REVAQ – the Swedish certification system for sludge application to land – Experiences at the Rya WWTP in Gothenburg and challenges for the future

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Abstract

REVAQ is a voluntary certification system used to regulate the application of wastewater sludge on agricultural land in Sweden. The system ensures that nutrients from wastewater fractions can be sustainably reintroduced to agricultural land in accordance with national environmental regulations and goals. The system provides stakeholders with information regarding the composition and end use of the sludge and sets guidelines for the continuous improvement in the quality of influent wastewater and sludge with respect to metals and other prioritised substances.

The REVAQ system started in 2002 as a development project involving Swedish Water, LRF (The Federation of Swedish Farmers), Lantmännen (agricultural supplier cooperative) and grocery chains. Swedish Water is the sole owner of the system today in its current form. Currently half of the sewage sludge produced in Sweden is produced at plants with REVAQ certification.

The Rya WWTP, which is one of Sweden's largest wastewater treatment plants, has been licensed according to REVAQ since 2009. The quality, quantity and common end use methods for sewage sludge in Sweden compared to the EU are summarised. The requirements needed to qualify as a REVAQ plant, the activities required to maintain the certificate and experiences and challenges regarding the production and end use of REVAQ sludge are also described.

Keywords

Agriculture, environmental pollutants, heavy metals, recycling, regulatory system, REVAQ, wastewater sludge nutrients.

Gryaab, the Rya wastewater treatment plant and Gothenburg

Gryaab and Rya wastewater treatment plant

Gryaab AB owns and operates the Rya wastewater treatment plant (WWTP), treating wastewater from 650 000 persons within the Gothenburg region on the west coast of Sweden. The plant also receives a relatively significant loading from industrial sources giving a total estimated combined loading of 865 000 p.e. Gryaab is a public company owned by seven local municipalities. The company has two main areas of operation:

The first is the management and operation of a tunnel system which has a combined length of about 130 km, a total flow attenuation capacity of about 250 000 m^3 and a time of concentration of between 5 and 35 hours. The wastewater flows in the tunnel by gravity feed with an average slope of 0.1 %. The local sewerage systems are the responsibility of the municipalities and these are connected to the tunnel system at designated connection points.

The second and main area of operation is the treatment of wastewater with respect to biodegradable organic material (BOD_7), phosphorus (P) and nitrogen (N). The plant was initially commissioned in 1972 and treats a highly variable influent flow which can be attributed to a significant fraction of stormwater and drainage water entering the sewerage systems. Gothenburg receives a yearly average rainfall of 800 – 1100 mm, resulting in a large difference between the lowest daily average flow of 2.2 m^3/s and the maximum daily average flow to treatment of 14.6 m^3/s. The average flow to the plant is around 4 m^3/s. The plant has a series of relatively advanced physical, chemical and biologically treatment process and has been expanded several times during the last 40 years. Treated effluent is led through a tunnel and pipeline out into the Göta River estuary. Gryaab's discharge consents are currently 0.3mg/l for Phosphorus and 10mg/l for both BOD_7 and Nitrogen, based on a yearly averages (daily composite sampling – flow based). Discharge consents are expected to be tightened relatively soon especially with regards to Nitrogen.

Since the 1960's Gryaab and its owner municipalities have had dedicated personnel involved with reducing pollutants of the wastewater (up-stream management). The focus of this work has developed over time. Although initially focusing on reducing risk of clogging, degenerating sewers, occupational hazards and protecting the processes of the WWTP, a main focus now is on protecting receiving water and land from pollutants. Heavy metals are the main concern in the agricultural use of sludge whereas in the author's opinion hazardous organic substances are a greater issue for receiving waters than for agricultural land. Today there is less heavy industry and more service sector businesses in Gothenburg. A drastic reduction in point source emissions as well as bans of the use of cadmium, mercury and lead in most applications have contributed to better influent wastewater quality. Improved air quality has resulted in less deposition of metals as well as less corrosion of buildings and other structures. This has improved the quality of the storm water entering the WWTP, as well as storm water going to receiving waters (Månsson et. al., 2009).

By products from the treatment process are Biosolids, Biogas and heat energy. Biosolids, which are produced in the form of dewatered sludge, are mainly composted and used for the production of soil or soil enhancement products. A smaller fraction of the sludge is applied to agricultural land as a natural fertiliser. Raw biogas is produced by anaerobic digestion of thickened primary sludge and is sold to the local energy company for upgrading to natural gas quality; and then sold as vehicle fuel. The annual production of biogas is around 60 GWh. Heat energy is also recovered from the final effluent by the local energy company using heat pumps and distributed within Gothenburg's district heating system. The net yearly production of district heat energy from wastewater is around 200 GWh.

Gothenburg

When the Rya WWTP was commissioned in 1972, the Gothenburg region was a typical industrial area with heavy industry, shipyards, oil refineries and manufacturing industries such as Volvo, SKF, surface treatment and pulp and paper, etc. The air was polluted both by local emissions and emissions from other countries. Since then there has been an ongoing effort to reduce both water and airborne emissions. At the same time the industrial structure in the region has changed. Today there is less heavy industry and more service sector businesses. The industrial loading to the plant has successively reduced during the last forty years due to an active cooperation between Gryaab's environmental engineers and local industries. The region has a strong tradition of industrial production and the loading from industrial output is not expected to diminish further, but a continuous improvement in the reduction or remediation of identified pollutants or pollutant streams at source will continue to be pursued. The Gothenburg region has a moderate amount of agriculture and therefore the potential for agricultural application of sewage sludge is relatively limited locally. Larger areas with the potential to receive significant quantities of sewage sludge are within a radius of around 120 – 150 km. This means that economically and environmentally viable options exist for the reintroduction of nutrients from wastewater sludge to agricultural land.

End use of sludge at Gryaab

Gryaab has historically adopted a number of different sludge end use options including agriculture, landscaping, covering of landfill sites and more recently soil production (see Figure 1). From 1975 to 1991 slaked lime was added to the sludge for stabilisation, the production of sludge also steadily increased during this period due to an increase in the number of citizens connected to the plant coupled with increased wastewater treatment process efficiency. In 1991 an anaerobic digestion plant was commissioned, which resulted in sludge stabilisation and a significant reduction of sludge mass. Since 2002 all of the sludge has been composted with other structural material for the production of various types of soil or soil enhancement products, which are used in building projects, earthworks, golf courses or land reclamation. Since 2008 Gryaab has followed a strategy for the end use of sludge which involves four main options:

- To continuously improve sludge quality in order to meet standards set within REVAQ and thereby making it possible to apply sludge to agricultural land.
- To use the greater part of the sludge production to produce soil for local landscaping.
- To maintain the possibility to dispose of sludge in a rock cavern formerly used for crude oil storage.
- To monitor development of alternative technologies for phosphorus recovery, i.e. from sludge incineration ashes.

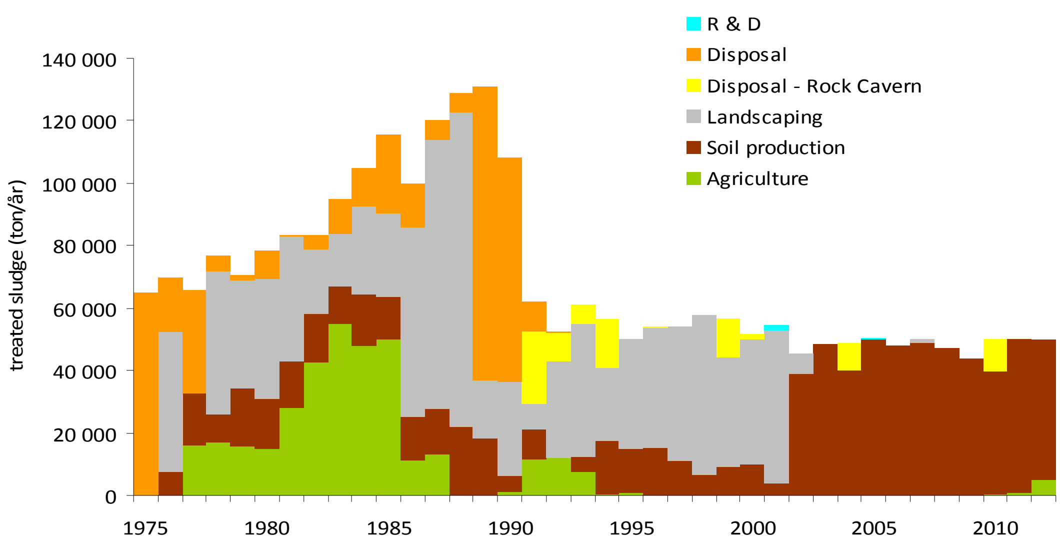

Figure 1: End use routes for Gryaab sludge 1975 – 2011.

Sludge quality and end use in Sweden

Swedish sewage sludge to land

The Swedish parliament had earlier set as a target in its environmental goals that 60 % of the phosphorus in wastewater should be recycled by year 2015, whereof at least 50% to agricultural land. This environmental goal still exists but is currently being re-evaluated. At the same time there is public concern and ongoing debate in Sweden about the presence of pollutants in the sludge used in agriculture (Bengtsson and Tillman, 2004).

During the last two decades major focus has been on improving sludge quality in order to achieve recycling of nutrients to agricultural land with particular focus on phosphorus which is a limited resource. Cordell states that food supply security cannot be reached without better management of phosphorus (Cordell, 2010). During the last decade several stakeholders have shown increased interest in sludge recycling as a means of reintroducing phosphorus from wastewater to productive soil. The amount of sludge applied to agricultural land in Sweden is relatively low when compared to other EU countries in terms of the percentage of total sludge production. In 2010 42,000 tons DS, or 20 % of the total yearly production in Sweden was applied to agricultural land (yearly report REVAQ 2010), an increase compared to 30,000 tons DS spread in 2008. (See Figure 2). In 2010 65% of sludge to land originated from plants within the REVAQ system, whereas in 2008 it can be assumed that the majority of the sludge was applied directly to land according to local agreements. One of the main aims of REVAQ is that all sludge to land be applied according to the certification system.

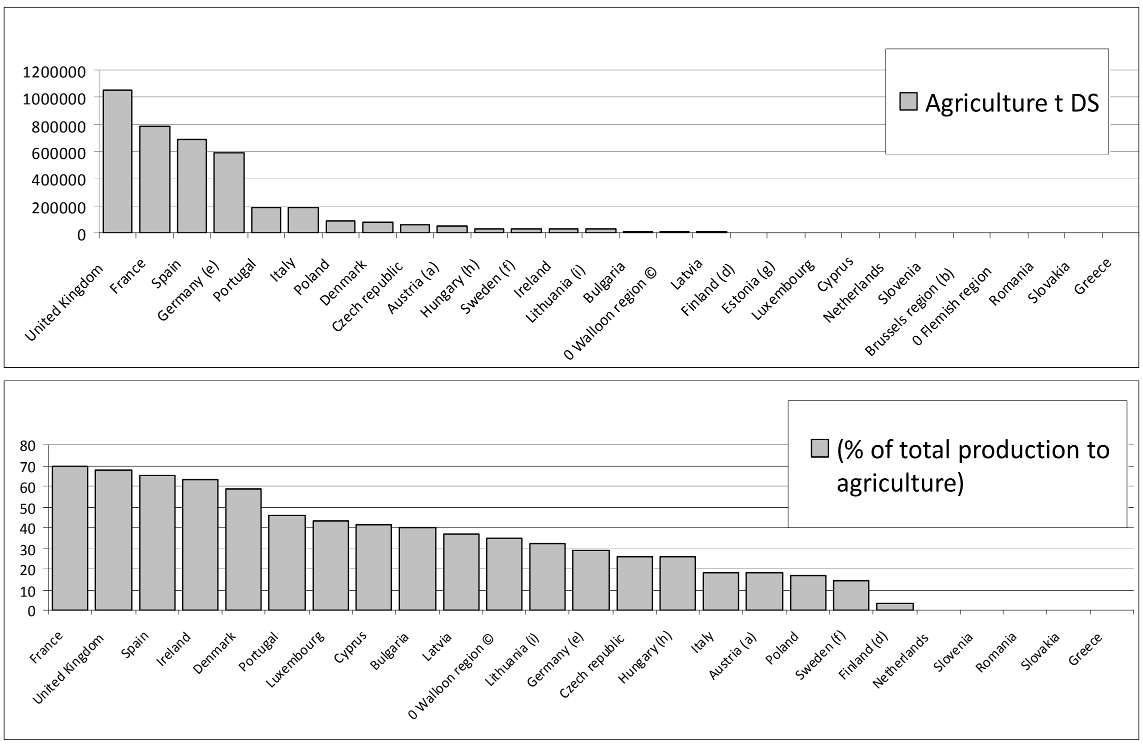

Figure 2: Sludge to agriculture within EU based on ton DS and as a percentage of the individual countries total yearly production (2008). Adapted from Salado et al., 2008

Sludge quality - heavy metals

With regard to most heavy metals, sludge in Sweden is among the cleaner in Europe (Salado et al., 2008) (see Figure 3) with the exception of copper which is attributed to the widespread use of copper plumbing in buildings combined with soft water in many parts of Sweden. The limits with respect to heavy metals in Sweden are stricter than those of the EU. However even stricter limits concerning heavy metals will be implemented on a national basis in the future.

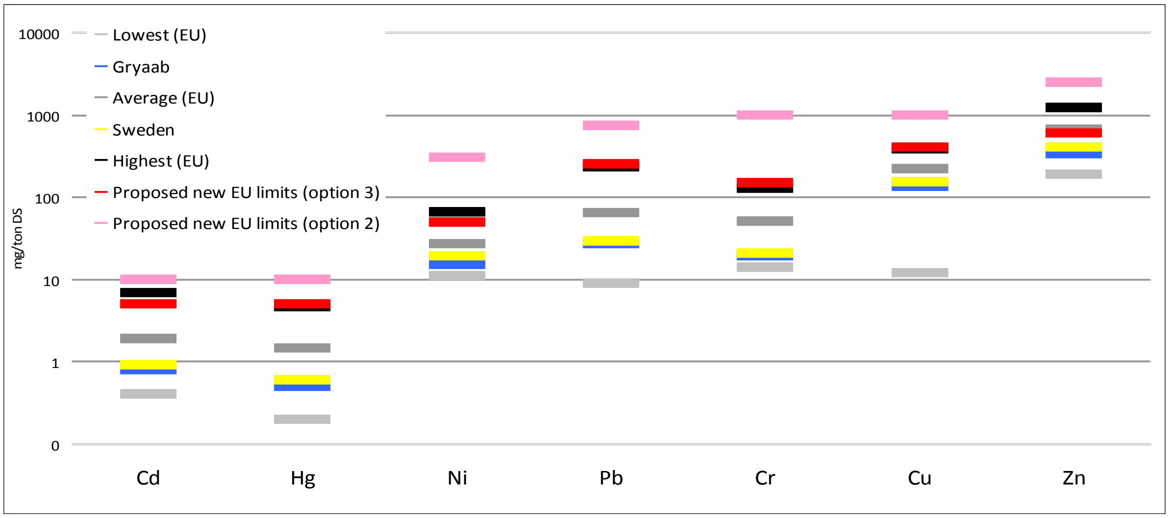

Figure 3: Metal concentration in sludge EU, Sweden and Gryaab, including proposed guidelines for maximum concentrations according to limits option 2 or limits option 3. Adapted from Salado et al., 2008

The amount of sludge which has been applied to land in Sweden differs regionally and over time due to a number of factors:

- The amount of agricultural land locally available
- Local or regional willingness from farmers for applying sludge to land.
- Scepticism from environmental organisations and pressure groups, which ultimately resulted in periodical bans on the use of sludge in agriculture in some areas.
- Opinion about the risks associated with the use of sludge has in turn affected a sceptical and cautious stance within stakeholder organisations such as food supply retailers and distributors.

This meant that focus was upon the wastewater industry to highlight the benefits of the use of sewage sludge as an effective method for the reintroduction of nutrients and organic material to agricultural soil. This ultimately resulted in the REVAQ system.

Proposals for new guidelines or laws are currently being prepared regarding the use of bio-solid fractions containing phosphorus. The guidelines will govern the quality and distribution of bio-solids from a number of sources, including sludge from wastewater treatment, manure from farming and digestate from biogas production plants.

The REVAQ system

REVAQ

REVAQ is a voluntary certification system used in Sweden to regulate the quality of sewage sludge for use in agriculture. The REVAQ system started in 2002 as a development project involving Swedish Water (the national branch organisation), the Federation of Swedish Farmers (LRF), Lantmännen (an economic association operated as a producers cooperative) and number of food retailers and distributors. The current REVAQ system is today owned and administered solely by Swedish Water. Certification according to REVAQ means that the plant must work actively with continuous improvements in the quality of influent wastewater and therefore the resulting sewage sludge. The sludge must also be hygienised by one of a number of defined methods to prevent the distribution of pathogens and viruses to farmland. The system even ensures that information regarding the continuous improvement in sludge quality and traceability regarding the end use of the sludge is readily and easily available for all parties.

An ever increasing number of wastewater authorities are currently certified according to REVAQ. Sludge produced by these authorities represents 50% of the total amount of sludge produced in Sweden. The number of certified authorities has grown steadily year after year and a number of plants have pending applications to enter the system. In working within REVAQ, municipalities, the commercial sector and agriculture can interact to phase out undesirable prioritised pollutants.

REVAQ requirements and goals

Initial certification according to REVAQ involves the inspection of the organisation by an independent party to ensure that its production methods and product meet the required demands. A continuous control system consisting of the certificate holder’s quality control procedures, and second and third-party audits, ensure that the requirements are met continuously during the whole of the certification period.

The general rules for REVAQ are also audited by a number of organisations both from within Swedish Water and other related industries and stakeholders, specifically those involved with food production. Opinions or questions about the REVAQ system and rules are openly welcomed and administered by Swedish Water. WWTPs certified according to REVAQ must fulfil a number of requirements regarding the quality of the sludge in order to achieve and maintain their certificates and follow the long term goals of REVAQ.

The sludge is required to be analyzed (yearly composite sample) at least every three years for 60 of trace elements (including heavy metals) For the non essential trace elements the accumulation rate in agricultural soil must not exceed 0.2% by the year 2025. This means that concentrations in agricultural land should not be doubled at a higher rate than 500 years at the limiting sludge application rate. Each WWTP will as a result of this analysis identify a number of prioritised trace elements, that have to be reduced in order to reach the limit of 0.2 % accumulation per year in year 2025. For Cadmium, the goal is that no accumulation whatsoever will take place after 2025. The current allowed discharge quotient for the ratio of cadmium to phosphorus is 33mg Cd /kg P and this must be reduced to 17 mg Cd / kg P by 2025, this coinciding with the earlier proposal for stricter limits on sludge fertilization presented in the Swedish Environmental Protection Agency's regulation proposal from 2002.

REVAQ requires that an accepted method is used for hygienisation of the sludge to eliminate pathogens (bacteria, viruses, parasites, fungi and yeast). The sludge batch must be free from salmonella to eliminate the risk of transmission of infectious diseases to agricultural soils. Accepted methods for the reduction of pathogens are pasteurisation, thermophilic anaerobic digestion (with batch hold time), lime addition (quicklime or slaked lime) or long-term storage for a minimum of 6 months. Sampling and analysis is then required to ensure that the sludge is salmonella-free prior to application.

A long term goal is that the content of metals and undesirable organic substances in the incoming wastewater should not exceed that of the wastewater from households. The long term aim is that the levels of non-essential metals in agricultural land will reach equilibrium allowing a well regulated, sustainable reintroduction of phosphorus to agriculture, without a negative impact on the crops or the organisms within the soil.

REVAQ today

Around 45 % of Sweden's population in 2010 was connected to REVAQ certified wastewater treatment plants. Added to this is also the additional load from industries and businesses. The amount of sludge produced by the REVAQ certified plants in 2010 was 324 000 tons of dewatered sludge or 84 000 tons DS sludge, this represents 40% of the Swedish sludge production at around 40 REVAQ certified plants. By 2012 this number is expected to rise to 50%. Of all sludge produced at REVAQ certified treatment plant in 2010, 25,200 tons of 84,000 tons DS, i.e. about 40% of the sludge from REVAQ certified authorities was actually applied on agricultural land. The total amount of sludge to land was 42,200 tons DS meaning about 65% of this sludge came from REVAQ certified plants. The goals for REVAQ are that all sludge to land will be distributed within the REVAQ system and that all plants will be produced at REVAQ certified WWTPs.

Production of REVAQ sludge at Gryaab

Production cycle

Sludge for REVAQ production is produced in designated batches, in Rya WWTP's case these batches consists of one week's production (about 280 ton DS). Production and delivery of each REVAQ sludge batch is documented within the quality assurance system.

Figure 4 is a process block chart showing the processes for production, storage, delivery and application. The diagram includes the process carried out at the plant, the process and responsibilities carried out by the designated sludge contractor and of the end user (farmer).

REVAQ sludge batches are identified with the year and week number when the production of the batch is initiated, for example 1233 (week 33, year 2012).
During normal production every batch has a processing cycle of around 3 weeks before the batch can leave the plant for further processing. The processing cycle consists of 1 week for production, 1 week for analysis and 1 week for finalisation of quality control and transport to long term storage.
Before initiating the production of a REVAQ batch the storage site is scraped clean from old sludge and other material. The manager of operations, or an appointed deputy, verifies and approves the storage location for receiving REVAQ sludge and informs the laboratory staff, who during the production cycle, are responsible for taking daily samples. The samples are mixed to a composite sample at the end of the production cycle and sent to a certified laboratory for analysis. The exact start time and stop time for the produced batch is noted on a special batch journal within the quality assurance system. The REVAQ batch is labelled on site with its specific batch number and current production status, this is to ensure good quality assurance and avoid mix ups with non REVAQ sludge: The sludge batch can have one of four statuses during production:

REVAQ sludge batch during production.
REVAQ sludge undergoing analysis.
REVAQ sludge approved for immediate shipment.
REVAQ sludge batch fail.

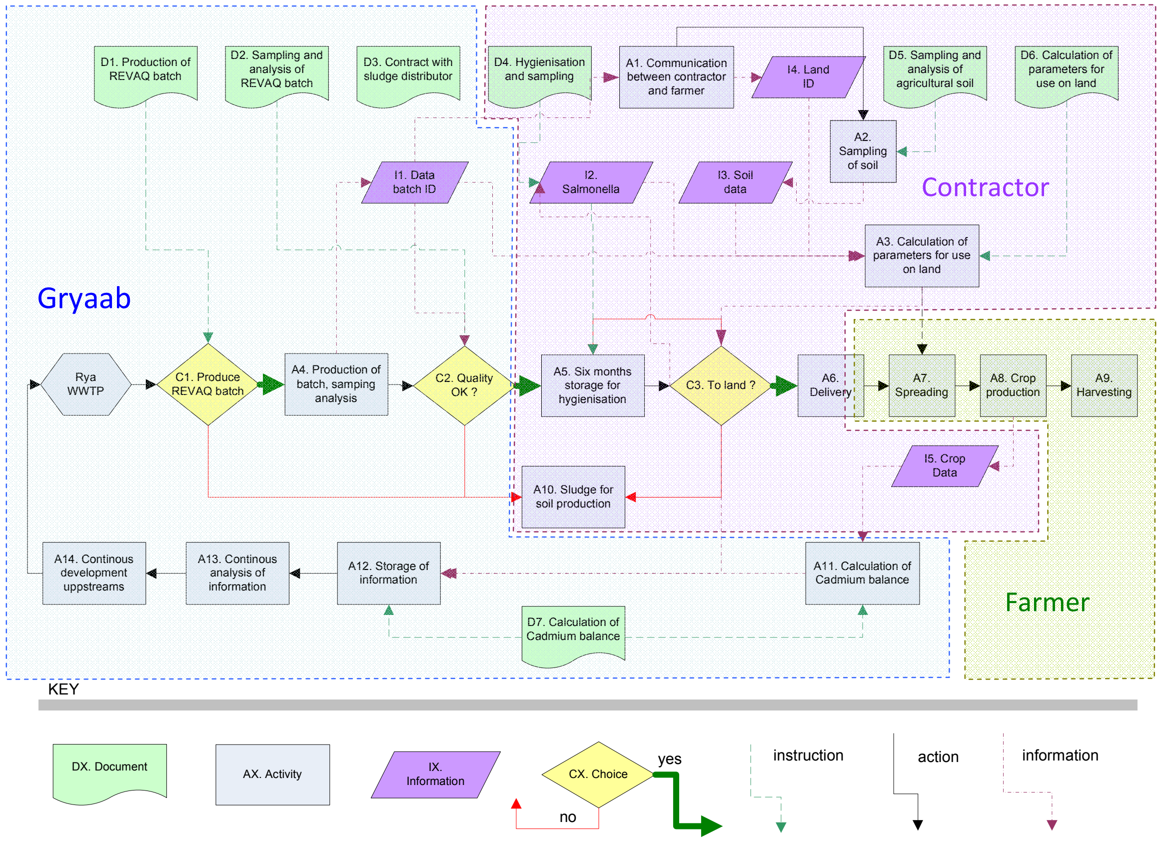

Figure 4: Process block chart for the production, storage, delivery and application processes of REVAQ sludge batches.

The production process is checked and documented every day by members of the operations staff to ensure that production proceeds correctly before a number of control processes are initiated to determine if the batch meets REVAQs quality standards.

Quality control and suitability for agriculture

Once a REVAQ batch has been produced the analysis protocol for the batch is examined by the quality co-ordinator at the plant. The analysis parameters are checked for:

- Concentration limits for heavy metals for sludge to agriculture according to Swedish law, (these are generally less stringent than the requirements defined within REVAQ).
- The calculated maximum distribution rate of the fractions within the sludge as not to exceed phosphorus and metal distribution intensity concentrations. See table 1. These are for phosphorus 22kg/hectar per year, five year average, and non-essential metals (Pb, Cd, Hg, Ag and Sb) must not exceed specified limits in g/hectare per year, five year average. There is also a range of distribution intensity limits for Nitrogen and Ammonia (40 - 170 kg/hectare) depending on the sensitivity of the area to eutrophication.
- Each REVAQ plant has its own priority schedule regarding 60 different ground elements; historical analysis of the levels of these pollutants within the sludge dictates which of the elements on the schedule are prioritised for each particular plant. In the case of the Rya WWTP five of the elements are identified as prioritised, these being Pb, Cd, Hg, Ag and Sb.

The regulation of these elements ensures that an accumulation on agricultural land does not exceed 0.2% per year, meaning a doubling in concentration over 500 years. The REVAQ goal is that none of the 60 identified elements (that are not essential) exceeds an accumulation rate of 0.2% per year in 2025. This is achieved by a successive tightening of the limits from now to 2025. The concentration levels of essential elements can also limit the potential distribution intensity for phosphorus of 22kg/ha/year, i.e. the sludge has a low concentration of the essential metal in relation to the amount of phosphorus. This is regulated within REVAQ as a long term states that metals which have a concentration of more than 50% of the limit according to (SNFS 1994:2) should also be prioritised.

Table 1: Permitted limits for prioritised metals in sludge according to Swedish law and REVAQ in 2012 and 2025, with full distribution intensity for P (22 kg P/ha /year)

		Limits according to Swedish law (SNFS 1994:2) and REVAQ	Specific limits for the Rya WWTP according to REVAQ (2012)	Specific limits for the Rya WWTP according to REVAQ (2025)
		(g/ha, year)	(g/ha, year)	(g/ha, year)
non-essential metals				
Lead	Pb	25	25	25
Cadmium	Cd	0.75	0.72	0,37
Mercury	Hg	1.5	1.06	0,23
Antimony	Sb		14.6	1,6
Silver	Ag	6	5.26	0,56
essential metals (2011)			higher concentration than 50% of limit (SNFS 1994:2)	Causes limit on full distribution intensity for phosphorus (2011)
Copper	Cu	300	Yes	Yes
Chrome	Cr	40	Yes	No
Nickel	Ni	25	Yes	No
Zinc	Zn	600	Yes	Yes

If all of the above requirements are met for non-essential metals the sludge batch can now be transferred for long term storage (six months), this is to meet requirements for the reduction of bacteria and viruses.

From storage to end user

The responsibility for the REVAQ sludge is transferred to a designated contractor for storage and final delivery to the end user. This is defined as part of a contractual agreement between the two parties. The agreement states that the contractors fetch, weigh, store and then finally transport the sludge to the end users. Until a REVAQ sludge batch has been given the status " approved for immediate shipment ", no sludge from that batch can be used in agriculture. The sludge contractor is also responsible for the sampling and analysis of the soil on which the sludge is to be applied, testing and analysis of the sludge for salmonella and for communication with the farmer. At the end of the storage period the sludge is sampled and tested to ensure that it is free from salmonella. If the batch is free from salmonella it can then be transferred to the farmer for use on land. The treatment plant, or as in most cases, the sludge distribution contractor is responsible for informing the environmental authority in the local municipality according to law. The regulation for REVAQ states that the treatment plant has to keep records regarding the destination of all REVAQ batches. This enables the effects of sludge use on land to be analysed and documented, both in the short and long term.

The farmer is responsible not only for the application of the sludge according to the designated application intensity but also for the delivery of data regarding the crops that are grown on the soil.

REVAQ batches - Production history

Fifteen sludge batches (4200 ton DS) have been produced at Gryaab during the last three years which represents around five percent of the total sludge production during that time. Of the 15 batches 11 (3080 ton DS) were of the required standard regarding the concentration relationship between Cadmium and Phosphorus of between 33 - 35 mg Cd / kg P for application to land, the remaining batches were transferred for soil production. Around one third (1000 ton DS) of the produced batches has been or is awaiting application to land. During 2012 five sludge batches (4200 ton DS) have been produced representing around ten percent of the total sludge production during that time. All 5 batches were of the standard required. Three of the batches have already been applied to land and the remaining two are undergoing hygienisation awaiting application next spring.

Ensuring continuous sludge quality improvements

Improvement in sludge quality historically and in the future

As a consequence of the broad positive development in influent wastewater quality due to the activities of the environmental engineers in addressing upstream industrial input, sludge quality has also improved. The concentration of six of the seven regulated heavy metals has decreased to between one tenth and one third of the concentrations in the 1970´s. The exception is for copper where no major change has occurred.

Priorities for the future regarding metals

In order to meet the goals REVAQ lead and zink must be reduced by about 20 % and cadmium and copper by at least 50 % by 2025. The mass flow distribution of heavy metals within the influent to the plant come from three main sources these are, constant sources such as households and industries, urban run-off and infiltration/inflow. Studies conducted at the Rya WWTP, show that 20-30 % of the cadmium, zinc, copper and lead reaching the wastewater treatment plant comes from a combination of infiltration/inflow and urban runoff (Mattsson, A., Davidsson, F., Jacobsson, D., Jansson, J. - unpublished data). This implies that addressing infiltration/inflow and urban runoff in addition to the traditional approach of addressing upstream industries and other sources is a priority. The annual reduction in mass flow to the Rya WWTP for six prioritised metals between 1998 and 2009 is summarised in table 2 below. Values for the expected reduction and the calculated reduction needed to maintain the goals set down in REVAQ are also included. The calculated mass flow reduction of cadmium in the sludge from the plant is shown in Figure 5, the dashed line show the historic trend (1998-2009) and expected trend (2009- 2025). Solid line shows the necessary development in order to meet REVAQ or Rya WWTP’s goals (2009- 2025). (Mattsson, A., Mattsson, J., Davidsson, F., - unpublished data).

Table 2: Annual reduction of mass flow of non-essential metals in sludge at the Rya WWTP (%/year).

	Observed 1998-2009	Expected reduction in mass flow (2009 - 2025) based on observed data (1998-2009)	Required reduction 2009-2025 in order to no longer be a priority
Lead (Pb)	5	2.5	0.6
Cadmium (Cd)	5.5	2.8	4.2
Mercury (Hg)	1	1	5.6
Silver (Ag)	15	7.5	6

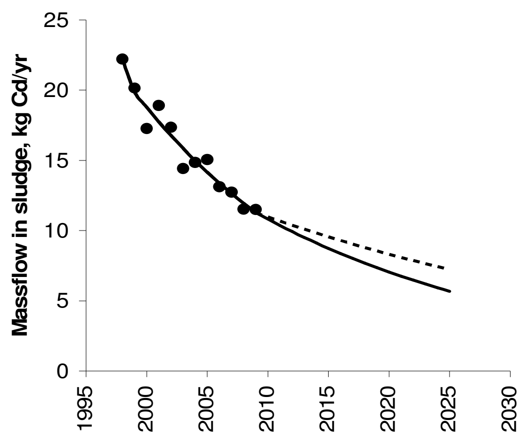

Figure 5: Mass flow of cadmium in sludge from the Rya WWTP from 1998 to 2009 (points). Dashed Lines show historic trend and expected trend. Solid lines show necessary development in order to meet the REVAQ goals.

Effectively achieving the goals of REVAQ will require a combined effort from a number of stakeholders within the municipalities connected to the plant, regarding the quality and quantity of urban run and infiltration/inflow reaching the plant. It is therefore important that issues regarding the water balance within the city and municipalities are given the relevant priority. A cost effective example of this is the improvement the sewer system in phase with planned road maintenance or re-exploitation within the city or municipalities. The activities carried out by environmental engineers regarding reduction of pollutants from constant sources will continue.

Activities are ongoing in a number of areas at the Rya WWTP in order to meet the current and future demands of REVAQ, these include:

- On-going cooperation with the municipalities' sewage network owners to reduce urban run-off and infiltration/inflow to the grid.
- A predictive tool for the mass flow of metals to the plant during varying influent flow conditions and the influence on metal concentrations in the sludge.
- Long-term strategies for the reduction of metals and prioritised pollutants in the sludge including action plans for certain prioritised metals and the inventory of smaller industries with regard to the usage of prioritised pollutants.
- The disconnection of leachate from two landfill sites.
- Communication plan with all of the owner municipalities regarding REVAQ.
- Ongoing procurement of a new sludge contractor for REVAQ sludge.
- Procurement of a new large sludge storage area for REVAQ sludge.

- Investigation of alternative methods for the hygienisation of sludge.

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