

Chapter 13

Constructed Wetlands and Groundwater Infiltration Treating Industrial Wastewater, Treatment Efficiency, and Pollution Tracing



Ketil Haarstad

Abstract Three treatment systems for wastewater from two landfills, one active and one closed, and an industrial location including a quarry have been monitored continuously for over a decade. The wastewater from the active landfill is infiltrated through an extensive unsaturated zone into groundwater and subsequently into a large river system. The wastewater from the closed landfill is treated in a constructed wetland (CW) and the industrial low-grade wastewater in filter dams. The treatment systems operate well with the specific wastewaters, high-concentration leachate from waste in infiltration systems, low-concentration leachate in constructed wetlands, and wastewater from inert waste in filter dams. The landfilling of organic waste was restricted to low limit values for more than a decade ago, but it is hard to see any changes in leachate due to changes in waste landfilling regulations. The heavy carbon stable isotope ^{13}C is useful in tracing landfill leachate and to evaluate dilution into other water bodies. The adding of P to the aeration pond treating low-concentration leachate did not help in the removal of N; on the contrary, the concentration of ammonia was sharply decreased when the adding of P was discontinued.

Keywords Industrial sites · Tracers · Constructed wetland treatment

13.1 Introduction

How do wetlands compare to soil infiltration when it comes to treating industrial wastewater? This chapter looks at two types of industrial wastewater, (a) from a sanitary waste landfill for ordinary waste and (b) wastewater from low-risk industrial activities such as quarries and inert waste landfilling. The wastewater from these types of locations is very different. Wastewater or leachate from waste landfills is, depending on their age, characterized by high concentrations, dominated by organic

K. Haarstad (✉)

Research Professor, Division of Environment and Natural Resources, NIBIO—Norwegian Institute of Bioeconomy Research, No-1431 Aas, 115, Oslo, Norway
e-mail: ketil.haarstad@nibio.no

matter, nitrogen, and selected heavy metals, but potentially also a number of highly toxic organic pollutants, most typically aliphatic hydrocarbons, aromatics, polyaromatics, and others. The recipients are often evaluated based on health risk classes, from 1 (background levels) to 5 (extremely polluted/hazardous waste). Changes of classes due to emissions are not beneficial, although a change from class 1 to class 2 is not critical, while from class 4 to class 5 means a full risk assessment has to be made (SFT 2003). For compounds without any acceptance limit values, the concept of pollution index can be used. This says that if the concentration of a wastewater is 10 times higher than the corresponding concentration in a particular recipient a risk evaluation will have to be carried out.

For groundwater infiltration, an area of influence can be established, in such a way that the industrial area including a zone 200 m downstream may be acceptable for increased concentrations due to diffuse emissions and assuming that the groundwater further downstream is unaffected and that the internal aquifer is of no significant interest (SFT 2003).

Wetlands can remove a large range of pollutants, also from Norwegian locations (Haarstad 2008; Haarstad and Borch 2008; Haarstad and Mæhlum 2008, 2009; Haarstad et al. 2012), due to a versatility in removal processes and materials. They are, however, also sensitive to climate and large variations in wastewater volume. For example, a review of the removal by CWs the highest pesticide removal by Vymazal and Brezinova (2015) was achieved for pesticides of the organochlorine, strobilurin/strobin, organophosphate, and pyrethroid groups, while the lowest removals were observed for pesticides of the triazinone, aryloxyalkanoic acid, and urea groups. The removal of pesticides generally increases with increasing value of KOC, but the relationship is not strong. However, at the location “closed landfill” the pesticide mecoprop, belonging to the aryloxyalkanoic group, was successfully removed in the CW, probably due to relatively high concentrations (Haarstad and Mæhlum 2008).

Non-hazardous industrial wastewaters are different from leachate, usually carrying suspended solids and, depending on the source of soil landfilling, other pollutants such as heavy metals. The example here has emission targets saying that 90% of a weekly mixed sample shall not exceed 50 mg/l suspended solids (SS), 10 mg/l hydrocarbons, and a pH between 6 and 9 (EPA, 9.12.2014).

For waste operation that includes organic waste, the leachate will usually have increased level of the heavy stable isotope ^{13}C (Haarstad and Mæhlum 2012), mainly due to the sequencing by methanogenic bacteria. This is used to trace waters polluted by landfill leachate. The content of the isotope is given as per mille relative ratio between the sample and a reference value.

The purpose of this chapter is to study the difference of the treatment of industrial wastewater in processes based on groundwater infiltration, constructed wetlands, and ponds/dams by looking the typical landfill leachate parameters and the emission permit parameters. In addition, the usefulness of using the stable isotope heavy carbon as a tracer is studied.

13.2 Methods—Locations

13.2.1 *Active Landfill*

The wastewater from the active landfill has a volume of 21,000 m³/yr. (last 5 years average). It is treated in an aeration pond before infiltration to groundwater (Fig. 13.1). The unsaturated zone is approximately 30 m thick. The distance to the river recipient is ca 300 m. Two groundwater recharge points are sampled just before the groundwater reaches the river. Infiltration systems depend to a large degree on the biological activity of the top soil zone and the particle size and mineralogy of the unsaturated zone. Beyond the soil layer, there is not biological activity.

Treated leachate samples are collected in a well where the groundwater exits the area (B4). The unsaturated zone at this point is 22 m.

13.2.2 *Closed Landfill*

The wastewater from the closed landfill has a volume of 27,000 m³/yr. (last 5 years average). It is treated in an aeration pond, a biodam with emergent plants, and finally in a horizontal flow constructed wetland (CW) (Fig. 13.2).

Constructed wetlands can be designed with a multitude of treatment elements, and for horizontal or vertical flow. The flow, however, is difficult to control and is often a major treatment limitation.

A downstream groundwater well is also sampled in addition to upstream and downstream creek working as a recipient. The sampling is carried out according to a simplified program compared to active landfills, but with a more comprehensive program every fifth year.

13.2.3 *Quarry*

The quarry is located in Oslo and is receiving inert waste such as non-polluted soil and construction materials. The wastewater from the quarry has a volume of 40,000 m³/yr. It is treated in three constructed dams with barriers that are constructed to remove particles by filtration (CW) (Fig. 13.3). The wastewater is led to a local creek with sensors both upstream and downstream measuring turbidity, suspended solids, electrical conductivity, and temperature and water level. The quarry is licensed with limited values for the wastewater; 90% of weekly logging values are below 50 mg/l suspended solids (SS), 10 mg/l hydrocarbons, and a pH value between 6 and 9 (Fylkesmannen, 9.12.2014). Filter dams are easy to construct but are subject to flow problems due to clogging or a lack of effect due to bad design.



Fig. 13.1 Active landfill with leachate infiltration to groundwater. *Photograph Haarstad*

13.3 Sampling

The sampling is part of ongoing monitoring programs at each site. The waste treatment is regulated by law and supervised by the local EPAs. The samples are analyzed according to a recommended program, with more comprehensive sampling every



Fig. 13.2 Closed landfill with leachate treatment in wetland. *Photograph Haarstad*

fifth year (SFT 2003). There is a separate program for industrial activities handling assumed un-polluted soil and waste. These mostly focus on the emission of particles. Sampling programs for landfills include both grab and time proportional mixed samples, taken at a minimum of four times a year and fortnightly, respectively. The quarry is also sampled quarterly but is in addition monitored by continuous loggers in the creek upstream and downstream.



Fig. 13.3 Quarry with gravel production, wastewater treatment in ponds. *Photograph Haarstad*

13.4 Results

13.4.1 Active Landfill

Figure 13.4 shows the concentrations of selected parameters in raw and treated leachate. Nitrogen and COD dominate the leachate. As a consequence of adopting the EU waste directive, the content of organic matter in landfilled waste was regulated in 2004 (FOR 2004), limiting the TOC to 10% or the glow loss to 20% DM. This cannot be seen as a reduction in COD over the period 2004 to 2016 (Fig. 13.4), which shows a stable and high, for Norwegian conditions, level, and indeed not in the concentrations of BOD. In addition, there are relatively high concentrations of hydrocarbons (oljeforbindelser) here represented by the sum of aliphatic hydrocarbons with C10–C40 reaching 40 mg/L. The source of the hydrocarbons has been shown to be predominately biosolids wastewater from a biogas reactor on the location.

It is obvious from the figure that the infiltration system is able to remove most of the pollutants except for PAH (Fig. 13.4). There are large and systematic variations in the concentrations of COD and $\text{NH}_4\text{-N}$, probably due to hydraulic conditions. The concentration of hydrocarbon shows high variation and concentration over a shorter period. The source of this increase is under investigation.

The mean value of the stable isotope ^{13}C in the leachate (sigevann) is 15.8 and in the treated groundwater (B4) 10.3 (Fig. 13.5), indicating a dilution factor of 1.53. The values in the unaffected groundwater (B8, K1, and K2) and the river (elv) are all negative, with the upstream well (B8) showing the lowest values. The groundwater at the point of discharging into the river, and the river itself, shows no sign of pollution from the leachate.

The removal is far the greatest for COD with ca. 265 tonnes per year from the leachate (Table 13.1), followed by nitrogen (45 tonnes), mostly as ammonia. The removal is good for all parameters in Table 13.1 except for iron (Fe), which is mobilized from the soil due to emissions of large amount of oxygen-depleting compounds creating anaerobic conditions in parts of the aquifer.

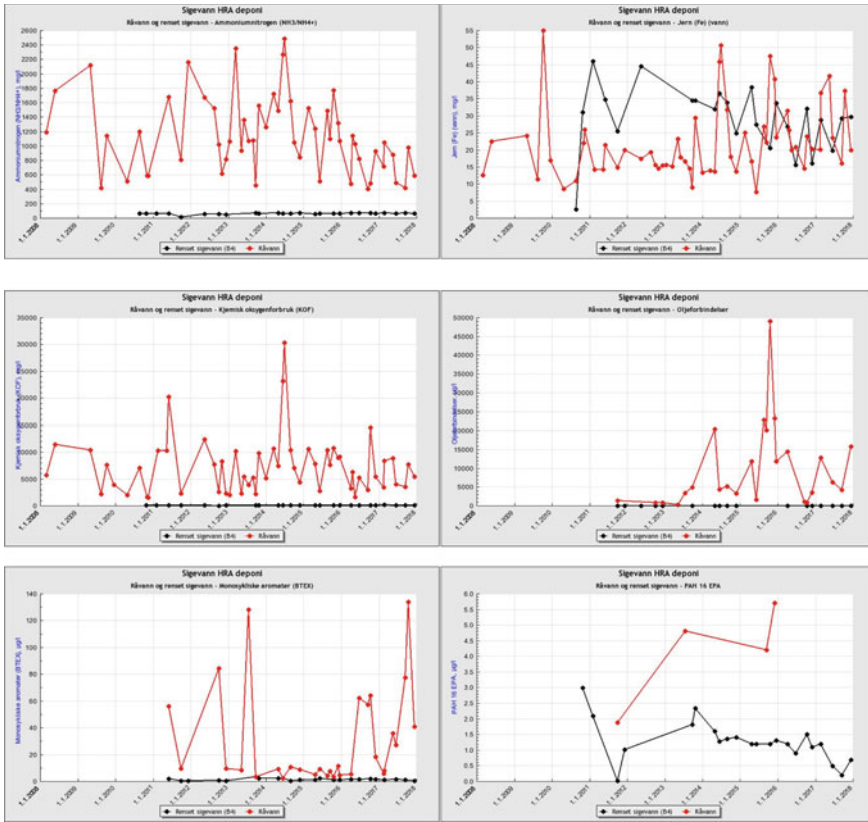


Fig. 13.4 Concentrations from 10 years of grab sampling of ammonia (NH₄-N), iron (Fe), chemical oxygen demand (KOF), hydrocarbons (oljeforbindelser), aromatics (BTEX), and PAH in raw and treated leachate from the active landfill. *Source* own data

13.4.2 Closed Landfill

Figure 13.6 shows the concentrations of selected parameters in raw and treated leachate at the closed landfill. This leachate is in the same way as the leachate from the active landfill, dominated by nitrogen and COD, but at much lower concentrations. The system is able to remove most of the pollutants. Pre-2004, the leachate was showing very high concentrations of pesticides, but they disappeared probably because a container was emptied. A striking effect is the disappearance of ammonium in the treated wastewater after 2013, corresponding with the end of a routine of adding phosphorus to the aeration pond. There is no corresponding reduction in the concentration of COD or a systematic change in the content of the stable isotope ¹³C in the treated wastewater (Fig. 13.7).

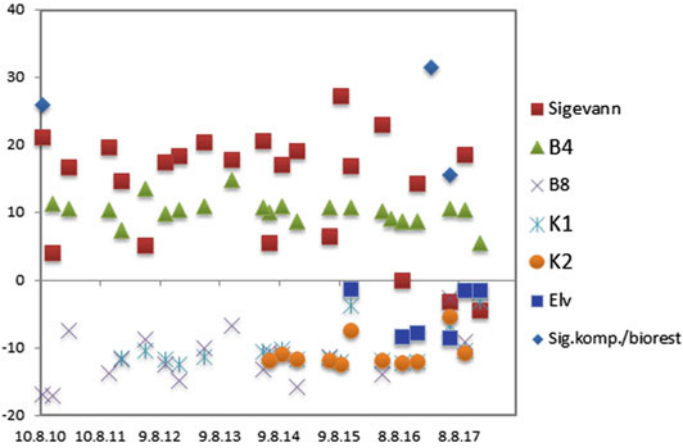


Fig. 13.5 ¹³C (%) in leachate (sigevann), wells (B4, B8), groundwater (K1, K2), and river (elv). Source own data

Table 13.1 Removal (kg/year and percentage) from the infiltrated leachate from an active landfill

	2016	2015	2014	2013	%	Average	Non-diluted
<i>NH₄-N</i>	19,400	38,956	41,025	11,061	95	24,103	36,878
<i>BOD</i>	–	–	–	12,974	99	12,974	19,850
<i>P, total</i>	–	–	–	179	99	179	274
<i>Fe</i>	–7	–121	–180	–159	–61	–146	–223
<i>COD</i>	153,819	275,357	328,594	47,813	99	173,401	265,304
<i>N, total</i>	24,236	45,132	53,933	11,131	95	29,102	44,525
<i>Suspended solids</i>	–	–	–	93	–	13,456	20,588

Source own data

The mean ¹³C in the leachate is 6.1 and in the treated groundwater –4.3, indicating a dilution factor of 1.70 (Fig. 13.7).

The removal in the CW at the closed landfill shows that the plant operates well although the removal percentage for COD is low (Table 13.2). The COD from old landfill is usually very inert and hard to remove, but also shows low toxicity and constitutes minor problems. The annual removals including dilution are much lower than for the active landfill (Table 13.2).

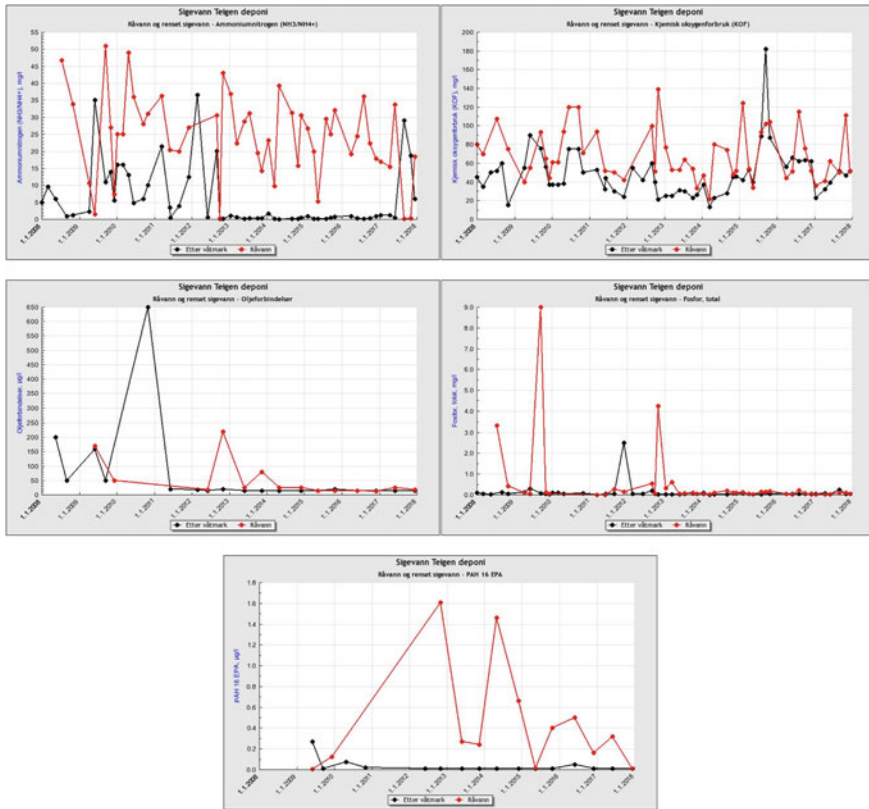


Fig. 13.6 Concentrations from 10 years of grab sampling of ammonia (NH₄-N), chemical oxygen demand (KOF), hydrocarbons (oljeforbindelser), phosphorus (F), and PAH in raw and treated leachate from the active landfill. *Source* own data

13.4.3 Quarry

The treatment at the quarry is designed to remove particles measured as suspended solids. The mean size of the dust from the area is about 100 μ m. According to filtration theory, a filter can remove from water particles that are up to 4 times finer than the mean grain size of the filter, indicating that the ultimate filter should be around 400 μ m. We had no means of separating the fractions according to this, so the finest filter used as core in the filter was made up of the fraction 1–2 mm and an outer layer of 2–4 mm gravel. As shown in Fig. 13.3, it seems to function well producing a visibly transparent water in the final dam before emission.

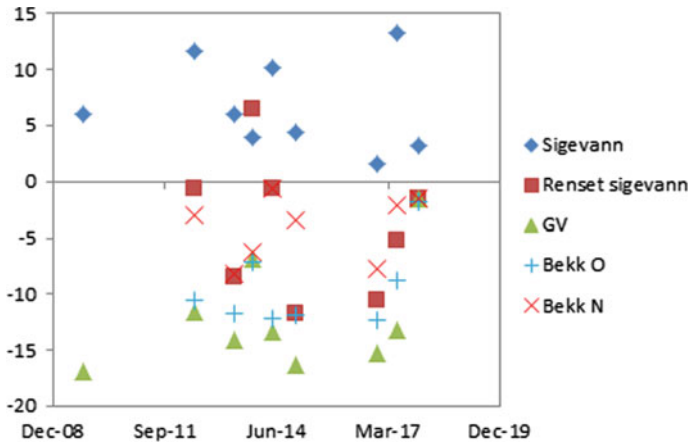


Fig. 13.7 ^{13}C (‰) in leachate (sigevann), treated leachate after wetland (renset sigevann), well (GV), and creek upstream (Bekk O) and downstream (Bekk N). *Source* own data

Table 13.2 Removal (kg/year and percentage) from the infiltrated leachate from a closed landfill.

	2016	2015	2014	2013	%	Average	Non-diluted
<i>NH₄-N</i>	625	813	769	540	89	604	1026
<i>BOD</i>				11	98	11	18
<i>P, total</i>	1	2	1	3	61	8	13
<i>Fe</i>	32	380	599	206	80	563	958
<i>COD</i>	154	108	686	626	32	535	909
<i>N, total</i>	722	–	–	557	92	640	1087
<i>Suspended solids</i>	1546	2390	1780	1490	97	2125	3613

Source own data

The concentrations of selected parameters in grab samples from the creek upstream and downstream the quarry are the same, except for a slightly higher value for electrical conductivity downstream (Fig. 13.8). The logger unit downstream, however, shows a different picture with repeated but infrequent violations of the limited value of 50 mg/l SS. Seen as weekly samples, the limit of 90% of the values does not exceed the limited value, showing good performance of the filtration dams.

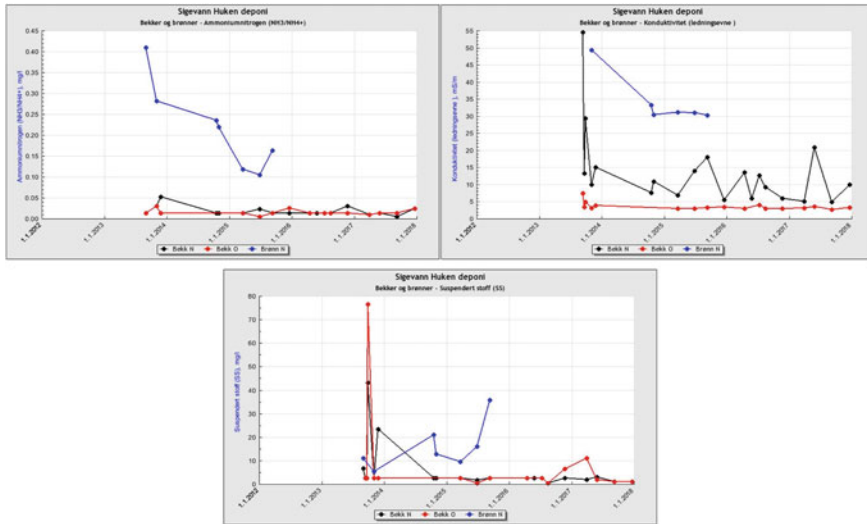


Fig. 13.8 Concentrations from 3 years of grab sampling of ammonia (NH₄-N), electrical conductivity and suspended solids in the creek upstream (Bekk O) and downstream (Bekk N) the quarry. Also included samples from abandoned well (Brønn N). *Source* own data

13.5 Conclusions

- The treatment systems operate well with the specific wastewaters, high-concentration leachate from waste in infiltration systems, low-concentration leachate in constructed wetlands, and wastewater from inert waste in filter dams.
- It cannot be expected to see changes in leachate due to changes in waste landfilling regulations.
- The heavy carbon stable isotope ¹³C is useful in tracing landfill leachate and to evaluate dilution into other water bodies.
- The adding of P to the aeration pond treating low-concentration leachate did not help in the removal of N; on the contrary, the concentration of ammonia was sharply decreased when the adding of P was discontinued.

References

For (2004) Regulations on recirculation and treatment of waste. Miljødepartementet, Oslo
 Haarstad K (2008) Longterm leakage of DDT and other pesticides from a tree nursery landfill. Ground Water Monit Rem 28(4):107–111
 Haarstad K, Borch H (2008) Halogenated compounds, PCB and pesticides in landfill leachate, downstream lake sediments and fish. J Environ Sci Health, Part A 43:1346–1352
 Haarstad K, Mæhlum T (2008) Pesticides in Norwegian landfill leachate. Open Environ Biol Monit J 1:8–15

- Haarstad K, Mæhlum T (2009) Removal of environmental pollutants from landfill leachate—a screening from four treatment plants. *Norwegian Engl Summ. Vann* 2(44):178–186
- Haarstad K, Mæhlum T (2012) Tracing solid waste leachate in groundwater using ^{13}C . *Isot Environ Health Stud* 48(3):1–14
- Haarstad K, Bavor J, Mæhlum T (2012) Organic and metallic pollutants in water treatment wetlands: a review. *Water Sci Tech* 65(1):76–99
- Vymazal J, Brezinova T (2015) The use of constructed wetlands for removal of pesticides from agricultural runoff and drainage: a review. *Environ Int* 75:11–20