5214, 2002) One major point source is the industry and today many Swedish industries have their own treatment plants. This is due to regulations that they need to clean their wastewater to a certain extent before letting the water out into a recipient or to the public sewage network. (Naturvårdsverket 5217, 2003)

The reduction of discharge of chemicals from industries to waste water can include different instruments (Naturvårdsverket 5217, 2003):

- Substitution of specific substances.
- Re-circulation inside plant.
- Collection of dangerous fractions of the wastewater for special treatment.
- Pre-treatment before discharge to public sewage systems.

In order to regulate the effluent water from industries there can be discharge standards prohibiting the industry from high discharge of pollutants. Such standards are in use in many different countries as for example Sweden and China. (Mr Chen Zhaozhao, 2004) However, it is of great importance that the effluent water from the industry is monitored and controlled by some authority in order to decrease pollutants in the wastewater hence the pollutants in the sludge.

4.7.2 Diffuse sources

Today, most of the metals in the influent wastewater to Swedish wastewater treatment plants are probably coming from diffuse discharges in the society, which are much harder to trace and regulate. (Naturvårdsverket 5214, 2002)

In order to reduce the amount of pollution, the entire society needs to be changed. Hazardous metals and organic substances but also other pollutants need to be banned from being used. The households stand for most of the use of different chemicals today. This usage needs to be reduced, hazardous chemicals substituted and the information about the correct usage needs to be improved. Little is know today about the content of different substances from household water, water from laundry, dishes and bath. (Naturvårdsverket, SLU, Urban Water, 2002) Activities to reduce pollutants in society are going on also within the work of Integrated Product Policy *(IPP)* where work is conducted in order to decrease the environmental influence of products. (Naturvårdsverket 5214, 2002)

EU has presented the EU White Paper *"Strategy for a future Chemicals Policy"* which has its overriding goal: Sustainable development. It is a proposal in order to reduce substances with undesirable properties. The **REACH**-system is the central part of the proposal and it introduces requirements for **R**egistration, **E**valuation, and **A**uthorisation of **CH**emical substances. It is suggested that burden of proof should be reversed so that the industry must demonstrate that the risk with a substance is negligible. This is proposed for substances of very high concern, which are carcinogens, mutagen substances, reproductive toxicants and substances with Persistent Organic Pollutants *(POP)* characteristics. (Naturvårdsverket 5217, 2003)

There are also efforts made on international level as for example The Stockholm Convention on Persistent Organic Pollutants was acknowledge by the United Nations Intergovernmental Negotiating Committee in December 2000. It is a legally binding treaty that requires governments to minimise and eliminate 12 POPs. The initial POPs include eight pesticides, two industrial chemicals and two unwanted by-products of combustion and industrial processes. (Naturvårdsverket 5217, 2003)

A significant source is metals in the influent stormwater and the content of metals in the sludge could be reduced if the stormwater was treated separately instead of at the municipal wastewater treatment plant (Naturvårdsverket 5214, 2002). The stormwater carries a lot of different chemicals from for example deposition, traffic, roofs, and gutters (Naturvårdsverket 5217, 2003). Stormwater also increases the amount of water that needs to be treated which leads to a dilution of substances. It is harder to purify the water if the pollutants are present in low concentrations (Dr Zhou Jun[1], 2004).

In some countries copper pipes are used for the distribution of potable water. This leads to an increase of copper in the sludge, due to corrosion of the pipes. These pipes should be replaced and other material should be used at new construction. (Naturvårdsverket 5214, 2002) There might also be problems with high levels of zinc due to pipes that is galvanised. This is a problem in for example China. (Mr Zhang Jun, 2004)

5 Field study

The field study was conducted in the area of Beijing, China, in cooperation with Beijing Drainage Group Co. Ltd. The company established cooperation with Sida in 1997 when Sida decided to support the foundation of a training centre at the Gaobeidian Sewage Treatment Plant in Beijing. In 2004 the cooperation with the Lund University was established. Much of the following information was given during several interviews conducted in Beijing. Help with arranging and interpretation of these meetings was given by Mr Wang Jiawei, Dr Zhou Jun and the supervisor Ms Gan Yiping.

Beijing Drainage Group Co. Ltd is a public company and the company is responsible for the treatment of wastewater in Beijing and for the disposal of the produced sewage sludge. The company is divided into several sub-companies and all the wastewater treatment plants in Beijing belong to this company except one, which is operated privately. (Dr Zhou Jun[2], 2004)

5.1 The area of Beijing

Beijing is situated in the north corner of the triangular shaped Yellow Plane in the north-eastern part of China, which is the most extensive agricultural region within the country (NE[5], 2004). A schematic illustration of the location of Beijing is shown in Figure 3 (CNN, 2005). Wheat is the most important crop in this region but other common crops are barley, corn, durra, soybeans and cotton (NE[6], 2004). The city limits extend some 80-km including the urban and the suburban areas (Lonely Planet, 2004).

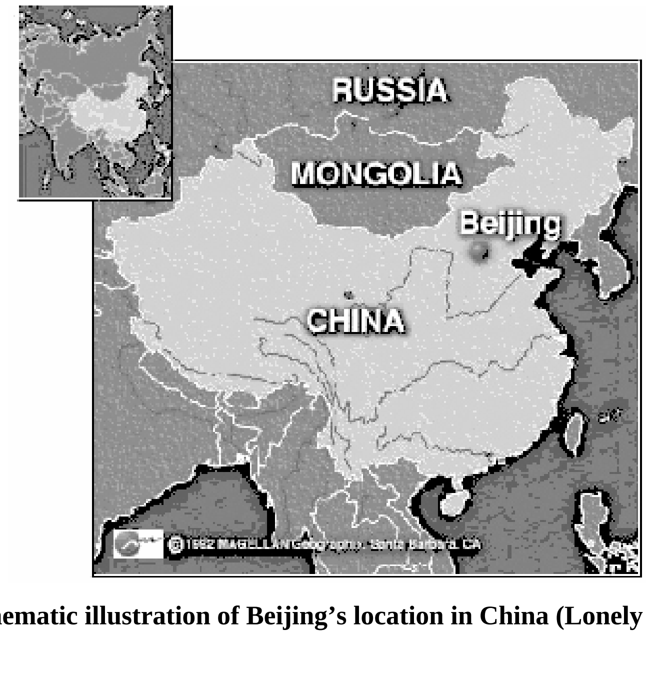

Figure 3 Schematic illustration of Beijing's location in China (Lonely Planet, 2004).

5.1.1 Population

About 1.3 milliard people lives in China today and one third of these live in the cities while two thirds live on the countryside (Landguiden, 2004). The area of Beijing has 13.8 million inhabitants of whom 7.5 million live in the city itself. Beijing has the second most inhabitants in China, only Shanghai is larger. (NE[5], 2004)

About half of the Chinese population are working with agriculture (Landguiden, 2004). The north-eastern plain or the Yellow Plain is the breadbasket of China and it has about 100 million people living there (Boon et al, 2000).

5.1.2 Climate

The area of Beijing has a temperate, continental, monsoon climate. The winter monsoons from the north and north-west Siberia brings down cold and dry air and this give northern China a cold, dry and windy winter (Landguiden, 2004). The average temperature around Beijing is -4.8˚C in January. The southern summer monsoon brings in more moist air giving a warm and humid summer with an average temperature of 25.8˚C in July. (NE[5], 2004)

The water distribution in China is very uneven. The humid southern regions contain the largest water resources while large parts of the north, especially the Yellow Plain, are deficient in water. Most of the productive and cultivated land lies in the north though and most water is needed in the spring, which is the growing season for wheat. The agriculture development is very limited here by the fact that rainfall is scarce in the spring and the fairly high temperature and dry winds often make the evaporation rate high. This region has been known to experience drought in nine years out of ten. (Boon et al, 2000) There is an on-going project where water from the Yangtze River Basin in the south of China will be taken to the northern parts. It has been proposed that 44 milliards cubic meters of water per year could be moved through three canals. Two out of three canals are already today under construction. (US Embassy Beijing, 2005)

5.1.3 Infrastructure

The public transport in Beijing includes busses and about 45-km subway (NE[5], 2004). New subway lines are also to be constructed with the Summer Olympics in 2008 approaching. (Dr Zhou Jun, 2004) Roads are highly overloaded by cabs, trucks, cars and 8 millions of bicycles and therefore a number of peripheral ways around the city are being built (NE[5], 2004).

Severe improvements of the road network were started in the beginning of 2000 and today China has a modern network in more urban areas. But in rural areas the problems with bad roads still exist. It can be hard for the farmers to transport larger surplus of crops and the production is thereby inhibited. Large highways connect the urban areas and there is also a large railway system. The river and canal systems have many branches and are still playing an important role in the transportation of gods in China. (Landguiden, 2004) However, there is no large river with significant transportation in the area of Beijing.

5.1.4 Trade and Industry

The guidelines for *"The second revolution of China"* were drawn up at a party meeting in 1978. The intentions were to make the economy more efficient, increase consumption and raise the living standards and this would be done by deregulating the economy and by allowing more private initiatives. The reforms included more free prices on goods and services, rationalisation of unprofitable stately owned companies and trials with new kinds of ownership such as stocks. (Landguiden, 2004)

The economy became more liberal and China began to open up after 1978. The economic growth has been faster than for any other country in the world and one reason for this is the extensive foreign investments that have been made in China. The reforms have also given the country a fast industrialisation with hundreds of thousands of new privately owned small businesses. (Landguiden, 2004)

A diverse industry exists in Beijing. There is an extensive manufacturing industry, producing agriculture and mine machinery's, cars, generators, locomotives, jeeps and bikes. The heavy industry started to expand in the 1950s and there are steelworks with connected metal industries as well as oil refineries and petrol chemical factories. The largest concentration of electronic companies and other high technology companies in China can be found in Beijing and these started to grow during the late 1980s. Another industry that has had a large increase during the latest decade is the manufacturing of household machinery's, paper and packaging as well as precision instruments. (NE[5], 2004)

China is still to a great extent an agricultural country but this sector has also become more efficient. Because of this, many of the farmers have more time on their hands and have become more engaged in trade, handicraft and service industry. The development of higher wages for the workers in rural areas is far behind the development in the cities in spite of the progresses made in agriculture. (Landguiden, 2004)

5.2 Present situation

Almost half of the population in Beijing is today connected to the sewage network. The wastewater is being treated mechanically and biologically at different wastewater treatment plants. This produces sewage sludge that needs to be treated and thereafter disposed. The quality of the sludge is reflecting the society and it has an impact on the choice of disposal.

5.2.1 An overview picture of the situation

In the area of Beijing, about 5 million people are connected to the sewage network system. The whole population in Beijing excluding the suburban area is about 7 million people and about 13 millions including the suburbs. (Mr Zhang Jun, 2004) This means that 40% of the population of Beijing is connected to wastewater treatment plants compared to 6% of the population in urban areas in the whole of China (Särner, 2002).

Today there are nine different wastewater treatment plants in Beijing. These plants are shown in Figure 4 and are named; Qinghe WWTP, Beixiaohe WWTP, Jiuxianqiao WWTP, Gaobeidian WWTP, Fangzhuang WWTP, Wujiacun WWTP, Lugouqiao

WWTP, Xiaohongmen WWTP and Xiaojihae WWTP. Xiaojiahe WWTP is privately owned. (Mr Wang Jiawei[2], 2004) These plants are together treating wastewater from households and industry corresponding to 5 million personal equivalents *(PE).* (Mr Zhang Jun, 2004) One PE corresponds to 0.4 m^3 per day of wastewater. The largest plant is Gaobeidian Sewage Treatment Plant where 25% of the wastewater is treated. (Mr Chang Jiang, 2004)

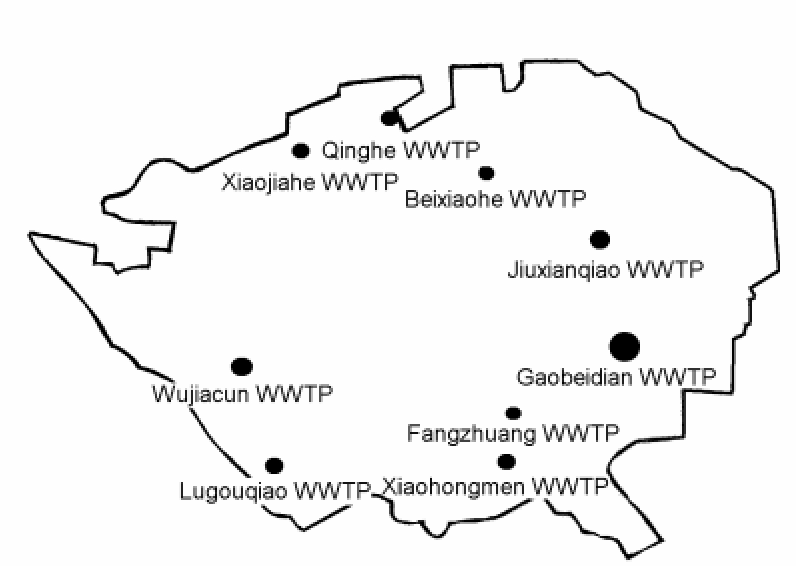

Figure 4 Schematic illustration of Beijing with the nine wastewater treatment plants operating today marked out.

The plants have different wastewater treatment but they are all based on a traditional combination of mechanical and biological treatment. The wastewater is first treated mechanically by a combination of a screen and an aerated sand filter. A primary sedimentation tank, where the primary sludge is removed, follows this treatment. In order to remove organic matter, nitrogen and phosphorus the wastewater is treated biologically. The biological treatment involves a series of anoxic and aerated zones. A secondary sedimentation tank follows where the secondary sludge is removed. Some of the treatment plants also have advanced treatment of the water so it can be reused as for example irrigation water. (Mr Wang Jiawei[1], Ms Zhi Yuan, 2004)

The sludge is produced in the primary sedimentation and the secondary sedimentation tanks but can also be produced during the advanced treatment (Mr Wang Jiawei[1], Ms Zhi Yuan, 2004). There are different treatment methods of the sludge at the treatment plants. Most of the plants have a combination of a thickening tank and a filter belt in order to reduce the water content. Two plants instead have a thickening tank in combination with a centrifuge. At Gaobeidian Sewage Treatment Plant the sludge is treated further and here anaerobic digestion tanks are used in order to stabilise the sludge. The digestion also produces biogas, which is utilised at the plant. (Mr Zhang Jun, 2004)

Today about 240 tonnes of DS of sludge are produced every day in the area of Beijing. The water content is less than 80% and this makes up about 360 000 tonnes of sludge cake per year. (Mr Zhang Jun, 2004)

There are three different disposal methods that are being used (Mr Zhang Jun, 2004):

- 40% is composted at Daxing Sludge Disposal Plant.
- 30% is deposited at different landfills.
- 30% is disposed by contractors.

Sludge from Gaobeidian Sewage Treatment Plant is disposed at Daxing Sludge Disposal Plant 54 km away from Gaobeidian (Mr Zhang Jun, 2004). Daxing normally only receives sludge from Gaobeidian (Mr Chen Zhaozhao, 2004). At landfills the sludge is either deposited or local farmers might use some of it as fertiliser. Farmers will go to the landfill themselves to collect sludge. There is no number of how much of the deposited sludge that is used this way. When contractors dispose sludge it is often deposited at landfills. The contractors are paid to control the quality of the sludge and to collect it at the wastewater treatment plants. (Mr Zhang Jun, 2004) According to Mr Li Shengtao, engineer at Jiuxianqiao Sewage Treatment Plant, some of the contractors also sell the sludge to local farmers, which will compost the sludge and then use it as a fertiliser.

There is no intermediary storage in Beijing where treated sludge is collected. The sludge is kept at the different wastewater treatment plants until sufficient amounts of sludge have been produced. Then trucks transport it away for disposal. One of the trucks used for this transportation is shown in Figure 5. (Mr Zhang Jun, 2004)

Figure 5 Truck that is used for transportation. In front of the truck is a small tractor used at Daxing Sludge Disposal Plant.

Beijing is located in a region with distinctive seasons as mentioned previously. However, there is no difference in the system of storage and transportation throughout the year. (Mr Zhang Jun, 2004) The composting process is dependent on the temperature and how this is taken into consideration is further described in chapter *“5.4.2.1 Daxing Sludge Disposal Plant”*.

5.2.2 Quality of the sludge

Monitoring the quality of the wastewater and the produced sludge is important in order to protect the recipient and to control the performance of the wastewater treatment plant. The quality of the influent- and effluent water to all the wastewater treatment plants is analysed every day. The amount of Suspended Solids *(SS)*, Biological Oxygen Demand *(BOD)*, Chemical Oxygen Demand *(COD)*, total nitrogen, total phosphorus and different heavy metals are measured. Wastewater treatment plants have discharge standards so they have to keep records of the quality of the effluent water. (Mr Ke Zhenshan, 2004)

The quality of the sludge is also analysed but this is done less frequently, only 4 times a year. Measures are taken for DS, organic matter, total nitrogen, total phosphorus, total potassium, heavy metals, some organic pollutants and some bacteria. The quality is measured at different steps in the treatment process of the sludge. It is measured in the primary sedimentation tank, the secondary sedimentation tank, the digestion tank and in the sludge cake (sludge after treatment). (Mr Ke Zhenshan, 2004)

All the analyses in Beijing are performed by the Water Quality Analysis Centre, a sub-company at the Beijing Drainage Group Co Ltd, except for Xiaojiahe WWTP which is privately owned. The Water Quality Analysis Centre is responsible for analysing the water and the sludge and they have modern and advanced technology. The government has accredited this Analysis Centre. (Mr Ke Zhenshan, 2004)

Wastewater discharge control and monitoring of water quality is handled by the State Environmental Protection Administration, while the Ministry of Construction administers the water supply to urban areas. This includes both domestic and industrial use of water. (Boon et al, 2000)

Table 27 shows the quality of the sludge cake at three different wastewater treatment plants in Beijing and these wastewater treatment plants are Fangzhang WWTP, Gaobeidian WWTP and Jiuxianqiao WWTP. These were the treatment plants visited during the field study. The water content, the organic content and the pH is measured every day; hence the values in the table are monthly averages. The organic content is measured in volatile solids *(VS)*. The remaining concentrations are measured four times a year and the values in the table show the measurements from May and December. All the concentrations in this table are from the year 2003. (Mr Ke Zhenshan, 2004)

Table 27 Measured quality of the sludge cake from wastewater treatment plants in Beijing (Mr Ke Zhenshan, 2004).

	Fangzhang WWTP		Gaobeidian WWTP		Jiuxianqiao WWTP	
	May	**December**	**May**	**December**	**May**	**December**
Water Content (%)	74.20	74.40	79.00	75.40	79.70	80.90
pH	6.16	7	8.2	8.31	6.76	7.03
VS (% DS)	72.10	64.50	53.00	47.10	65.30	62.20
Metals (mg/kg DS)						
Zinc, Zn	1556	1400	1562	906	1558	1200
Cupper, Cu	156	195	156	247	156	155
Lead, Pb	265	336	265	233	265	442
Chromium, Cr (Total)	285	62.4	285	94.5	285	99.4
Nickel, Ni	55.5	39	56	29.1	55.5	11
Cadmium, Cd	-[B]	-[B]	-[B]	-[B]	-[B]	-[B]
Mercury, Hg	-[A]	148	-[A]	46.8	-[A]	78.2
Arsenic, As	-[A]	-[B]	-[A]	-[B]	-[A]	1.84
Boron, B	156	54.6	156	124	156	166
Nutrients						
Total-N (% DS)	2.81	0.87	2.56	0.96	3.86	0.85
Total-P (% DS)	0.12	0.21	0.59	0.23	0.35	0.32
Total-K (mg/Kg DS)	3228	7870	3221	5230	3222	6660
Organic Compounds (mg/kg DS)						
Phenol	1.23	2.6	0.732	2.55	0.584	0.922
Petroleum	23500	5830	3750	3410	2330	2100
Benzene-(a)-pyrene	-[B]	-[B]	-[B]	-[B]	-[B]	-[B]
Pathogens (number/g DS)						
Fecal Coli	-[A]	$4.1 \cdot 10^6$	-[A]	$2.3 \cdot 10^6$	-[A]	$5.8 \cdot 10^6$
Coli	$3.5 \cdot 10^7$	$5.0 \cdot 10^7$	$1.8 \cdot 10^7$	$2.5 \cdot 10^7$	$3.2 \cdot 10^7$	$3.9 \cdot 10^7$
Total-Bacteria	$3.4 \cdot 10^{11}$	$5.0 \cdot 10^{12}$	$5.4 \cdot 10^{11}$	$2.7 \cdot 10^{10}$	$2.9 \cdot 10^{11}$	$8.0 \cdot 10^{11}$

[A] *These values were not measured due to SARS.*
[B] *Undetectable amount of the pollutant.*

5.3 Chinese legislation

The treatment and disposal of wastewater sludge from municipal wastewater treatment plants is regulated in "*Discharge standard of pollutants for municipal wastewater treatment plant, GB 18918-2002"* and was implemented in Chinese law on the 1st of July 2003. According to the law, sludge from municipal wastewater treatment plant should be stabilised and meet the control standard in Table 28.

Table 28 Control index for stabilised sludge (GB 18918-2002).

Stabilisation method	**Control item**	**Control index**
Anaerobic digestion	Degrading rate of organic matter (%)	>40
Aerobic digestion	Degrading rate of organic matter (%)	>40
Aerobic compost	Moisture content (%)	<65
	Degrading rate of organic matter (%)	>50
	Death rate of worm's ovum (%)	>95
	The group value of faecal coli form bacteria	>0.01

This law requires dewatering of the sludge and the water content should be less than 80% after dewatering.

According to GB 18918-2002, the content of pollutants should meet the request in Table 29 when sewage sludge is used in agricultural areas.

Table 29 Control standard for limit values of pollutants in sludge for agricultural use (GB 18918-2002).

Control Item	Maximum permitted content (mg/kg DS)	
	On acid soil (pH <6. 5)	On neutral and alkaline soil (pH≥6. 5)
Cadmium, Cd[A]	5	20
Mercury, Hg[A]	5	15
Lead, Pb[A]	300	1000
Chromium, Cr[A]	600	1000
Arsenic, As[A]	75	75
Nickel, Ni[A]	100	200
Zinc, Zn[A]	2000	3000
Copper, Cu[A]	800	1500
Boron, B	150	150
Petroleum	3000	3000
Benzene (a) pyrene	3	3
PCDD/PCDF[B] (ng TE /kg DS)	100	100
AOX[C]	500	500
PCB[D]	0.2	0.2

[A] *The total amount of the metal.*
[B] *Polychlorinated dimension-p-dioxins and –furans.*
[C] *Halogenated organic halides based on the content of Cl.*
[D] *Polychlorinated biphenyl.*

According to GB 18918-2002, further restrictions concerning the usage of sludge in agriculture is regulated in GB 4284-84. The "*Control standard for pollutants in sludge for agricultural use, GB 4284-84*" was implemented in Chinese law on the 1st of March 1985. This standard is specially instituted, in order to prevent soil, crops, surface water and groundwater from being polluted by sludge used in agriculture.

The *Control standard for pollutants in sludge for agricultural use* states that spreading of sludge on agricultural land should not exceed 30 tonnes dry solids per year and hectare. The sludge is not to be used on the same soil for more than 20 years in succession if the content of any inorganic compounds in the sludge approaches the standard values in Table 29. If the sludge is used every other year the standard for the mineral oil and benzene combine (a) can be properly increased. (GB 4284-84, §2.1) When the content of many of the regulated substances is close to the standard values, the sludge consumption should be reduced according to the circumstances (GB 4284-84, §2.5).

It is not permitted to use raw sludge on agricultural soil. Before the sludge can be used it must be decomposed in high temperature or digested and then the sludge can be used on agricultural land, gardens, and flower plantations. The control standard states that it is unsuitable to use sludge as fertiliser in the vegetable area and on meadows that is to be grazed the same year. (GB 4284-84, §2.3)

In order to prevent pollution of groundwater, the standards states that it is unsuitable to use sludge on sandy soils and on farmland with high water table (GB 4284-84, §2.2). When sludge is used on acid soil, lime should be used every year at the same time in order to neutralise the soil (GB 4284-84, §2.4).

According to legislation the usage of sludge should be stopped when the growth and development of crops is influenced or the hygiene standard of agricultural product is exceeded (GB 4284-84, §2.6). The sludge as well as the soil and the crops where sludge is being used must be monitored for a long time in fixed position by agriculture and environmental protection department (GB 4284-84, §3.1).

There is no legislation concerning the storage or the transportation of sewage sludge (Dr Zhou Jun[1], 2004). Law GB 18918-2002 requires that the relevant environmental protection requirements for a safety landfill are being fulfilled when the treated sludge is disposed in landfill. There are today no regulations concerning the usage of sludge as constructing material. (Mr Chen Ziting, 2004)

5.4 A selection of sludge facilities in Beijing

Sewage sludge is produced when wastewater is being treated at wastewater treatment plants. In Beijing most of the sludge is treated at their origin and then transported away for disposal.

5.4.1 Sludge treatment facilities

The sludge is treated at the different wastewater treatment plants where it has been produced. A selection of these was visited during the field study and they are described in the following chapter.

5.4.1.1 Fangzhuang Sewage Treatment Plant

The Fangzhuang Sewage Treatment Plant is located in a housing area and here water from households is treated together with stormwater. Figure 6 shows Fangzhuang Sewage Treatment Plant with the surrounding area. There is no water from industries going into the plant. 40 000 m^3 of wastewater is treated here every day and this is considered as a rather small plant. The wastewater is treated mechanically and biologically as described in the chapter *“5.2.1 An overview picture of the situation”*. This plant also has an advanced treatment of the wastewater where lime is added to precipitate pollutants and SO_4 is then added in order to adjust the pH. (Ms Zhi Yuan, 2004)

Figure 6 Thickening tank at Fangzhuang Sewage Treatment Plant with the surrounding housing area.

Sludge is produced in the primary sedimentation tank, the secondary sedimentation tank and in the advanced treatment step. All the sludge is mixed and treated together. First the sludge is thickened in a concentration tank. Thereafter polymers are added in order to facilitate the dewatering process, which is performed by centrifuges. The design value for these centrifuges is 30 tonnes per hour. This dewatered sludge is collected in a container before it is transported away from the plant by trucks. (Ms Zhi Yuan, 2004) A schematic illustration of the sludge treatment is shown in Figure 7.

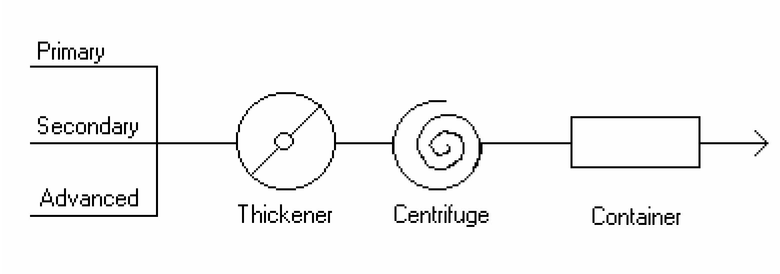

Figure 7 The sludge treatment at Fangzhang Sewage Treatment Plant.

In the primary sedimentation tank, 800 tonnes sludge per day with water content of 99% is produced. The secondary sedimentation tank produces 200 – 400 tonnes sludge per day with water content of 99.5%. A small quantity of sludge is also produced in the advanced treatment. After treatment the water content is reduced to 70 – 80%, which results in a total production of 30 tonnes of sludge cake per day. (Ms Zhi Yuan, 2004)

All the sludge used to be deposited at a landfill, but today this landfill is full and for the moment the sludge is transported to Daxing Sludge Disposal Plant where it is composted. The old landfill was located 10 km away and Daxing is located about 40 km away. (Ms Zhi Yuan, 2004)

In the future the sludge from the primary and secondary sedimentation tanks will be treated separately. The sludge from the secondary sedimentation tank will go directly to the centrifuge without being thickened. Also a thermal drying process is planned at the wastewater plant and this equipment is to be installed after the centrifuge equipment during 2005. Thermal drying is regarded as the most efficient and suitable treatment method for this small plant. It has not yet been decided how the sludge will be disposed after this treatment but it will probably be used as a fertiliser, soil improver or as construction material. (Ms Zhi Yuan, 2004) Ms Zhi Yuan regards the quality of the sludge to be comparatively high due to the fact that there is no inflow of water from any industries. Hence this sludge is good to recycle.

5.4.1.2 Gaobeidian Sewage Treatment Plant

Gaobeidian Sewage Treatment Plant is the largest plant in Beijing and it is designed to treat 1 000 000 m^3 of wastewater per day. Today it receives and treats about 740 000 m^3 of wastewater every day. This can be compared to the amount of wastewater being treated in Beijing, 3 000 000 m^3 per day. Thus Gaobeidian treats about 25% of all the wastewater. About 80% of the wastewater comes from households and 20% from industry. The plant also receives stormwater due to the fact that the sewage system in this area is a combined system. (Mr Chang Jiang, 2004)

The wastewater is treated mechanically and biologically as described in the chapter *“5.2.1 An overview picture of the situation”*. The biological treatment is suspended growth bacteria where organic matter, nitrogen and phosphorus are removed. (Mr Chang Jiang, 2004) This plant also has an advanced treatment for some of the water where chemicals are added in order to coagulate pollutants. These pollutants are then removed in a sand filter and the water is reused for irrigation of the gardens at the plant. (Mr Wang Jiawei[1], 2004)

Sludge is produced both in the primary and the secondary sedimentation tank and the sludge is treated separately. About 50% of the sludge comes from the primary sedimentation tank and 50% from the secondary. Sludge from the primary sedimentation tank is first thickened by gravity in a concentration tank. The sludge is then either treated in an anaerobic digestion chamber or dewatered directly by filter belts. The amount of sludge treated by digestion depends on the capacity of the digestion chambers and it is not known how much of the sludge that is digested each year. There are 16 digestion chambers and each have a volume of 7 848 m^3. The sludge is digested in two steps. The first step includes digestion for 21 days and the second step for 7 days and both steps are operating at mesophilic temperatures. (Mr Chang Jiang, 2004) The biogas produced in the digestion chambers is used at the wastewater treatment plant to produce power used at the aeration process. Filter belts also dewater the sludge that has been digested. (Mr Wang Jiawei[1], 2004) Figure 8 shows four digestion chambers at Gaobeidian Sewage Treatment Plant.

Figure 8 Digestion chambers at Gaobeidian Sewage Treatment Plant.

Sludge from the secondary sedimentation tank is both thickened and dewatered in a combined process. The thickening of the sludge is carried out by the principle of gravity and filter belts treat the sludge in order to dewater it. (Mr Wang Jiawei[1], 2004) Polymers are used in order to facilitate the dewatering of the sludge, from both the primary sedimentation tank and from the secondary (Mr Chang Jiang, 2004). A schematic illustration of the sludge treatment is shown in Figure 9.

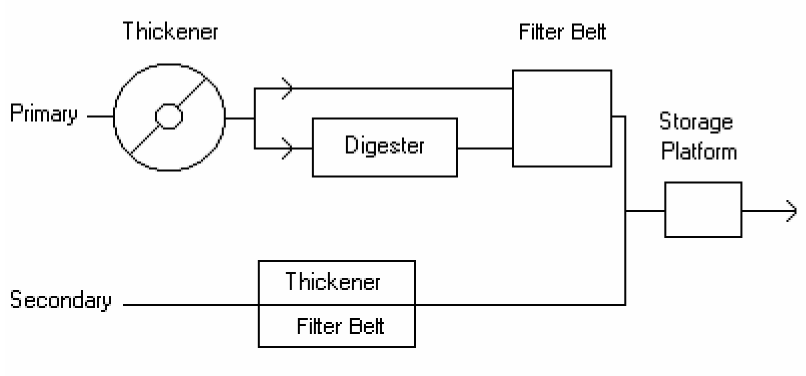

Figure 9 The sludge treatment at Gaobeidian Sewage Treatment Plant.

All the sludge is mixed together when it comes out from the dewatering houses. The sludge is then gathered on a platform made of concrete with a sheltering roof and here the sludge lay until it is transported away by trucks. It is transported to Daxing Sludge Disposal Plant where the sludge is composted and sold as fertiliser or soil improver. (Mr Chang Jiang, 2004) The distance to Daxing is 54-km (Mr Chen Zhaozhao, 2004).

The total amount of sludge produced at Gaobeidian Sewage Treatment Plant after treatment is 110 m^3 of dry solids per day with water content less then 80% (Mr Chang Jiang, 2004). Daxing Sludge Disposal Plant receives about 100 000 m^3 of sludge per year from Gaobeidian (Mr Chen Zhaozhao, 2004). All the sludge is disposed at Daxing Sludge Disposal Plant, hence the sludge production at Gaobeidian do not exceed 100 000 m^3 per year (Mr Chang Jiang, 2004).

The biological treatment of the wastewater is not working properly at the moment and this treatment step will be improved in the future. The government has pointed out how important the removal of nitrogen and phosphorus is. (Mr Chang Jiang, 2004) Mr Chang Jiang, who is director at the General Engineers Office at Gaobeidian, states that *"it is important to try to reduce the amount of sludge that is produced. This could be done by sludge eating bacteria. The most important aspects for the sludge disposal in the future is that it is environmental and economical sustainable."*

5.4.1.3 Jiuxianqiao Sewage Treatment Plant

The Jiuxianqiao Sewage Treatment Plant treats 200 000 m^3 of wastewater per day and this wastewater originate from households and industry. Household wastewater constitutes about 70% of the total amount of the wastewater. The sewer system is combined so the plant also receives stormwater. (Mr Li Shengtao, 2004)

The wastewater treatment at this plant differs from the other wastewater treatment plants in Beijing. The wastewater is first treated in screen and grid chambers and is then lead to an anaerobic tank, which is called a selector tank. Here the mixed liquor suspended solids *(MLSS)* is about 10 g/l and bacteria removes nitrate and it also favours the biological treatment of phosphorus. An oxidation ditch is the next step in the treatment process and hydraulic retention time here is about 8 hours and the MLSS concentration is 4-6 g/l. The wastewater is surface aerated while the bottom environment remains anaerobic. This process favours the removal of COD as well as nitrogen and phosphorus. (Mr Li Shengtao, 2004)

A clarifier follows the oxidation ditch and here the sludge is separated. The sludge is first thickened by gravity in a thickening tank and then polymers are added to the sludge. Dewatering process is conducted by filter belts. The sludge cake is collected directly by trucks and transported away from the wastewater treatment plant. (Mr Li Shengtao, 2004) Figure 10 shows a schematic illustration of the sludge treatment.

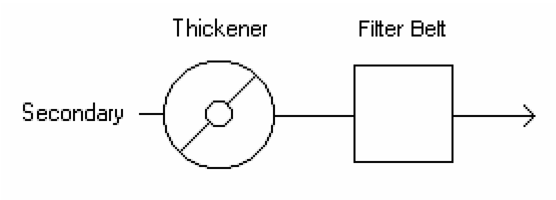

Figure 10 The sludge treatment at Jiuxianqiao Sewage Treatment Plant.

All the sludge from this treatment process is produced in the secondary sedimentation tank; hence there is no primary sedimentation. The water content after the dewatering process is about 82% and the total amount of produced sludge cake is 200 m^3 per day. All the sludge is disposed by contractors, which are paid to dispose the sludge. (Mr Li Shengtao, 2004) According to Mr Li Shengtao, Engineer at Jiuxianqiao Sewage Treatment Plant, most of this sludge is deposited at landfills or composted by local farmers. The farmers can then use the sludge as a fertiliser.

In the future the plant will be expanded and will then be able to treat 350 000 m^3 of wastewater per day. To be able to meet the effluent standard of phosphorus some chemical precipitant might be used in order to increase this removal. (Mr Li Shengtao, 2004)

5.4.2 Sludge disposal facilities

Most of the sludge produced in Beijing today is either deposited at landfills or composted and then utilised as fertiliser. There is only one composting facility operating today but there are several landfills in operation.

5.4.2.1 Daxing Sludge Disposal Plant

Daxing Sludge Disposal Plant is a composting facility just south of Beijing. The plant occupies an area of 140 000 m^2 and is surrounded by agricultural land. Most of the sludge composted here comes from Gaobeidian Sewage Treatment Plant, who is located 54-km away. Trucks transport the sludge here and this plant receives 100 000 tonnes of sludge per year. (Mr Chen Zhaozhao, 2004)

The sludge is pilled in long rows outdoor, so called windrows, and they are turned over every 2nd to 10th day in order to be aerated. There is no mixing with other material at this composting plant. The turn over is performed with loaders and small tractors are used to harrow the piles in order to grind them into finer particles. (Mr Chen Zhaozhao, 2004) A picture from the plant is shown in Figure 11.

Figure 11 Long rows with sludge that are being composted at Daxing Sludge Disposal Plant. The loader to the right is used to turn the piles over.

The sludge is composted during 25 days. During the winter or the rainy season the compost is covered with plastic in order to increase the temperature in the piles and to exclude the rainwater. Another way to improve the performance of this composting facility during the winter, due to the decreased temperature, is to double the composting time. The sludge is pelletized after composting and then the water content has decreased to 20% and the pellets are stored under roofs. After composting the sludge is stabilised and it contains lower concentrations of pathogens. During the composting process organic matter is oxidised to carbon dioxide. (Mr Chen Zhaozhao, 2004)

Daxing Sludge Disposal Plant produces 32 000 – 40 000 tonnes of composted and pelletized sludge per year. This pelletized sludge is mainly used as fertiliser on agricultural land or as a soil improver on sandy soils to increase the content of organic matter. Farmers will collect the pelletized sludge themselves or it will be transported away by trucks when larger amounts are sold. When the fertiliser is to be transported away with trains to other parts of China it is packed in plastic bags. This composting facility is the only plant in the area of Beijing and the largest one in China. (Mr Chen Zhaozhao, 2004)

The quality of the sludge is measured after it has been composted. Then the organic matter, nutrients (N, P and K), pathogens (E-coli bacteria) and metals (Hg, Cu and Zn) are measured. The content of metals might sometimes be higher than the quality demands and then the sludge can be used as soil improver. (Mr Chen Zhaozhao, 2004)

5.4.2.2 Bei Shen Shu Sanitary Landfill Site

Bei Shen Shu Sanitary Landfill Site is a landfill located just south-east of Beijing. The landfill is designed to be able to receive 4.63 million tonnes of solid waste before it is full and this is equivalent to 5.14 million m^3 of solid waste. Every day, 1 300 tonnes of solid waste is deposited. All the waste is transported here by truck and it originates from households. (Mr He Liang, 2004)

The landfill is designed with a lining system to prevent leakage to the surroundings. In order to collect and treat the produced leakage the landfill is designed with a collecting system. The leakage is treated and purified at the landfill site. A landfill normally produces biogas and this can be utilised as an energy source. Bei Shen Shu Sanitary Landfill Site has a collecting system for the biogas and the gas is then combusted and electricity is being produced. In order to prevent the waste from being transported away by wind, there are protecting fences. Soil is being mixed with the waste in order to prevent such spreading and also to improve the mineralization of the waste. (Mr He Liang, 2004)

This landfill used to receive sewage sludge from Gaobeidian Sewage Treatment Plant. The high content of water in the sludge creates problem with leakage. The characteristics of the sludge also create problem with the stability of the waste piles and the landfill can then become hard to manage. Therefore this landfill is no longer accepting sewage sludge. (Mr He Liang, 2004) According to Mr He Liang, director of Bei Shen Shu Sanitary Landfill Site, the sludge most have water content less then 65% in order to be allowed in landfills. The sludge cake from Gaobeidian does not meet this demand.

5.5 Pollution sources and control strategies in the area of Beijing

Pollutants entering the sewage network accumulate in the sludge and they reflect the usage of chemicals in the whole society. It is important to minimise both point sources as well as diffuse sources in order to improve the quality of the sludge. One way of minimising the discharge of pollutants from point sources is to regulate the discharge from these sources. All the industry in Beijing is connected to the municipal sewage network. China has set discharge standards for the industry, which forces the industry to treat their wastewater if they exceed the standard, before discharging the water to the sewage network. These can be found in *"Discharge standards for the industry CJ 3082-1999"*. The State Environmental Protection Administration is responsible for the control of the discharge from industries. They may also impose penalties if the standard is not complied. The quality of the influent wastewater is analysed in order to trace pollutants. Different monitoring stations exist where measures can be taken, it is therefore possible to trace from where the pollutants are entering the sewage network. (Mr Ke Zhenshan, 2004)

Beijing is a city in change. The city plan will change dramatically in a near future and for example will large industries be moved outside the city. This will lead to that the wastewater treatment plants will receive fewer pollutants in the future and this will lead to the improvement of the sludge quality. (Mr Zhang Jun, 2004)

Today there is a problem with heavy metals in the sludge and especially high levels of mercury (Mr Ke Zhenshan, 2004). At Gaobeidian Sewage Treatment Plant, the largest wastewater treatment plant in Beijing, all concentrations of heavy metals are below the limit values in the quality demands for agricultural use except for mercury. The concentrations of other heavy metals have decreased during the last years except for mercury where the concentration has stagnated around 15 mg/kg of dry solids. (Dr Zhou Jun[1], 2004) Dr Zhou Jun PhD Senior Engineer at Technology Development Department at Beijing Drainage Group CO. Ltd consider this to be strange since mercury is only rarely used by the industry and research is performed in order to investigate the sources of mercury. According to Mr Ke Zhenshan Vice director Senior Engineer at Water Quality Analysis Centre at Beijing Drainage Group Co. Ltd. it is hard to see other trends in the sludge quality since it is just being measured four times a year.

There is also a problem with high concentrations of zinc due to galvanisation of sewage pipes. Galvanisation is used to reduce corrosion of the pipes. When new houses are built these pipes are sometimes replaced with pipes made of other materials but there is no legislation demanding this replacement. (Mr Zhang Jun, 2004)

Stormwater can be a diffuse source of pollutants of major importance. Combined systems are still in use in older areas of Beijing. Today separate systems are being introduced when the pipe network is extended to new areas. Separate systems allow the stormwater and municipal wastewater to be treated separately. (Mr Wang Jiawei[1], 2004)

Diffuse sources are harder to trace and to control than point sources. Many chemicals are used in households and it is of major importance that all of these do not end up in the sewage network. Therefore it is important to improve the public's knowledge of the environment and especially of the wastewater treatment process. An educational centre is under construction at Gaobeidian Sewage Treatment Plant. The purpose is to bring children here in order to educate them in environmental issues. (Mr Wang Jiawei[1], 2004)

5.6 Strategy for the future

Water is a scarce resource in the area of Beijing and hence the treatment of wastewater is important in order to prevent watersheds from being polluted. The goal is that 100% or 9 million people are connected to the sewage network in Beijing excluding the suburbs by 2010. (Mr Zhang Jun, 2004)

The Department of Project Design at the Beijing Drainage Group Co Ltd is co-operating with governmental departments concerning land, environment, agriculture and forestry (Mr Zhang Jun, 2004) and they are responsible for the future planning within the company (Mr Wang Jiawei[2], 2004). They are working with a sludge handling strategy for the future and this will be presented by the end of the year 2004. The work includes the estimation of future sludge quantities and analyses of different treatment and disposal methods. Also the capacity of the soil has been measured in order to receive the possible maximum disposal of sludge on land and they have also been trying to foresee the international trends in sludge disposal. This work has lead to a plan where *"the best technology adapted to the Beijing possibilities"* is used. (Mr Zhang Jun, 2004)

It is estimated that 2 500 tonnes of sludge with water content less than 80% will be produced per day by 2010. This number can be compared with the present production of 1 000 tonnes per day. (Mr Zhang Jun, 2004) Strategy for the future is to use three different methods (Mr Zhang Jun, 2004):

- 60% is to be composted.
- 30% is to be treated by thermal drying.
- 10% is to be incinerated or deposited at landfills.

The amount of sludge that is planned to be composed is about 1 500 tonnes per day. Therefore three new composting facilities are being constructed. In order to increase the composting rate there will be a step in the process added after the natural composting where the sludge is treated in a chamber with increased temperature. This leads to that the area of the compost can be reduced. The feasibility report has been presented for one of the plants and the localisation is being selected for the other two. The Daxing Sludge Disposal Plant will be re-constructed in order to introduce the new step in the process. After the composting treatment the sludge can be used as fertiliser, soil improver or as constructing material. (Mr Zhang Jun, 2004)

A process that is not being used in Beijing today is thermal drying but this process will stand for about 30% of the future treatment. Three new facilities are planned where one will be built during 2005 and feasibility reports have been presented for the other two. (Mr Zhang Jun, 2004) Thermal drying will, for example, be built at the Fangzhuang Sewage Treatment Plant as mentioned previously (Ms Zhi Yuan, 2004). This treated sludge can also be used as fertiliser, soil improver or as constructing material (Mr Zhang Jun, 2004).

Composts demand large areas since it is a rather slow process compared to for example thermal drying. In large cities like Beijing this will cause a problem since most large cities are expanding. Thermal drying is therefore regarded as a good option to composting since it also produces fertiliser and soil improver where the nutrients are being recycled. (Mr Zhang Jun, 2004) Thermal drying is a more expensive process but it demands less area (Mr Chen Zhaozhao, 2004).

Sludge will also be incinerated or disposed at landfills and this amount is estimated to be about 10% in the future. The plan is to dispose the sludge with the lowest quality either of these two ways. (Mr Zhang Jun, 2004) No incineration facilities will be built before the Olympic Games in Beijing 2008 since the air needs to be of as good quality as possible (Mr Wang Jiawei[2], 2004). Most of the solid waste from households is today disposed by deposition at landfills but in the future this waste will be incinerated. The plan is to incinerate sludge and waste together. Incineration is regarded as a good method since the ashes can be used as constructing material and it demands less area compared to landfills. The energy from incineration can also be utilised. (Mr Zhang Jun, 2004)

"Today sludge is considered as a problem to get rid off but it might be regarded as a resource in the future" says Mr Jun Zhang at the Department of Project Design of Beijing Drainage Group Co Ltd. In the future 90% of the sludge is to be reused by either composting or thermal drying. A large amount of the nutrients can then be recycled when sludge is used as a fertiliser or soil improver. According to PhD Professor Lin Hai at the department of Environmental Engineering at University of Science and Technology, Beijing, composting is the first choice in the present situation. But he also states that one disposal way is not enough. According to Mr Chen Zhaozhao at Daxing Sludge Disposal Plant all of the sludge can not be used as a fertiliser. In his opinion the usage of sludge as soil improver or as constructing material are also good options since some farmers will not accept sludge as a fertiliser. The farmers are aware of the risks regarding the usage of sludge on agricultural land.

Zhongguancun is a Science Park located in the north-west of Beijing and here the technology and the knowledge are gathered and this creates a good environment for the development of new ideas and new technique. Zhongguancun Sewage Sludge Disposal Union was founded in November 2003 by initiative of the government. It is cooperation between government departments, universities, institutes and companies and it was an attempt to create a bridge between the government and the industry. They are working together in order to solve the problems with sludge handling. At Zhongguancun there are companies working with the development of a process were sludge is used as a constructing material but also with other solutions for the sludge handling. (Mr Chen Ziting, 2004)

5.7 The Yellow Plain

The Yellow Plain is an agricultural area south of Beijing. The soil is very fertile due to deposition of material from the Yellow River and the area has been cultivated for thousands of years. The most important crops are wheat, corn and barley. (Landguiden, 2004) The production of crops is mainly limited by the amount of water in the area. In Chinese the Yellow Plain is called the Huabei Plain (Mr Wang Jiawei[2], 2004).

5.7.1 Geology and soil characteristics

The Yellow Plain is situated south-east of Beijing and it is an alluvial deposition. The Yellow River flows through the plain and hence have shaped and created the plain. The Yellow Plain is 320 000 km^2 and it is built up by silt and clay material that has been deposited by the river. (Clark, 1983)

The Yellow River originates in the Tibetan highland 4 450 m above sea level and is called Huanghe by the Chinese people. Here the water is clear and the river is less than 100 m wide. In the province of Gansu the velocity and the flow of water increases. The river flows 1000 km through a spectacular yellow landscape and this is a loess plateau, which is situated in the Shanxi and Shaanxi province. A 130 metre thick layer of yellow-brown loosely stored particles covers the plateau. This is one of the most easily eroded lands in the world. (Clark, 1983)

Loess, in Chinese *huang tu* (Boon et al, 2000), is created by the deposition of material carried by the wind. The material is fine, mainly silts, and originates from weathered material in desserts and steppes but also from glacial depositions. In some parts of Asia these depositions is about 200 m thick. The wind can transport fine material for long reaches and (Byggforskningsrådet, 1983) the loess at the plateau in Shanxi and Shaanxi is believed to originate from the Gobi dessert in Mongolia (Clark, 1983).

The composition of minerals in loess constitutes mainly of quarts, feldspar, calcspar and other forms of lime. The lime constitutes a binding material between particles but can easily be dissolved by water. The occurrence of lime makes the loess very fertile and the grain size varies around the world but the most dominant is the particles in the silt size. Loess is as mentioned before easily eroded and great damage can occur during a short period of time for example caused by heavy rain. (Byggforskningsrådet, 1983)

The Yellow River transports enormous quantities of material when it flows through the loess plateau. The transport is measured to 46% by weight when leaving the plateau. 10% is normally considered to be unusually high. The yearly transportation of material is 1.6-milliard tonnes when passing Mengjin in the Henan province just before it reaches the Yellow Plain. Downstream Menggjin the slope of the watercourse is just 15 cm per km, which is not enough to keep the material suspended in the water. The distant from here to the ocean are 800 km. The river deposit material its whole way to the ocean and just one fourth of the material reaches the ocean. This deposition has and is creating the Yellow Plain. (Clark, 1983)

The riverbed rises due to deposition and so does the water level and this increase the risk for flooding. In order to control the river the people has built walls. These walls are 20-metre width at the foot and 15 metre at the top and 9 metre high. The Yellow River is called the Chinese sorrow and it has flooded 1500 times during the past 3500 years. (Clark, 1983)

At first the amount of organic material in a soil increases when the soil is being cultivated. Equilibrium is later reached between the added amount of organic material and the increased decomposition. The decomposition rate depends on the climate, i.e. precipitation, temperature etc. but also on the location. The Yellow Plain has been cultivated for thousands of years. (Mr Conny Svensson, 2004)

As mentioned before loess is a very fertile soil and it contains lime but this also affects the pH of the soil. The soil of the Yellow Plain is alkaline and the pH is around 7.5-8.5. (Mr Wang Shenjian, 2004) The pH affects the mobility of metals, where metals tend to be less mobile in alkaline soils compared to acid soils.

5.7.2 The agriculture on the Yellow Plain

The characteristics of the soil and the geology of the Yellow Plain make this land very suitable for agriculture. In this agricultural area several different crops are cultivated but mainly wheat, corn and broomcorn but also barley, vegetables, fruits and sunflowers. (Mr Chen Zhaozhao, Mr Wang Shenjian, 2004) At the Yellow Plain the land is either divided into small farms and these are run individually or the farm is run cooperatively between several farmers. The cooperative farms are normally bigger and here more advanced technology is being used. Individually farmers usually do all the work at the farm by hand but cooperative farms rent or borrow machines to do some of the work at the farm with these. (Dr Huang Zhanbin, 2004)

The rainy season is during the summer but if it does not rain enough, the fields need to be irrigated. Irrigation is mainly performed by leading water out to the fields in channels, but large fields with more modern equipment might use sprinklers. (Mr Chen Zhaozhao, 2004) Shortage of water at the Yellow Plain and the need of irrigation of the crops have lead to a high withdrawal of groundwater leading to a sinking groundwater table. The Chinese government is investing a lot of resources in water saving technologies. (Dr Huang Zhanbin, 2004)

The annual amount of precipitation is 500-550 mm in the Yellow Plain and water is the limiting factor for the production of crops in this area. (Mr Wang Shenjian, 2004) This has impacts on the usage of different fertilisers. According to Dr Huang Zhanbin more water is needed to the crop when artificial fertiliser is being used compared to when organic fertiliser is being used. This is one advantage of organic fertiliser in this area due to the shortage of water. But farmers also have the opinion that raw sludge for example is not to be used as a fertiliser because it demands more water to the crop compared to pelletized sludge according to Dr Zhou Jun, PhD Senior Engineer at Technology Development Department at Beijing Drainage Group CO. Ltd.

The organic fertiliser also has the advantage of being a slow fertiliser so the nutrients are released under a long period of time. This is due to the high content of organic material that needs to be mineralised before the plants can make use of the nutrients. There is research today where an agent is added to artificial fertilisers in order to slow down the release of nutrients. The disadvantage of the usage of sewage sludge is the bigger amount of fertiliser that needs to be spread compared to artificial fertiliser hence the lower concentration of nutrients. There is also the problem with pollutants in the sewage sludge. (Dr Huang Zhanbin, 2004)

Artificial fertiliser is in general acid and hence the pH in the soil will drop when this is being used. Organic fertiliser such as sewage sludge or stable manure is generally considered to be neutral. However, during mineralising of the organic material in stable manure and sewage sludge ammonium ions will be released, which will also lead to a decrease in pH in a longer time perspective. (Mr Göran Areskoug, 2004)

The spreading of fertiliser takes place in the spring or in the autumn. This spreading is either made by hand at smaller farms or by machines at the cooperative farms. (Dr Huang Zhanbin, 2004) Today both pelletized sludge as well as artificial fertiliser is used. The artificial fertiliser is 5 to 10 times as expensive as the sludge fertiliser is (Mr Chen Zhaozhao, 2004). Also stable manure is being used as a fertiliser but it is used as a base fertiliser hence its slow release of nutrients. The urine from domestic animals is considered to be a better fertiliser after fermentation. Stable manure has a low content of nutrients and should therefore be used together with artificial fertiliser if that is possible. Stable manure is also a rather inexpensive fertiliser. (Mr Wang Shenjian, 2004)

5.8 Attitude towards the usage of sludge as a fertiliser

The general opinion in China is that it is very important to recycle the nutrients in the sludge. China is an agricultural country so the sludge can be seen as a resource and not just as a problem. (Ms Zhang Hui, 2004) For the future 60% of the sludge will be composted and 30% treated with thermal drying, as mentioned before. The treated sludge will be used as fertiliser but also as soil improver and as constructing material. (Mr Zhang Jun, 2004) The percentage of these three different usage methods is not known today.

There are different opinions about the risks linked with the usage of sludge on agricultural land. Dr Zhou Jun PhD Senior Engineer at Technology Development Department at Beijing Drainage Group CO. Ltd believes that the usage of sludge as fertiliser is fairly safe. There exists no problem if this fertiliser is used on crops which are not to be food. More research can be performed so the usage of sludge as fertiliser also can include crops that are produced for food. Dr Zhou Jun thinks that it is very important to recycle the nutrients in the sludge. Sludge from bigger wastewater treatment plants, such as for example Gaobeidian, has a fairly stable sludge quality compared to a smaller wastewater treatment plant and therefore this sludge is more suitable for the usage as fertiliser.

On the other hand, risks connected to the usage of sludge on agricultural land are given more attention at universities. Apart from the problems with accumulations of heavy metals in the soil, there are great concerns about the public health. PhD professor Lin Hai sees a risk with the accumulation of heavy metals also in the human bodies after the consumption of crops that have been fertilised with sludge. More research is needed before the usage of sludge can be regarded as safe and a lot of research is performed in this field here in China. But PhD professor Lin Hai thinks however that it is very important to recycle the nutrients in sludge and that sludge is regarded as a valuable resource as fertiliser. These opinions about the usage of sludge as fertiliser regard raw sludge as well as composted sludge. PhD professor Lin Hai does not think that the public can see the difference between raw sludge and composted sludge.

Mr Chen Zhaozhao, engineer at Daxing Sludge Disposal Plant, consider the fertiliser produced at the composting plant is a good fertiliser and that the farmers benefits from the usage hence it is less expensive then artificial fertiliser. The quality of the sludge is being measured and sludge that does not pass the standard will instead be used as soil improver. Research on the usage of this composted sludge is being performed at the plant.

Most farmers see that the crops are growing faster when fertiliser is being used and are therefore happy to use the sludge fertiliser, but some farmers have also concerns about this usage of sludge. (Mr Chen Zhaozhao, 2004) Dr Zhou Jun PhD Senior Engineer at Technology Development Department at Beijing Drainage Group CO. Ltd thinks however that the usage of sludge as fertiliser will expand and that more farmers will use this fertiliser in the future. He does not think that the farmers will have any problems with selling their crops if the have been fertilised with sludge.

However, farmers regard the usage of dewatered sludge, which has not been composted, as harmful for the plants. They state that plants will die if they are being fertilised with dewatered sludge. Farmers also prefer the usage of composted and pelletized sludge because this usage demands less irrigation of the plants (Dr Zhou Jun[1], 2004). Composting of the sludge also reduces the water content, which facilitates the transportation of the sludge. Also the pathogens and the organic matter in the sludge will be reduced due to composting, which is of course considered to be good. (Mr Wang Shenjian, 2004)

Dr Huang Zhanbin, professor and director of the Bioengineering Department at China University of Mining and Technology, stress the importance of research concerning the risks and possibilities with the usage of sewage sludge as a fertiliser. It is important that these findings reach the public so that the public’s opinion about sludge as fertiliser is based upon facts and not speculations. He considers the sludge to be a valuable resource as a fertiliser.

5.9 Other options for the disposal of the sludge

There are expectations that the usage of sludge as a fertiliser will increase in the future. It is important to create a sustainable society where the nutrients in the sludge can be utilised. However, it might not be possible to use all the sludge in this way. The usage of sludge as constructing material or as soil improver is considered to be valuable for the future. Still, some of the sludge will be deposited at landfill. Landfills are regarded as the most economical disposal method but it is not a good solution for Beijing due to the demands of large areas, according to Mr Jun Zhang at the Department of Project Design of Beijing Drainage Group Co. Ltd. Incineration is also a disposal method being evaluated for the future.

5.9.1 Incineration

About 50% of the solids in sewage sludge are organic matter and this can be combusted in incineration chambers. When incinerating the sludge the water content of the sludge is of major importance. To incinerate the sludge without auxiliary fuel the DS content must be around 40%. This auxiliary fuel could for example be solid waste. When incinerating solid waste and/or sewage sludge, the heat can be taken care of in order to use it as an energy source. Incineration reduces not only the volume of the sludge drastically but also organic pollutants and pathogens. The ash contains mainly inorganic material such as for example heavy metals.

All solid waste in Beijing is today deposited at landfills outside the city and there are no incineration facilities. There is however a pilot-study where sewage sludge is incinerated with solid waste. About 10% of the sewage sludge will be either deposited or incinerated in the future. The sludge with the lowest quality is most likely to be disposed in either of these ways. It might be possible to use the ash as a constructing material or the ashes can just be deposited at a landfill. (Mr Zhang Jun, 2004)

Beijing is hosting the summer Olympics in 2008 and the city will therefore be in focus during the years to come. It is important that the air quality is high and therefore it might not be possible to build an incineration facility before 2008. (Mr Wang Jiawei[2], 2004) Incineration involves discharge of carbon dioxide but also of other pollutants. This would further put pressure on air in Beijing, where the main energy source comes from the coal and oil industry. These energy sources stand for 75% of Chinas requirements of energy. (Landguiden, 2004)

5.9.2 Soil improver

Sewage sludge contains nutrients and organic matter and can therefore be useful as a soil improver. It can improve the soil by increasing the content of organic matter and also increase the performance of the soil since nutrients are added. This way of disposing the sludge could be valuable when the quality of the sludge does not meet the standards for agricultural use but still have a value regarding its content of nutrient and organic matter. (Mr Chen Zhaozhao, 2004)

A part of the sludge that is composted at Daxing Sludge Disposal Plant is used as soil improver. It is for example used on sandy soils where the content of organic matter needs to be increased. According to Mr Chen Zhaozhao, engineer at Daxing Sludge Disposal Plant, the composted sludge could also be used in desert areas in order to inhibit further desertification of the land. Since the soil improver makes the soil more fertile the land can then be cultivated. The nutrients in the sludge are also valuable and can improve soils that are intended for different usage. When constructing a golf course or a park for example, sludge can be used as a soil improver. Composted sludge from Daxing Sludge Disposal Plant is sold and transported by train to south China where it is used as soil improver when constructing golf courses. (Mr Chen Zhaozhao, 2004)

The Department of Project Design of Beijing Drainage Group Co Ltd regards the usage of sludge as soil improver to be an interesting option also for the future. According to the Department of Project Design about 90% of the produced sludge from wastewater treatment plants will be either composted or treated with thermal drying in the future. A part of this sludge will not be used as fertiliser in agriculture or as constructing material but instead as soil improver. (Mr Zhang Jun, 2004)

5.9.3 Sludge as constructing material

There are many people in the wastewater field that consider the usage of sludge as constructing material as a good solution for China in the future (Mr Zhou Jun[1], Mr Chen Zhaozhao, Ms Zhi Yuan, 2004). People at universities also agree that the usage of sludge as constructing material is a good option. This usage is regarded as rather safe for the environment and for the public health. (Li Tianxin, Mr Zhou Jun[1], 2004) China is fast developing and the need for constructing material is great. The usage of sludge would be a less expensive resource. (Li Tianxin, Mr Zhou Jun[1], 2004) Figure 12 shows a typical skyline from Beijing the autumn 2004. A lot of construction is conducted in the city.

Figure 12 Skyline in Beijing autumn 2004. New constructions are being built everywhere in the city.

5.9.3.1 Sludge used after thermal drying or incineration

There are several different processes, which makes it possible to use sludge as constructing material. One example is when the sludge is incinerated and the ash is used when producing bricks etc. This process is used for example at an incineration plant in Japan. These bricks are dense and rather expensive to produce. (Dr Zhou Jun[1], 2004) 10% of the sludge in Beijing is to be disposed either by landfill or by incineration. According to Mr Zhang Jun, Engineer at the Department of Project Design of Beijing Drainage Group Co Ltd, it might be considered to use ashes from incineration to produce constructing material.

Pathogens and unwanted organic substances are destroyed when incinerating sludge due to the high temperature. The aches constitute therefore no sanitary risk. The aches contain inorganic material such as different metals and heavy metals. (Naturvårdsverket 5214, 2002) Metals are in oxidised form after incineration and they are therefore relatively immobile and examples of metal compounds in the ach are Fe_2O_3 and MgO (European Commission, 2001). When incinerating the sludge of course the volume is reduced and the water content drastically decreases. There is neither a problem with odour.

In the future, 30% of the sludge will be treated with thermal drying according to the Department of Project Design of Beijing Drainage Group Co Ltd. This product will mainly be used as fertiliser but some might also be used as constructing material (Mr Zhang Jun, 2004). There is research at universities in this field, investigating the possibilities to thermal dried sludge as constructing material. However, this research is performed in small scale and there is according to Dr Zhou Jun, Senior Engineer at Beijing Drainage Group Co., Ltd, no pilot plant of significance.

The high temperature during thermal drying kills off pathogens in the sludge (Naturvårdsverket 5215, 2003). This method of course also reduces the water content in the sludge (European Commission, 2001).

5.9.3.2 Sludge used directly after dewatering

A process under developing is when sludge is used as constructing material directly after dewatering and here lime is added to the dewatered sludge (Mr Chen Ziting, 2004). These bricks are less dense and this process would be a more suitable process for China according to Dr Zhou Jun, because it might be less expensive. Hence no incineration or thermal drying facility needs to be built when the sludge can be used directly after dewatering.

One leading company in this field is Beijing Aoliaide S & T Development Co. Ltd. They are a part of the Sewage Sludge Disposal Union at Zhongguancun Science Park as mentioned in chapter *"5.6 Strategy for the future"*. They have developed a process where lime mixed with sludge creates a product suitable as constructing material. (Mr Chen Ziting, 2004)

The first step in this process is to add lime to dewatered sludge and the water content of this sludge should be about 80%. Also other chemicals are added in order to create the heat needed for the reaction. The company patents the process and these chemicals. The temperature rises to about 100°C for 5-7 minutes. According to Mr Chen Ziting, the president of the company, the metals and the heavy metals are oxidised into compounds such as CaO, Al_2O_3, SiO, MnO, $CaCO_3$ and PbO. The produced product consists mainly of inorganic material and has a water content of less then 20%. This process is not sensitive to different sludge qualities as long as the sludge contains enough amounts of water. (Mr Chen Ziting, 2004)

There are six goals, which they have set up for the disposal of sludge that they consider is fulfilled in this process (Mr Chen Ziting, 2004):

- Kill pathogens.
- Dewater the sludge (also cellular water).
- Control the activity of metals.
- Reduce the organic content and stabilise the sludge.
- Remove odour.
- Make reuse of the sludge possible.

The killing of pathogens occurs due to the high temperature in the process. Tests have shown a non detectable concentration of faecal bacteria. The sludge is dewatered and also the cellular water is reduced. Hence the metals are oxidised they are less mobile and can therefore be controlled. They are bound to the material and will remain so even after the adding of water. The organic content is reduced and stabilised and odours are therefore removed. According to the company’s own measures the product contains about 3% organic material compared to 40% before the treatment. This is all according to Mr Chen Ziting, the president of Beijing Aoliaide S & T Development Co. Ltd.

However there is no evidence for how the process is working. It is not clear which compounds that are formed and what the exact content of the product is. There is no proof for Mr Chen Ziting’s statement about the fulfilling of all the goals. For example, according to Mr Chen Ziting all metals are oxidised but this might not be correct according to Dr Zhou Jun. Instead different forms of hydroxides might be formed. These are also less mobile but not to the same extent as oxides. The content of the product is likely to be (Dr Zhou Jun[1], 2004):

- Metal hydroxides ($M(OH)_n$).
- Lime.
- Organic material.
- Inorganic compounds.

The content of lime is about 20-40%. This makes the product very suitable for the cement industry and the product can replace 30% of the lime used here. The product can be seen in Figure 13 and it is hard pebbles in the size of 4-12 mm in diameter. These pebbles can also be used for example during road construction. (Mr Chen Ziting, 2004)

Figure 13 Processed sludge that are ready to be used as constructing material. Hard pebbles in the size between 4-12 mm.

The equipment brand is ORIENT and it has been exported to Japan and Singapore. It is mobile and can be moved between different facilities. The equipment is manufactured in different sizes. So far only experiments in pilots scale have been performed and a total amount of 3 000 tonnes of constructing material has been produced and sold to the cement industry. The company is awaiting the government to establish a policy for this usage and also legislation. (Mr Chen Ziting, 2004)

6 Discussion and evaluation

A discussion of the field study will follow in this chapter. This discussion will summarize the present sludge handling in Beijing and the future strategy. There is a need for fertiliser in this agricultural area and it is interesting to compare the measured sludge quality with the legislation for usage of sludge in agriculture. A comparison of Chinese condition with the conditions in Sweden, EU and USA in regards of legislation and sludge treatment and disposal methods is also conducted. This is followed by an evaluation of the different treatment and disposal methods of interest for this area.

6.1 Field study

A part of the population in Beijing is connected to the sewage network with nine plants operating in a similar way. Most of the sludge is either composted and used as a fertiliser or soil improver, or deposited at landfills. The sludge quality is measured and this can be compared to the Chinese legislation regarding the usage of sludge as a fertiliser. In the future, more sludge will be generated and composting and thermal drying will be used for the majority of the sludge, enabling a larger recycling of nutrients. This is important for this area which is close to the large and fertile Yellow Plain.

6.1.1 Present situation in Beijing

Beijing has 13.8 million inhabitants and about 40% of the inhabitants are connected to the sewage network. There are nine wastewater treatment plants, which are treating wastewater corresponding to 5 million PE. These wastewater treatment plants differ in their treatment methods but they are all based on a traditional combination of mechanical and biological treatment. No chemicals are used in order to precipitate phosphorus or nitrogen, this removal of nutrients is instead performed biologically by bacteria. Sludge is produced in the primary- and secondary sedimentation tank. At some wastewater treatment plants there are advanced treatment for reuse-water, this step also generates sludge.

The produced sludge is treated differently at different wastewater treatment plants but the treatment is in general just a mechanical treatment in order to dewater and thicken the sludge. Two of the wastewater treatment plants have a combination of a thickening tank and a centrifuge. Fangzhuang Sewage Treatment Plant is one of the treatment plants where this method is used. Here the sludge from the primary and the secondary sedimentation tank is mixed and treated in the same centrifuge. After this treatment the sludge contains less than 80% water. Most of the other plants instead have a combination of a thickening tank and a filter belt. This method is used at for example Jiuxianqiao Sewage Treatment Plant and the treatment reduces the water content to about 82%. At Gaobeidian Sewage Treatment Plant the treatment of the sludge is extended and also includes a biological step where the sludge is treated in an anaerobic digester in order to stabilize the sludge. This stabilised sludge is then treated mechanically by filter belts in order to further reduce the water content. Not all the sludge produced at Gaobeidian is treated in the digester but some is dewatered directly by filter belts. When the sludge is treated it is collected at a platform and then transported away for disposal at Daxing Sludge Disposal Plant. Sludge that is digested and dewatered is collected together with sludge that has been directly dewatered. In order to facilitate the dewatering process at the wastewater treatment plants, polymers are added to the sludge. This is the only chemical added to the sludge during the treatment at the wastewater treatment plants that was visited during this field study.

240 tonnes DS of sludge is produced every day in the Beijing-area. The water content is less than 80% but this still makes up a total production of sludge cake of 360 000 tonnes per year. 40% of this sludge is composted at Daxing Sludge Disposal Plant 54 km southeast of Beijing. All of the sludge produced at Gaobeidian Sewage Treatment Plant is transported by truck to this composting facility. Normally Daxing Sludge Disposal Plant only receives sludge from Gaobeidian. At Daxing the sludge is composted in windrows out in the open for 25 days and the rows are mixed and aerated by turning them over by trucks. The composted sludge has a water content of less than 20% and it is sold all over China as soil improver or fertiliser.

30% of the produced sludge cake is deposited at different landfills in the Beijing area. The remaining part of the sludge is disposed by contractors. Also when contractors dispose the sludge most of it is disposed at landfills. At landfills some sludge can be collected by farmers and used as fertilisers but this quantity is not known.

6.1.2 Quality of the sludge related to Chinese legislation

The quality of the sludge is measured four times a year and measures are taken for dry solids, organic matter, total nitrogen and total phosphorus but also for some heavy metals, organic pollutants and bacteria. These measurements are taken at different steps in the treatment process of the sludge and all of the analyses in Beijing are performed by the Water Quality Analysis Centre, a sub-company at the Beijing Drainage Group Co Ltd, except for Xiaojiahe WWTP.

Table 27 shows the measured concentrations of the quality of the sludge cake from three different wastewater treatment plants in Beijing. If the values in Table 27 are compared to Table 29, which shows the maximum permitted content of compounds in the sludge when it is to be used on agricultural land, some conclusions can be drawn about the quality of the sludge. Most of the measured concentrations of metals in the sludge cake is lower than the by law permitted concentration. This is the case for nickel, cadmium, zinc, copper, chromium and arsenic. These metals meet the standard demands for as well alkaline as acid soils. All measurements of boron, except two, are slightly above the standard demand. The concentration of lead is slightly higher than the standard demand for acid soil in two out of six measurements but it meets the standard for alkaline soil in all measurements. There is no general trend that the concentrations of metals decrease or increase from May to December. Some metals increases and some decreases but the same trend can be seen for all of the three wastewater treatments plants for the same metal. Also organic pollutants are measured. Benzene (a) pyrene is not detectable when measured and phenol is measured but there is no standard demand for phenol in the Chinese legislation. However, phenol is regarded as a good indicator also for other organic substances present in sludge. However, there are standard demands for PCDD/PCDF, AOX and PCB but these concentrations are not available in this study. The concentrations of petroleum are higher than the standard demands but the values are decreasing when comparing the values from May and December. The concentrations of mercury are just measured in one of the two occasions and these values are significant over the standard demand.

The quality of the sludge can however always be improved, which is beneficial for the environment as well as the public. A first step in order to achieve this improvement is to reduce the point sources, which China has done by implementing discharge standards for the industry. The State Environmental Protection Administration is responsible for the control of the discharge from industries and they may also impose penalties if the standard is not complied. Also the quality of incoming wastewater is monitored, which makes it possible to trace pollutants back in the system. In the future the industry in Beijing will be forced to move outside the city, which will also further improve the quality of the wastewater and hence also the sludge.

Today there is a problem with high concentrations of especially two metals, mercury and zinc. The reasons for the high levels of mercury are unknown and investigations are conducted in order to find the sources of this pollutant. High concentrations of zinc are due to the galvanisation of sewage pipes. These pipes can be replaced by pipes of other materials, which are sometimes done when building new pipes.

Diffuse pollutant sources are harder to trace and to improve. One way is to use separate systems for wastewater and stormwater, which is built when constructing new pipe systems. Another area is to increase the public's awareness of the usage and handling of chemicals. For example is an educational centre under construction at Gaobeidian Sewage Treatment Plant. The purpose is to bring children here in order to educate them in environmental issues.

6.1.3 The need for fertiliser

China has a large population and the need for agriculture and the production of provisions is of major importance. Beijing, as mentioned before, is located in the north corner of the triangular shaped Yellow Plain in the north-eastern part of China. This area is the most extensive agricultural area in the country. The plain is an alluvial deposition of fine fertile material called loess, as mentioned before, and this is one of the reasons for the high production of crops in the area. Loess contains lime and this makes the soil fertile and it also contributes to the high pH in the area. The pH is around 7.5-8.5 and metals tend therefore to be less mobile in the area compared to other areas with lower pH.

One way to increase the agricultural production is to fertilise the soil with nutrients. There are different opinions about which fertiliser to use. Artificial fertiliser is commonly used all over the world but it is a finite resource and it is expensive to buy for the individual farmer. Many farmers also use stable manure as an organic fertiliser and it has the advantage of being a slow fertiliser but the disadvantage of lower concentrations of nutrients compared to artificial fertiliser. Another option is the usage of treated sewage sludge, which contains nutrients and is also a slow fertiliser. A problem with the usage of sewage sludge is its content of pollutants but the quality of the sludge can be improved by improving the quality of the influent wastewater. The sludge is less expensive than artificial fertiliser and the nutrients in sludge originate from the farmland. By using sludge as a fertiliser a recycling of nutrients is possible.

The deficient of water in the area limits the agricultural development and the region has been known to experience drought in nine years out of ten. Therefore large quantities of water are used for irrigation. High withdrawal of groundwater in the area has lead to a sinking groundwater table. The Chinese government is investing a lot of resources in water saving technologies. The limitation of water has an impact on the usage of different fertilisers according to Chinese expertise. More water is needed for irrigation when the crop is fertilised with artificial fertiliser compared to organic fertiliser. This would be another advantage of the usage of sewage sludge as a fertiliser hence it is an organic fertiliser. But farmers also have the opinion that raw sludge for example is not to be used as a fertiliser because it demands more water to the crop compared to pelletized sludge. Therefore the usage of pelletized sludge would in this respect be optional.

When comparing the content of nutrients in sludge from Fangzhang WWTP, Gaobeidian WWTP and Jiuxianqiao WWTP with the content of nutrients from an average Swedish sludge, it is shown that the nutrient content in the sludge in Beijing is lower. An average Swedish sludge contains 3% phosphorus and 4% nitrogen measured in percentage of dry solids. In Table 27 measures from the three different wastewater treatment plants in Beijing is shown. The measurements of Total-N in percentage of DS vary from 3.86% down to 0.85% and the measurements of Total-P vary from 0.59% down to 0.12%. The values are, as mentioned, lower compared to the average Swedish sludge (see Table 1). However, the measurements from Beijing are point measurements and not monthly averages. It is hard to measure the content of substances in sludge and the values do not necessary reflect the average content of nutrients in the sludge from the wastewater treatment plants. There can be fluctuations in the influent wastewater and that will reflect the composition of the sludge. It is therefore desirable to measure the content of the sludge more regularly but this is expensive and time consuming.

6.1.4 Strategy for the future in Beijing

The sewage system will be expanded further in the future and this will lead to an increased sludge production. It is estimated that 2 500 tonnes of sludge with water content less than 80% will be produced per day by 2010 and this number can be compared with the present production of 1 000 tonnes per day. The sludge will be composted or dried thermally and a small percentage will be either incinerated or deposited at landfills. Thus 90% of the sludge may be reused as fertiliser or soil improver but maybe also as constructing material. This is a high value of reused sludge and a desirable scenario. New facilities are under construction in order to conduct this future treatment of the sludge and old ones are being reconstructed.

The general opinion in China is that it is very important to recycle the nutrients in the sludge. China is an agricultural country so the sludge can be utilised and the nutrients in the sludge can be made use of. But there is however risks linked with the usage of sludge that has been discussed in previous chapters. The content of pollutants, spread of diseases and the public acceptance for the usage of sewage sludge on crops cultivated for food production. The risks connected with the usage of sludge on agricultural land are given more attention at universities and there the opinion of first using sludge on crops that is not to be eaten is dominating. More research is proclaimed in the field first in order to not make any mistakes and to base the opinion upon facts and not assumptions. The main opinion however is that sludge needs to be considered to be a valuable resource.

There are different opinions among farmers about the usage of sludge as a fertiliser. It is an inexpensive and good fertiliser. However, some farmers regard the usage of dewatered sludge as fertiliser that has not been composted as harmful for the plants. They state that plants will die if they are being fertilised with dewatered sludge. There is no evidence for this statement but it is an opinion among some farmers. Some farmers also prefer the usage of composted and pelletized sludge because this usage demands less irrigation of the plants.

6.2 Comparison of Chinese conditions with Sweden, EU and USA

Sweden, EU, USA and China all have legislation concerning the usage of sludge but they differ from each other in several aspects. In China, there only exists specific legislation for the usage of sludge when it is used as a fertiliser in agriculture. This is also the case for EU and Sweden, but in the USA all usage and disposal of sludge is regulated in one federal regulation. Further in the USA, when sludge has been treated it is referred to as biosolids instead of sludge. This probably gives a more positive sound to the recycling of a waste fraction like sludge.

The EU is working on a new directive concerning the use of sewage sludge. This legislation will not only deal with the usage of sludge in agriculture as a fertiliser but also other land application. Management of sludge on green areas, in silviculture and on reclaimed land will all be included in the new legislation. The Swedish government is also working on new regulations and also here are the intentions to broaden the application of the law to include all land usage of sludge.

6.2.1 Quality standard demands for agricultural usage

There are different quality demands for the sludge when it is to be utilised in agriculture. China has demands on the content of nine different metals but also on five organic compounds. Sweden, EU and USA also regulate the content of a number of metals but no organic compounds. Table 30 shows the limit values for the metals regulated by legislation in the different regions.

Table 30 Limit values for concentrations of heavy metals in sludge intended for agricultural use.

Control Item (mg/kg DS)	China		USA[A]	EU	Sweden
	pH <6. 5	pH≥6. 5			
Cadmium, Cd	5	20	39	20-40	2
Mercury, Hg	5	15	17	16-25	2.5
Lead, Pb	300	1000	300	750-1200	100
Chromium, Cr	600	1000	-	-[B]	100
Arsenic, As	75	75	41	-	-
Nickel, Ni	100	200	420	300-400	50
Zinc, Zn	2000	3000	2800	2500-4000	800
Copper, Cu	800	1500	1500	100-1750	600
Boron, B	150	150	-	-	-
Selenium, Se	-	-	100	-	-

[A] *Monthly average concentrations of heavy metals in sludge.*
[B] *No value has been established.*

As can be seen in the figure, Sweden regulates the same seven metals as the EU which is natural considering that Sweden is a member of the EU. However, Sweden has chosen to implement considerable stricter limit values than the EU. In the USA there are limit values called ceiling concentrations for eight metals. These have to be met for all land application of sludge. If bulk sewage sludge is applied to agricultural land there are further quality demands. The monthly average concentration of metals in the sludge has to be met and if this is not possible there is also an option for the user to comply with the cumulative pollutant loading rate instead. In China consideration is given to the pH of the agricultural land where the sludge will be applied. There are two different quality demands depending on whether the soil is acid or alkaline which can be seen in the table. Metals in the sludge constitute a higher risk to the environment when sludge is applied on acid soils since metals become more mobile when the pH decreases. Therefore, China has chosen to have stricter demands on the sludge quality when applied to acid soils for seven different metals. The metals cadmium, mercury, lead, nickel, zinc and copper are regulated by all legislations and the Swedish regulations contain the lowest limit values. China has like the USA chosen to include arsenic but also boron while the USA instead regulates selenium. Both China and Sweden regulates chromium and Sweden has the most stringent demand.

EU and also Sweden have limits on the total annual amount of metals that may be distributed to the land. Also in this case, Sweden has chosen much lower values and another difference is that these values are an average for seven years while the EU has averages for ten years. In China there is a limit on how much sludge that may be applied to the land; 30 tonnes of dry solids per year and hectare. This will indirect give an upper limit to the total annual amount of pollutants that can be spread with sludge. In the USA, if the limits for monthly average concentration of metals are met there is not any maximum annual amount of metals for the spreading of bulk sewage sludge on agricultural land. However, for the spreading of sludge given away in bags or similar containers the monthly average concentration limits must be met but it is also possible to use the limit values for annual pollutant loading rate.

Besides regulating the content of metals in the sludge, it is possible to consider the content of metals in the soil on which sludge will be applied. Both EU and Sweden have limit values on the concentrations of metals that the soil might contain and there are demands on evaluating the soil before sludge is applied.

There is an ongoing work in both EU and Sweden to implement new regulations concerning the usage of sludge and these will include more stringent demands for the concentrations of metals. EU is also evaluating the possibility to regulate a number of organic substances and dioxins. Two more metals, tin and silver, may be introduced in Swedish legislation and EU wants to have different quality demands depending on the pH of the soil. Both regions also want to have the possibility to follow either limit values for the concentrations of pollutants in the sludge based on the dry content or the phosphorus content of the sludge. The American EPA is in the process of conducting further studies including risk assessments on chemical limits.

6.2.2 Demands on treatment and hygienisation

Chinese legislation states that sludge from municipal sewage treatment plants must be stabilised. For anaerobic and aerobic digestion and for aerobic composting, there are standards for the percentage of degraded organic material that has to be met. For composting there are also limit values on worm's ovum and faecal coliform bacteria. The law also requires the sludge to be dewatered to a certain extent. In the Chinese legislation, regarded the usage of sludge as a fertiliser in agriculture, it is stated that the sludge must have been treated before usage. It must have been decomposed at high temperature or digested. The EU only states that sludge must be treated before it is used in agriculture but also allows member states to choose whether they will allow untreated sludge that is tilled into the soil. With treated sludge means: sludge which has undergone biological, chemical or heat treatment, long-term storage or any other appropriate process so as significantly to reduce its ferment ability and the health hazards resulting from its use. However, there are no control standards or specific process parameters given for these treatments. In Sweden it is allowed to use untreated sludge if it is tilled into the soil within one day and not causes any inconveniences for people living close by. As for the EU, there is a total lack of specific regulations for treatments of the sludge. USA on the other hand has more recognised the importance of hygienisation of the sludge in order to reduce the risk for spreading pathogens and there are extensive regulations for this. There are different treatments specified resulting in either Class A biosolids or Class B biosolids with respect to pathogen reduction. There are both process parameters and limit values for certain micro organisms stated. Class A biosolids is regarded as totally safe to use and there are no further restrictions when using the sludge except for demands on vector attraction reduction, which also applies to Class B biosolids.

Both EU and Sweden are working on new regulations which will include demands on hygienisation. They are well aware of the potential risks of spreading of pathogens and the new legislation will contain specific demands on the treatments processes and further restrictions of spreading for different classes of sludge.

6.2.3 Demands on spreading

In China sludge should not be spread on vegetables or on meadows which shall be grazed the same year. The same rule applies to the EU and that legislation also states that here must be a certain time between spreading of sludge and harvest for pasture land. Sweden has also included these rules and has added berries and potatoes besides vegetables. In the USA, Class A biosolids can be spread without further restrictions. For Class B biosolids there are regulations concerning the time between the application of biosolids and the harvest, the time between application and the grazing of animals and the public access to the land.

There is a common goal in all the legislation to prohibit eutrophication of surface waters or groundwater as a result of sludge spreading. Chinese law states the spreading of sludge on sandy soils and farmlands with high water table must be avoided. In the USA the user must ensure that the biosolids do not enter surface waters or wetlands, nor may biosolids be applied closer than 10 meters to waters. The USA has also taken another precaution by saying that the whole sludge application rate must be equal or less than the agronomic rate. The EU requires consideration to the demand of nutrients by different plants and Sweden has chosen to set limit values on the total amount of phosphorus and nitrogen applied to the land with sludge. In China there is the limit of 30 tonnes of dry solids per year and hectare that may be applied to the land.

6.2.4 Treatment and disposal methods for sludge

All the sludge in Beijing today is treated with some dewatering process, either filter belt or by centrifuge. At Gaobeidian some of the sludge is treated by anaerobic digestion before the dewatering process. 40% of the sludge is then further treated at Daxing Sludge Disposal Plant by composting in windrows and then reused as fertiliser or soil improver. 60% of the sludge undergoes a dewatering process and is then disposed at landfills or by contractors. But there are facilities being built in order to conduct the increasing amount of sludge that needs to be treated. In year 2010, 60% of the sludge will be composted and 30% will be treated with thermal drying. These two methods both meet the requirements for Class A sludge in USA.

In USA the most common treatment methods are composting, thermal drying, advanced alkaline stabilisation and thermophilic digestion for Class A biosolids. Common treatment methods that meet Class B standard are anaerobic digestion, aerobic digestion and lime stabilisation. In Sweden most of the sludge is treated by mesophilic digestion at 35ºC but also other methods are used. In EU a wide variety of treatment methods are being used. Most likely, the treatment methods within EU will change when new regulation about hygienisation is implemented.

In Beijing the sludge is either reused as fertiliser or soil improver or deposited at landfills. 40% of the sludge is composted and then reused in Beijing today. Most likely some of the sludge will be used as constructing material in the future but the amount of sludge disposed this way is not clear. 60% of the sludge is today disposed at landfills or by contractors. However, most of the contractors do dispose the sludge at landfills.

Table 31 shows the disposal methods used for Sweden, EU, USA and China in percentage of the total amount of sludge that is disposed. According to these numbers, USA has the highest percentage of sludge that is reused in agriculture or other land application. But percentage of sludge that is reused is around 50% for all the regions. Sweden has the highest percentage of sludge that is disposed at landfills but this number is likely to decrease due to the fact that sludge deposition at landfills is prohibited from year 2005. 8% of the sludge in Sweden is disposed at intermediate storage but it is however not clear today what will happen to this sludge after storage. Incineration is a common method used within EU and in USA but no sludge is today incinerated in Sweden or China.

Table 31 Disposal of sewage sludge in Sweden, EU, USA and China in percentage.

Disposal method	Sweden	EU	USA	China
Agricultural use and Other land application	53	46	60	40
Deposition at landfill	34	18	17	30
Incineration	0	12	20	-
Intermediate storage	8	-	-	-
Others	-	12	3	30
Not presented Disposal	5	12	-	-

6.3 Limitations and possibilities

All treatment and disposal methods have different advantages and disadvantages and these also depend on local conditions. One of the aims with this field study was to investigate possibilities and limitations with different treatment and disposal methods of special interest for the area of Beijing, China.

6.3.1 Composting and thermal drying

There are today two treatment methods for sewage sludge that will be of major importance in the Beijing area in the future. The Department of Project Design at the Beijing Drainage Group Co Ltd are planning that by the year 2010, 90% of the sludge will be composted or treated with thermal drying.

Composting facilities has the advantage of producing a product that looks treated and earth like to the naked eye. This product therefore have an psychological advantage compared to for example digested sludge, which still looks very much like untreated sludge cake. This can increase the acceptance among users and the public. The acceptance can be further increased by pelletizing the composted sludge which creates a product that looks very much like artificial fertilisers. This is also an advantage for sludge treated with thermal drying. Another advantage is that these two methods result in a product that has little or no odour and also pathogens are killed off.

China is the world’s third largest country and this leads to that the distance within the country is large. Beijing is China’s second largest city with respect to inhabitants. Sewage sludge is produced and treated at wastewater treatment plants within the city and then the product needs to be transported out to the country side if the product is to be used on agricultural land as a fertiliser. The distance from, for example, Gaobeidian Sewage Treatment Plant to Daxing Sludge Disposal Plant where sludge is composted is 54 km. Then the composted sludge needs to be transported out to the country side and the distance here will of course vary. Thermal drying can be conducted directly at the wastewater treatment plant and transported away to the area where it is to be used. Composted or thermal dried sludge, which are also pelletized, can be easier to handle and to transport compared to untreated sludge cake. This is further another advantage with sludge that has been treated by one of these two methods.

As mentioned before composts demand large areas since it is a rather slow process compared to for example thermal drying. In large cities like Beijing this will cause a problem since most large cities are expanding. This is a major disadvantage with composting facilities. Thermal drying is regarded as a good option to composting since it also produces fertiliser and soil improver where the nutrients are being recycled but it demands less area. This leads to that these facilities can sometimes be situated directly at the wastewater treatment plant, which is the case at for example Fangzhuang Sewage Treatment Plant. The disadvantage with thermal drying is the demand for energy to maintain the process and this makes it rather expensive.

The major advantage with these two processes is however that the product can be used as fertiliser in agriculture or as soil improver. This usage would create a recycle of nutrients back to the farmland. This recycling is essential for a sustainable society.

6.3.2 Usage of sludge as fertiliser

The usage of sludge as a fertiliser has been discussed in chapter *"4.3 Different aspects of the usage of sludge as a fertiliser"*. It was concluded that this usage leads to a recycling of nutrients back to farmland which is important. China is to a great extent an agricultural country and there is therefore a great need for fertiliser. An advantage with sludge is that it is a rather inexpensive fertiliser compared to artificial fertilisers. As mentioned previously, 90% of the sludge will be treated with thermal drying or composted and this makes it possible to use these products as fertilisers in agriculture. There is already today some sludge being sold as fertilisers after composting at Daxing Sludge Disposal Plant.

There is however some disadvantages or problems with the usage of sludge as a fertiliser, which has been discussed in the chapter *"4.3 Different aspects of the usage of sludge as a fertiliser"* in more detail. A prolonged fertilising with sludge decreases pH in the land more than other fertilisers used, as for example artificial fertiliser, manure from stables and green fertiliser. Sludge can also contain different pollutants such as heavy metals, organic compounds, pathogens and hormones. These pollutants can cause problems such as accumulation of metals in land, spreading of diseases and also spreading of other pollutants in the environment. These problems need to be taken care of and therefore it is important with a high quality of the sludge, which can be reached by different control strategies for pollutants as discussed previous in the report. A higher quality of the influent wastewater will produce sludge with higher quality. In Beijing there are problems especially with mercury, as mentioned previous, which is above the control standard for spreading of the sludge on agricultural land. There is also a need for sanitation of the sludge in order to stop the spreading of diseases but most of the sludge in Beijing will be hygienisated in the treatment process by the year 2010. It is however of great importance to measure and control different pollutants so they will not spread in the environment.

An advantage of using sludge from the wastewater treatment plants in Beijing is that these are of rather large scale and therefore it is possible to obtain a more stable quality of the sludge. Sludge is also an organic fertiliser and this increases the water holding capacity of the land due to the increase of organic matter in the soil. This effect can be of importance at the Yellow Plain with its low precipitation and high evaporation. This effect decreases however when the sludge is composted or thermally dried. Another advantage of sludge as a fertiliser is that it is a slow fertiliser and hence releases the nutrients under a longer time period compared to artificial fertiliser.

Sludge can be spread on agricultural land after for example digestion but the disadvantage of this sludge is that it looks more like sludge cake. Therefore people’s acceptance might be lower when it comes to this form of sludge compared to for example sludge that has been composted. Pelletized sludge is easier to transport and easier to handle as mentioned before. This product can for example easily be spread with equipment used for the spreading of artificial fertiliser.

Sludge can also be used as soil improver due to its content of organic material and nutrients. In Sweden sludge is used as covering material when covering landfills. The nutrients in the sludge create a good environment for plants to grow and mixed with some other material it has good stability. The problems with pollutants can then be “neglected” due to the landfills leakage collecting system and due to the fact that a landfill already is an area heavily polluted from the destruction of the solid waste. The sludge in Beijing could for example be made use of in this way hence there are old landfills being covered. Sludge is also an inexpensive fertiliser to use in other “green areas” such as golf courses etc where the nutrients to some extent is made use of.

The most important advantage of the usage of sludge as a fertiliser in agriculture is the recycling of nutrients. The problems with the sludge can be minimized with proper treatment for sanitation and improved quality of the sludge. The quality of the sludge can always be improved, but so can all the discharges from the society.

6.3.3 Sludge used as constructing material

In China there are many people in the wastewater field and at universities that consider the usage of sludge as constructing material as a good solution for China in the future. One advantage is that the product is regarded as rather safe for the environment and the public health due to the immobility of pollutants. Sludge with poor quality could be used this way instead of being deposited at landfills. Also pathogens and organic substances are destroyed in the process due to the high temperature. The problem with odour can also be neglected hence the sludge is stabilised and processed.

The usage of sludge in constructing material would also decrease the withdrawal of raw material, which of course is positive for the overall environment. China is a country in fast change and this is especially true for the Beijing area with the Summer Olympics coming up year 2008. Many major constructions are being built and this demands a lot of constructing material. An advantage with the usage of sludge would be that this usage of some of the raw material could be replaced. Another advantage of using raw sludge in the process would be that no new facilities for incineration or thermal drying are needed. This further reduces the cost for this disposal method.

The greatest disadvantage is however that the nutrients are not recycled to farmland. Another problem with this disposal method is that new legislation needs to be established for this kind of usage. Today there is no legislation concerning the usage of sewage sludge as constructing material.

6.3.4 Incineration and deposition of sludge

Incineration has the advantage of reducing the mass and the volume of the sludge and the process also produces heat energy. But this solution may not be the best for the Beijing area due to the discharge of pollutants which will further but pressure on the air in Beijing. The air in the area is already polluted and the government is struggling to improve the quality of the air. This is also the case for other big cities in China. An advantage with incineration would be that the sludge could be incinerated with solid waste. However, this would neither be an optional solution for Beijing.

Deposition could be an option for sludge with poor quality if the landfills are correct designed with leakage collecting- and lining systems. But deposition has few or no advantages if a sustainable society is to be achieved. There is other and better options available as mentioned above in this chapter. The optimum is if the nutrients in the sludge can be made use of and recycled.

7 Conclusions

There are many different treatment methods for sludge being used around the world today. Treatment methods that facilitate reuse of the sludge are desirable hence this enables recycling of nutrients. Composting is a good treatment method in this perspective but it demands a large area and therefore thermal drying is a good alternative. The thermal drying process is planned to expand in Beijing in the future but also the composting process. These are good treatment methods hence it also increases the public acceptance for sludge as a fertiliser. The sludge looks more “clean and treated” after thermal drying and composting. Also the handling and transportation of the treated sludge is easier when the sludge is dry and pelletized. It can then be transported and spread with the same technique as for example artificial fertilisers. The future strategy for sludge handling includes composting and thermal drying for 90% of the sludge. This enables high reuse of sludge as fertiliser or soil improver, which of course is desirable.

There are worries that sludge as a fertiliser might be harmful for the agricultural land but most people agree that sludge should be considered to be a valuable resource for the future as a fertiliser and soil improver. But just by recognizing the problem the first step to sludge with higher quality is taken. The quality of the sludge can be improved with control strategies for pollutants and China has already today for example discharge standards for the industry. It is however of major importance that the authorities regularly supervise and control that the legislation is complied with. Also more frequent measurements of the quality of the sludge are desirable but this is the case for most countries in the world. The recycling of sludge will increase when the composting treatment and the treatment with thermal drying expands. Sludge will be used both as fertiliser, soil improver but maybe also as constructing material.

The usage of sludge as constructing material might be an exciting and good alternative for Beijing in the future. A lot of constructing material is being used in Beijing today and China is a developing country so also in the future constructing material will be needed. The usage as constructing material might also be a good alternative in respect to the environment. Fewer raw materials are then needed as constructing material but also the risks for spreading of pollutants from the sludge can be reduced. This process does not facilitate recycling of nutrients to agricultural land. However, it could be a better option for sludge of lower quality compared to incineration or deposition.

The content of nutrients might be lower in Beijing compared to Swedish values but this might be explained by the fluctuation of the influent water and the fact that the values are point measurements. More frequent measurements of the quality of the sludge are desirable but it is hard to measure the quality of the sludge and the measurements consume time and money. Also if more phosphorus from the influent water are precipitated by chemicals or removed biologically by bacteria, this phosphorus would end up in the sludge cake. This would increase the value of the sludge as fertiliser. Since China is a big country with a large population it would be desirable if sludge could be recycled and the nutrients be made use of in agriculture. Beijing is also located in an area known as good agricultural land. The distance that the sludge needs to be transported is therefore not as long as it might be in other parts of the country.

It is hard to compare legislation from different countries since the structure of the legislation might vary. China does have legislation concerning the usage of sludge as a fertiliser in agriculture. This encourages a proper usage of sludge as a fertiliser and reduces the negative impacts on the environment that this might induce. Sludge is not allowed to be used on vegetable areas or on land which is to be grazed the same year. There is also a highest usage limit of 30 tonnes DS of sludge per year and hectare. Nine metals and five organic pollutants have concentration demands and none of them except arsenic have the highest concentration demand when comparing with Sweden, EU and USA. The importance of hygienisation is known today and the legislation in USA has well defined demands on treatments to achieve this and also demands on vector attraction reduction as an additional barrier against the spreading of pathogens. Sweden and the EU will implement specific demands on hygienisation in their legislations. China defines some treatment demands if the sludge is composted or aerobic and anaerobic digested. In the legislation regarding the usage of sludge as a fertiliser it is stated that untreated sludge is not allowed to be used. Instead it must have been treated at high temperature or digested. However, it would be desirable to have more specific demands regarding stabilisation in order to avoid the risk of spreading pathogens.

Incineration stands for 20% of the disposal in USA and 12% in EU but is not used in either China or Sweden. Incineration does not in general lead to any recycling of nutrients but a discharge of nitrogen oxides and acid gases amongst other things. The agriculture usage and other land application stands for about 50% in all the regions but is a bit higher in the USA. Thermal drying and composting are considered to be treatment methods used to produce Class A biosolids in the USA and this will be the most common treatment methods used in Beijing. This is favourable in respect to hygienisation of the sludge. In Sweden and Europe most sludge that is composted are mixed with some other material in order to improve the aeration of the compost. Mixing the sludge might also further improve the compost process in Beijing. In Sweden sludge is also mixed with other filling material and used as covering material at landfills. This might also be a land application that could be used in the area of Beijing since landfills are being used and they eventually need to be covered when they are full.

Beijing is as mentioned a city in change. The development and modernisation are fast and this put pressure on the environment. At the same time, the expansion of the sewage network for example is positive for the environment. It is important to implement measures for a sustainable society as early as possible when developing a modern city. The strategy of using composting and thermal drying for most of the sludge will enable a larger recycling of important nutrients in the future. Also, the recognition of problems with pollutants and of the importance of control strategies, as for example the discharge limits for the industry and the plans of an educational centre for youths at the Gaobeidian Sewage Treatment Plant, shows an increasing awareness of the environment.

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Appendix I – Disposal Methods in EU

Disposal Method (10^6 kg DS)	Belgium (1998)	Denmark (1998)	Germany (1998)	Greece (1990)	Spain (2000)	France (1998)	Ireland (2000)	Italy (1990)	Luxembourg (1999)	Netherlands (2000)	Austria (2001)	Finland (2000)
Total sludge production	78,30	153,80	2482,00	48,20	853,50	980,00	33,70	816,00	16,50	346,00	243,70	160,00
Total sludge disposal	78,30	153,80	2107,00	48,20	853,50	980,00	33,70	816,00	16,50	336,00	243,70	160,00
Agricultural use	27,70	91,00	788,00	4,80	454,30	383,00	13,50	269,00	11,60	-	36,80	19,00
Compost and other application	0,60	4,20	716,00	-	-	13,00	-	-	1,80	39,00	-	128,00
Landfill	25,50	20,30	207,00	43,40	153,10	115,00	17,20	449,00	3,10	64,00	43,00	10,00
Incineration	18,20	31,90	396,00	-	70,20	78,00	-	-	-	180,00	78,80	-
Others	6,20	6,40	-	-	176,90	391,00	3,00	17,00	-	52,00	87,10	3,00
Not presented disposal	-	-	375,00	-	-	-	-	81,00	-	10,00	-	-

Disposal Method (10^6 kg DS)	Scotland (2001)	Northern Ireland (2001)	England and Wales (2000)	Czech Republic (2001)	Estonia (2000)	Hungary (2000)	Lithuania (2001)	Poland (2001)	Slovenia (2001)	Slovak Republic (1998)	Sweden (2000)
Total sludge production	99,40	29,10	937,00	205,60	317,20	102,10	242,00	397,20	8,20	116,80	230,00
Total sludge disposal	99,40	29,10	937,00	205,60	-	102,10	-	397,20	8,20	116,80	223,00
Agricultural use	36,20	1,60	559,00	159,30	-	27,10	-	49,30	0,50	84,40	46,00
Compost and other application	-	-	9,00	-	-	22,80	-	27,60	0,90	-	70,00
Landfill	7,50	7,50	66,00	37,90	-	46,60	-	198,60	6,80	32,40	78,00
Incineration	0,20	20,00	209,00	-	-	0,00	-	6,90	-	-	-
Others	55,50	-	94,00	8,40	-	5,60	-	114,80	-	-	29,00
Not presented disposal	-	-	-	-	317,20	-	242,00	-	-	-	7,00