PHYTOREMEDIATION OF LANDFILL LEACHATE AND PEAT FILTER TREATMENT IN CONSTRUCTED WETLAND: AN INITIAL STUDY AT ØDEGÅRD LANDFILL, NORWAY

Marika Hogland
LundaHydro AB, Sweden;
Linnaeus University, SE-391 82, Kalmar, Sweden
Bjørn E. Berg
GLT-Avfall, Norway
Jan Stenis
LundaHydro AB, Sweden

ABSTRACT

It's universally known that landfills leaking emissions into surroundings have negative environmental impacts and in response to the EC Landfill Directive (1999/31/EC) and later the Waste Directive 2008/98/EC of 19th November 2008, many landfills sites have been forced to close down and many needs remediation. The landfill operator is responsible for the final coverage and after-care control of the site for a period of at least 30 years after the closure. In this case study, Ødegård landfill in Norway (associated member of EU), has received total 600 000 tons of solid waste from automobile shredder and contaminated soil during the period 1992-2009. The leachate is pumped from the collection tank up to a SBR Byggingenjörerna reactor plant for chemical and biological treatment. The residual sludge from the SBR plant is collected in the sludge pit and then returned to the landfill and the treated leachate discharged into the river Drogga. Most of the organic compounds in the raw leachate have concentrations over the emission limit before lead into the SBR treatment and in particular high of pesticides. To investigate the ability of peat to uptake pollutants from the leachate from Ødegård, column tests with ash mixed with peat as filter media were performed. Chemical analyses show a high metal concentration and the discharge of Cu, Ni, Cr and Zn reaching high level over emission limits for the recipient. The aim of the study is to compose purification and treatment steps for leachate in a natural based constructed wetland. The steps include:

- Sedimentation basin, straw filter, peat filter, irrigation area of *Salix* (energy crops),
- Wetland pond with plants for assimilation of contaminants, sand/stone filter,
- Aeration in a water wheel and meandering water into planted wetland pond,
  From the waterfall the leachate is lead into a sedimentation pond (excavation started summer 2012).

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KEYWORDS

Landfill, leachate, treatment, SBR, phytoremediation, artificial wetland

1 INTRODUCTION

The owner of the landfill Ødegård is responsible for the leachate discharged into the river Drogga not contain contaminants that adversely affect ecosystems and water quality downstream. On demand from the local EPA, emission limits for inorganic and organic pollutants and the emissions of As, Cr and Ni should be halved. The maximum allowable emissions into the river Drogga has been sat to 0.1 μg/l for As, Cd, Co, Cr, Cu, Ni, Pb, Zn, Sb and Mo and 0.01μg/l for Hg [10].

During the period 2000 to 2009, emissions from the area monitored by a sampling program based at nine points called St. 1 to St. 9. Sampling points St. 8 and St. 9 are located in Drogga upstream and downstream of the discharge point from the Ødegård area.

The study shows that the runoff from Ødegård area contributes to significant increased levels of several water quality parameters in the river Drogga [4]. The metal of measurements performed between 2004 until about the middle of 2007 shows a fluctuating variation of content of metals. Changes in quality class for heavy metals Cr and Ni have been observed which cannot be accepted. Chromium is the element that is higher than the others, varying between 300 and 1000 μg/L during the period. The nutrient supply into Drogga is too high and the requirement of the SBR installation which cleans the leachate from Ødegård landfill is 90% reduction in terms of phosphorus, P_{tot}, which has not been held through the years. Also the value of arsenic is much too high over the draft requirement [4]. Pesticides are also among the pollutants affecting the flora and fauna in Drogga. Concentration of COD in the leachate was measured during the period 2002-07 at 16 measurement occasions 1500 mg/L. It almost tripled from 1500 mg/L during this period to a level that is 450 times higher than emission limit into Drogga [3], [4].

The BOD_7 reaches high concentrations in the leachate, between 1500 and 3000 mgO_2/ L, and it's possible that it may also be diluted with rainwater and drainage water from the area upstream of the measurement point SBR_{out}. The maximum allowable emission to the recipient has been sat to 10 mgO_2/ L. To follow development in the Leachate a flora and fauna investigation was made in 2002, 2003 and 2007 [3]. It was found that the ecosystem influenced negatively and wiped out more sensitive species.

Peat filter is indicated to perform an efficient purification regarding both organic and inorganic contaminants and among the metals a good separation of Cu, Pb, Fe, Mn, Sn and Hg [7]. The levels are still higher than the emission limit for the metals but the peat filter can be used as additional purification steps. The same study showed, however, that separation of Cd, Sb and Zn is not clear. Full-scale studies have shown reduction of TOC, BOD, COD and pesticides and removal of NH_4-N that transforms to NO_3-N however not being completely taken despite of filters. An observation on phenol degrading and heterotrophic bacterial was observed in the filter. In research carried out on behalf of the Scottish Office [1], it was concluded that peat treatment of ammonia in landfill leachate would be limited by cat ion exchange capacity of the peat, restricting the use of this treatment method to final polishing at low application rates. Their research used 24 h leachate/peat contact tests to investigate the treatability of leachate. Their work demonstrated that the peat uses as little as 6% of the available cat ion exchange capacity (CEC) in ammonia removal.

The studies performed by Kängsepp [8] also show- reduction of POPs such as PCB congeners and no sign of PBDEs were found. The reduction of the total phthalate is significant as well as the adsorption of phenols and also the reduction of a plurality of semi-volatile compounds (SVOCs) were significant. This might be due to the microbial growth and metabolism activity in peat.

2 METHODOLOGY

A descriptive approach is employed in that the intended modus operandi is described. Thereby, after a general introduction giving the scientific background, the area of study in question is presented as regards relevant biochemical and geographical data. Next, the method to improve the leachate from the current landfill and how it is meant to be purified is given in the form of a logical three step-approach. Finally, the conclusions reached at are outlined. Information is gathered through both qualitative and quantitative data since both personal interviews with experts and information from fact-books constitutes sources that support the current findings. The research design emphasis development of theories and models and change. The landfill area is viewed as a complex eco-system wherein the relations of the parts are important. Thus, a systems approach is mainly employed. The research approach of this work is positivistic since an analytical, normative model mainly is used. The validity of the method is evaluated by applying commonly accepted, ecological theories. The reliability of the results is good due to relevant text books and other well recognized sources being used.

3 POTENTIAL CONTAMINATION SOURCES IN THE ØDEGÅRD AREA

There are six owners of the land where the waters are generated and which leaves Ødegård area at the same place as the leachate from the Ødegård landfill. They affect the water quality in the test point St. 9 downstream in Drogga. These properties will jointly affect the river even when the new treatment system for leachate from Ødegård landfill has been constructed and implemented. Drainage water from six different sub catchments in the Ødegård area are mixed before they discharge into Drogga. The areas are as follows.

• **Agriculture land**: surface runoff, drainage, storm water and roof water;
Agriculture is usually characterized by diffuse sources of pollution that leaks nutrients as nitrogen and phosphorus. Pesticides to control weeds and pests are used in agriculture. It can also leak sewage containing feces, detergents from households but also leak water from other waste. Often these agricultural properties heap less waste and scrap that can contribute to pollutants to nearby streams or watercourses. Properties with livestock contribute to the leakage from manure and urine associated with manure handling and storage. The machinery contributes oils and lubricants and diesel which are easily spread in the area. Pollutant contribution from roof surfaces is dependent on dust fallout and rain water quality and the roof surface material and that also contains nutrients.

• **Forestry**: surface runoff, drainage; In the forest, in many watersheds in recent decades it is found that watercolor is increased due to increased humus content. Inventories of the surrounding agricultural properties have not yet been made.

• **Road area**: Runoff water from the road; Water from road areas usually contains erosion remnants of asphalt and bitumen, so called road sediments and vehicles and their emissions from fuels. Cigarette butts, plastic, glass, cans, paper, garbage, animal droppings and during winter deicing agent are present in the road area.

In the ditch along the road Fv 479, the surface and drainage water are mixed with water from agricultural properties and the road area water. This storm water contains soil particles, nutrients, organic and inorganic substances, pesticides, etc. Finally, this water is totally mixed with the remaining water from Ødegård area and the treated leachate from the SBR plant.

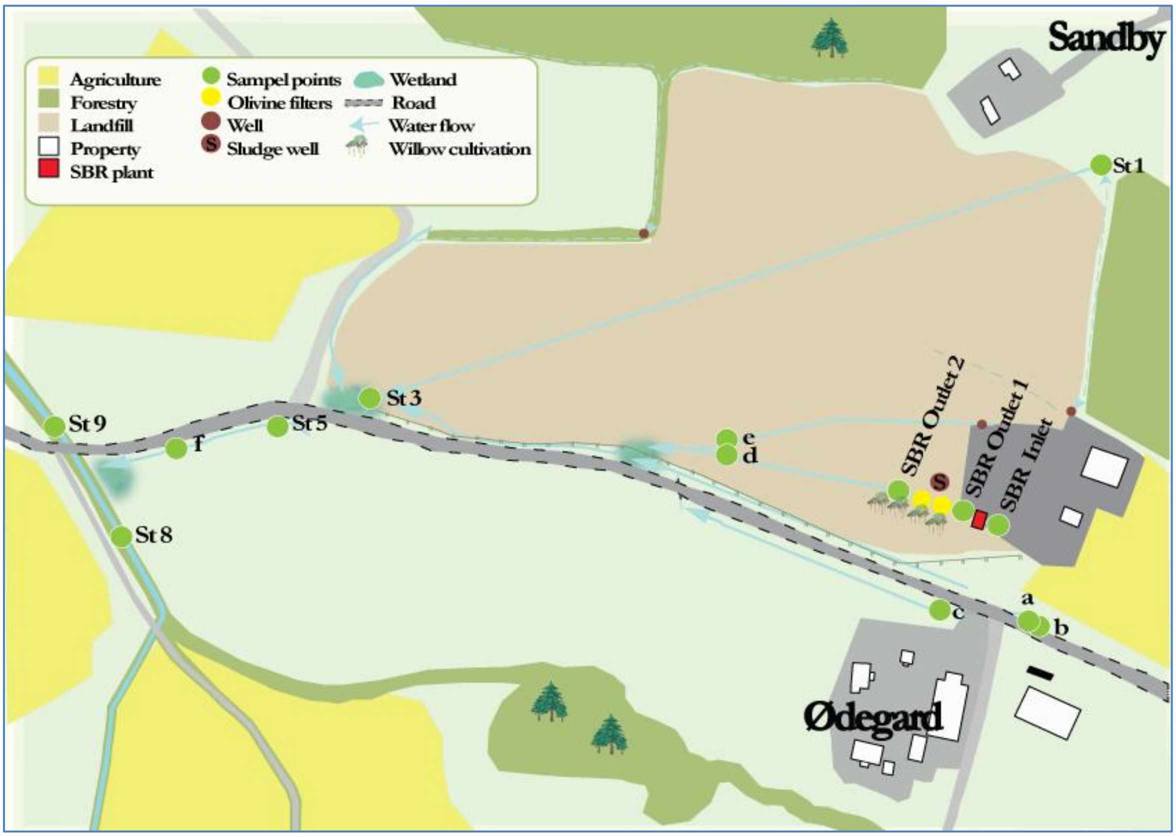


Figure 1. Map of the water flow at Ødegård area and the measuring points a, b, c, d, e, SBR inlet, SBR outlet 1 and outlet 2, St. 1, St. 3, St. 5, St. 8 and St. 9.

• **Landfill**: Leachate, Storm water and roof water: However, it is likely that pollutions from Ødegård landfill dominate the emissions to Drogga and subsequently have impact on the river section between St. 8 and St. 9. It is desirable that a purification system construction must be capable to reduce the old landfill long-term impact on the sharp feature since the two agricultural properties leak and the road areas drain water.

4 DESCRIPTION OF THE ØDEGÅRD LANDFILL

The Ødegård landfill became operational in 1992. It has had permission to receive the following types of waste: cardboard, paper, glass, wood, plastic, iron, metals, construction and demolition waste. In 2008, it was also permitted to receive contaminated soil.

Even waste loads from automobile shredding facilities have been received at the landfill during the disposal period. A total of 600 000 tons of waste was deposited up to 2009, which has been deposed into in total 17 landfill cells. The landfill is equipped with a gas collection system and is used in a gas engine to produce electricity. In 2000, a local solution for leachate treatment in the form of an SBR reactor was installed, and excess water was returned to cell 10.

A 300 mm transmission pipe for surface water runs through the landfill located at the landfill bottom. In 2004, rupture occurred on this pipe, which was discovered in test point St 3, but the pipe was repaired. Leachate production has varied from 3500 to 6000 m^3 per year with a linear increase of 413 m^3 per year until 2008. Up to 2010, there has been an increase in leachate production by 50-75% based on the 2008 values and the highest leachate production in 2009 of 10 500 m^3. Rainfall over the past two years has been relatively high, implying that it is important to end the coverage of the entire landfill.

5 LEACHATE QUALITY

5.1 The SBR plant

Transportation takes place from the collection pit downstream of the landfill up to the SBR plant where the water undergoes chemical and biological treatment. The purified water from the SBR plant is led to two olivine filters and then transported through two olivine filters and three wetlands before it finally flows into the receiving water Drogga. The residual sludge from the SBR plant is collected in the sludge pit and then returned back to the landfill.

5.2 Leachate and drainage composition

The shape of the metal is relevant for the effect and the form of toxicity and bioavailability. The chemical composition of metals and semi-metals are determined by, for example, pH, concentration of complex-forming compounds and the redox potential. Studies made by Berg and also in this study with sample taken in August 2011 show that heavy metals increases in concentration as regards the contents of cobalt, copper, chromium, quicksilver, molybdenum and nickel after the treatment in the SBR [2], [3], [4], [5].

The source of pesticides usually origin from agriculture land. The concentration of arsenic mainly used as insecticides and other pesticides in the treated leachate is too high in the relation to the set emission-limits for Drogga. The question is whether this is an indication of what is in the landfill, or if it comes from the inflow upstream of the farmlands. Thus, further research is needed. Chromium, nickel and cadmium are used as alloying elements. Cadmium is emitted during the combustion of oil and wood and may also be present in high concentrations in agricultural crops. Other areas of use are the plating of iron objects, stabilization of PVC plastic and batteries. However, the concentration of cupper almost tripled after the treatment in the SBR plant and like mercury it occurs in batteries. The metals mercury and lead are complexly bound to the organic materials and clay in the Ødegård area.

	As (μg/L)	Cu (μg/L)	Ni (μg/L)	Zn (μg/L)	Cr (μg/L)
2004-07	29-32	10-17	85-91	9.3-64	300-1000
Nov. 2010 to Apr. -11	40-140	10-50	75-150	75-170	330-440
Aug 2011	41	3,0	100	12	2

Table 1. Contents (μg/L) of arsenic, copper, nickel, sink and chrome after treatment in SBR.

The SBR plant has a great effect on the carbon compounds such as phenols, methyl-phenols, benzenes and toluene. And the emissions of PAHs, chlorinated benzenes, BTEX (benzene, toluene, ethyl benzene, and xylenes) are in general low in the leachate. Phenols are usually derived from agriculture and seemingly high but did not stand out noticeably. The sources for chlorinated phenols are usually from combustion residues, industrial waste and the chemical and technical industry. The aromatic hydrocarbon, toluene, is an important organic solvent and are used as an industrial feedstock and as a solvent. Toluene is found in crude petroleum and used mostly as motor fuel.

Most of the organic components are over the limit for leachate before the treatment, in particular pesticides such as micro biocides, fungicides and insecticides. Hydrocarbon can be generated by complete combustion of wood, gasoline etcetera but are also used for the preparation of pesticides. Even methyl phenol can be used as a disinfectant, preservative and fungicide.

The SBR reactor has a reduced effect on many organic compounds but more data is needed to say how large the effect is or how efficient the reactor is. Some assay values is a bit strange, for example, Pentachlorophenol has high toxicity and a slow biodegradation and is mostly used as herbicide, insecticide, fungicide, algaecide and disinfectant in agricultural seeds and the use of masonry azinphosuses as pesticides and anthracene increase. More sampling should offer a more representative analyses based on many small withdrawals which are taken to get a fairer result. Furthermore, analyses are needed on pH, conductivity, suspended substances, BOD_7, COD, Cr, alkalinity, ammonia nitrogen, total nitrogen, total phosphorus, P and N.

6 COLUMN AND TERRA TEST

Multi-annual studies of leachate from the landfill at Stena Metall AB automobile shredding facility in Halmstad, Sweden has shown good treatment results with peat as adsorbent [8]. Observations were carried out in order to see if peat filters also could be used for purification of leachate from the Ødegård landfill. A column test was made with the same type of peat and ash used in peat filter in Halmstad. The filter function has been evaluated in an up of flow column test, so called "up flow column test". The columns were equipped with a 2.16 L filter and were operated with a flow of 199 mL / hour during 27 days. This means that the S / L ratio (0.1) used in the batch test was achieved after nine days. The sampling from the columns was performed three times a week: Monday, Wednesday and Friday.

Color analysis of leachate samples from Ødegård shows that there is no major change in color after the leachate is treated in peat filter. In Halmstad, Sweden, the filter gives the water a more reddish color and investigation is in progress to investigate why the filter makes the leachate more lucent. It can be concluded that the amount of visible particles in the leachate decreased during passage through the filter. The color of the water is slightly brighter after passage through the filter. Discharge of dark colored water should be avoided because the color can affect the photosynthesis of vegetation in the river.

There are six different water discharges from the Ødegård area that are mixed before they are discharged into Drogga. To reduce the risk of confusion and that disputes will arise over the next 30 years when the landfill should be checked and leachate treated, according to the demand of the EU Directive, all these water discharges flow should be determined and their water quality estimated by for instant Terra Test analysis. However, the discharge from all the six drainage areas doesn´t necessarily has to be sampled with the same frequency as the discharge from the landfill.

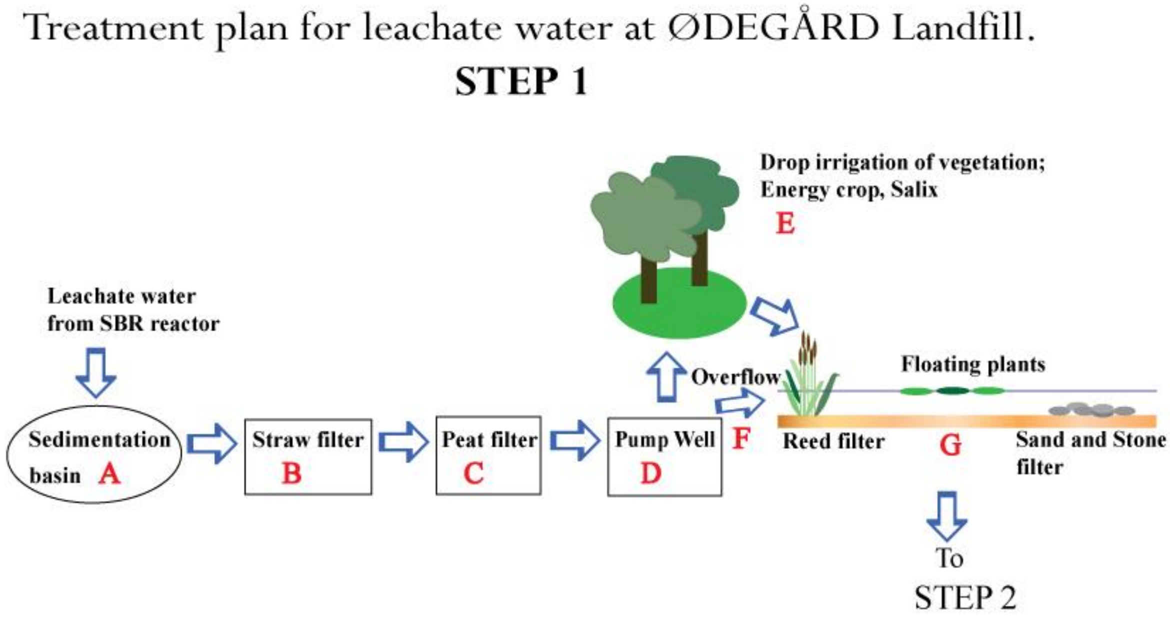
Purification systems such as peat ash column but also the SBR reactors, do not remove much metal, but concentrate them in the treated leachate. Column tests showed an increase of Cu, Cd, As, Hg and Co in the first test of the peat filter but with a tendency to decrease with time. The question is if this will continue with longer sampling periods.

Metals as Zn, V that mostly is used as alloy, Sn, Ni, Cr and Ba increase but the metals Mo, Pb and Arsenic decrease. In this case, the purification with peat is worse than for the SBR plant and some phenols such as 2, 5/3, 5 Dimethyl phenol, 4-Ethylphenol and Thymol rises between 2000-20 000% in concentration after treatment with the peat filter. With the good result in Halmstad, the question is if the ash in peat filter in the Ødegård test has been contaminated.

7 PROPOSAL FOR PURIFICATION OF WATER FROOM THE ØDEGÅRD AREA

To construct artificial wetlands and utilize nature's ability to reduce concentrations of fine particulates and dissolved pollutants in leachate is a well-used treatment method. The purpose of the construction of wetland systems, besides the cleansing ability, is to raise the value of the land and make the Ødegård landfill an area that better fits into the beautiful and hilly, cultural landscape.

There is no doubt that the most expected water of the six waters that drains the Ødegård area that provides the greatest environmental impact on Drogga at the St. 8 and St. 9 is the water from the Ødegård landfill. The following proposal for purification of the water from the Ødegård landfill also includes cleaning of all remaining waters from the Ødegård area. The aim of the system function is to improve the long-term chemical and ecological status of the watercourse Drogga over the next 30 year period, with the main focus on the pollution coming from Ødegård landfill but also the surface and drainage water from the abutting land. The intention is also to establish a monitoring program for the leachate treatment operation for at least the first five years after closure of the landfill. Construction of the wetland will be done in three steps in order for each step to give the opportunity for establishment of the vegetation before the downstream existing wetland parts (Step 2 and Step 3) is constructed.



7.1 Step 1

Outlet water from the SBR plant is led through Olivine filters (1) and (2) into Step 1 of the wetland. In the olivine filter, some adsorption of impurities is done and buffer of pH occurs. Thereafter, it is led into a larger sedimentation basin (A) in which the particle-bounded contaminants are deposited in the form of sediment by gravity. Sun and wind also affect treatment in this stage. In the sediment stones and wood chips such as birch, aspen and garden waste may promote the microscopic mobilization. This will level off the high concentrations and pre-treatment of leachate occurs. Furthermore, the water goes into a straw filter (B) which acts to trap nitrogen (N) and promotes humification. Every third year, the straw-bales should be replaced. Furthermore, the functional purification of straw-bales should be investigated and be compared as an alternative to treatment with reed bed.

After the straw filter, leachate runs over a peat filter (C) mixed with wood ash. Phosphorus is added to promote the growth of bacteria, to capture nutrition and to reduce the level of COD and provide pH stabilization. After the peat filter, the water is pumped (D) to an irrigation area of energy crops (*Salix*) (E). Drip irrigation is done to prevent aerosols dispersed by the wind. Irrigation of the surface gives an evaporation of leachate, improves nitrogen and phosphorus balance and reduces BOD and COD values as well as it separates a number of other pollutants including those of toxic nature.

On the downside irrigation area in direction towards the road Fv 479, a number of birch trees are placed to soak up any excess water. In the long term, one might consider to disconnect the SBR plant under the assumption that wetland achieve emissions standards for treatment. The sludge from the SBR plant must also be taken care of. It is recommended to bring the sludge to the energy forest.

From the irrigation of the surface, excesses water is drained to the wetland (F) with cattails, reeds, for example, *Phragmites* and floating plants, for example, water hyacinth and duckweed that are separated only by a clay wall or a wooden wall. Sand and stone filters may become a necessity. Wetlands act as detention storage and wintertime it might act as storage of water. In case of lack of drainage during the summer months, the water from the detention storage is used for irrigation of *Salix* [6].

7.2 Step 2

Reduction of the levels of ammonia nitrogen by nitrification and denitrification processes and readily biodegradable material (BOD) is made in the aerated leachate water wheel (G).Some reduction of metals can occur by oxidation. To extend the residence time in the wetland system and delaying the release to receiving waters after the aeration step, a meandering water lode with adjacent wetlands (I) is built. Wetlands with open water areas and vegetated areas with cat tail, reeds and floating plants is constructed separated only by a clay wall or wooden wall. To preserve the cultural landscape profile as much as possible, spontaneously growing vegetation with many of the plants adapted to sustain existing pollution condition and the existing vegetation within the area will be used. This part of the landfill slopes steeply down into the meandered parts of Step 2 and the risk of erosion is noticeable in the area. Here is soil and horse manure supplied and erosion protection and soil reinforcement are placed near the edge down to the wetland and pond enhanced with a plant establishment media for increased stability. It is possible to have a double ditch, a ditch on the agricultural and SBR drainage water and another trench for the leachate and storm water from the yard at Ødegård landfill which then is passed through purification Step 2 without the involvement of any other water than from the landfill. In this case, it is not possible to also reduce the level of contamination in the water area by means of Step 2 and Step 3.

According to the guidelines set out in the EU directive for completion, the amount of leachate from the landfill will reduce once the landfill is covered due to the prescribed, final covering and control of landfill sites for at least 30 years,. Surface water created after the final coverage is collected in ditches and diverted to the wetland bottom to Step 3.

7.3 Step 3

When the water is led into Step 3, all waters from the area that will be treated in the last wetland area where it is mixed. Only a certain amount of water and pollution of a diffuse character comes from the farmland along the southern part of the wetland. A V-shaped measure wire is placed at the entrance to the waterfall where it finally again increases the oxygenation of the water before it is released into Drogga river. Before the measuring of the wire, a sedimentation pond is built. At the exit of each purification step, similar wires with associated minor sedimentations ponds are built. Before the leachate is released into Drogga, the water is distributed along the entire length of the wetland nearby Drogga. Emissions will have a more diffuse character than the previous traditional point.

8 CONCLUSIONS

To reduce emissions from leachate, it is important to reduce the amount of leakage-water to the lowest possible level. The test with peat filter shows a minimized reduction of just some metals but less than was expected. In this case, the purification with peat is worse than for the SBR plant. Some phenols were raised that differ from other studies made on peat. Considering the good result in Halmstad, the question is if the ash in peat filter in the Ødegård test has been contaminated. Thus, it is also important that controls are made on the ashes. Further tests are needed to see if the levels on metals continue to decrease during a longer sampling period.

To plan the wetland treatment plant on the site at the Ødegård area is a low cost and a low technical alternative to solve the emissions problem as regards Drogga. The plan with this project is to build a wetland system that is so efficiently structured so that the SBR system can be shut down in the future. More tests are needed as regards how the SBR affects the leachate content since the metals cannot raise themselves in the reactor.

The column tests showed an increase of Cu, Cd, As, Hg and Co in the first test of the peat filter but with a tendency to decrease with time. It is hence desirable to perform more tests in order to study if the levels decrease for longer sampling-periods. It is also important to continue with the tests of flora and fauna. Many of the emissions in the leachate are namely bio-accumulative and toxic to aquatic and warm-blooded animals.

Full-scale studies have shown reduction of TOC and NH_4-N transformed to NO_3-N, but it is not completely taken despite of filters. Therefore, it is important that there is a continuous control of N_{tot} so concentrations not exceed the current requirements, which can be mounted downstream as polishing step and wetlands.

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