

SWEDISH DEBATE ON SLUDGE HANDLING

Bengt Hultman, Erik Levlin and Kristina Stark

Div. of Water Resources Engineering, Royal Institute of Technology (KTH), S-100 44 Stockholm, Sweden

ABSTRACT

Present and future developments in sludge handling are very much under debate in Sweden. Different actors as the Swedish Environmental Protection Agency (SEPA), Swedish Water and Wastewater Association (VAV), National Organization of Agricultural Workers (LRF), different individual municipalities, environmental organisations, researchers etc have quite different and often contradictory opinions on how to solve present and future sludge handling. These opinions and their motives are discussed and their influence is discussed on different sludge handling strategies. These include the use of deposits, agricultural use, incineration, other uses of sludges, separation of streams, and product recovery from sludges.

KEY WORDS

Agriculture, deposits, incineration, product recovery, stream separation, sludge, strategies

INTRODUCTION

About 6.5 millions tonnes dry solid were disposed of or recycled in the 12 Member States of the European Union in 1994 (European Commission, 1997). Trends in sludge production and final sludge handling is illustrated in Figure 1. It is expected to 2005 a significant increase in sludge production, a decrease in disposal and an increase in recycling and incineration.

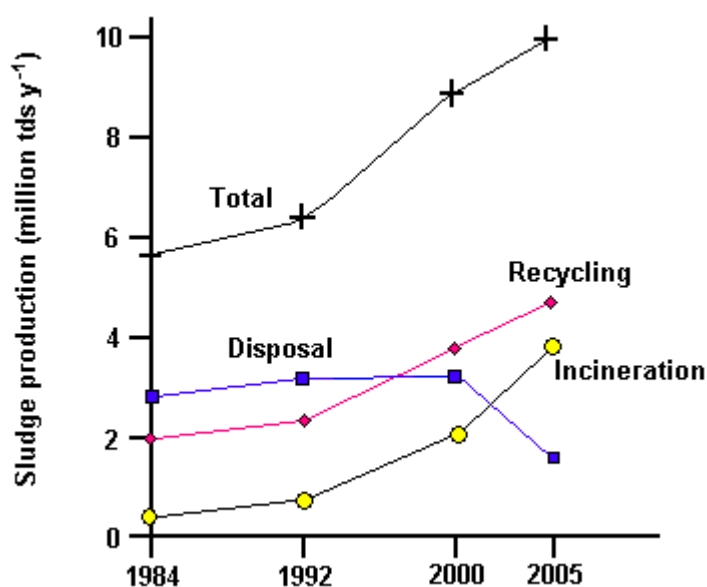


Figure 1. Sludge production and final sludge handling in the 12 EU Member States 1984-2005 (European Commission, 1997).

Sludge production in Sweden is about 240,000 tonnes dry solids per year. Final sludge handling was in 1988 in Sweden: Agriculture 35%, deposition on landfill 40%, land restoration 15%, and green belts 10% (VAV, 1991). Ten years later (1998) the agricultural use had declined to 25% and disposal on landfill had increased to 46 % (SEPA and SCB, 2000). At present, agricultural use is low due to the recent recommendation (Autumn 1999) by LRF that agricultural spreading should be suspended because of the presence of brominated flame retardants in sludges and their possible negative effects on soils and organisms. Deposition on landfill of organic sludges will be forbidden in 2005, and there is little experience on sludge incineration in Sweden. The recommendation not to spread sludge on agricultural land, prohibition to dispose organic sludges on landfills in the near future and the little experience on incineration have given a large pressure on municipalities to change final disposal routes and different actors have very different opinions on suitable routes. It is therefore natural that there exists at present an intensive sludge debate in Sweden.

FACTORS INFLUENCING FUTURE SLUDGE HANDLING STRATEGIES

Four factors have a major influence on future sludge handling technologies:

- Legislation concerning environmental and resources recovery
- Economical incentives and fees
- Acceptance
- Technical developments

Legislation

Sweden has at present very stringent rules concerning limiting values of metal concentrations in sludge and they have gradually been strengthened (see Table 1). In addition there are guidance values of maximum concentrations of indicator organic materials (nonyl phenol, toluen, total PAH and total PCB).

Table 1. Limiting values for metal concentrations in sludge in 1973 and 1995 (Wilson and Jones, 1995), 1987 (Jansson, 1994), 1998 (SEPA and SCB, 2000) and long range goals according to SEPA (Jansson, 1994).

Year	Limiting values of metals in sludge (mg metal/kg dry solids)							
	Metals:	Pb	Cd	Cu	Cr	Hg	Ni	Zn
1973		300	15	1500	200	8	100	3000
1987		200	4	600	150	5	100	1500
1995		100	2	600	150	2.5	100	1500
1998		100	2	600	100	2.5	50	800
Long range goals		20-50	0.5-1.0	100-200	~25	0.2-1	~25	300-500

The percentage reduction of limiting metal concentrations from 1973 to 1998 is compared with percentage reduction of actual average metal concentrations in sludges between 1973 and 1988 in Table 2. It is shown that the reduction of actual values is higher than limiting values for lead, chromium and nickel, the same for cadmium and zinc and somewhat less for copper. Similarities between reductions in actual and limiting values indicate that the limiting values have been set based on what has been practically achievable. The limiting metal values as long range goals are compared with measured data for sludges (Table 3).

Table 2. Percentage reduction of limiting metal concentrations from 1973 and 1998 (based on Table 1) and actual values between 1973 and 1998 (compilation of data by Tideström, 2000)

Reduction (%) between 1973 and 1998	Metal						
	Pb	Cd	Cu	Cr	Hg	Ni	Zn
Limit values	67	87	60	50	69	50	73
Actual average values	82	87	44	89	-	83	74

Table 3. Long range limiting metal values compared with measured data.

	Metal concentration, mg/kg						
	Pb	Cd	Cu	Cr	Hg	Ni	Zn
Long range goals (see Table 1)	20-50	0.5-1.0	100-200	25	0.2-1	25	300-500
Data for municipal sludges in Sweden 1997 (Levlin and Kapilashrami, 2000)							
10-percentile	13	0.59	120	13	0.35	6.6	264
20-percentile	17	0.70	165	16	0.50	8.0	320
Median	27	1.1	270	23	0.8	12	450
Data for municipal sludges in Denmark 1997 (Miljøstyrelsen, 1999)							
10-percentile	28.4	0.8	120	12.7	0.45	10	380
20-percentile	35.8	0.99	160	16.0	0.70	13	512
Median	58.3	1.4	247	28.0	1.20	19.1	783
Wastes from composting toilets (VAV, 1989)							
	3	0.5	17	1.4	0.3	3	120
Manure (VAV, 1989)							
	5.6	0.3	37	4.5	0.08	7.1	190

The table shows slightly higher values of metal concentrations in Danish sludges compared with Swedish. The values are not totally comparable as the Swedish fractiles are based on samples and the Danish on sludge mass. The suggested long range goals correspond approximately to the 20 percentile. The quotient between 20-percentile values and median values is approximately 0.65 and similar for all metals. This indicates that for sludges with median values of the metal content this value should be decreased by about one third to reach long range goals.

Recently rules have also been given on the maximum amount of sludge that can be spread on agricultural land based on values of kg P/ha,year and kg metal/ha,year. This means that the amount of sludge that can be spread might be much less than earlier even if the requirements for limiting metal concentrations in the sludge are fulfilled.

At present it is discussed if phosphorus recovery should be generally required in case incineration of sludge is used. The recovery might be done either before or after incineration (Hellström, 2000a). Phosphorus recovery has already been required in two cases for plants having obtained permits for incineration.

Rules have also been given for disposal of organic solids and sludges. In 2002 a forbid will be given for disposal of combustible sorted organic wastes and from 2005 for organic wastes including sludges from wastewater treatment plants (Johansson, 1999a).

Economical incentives and fees

Economical incentives were earlier given from the Swedish Environment Protection Agency for support of new technologies. Product recovery by use of the KREPRO process was for instance given this support in the development of the process technology. However, this support has been withdrawn.

A tax must since 1 January 2000 be paid (250 SEK/tonne wet sludge) if the sludge is disposed on a land deposit. It is also discussed if a new tax should be introduced in incineration.

Acceptance

The legislative assembly is the Parliament and the executive is exercised by the Government. However, much of the responsibility for public administration lies with autonomous bodies at central, regional or local levels.

Interest organisations have good possibilities to argue for changes in legislation or policies of implementation of different rules. Important interest organisations concerning sludge policies are for instance the National Organization of Agricultural Workers (LRF) and the Swedish Water and Wastewater Association (VAV).

In an attempt to find a general acceptance and rules for sludge use in agriculture a national consultation group has been formed in Sweden in order to stimulate the use of sludge in agriculture and to agree upon different actions and voluntary precautionary measures to prevent the supply of unwanted chemicals and substances into the sewer net. The precautionary measures are brought out to satisfy the interests from the public and agricultural sector and consists of restrictions concerning the choice of crops and the necessary time between fertilising with sludge and harvesting of the crop. The national consultation group consists of representatives from LRF, VAV, and the Swedish Environment Protection Agency (SEPA). In addition other interested parties are invited to participate in the group.

The national consultation group has come to an agreement on a sludge quality guarantee in use of sludge on agricultural land. Before use of sludge in agriculture it is implied that consultations take place at least between the sewage works, the municipal environmental office, and representatives of consumers and agriculture to reach agreements on the status of performed measures and how the handling will be carried out (Mossakowska et al., 1998).

About five years ago VAV ordered a product certification system from the Swedish Testing and Research Institute (SP). The first certificate was given 26th August 1999 to Rya wastewater treatment plant in Gothenburg. This P-labeling has similarities with ISO 9002 (Johansson, 1999b). The name Biomull has been given to a sludge fulfilling certain requirements. The food industries interest organisation (LI) has in its sludge policy that a sludge should be quality secured in a certification system (Johansson, 1999c).

The sludge agreement from the national consultation group or a P-label is, however, no guarantee that the sludge is accepted for use in agriculture. The 12th October 1999 the Swedish radio reported that brominated fire retardants were found in sludge. Already the same day LRF recommended that sludge from sewage works should not be used in agriculture until the risks were evaluated. Although this alarm does not change legal aspects on agricultural use of sludge, the recommendation in practice has reduced the agricultural use to a low level.

A main reason for LRF's recommendation to stop sludge use in agriculture seems to be the general goal that Swedish agriculture should work for getting the cleanest agriculture in the world. The latest alarm concerning the brominated flame retardants together with other alarms on silver, cadmium, PCB and hygienic risks had led to a distrustfulness between the consumers and farmers. It was considered from LRF that the goals in the sludge agreement had not been fulfilled (Eksvärd, 1999).

Recently Bengtsson (2000) director general at the Swedish National Chemicals Inspectorate expressed his views on spreading sludge on food producing land and stated: "My conclusion is that today's chemical society is far apart from the established demands of a poison-free environment. This includes the practice of spreading sludge on farm land". The views were based on environmental quality goals for a poison-free environment approved by the parliament Miljökommittén (2000). The goals included:

- Pollutant levels should be near background values, i.e. the supplied amount of pollutants should not exceed significantly the removed amount
- Pollutant levels should be near zero for substances unfamiliar under natural conditions
- Effective limitation of most dangerous pollutants; for metals mercury, cadmium and lead and for organic micropollutants compounds as PCB, dioxines and dieldrin.
- Systematic work to reduce other harmful substances

From VAV's side it was considered that the recommendation to stop agricultural use of sludge was unjustified. Problems related to pathogens in sludge, silver and flame retardants (Hellström, 2000a) were regarded as neglectable (Hellström, 2000b). In a debate article Hellström (2000c) states (similar views have earlier been presented by Hellström, 1994):

- The food industries (LI) estimates that spreading of sludge may give food products a negative rumour and therefore this threat is avoided. Thereby, the food industry does not take responsibility to bring about eco-cycling of nutrients.
- "Environmental activists" together with journalists have caused maximum uneasiness to the public of sludge use in agriculture
- Risk analysis should be the basis for evaluation of sludge use on agricultural land
- Large security marginals exist on sludge spreading related to heavy metals and toxic organic materials for spreading the next 1000 to 10,000 years
- Much resources are needed to reduce the uneasiness of the public of sludge use in agriculture

The views by Hellström (2000b) are not in accordance with views by LRF, Swedish National Chemicals Inspectorate or SEPA, which organisation successively have strengthened limiting values if sludge is used in agriculture. Specialists on hygienic risk evaluations recommend that the rules for sludge use in agriculture should be reevaluated due to many disease spreading routes and a general lack of scientific investigations in this area (Johansson, 1998). Expressed views by VAV on toxicity of cadmium have been questioned by a medical expert (Vahter, 2000).

The policy of VAV focuses on use of sludge in agriculture due to possibilities for eco-cycling and low costs. Different ways to increase this use will be tried such as work with sludge certification, risk analyses and campaigns to get acceptance for the sludge. In a sludge policy formulated by the governing board it is also said that VAV will support the development of new technologies for future sludge handling.

The sludge debate in Sweden has shown that there are significant differences in opinions and policies between different organisations and municipalities. Stockholm Water being the largest member of VAV has developed its own sludge policy that to some extent differs from the official policy from VAV. Work on short term basis (5 years) should secure disposal of sludges with priority order: (1) agricultural use, (2) production of soils for use at different installations, and (3) co-incineration. For these applications the intention is to use the sludge as a resource and for instance phosphorus should be used in an eco-cycle (Anonymous, 2000). In this respect the policy of Stockholm Water focuses on eco-cycling but considers actively other alternatives than direct agricultural use. This is further stressed in works with a 5 – 10 years perspective there the purpose is to develop a new sludge handling method to obtain products that either facilitates the wastewater treatment processes or can be used as external products as phosphorus and energy-rich compounds.

Special sludge uses and technology development

Sludge as forest vitalisers or forest fertilisers has received a growing attention from forest companies and scientists. Sludge can be spread as dried sludge in pellet form on mineral soil to compensate for nitrogen losses due to soil acidification and intensive forestry. Pellets from ash may be used for peat land due to its phosphorus contents (Tideström et al., 2000).

Sludge based products and soil conditioners can be used on reclaimed land, parks, golf courses, green areas etc (there are about 400,000 hectares of green areas in Sweden). Sludge can also be used as raw material for sealing and protective layers for final covering of landfills. About 10 – 15% of the Swedish sludge production is currently used for these purposes (Tideström et al., 2000).

The need to solve sludge problems has induced different technical developments. One direction is to improve the sludge properties to facilitate further sludge handling. Different methods include:

- Sludge composting or composting together with solid wastes
- Heat drying and formation of pellets
- Use of reed beds
- Supply of sludge into top-soil for 3-7 years for future use as soil in constructions etc

Another direction is to find methods to diminish the produced sludge amount as:

- Changes in process technology as substitution of part or all of the chemical precipitation for phosphorus removal with biological phosphorus removal
- Thermal pre-treatment of sludges before digestion to dissolve sludge compounds and to increase biodegradability of the sludge. Such a system (Cambi) is for instance used in the Norwegian plant Hamar.
- Treatment of sludges with ultrasonics before digestion to dissolve sludge components and to increase biodegradability. A small Swedish company (UltraSonus) will test this method in full scale at a small city (Östhammar) about 100 km north of Stockholm.

A far-reaching technology for sludge use is fractionating of the sludge into products and with possibilities to remove toxic metals in a small stream. Sludge fractionating normally means a complete hygienisation and if incineration is used for the rest-fraction organic toxic substances may be eliminated. In Sweden, KREPRO is the main studied technology in which digested sludge is treated by heat, pressure and acids. The dissolved sludge components are recovered as different products (iron phosphate, precipitation agents and energy) and a small stream of toxic metals can be handled separately. Far-reaching plans exist to install KREPRO in Sjölanda treatment plant in Malmö, Sweden. The Cambi system may also be developed for product recovery. The Danish company, BioCon A/S, has recently developed a system with heat drying of dewatered sludge, incineration followed by product recovery. The product recovery is based on dissolution of the formed ashes followed by product recovery (phosphorus acid, ferric iron, potassium hydrogen sulphate and heavy metals) by use of a system with four ion exchangers. The system is planned to be built in the medium-sized city Falun in Sweden.

EARLIER VIEWS AND TRENDS IN SWEDISH SLUDGE DEBATE

Earlier sludge debate in Sweden

Land application of sewage sludge has been a matter of discussion for a long time in Sweden. A series of discussions of sludge application on land started around 1985 due to presence of certain organic micro-pollutants in the sludge (e.g. dioxines). Major issues of the debate are shown in Table 4. Motives for sludge stop on agricultural land were mostly connected with organic micro-pollutants and statements could be given as "large proportions of all chemicals used in the society will end up in wastewater. When treating this, a

great deal of the chemicals will be found in the sludge. Thus, the sludge, with its contents of nutrients and organic substances, should not be regarded as a resource, as sludge is an end station for many harmful chemicals used in the society. Therefore sludge should be regarded as a hazardous waste and treated respectively". The background data on the contents of organic compounds in sludge was often weak and it was considered that emotions had an important role in the sludge debate (Palm et al., 1989).

Table 4. Major issues during the sludge debate in Sweden between 1985 and 1989 (Palm et al., 1989).

1985	Within the Sewage Works Evaluation Project (SWEP) a number of measurements of organic micro-pollutants was made.
Autumn 1985	A gardener in Gothenburg brought a case to court claiming that the compost soil he was using, originating from the wastewater treatment plant in Gothenburg (Ryaverket), has poisoned his garden.
Autumn 1985	SNV (National Environmental Protection Board) gave VAV, a commission to review the literature concerning occurrence and effects of organic micropollutants in sludge.
Spring 1986	The farmers association (LRF) claimed a ban for land application of sludge. The ban was related to ongoing negotiations about food prices.
Summer 1986	The ban for land application was ceased. LRF recommended their members to have an agreement between themselves and the wastewater treatment plant, where the plant should agree to take all future responsibility if negative effects, due to land application of sludge, on land or crop could be proven.
Summer 1987	Greenpeace in Sweden published an investigation of organic micro-pollutants in sludge from one of the largest wastewater treatment plants in Sweden (Ryaverket in Gothenburg)
Autumn 1987	SNV released new regulations for land application of sludge
Autumn 1988	The government gave SNV a commission to develop new regulations for land application, as well as other disposal methods for sludge. The risks associated with organic micro-pollutants in sludge should especially be evaluated.
Winter 1988	A television and a radio program, which both criticized land application of sludge
Winter 1989	The farmers association (LRF) claimed a new ban for land application of sludge

It is seen from table 3 that the debate between 1985 to 1989 has many similarities with present sludge debate as:

- Same major actors (SEPA (SNV), LRF, VAV, interest organisations)
- Possible influence of sludge application on food prices
- Long range effects on soils and health
- Use of recommendations to ban sludge use (by LRF)
- Use of agreements between municipalities and farmers
- Limiting values for components in sludge for agricultural use
- Role of emotional factors

The sludge ban raised the question of other ways of sludge disposal than use on agricultural land and a seminar was arranged at KTH to discuss different alternatives (Cederwall et al., 1987). Main alternatives discussed were land disposal, sludge incineration, different methods for reduction of sludge volume and

mass, and product recovery. The seminar recommended research related to (1) methods to reduce sludge volume and mass, (2) methods to reduce the sludge content of harmful substances and microorganisms and (3) cost and risk evaluations of different uses of sludges. The seminar, thus, presented similar ideas of alternative uses of sludges as suggested today. Unfortunately, only minor interest was given to financially support sludge studies which makes present sludge debate to be based on a rather low scientific basis.

At the seminar Jansson (1987) presented discussions in Stockholm on alternatives to agricultural use of sludge. Main alternatives were:

- Grinding together with solid wastes and disposal on landfill
- Disposal on landfill together with solid wastes
- Disposal on a permanent landfill of sludge only
- Incineration

The first two alternatives were not considered. Solid wastes were instead expected to be used for energy production. A separate landfill for sludge was judged to need too large areas and be costly as it needed control for a long time period. This alternative was therefore not considered to be a suitable final solution.

The alternative that was estimated to be worth closer technical, economical and environmental evaluations was incineration of digested sludge – with and without solid wastes. A change to incineration was estimated to take about 5 years. Therefore it is investigated parallel with the incineration alternative prerequisites for temporary storage of sludge in one or two deposit places for five to ten years sludge production.

General aspects

A wastewater treatment plant produces two streams, one stream containing treated wastewater and one stream containing separated sludge from the wastewater. Both streams have requirements from authorities for discharges or uses for different purposes. Requirements for wastewater discharges have successively been strengthened and more efficient treatment processes have been implemented. The improved treatment efficiency also means that an increasing percentage of unwanted pollutants in the wastewater (as heavy metals and organic micropollutants) have been transferred into the sludge phase. The traditional sludge treatment technology is in general inefficient to remove toxic metals or micropollutants from the sludge.

The general way to improve sludge quality at municipal wastewater treatment plants and from society is to try to reduce the supply of unwanted substances to the treatment plant as much as possible. This may be done in several ways as:

- Forbid or restrictions from authorities of a certain compound (as Cd and PCB). In general, these restrictions have been successful to reduce cycling of toxic substances in society
- Efficient control of industrial discharges into sewer net
- Use of ecologically friendly products in households and campaigns to the households not to use toilets for discharge of toxic compounds
- Avoidance of inlet of certain polluted waters into the sewer net as polluted stormwater and leachate from landfills
- Special remedies to remove old deposits of toxic metals in sewer net or from wastes from dental practice, laboratories etc
- Actions to reduce corrosion of water mains and service lines
- Use of environmentally friendly building materials

These actions together with internal works with sludge quality control, certification, P-labeling etc has caused a very significant drop of toxic substances over the last two decades. This drop has as a parallel in the successively more stringent requirements from authorities on sludge quality (see Table 1). The concentration of copper seems to have increased a little during the last decade. Some newly introduced organic materials

(as brominated flame retardants) have also increased. The motive to improve the sludge quality is to accomplish eco-cycling of the sludge or sludge components.

Although the decrease of pollutants in sludge is very significant calculated over the last two decades, short term trends does not show a similar significant trend. This may indicate that it is difficult to reach very low values as stated as long range goals in Table 1. Although several municipalities reach these values for an individual metal (Table 3) it is extremely difficult to reach these values for all metals in the sludge. It has been shown that the correlation between concentrations of metals in sludges is low (Levlin and Kapilashrami, 2000). This is in agreement with the observation that the sources of metals are very divergent (SNV, Report 4677, 1996).

Present efforts to use sludge for agricultural use have in general been focused on control of sources of pollutants supplied to the sewer net. However, it may be better to form a sludge handling strategy more to improve all barriers to stop cycling of harmful substances (cf Plaza et al., 2000). In this strategy combined use of source control, removal of old deposits of pollutants for instance in sewer net, special sludge handling methods as sludge fractionation, special restrictions in choices of crops etc is considered. With many barriers a high safety is obtained in eco-cycling of sludges and sludge products.

Disposal on land

Although disposal on landfills may have increased during the last period due to recommendations to avoid sludge in agriculture, it seems reasonable to predict a decline due to (similar to predicted trends in EU-countries, see Fig. 1):

- Decisions made on a forbid to dispose organic wastes by 2005
- Deposition tax recently introduced (1 Jan. 2000)
- Environmental concerns related to release of methane gas (although a large fraction can be recovered) and possible release of phosphates into nature from the deposits
- Difficulties to find new land areas or getting permits for the disposal

Due to the short time to implement other solutions than landfill Balmér (2000a) recommends that VAV should act to stop the deposit tax as most municipalities do not have an alternative. Further, it is recommended that obligations should be given from the notified forbid of disposal of sludges containing organic material in 2005.

Use in agriculture

Use of sludge in agriculture at present seems to be the most controversial sludge disposal route. While VAV has, in general taken the opinion, that present sludge quality with a large marginal can be safely applied on agricultural land SEPA has strengthened maximum limits.

Agricultural use of sludges has the advantages of being inexpensive and is a logical way of eco-cycling of nutrients and to be used as a soil conditioner (Palm et al., 2000). Future use of sludges in agriculture may, however, be diminished due to:

- Risk assessments from different organisations and researchers vary significantly indicating that scientifically based reports and evaluations should be made
- Many sludge analysis indicate that about 50% of the samples may have a too high concentration of at least one metal, while the concentration of the other may be significantly below the limit value (Levlin and Kapilashrami, 2000)
- Less sludge per ha will in many cases be the result of new values related to maximum metal supply as g Me/ha,year. The need to spread out sludge over a larger area than before will increase the costs for sludge use in agriculture

- Costs for measuring limiting and guideline parameters are high
- Some uncertainties exist concerning the availability of phosphorus from chemically precipitated phosphorus (Linderholm, 1997)
- Technical development may lead to competitive alternatives of eco-cycling to agricultural use
- Another sludge disposal route may be chosen by the municipality – even if the costs are higher than use in agriculture – in order to secure a safe and long range disposal of sludge
- The sludge may – even if it has a very low concentration of pollutants – not be accepted by LRF, food industries and the public

The last point is probably the most significant and the most difficult to predict. In general, a lot of alarms are published concerning emissions of organic pollutants in different fields including sludges, injection agents in tightening tunnels (Hallandsåsen), emissions from mobile telephones and effects on seals. Alarm from one field or finding a new organic pollutant may therefore adversely effect sludge use in agriculture. It therefore seems necessary that a municipality should have at least one more route for sludge disposal than agricultural use.

Incineration

Incineration is a well established method in Sweden related to solid waste handling. However, no plant exists at present for incineration of only sludge. Co-incineration with solid wastes may be an interesting alternative although it seems that most incineration plants for solid wastes do not have the overcapacity to also incinerate sludges in the existing plant.

Two special factors will influence the use of incineration of sludges in Sweden:

- Possibilities that a certain tax will be introduced for incineration
- Possible requirement to get a permit for incineration that phosphorus must be recovered either before or after the incineration

Incineration is a technically well-proven technology that is used at many places for instance in Europe. Treatment of exhaust gases and handling of ashes can be done in an environmentally safe way but this is complex and thereby expensive and at present mainly suitable for large plants. The use of incineration is predicted to increase in the EU-countries (see Fig. 1). Implementation of incineration in Sweden still needs to be investigated in detail although some preliminary studies have been done, including the possibilities to recover phosphorus from ashes in co-incineration plants (Levlin, 1999).

Other uses of sludges

Other uses of sludges include (Tideström, 2000):

- Production of new soil
- Improvement of existing soil
- Fertilising and covering of soil

The produced soil may be used for several applications (Tideström, 2000):

- Golf courses, football grounds etc
- Road slopes
- Green areas
- Deposits and protection covers

Depending on the type of application different mixtures may be made to obtain the right nutrient content, soil properties, hygienic properties etc. The sludge should in general fulfill the same quality (guidance values) as sludge used for agricultural land to be used on green areas.

Soil production seems to be an interesting alternative to sludge use in agriculture if this use is not possible. This application is about 10-15% in Sweden and about 30% in Finland (Tideström, 2000).

Separation of streams

The different streams (urine, toilet wastes, grey water, industrial waters, stormwater etc) can be handled separately. Different systems have been studied to for instance handle urine and/or toilet wastes separately. By this way the sludge amount from the central system is reduced and a major fraction of nutrients may be recovered. However, these systems are still in a development phase and several problems related to function and operation (Haglund and Olofsson, 1997).

Much work has been done to separate streams with harmful substances (cf SEPA and SCB, 2000) from the sewer net in order to obtain a sludge with a high sludge quality. Lindgren (2000) suggests that urine and faeces should be treated separately and with resources recovery and the central treatment plant should be used for treatment of different types of polluted streams for destruction or separation of pollutants. The function of the treatment plant would thereby have a similar function as a kidney.

The advantages and disadvantages to separate different streams need to be better evaluated (combined or separate sewer net, separate handling of urine and/or toilet wastes etc). In general, costs for urine separation in already built central systems is considered to be high.

Product recovery

Product recovery is a method that "in principle" can solve sludge handling and disposal problems. By sludge fractionation hygienisation is normally obtained, heavy metals can be released from the sludge and handled separately, and toxic sludge-bound organic materials may be destructed by incineration of a rest fraction during the fractionation. During the sludge fractionation the sludge amount may be reduced significantly by dissolving inorganic materials for use as precipitation agents and the fraction of biodegradable substances can be increased. The sludge normally gets better dewatering properties. Different sludge products are obtained making it possible to obtain far-reaching goals for eco-cycling of resources.

Sludge fractionation for product recovery has been studied in laboratory and technical scale since a long time but not been technically-economically feasible. Technical problems may be related to process function, odour, safety and corrosion, while economy has been related to energy and/or chemical consumption and also for high costs and complexity of the installations. The difficulties to find suitable sludge disposal options have, however, increased the interest for sludge fractionation for product recovery. Many companies today supply equipment for sludge fractionation (heat treatment, use of rapid mechanical stirring, ultrasonics etc) for full scale application. Other companies try to offer full-scale systems for sludge fractionation followed by product recovery (KREPRO, BioCon A/S etc). CEEP which is an interest organisation for the European phosphate industry is today active to promote and support works to use phosphate rich compounds from wastewater treatment plants as a raw material in production of different phosphate products.

The rapidly increasing publications concerning product recovery will probably in the near future give a rational basis for evaluation of the technical-economical feasibility of different systems. Full-scale experiences will also be available to an increased degree in the near future.

Research and development

Present sludge production in Sweden is about 250,000 tonnes DS per year. If the dry solids concentration is about 25% of deposited sludge the state tax would be about 250 million SEK if all produced sludge was deposited. To this state tax deposit fees should be added. There are therefore economic incentives to find alternative ways of final sludge handling. Based on the earlier sludge debate 1985 – 1989 the present debate could not be considered as unexpected. Surprisingly little has, however, been done from authorities and municipalities (although with many exceptions from individual municipalities and also some exceptions from research organisations) to find and evaluate different alternative sludge handling routes. These alternative routes are often considered to be less environmentally friendly than use in agriculture (Balmér, 2000b).

Most of the developments on new sludge handling processes is performed at private companies. The need to make rapid decisions on sludge handling involves certain risks that new technologies will cause different operational problems (odour problems, corrosion, labour safety, etc) that may be difficult to solve. The sludge debate in Sweden clearly shows the need to have a better knowledge base for decision making on future sludge handling strategies. The resources needed to obtain a sufficient knowledge base have so far been underestimated by responsible organisations.

DISCUSSION

Role of general environmental policy

After the publication of the Brundtland Commission's report in 1987 and the Rio Conference in 1992 much work has been done to implement sustainability concepts. In for instance one report from the Environmental Advisory Council (SOU, 1994) general concepts were described to pursuit sustainability including ecocycling, critical loads, the precautionary principle, the substitution principle, best available technology and the polluter-pays principle. The ecocycle society should promote that:

- o Flows from society into nature can be added to the natural cycles without causing unacceptable environmental impact, even in a very long-term perspective
- o Extraction of non-renewable materials is done on a limited basis so as to preserve resources for coming generations
- o Biomass and water supplies satisfy human needs without extraction that exceeds growth or inflow

These principles, the four principles formulated by Holmberg et al., (1994) for the exchange flows between society and nature, recently adopted 15 environmental quality goals by the Swedish Parliament, etc. should be seen as general guidelines for all environmental activities of which municipal wastewater handling (including sludge handling) in one example. This means that all environmental influencing activities should follow similar rules.

Agricultural use of sludges should in principle be seen as a good example of ecocycling with respect to transfer of nutrients and soil improvement materials from urban areas to agricultural land. By that reason authorities as SEPA have in general encouraged the use of sludge on agricultural land if the sludge quality fulfils certain quality requirements (Ministry of Foreign Affairs and SEPA, 1998). Ecocycling of sludges by agricultural use has therefore been a rational basis for the sludge agreement. The general actions in society to fulfil different principles supporting sustainability should also lead to better sludge qualities.

However, agricultural use of sludge may also be counteracted by other principles or goals. Goals of a poison-free society, no accumulation of metals on soil due to sludge applications etc may be important reasons to question the practice of spreading sludge on farmland (cf Bengtsson, 2000). The uncertainties of risk estimations (for instance related to cadmium) may be arguments to use the precautionary principle.

Developments in technology for instance in product recovery may be reasons to use the best available technology principle in combination with other sludge handling methods as an alternative ecocycling method. An example could be the recovery of resources from sludges (nutrients, biogas and precipitation chemicals) followed by incineration of the remaining sludge.

The general principles in Sweden concerning environmental policy strongly encourages ecocycling, although agricultural use is questioned mostly due to uncertainties on effects of long-term effects. Land disposal is discouraged both by coming legislation and recently introduced taxes as not being in agreement with ecocycling and possible negative environmental effects. Incineration of dewatered or heat dried sludge can not be regarded as ecocycling if resources are not recovered before and/or after the incineration process. Restrictions to incineration may come as needs for recycling of phosphorus and an incineration tax may be introduced. The need to find different approaches of sludge handling will therefore cause a rapid increase of interest of new uses of sludges and of new sludge handling technologies.

Role of local environmental policy

The local authorities have the important task to implement the general environmental principles on a local scale. In that respect knowledge of the sludge quality is important. The sludge quality reflects much of the activities of the municipality, the used materials and the way to handle stormwater. The quality data may for instance be used in the following two ways:

- Evaluation of uses of the sludge (agriculture, land building, other uses)
- Help in evaluation of material flow of different harmful substances in the municipality to give guidance to priority actions to reduce this flow

It should be noted that metals being elements must be carefully considered whatever sludge handling method that is used. The metals must be handled both in the gas phase and in ashes if incineration is used. Deposited metals in sludges or ashes may be transferred to the environment. It may therefore be concluded that efficient control should be encouraged of harmful substances into the sewer net to facilitate sludge handling in the treatment plant.

Risk analysis and fate of pollutants

Much of the present resistance towards agricultural use of sludges has the background of possible risks. In order to get some degree of consensus on agricultural use it seems to be important to have a better scientific base related to risk assessments and the fate of pollutants.

Hellström (1994) states: "What is needed to do is to continue to make clear risk levels better for as many substances as possible. Measures must of course be taken rapidly and in an effective way when justified. Such are on the other hand not actual as it usually does not exist any environmentally harmful substances in sludge". Although this statement may be regarded as an "outlier" in the debate it should be noted that Swedish regulations on agricultural sludge use are much more stringent than for instance the EU Sewage Sludge Directive (86/278/EEG). The basis for these differences should be better clarified.

Another factor that should be considered is the long range accumulation of metals. The time to get a double amount of metal contents in soils may be based on a certain additional percentage contribution per year or be based on doubling times for metals at a given applied amount of sludge. Such calculations indicate that only very low metal concentrations in the sludge can be allowed (Bengtson, 2000). In the debate, however, Hellström (1994) have argued that the problem of long term metal accumulation will be of minor importance as many metals (including cadmium, lead and mercury) based on estimated reserves and present rate of production will not last more than a few decades.

Public participation and acceptance

Public participation and acceptance have a large influence on sludge handling. The use of sludge for food production has – related to public acceptance – many similarities with use of wastewater – directly or indirectly – as source for drinking water production. In both cases it is necessary to have different barriers to minimise health and other risks. Public acceptance of sludge use in agriculture seems to be a major factor for the food industry to accept agricultural use of sludge. It may also be mentioned that sorting of wastewater in different streams (as the use of urine separating toilets), as another way of ecocycling, is much based on public acceptance.

Strategies for sludge handling

A general consensus seems to prevail that sludge should be handled in an "ecocycling" way with resources recovery and without harming the environment also in a long term perspective. It is therefore natural that other methods than use of a land deposit are encouraged. This is reflected by deposit fees and laws on land disposal. The requirement of ecocycling means that it is necessary to find strategies to reduce the amount of harmful substances supplied to the sludge and methods to separate harmful methods from the sludge.

Agricultural use has usually been considered as the main cost effective method of ecocycling of sludges although some studies have been done to use sludges in forests etc. As sludge use for agriculture is questioned by some authorities and organisations it is important to develop other ecocycling methods.

Incineration may be regarded as an "end-of-pipe"-solution. Ecocycling may, however, be partly achieved if resources as phosphorus are recovered before or after the incineration process. The ashes produced after processing may be used for instance in the building industry.

Flexibility is important in sludge handling. For a large municipality it may be argued that a short term sludge storage place should be a complement to the use of incineration in combination of product recovery. The short term storage place could be used for improvement of the sludge quality (increase of dry solids concentration and further degradation of organic pollutants) by use of mechanical or biological methods, for soil production etc. The sludge with best quality could be used directly for agriculture, green belts etc, while sludges with lower quality could be used after increase of the dry solids concentration for incineration.

The combination of product recovery, short term sludge storage and incineration should be seen as one of several methods of ecocycling of resources from sludges. This means that sludge use in agriculture should be seen as only one interesting way to ecocycle sludges. Different ways of ecocycling sludges should be carefully evaluated.

CONCLUSIONS

- (1) The Swedish debate on sludge disposal has its base on difficulties to use the two most common disposal routes at present (disposal on landfill and use in agriculture). Disposal on landfill will be forbidden for sorted organic material in 2002 and for organic sludges in 2005. The use of sludge on agricultural land is uncertain due to difficulties to reach very stringent requirements and lack of acceptance.
- (2) The debate on sludge handling has focused much on sludge use in agriculture and with very different opinions on its suitability and long term risks. The general environmental policy in Sweden is to promote eco-cycling. If agricultural use for different reasons is not suitable ecocycling will still be promoted as the use of phosphorus recovery if incineration will be implemented.

- (3) Independent of sludge disposal route, sludge handling is much facilitated if the sludge quality is high. In incineration metals must be separated to a solid phase and prevention must be taken to avoid leakage of metals. Product recovery is facilitated by low concentrations of harmful substances in the sludge. A systematic approach to improve source control, certification of sludge handling, etc. should therefore be encouraged.
- (4) Many strategies can be used to find new cost-effective methods of ecocycling of resources from sludge such as combined use of product recovery, short term storage of sludge with possibilities to use natural processes to improve sludge properties (as dry solids concentration) and incineration.

REFERENCES

- Anonymous (2000). Ny slamstrategi i Stockholm (New sludge strategy in Stockholm). VAV-NYTT, 2/2000, 29.
- Balmér, P. (2000a). Så här borde VAV agera i slamfrågan (How VAV should act in the sludge question). VAV-NYTT, 2/2000, 33.
- Balmér, P. (2000b). Det finns andra lösningar – miljömässigt sämre (There are other solutions – environmentally worse) VAV-NYTT 2/2000, 42-43.
- Bengtsson, G. (2000). Är kemikaliesamhället ett problem för slamhanteringen? (Is the chemical society a problem for sludge depositions?). VAV-föreningen med föreningsstämma, Strömstad 25 maj 2000, <http://www.safesoil.com/kemiinsp>.
- Cederwall, C., Hultman, B., Larsen, I. and Rennerfelt, J. (eds.) (1987). Slamhantering. Alternativ till jordbruksanvändning. (Sludge handling. Alternatives to agricultural use). Slamseminarium vid inst. för Vattenbyggnad, KTH, 30 maj 1986.
- Eksvärd, J. (1999). Går det att få förtroende för slammet? (Is it possible to get confidence in sludge?). VAV-NYTT, 5/99, 38-39.
- European Commission (1997). The comparability of quantitative data on waste water collection and treatment. Final report to the European Commission DG XI B1. EWPCA.
- Haglund, J.E. and Olofsson, B. (1997). Utvärderingar av VA- lösningar i ekobyar (Evaluation of water and wastewater solutions in eco-villages). VA-FORSK Rapport 1997-1.
- Holmberg, J., Robèrt, K.H. and Karlsson, K.E. (1994). Socio-ecological principles for a sustainable society. Report 94-11, Institute of Physical Resource Theory, Chalmers University of Technology, Gothenburg.
- Hellström, T. (1994). Risker och problem vid användning av slam i jordbruket (Risks and problems in use of sludge in agriculture). Meddelande VAV M82, 84-90.
- Hellström, T. (2000a). Bromerade flamskyddsmedel (PBDE och PBB) i slam – ett problem? (Brominated flame retardents (PBDE and PBB) in sludge – a problem?) Meddelande VAV M113, ISSN 0347-1802.
- Hellström, T. (2000b). Problems with sludge use in Sweden. IWA Yearbook 2000, 12.
- Hellström, T. (2000c). Fakta på bordet ska bryta slammets oroscirkel (Facts on the table should break the circle of worry of sludge). VAV-NYTT, 1/2000, 55-57.
- Jansson, L. (1987). Slamdisponeringen i stockholmsregionen (Sludge disposal in the Stockholm region). In Cederwall et al. Slamhantering. Alternativ till jordbruksanvändning. Slamseminarium vid inst. för Vattenbyggnad, KTH, 30 maj 1986.
- Jansson, L. (1994). Slam och slam användning – igår och idag (Sludge and sludge use – yesterday and today). Meddelande VAV M82, 74-77.
- Johansson, B. (1998). Förebygg förtroendekris – ta smittriskerna på allvar (Prevent confidence crisis – consider infection risks seriously!). VAV-NYTT 4/98, 87-89.
- Johansson, B. (1999a). Vad krävs för att slamstoppet skall hävas? (What is need to remove the sludge stop?). VAV-NYTT 5/99, 41-43.
- Johansson, B. (1999b). Göteborg fick första P-märket (Gothenburg got the first P-label). VAV-NYTT, 4/99, 46.
- Johansson, B. (1999c). P-märke på biomullen visar att tillverkaren vet vad han gör (P-label on biosolids shows that the manufacturer knows what he is doing). VAV-NYTT 4/99, 46.

- Levlin, E. (1999). Resources recovery from incineration ashes. Proc. Polish-Swedish Seminar, KTH, August 24, 1999. Joint Polish-Swedish Reports, 5. Div. Water Resources Engineering, KTH, 43-53.
- Levlin, E. and Kapilashrami, S. (1997). Sludge quality in Sweden – Inquiry results for year 1995 to 1997. This report.
- Lindgren, G. (2000). Reservera reningsverken för de värsta vattnen! (Reserve the treatment plants for the worst waters!). VAV-NYTT, 2/2000, 38-40.
- Miljökommittén (2000). Framtidens miljö – allas vårt ansvar (The future environment – the responsibility for all). SOU 2000:52
- Miljøstyrelsen (1999). Spildevandsslamm fra kommunale og private renselanlaeg i 1997 (Sewage sludge from municipal or private treatment plants in 1997). Miljø- og energiministeriet, Miljøstyrelsen, Copenhagen, Nr 473, ISBN 87-7909-330-2.
- Mossakowska, A., Hellström, B.G. and Hultman, B. (1998). Strategies for sludge handling in the Stockholm region. Wat. Sci. Tech., 38, 2, 111-118.
- Palm, O., Dahlberg, A.-G. and Holmström, H. (1989). Sludge quality from municipal wastewater treatment plants in Sweden - Past and future trends. Vatten, 45, 1, 30-35.
- Palm, O., Löwgren, M. and Wittgren, H.B. (2000). Organiskt avfall som växtnäringsresurs (Organic waste as a plant nutrient resource). VA-FORSK, rapport 2000-9.
- Plaza, E., Hultman, B., Löwén, M. and Trela, J. (2000). Product recovery in future sustainable urban water systems. This report.
- SEPA and KI (2000). Att finna farliga flöden. Kemikalier i samhället (To find harmful flows. Chemicals in the society). Naturvårdsverket och Kemikalieinspektionen. Report 5036, ISBN 91-620-5036-2.
- SEPA and SCB (2000). Utsläpp till vatten och slamproduktion 1998. Kommunala reningsverk samt viss kustindustri. (Discharges into water and sludge production 1998) Statistiska meddelande. Beställningsnummer Mi 22 SM 9901.
- SOU (1994). On the general principles of environment protection. Environmental Advisory Council, Fritzes, Stockholm, ISBN 91-38-13675-9.
- Tideström, H. (2000). Personal contact.
- Tideström, H., Starberg, K., Ohlsson, T., Camper, P.A. and Ek, P. (2000). Användningsmöjligheter för avloppsslam (Possibilities to use sludge). VA-FORSK Rapport 2000-2.
- Vahter, M. (2000). Allvarliga felaktigheter i VAV:s hälsoriskbedömning av kadmium (Serious mistakes in the VAV health risk evaluation of cadmium). Letter sent to VAV 2000-05-15.
- VAV (1989). Metoder för behandling och avyttring av slam (Methods for treatment and disposal of sludge). Swedish Water and Wastewater Association, VAV M66.
- VAV (1991) Municipal wastewater treatment in Sweden. International Public Health Engineering, Kean Publ. Ltd., 97-98
- Wilson, R. and Jones, B. (1995). The Swedish phosphate report. Landbank Environmental Research Consulting, London, ISBN 0 9525639 0 8.