Sewage Sludge Disposal in Switzerland

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Sewage sludge was used as fertilizer in agriculture in Switzerland since the beginning of modern waste water treatment. During the last 40 years several difficulties arose with the agricultural use. The problems with pathogenic germs could be solved with a pre-pasteurisation. The contamination with heavy metals was reduced during the years but remained a cause for concern. The fear of mad cow disease and the contamination with persistent organic pollutants were 2003 the reasons for a ban of sewage sludge in the Swiss agriculture. At present the recycling of the phosphorus contained in sewage sludge and in other wastes is a goal of the Swiss policy.

1. Sewage sludge, a product of waste water treatment

In a country of now 7.9 million inhabitants for a surface area of only 40,000 km2, where most of the population and most economical activities are concentrated on one third of the surface, the problems related to waste water became obvious in the 1950ies. Polluted rivers convinced the population of the need of a water protection policy. In 1955 a first water protection act came in to force. This first law already defined as goals, that water in all rivers and lakes should have a sufficient quality for fishes, for the production of drinking water and for irrigation in agriculture. This meant we needed sewage treatment plants. The law of 1955 unfortunately did not define clearly who was responsible for the construction of these sewage treatment plants and which quality should be achieved in the cleaned waste water. As a consequence the construction of treatment plants was rather slow in the first years and the quality of Swiss rivers and lakes became even worse, because sewer systems (canalisations) were built, which discharged the untreated waste water directly in our rivers.

Under the pressure of a popular initiative the federal parliament enacted in 1971 a new water protection act. The tasks of cantons, towns and villages and of the industry were well defined. With the goal to encourage and to accelerate the construction of the necessary treatment plants the federal government and the cantonal authorities paid both subsidies to towns and villages when new sewage treatment plants were built.

This policy was successful, about 900 sewage treatment plants were built and today about 94 % of the population are connected to a sewage treatment plant. During the years many little plants were closed and replaced by centralised and more effective treatment plants. In 2009 still 759 sewage treatment plants were in operation. Their total capacity is 16.7 Mio. inhabitant equivalents. The average load is 10.4 Mio. inhabitant equivalents. In the catchment area of lakes the elimination of phosphorus is mandatory to fight the over fertilisation (eutrophication). The elimination of phosphorus must achieve 80 % and the allowed maximum concentration in the treated water is 0.8 mg P/l. Downriver of the lakes the plants with more than 10'000 inhabitant equivalents have to fulfil the same requirements. As result 80 % of the plants eliminate phosphorus compounds from the waste water, most of them using simultaneous precipitation. About 90 % of the phosphorus arriving in a sewage treatment plant is transferred to the sludge. The total quantity of sewage sludge is about 210,000 tons (dried matter) per year or about 20 kg per inhabitant equivalent.

Most plants are activated sludge plants. The waste water comes first to a settling tank, where sand and a part of the suspended matters are settling. In a next step the waste water comes in the aeration basin were the dissolved compounds are degraded biologically by bacteria and other micro organisms. In about 80 % of the plants phosphorus is precipitated by adding a solution containing iron salts or aluminium salts to the aeration basin. The water with the suspended biomass and the insoluble phosphates flows to a second settling basin where the biomass forms sludge at the bottom. This sludge is removed mechanically; a part is pumped back to the aeration basin and the excess is removed as sewage sludge. The raw sewage sludge contains more than 96 % of water.

Most plants in Switzerland used and are still using the anaerobic digestion as a first treatment step for the sewage sludge. By this process a part of the organic matter can be transformed in to methane. This methane is then used in a gas powered combined heat and power unit. The electric power generated can cover an important part – 30 up to 60 % – of the electric energy needed by a sewage treatment plant. The resulting heat is used for the heating of the raw sludge. This is important, because the raw sludge in most plants must be treated first at 65 °C to destroy germs as salmonellae or eggs from round worms. The anaerobic fermentation in the digester then needs temperatures around 35 °C.

2. The composition of sewage sludge and the content of nutrients

The composition of sewage sludge is of course depending from the composition of the treated waste water. In plants treating mainly domestic waste water the composition of the sludge is rather stable, at least concerning the major constituents.

About 50 % of the dry matter in sewage sludge is organic and is lost in ignition. Sewage sludge is of some interest for the agriculture because of its content of nutrients. As comparison, the annual flows of nutrients in some fertilizers are shown in Table 2.

Table 1: Typical composition of sewage sludge

	Unit	1984	1898	1999
Dry Matter (d.m.)	%	5.7	5.9	5.9
Loss on ignition	kg/t (d.m.)	435	460	456
Total Nitrogen	kg N/t (d.m.)	40	45	44
Phosphorus P (with P precipitation)	kg P/t (d.m.)	38	25	25
Phosphor P (without P precipitation)	kg P/t (d.m.)	20	16	20
Potassium	kg K/t (d.m.)	2	2	2.5
Calcium	kg Ca/t (d.m.)	73	64	58
Magnesium	kg Mg/t (d.m.)	5.7	5.1	5.3

Source: Gujer, W.: Siedlungswasserwirtschaft. Berlin, Heidelberg; Springer Verlag, 2007, modified

Table 2: Nutrients in sewage sludge and in different fertilizers in Switzerland

Fertilizer	nitrogen in t N	phosphorus in t P
Manure	160,000	29,000
Mineral fertilizer	70,000	5,800
In sewage sludge in Switzerland total	12,000	5,900
In sewage sludge used as fertilizer in 2,000 (about 38 % of the total sludge)	4,000	2,000

Source: Bundesamt für Umwelt, Wald und Landschaft: Faktenblatt zum Klärschlammverbot. Bern, März 2003

The sewage sludge has a certain importance because of its phosphorous flow. The other constituents, as e.g. nitrogen and potassium are marginal compared to the needs of agriculture and to the contribution of the other fertilizers.

During years the sewage sludge in Switzerland was promoted as a phosphorous fertilizer. Many treatment plants, in particular those without an important fraction of industrial waste water, developed a strategy for the use of sludge in agriculture.

There were a least two reasons for this development:

1. It is – or a least it was – a very easy and inexpensive solution for the sewage treatment plants,
2. It allows recycling a part of nutrients.

In 1975 about 70 % of the sludge was used in agriculture. In the following years the quantity of sludge rose but the amount used in agriculture remained more or less stable. For this reason, the percentage dropped slowly to 50 % in 1985. Unfortunately several problems were discovered and limited the use of sludge as fertilizer:

1. Contamination of sludge with pathogenic germs
2. Contamination of sludge with heavy metals
3. Contamination of sludge with persistent organic compounds
4. Possible contamination with prions, responsible for mad cow disease.

3. The problem with pathogenic germs

In the 1970ies a lot of new plants were put into operation. The sludge was given to agriculture after an anaerobic digestion at 35 °C. Unfortunately not only nutrients were dispersed but also pathogenic germs as e.g. Salmonella or eggs of round worms. These germs and the worm eggs could be detected on grass and there was a fear that also cows could be infected and that even a health risk for consumers would result.

The production of dairy products, especially of milk and cheese, is very important for the Swiss agriculture. So it's quite understandable that association of farmers and dairy producers were alerted. The authorities responsible for water pollution control looked for possibilities to avoid the hygienic problems. In a first stage a pasteurisation of the digested sludge was tried. The result was a clear failure: The pasteurized sludge showed to be a nutrient medium for any germs and was therefore contaminated very easily by germs. At sewage treatment plants the risk of contamination by pathogenic germs was too great. In some cases the same tubes and pipelines were used for the raw sludge and the pasteurized sludge. Other contaminations occurred in aeration of staple tanks or when the sludge was transported.

The solution of this hygienic problem was found by treating the raw sludge at 65 °C in a sort of pre-pasteurization followed by the digestion of the sludge. The resulting digested sludge showed to be much more resistant to a bacterial contamination and could be used in agriculture.

4. The constant worry with heavy metals

Due to its origin, the sewage sludge contains beside some nutrients and beside several principal constituents as calcium, aluminium or silicium also a range of heavy metals. When sludge is used as fertilizer, these metals are dispersed on the soil where they accumulate. This may not be a problem for the short term, because the concentrations in the sludge are normally not very high. But if sludge is used on the same agricultural area during decades, this would result in increasing concentrations of heavy metals in the soil. Above a certain level of heavy metal concentrations in the soil the produced agricultural product, e.g. vegetables, will be not suitable for consumption and even the fertility of the soil will be reduced.

To avoid this danger, the heavy metal concentrations in sludge and the annual charge of sludge to a given surface have to be limited. In Switzerland a first ordinance on sewage sludge was enacted in 1981, [3]. The application rate was limited to 0.75 kg of sludge (dry matter) per square meter in three years.

Table 3: Limit values in sewage sludge in 1981

metal	**Limit value in mg per kg** (dry matter)
lead	1,000
cadmium	30
chromium	1,000
cobalt	100
copper	1,000
molybdenum	20
nickel	200
mercury	10
zinc	3,000

Source: Schweizerischer Bundesrat: Klärschlammverordnung vom 8. April 1981, (later replaced by the same regulations in the Stoffverordnung and then by the Chemikalien-Risikoreduktions-Verordnung)

The application rate of sludge per surface was limited by the phosphorous content. The limits for the heavy metals were fixed with the goal, to increase the concentrations of the metals in the soil during the next 50 years to maximal the half of the tolerable concentration.

The authorities feared the accumulation of heavy metals from sewage sludge in then soil and launched a campaign to reduce the metal loads in the waste water. With chemical analysis of thousands of waste water samples important point sources of metals were detected and the concerned processes improved. The ordinance on waste water discharge set limit values in industrial waste water discharged to sewers or to rivers of 2 mg zinc/l, and 0.5 mg/l copper.

Electroplating shops took effective bur rather expensive measures to reduce the concentrations and loads of heavy metals in the discharged waste water. Other industries with important flows of heavy metals to the sewer system did the same.

By these measures the metal load from point sources could be diminished. The concentrations of heavy metals in sewage sludge were reduced. Between 1980 and 1999 the concentrations of cadmium and lead in sludge were reduced more than 85 %. This important reduction was possible because the use of the cadmium was banned in most applications and because leaded gasoline was banned in the 1990ies. Nevertheless the reduction was less important for metals as zinc and copper which are both widely used.

The concentration of zinc could be reduced about 60 % whereas the reduction was only 30 % for copper. Zinc is used widely used for corrosion prevention; even in galvanized drinking water tubes. The input of copper in the sewer system has a lot of sources as copper roofing or copper pipes. As a general rule we found it much more difficult to reduce the input from diffuse sources than to take measures at some well know points.

Table 4: Limit values for heavy metals in sewage sludge for agricultural use and measured average concentrations in sewage sludge in Switzerland

	Limit values for sewage sludge 1998 [Schw. Bundesrat] mg/kg dry mater	**average values 1980** mg/kg dry mater	**average values 1989** mg/kg dry mater	**average values 1994** mg/kg dry mater	**average values 1999** mg/kg dry mater
Lead	500	610	232	133	94
Cadmium	5	16.9	4	2.4	1.7
Chromium	500	311	129	84	74
Cobalt	60	15.6	10	7.9	9.8
Copper	600	510	388	380	341
Molybdenum	20	10	7	5	5
Nickel	80	96	42	40	31
Mercury	5	*)	3.6	1.9	1.7
Zinc	2,000	2,273	1,389	1,110	929

*) no data

Sources:

Schweizerischer Bundesrat: Chemikalien-Risikoreduktions-Verordnung (vgl. Anhang 2.6), SR814.81, vom 18. Mai 2005

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5. Organic pollutants and the mad cow disease

The percentage of sewage sludge used or recycled in agriculture diminished during the years. New analytical methods allowed detecting almost every persistent pollutant in the sludge. Sewage sludge is somewhat the *collecting basin* receiving every pollutant which is discharged in the water. We can find hormones, endocrine disrupters from medicaments and cosmetics; we find PCBs and of course also polycyclic aromatic hydrocarbons from the deposition of atmospheric pollution and run out of old landfill sites. We find the whole range of substances used industrial processes, when this processes produce waste water. So we observed an increasing mistrust in the agriculture.

In a research project from 1993 the median concentration of adsorbable organo-halogen compounds (AOX) in sewage sludge was found to be 275 mg Cl/ kg dry matter. This means, a kilogram of dry sludge contains about 1 g of xenobiotic organohalogen compounds. The well known persistent organic pollutants (POP's) as PCB, DDT, and their metabolites are only a rather small fraction of the total amount.

Polyaromatic hydrocarbons were found in concentrations of about 350 Microgram per kg dry matter [6]. In some rivers, down stream of waste water treatment plants, fishes show defects in their reproduction organs. So it is no surprise, when endocrine disrupters are also detected in sewage sludge.

The end of the direct use of sewage sludge in Switzerland came when BSE, the bovine spongiform encephalopathy, the so called *mad cow disease* broke out. In 1997 24 cows in Switzerland were killed because of the mad cow disease. And it became worse: scientists proved that that normal sterilization with steam at 143 0C was not sufficient to destroy the prions, which are thought to be responsible for BSE. The pre-pasteurization of sewage sludge 65 °C is certainly insufficient to destroy these prions. The waste water of slaughter-houses flows to sewage treatment plants. So if an infected cow is killed in a slaughterhouse, the prions could get with the waste water into the sewage sludge an end up on grass on farmland. At the end this might cause a propagation of BSE.

There was a also a fear that not only cows, sheep and cats, but also human beings could be infected. Scientists found some connection between a new form of the Creutzfeldt Jacob disease and BSE. Food as origin of fatal disease was a really horrifying imagination. After the year 2000 the use of sewage sludge in agriculture was discussed very contradictorily. Many farmers, association of farmers but also retail shops feared the image of their products would be damaged. Even worse was the suspicion, that eventually consumers could be infected with a mortal disease.

The percentage of sewage sludge used in agriculture dropped to from 38 % in 2000 to 21 % in 2002. In the same time association of farmers, representatives of food processing industry, and bio farmers required a total ban of sewage sludge in agriculture.

The Swiss government proposed a phase out. In Mai 2003 a ban for sewage sludge on agricultural surfaces used for animal feed and for vegetables came in to force. On all other surfaces the use was banned after October 2006.

6. Disposal of sewage sludge after the ban of use as fertilizer

In the 70ies up to 70 % of the sewage sludge was used in agriculture. The different problems caused a stepwise reduction to about 45 % in the 1990. As shown before, the percentage of sludge used as fertilizer in agriculture diminished already before the ban to 38 % in 2000. There were two ways for the elimination of the not recycled sewage sludge, disposal of dewatered sludge: landfills and incineration. Landfilling may cause problems, because the sludge is not mechanically stable. Therefore the sludge was mixed on the landfill sites with urban solid waste to get a manageable mixture. For the incineration the sludge was dewatered until it reached about 30 to 35 % dry matter. If the sludge was used as alternative fuel in a cement kiln, it had to be dried further.

When the ban in agriculture entered into force in 2003 the incineration capacity was sufficient for 80 % of the sludge. Dedicated plants for the incineration of sludge could burn 39 % of the sludge, municipal solid waste incinerators about 13 %, and cement kilns 19 %. 6 % of the sludge was exported to fossil fired power plants and burnt together with coal or lignite. [7].

The disposal of sewage sludge after the ban did not cause major problems, because of the possibility to eliminate excess sludge in foreign, coal fired power plants, and because some uses were still allowed in agriculture during a transition period.

As the farmers were hesitating from time to time in accepting the sludge, there had been already before the ban an obligation for the big sewage treatment plants to look for other disposal ways. So at least the big sewage treatment plants were rather well prepared to dispose off the sludge. The Swiss laws and ordinances regulating the waste management have fixed the goal to dispose off wastes as urban solid waste and sewage sludge in Switzerland. In the first years after the ban was the capacity of the incinerators not sufficient to reach this goal. The necessary drying and incineration plants were built up in a short time, because there was no risk for the investments. Exportations were not allowed any more, when the Swiss plants could treat the sludge.

The ban for sewage sludge in agriculture had of course also an effect on the costs. In a first survey we found costs of 600 CHF per ton of dry matter in cement kilns, 750 CHF in a dedicated sludge incinerator and 800 CHF in a MSW Incinerator. The costs depend from the water content of sludge [7]. It is important to eliminate the water to a content of at least 30 % dry matter before drying. Otherwise the costs for transportation and drying are much higher.

7. The importance of phosphorus

Phosphorus in the form of phosphates is essential for the life of plants and animals. In many cases the growth of plants is limited by the available nutrients as phosphorus or nitrogen. Plants need these nutrients and absorb them from the soil. On a global level we are in need of rich agricultural harvest for the nourishing of an increasing population. The high crops are only possible with the use of fertilisers as manure and mineral fertilizer. With manure and with mineral fertilizers we can replace the nitrogen and phosphorus in the soil which were absorbed before by the plants. So fertilizers are of crucial importance for humanity.

By the natural erosion but also by leaching from cultivated land phosphates and nitrogen compound are washed out and transported in rivers. We loose these nutrients for future use in agriculture.

Whereas nitrogen fertilizers can be produced artificially by transforming nitrogen from the ambient air to ammonia and other compounds, we depend on geological deposits for phosphorous fertilizers. The U.S. Geological Survey estimated the annual mining of phosphate rocks to 176 million tons in 2010. The total reserves are estimated to be about 65,000 million tons. This quantity was revised due to new figures about the Moroccan reserves.

Based on these figures we can estimate that reserves will be depleted in 350 years. Unfortunately mines with a good quality of phosphate rocks are not abundant. In many deposits the phosphates are contaminated with cadmium or with uranium. Because of the depletion of mines we are depending more and more from mines with a poor quality.

Because of the crucial importance of phosphorus and because of the depletion, which is on the horizon the recycling of wastes with high concentrations of phosphorus is of increasing interest. Several European nations have projects for the recycling of phosphorus from wastes and waste water (see also: http://www.phosphorrecycling.eu/).

8. Recycling possibilities

Waste water contains phosphates. During the last decades several processes were developed for recycling of phosphates either from waste water or from the ash of the sewage sludge incineration. A general survey can be found at [8]. One important possibility to recover phosphorus directly from waste water is the crystallization of insoluble phosphates either in the main stream of treated waste water or then in a by pass, using water from the sludge digesters. An other possibility is the precipitation of insoluble phosphorus compounds as the insoluble Magnesium- Ammonium Phosphate, struvit, ($MgNH_4PO_4 \bullet 6H_2O$) in the treated water mainly after a biological treatment.

The precipitation needs a good control of the pH in the water and careful dosing of chemicals. Good results are possible, when rather high concentration of phosphates are present, e.g. in a industrial waste water rich in phosphorus. The process is used also in the water from dewatering the sludge, where phosphorus is present in a high concentration. In this case the phosphate are not recovered from the main stream of water, but in sort of by-pass.

Table 5: Annual phosphorous flows in Switzerland

waste	annual quantity in t	Concentration of phosphorus in g P/kg	Phosphorus per year in t
Urban solid waste	2,500,000	0.6	1,500
Sewage sludge (dry matter)	210,000	27.9	5,860
bone meal	20,000	80	1,600
meat meal	45,000	30	1,350
compost	208,000	3.5	728
Total			**10,750**

Source: Bundesamt für Umwelt: Phosphorflüsse in der Schweiz, Stand, Risiken und Handlungsoptionen. Bern, 2009

Most of the Swiss sewage treatment plants are equipped for phosphorus elimination. As an average, about 90 % of the phosphorus contained in raw water can be transferred to the sludge. When dried or dewatered sludge is burnt in dedicated plants, we get an ash containing most of the phosphorus originally present in the raw water. There is no important loss of phosphorus when sludge is dried and incinerated. Volatile metals as mercury, cadmium and to a lesser extent zinc and lead are transferred in the gaseous phase and removed by the flue gas cleaning equipment of the incinerator. The remaining ash contains rather high concentrations of pyrophosphates. These compounds are hardly soluble; therefore they don't have an immediate fertilizing effect on plants.

Thus the ash from sewage sludge has to be processed further for the use as fertilizer. There exist several ways do get a soluble product. The ash is heated in a thermal processes or the ash can be treated with acids. A well known thermal process is the Ash Dec process. A lot of experiments were done in a pilot plant in Austria. The ash is heated together with alkali chlorides in a reactor. Heavy metals as copper or zinc are removed as volatile chlorides and recovered in the flue gas cleaning system. The phosphorus compounds in the treated ash are rather soluble. In the pilot plant several batches were produced and transformed to commercial fertilizers.

The RecoPhos process was developed in Germany. The ash form sewage sludge is treated with a strong acid, to get soluble phosphates. In this process the elimination of heavy metals occurs only in the sludge incineration. Therefore sludge quality has to be controlled. When phosphoric acid is used, the resulting fertilizer has high contents of phosphorus and can be compared with commercial triple super phosphate. The product is commercialized in Germany.

9. Conclusion

Phosphorus is an important element for the fertility of soils. The actual practise in waste elimination causes important losses of phosphorus coming from the incineration of sewage sludge and then burning of bone and meat meal in plants, which do not allow recovering the phosphorus.

1. Wastes as bone and meat meal are so rich in phosphates that a recovery of phosphorus is of priority, as long as these materials are not used directly. Incineration in dedicated plants and re-use of the resulting fly ash is an option, which allows destroying of disease causing pathogens, prions included. The resulting ash may be transformed to fertilizer by several processes. Because of the high phosphorus concentration, the ash can contain up to 50 % of Calcium phosphate, the recovery of these wastes is of absolute priority.
2. Sewage sludge is relatively rich in phosphorus. In Switzerland about 80 % of the sewage treatment plants are equipped for improved phosphor elimination. The recovery rate in these plants is about 90 % of the phosphorus contained in waste water. Because of the contamination with persistent organic pollutants and with the goal to prevent any dissemination of the mad cow disease, all sewage sludge in Switzerland is burnt. For a recovery of phosphorus we need to burn the sludge in dedicated plants, which allow recovering of the phosphorus from the ash. This means, the co-incineration of sewage sludge or even bone meal in municipal solid waste incinerators should be phased out. Also the use of dried sewage sludge as alternative fuel in cement kilns will end in some years.
3. There exist several technical processes for transforming the ash from sludge incineration to a fertilizer with a high percentage of soluble phosphates. However the available capacity for the treatment of ash will certainly not be sufficient in the next years. Since the stockpiling of ash from sewage sludge and of other wastes as bone meal is no problem, the Swiss authorities will encourage or stipulate that the ash is stockpiled until there is sufficient capacity for the processing to a fertilizer.
4. Removing of heavy metals from the sludge is rather difficult. Only the volatile metals as cadmium and mercury are transferred to the flue gas during incineration. Metals as copper, zinc or lead remain at least partly in the ash. Therefore we should not reduce our efforts to limit the heavy metal concentrations in waste water.

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