Handling and assessment of leachates from municipal solid waste landfills in the Nordic countries

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in the Nordic countries**

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Preface

This project was initiated by the Nordic Council in 2003. It is a collaboration with consultants from Denmark, Finland, Iceland, Norway and Sweden. Norway and Iceland have edited the report, but the consultant group is responsible for the content. Each consultant is responsible for the submission of the national data and presentation.

Summary

EU-legislation, in particular the Landfill Directive, requires environmental monitoring of landfills, both pre- and post closure. The content of the guidelines of the Nordic countries that are brought together in this report are based on the requirements given in European legislation. Thus, the guidelines in this report are relevant for landfills subject to EU legislation.

Current leachate monitoring guidelines and practices differ among the Nordic countries. The differences are mainly based on different interpretations by the Nordic countries of the requirements in the Landfill Directive, resulting in differences in national policies. Also, economic and environmental considerations may be differently emphasised. Thus, existing guidelines are often built on a country specific trade-off between European legislation, scientific and environmental risks and socio-economic considerations. In Denmark the parameters given in the EC Directive are to be supplemented by organic parameters such as BTEX, PAH, PCB and mineral oil. Norway has new guidelines on both diffuse and point source emissions of leachate. The guidelines reflect the Norwegian list of priority hazardous substances and contain more parameters than those included in the EC Council Decision on waste acceptance criteria.

In this report a comparison is given on national leachate monitoring guidelines that were described by the consultants of Norway, Finland, Denmark, Sweden and Iceland. Based on the information that was given by these consultants suggestions for a minimum requirement monitoring program are given. This project has identified a lack of knowledge on a number of parameters in leachate monitoring within the Nordic countries, getting this knowledge might be considered to give a better understanding of possible impacts of leachate released from landfills into the environment. (or landfill leachate emitted into the environment).

From the existing leachate data that the participating countries submitted the following can be summarized:

Denmark has no national collection of leachate data, monitoring is organized at a County level, in various ways. The presented leachate data represent a limited number of landfills, mainly with mineral wastes such as ash, but also other wastes.

Finland has no target values on leachate emissions to wastewater treatment plants. Leachates are generally evaluated on quantity, COD, BOD, NH₄-N and heavy metals. Data are presented from 45 landfills that were operational until 1987 and 2 landfills that have been operational after 1987. The data show that organic matter in leachate in Finland is comparable to that in domestic wastewater, but leachate is higher in N.

Cl levels in leachate are high enough to cause corrosion. The content of heavy metals in leachate is generally low. The most prevailing organic pollutants are PAH and phthalates. The leachate shows some toxicity, both measured with daphnia and algae.

In *Iceland* time series of leachate data exists on a national level, but vary in frequency and the number of parameters that are monitored per landfill, as bigger landfills are monitored more extensively than smaller ones. Only non-hazardous and inert waste is landfilled, but a landfill for hazardous waste is under construction.

Leachates from *Norwegian* landfills are being monitored, with a wider spectrum of substances than in most other nordic countries, following an update of regulations in 2005. The current Norwegian leachate data show that concentrations in leachate are significantly higher compared to domestic wastewater. This is particularly the case for concentrations of COD and some heavy metals (Cd, Cr and Pb), both as mean concentration (1 to 5 times), but even more pronounced for maximum concentrations (> 10 times), especially in periods when there is relatively little precipitation and subsequently the leachate flow relatively concentrated. Studies on diffuse emissions from landfills show that the threshold values are exceeded to a large degree when evaluated according to general parameters (8 to 286 times), less by heavy metals (2 to 80 times) and least by organic pollutants (1 to 10 times). In leachate sediments the parameters measured above the threshold limits were phenols, PAH and tin organic compounds.

In *Sweden* leachate characteristics have been studied in several research projects and control programs, including more than 400 parameters from 30 sites. The leachate showed both estrogenic and androgenic activities. More than 8 million m³ of leachate was collected in 2003, of which 5 million m³ was treated in municipal wastewater treatment plants. The number of active landfills was 192 in 2003, expected to decline to 100 by 2008.

It is difficult to compare the reported leachate data from the different nordic countries, because of the differences in collection routines, site specific conditions, waste sorts landfilled and other factors. Denmark has presented more data on mineral waste, including ash from incineration plants, compared to the other countries. These data might represent future leachate quality if incineration of waste is going to be more important. The leachate quality reported from Denmark show relatively high concentrations, surprisingly also for COD and nitrogen. When nordic leachate quality are compared within the Nordic countries, there seem to be relative small differences, except high maximum values for Fe and Zn in Norway. Finland reports higher levels for Zn.

Based on this study, the following guideline recommendations can be made for the Nordic countries:

Denmark: a fixed system for sampling frequency is suggested, with the Counties defining the sampling parameters applicable locally.

Finland: all leachate should be collected and treated.

Iceland mentions locally adaptation of monitoring programs and flow-based evaluation of the emissions.

Norway: hydraulically based monitoring is suggested as well as specific guidelines on sampling and analysis and monitoring of acute and chronically toxicity of leachate. Emissions to the atmosphere should also be included in the monitoring, and also time or weight specific threshold values of emissions.

An overall conclusion might be that although the Nordic countries are subject to the same EU-legislation on waste treatment and leachate, both the reported experiences and the present guidelines on leachate collection, monitoring and analysis differ to a relatively large extent. Regions might benefit from a stronger consensus on leachate control, both on a national and Nordic level. Recommendations and a suggestion for a minimum level of leachate monitoring is given in chapter 7.

Sammendrag

EUs lovgivning, og i særdeleshet Deponidirektivet, foreskriver miljørettet monitorering av deponier, både i drifts- og i etterdriftsfasen. De nordiske retningslinjer og veiledere som er gjengitt her er basert på krav gitt i EUs lovgivning, og er dermed relevante for deponier underlagt denne lovgivning.

Nåværende retningslinjer og praksis for monitorering av sigevann er ulike i de nordiske landene. Forskjellene er i hovedsak basert på ulik forståelse av krav gitt i Deponidirektivet og som har gitt ulike nasjonale fremgangsmåter. I tillegg kan økonomiske og miljømessige forhold vektlegges ulikt. Dermed vil eksisterende retningslinjer ofte bestå av en balanse mellom europeisk lovgivning, vitenskapelig og miljømessig risiko og sosioøkonomiske vurderinger. I Danmark er parametrene som er gitt i EUs deponidirektiv supplert med organiske parameter som BTEX, PAH, PCB og mineralolje. I Norge er det gitt ut nye retningslinjer både når det gjelder diffuse utslipp og punktutslipp. Retningslinjene reflekterer den norske listen over prioriterte miljøgifter og omfatter flere parametre enn de som er inkludert i EUs direktiv over karakterisering av avfall.

I denne rapporten er det gitt en sammenligning mellom nasjonale retningslinjer for overvåking av sigevann, som beskrevet av konsulenter fra Danmark, Finland, Island, Norge og Sverige. Et minimumsnivå for overvåking av sigevann er gitt, basert på informasjon gitt av de ulike konsulentene. Prosjektet har identifisert kunnskapshull når det gjelder en rekke parametre innen sigevannsmonitorering i de nordiske landene, som kan gi mangelfull håndtering av de effekter som utslipp av sigevann fra deponier kan gi i miljøet.

I det følgende er det gitt sammendrag angående eksisterende sigevannsdata i de deltagende landene:

Danmark har ingen nasjonal innsamling av sigevannsdata. Overvåking er organisert av de ulike amter, på ulike måter. De data som presenteres representerer et begrenset antall deponier, mange med mineralsk avfall som f.eks. aske, men også andre avfallstyper.

Finland har ingen terskelverdier når det gjelder påslipp av sigevann til renseanlegg for avløpsvann. Sigevann blir generelt vurdert mht. mengde, KOF, BOF, NH₄-N og tungmetaller. Data er presentert for 45 deponier, som var i drift inntil 1987, og 2 deponier som er i drift etter 1987. Dataene viser at organisk stoff i sigevann i Finland er sammenlignbart med avløpsvann fra husholdninger, men inneholder mer N. Innholdet av Cl er tilstrekkelig til å gi problemer med korrosjon. Innholdet av tungmetaller er generelt lavt. De organiske miljøgifter som forekommer hyppigst er

PAH og ftalalter. Sigevannet er noe toksisk, både målt med daphnia og alger.

Island har tidsserier på sigevannsdata på nasjonalt nivå, men antall parametre og frekvensen av målingene varierer siden store deponi måles hyppigere enn små. Kun ordinært og inert avfall blir deponert, men et deponi for farlig avfall er under bygging.

Sigevann fra norske deponi blir overvåket med et bredere spekter av stoffer enn de fleste av de øvrige nordiske landene, etter en oppdatert veileder fra 2005. Eksisterende sigevannsdata viser at konsentrasjonene er betydelig høyere enn i avløpsvann. Dette gjelder særlig for KOF og enkelte tungmetaller (Cd, Cr og Pb), både som middelerdi (1 til 5 ganger høyere), og særlig som maksimumsverdi (> 10 ganger høyere), særlig i perioder med lite nedbør og lav sigevannsproduksjon. Studier av diffuse utslipp fra deponier viser at eksisterende terskelverdier overskrides i høy grad både målt som generelle parametre (8 til 286 ganger), i noe mindre grad for tungmetaller (2 til 80 ganger), og i mindre grad for organiske forbindelser (1 til 10 ganger). Parametre som overskrider terskelverdier i sigevannssediment var fenoler, PAH og tinorganiske forbindelser.

Karakterisering av sigevann i Sverige er beskrevet i flere forskningsprosjekter og kontrollprogram, og har inkludert mer enn 400 parametre fra 30 lokaliteter. Sigevannet viste både østrogen- og androgenaktivitet. Mer enn 8 millioner m³ av sigevann ble innsamlet i 2003, hvorav 5 millioner m³ ble behandlet i renseanlegg for sigevann. Antall aktive deponier var 192 i 2003 og forventes å avta til 100 innen 2008.

Det er vanskelig å sammenligne eksisterende sigevannsdata fra de nordiske landene, fordi ulike rutiner i innsamling, stedsspesifikke ulikheter, ulike avfallstyper og andre faktorer varierer. Danmark har presentert mer data på mineralske avfallstyper, f.eks. aske fra forbrenningsanlegg, sammenlignet med de øvrige landene. Disse data kan representere forventet sigevannskvalitet i fremtiden siden avfallsforbrenning forventes å bli viktigere.

Sigevannskvaliteten rapportert fra Danmark viste relativt høye konsentrasjoner, overraskende nok også for KOF og nitrogen. Når sigevannskvaliteten sammenlignes innen de nordiske landene ser det ut til å være små forskjeller, kanskje med unntak av høye konsentrasjoner for Fe og Zn i Norge, og høye verdier for Zn i Finland.

Følgende forslag til retningslinjer for overvåking av sigevann er fremkommet i dette prosjektet:

Danmark: et system for innsamlingsfrekvens er foreslått, mens de ulike amter definerer parametre med lokal tilpasning.

Finland: alt sigevann må innsamles og behandles.

Island: lokal tilpasning av monitoreringsprogram og mengdebasert evaluering av utslippene.

En overordnet konklusjon fra prosjektet er at til tross for at de nordiske landene er underlagt felles EU-lovgivning når det gjelder avfalls- og sigevannsbehandling, er det relativt store forskjeller i eksisterende veiledere og retningslinjer for sigevannsinnsamling, prøvetaking og analyse. Regioner innen de nordiske land kan dra fordel av en større consensus når det gjelder kontroll av sigevannet. Anbefalinger og forslag til et minimumsprogram for sigevannsovervåking er gitt i kapittel 7.

Objective

The main objective of this project is to summarise national guidelines and give recommendations for leachate monitoring in the Nordic countries, based on today's knowledge of leachate quality and quantity in these countries.

Final milestone:

The aim is to give recommendations to the Nordic countries on how to fulfil the requirements for leachate monitoring that are based on the Landfill Directive. The recommendations must include suggestions of suitable leachate parameters. Leachate parameters might give an indication for the degree of stabilisation of a landfill, i.e. the progression to final storage quality, and thus assist with estimating the necessary length of the aftercare period.

Further recommendations will be given on how to evaluate environmental impacts from leachate analysis. These recommendations will be given in the view of obligations from international conventions (such as the Stockholm-convention). Lastly, recommendations are given for possible further investigations and research concerning environmental impacts of discharge of leachate into the environment, that might be helpful to reach a more consistent approach of leachate monitoring and treatment within the nordic countries.

1. Background

The extent of environmental effects of the release of municipal solid waste (MSW) leachate into the environment is still under debate. Environmental impact assessments on the discharge of landfill leachates into the environment are often unsatisfactory because of the focus on a limited number of factors and substances, usually nutrients and metals. Little is known about the abundance and possibly environmental impacts of organic pollutants such as the PCB (polychlorinated biphenyl), DDT (dichlorodiphenyltrichloroethane), and brominated flame retardants, chlorinated solvents, phenols and phthalates, hormonally active agents (HAA's), pharmaceuticals and others in leachate. A number of studies and reports have shown presence of these substances. Logically, landfills are suspected to contain most of the substances that are produced and used in our society, but little is known about their concentrations in leachate, degradation, mobilisation and possible (co-)effects in ground- and surface waters and surrounding ecosystems.

The Landfill Directive (1999/31/EC) stipulates that leachate from landfills must be collected and treated to the “*appropriate (national) standard*” that is required for their discharge. Typically, this means leachate from landfills for non-hazardous and hazardous waste. An appropriate standard remains to be defined, and depends today in most cases on local evaluation. There are also requirements to control water from precipitation, surface water and groundwater entering into the landfill body. Furthermore, the Directive stipulates that control and monitoring systems should reflect the characteristics of the landfilled waste.

It is assumed that the Nordic countries generate similar waste types, and have comparable techniques of landfilling. Climatic conditions are relatively similar with cold and cold temperate climates including dry winter seasons and periods with snow-melting or heavy precipitation. Many recipients are sensitive for surges of water pollution.

An important aspect of monitoring landfills is to identify when a site no longer presents a significant risk of pollution or harm to human health or the environment, which indicates that it is stabilized.

1.1 Chemicals of concern

The European environmental authorities operate with lists of priority chemicals of particular environmental concern, see Table 1.

Table 1. Examples of lists of hazardous chemicals

	Name	No. of chemicals	Reference
Denmark	Max. C of substances in groundwater	26	Statutory order of landfills
Norway	The Observation List	>250	White paper no. 58, 1996–1997 (See Annex D.2 to this report)
Norway	List of Priority Substances	33	White paper no. 58 2002–2003 (Annex D.3)
Norway	Guidelines on leachate monitoring	Leachate: 24 Screening: 17 Sediments: 15	SFT guideline no. TA–2077/2005 (Annex D.4)
Norway	Guidelines on risk assessment of landfills	Leachate: 42 Sediment: 28	SFT guideline no. TA–1995/2003 (Annex D.5)
Finland	List of major contaminants for which permit values are set	12 groups of substances	National Regulation 169/2000 (Water Framework Directive 2000/60/EC, list VIII) Annex G.2
Germany	Requirements for leachate emissions	17	
EU	Pollution Inventory	91	Council Directive 1996/61/EC (Annex G.1)
EU	Leachate limit values for inert waste and hazardous waste going to landfill	17	Council Decision 2003/33/EC

For Norway: The Observation List includes chemicals with particular risk to human health and the environment and is a part of the national regulation on classification and labelling of hazardous chemicals. The Priority List includes chemicals of concern because of their toxicity, mobility and availability.

1.2 Leachate monitoring

Leachate monitoring programmes may vary according to landfill category (type of waste, capacity), and whether the landfill is operational or closed. In addition to a basic programme, landfills are required to carry out extended monitoring programmes. Common reporting practices are to evaluate contents of organic matter, nutrients and toxicants leachate, relative to total emission limit values that can both be recipient independent or -dependent.

In some countries only a few of the listed substances causing concern are regularly monitored in municipal solid waste (MSW) leachate, although most of them are fairly common in many types of waste. In this report, many of the substances that are mentioned in the list above have not been monitored until now but should be monitored according to current (EU) legislation.

1.3 Environmental effects of leachate

Common environmental effects from landfill leachate are saprobiation, eutrophication and toxic effects.

Saprobiation

Large organic loads can make bacteria and fungi grow in large numbers which will consume the oxygen in the water. Such growth can be seen as white or grey mats in the bottom of a watercourse. Reduced level of oxygen deteriorates the living conditions, and the natural distribution of for example bottom animals and fish can be disturbed. Saprobiation can be addressed by setting emission limits of organic matter, or maximum allowed levels of oxygen depletion in the recipient.

Organic matter is usually analyzed as total organic carbon (TOC), chemical oxygen demand (COD), biochemical oxygen demand (BOD), either on filtrated or undisturbed water samples.

However most of the organic carbon in a treated (aerated) leachate are thought to be humic and fulvic acids. Fulvic acids consist of large molecules that have low biodegradability and thus low impact on the oxygen consumption.

Eutrophication

Leachate may have high concentrations of P, N and Na, Ca, K, Mg, Mn. Excess plant nutrients, mainly phosphorus and nitrogen, lead to eutrophication which is algae blooms and the presence of nutrient demanding species. Some blue green algae produce toxins.

Ecotoxicological effects

Some substances are harmful to water-living organisms and can cause ecotoxicological effects. These substances can be organic or inorganic, natural or anthropogenic. The most harmful substances are toxic, slowly degrading and bio accumulating. Degrading substances can also cause effects, especially from long-term exposures, but with limited impact. The toxicological effects from leachate can to some degree, be evaluated from chemical analyses of known toxicants. A lot of substances are listed with data on degradation (hydrolysis, photo degradation, soil, air and water half lives), potential bioaccumulation and toxicity towards different species (algae, bacteria and other). Leachate will, however, contain a large number of unknown substances necessitating toxicity tests in addition to chemical analyses. Such tests measure, to a variable extent, the accumulated toxicity in the leachate.

Biological investigations in receiving waters can reveal ecotoxicological effect such as redistributed or missing species downstream of a leachate emission point. If the leachate also contains high concentrations of organic matter and nutrients, the saprogenic effects and eutrophication

can mask toxicological effects. The most pronounced masking effect in leachate is due to ammonia toxicity, especially at high pH.

Besides acute toxicity, long-term or chronic effects have to be considered. Recently such effects, linked to reproduction and development in animals through hormonal activity, have received increased attention. Release of substances into the aquatic environment through municipal and industrial discharges has been shown to interfere with hormone directed processes in the organisms. Some circumstantial evidence has been presented that substances from landfill leachates may cause impaired reproduction in some fish species (Linderoth et al. 2000, Noaksson et al. 2001, 2003). Both estrogenic and androgenic hormonal effects have been detected by in vitro testing in landfill leachates (Svenson et al. 2004 a,b). According to Svenska renhållningsverksföreningen (2003) the crustacean *Nitocra spinipes* are recommended for testing ecotoxicological effects from leachate, because it has sexual reproduction, has a short and well defined life cycle and lives in salty or brackish waters.

Hormone disrupting effects from landfill leachates

Landfill leachates contain substances that affect the hormone regulation if exposed to higher aquatic animals, such as fish and amphibians. Substances identified so far have been the natural and synthetic steroids estradiol and ethinylestradiol, and the industrial chemical bisphenol A, which are known to interfere with the estrogen receptor (Svenson et al. 2004b). The chemical identity of substances causing androgenic effects is not known. Their composition is heterogeneous and their water-solubility properties vary (Svenson et al. 2004a).

Estrogens and androgens can be found in leachates. If the hormones are released into waters, they may affect aquatic organisms. Similar levels to those detected in leachates have also been recorded in treated municipal wastewaters. The effects of wastewater treatments on the hormone disrupting effects in landfill leachates have been studied (Ek et al. 2003). There are methods capable of reducing the hormonal reducing effects in landfill leachates.

1.4 Degree of stabilisation/maturation (Final Storage Quality)

The waste degradation processes in a landfill goes through a number of phases, see Figures 1 & 2. The gas phase emission goes from “normal” air quality to intermediate phases where CH₄ and CO₂-concentrations increase. Closer to the maturation of the waste, the landfill air quality returns to its initial quality with high concentrations of nitrogen and low concentrations of CH₄ and CO₂. According to this, a landfill can be considered to be stable when these gases in intermediate phases, are strongly

reduced after relatively high levels (50–60%), assuming that other factors are not limiting. This is reflected in recommendations from the UK where there are limit values for diffuse emissions of methane equal to $1 \cdot 10^{-3}$ mg/m²*s, equivalent to 0.004 m³ methane per tonne per year for a 10 m deep landfill (Knox, 2004).

The processes reducing the concentrations of organic and inorganic substances in the leachate phase with time are more complex than for gases, since several of the reduction rates level out for long periods of time, e.g. for NH₄, Cl and COD, see Figure 2. For a number of organic and inorganic parameters a late release from a landfill cannot be ruled out, e.g. for heavy metals (see Figure 2).

Figure 1. Distribution of landfill gas with time (Christensen & Kjeldsen, 1995)

Figure 2. Distribution of landfill leachate concentrations with time (Christensen & Kjeldsen, 1995)

The definition of final storage quality (FSQ) has implications for the operation and management of a landfill site, both during its operation and after its closure. FSQ is generally defined as the state of the landfilled waste at the time when the emissions become and remain acceptable, and active environmental protection systems become unnecessary (Hjelmer et al., 2004). FSQ might be technically defined in different ways, either as a flux or as concentrations of contaminants, the first being more achievable within a reasonable timeframe, and the latter being easier to control. It is generally believed that FSQ is not possible to reach in a reasonable timeframe unless the waste is treated prior to or during landfilling.

Residual material from the degradation of organic waste can be defined as stable or mature. A stable material consumes little oxygen in an aerobic process, has a high C/N-ratio (see Table 2), and a specific microbial flora characterised by moderate temperatures (20 °C), such as actinomycetes and other soil micro organisms. A mature material can be described as a material not being anti germinating (except for possible high levels of salts), and having a low content of fatty acids, a high content of humic acids, and a mineralized nitrogen consisting of mainly of nitrate and not ammonium.

Table 2. Examples of organic matter and nitrogen in waste and leachate (Norway).

		Landfill 1 *	Landfill 2	Mean landfills	Landfill3	Biocell
		Leachate			Waste	
KOF	mg/l	138	264			
TOC	mg/l	46	88	85		
Tot-N	mg/l	7,5	8,3	100		
C/N	-	6,1	10,6	0,85	3	16

* Landfill 1 & 2: leachate from old landfills (closed > 30 years ago). Mean landfills = mean value Norwegian leachate 1998-2002. Landfill 3 = excavated and sieved MSW from an active landfill. Biocell = excavated from household organic waste biocell.

According to Heyer & Stegmann (1997) a model estimate of BOD half-life is 6 years during anaerobic degradation of organic matter in conditions with 30°C. This half-life can be tripled with a temperature reduction to 10 °C (Nielsen & Petersen, 2000), see Figure 3 and Table 3. The fatty acids will, measured as BOD, be consumed during the active period of the landfill. Under warm conditions, an 85% reduction of organic matter requires less than 20 years. In cold climates, e.g. in the Nordic countries, this process takes more than 50 years.

Table 3. Estimate of time periods to reach limit concentrations (after Heyer & Stegmann, 1997)

Parameter*	Limiting C mg/l	Concentration at the beginning mg/l	Half-life Years	Period to limit value Years
COD	200 (Germany) 60 (Switz.)	2000–43 000	25–96	120–220 200–300
TKN	70 (Ger.) 5 (Switz.)	800–3900	40–150	120–300 280–580
Cl	100	500–4200	40–90	120–220

*TKN=Total kjeldahl nitrogen

A similar reduction can be observed for VOC in the gas from composting (Figure 4), with a half-life of ca. 23 days, equivalent to 47% of the total degradation period (Bergersen & Berg, 2001). The total annual VOC emissions from incineration in Norway are estimated to 300 tons (Weidemann, 1997). Composting plants have different control measurements, usually for temperature, O₂ and CO₂, more seldom CH₄, VOC and others (Østdahl & Tronstad, 1995). The operation of a landfill is, however, different from operating a compost or digestion plant, with significantly less operational control.

Figure 3. Model reduction of VOC under 30 °C (diamonds) and 10 °C (circles).

Based on leaching tests in landfill simulators the half-lives and the corresponding times for achieving specified concentration limits in leachate have been calculated according to the equation below, see Table 3 (Heyer & Stegmann, 1997):

$$C_t = C_o * e^{-k(t-T_o)}$$

C_t is concentration at time t

C_o is start concentration

k = half life constant

t = test period (days)

T_o = start of leachate recirculation in test (days)

Figure 4. Measured reduction of VOC during composting (Bergersen & Berg, 2001).

A number of parameters and factors are listed below. These can be used to evaluate the FSQ. The parameters are not in a priority sequence. Their suitability will vary depending on local site specific conditions.

Leachate is found to contain substances represented in all the waste that is landfilled. Landfill gas on the other hand, can vary more. For example, typical municipal and organic waste have gas potentials of 150–300 litre/kg DM, while typical extraction rates of landfill gas are 30–50 litre/kg DM, thus only representing a small fraction of the gas produced.

Measuring biological degradability of solid waste samples also raises many methodological and statistical questions. Also, waste and landfill types vary, e.g. monolandfills to municipal waste landfills. Another problem might be the evaluation of potential emissions based on “harmless” factors such as residual COD.

Suggested parameters for evaluating final storage quality (FSQ):

Leachate specific parameters

- Comparisons with landfill acceptance criteria (i.e. leaching criteria for inert waste, for example $C_o=160$ mg/l for DOC, see Council decision 2002 of the Waste Directive 1999/31/EC, Annex G.3). Comment: These are criteria for receiving waste to final treatment and are not necessary suitable for leachate emissions
- Specific limit values (COD<200 mg/l, TKN<70 mg/l Germany; COD<60 mg/l, TKN<5 mg/l, Cl<100 mg/l Switzerland)
- Low BOD/COD ratio (<0.1 – 0.2)
- High ratio of non-degradable/degradable organic matter (i.e. humic acid*/BOD-ratio)
- High C/N ratio
- High NO_3 concentrations
- No volatile organic acids(*)
- Occurrence of (specific) humic acids*
- Occurrence and disappearance of a secondary release of pollutants, for example selected heavy metals*

Gas specific parameters

- $CO_2 < 1.5\%$ and $CH_4 < 1\%$ for at least 2 years (UK), or
- $CO_2 < 22$ l/hour and $CH_4 < 15$ l/hour from any borehole for > 2 years (UK).
- $CH_4 < 25$ m³/hour as total from landfill, or
- $CH_4 < 5$ m³/hour and hectare (DK).
- Comment: this might be a “strict” criteria, see e.g. Table 5.
- VOC in the gas* Comment: VOC in landfill gas from active sites vary from 2–22 ppm (Haarstad & Bergersen, 2004; Bergersen & Bøen, 2004)
- Other waste gases (e.g. H_2S , CO)*

Waste specific parameters:

- Measurable degradable materials (cellulose, hemicelluloses, or acid digestible materials)*
- “Indirect” measurements such as loss on ignition (LOI), COD, TOC, BMP, aerobic oxygen consumption (AT), and others. Comment: the degradation of individual substances is generally of less importance than the overall degradability measured by indirect measurements
- Biological methane potential (BMP)<0.1 m³ methane per dry tonne (or > 99.9% degradation)
- Directive for bio waste (proposal) $AT_4 < 10$ mg O/g dry matter (DM)
- Compare with Directive for bio waste (proposal) <30 Nm³ gas /t dm or ~ 85% degradation

- Guidelines for mechanical biological pre-treatment (MBP) from Austria: sum gas generation $GS_4 < 20 \text{ Nm}^3/\text{t DM}$, $AT_4 < 7 \text{ mg O}_2/\text{g dry matter (DM)}$; from Germany: $AT_4 < 5 \text{ mg O}_2/\text{g DM}$ or biogas potential over 21 days, $GB_{21} < 20 \text{ Nl/g DM}$
- Presence of microbial flora typical of low-temperature ($< 20^\circ\text{C}$); micro organism typical for soil or actinomycetes typical for aerobic conditions dominate over typical waste degradation micro organisms such as methanogens, acetogenic and sulphate reducing bacteria

* Parameters and factors with few data and experience

2. Sampling Guidelines/Programmes

2.1 Denmark

The Guidelines on Landfilling (Miljøstyrelsen, 1997) provide some guidance to be used as a starting point when setting up a leachate monitoring programme for landfills for inert waste, mineral waste and non-hazardous, mixed waste, respectively. They are presented in Table 4.

Table 4. Proposed analytical programme for monitoring of leachate from Danish landfills (Miljøstyrelsen, 1997).

Parameter	Unit for inert waste*		Unit for mineral waste		Unit for non-haz. mixed waste	
	Extended	Routine	Extended	Routine	Extended	Routine
pH	P	P	P	P	P	P
Conductivity	P, M	P, M	P, M	P, M	P, M	P, M
TDS	P	P	P, T	P, T	P, T	P, T
BOD5					P, T	
NVOC/DOC	P, M		P, M, T		P, M, T	P, M, T
AOX			P, M, T		P, M, T	P, M, T
GC-FID screening					P, M	
Total N	P		P, T		P, T	
Ammonia N					T, M	T, M
Chloride	P, M	P, M	P, M, T	P, M, T	P, M, T	P, M, T
Sulphate	P, M		P, M	P, M	P, M	P, M
Sulphide	P		P, T	P, T	P, T	P, T
Na	P, M		P, M		P, M	
K			P, M, T			
Ca	P, M		P, M		P, M	
Fe			P, M		P, M	
Cd			P, M		P, M	
Cr (total)			P, M		P, M	
Cu			P, M		P, M	
Ni			P, M		P, M	
Pb			P, M		P, M	
Zn			P, M		P, M	

P: Parameter related to the general pollution potential of the landfill

M: Parameter related to the monitoring of groundwater and surface water

T: Parameter related to the treatment of leachate

*: At inert landfills where leachate collection is possible

The Guideline states that the leachate monitoring programme for a specific landfill does not necessarily need to include all the parameters listed in Table 4 and that, on the other hand, it may be necessary in specific cases to add further parameters that are not listed in the table. Table 4 indicates the choice of parameters. It shows whether they were chosen to provide information in relation to the general pollution potential of the landfill (P), the groundwater or surface water monitoring programme (M)

or the loading or influence on the leachate treatment system (T). The Guideline also states that the leachate should be analysed for all parameters that occur in the groundwater/surface water monitoring programme. New Guidelines will be released once the Council Decision has been implemented into national legislation.

It seems reasonable to assume that future leachate monitoring programmes will include analyses of the parameters for which leaching limit values have been set in the acceptance criteria of Council Decision 2003/33/EC and the national implementations. The DEPA intends to add leaching criteria for some organic substances or groups of organic substances to the list of leaching limit values for inorganic parameters (and DOC/phenols) given in the Decision. These organic parameters (such as BTEX, PAH, PCB and mineral oil) are therefore likely to become a part of the standard analytical programme for future leachate monitoring schemes at Danish landfills, at least for the extended analysis version.

Annex A.1. includes a listing of maximum concentrations in groundwater as a basis for a risk assessment of leachate emissions to groundwater.

2.2 Finland

The monitoring requirements for the groundwater in Finland are:

- The monitoring program for specific locations shall follow the general and specific specifications given in the relevant directives and country specific regulations (§§14 and 15. and appendices I & III)
- Monitoring of groundwater must include at least two monitoring points in the groundwater outflow region and at least one monitoring point in the groundwater inflow region
- Groundwater wells utilised for drinking water purposes have to be monitored
- The water level inside the waste filling has to be monitored every six months. The groundwater level has to be monitored every sixth months. If the groundwater level varies, the monitoring level has to be increased.
- The sampling frequency and the analysed substances are determined site specifically. In addition, the velocity of the groundwater flow has to be taken into account. The measurements should provide information on water quality changes.
- If the quality of the groundwater is found to be deteriorated or permit levels are exceeded, the instruction in the permit should be followed.
- The measurements and the quality data has to be collected, registered and presented in the form of table that allows easy detection of any changes in the water quality

The monitoring requirements for the surface water in Finland are:

- At least two monitoring points are selected, one in the inflow region of the landfill and one in the outflow region of the landfill. These points are monitored for the quantity and quality of the water four times a year and after the closure of the landfill twice a year.

The monitoring requirements for the leachate in Finland are:

- The quantity and quality of the leachate has to be monitored at every discharge point of the leachate.
- The leachate conducted to the treatment has to be monitored so that the effectiveness of the treatment and the pollution discharge of the landfill can be evaluated
- The quantity and the electrical conductivity have to be measured every week except during the peak discharge every day.

The other quality parameters are analysed every three months. During the after-care phase of a landfill the parameters are monitored every six months. The quality parameters included in the analysis program are determined by the quality of the waste

In practice, the monitoring points of the groundwater have been more than minimum three points in almost every case. The leachate monitoring contains normally more substance analysis than other monitoring and is utilised for the evaluation of the possible pollution discharge to the groundwater and the surface water.

It is a general requirement that both the quantity and quality of the leachate are measured. Also the sediment in the leachate should be analysed in order to measure substances with low water solubility.

2.3 Iceland

Landfills are categorized according to capacity and type as following:

- Cat. 1: landfills for non-hazardous waste, capacity > 5000 tonnes a year (4 total)
- Cat. 2: landfills for non-hazardous waste, cap. 500–5000 tonnes a year (7 total)
- Cat. 3: landfills for non-hazardous waste, cap < 500 tonnes a year, and also landfills for inert waste with a capacity of > 20,000 tonnes a year (17 total)
- Cat. 4 landfills for inert waste, cap. < 20,000 tonnes a year (10 total)

Standard parameters that have to be monitored at all landfills in category 1–3 are typically COD, $\text{NH}_4^+/\text{NH}_3$, conductivity, pH and temperature. Furthermore, the range of pollutants/parameters to be monitored and frequency of leachate sampling is related to capacity of the landfill as shown below.

Table 5. Monitoring programme for Icelandic landfills, Cat. 1–4

Category	Parameters to be monitored	Frequency	Type of sample
1	pH, conductivity, temperature, COD, $\text{NH}_4^+/\text{NH}_3$	2 times a year	Leachate before & after treatment* and/or in boreholes up- and downstream of landfill
	Leachate flow	weekly	Leachate before & after treatment* and/or in boreholes up- and downstream of landfill
	NO_3^- , total-N, total-P, Pb, Hg, Cd, AOX, oil/fat	Once a year	Leachate before & after treatment* and/or in boreholes up- and downstream of landfill
	Fe, Cr, Cu, Zn, As, Ni	Once every 3–4 years	Leachate before & after treatment* and/or in boreholes up- and downstream of landfill
	Pb, Cd, Hg, AOX	Once every 4 years	In mussels and sediment near outlet
2	Groundwater level		In boreholes near landfill
	pH, conductivity, temperature, COD, $\text{NH}_4^+/\text{NH}_3$	Once every 2 years	Leachate before & after treatment* and/or in boreholes up- and downstream of landfill
	Groundwater level	4 times a year	Leachate before & after treatment* and/or in boreholes up- and downstream of landfill
	Other parameters	In case of high levels in standard package	Leachate before & after treatment* and/or in boreholes up- and downstream of landfill
3	pH, conductivity, temperature, COD, $\text{NH}_4^+/\text{NH}_3$	2 times a year	Measured in recipient**
	Pb, Hg, Cd, AOX, NO_3^- , total-N, total-P, oil/fat	In case of high levels of standard package	Measured in recipient**
4	Groundwater level	4 times a year	In boreholes near landfill
	pH, conductivity, temperature, COD, $\text{NH}_4^+/\text{NH}_3$	Once a year	Measured in recipient**
	Pb, Hg, Cd, AOX, NO_3^- , total-N, total-P, oil/fat	In case of high levels of standard monitoring	Measured in recipient**
	Groundwater level	Four times a year	In boreholes near landfill

* Treatment options used in Iceland: fat/oil separator, sand or peat filter, oxidising pond

** Leachate collection and treatment not obligatory if values within the limits of the permit. Recipient can both be surface- and groundwater

In one case (Álfsnes, Sorpa, Reykjavík, capacity over 100.000 tonnes a year, Iceland's largest landfill for municipal waste) monitoring of the sediment as well as mussels in the neighbourhood of the leachate outlet (sea) has to be monitored once every 4 years. On another landfill, Kirkjuferjuháleiga in South-Iceland, sediment in the recipient (river Ölfusá) is monitored on a every fourth year.

Where leachate is collected, also leachate flow in the outlet to the recipient has to be monitored on a weekly basis, but there are only a few landfills operating such a system today (has to be in place by 2009 under the LFD).

In Table 5, leachate data from respectively category 1 and category 2 landfills are brought together for the period 1998–2004. These are the most recent and accurate data available in Iceland today. These values are based on samples taken after treatment of the leachate, i.e. as it enters the recipient. (Leachate collection and treatment is not carried out with landfill-categories 3 & 4 in Iceland and therefore monitoring programs there are based on quality control of the ground- and surface water near the landfill).

2.4 Norway

The waste hierarchy in Norway aims to minimize the generation of waste, and to ensure the best management of the waste generated. Also, regulations are implemented to protect the environment from emissions from landfills. The recipients must be protected, preferably according to the guidelines TA-1467 and TA-1468.

The two most relevant guidelines regulating landfills and leachate are:

- Guidelines on *environmental risk assessments* on landfill bottom liners and leachate collection, TA-1995/2003, issued in 2003. It seeks to control diffuse pollution from landfills. The guidelines for environmental risk assessment prescribe a three level investigation of landfills. The evaluation is based on three steps:
 - a) Source characterization – leachate and waste
 - b) Transport characterization – establish a water balance for the landfill and the local dissemination of leachate to the environment
 - c) Recipient characterization – establish a model of the diffusion of leachate into recipients and verifying effects
- Guidelines on *monitoring of leachate* from landfills, TA-2077/2005, issued in 2005. This regulates the controlled emissions of leachate from landfills.

The guidelines include a sampling programme with 13 general parameters (of which 3 with defined thresholds), 13 metals and elements (of which 10 with defined thresholds), 12 organic pollutants (groups) (of which 7 with defined thresholds), and 4 toxicological (3 when leachate is going to a wastewater treatment plant), see Annex D.5. In addition there are 28 parameters in leachate sediments (of which 19 with defined

thresholds). 23 substances listed in the guidelines are also listed in the Pollution Inventory (Robinson & Knox, 2003).

Guidelines on landfill leachate monitoring include an annual sampling programme with 24 parameters, of which 10 are general, 10 are metals and 4 are organic pollutants (groups), see Annex D.4. In addition, there are 16 parameters for leachate sediments, 3 general, 10 metals and 3 organic pollutants. There is also a sampling programme with 5 year intervals, consisting of 14 organic pollutants (group), 3 toxicity and 15 parameters for leachate sediments.

A summary of the guidelines and parameters included in them are given in the Appendices.

2.5 Sweden

The Swedish guidelines give recommendations on the design of a monitoring programme for leachate, surface water, sediments and groundwater. Specifically, there are recommendations on suggested parameters, sampling methods, sampling frequency and data reporting. A description on how to carry out hydrological evaluations is also included.

The monitoring programmes are usually separated into phases, e.g. a basic and an extended phase, screening etc.

Common reporting practices are to evaluate total emissions of organic matter, nutrients and toxicants relative to emission limits that are recipient independent. Another phase can be recipient specific investigations considering local conditions such as e.g. dilution. The plume of substances is evaluated relative to acceptable influential areas beyond which no negative effects are accepted.

2.6 Examples of leachate reporting in some EU countries

In the UK emissions are monitored and reported through the landfill leachate Pollution Inventory reporting tool (Robinson & Knox, 2003). The Pollution Inventory (PI) for England and Wales requires operators at up to 1000 landfill sites to report their annual emission load of PI substances in leachate, for the first time in 2003. The substances are listed in the table in Annex G.1. Each substance is listed with a reporting threshold value, given as annual mass flow. The reporting is carried out at 3 levels; NA (not applicable), when there are no emissions, BRT (below reporting threshold), and Emission.

- In Germany leachate emissions are controlled through limit levels of 17 parameters, see Annex G.2.

2.7 Differences in limit values

There are a number of limit values both for leachate emissions and for maximum concentrations allowed in the recipient (groundwater) in use in the Nordic countries and in the EU, see Table 6.

Table 6. Comparison of limit values

	DK*	N**	D***	EU1****	EU2*****
General parameters (mg/l)					
Cl	150			460	46 000
Sulphate	250			1500	
NVOC	3	5 ^a	200 ^k	160 ^h	1160 ^a
Tot N (– nitrate)	1 + background	0.5 ^b	70		1160 ^b
NH ₄	0.5 + background				
Tot-P		0.16	3		
Metals and elements (µg/l)					
Fe		200			
As	8	2	100	60	0.13
Ba				4000	
Pb	10	1.9			0.5
Cd	2	0.2	100	20	0.02
Cr	25	6.3	500	100	0.5
Cr VI	1		100		
Cu	100	2.3	500	600	0.5
Hg		0.01	50	2	3.0
Mo	20			200	
Mn		0.1			
Ni	10	5	1000	120	0.5
Zn	100	35		1200	0.5
Organic pollutants (µg/l)					
AOX			500		0.02
Chlorinated solvents	1	50 ^c			0.02
Chlorinated benzene		10			
DEHP	1				0.02
1,2-dibrommethane	0.01				0.02 ⁱ
PAH	0.2				0.11
MTBE	5				0.02
Hydrocarbons, total	9		10000		
Pentachlorophenol	<detectable	1 ^d			1.2
Pesticides					
Total	0.5	0.5 ^e			
Single	0.1				
Chlorinated	0.03				0.01 ^j
Phenoles	0.5			0.3 ^f	
PAH		2			0.11
Tin organic		0.01			0.11
Vinylchloride	0.2				

* DK=maximum allowed concentrations in groundwater. Based on risk assessment, <http://www.retsinfo.dk/> **

N=environmental risk assessment threshold values for diffuse emissions. *** Requirements for leachate emissions in Germany (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany, 2004). ****

Council Decision 2003/33/EC limit values from percolation test defining inert waste. *****Pollution Inventory leachate reporting values assuming average Q=118 m³/d (Robinson & Knox, 2003) ^a as TOC ^b as Tot-N ^c volatile chlorinated hydrocarbons ^d chlorinated phenols ^e phenoxy acids ^f phenol index ^g DOC ^h as PBDE ⁱ as aldrin ^j as COD

The Danish limit values refer to concentrations in groundwater to evaluate the environmental risk; the Norwegian threshold values refer to leachate (and leachate sediment) samples as diffuse emissions, also as guidance to evaluate the environmental risk; the German limits refer to leachate samples; the limits in the EU directive are to be used on percolation tests limits for inert waste, and the Pollution Inventory are generally

for all (industrial) emissions, where an equivalent leachate volume has to be defined in order to calculate emission concentrations. It is clear that the EU1 limits are, as can be expected, high, but also the German limits are systematically high. Also, the German limits and the EU1 in practice almost set no limits for organic pollutants. The Pollution Inventory has, assuming a certain leachate discharge, high limits for general parameters, and very low limits for heavy metals and organic pollutants.

3. Existing Leachate Data – National Levels

The leachate data reported here are not necessarily collected according to the guidelines listed in the previous chapter.

3.1 Denmark

There is no central collection and management of landfill leachate monitoring data on a national level in Denmark. Each of the 13 Danish counties manages its own leachate monitoring data. In many cases, the data are merely stored as raw data. To collect and organise the leachate monitoring data from all the Danish counties and make them compatible and suitable for statistical analysis is a major undertaking, which goes beyond the scope of this project. Instead, we have chosen to organise and present a time series of leachate quality data from a limited number of selected landfills. In this way, the data can be related to specific categories of landfills and to the age of the landfill (in one case for mineral waste to the liquid-to-solid (L/S) ratio). A listing of leachate monitoring is given in Annex A.1.

A few comments on the landfill cells at Ganløse, Denmark

Cells 1 and 2 were established in 1979 and closed and covered with a clay and topsoil cover in 1983/84. The cells contain the following waste:

Bottom ash, fly ash and scrap metal from a MSW incinerator	82,000 m ³
Refuse from a container site and recycling station	11,000 m ³
Wastewater treatment sludge	7,000 m ³
Household waste (placed during the first half year due to an emergency)	41,000 m ³

Leachate has been collected throughout the lifetime of the landfill cells. Cell 3 was established in 1983. It was filled up and covered with a clay and topsoil cover by the end of 1986. It is also a mineral waste landfill, and contains mostly MSW incinerator bottom ash, fly ash and scrap metal.

Leachate has been collected throughout the lifetime of the landfill cell, but only data from 1990 and onwards are included in this study. BOD and COD are reduced to 1% and 5% of the initial concentrations in 24 years, respectively, and Tot-N to 35% in 18 years.

3.2 Finland

In Finland, there are no specific targets on environmental quality standards for leachate that is transported to municipal waste water treatment plants. The effect of the leachate on municipal waste water treatment is normally estimated by comparing the quantity of the effluent on the quantity of the municipal waste water and the concentrations of BOD, COD, ammonia and metals. Toxicity tests may be utilised also for assessment of the treatment (Marttinen et al., 2000). The municipal waste water treatment in Finland is mostly based on biologically activated sludge (ammonia, BOD) and chemical precipitation (phosphorus).

The leachate is a mixture of thousands of dissolved and solid substances. The concentrations and compositions of substances present in the leachate are changing due to the biological, chemical and physical processes in the landfill. It is possible to divide the development of the landfill maturing in five phases, which describe the development of the biological processes in the waste filling in time (Marttinen et al., 2000):

Phase 1. Aerobic phase

Phase 2. Transitional phase

Phase 3. Anaerobic acid phase

Phase 4. Methane production

Phase 5. Humic phase or developed phase

The quality of the leachate and the landfill gases is different in each phase. For example, the COD, volatile fatty acids and heavy metal concentration in the leachate are at their highest and the pH in the lowest in the anaerobic phase. The COD/BOD relation in the leachate reveals the age of the waste filling in the landfill. The higher the relation, the older the landfill is. Ammonium, nitrogen, phosphorus and chloride concentrations are not dependent on the aging stage of the waste filling. So-called typical landfill leachate with regard to substance concentrations is impossible to define (Marttinen et al., 2000; Whalström et al., 2004).

Data of leachate quality reviewed in a study in 2001 is collected in table B.1.1. Here, data from 45 closed municipal waste landfills established before 1987 is collected in addition to data from two municipal waste landfills established after 1987 (Marttinen et al., 2000).

Annex B.1.2. shows leachate quality data from six landfills. These data are on quality of percolated water in the landfill and on quality of the water in the surrounding ditches. The leachate of the landfill normally includes other water from the landfill area (Kettunen et al. 2001).

The general conclusion from this study was (Kettunen et al. 2001):

- The water samples were diluted compared to the results in other European countries
- The leachate total organic carbon and chemical oxygen demand are at the same level as in the municipal waste water
- The nitrate concentrations were high compared to municipal sewage except in one landfill
- The chloride concentration is high enough to cause corrosion
- Manganese and iron concentrations were high
- Heavy metal concentrations (chrome, copper, nickel) were most of the time below detection limit (0.1 mg/l)
- The concentrations vary depending on the season
- The concentrations in the waste filling were higher than in the leachate collected at the collector basin (2–4 times higher)
- The concentrations in the ditch-water were in two of the cases higher and in one case lower than the quality of the leachate. This was probably due to dilution of leachate by other water in the landfill area.

In another study, samples from 60 municipal waste and industrial waste landfills were analysed for heavy metal and other chemical element concentrations in the leachate. It was concluded that these concentrations were low (Al, As, B, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Zn, Ca, Fe, K, Na, P, S) (Marttinen et al., 2000).

Also, 42 different organic substances were analysed in five landfills (Kettunen et al. 2001). The substances are known to be toxic for health or environment. None of the substances were detected in two of the landfills. In the rest, only some substances exceeded the detection limits. The highest concentrations and more frequent substances found in the leachate were PAH substances (at most 10 times the target value set for drinking water) and phthalates.

Organic substances have been tested in at least 60 landfills, and the concentrations are found to be low (Marttinen et al., 2000).

3.2.1 Toxicity

There were carried out toxicity tests of the leachate in six municipal landfills. (Kettunen et al. 2001). The toxicity was tested with *Daphnia* and *Raphidocelis subcapitata*. It was concluded that the leachate was toxic to *Daphnia* in concentrations 18–48 % (LC50). If the leachate is diluted to 1/2 – 1/5 parts, it would not be toxic to water fleas. The toxicity was remarkably reduced in almost all leachate treatment plants (Kysely, 2002).

Results from inhibition tests with algae shows a toxicity of leachate at concentrations of 7–24 % (EC50). This means that alga growth was decreased by 50 % at concentrations of 7–24% of leachate. The toxicity was

significantly decreased in the treated leachate water. However, in one test of landfill leachate mixed with treated municipal wastewater, the effluent was toxic to algae but not to water fleas. This may be due to ammonia and iron present in the effluent. If the leachate was diluted from 1/20 to 1/100 it was not toxic but increased the growth rate of algae and thus increased the eutrophication in the receiving waters. The leachate pH was adjusted to 7.0 and solids were filtered out before testing. The test was thus testing diluted and biologically available substances (Kettunen et al. 2001).

In Finland the treatment was concluded to be important for organic compounds (COD, BOD₇, and TOC) and ammonia because of their significant concentrations in the leachate. In addition, all investigated leachates were toxic in water environment. However, the phosphorus and heavy metal concentrations were low except for iron and manganese. PAH substance, phthalate, phenol and cresol concentrations were highest of all the tested 42 organic substances, but in general all organic substance concentrations were low.

The leachate will become concentrated as the landfill structures are improved, i.e. the geological barriers, bottom liners and other structures required in the Directive of Landfills are built.

3.3 Iceland

There were approximately 30 operational landfills for municipal waste in Iceland in 2002. It is expected that the number of operational landfills will drop substantially after all the provisions of the Landfill Directive have come into force (2009). All operators of landfills had to send in an adaptation plan before 31 December 2003. Landfills not meeting the criteria of the Landfill directive have to be closed by no later than 16 July 2009.

Time series of leachate monitoring exist for most landfills in Iceland. However, the range and frequency of samples are a.o. dependent on the capacity and type of the landfill. In Iceland there are only landfills for non-hazardous waste from households, smaller companies, building and demolition waste (B&D), slaughterhouse waste etc., and inert waste e.g. soil, concrete, glass, stones etc. On many landfills for inert waste there is also a special area where garden waste, used in composting is stored. There are currently no landfills for hazardous waste in Iceland, but one such landfill is in preparation (including contaminated soil).

A summary of leachate monitoring from Iceland is given in Annex C.1.

3.4 Norway

There were approximately 100 operational municipal waste landfills in 2002. A survey in 2004 showed that 39 landfills were applying for continued operation. All landfills are supposed to operate according to The landfill directive since July 2005. By 2009 a total ban on the landfilling of organic waste is expected.

Investigations of reports to the county governors (Fylkesmenn) on regular annual leachate monitoring show that 65 parameters were analysed in untreated leachate, see Annex D.1, Tables D.1.1. to D.1.5. The data apply to the period from 1998 to 2002 and were added to a leachate database (DISIG, Haarstad et al., 2003). The values are averages of the annual mean for each location, eliminating differences in sampling frequency using the method of bias corrected means (Parking & Robinson, 1993).

The number of landfills reporting data was 51 up to 2004. These are mostly landfills for ordinary household waste, although waste characteristics are assumed to change over time due to changes in regulations and other factors, particularly after 2009 when landfilling of degradable organic waste will be banned.

The guidelines for leachate monitoring were published in 2005 by SFT, and are separated into an annual and a 5 year programme. The leachate quality and quantity is the basis for estimating the emissions that are evaluated against the environmental conditions in the recipient. Up to now the emissions have been evaluated against treatment target values, typically 50–75 % removal of COD, 30–50 % N, and 70–80 % Fe.

In Norway leachate quantities varied between 5 to >1023 m³/day, with a mean value of 118 m³/day. A previous study estimated the leachate quantity to 300 mm to 600 mm (Haarstad, Mæhlum & Kraft, 1998).

Table 7. Comparison of leachate and wastewater concentrations for selected parameters*

Parameter	Leachate	Leachate mean	Wastewater	Wastewater mean
General parameters (mg/l)				
COD	18–5028	430	200–600	77
BOD	9–1600	157	180–300	324
Tot-N	4–449	100	12–100	66
NH4-N	7–685	96		54
Tot-P	0,2–75	2,5	10–25	15
Heavy metals (µg/l)				
As	0.65–163	8		
Cd	0.025–95.8	1.2	0.29–0.76	0.51
Cr	1–645	20	2.7–9.2	7.3
Cu	1–1343	11	28–399	79
Hg	0.005–62	0.32	0.11–0.72	0.25
Ni	1–169	21	2.1–22.5	11.8
Pb	0.3–221	5.0	0.75–6.44	1.77
Zn	0.1–2163	101	20–195	84
Organic pollutants (µg/l)				
PCB	0.01–3.1	0	0.02–0.04	
Chlorinated phenols	0.5–1	0.7	i.p.	
Phthalates	0.01–250	3.64		
PAH	0.08–23.8	2.70	0.03–5.0	

* Midttun, 1997; Østeraas, 1987; Mosevoll et al., 1999.

Table 7 shows that leachate is generally more concentrated than ordinary wastewater, especially for COD and some heavy metals (Cd, Cr and Pb), both as mean (1 to 5 times) concentration but even more pronounced for maximum concentrations (up to > 10 times), mainly due to a more concentrated flow. Leachate generally also contains more substances.

After implementation of the Landfill Directive, the government introduced a graduated pricing of landfilling based on the environmental status of the landfill and the quality of the bottom liner. By late 2004, environmental impact studies had been conducted at 39 landfills (Amundsen et al., 2004), see Tables D.1.6. to D.1.10. The diffuse emissions are evaluated against target values. If these values are not met, the quantity of the diffuse emission is evaluated, and also the possible effects in the recipient. Studies on diffuse emissions from landfills show that the threshold values are exceeded to a large degree when evaluated according to general parameters (8 to 286 times), less by heavy metals (2 to 80 times) and least by organic pollutants (1 to 10 times). In leachate sediments the only parameters measured above the threshold limits were phenols, PAH and Tin organic compounds.

Time series of a) an active landfill and b) a closed landfill are presented in Annex D, Figures D.1 to D.16.

Landfill a) was established in 1962, covers nearly 20 hectares, with a volume of 500 000 m³, and received about 52 000 tonnes per year, 90 % of which was residual waste from manufacturing, construction and trade (2002). In 1995 household waste constituted 30 % of the landfilled waste. The leachate samples are analysed 4 times per year.

The COD has increased by a factor of 3 in 11 years, from approximately 1500 mg/l in 1993 to 4500 in 2004, but the values also show large systematic variations.

The Tot-N increased by a factor of 2.7 in 15 years from 1989 to 2004. Cl and electrical conductivity show a weak decline indicating an increased hydraulic load through the landfill. Fe shows no systematic trend but seems to have systematic variations. pH is slowly increasing.

Landfill b) was established in 1962 and closed in 1997. It covers 6 hectares, with a volume of > 500 000 m³. At the beginning of the period household waste dominated. Towards the end 35% of the landfilled waste was household waste. Hazardous waste was deposited up to 1970.

The COD decreased to 27% of the initial concentrations in 8 years at the closed landfill, from approximately 330 mg/l in 1996 to 90 in 2004. The BOD decreased by 50% to 75 mg/l, and NH₄-N to 40%. Also the electrical conductivity and Cl decreased to about 50% of the initial concentrations.

Landfill gas has been measured in an old landfill closed in the 1960's. The measurements were carried out in drill holes immediately after excavation. Table 8 shows that the gas concentrations are low for methane, CO₂ and H₂S, and approaching air quality for O₂. (Snilsberg & Haarstad, 2004, 12/04, 26 s.)

Table 8. Gas concentrations in an old landfill

Gas	Concentration (vol/vol)
CH ₄	1.3 – 11.8%
CO ₂	1.0 – 6.3%
O ₂	9.0 – 20.4%
H ₂ S	0
CO	25 – 136 ppm

Extracts from waste from 2 old landfills had concentrations of BOD of 44 mg/l to 60 mg/l.

3.5 Sweden

Results from characterisation of untreated landfill leachates in Sweden are given in Annex E.1. Landfill leachates have been characterised with different levels of significance both in research projects and in control programs. In several research projects IVL has made chemical and biological characterisation of municipal landfill leachates. Up to 400 parameters have been analysed in grab samples from 30 sites. Both percolate and ponds have been sampled. Samples from ponds are naturally more representative and less dependent on short-term variations e.g. in weather. The leachates in ponds are generally more diluted than the per-

colate. Summaries of some of the results for untreated leachates are presented in annex E1.

In vitro bioassays have shown that estrogenic effects vary within $<0.4\text{--}29$ ng estradiol equivalents L^{-1} in seven investigated landfills. The corresponding values for substances interfering with the androgen receptor were $< 1.0\text{--}69$ ng dihydrotestosterone equivalents L^{-1} in six landfill leachates.

Between the years of 1994 and 2003 the number of active municipal landfills in Sweden receiving more than 50 tonnes of waste per year decreased from 300 to 192 according to a survey conducted by the RVF, The Swedish Association of Waste Management. The number is believed to decrease to fewer than 100 in 2008. In 2003 these 192 landfills collected 8 million m^3 of leachate. The leachate is normally led to a municipal wastewater treatment plant, which was the case for 5 million m^3 of leachate in 2003.

The status on collection and treatment of municipal landfill leachates in Sweden (data from 2003) is presented in Annex E.1. Some landfill sites have both local treatment and treatment at the municipal wastewater treatment plant (WWTP).

4. Existing Leachate Data – Discussion

4.1 Trends in leachate Concentrations

Studies from Denmark show that BOD and COD are reduced to 1% and 5% of the initial concentrations in 24 years, respectively, and Tot-N to 35% in 18 years. Studies from Norway shows that the COD decreased to 27% of the initial concentrations in 8 years at the closed landfill, from approximately 330 mg/l in 1996 to 90 in 2004. The BOD decreased by 50% to 75 mg/l, and NH₄-N to 40%. Also the electrical conductivity and Cl decreased to about 50% of the initial concentrations. The studies show that obtaining a final storage quality takes longest time for nitrogen and ammonia.

4.2 Leachate Concentrations

Annex F.1. summarizes leachate data from the Nordic countries. The parameters are briefly described, and the range of reported mean (arithmetic mean, median etc.) and maximum values from the Nordic countries are given. Relevant reference values are also given as concentration ranges (Kjeldsen et al., 2002; Christensen et al., 1992). In some cases the range of concentrations measured in the Nordic countries are significantly **lower** (BOD, COD, NH₄-N, Tot-N, Kjeldahl-N, PO₄-P, suspended solids, SO₄-S, Sulphide, TOC, As, Cr, Cu, Fe, Na, K, Pb, Mg), and in some cases **higher** (Cl, EC, NO₃-N, Ni, Zn, PAH) than the reported reference ranges. The reference levels include industrial countries worldwide. These ranges do not reflect typical values for leachates. The most probable reason for these differences is biased selection of landfill categories, but may also reflect differences in climate, hydrology and other factors. The values are also compared to the limit percolation test values given in Annex III in the Directive on the landfill of waste, for inert, non-hazardous and hazardous waste, where they are stated.

Figures 5 to 9 show statistics of the main leachate constituents.

Figure 5. Reported levels of biological oxygen demand. DK1&2=two categories of landfills from Denmark, Is1=Category 1 landfill, Iceland, Is2=Category 2 landfill, Iceland, N1=ordinary monitoring programme, Norway, N2=risk assessment programme, Norway, S=Sweden, SF=Finland. Max for Dk1=8300

Figure 6. Reported levels of COD in Nordic leachate data. (Max for DK1=16000)

Figure 7. Reported levels of Tot-N in Nordic leachate data.

Figure 8. Reported levels of Fe in Nordic leachate data.

Figure 9. Reported levels of Zn in Nordic leachate data (Max for DK1=22 000, for SF=110 000).

5. Gaps in Leachate Data

5.1 General

The Landfill Directive states that

- Water from precipitation, surface water and ground water shall be prevented from entering the landfill
- Polluted water and leachate shall be collected
- Polluted water and leachate shall be treated to an appropriate standard for emission

The appropriate standard is not defined in the Directive. This is also not defined in any of the guidelines in the Nordic countries, and needs to be addressed.

Implementation of the Landfill Directive will lead to a lot of data from leaching tests on waste samples. It will be necessary to compare these with real leachate data.

Annex G.4 shows examples of literature data on isotopes in leachate and other water types. It is clear that isotopes are potentially useful in hydrological studies of leachate emissions to the environment.

5.2 Finland

In Finland the leachate of landfills is in most of the cases led to the municipal waste water treatment plants for treatment. The qualities of waste water that can be conducted to the plant are determined by the treatment plants, and there are no national target values for waste water piped to municipal waste water plants.

The establishment of a landfill requires a permit from the environmental authorities. The permit application requires specific design details for leachate treatment and specific programming of follow-up of ground-water, surface water and leachate quality as set in the Landfill Act. The more specific requirements concerning for example substances to be analysed are set by authorities at the regional level, not at the national level. There is not yet any national guidance on follow-up parameters for leachate quality.

In Finland there has been no extensive investigations of more concentrated leachates that are anticipated to develop in the new landfills with better liners etc. Nor are there any estimates as to how this will affect treatment alternatives.

5.3 Iceland

Leachate collection is not operational at all Icelandic landfills. This might give a flawed impression of concentrations since the mixing of leachate with precipitation water and groundwater can be considerable. However, most landfills have a drainage system around them to divert precipitation water away from the landfill body.

5.4 Norway

There are limited data on leachate from different categories, and no data correlating information on waste types and leachate quality. Considering the variability of leachate quality and the complex nature of measuring effects from leachate it is recommended to increase the knowledge on leachate quality and toxicity.

There are little or no systematic data on substances such as metal organic substances, hormonally active substances, pharmaceuticals, personal care products, microbiological parameters. Some organic pollutants are also missing, such as perfluor substances and others.

5.5 Sweden

Little is known about ecotoxicological effects of leachate after treatment. What concentrations or masses of different substances can be lead to the recipient without environmental risk? More research and development of methods are needed to meet the needs for regulation of leachate effluent. Values for no effect of leachate substances are needed for the specific local recipient.

Only a small fraction of the TOC has been identified as specific organic substances. The main fraction in leachate from a landfill in the methanogenic phase is thought to be humic and fulvic acids (Ågren. S. 2001) but this should be confirmed with studies of leachates from other landfill sites. Often a value for COD, without any ecological motivation, is used to regulate the effluent of leachate.

More research is needed to understand the metal interactions with dissolved organic matter and how this affects the treatment possibilities.

6. Guideline Recommendations

Present leachate monitoring guidelines differ among the Nordic countries. The differences are based on lack of specifications/definitions in the Landfill Directive and other relevant legislation and differences in national policies, as well as economic and environmental considerations. Furthermore, existing guidelines often include a trade-off between EU legislation and country specific scientific and environmental risk assessments and socio-economic considerations. This project has identified a lack of knowledge on a number of components and parameters in leachate monitoring within the nordic countries that might be considered to enhance a better understanding of possible impacts of leachate release from landfills into the environment.

6.1 Denmark

The existing Statutory Order No. 650 on Landfills lays down the principles of leachate monitoring, including the initial frequency of sampling both during the operation and aftercare periods, but it does not specify the chemical analytical programme to be performed on the leachate. During the operational phase, the initial monitoring programme calls for 4 annual leachate samples per landfill unit or cell: three samples to be subjected to “routine” analysis (a limited analytical programme) and one to be subjected to a more extended analytical programme. During the initial after-care phase, the annual monitoring programme may consist of either two samples with routine analysis or one sample with routine analysis and one with extended analysis. The permitting authorities (currently the counties) decide which chemical analyses should be included in the routine and extended programs, and they are required to adjust both analytical programmes and sampling frequency as needed.

6.2 Finland

According to Regulation on Waste Treatment based on Law of Waste (1072/1993), the run-off water and the leachate of landfills have to be treated or conducted to be treated. The Landfill Directive requires environmental monitoring of the leachate of the landfills and the groundwater.

6.3 Iceland

Regulation no. 786/1999 on environmental controls gives guidelines for the frequency and extension of compliance controls. Based on this regulation, frequencies and extent of monitoring and sampling schedules are given in permits, and typically are dependent on the treatment capacity of a landfill. In addition, the sort of waste landfilled, the location, weather conditions and geology and hydrology at the site can influence the monitoring program. Furthermore, at category 1 landfills the sediment of the recipient near the outlet of leachate has to be monitored on a regular basis. In one case (Álfsnes, Reykjavík), additional monitoring of molluscs near the outlet in the sea is required.

Iceland is working towards a monitoring system of the water balance of landfills. Apart from the above-mentioned monitoring schedule, landfill operators are now required to register weather conditions on (or near) the landfill and – where applicable – leachate flow and flow of the recipient itself. By registering both leachate flow and pollutant-concentrations in the leachate from a landfill it is possible to assess the total release of pollutants into the recipient, and subsequently the environmental pressure of the release. Furthermore, this extended monitoring scheme may be used as an indicator for the extent of stabilization of the landfill body to determine the aftercare period that is needed.

6.4 Norway

Hydrological evaluations can be included in order to secure monitoring of all major hydrological events. Guidelines may also list how to prepare, store and transport samples.

The guidelines include screening of the acute toxicity of the leachate. This may necessitate extensions of the monitoring programme. Screening of the chronic toxicity may also be included. This would give a more comprehensive picture of the leachate toxicity.

Emissions of pollutants may have a toxic effect, bioaccumulation and geoaccumulation both in the recipient and nearby areas. In addition, emissions relevant on a global scale through atmospheric transport can be included. Limits on emissions need to address all these factors. Emission limits could include recommended thresholds, e.g. in kg per year or mg/l, or kg per tonne landfilled.

6.5 Sweden

One positive but limited effect from the Landfill Directive that can be seen in the actors plans is the suggestions of expanding the methane gas

and leachate water collecting plants. Furthermore in 2004 more rules were implemented in Sweden through the new waste receiving criteria at landfills.

6.6 Suggestion for a common minimum requirement for leachate monitoring

Table 9 presents suggestions for a common minimum requirement for leachate monitoring of active landfills, based on the risk for undesired environmental or health effects. Also, the aspect of local adaption is considered important.

Table 9. Suggestion for a minimum requirement for frequent and periodically leachate monitoring of active landfills*

		Leachate		Leachate sediment	
Parameter	Short name	Unit	Detection limit	Unit	Detection limit
Frequent (<4 times a year)					
Flow	Q	m ³ /day			
Acidity	pH				
Dry matter	DM			%w	
Chemical oxygen demand	COD	mg/l	10		
Biochemical oxygen demand	BOD	mg/l	10		
Total organic carbon	TOC	mg/l	10	mg/kg DM	1
Total nitrogen	N-tot	mg/l	0,1		
Ammonium nitrogen	NH ₃ / NH ₄ ⁺	mg/l	0,1		
Iron	Fe	mg/l	1	mg/kg DM	1
Zinc	Zn	µg/l	3	mg/kg DM	3
Copper	Cu	µg/l	1,5	mg/kg DM	1,5
Lead	Pb	µg/l	1	mg/kg DM	1
Cadmium	Cd	µg/l	0,1	mg/kg DM	0,1
Nickel	Ni	µg/l	5	mg/kg DM	5
Cromium	Cr	µg/l	1	mg/kg DM	1
Arsenci	As	µg/l	2	mg/kg DM	2
Mercury	Hg	µg/l	0,01	mg/kg DM	0,01
Phenols		µg/l	0,5	mg/kg DM	0,5
Hydrocarbons	Upolar HC	µg/l	100	mg/kg DM	100
Polycyclic aromatic hydrocarbons	PAH16	µg/l	0,2	mg/kg DM	0,01
Monocyclic aromatics	BTEX	µg/l	0,2		
Polychlorinated biphenyls	PCB7			mg/kg DM	0,002
Acute toxicity screening		TU			
Periodically					
Broad analysis of heavy metals		µg/l		mg/kg DM	
Polybrominated diphenylethers	PBDE	µg/l	0,001	mg/kg DM	0,001
Hexabromocyclododekan	HBCD	µg/l	0,01	mg/kg DM	0,01
Tetrabrom bisphenol A	TBBPA	µg/l	0,005	mg/kg DM	0,005
Alkylphenols and -etoxilates		µg/l	0,5	mg/kg DM	0,05
Chlorinated phenols		µg/l	0,5	mg/kg DM	0,5
Tinnorganic compounds		µg/l	0,01	mg/kg DM	0,01
Phtalates		µg/l	1	mg/kg DM	1
Chlorinated benzenes		µg/l	0,5	mg/kg DM	0,5
Volatile chlorinated hydrocarbons		µg/l	0,2		
Linear alkylbenzensulfonates	LAS	µg/l	20		
Phenoxy acids		µg/l	0,5		
Chlorinated paraffins				mg/kg DM	0,001
Polychlorinated naftalens				mg/kg DM	0,1
Polychlorinated dibenzodioxins/furans ²	Dioxins			mg/kg DM	0,000001
Chlorinated pesticides				mg/kg DM	0,05
Acute toxicity water plants/algae		TU			
Acute toxicity crustacea		TU			
Mutagenity test					

* Shaded areas=not measured. Parameter list should be subject to local adaption after landfill closure

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8. List of Annexes

Denmark

Annex A.1: Leachate monitoring results from Denmark

Finland

Annex B.1: Monitoring results from Finland.

Iceland

Annex C.1: Monitoring results from Iceland.

Norway

Annex D.1: Monitoring results from Norway

Annex D.2: OBS-listen

Annex D.3: Chemicals with priority

Annex D.4: Leachate monitoring programme

Annex D.5: Monitoring programme for environmental risk assessment of landfills

Annex D.6: Sampling guidelines

Sweden

Annex E.1: Monitoring results

Summary of leachate concentrations in the Nordic countries

Annex F.1: Summary of the leachate monitoring data in the Nordic countries

Annex F.2: Comparison of limit values

Limit values and special analyses

Annex G.1. Leachate sampling substances and threshold values in the UK

Annex G.2. Requirements for leachate emissions in Germany

Annex G.3. Limits (Co) concentrations for inert waste.

Annex G.4: Isotopes and tracer studies

Annex A 1. Leachate monitoring results from Denmark

Table A.1.1. Kara landfill in Hedeland

Leachate analyses: KARAs landfill in Hedeland

The landfill was opened in 1980. The bottom layer (0-2m) consists mainly of household waste on top of which there can be found different waste types, such as oil-polluted soil and a considerable amount of shredderwaste. Garden waste and ash can be found as well.

Compound (parameter)	unit	Values below detection limit included (as detection limit)						Values below detection limit excluded				
		Minimum value	Maximum value	Median value	Average value	n(<)*	N*	Minimum value	Maximum value	Median value	Average value	N
settling after 2 hours	ml/l	< 0,10	15	0,20	0,59	35	59	0,10	15	0,20	1,2	24
conductivity	mS/m	220	16000	2300	2900	18	18	220	16000	2300	2900	18
pH	pH	5,9	7,7	7,2	7,1	83	83	5,9	7,7	7,2	7,1	83
TDS-total dissolved solid	mg/l	10000	13000	12000	12000	9	9	10000	13000	12000	12000	9
organic carbon NVOC	mg/l	3,4	420	270	270	18	18	3,4	420	270	270	18
BOD 5	mg/l	21	8300	89	1200	61	61	21	8300	89	1200	61
COD total	mg/l	110	16000	1100	3100	72	72	110	16000	1100	3100	72
N-NH ⁴⁺	mg/l	12	760	570	520	11	11	12	760	570	520	11
N-total	mg/l	12	970	510	480	71	71	12	970	510	480	71
P-total	mg/l	0,050	13	3,1	3,2	62	62	0,050	13	3,1	3,2	62
Na	mg/l	2200	13000	3200	3900	22	22	2200	13000	3200	3900	22
Cl	mg/l	590	100000	6700	7800	83	83	590	100000	6700	7800	83
sulphate	mg/l	< 0,10	180	5,5	14	11	48	0,10	180	8,4	17	37
sulphide-S	mg/l	< 0,000010	3,7	0,020	0,16	32	71	0,010	3,7	0,060	0,28	39
Cd	mg/l	< 0,000010	0,33	0,0030	0,023	37	67	0,00030	0,33	0,020	0,029	30
Cr	mg/l	< 0,0040	0,44	0,060	0,086	28	69	0,0050	0,44	0,049	0,071	41
Cu	mg/l	< 0,0018	0,14	0,050	0,042	4	9	0,0018	0,14	0,013	0,035	5
Fe	mg/l	0,016	450	23	85	72	72	0,016	450	23	85	72
Hg	mg/l	< 0,000050	0,090	0,00019	0,011	5	9	0,00010	0,0070	0,0022	0,0029	4
Ni	mg/l	< 0,040	58	0,060	5,3	3	11	0,040	58	0,056	7,3	8
Pb	mg/l	< 0,00030	2,0	0,032	0,12	26	69	0,0040	0,72	0,068	0,13	43
Zn	mg/l	< 0,0096	22	0,12	0,82	11	66	0,0096	22	0,19	0,97	55
oil	mg/l	< 2,0	38	3,1	7,1	15	50	2,0	38	5,0	9,4	35
oil and grease	mg/l	< 2,0	890	19	84	6	68	2,0	890	20	92	62
2,6-DCPP	mg/l	< 0,00010	0,00050	0,00038	0,00033	1	3	0,00038	0,00050	0,00044	0,00044	2
2-M-6-CCP	mg/l	0,0020	0,0030	0,0025	0,0025	2	2	0,0020	0,0030	0,0025	0,0025	2
4-CPP	mg/l	0,15	0,17	0,16	0,16	2	2	0,15	0,17	0,16	0,16	2
dichlorprop	mg/l	< 0,00017	0,024	0,0010	0,0032	2	10	0,00017	0,024	0,0010	0,0037	8
MCPA	mg/l	< 0,00010	0,0010	0,00050	0,00057	7	9	0,00010	0,00040	0,00025	0,00025	2
dechlorprop	mg/l	0,061	0,62	0,093	0,14	11	11	0,061	0,62	0,093	0,14	11
phenoxy acids	mg/l	< 0,15	2,2	0,25	0,57	1	6	0,15	2,2	0,24	0,51	5
2,4-D	mg/l	< 0,000050	0,0012	0,00050	0,00065	8	9	0,0012	0,0012	0,0012	0,0012	1

*n(<) : number of measurements below detection limit ; N : total number of measurements

Table A.1.2. Kara landfill Køge

Leachate analyses: KARA Koege

The landfill was opened in 1995 and is adjacent to an old uncontrolled landfill cell.

The landfill is situated on the coast line but lies above sea level. Mixed waste, such as industrial waste, sludge and similar material is landfilled.

Waste height does not exceed 2 m yet. Capacity is secured until after 2009.

Period: 1997 - 2004		Values below detection limit included (as detection limit)						Values below detection limit excluded					
Compound (parameter)	unit	Minimal value	Maximum value	Median value	Average value	n(<)*	N*	Minimal value	Maximum value	Median value	Average value	N	
conductivity	mS/m	220	740	520	530		14	220	740	520	530	14	
pH	pH	6,7	7,4	7,1	7,1		14	6,7	7,4	7,1	7,1	14	
BOD 5	mg/l	23	3000	68	330		14	23	3000	68	330	14	
COD total	mg/l	220	4700	830	1100		14	220	4700	830	1100	14	
N-NH ⁴⁺	mg/l	< 0,050	2,9	0,11	0,68	3	9	0,093	2,9	0,78	0,99	6	
N-total	mg/l	15	380	160	190		14	15	380	160	190	14	
Kjeldahl-N	mg/l	160	160				1	160	160			1	
P-total	mg/l	0,15	9,3	3,4	3,6		14	0,15	9,3	3,4	3,6	14	
Cl	mg/l	170	640	430	430		14	170	640	430	430	14	
sulphate	mg/l	12	800	230	250		14	12	800	230	250	14	
sulphide-S	mg/l	< 0,010	17	0,10	1,5	3	14	0,010	17	0,11	1,9	11	
Cd	mg/l	< 0,00010	0,30	0,0020	0,049	7	14	0,00010	0,30	0,0024	0,064	7	
Cr	mg/l	< 0,0020	0,053	0,025	0,024	1	14	0,011	0,053	0,027	0,026	13	
Cu	mg/l	< 0,00020	0,062	0,0086	0,016	3	14	0,0034	0,062	0,010	0,019	11	
Fe	mg/l	0,34	66	11	19		14	0,34	66	11	19	14	
Pb	mg/l	< 0,0010	0,18	0,0020	0,025	9	14	0,0010	0,18	0,0050	0,064	5	
2,6-DCPP	mg/l	< 0,00010				1	1						
4-CPP	mg/l	0,0038	0,0038				1	0,0038	0,0038			1	
dichlorprop	mg/l	0,0016	0,0016				1	0,0016	0,0016			1	
mechlprop	mg/l	0,0098	0,0098				1	0,0098	0,0098			1	
dichlobenil	mg/l	0,00016	0,00016				1	0,00016	0,00016			1	

*n(<) : number of measurements below detection limit ; N : total number of measurements

Table A.1.3. Grønløse landfill (Cells 1+2)

Leachate analyses: landfill in Grønløse (landfill cells 1+2)

Period: 1981-2004 Compound (parameter)		unit	Values below detection limit included (as detection limit)						Values below detection limit excluded					
			Minimum value	Maximum value	Median value	Average value	n(<)*	N*	Minimum value	Maximum value	Median value	Average value	N	
Conductivity	mS/m		200	3000	1900	2000		50	200	3000	1900	2000	50	
pH	pH		7,1	8,1	7,5	7,5		50	7,1	8,1	7,5	7,5	50	
Redox potential	mV		-230	410	-10	55		7	-230	410	-10	55	7	
Alkalinity	meqv./l		10	82	39	47		7	10	82	39	47	7	
BOD 5	mg/l		6,0	2000	15	86		48	6,0	2000	15	86	48	
COD total	mg/l		120	3600	220	360		50	120	3600	220	360	50	
N-total	mg/l		73	250	150	150		48	73	250	150	150	48	
P-total	mg/l		1,0	3,4	1,8	1,8		7	1,0	3,4	1,8	1,8	7	
Na	mg/l		2600	5500	4800	4600		7	2600	5500	4800	4600	7	
Cl	mg/l		3000	11000	5300	5800		50	3000	11000	5300	5800	50	
Sulphate	mg/l		250	2200	370	500		50	250	2200	370	500	50	
Sulphide-S	mg/l	<	0,010	320	0,10	11	36	48	0,030	320	0,88	43	12	
B	mg/l		3,2	4,6	4,2	4,1		6	3,2	4,6	4,2	4,1	6	
Ca	mg/l		110	390	140	190		6	110	390	140	190	6	
Cd	mg/l	<	0,00020	0,0080	0,00050	0,0011	19	49	0,00020	0,0080	0,0010	0,0015	30	
Co	mg/l	<	0,0010	0,0080	0,0040	0,0044	14	42	0,0030	0,0080	0,0040	0,0043	28	
Cr	mg/l	<	0,0010	0,040	0,0040	0,0073	2	49	0,0010	0,040	0,0050	0,0075	47	
Cu	mg/l	<	0,0020	0,23	0,0060	0,014	15	41	0,0020	0,23	0,0080	0,019	26	
Fe	mg/l		0,57	580	3,1	120		7	0,57	580	3,1	120	7	
Hg	mg/l	<	0,000050	0,20	0,00013	0,0085	23	42	0,000050	0,20	0,00018	0,011	19	
K	mg/l		3600	4400	4000	4000		7	3600	4400	4000	4000	7	
Mg	mg/l		16	81	43	45		6	16	81	43	45	6	
Ni	mg/l	<	0,0020	0,080	0,011	0,015	1	42	0,0040	0,080	0,011	0,015	41	
Pb	mg/l	<	0,0010	0,49	0,0080	0,025	19	49	0,0010	0,49	0,016	0,035	30	
Zn	mg/l	<	0,030	13	0,20	0,55	27	49	0,030	13	0,33	1,0	22	
Phenol	µg/l	<	0,10	1,6	0,10	0,31	17	33	0,10	1,6	0,40	0,54	16	
Cresole	µg/l	<	0,10	0,10	0,10	0,10	3	3						
Xylenole	µg/l	<	0,10	0,10	0,10	0,10	3	3						
2.3-dimethylphenol	µg/l	<	0,10	0,10	0,10	0,10	2	2						
2.4-dimethylphenol	µg/l	<	0,10	0,10	0,10	0,10	2	2						
2.5-dimethylphenol	µg/l	<	0,10	0,40	0,25	0,25	1	2	0,40	0,40			1	
2.6-dimethylphenol	µg/l	<	0,10	0,10	0,10	0,10	2	2						
3.5-dimethylphenol	µg/l	<	0,10	0,80	0,40	0,40	1	5	0,20	0,80	0,45	0,48	4	
3.4-dimethylphenol	µg/l	<	0,10	1,6	0,55	0,68	1	12	0,22	1,6	0,60	0,73	11	
2-methylphenol (o-cresol)	µg/l	<	0,10	0,30	0,10	0,17	2	3	0,30	0,30			1	
3-methylphenol (m-cresol)	µg/l	<	0,10	0,10	0,10	0,10	2	2						
4-methylphenol (p-cresol)	µg/l	<	0,10	0,60	0,20	0,28	2	4	0,30	0,60	0,45	0,45	2	

* n(<): number of measurements below detection limit; N: total number of measurements

Table A.1.4. Grønløse landfill (Cells 1+3)

Leachate analyses: landfill in Grønløse (landfill cell 3)

		Values below detection limit included (as detection limit)						Values below detection limit excluded				
Period: 1990-2004		Minimum	Maximum	Median	Average	n(<)*	N*	Minimum	Maximum	Median	Average	N
Compound (parameter)	Unit	value	value	value	value			value	value	value	value	
Conductivity	mS/m	3000	4200	3700	3700		45	3000	4200	3700	3700	45
pH	pH	7,3	8,4	7,9	7,9		47	7,3	8,4	7,9	7,9	47
BOD 5	mg/l	< 2,0	48	11	15	2	44	5,0	48	12	15	42
COD total	mg/l	< 84	640	270	270	1	47	84	640	270	270	46
N-total	mg/l	59	120	79	81		46	59	120	79	81	46
Cl	mg/l	8800	15000	13000	13000		44	8800	15000	13000	13000	44
Sulphate	mg/l	460	1200	780	830		47	460	1200	780	830	47
Sulphide-S	mg/l	< 0,010	22	2,7	4,7	11	44	0,030	22	4,0	6,2	33
Cd	mg/l	< 0,00020	0,0060	0,00050	0,0014	23	46	0,00020	0,0060	0,0020	0,0024	23
Co	mg/l	< 0,0010	0,0090	0,0040	0,0039	21	45	0,0010	0,0090	0,0035	0,0037	24
Cr	mg/l	< 0,0010	0,057	0,0030	0,0065	15	46	0,0010	0,057	0,0030	0,0085	31
Cu	mg/l	< 0,0010	0,14	0,0060	0,018	16	45	0,0020	0,14	0,012	0,026	29
Hg	mg/l	< 0,000050	0,0037	0,000090	0,00030	27	46	0,000060	0,0037	0,00025	0,00050	19
Ni	mg/l	< 0,0010	0,030	0,0065	0,0074	13	46	0,0020	0,030	0,0080	0,0089	33
Pb	mg/l	< 0,0020	0,17	0,0080	0,021	20	46	0,0040	0,17	0,028	0,035	26
Zn	mg/l	0,010	1,3	0,20	0,21			0,010	1,3	0,15	0,25	
P	µg/l	< 0,10	0,60	0,10	0,19	19	32	0,10	0,60	0,30	0,31	13
Cresol	µg/l	< 0,10	0,10	0,10	0,10	3	3					
Xylenol	µg/l	< 0,10	0,10	0,10	0,10	3	3					
2,3-dimethylphenol	µg/l	< 0,10	0,70	0,10	0,30	2	3	0,70	0,70			1
2,4-dimethylphenol	µg/l	< 0,10	0,10	0,10	0,10	2	2					
2,5-dimethylphenol	µg/l	< 0,10	0,10	0,10	0,10	2	2					
2,6-dimethylphenol	µg/l	< 0,10	0,10	0,10	0,10	2	2					
3,5-dimethylphenol	µg/l	< 0,10	0,60	0,20	0,30	2	5	0,20	0,60	0,50	0,43	3
3,4-dimethylphenol	µg/l	< 0,10	0,10	0,10	0,10	2	2					
2-methylphenol (o-cresol)	µg/l	< 0,10	0,20	0,10	0,13	2	3	0,20	0,20			1
3-methylphenol (m-cresol)	µg/l	< 0,10	0,10	0,10	0,10	2	2					
4-methylphenol (p-cresol)	µg/l	< 0,10	0,10	0,10	0,10	2	3	0,10	0,10			1

* n(<): number of measurements below detection limit; N: total number of measurements

Table A.1.5. Hvalsoe landfill (mineral waste)

Leachate analyses: Landfill A-90 in Hvalsoe
Section containing mineral waste

Results: mineral waste		Values below detection limit included (as detection limit)						Values below detection limit excluded				
Period: 1996-2003		Minimum	Maximum	Median	Average	n(<)*	N*	Minimum	Maximum	Median	Average	N*
Parameter	Unit	value	value	value	value			value	value	value	value	
Conductivity	mS/m	280	2600	730	1100		13	280	2600	730	1100	13
pH	pH	6.5	7.7	7.2	7.2		14	6.5	7.7	7.2	7.2	14
COD	mg/l	49	710	270	290		17	49	710	270	290	17
Total alkalinity	mmol/l	8.1	44	21	23		17	8.1	44	21	23	17
N-NH ₄ ⁺	mg/l	0.01	57	3.60	20		3	0.01	57	3.60	20	3
Na	mg/l	22	3200	990	1300		17	22	3200	990	1300	17
Cl	mg/l	370	8800	1200	2400		17	370	8800	1200	2400	17
Fe	mg/l	0.41	7.4	2.2	3.0		4	0.41	7.4	2.2	3.0	4
K	mg/l	3.40	4900	740	1500		17	3.40	4900	740	1500	17
Cd	mg/l	< 0.0001	1.3	0.0035	0.33	1	4	0.0031	1.3	0.0039	0.44	3
Pb	mg/l	< 0.004	0.23	0.05	0.08	1	4	0.03	0.23	0.061	0.11	3
Zn	mg/l	0.067	0.28	0.21	0.19		4	0.067	0.28	0.21	0.19	4
2,4-D	µg/l	< 0.1	0.20	0.14	0.14	3	4	0.17	0.17			1
2,6-dichlorobenzamide	µg/l	< 0.2	1.0	0.25	0.48	2	3	0.25	0.25			1
Dichloroprop	µg/l	< 0.1	< 0.2	0.10	0.13	4	4					
Dinoseb	µg/l	< 0.1	< 0.2	0.10	0.13	4	4					
DNOC	µg/l	< 0.1	< 0.2	0.10	0.13	4	4					
MCPA	µg/l	< 0.1	< 0.2	0.10	0.13	4	4					
Mechlorprop	µg/l	< 0.1	1.2	0.15	0.40	3	4	1.2	1.2			1
Simazine	µg/l	< 0.1	< 0.2	0.10	0.13	4	4					
Chloroform	µg/l	< 0.03	< 0.05	0.045	0.043	4	4					
Tetrachloromethane	µg/l	< 0.02	< 0.05	0.040	0.038	4	4					
Tetrachloroethylene	µg/l	< 0.02	< 0.05	0.040	0.038	4	4					
1,1,1-trichlorethane	µg/l	< 0.02	< 0.05	0.040	0.038	4	4					
Trichloroethylene	µg/l	< 0.02	< 0.05	0.040	0.038	4	4					
Benzene	µg/l	< 0.04	< 0.2	0.045	0.083	4	4					
Toluene	µg/l	< 0.04	< 0.2	0.045	0.083	4	4					
M+P-xylene	µg/l	< 0.04	< 0.5	0.045	0.16	4	4					
o-xylene	µg/l	< 0.02	< 0.5	0.045	0.15	4	4					
Ethylene benzene	µg/l	< 0.05	< 0.1	0.050	0.063	4	4					
Naphthalene	µg/l	< 0.02	< 1.0	0.035	0.27	4	4					

*n(<) : number of measurements below detection limit ; N : total number of measurements

Table A.1.6. Hvalsoe landfill (waste with low organic content)

Leachate analyses: Landfill A-90 in Hvalsoe

Section containing mixed waste with low organic content

Results: mixed waste		Values below detection limit included (as detection limit)						Values below detection limit excluded				
Period: 1991-2003												
Parameter	Unit	Minimum value	Maximum value	Median value	Average value	n(<)*	N*	Minimum value	Maximum value	Median value	Average value	N*
Conductivity	mS/m	280	1200	780	770		18	280	1200	780	770	18
pH	pH	6.6	8.0	7.3	7.3		22	6.6	8.0	7.3	7.3	22
COD total	mg/l	27	2900	480	590		24	27	2900	480	590	24
Dissolved oxygen	mg/l	17	26	22	22		2	17	26	22	22	2
Total alkalinity	mmol/l	7.2	45	31	31		19	7.2	45	31	31	19
N-NH ₄ ⁺	mg/l	1.000	140	49	62		9	1.0	140	49	62	9
Na	mg/l	12	1400	920	810		22	12	1400	920	810	22
Cl	mg/l	97	2200	1200	1300		23	97	2200	1200	1300	23
Fe	mg/l	< 0.02	39	2.400	11	1	8	0.61	39	2.7	12	7
K	mg/l	2.7	1300	410	470		23	2.7	1300	410	470	23
Cd	mg/l	< 0.00009	0.55	0.001	0.093	3	6	0.0005	0.55	0.0021	0.18	3
Pb	mg/l	< 0.003	0.13	0.004	0.025	4	6	0.0046	0.13	0.067	0.067	2
Zn	mg/l	< 0.05	0.2	0.095	0.10	1	6	0.047	0.12	0.079	0.082	5
2,4-D	µg/l	< 0.1	< 0.4	0.2	0.2	5	5					
2,6-dichlorobenzamide	µg/l	< 0.3	1.4	1.0	0.90	2	3	1.4	1.4			1
Dichlorprop	µg/l	< 0.1	0.25	0.2	0.17	4	5	0.25	0.25			1
Dinoseb	µg/l	< 0.1	< 0.2	0.10	0.12	5	5					
DNOC	µg/l	< 0.1	< 0.2	0.10	0.12	5	5					
MCPA	µg/l	< 0.1	< 0.2	0.20	0.16	5	5					
Mechlorprop	µg/l	< 0.1	10	1.8	3.5	2	5	1.8	10	5.0	5.7	3
Simazine	µg/l	< 0.1	< 0.2	0.10	0.14	5	5					
Chloroform	µg/l	< 0.03	< 0.1	0.05	0.05	5	5					
Tetrachloromethane	µg/l	< 0.02	< 0.1	0.05	0.05	5	5					
Tetrachloroethylene	µg/l	< 0.02	< 0.1	0.05	0.05	5	5					
1,1,1-trichloroethane	µg/l	< 0.02	< 0.1	0.05	0.05	5	5					
Trichloroethylene	µg/l	< 0.02	< 0.1	0.05	0.05	5	5					
Benzene	µg/l	< 0.04	0.31	0.20	0.18	3	6	0.2	0.31	0.25	0.25	3
Toluene	µg/l	< 0.04	< 0.2	0.045	0.08	6	6					
M+P-xylene	µg/l	< 0.04	0.5	0.090	0.18	3	6	0.07	0.33	0.11	0.17	3
o-xylene	µg/l	< 0.02	< 0.5	0.035	0.12	5	6	0.11	0.11			1
Ethylene benzene	µg/l	< 0.05	< 0.1	0.05	0.07	6	6					
Naphthalene	µg/l	< 0.02	2.2	0.035	0.55	5	6	2.2	2.2			1

*n(<) : number of measurements below detection limit ; N : total number of measurements

Figure A.1. Leachate compositions with time (pH, alkalinity and organic matter, average annual values)

Figure A.2. Leachate composition with time (nutrients and salts)

Figure A.3. Leachate composition with time (S and Ca, annual means)

Figure A.4. Leachate composition with time (Heavy metals, annual means)

Tabell A.1.7. Maksimalt innhold af stoffer i grundvandet, som lægges til grund for miljørisikovurderingen. <http://www.retsinfo.dk/>

Grundvandets hovedbestanddele (mg/l)	Maksimalt innhold
Cl	150
Sulfat	250
NVOC	3
Totalt kvælstof – nitrat	1 + bakgrund
Ammonium	0,5 + bakgrund
Metaller (µg/l)	
As	8
Pb	10
Cd	2
Cr	25
Cr VI	1
Cu	100
Mo	20
Ni	10
Zn	100
Organiske mikroforureninger (µg/l)	
Chlorerede opløsningsmidler (-vinylchlorid)	1
DEHP	1
1,2-dibrommethan	0,01
PAH	0,2
MTBE	5
Mineralolje, total	9
Pentachlorphenol	Ikke målbart
Pesticider	
Total	0,5
Enkeltstoff	0,1
Klorerede	0,03
Phenoler	0,5
Phtalater (-DEHP)	10
Vinylchlorid	0,2

Annex B.1. Monitoring results from Finland.

Table B.1.1. Leachate quality at municipal waste landfills in Finland, old landfills (established before 1987) and landfills established after 1987/4/.

Substance	Landfill established before 1987		Landfills established 1987 and after	
	Medium (mg/l)	Min and Max.	Medium (mg/l)	Min and Max.
pH	7,2	(2.8-8.6)	6,95	(6,2-7,8)
Electrical Conductivity (mS/m)	340	(4.6-820)	375	(47-780)
COD cr	550	(40-5200)	4600	(980-8300)
BOD 7	270	(1-3900)	2800	(200-5500)
NH ₄ -N	68	(<1-370)	130	(5,7-360)
Total N	87	(5-370)	130	(3,7-390)
NO ₃ -N	0,59	(<0,1-2,7)		
Cl -	230	(<1-1800)	300	(30-720)
SO ₄ ²⁻	110	(<1-1000)		
Total S	95	(6,3-250)		
PO ₄ ³⁻	0,096	(0,025-9,9)		
Total P	0,66	(<0,016-3,9)	2,35	(0,23-5,5)
Total Solids	83	(<1-520)	127	(7,6-550)
Alkalinity (mmol/l)	15	(1-56)	25	(16-34)

Quality values from another study /5/ conducted later are reviewed in table 2.

Table B.1.2. Leachate quality data of landfills in Finland /5/.

Parameter	Unit	Landfill leachate quality (Literature Review)			
		Mean	Median	Minimum	Maximum
Electrical Conductivity	mS/m	160	150	5	820
Chloride	mg/l	220	130	4,8	1 800
pH	-	-	7,0	2,8	8,6
Alkalinity	mmol/l	15	-	1,0	36
COD _{Mn}	mg/l	230	-	7,0	1 200
COD _{Cr}	mg/l	390	200	40	2 200
TOC	mg/l	180	-	0,04	590
BOD ₇	mg/l	270	-	< 1	3 900
P-tot	µg/l	513	-	< 16	3 900
N-tot	mg/l	74	-	5,0	370
NH ₄ -N	mg/l	33	6,4	-	340
F	mg/l	3,30	-	< 0,1	44
SO ₄	mg/l	110	-	< 1	1 000
Al	µg/l	4 600	-	600	12 700
As	µg/l	9,50	< 6	-	760
B	µg/l	500	250	-	2 900
Hg	µg/l	-	-	< 0,01	-
Cd	µg/l	0,80	< 6	< 0,01	70
K	mg/l	66	43	-	650
Ca	mg/l	67	-	-	-
Co	µg/l	35	30	-	260
Cr	µg/l	71	15	-	7 000
Cu	µg/l	22	20	-	190
Pb	µg/l	0,70	3,0	-	63
Mg	mg/l	42	-	24	60
Mn	µg/l	1 600	1 400	80	81 000
Na	mg/l	120	73	-	750
Ni	µg/l	260	12	-	3 200
Fe	mg/l	23	6,1	< 0,1	150
Zn	µg/l	1 200	90	-	110 000
AOCL	µg/l	160	37	-	3 200
AOX	µg/l	510	-	-	-
2,4,6-TCP	µg/l	0,82	0,09	-	6,00
2,3,4,6-TeCP	µg/l	0,74	0,10	-	5,60
PCP	µg/l	0,15	0,08	-	3,00
Chresols	µg/l	78,00	4,20	-	870
Syanide	µg/l	< 5	62	-	650
PCB	µg/l	0,49	< 0,05	-	3,80

Table B.1.3. Leachate quality, quality of the water percolated in the waste filling and quality of the water in the surrounding digs, five landfills.

Parameter	Unit	Leachate	Percolated water in the filling	Water in the digs
pH		6.8 - 8.0	6.4 - 7.1	6.7 - 7.6
Electrical conductivity	mS/m	100 - 760	550 - 900	350 - 1000
Alkalinity	mmol/l	9 - 60	45 - 95	34 - 91
Total organic compounds	mgTOC/l	60 - 290	230 - 370	84 - 400
Chemical oxygen demand(CODCr -total)	mgO ₂ /l	280 - 970	780 - 1700	240 - 1400
Suspended solids	mgSS/l	27 - 190	35 - 370	63 - 190
Total solids	mgTS/l	800 - 4600	3000 - 5800	2200 - 5200
Volatile solids	mgVS/l	420 - 1500	1000 - 2200	790 - 2000
Fixed solids	mgFS/l	380 - 3600	1900 - 3600	1400 - 3100
Volatile Fatty Acids	mgVFA/l	< 30 - 380	< 30 - 570	< 30 - 270
Total ammonium nitrogen	mgN/l	34 - 340	240 - 490	110 - 640
Ammonium nitrogen	mgN/l	20 - 320	220 - 450	not analysed
Chloride	mgCl ⁻ /l	60 - 1300	570 - 830	not analysed
Sulphate	mgSO ₄ ²⁻ /l	5.9 - 18	< 1.0 - 9.9	not analysed
Iron	mgFe/l	1.7 - 59	28 - 76	9.9 - 62
Manganese	mgMn/l	0.14 - 7.2	0.47 - 1.4	0.83 - 2.5
Chrome	mgCr/l	< 0.1 - 0.4	0.2 - 0.4	< 0.1 - 0.2
Copper	mgCu/l	< 0.1	< 0.1 (4.8)	< 0.1
Nickel	mgNi/l	< 0.1	< 0.1	< 0.1 - 0.2

Table B.1.4. Organic compounds in landfill leachates (two to three landfills, in two landfills no tested 42 organic compounds were found).

Compound	Concentration (µg/l)	Water Quality Target Value (Finnish VNP 74/94 or WHO) (µg/l)
PAH-compounds		0,2
Naphtalene	0.24 - 8.1	
Asenaphthene	0.19 - 2.1	
Fluorene	0.11 - 0.26	
Fluoranthene	0.1 - 1.0	
Pyrene	0.1 - 0.7	
Clorinated Aromatic Compounds		
1,4-diclorobenzene	0.1 - 0.5	300
Phthalates:		
Diethylphtalate(DEP)	0.77 - 5.0	
Di-n-butylphtalate (DBP)	3.9 - 17	
Di-(2-ethylehexyle)phtalate (DEHP)	0.97 - 89	8
Organic nitrogen compounds		
N-nitrosodiphenylamine	0.15 - 2.1	-

Annex C.1. Leachate monitoring results from Iceland

Pollutant/parameter	Category 1 landfills (4)	No of landfills considered	Category 2 landfills (7)	No of landfills considered
Leachate flow (l/sec)	0,1 - 7	2	No data	
nLeachate temp. (°C)	9-23	3	No data	
pH	6,6-7,8	4	6,6-8,0	4
Conductivity (µS/cm)	600-14.500	4	115-1490	4
COD (mg/l)	190-4820	4	<10-850	4
AOX (mg/l)	0,003-0,6	3	Below measuring levels	1
Oil/fat (mg/l)	5,5-20	1	No data	
Cl ⁻	1100-1500	1	No data	
SO ₄ -S	48-65	1	No data	
NH ₄ ⁺ /NH ₃ (mg/l)	16-1285	4	<0,03-15,9	3
NO ₃ ⁻ (mg/l)	0,01-120	3	0,1-0,6	1
Total-N(mg/l)	5-770	2	0,6-20,2	3
Total-P(mg/l)	0,02-6,6	2	<0,07-0,29	3
Pb(mg/l)	0,001-1 ⁽¹⁾	4	<0,05	3
Cd(µg /l)	0,08-0,47	4	<0,005	3
Hg(µg/l)	0,01-3	4	<0,05	3
Fe(mg/l)	18-130	3	0,2-26,6	2
Zn(mg/l)	0,08-5,4	4	<0,01-0,11	2
Cr(mg/l)	0,005-0,40	4	<0,03	2
Ni(mg/l)	0,09-0,2	2	<0,02	2
Cu(mg/l)	0,002-0,08	4	<0,02	2
As(mg/l)	<0,002-0,02	2	<0,01	2
Mn(mg/l)	2,5-5	1	No data	

Annex D.1. Leachate monitoring results from Norway.

Table D.1.1. Leachate monitoring in Norway 1998-2002. Standard monitoring programme, leachate. General parameters*

Parameter	Unit	N	N > 0	Min	Max	BCGM	Med
BOD	mg/l	89	86	9	1600	157	138
COD	mg/l	112	112	18	5028	430	415
TOC	mg/l	74	45	13.0	858	85	60
BOD/COD		4	4	0.58	0.64	0.61	0.61
LOI	mg/l	1	1		40		
SS	mg/l	42	14	16.0	519	105	97
El. conductivity	mS/m	149	145	3	1488	254	262
HCO ₃ -	mg/l	40	9	3.7	3679	163	1004
NH ₄ -N	mg/l	125	125	7	685	96	101
NO ₃ -N	mg/l	3	3	0.4	375	1.0	3.0
N-tot	mg/l	147	147	4	449	100	105
pH	-	145	143	5.9	8.0	7.0	7.0
PO ₄ -P	mg/l	1	1		0.014		
P-tot	mg/l	52	21	0.2	75.0	2.5	1.9
Q	m ³ /day	62	54	5.0	1023	118	130
Q ₂	l/sec	37	7	0.1	2.9	0.6	1.1
SO ₄ -S	mg/l	58	51	0.1	242	20	23
Temperature	°C	37	6	6.0	9.4	7.9	8.3
E.coli	no./100 ml	32	1		220		

* N=total number of samples. N<d.=number of samples below detection limit. N>0=number of samples quantified.
BCGM=Biased corrected geometric mean (Parking & Robinson, 1993). Med. = median.

Table D.1.2. Leachate monitoring in Norway 1998-2002. Standard monitoring programme, leachate. Elements and metals.

Parameter	Unit	N	N > 0	Min	Max	BCGM*	Med
As	ug/l	91	84	0.65	163	8.0	8.0
B	mg/l	68	53	0.485	1951	3.2	1.3
Ba	ug/l	39	10	0.22	310	86	185
Ca	mg/l	63	32	19	530	141	145
Cd	ug/l	117	97	0.025	95.8	1.2	1.0
Cl	mg/l	138	138	5	2240	203	203
Cr	ug/l	135	133	1	654	20	27
Cu	ug/l	113	105	1	1343	11	9
Fe	mg/l	153	152	0.1125	592	23	25
Hg	ug/l	78	48	0.005	62.0	0.32	0.17
K	mg/l	67	58	2.6	306	90	105
Mg	mg/l	52	21	19.4286	112	42	43
Mn	mg/l	42	11	1	4.7	2.0	2.0
Na	mg/l	75	69	14	796	209	223
Ni	ug/l	100	95	1	169	21	22
Pb	ug/l	125	121	0.3	220.7	5.0	4.3
Zn	ug/l	143	140	0.1	2163	101	138

* See Table D.1.1

Table D.1.3. Leachate monitoring in Norway 1998-2002. Standard monitoring programme, leachate. Organic pollutants. (g/litre)*

Parameter	N	N > 0	Min	Max	BCGM*	Med
AOX (EOX)	74	45	0.1	800	8.6	6.0
BTEX	63	50	0.21	683	21.9	40.0
DBA+IPY	1	1		3.85		
Phenoxyacids	40	9	0.07	190	2.6	2.8
Phenol	85	73	0.001	900	26	34
Chlorbensene	2	2	0.25	0.45	0.3	0.4
Chloro-hydrocarbones	1	1		0.5		
Chlorophenols	33	2	0.5	1	0.7	0.8
Chlororganic comp.	43	12	4	767	118	205
Oil in water	6	6	0.3	650	35	200
PAH	89	72	0.03	899	3.5	2.1
PCB	55	38	0.01	3.063	0.0	0.0
Pesticides	42	11	0.5	192	4.9	4.0

* See Table D.1.1

Table D.1.4. Leachate monitoring in Norway 1998-2002. Standard monitoring programme, leachate. Specific organic pollutants. (g/litre)*

Parameter	N	N > 0	Min	Max	BCGM*	Med
Acenaphtene	14	14	18	2981	274	215
Acenaphtylene	6	6	0.3	1.0	0.6	0.7
B(b),B(k)-fluorantene	1	1		0.15		
Benzo(a)pyrene	1	1		10.9		
Benzo(ghi)perylene	1	1		5.5		
Phenantrene	6	6	36	974	197	301
Fluorantene	4	4	81	212	125	126
Fluorene	10	10	0.0351	358	2.3	15.0
Naphtalene	5	5	0.64	430	3.0	1.4
Pyrene	4	4	0.57	0.91	0.7	0.7
bentazon	1	1	0.53	0.53	0.5	0.5
dichlorprop	1	1	0.2	0.2	0.2	0.2
mecoprop	1	1	230	230	230	230
Benzene	2	2	2.5	10	3.9	6.3

* See Table D.1.1.

Table D.1.5. Leachate monitoring in Norway 1998-2002. Standard monitoring programme. Sediments. Organic parameters.

Sediment parameters*	Unit	N	N > 0	Min	Max	BCGM	Med
Klorbensener	ug/kg	2	2	0.25	0.45	0.32	0.35
Fenoler	ug/kg	1	1		350		
Klorfenoler	ug/kg	33	2	0.5	1.00	0.67	0.75
TOC	%	74	45	13	858	85	60

* See Table D.1.1.

Table D.1.6. Leachate monitoring in Norway. Risk assessments 2003-2004. Leachate, general parameters*

Parameter	Unit	N	Min	Max	BCGM*	Median	Threshold
BOD	mg/l	23	5	1380	128.4	170.5	
Alkalinity	mmol/l	21	1	60	14.4	15.0	
Cl	mg/l	22	95	1730	309	360	
COD	mg/l	22	4	2630	531	993	
El. Conductivity	mS/m	24	118	838	273	300	
N-tot	mg/l	22	45	474	143	150	0.5
NH ₄ -N	mg/l	22	28	411	119	110	
P-tot	mg/l	21	0.04	2.2	1.4	1.4	0.16
Redox	mV	22	-101	310	39	52	
Suspended solids	mg/l	21	50	500	98	123	
pH	log (H ⁺)	23	6.4	8.25	7.3	7.3	
Temperature	° C	22	4.8	17.2	8.8	8.3	
TOC	mg/l	23	61	860	117	135	5

* See Table D.1.1.

Table D.1.7. Leachate monitoring in Norway. Risk assessments 2003-2004. Leachate, elements and metals*

Parameter	Unit	N	N<det.	Min	Max	BCGM*	Median	Threshold
Ag	µg/l	23	17	0.1	10	0.57	0.25	
As	µg/l	24	2	1.7	62.4	10.06	9.81	2.0
B	mg/l	23	0	0.34	5.18	1.51	1.5	
Ba	µg/l	21	0			120		
Cd	µg/l	24	5	0.024	13	0.34	0.2	0.2
Cr	µg/l	24	0	3.9	310	30.72	36.3	6.3
Cu	µg/l	24	2	1	3700	21.4	15.0	2.3
Fe	mg/l	23	0	0.04	97.3	15.9	17.3	0.2
Hg	µg/l	24	14	0.005	0.36	0.03	0.01	0.01
Mn	mg/l	22	0	0.01	760	1.88	1.65	0.1
Na	mg/l	22	0	90	1100	258	265	
Ni	µg/l	24	0	12	100	27	23	5.0
Pb	µg/l	24	4	0.02	53	5.0	4.1	1.9
Zn	µg/l	24	1	5	3992	155	120	35

* See Table D.1.1.

Table D.1.8. Leachate monitoring in Norway. Risk assessments 2003-2004. Leachate, organic pollutants (See Table D.1.1)

Parameter	Unit	N	Min	Max	BCGM*	Median	Threshold
Sum alkylphenols	µg/l	21	0.5	11.85	2.30	2.265	
Alkylphenoletoxilates	µg/l	22	0.7	5.6	1.50	2.28	
AOX	µg/l	20			0.07		
Benzene	µg/l	23	0.1	710	1.14	1.4	
BTEX	µg/l	23	1.2	1400	15.71	12.96	
24-D	µg/l	18	0.03	0.28	0.06	0.05	
24-DP	µg/l	18	0.02	0.3	0.05	0.088	
Dichlorprop	µg/l	18	0.1	1.6	0.21	0.29	
Diklorethane	µg/l	21	1	1	0.59	0.5	
Diklorethene	µg/l	21	1	5	1.62	3	
Dioxan	µg/l	14			12		
EOX	µg/l	22	0.5	440	7.49	17.5	
Ethylbenzene	µg/l	22	0.1	34	2.10	3.6	
Phenoxy acids	µg/l	22	0.02	49.9	1.25	3.14	0,5
Phenols	µg/l	22	0.11	145	20.09	19	
Phenoprop	µg/l	18	0.01	0.02	0.01	0.005	
Sum phtalates	µg/l	22	0.1	250	3.64	6	10
HBCD	ng/l	19	1	7.48	2.4017	4.49	
Chlorobenzene	µg/l	24	0.1	14.4	0.55	0.5	10
Chlorinated hydrocarbons	µg/l	23	0.1	18.28	0.24	0.15	50
Chlorophenols	µg/l	23	0.04	11.9	0.29	0.19	1
Omp-kresol	µg/l	14	95	834	156.05	464.5	
MCPA	µg/l	18	0.011	0.25	0.02	0.015	
MCPB	µg/l	18	0.02	0.25	0.05	0.1	
Mechlorprop	µg/l	18	3	6.3	4.42	4.9	
Hydrocarbons	µg/l	24	0.1	10480	198.89	150	
PAH		24	0.08	23.8	2.70	1.2	2
PBDE	ng/l	19	0.0168	11.14	2.3594	7.966	
PCB	µg/l	23	0.01	0.1	0.03	0.05	
Pesticides	µg/l	22	0.1	6.76	0.29	0.295	
SCCP (chloro paraffins)	µg/l	19	64	614	104.62	339	
245-T	µg/l	18	0.05	0.25	0.06	0.05	
TBBPA		19	2.419	2.419	2.42	2.419	
Tinorg. compounds	mg/l	23	0.01	167	0.10	0.076	0,01
Toluene	µg/l	23	0.5	110	3.23	2.65	
Trichloro ethene	µg/l	21	1	898	0.09	449.5	
Trichloromethane	µg/l	20	0.3	0.81	0.21	0.48	
Xylene	µg/l	22	0.56	57.8	6.88	10.15	

Table D.1.9. Leachate monitoring in Norway. Risk assessments 2003-2004. Leachate. Toxicological parameters (%).

Parameter	N	Min	Maks	BCGM*	50pst
Microtox 15 min EC10	2	14,75	20,7	17,22	17,73
Microtox 15 min EC20	2	28,4	43,1	34,23	35,75
Microtox 15 min EC50	13	2,6	101	54,98	101
<i>Pseudokirchneriella subcapitata</i> EC50	3	14	71	20,78	14
<i>Pseudokirchneriella subcapitata</i> 72t EC50	2	14	14	14,00	14
<i>Scenedesmus subspicatus</i> 72t IC50	8	12,7	101	35,58	39,3
<i>Skeletonema</i> EC50	3	0,5	63	3,31	42

* See Table D.1.1.

Table D.1.10. Leachate monitoring in Norway. Risk assessments 2003-2004. Sediments. General parameters and heavy metals.

Parameter	Unit	N	Min	Maks	BCGM*	Threshold
Dry matter	mg/kg	14	1,1	89	20	
TOC	%	15	0,07	34	2	
BOD	mg/kg	14	345	345	345	
Fe	mg/kg	15	13500	368000	70349	
S	mg/kg	15	470	62302	4354	
Sulfat	mg/kg	13	8500	24000	12483	
As	µg/kg	15	2,82	45	8	65000
Cd	µg/kg	15	0,147	3	1	6750
Cr	µg/kg	15	11,4	130	33	
Cu	µg/kg	15	8	242	43	375000
Ni	µg/kg	15	5,5	69	21	625000
Zn	µg/kg	15	137	22691	646	1875000
Hg	µg/kg	15	0,034	63	0	1050
Pb	µg/kg	15	3,47	111	18	625000

* See Table D.1.1.

Table D.1.11. Leachate monitoring in Norway. Risk assessments 2003-2004. Sediments. Organic pollutants (µg/kg)

Parameter	N	Min	Maks	BCGM*	Threshold
Deca-BDE209	1		0,63		
2234456-BDE183	2	0,07	10	0,06	
224455-BDE153	2	0,29	5	0,48	
224456-BDE154	2	0,28	5	0,46	
22445-BDE99	2	2,33	25	3,78	
22446-BDE100	2	0,52	4,6	0,85	
2244-BDE47	2	1,73	24	2,71	
244-BDE28	2	0,05	2	0,07	
PBDE	2	0,05	76,23	8,7282	
alfa-HBCD	1		100		
Alkylephenols	14	0,01	0,01	0,01	
Antimon	11	8	8	8,00	
Brominated flame retardants	15	0	30	1,40	5
EOX	15	0,26	21	1,29	
phenol	1		0,05		
Phenols	14	160	7500	502,07	500
Chlorobenzene	15	0,01	0,1	0,01	500
Chlorinated paraffins short chained	14	0,01	0,2	0,02	
Chlorinated paraffins	1	10	10	5,00	5
Chlorinated pesticides	15	0	0,1	0,01	500
Chlorophenols	15	0	0,12	0,01	500
Methylated mercury	15	0,003	2,4	0,27	30
Hydrocarbons	15	70	14000	576,32	
Sum alkylphenols	14	200	200	200,00	
PAH	8	0,015	9400	0,37	
Sum phtalates	15	0,2	54	0,73	1000
Sum chlorinated paraffins	14	0,01	0,09	0,02	
Sum PAH	7	140	2200	409,08	300
Sum pcdd/pcdf	15	8,9E-08	0,002	0,00	0,01
TBBPA	1	50	50	25,00	
Tinnorganic compounds	15	14	814	60,31	10
Toluene	13	0,4	0,4	0,40	
Xylene	13	0,3	0,3	0,30	
PCB	15	0,003	0,035	0,01	
Polychlorinated naphtalenes	15	0,0005	0,2	0,00	100

See Table D.1.1

Time series of a) an active landfill and b) a closed landfill are presented in Annex D, Figures D.1 to D.16.

Landfill a) was established in 1962, covers nearly 20 hectares, with a volume of 500 000 m³, and received about 52 000 t per year, 90 % of which was residual waste from manufacturing, construction and trade (2002). In 1995 household waste constituted 30 % of the landfilled waste.

Leachate sampling is timeproportional composite samples analyzed 4 times per year.

*Figure D.1. Time seire of COD from active landfill
(Heavy line=raw leachate, fine line=after lagoon, triangles=after wetland filtre)*

Figure D.2. Time serie of BOD from active landfill
(Heavy line=raw leachate, fine line=after lagoon, triangles=after wetland filtre)

Figure D.3. Time serie of electrical conductivity from active landfill
(Heavy line=raw leachate, fine line=after lagoon, triangles=after wetland filtre, lacking data 1996-2003)

Figure D.4. Time series of Cl from active landfill
(Heavy line=raw leachate, fine line=after lagoon, triangles=after wetland filtre)

Figure D.5. Time series of Tot-N from active landfill
(Heavy line=raw leachate, fine line=after lagoon, triangles=after wetland filtre)

Figure D.6. Time series of NH₄-N in raw leachate from active landfill

Figure D.7. Time serie of Fe from active landfill
(Heavy line=raw leachate, fine line=after lagoon, triangles=after wetland filtre, high value=1830 mg/l)

Figure D.8. Time serie of pH from active landfill

The COD has increased with a factor of 3 in 11 years, from approximately 1500 mg/l in 1993 to 4500 in 2004, but the values also show large systematic variations.

The Tot-N increased with a factor of 2.7 in 15 years from 1989 to 2004. Cl and electrical conductivity show a week decline indicating an increased hydraulic load through the landfill. Fe shows no systematic trend but seems to have systematic variations. pH is slowly increasing.

Landfill b) was established in 1962 and closed in 1997, covers 6 hectares, with a volume of $> 500\,000\text{ m}^3$. In the beginning of the period household waste dominated, towards the end 35% of the landfilled waste was household waste. Hazardous waste was deposited up to 1970.

Figure D.9. Time series for COD for closed landfill

Figure D.10. Time series for BOD for closed landfill

Figure D.11. Time series for electrical conductivity for closed landfill

Figure D.12. Time series for Cl for closed landfill

Figure D.13. Time series for Tot-N for closed landfill

Figure D.14. Time series for NH₄-N for closed landfill

Figure D.15. Time series for Fe for closed landfill

Figure D.16. Time series for pH for closed landfill

Annex D.2. OBS-listen

Alkaner (C7-C10)
Arsenforbindelser
Azofarger
Baseolje, enkelte bruksområder
Baseoljer som inneholder i 3% aromater i DMSO-ekstrakt
Bis(2-etylheksyl)heksandioat
Bisfenol A
Borater
Butan som inneholder i 0,1 vektprosent 1,3 butadien
4,4'-Diaminodifenylmetan
1,4-Dihydroksybenzen
Diklofluorid
1,2-Diklorbenzen
Diklortoluen
N,N-Dimetylformamid
Dinitrotoluen
Diuron
2-Etoksyetanol
2-Etoksyetylacetat
2-Etylheksansyre
2-Etylheksyldifenylfosfat
Ftalater
Grotan BK
Heksametylen-1,6-diisocyan
n-Heksan
Hydroklorfluorkarboner (HKFK)
Hydrazin
Hydrogenfluorkarboner (HFK)
Hydrogenfluorid
Hydroksytoluen, butylert (BHT)
Isotiazoliner
1-Klor-2,3-epoksypropan
Klorerte parafiner, høyklorerte, mellomkjedete, C14-C17
Lavtkokende nafta som inneholder i 0,1 vektprosent benzen
Limonen
Metandiisocyanater
2-Metoksyetanol
2-(2-Metoksyetoksy)etanol
2-Metoksypropanol
(1-Metyl-1,2-etandiy) bis[oksy(metyl-2,1-etandiy)]diakrylat

Metyl laurinat
Naftalen
1,1'-Oksybis-2-propanol
2,2,4,6,6,-Pentametyl heptan
â-Pentametyl-4-piperidinyldékandioat
Pfos-forbindelser
Polypropylen glykol
Propiconazol
Solvent nafta (petroleum) tung alifatisk, direktedestillert (straight-run)
kerosin
Solvent nafta (petroleum), tung aromatisk; kerosin – uspesifisert
Stenkulltjæreprodukter
Tiram
Toluen
Toluendiisocyanater
Tolyfluamid
Triclosan
Triglycidylisocyanurat (TGIC)
Tris-[2-klor-1-klormetyl(etyl)]fosfat
Troclosener

Stoffliste A

Brommetan (Metylbromid)
Halon
Høyklorerte, kortkjedete parafiner
Klorfluorkarboner (KFK)
Nonyl- og oktylfenoler og deres etoksilater
Pentaklorfenol
Polyklorerte bifenyl
Tensider (enkelte utvalgte)
Tetraklormetan
1,1,1-Trikloretan

Stortingsmelding nr 58 (1996-1997), liste B

Bly og blyforbindelser
1,2-Dikloretan
Dioksiner og furaner
Heksaklorbenzen
Kadmium og kadmiumforbindelser
Klorerte alkylbenzener (KAB)
Kobberforbindelser
Kromforbindelser
Kvikksølv og kvikksølvforbindelser
Muskxylen

Polyaromatiske hydrokarboner (PAH)
Tetrakloreten
Tributyltinn- og trifenyltinnforbindelser
Triklorbenzener
Triklloreten

Annex D.3. Chemicals with priority: significant reduction within 2000 and complete halt within 2005.

Chemicals	Known remaining sources/use	Rules and regulations
Høyklorete, kortkjede- te parafiner	Har vært brukt som mykgjørere i maling og plast, tilsetning i skjærevæsker for metaller	Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Nordsjødeklarasjonen/ OSPAR
Nonylfenol og nonylfe- noletoksilater	Bilprodukter og rengjøringsmidler	Vedtak om utfasing innen år 2000. Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Nordsjødeklarasjonen/OSPAR
Oktylfenol og oktylfe- noletoksilater	Bilprodukter og rengjøringsmidler	Vedtak om utfasing innen år 2000 Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Nordsjødeklarasjonen/OSPAR
Polyklorete bifenyl- (PCB)	Avfallsproblem. Små kondensatorer, isolerglass-lim, fugemasse, strømgjen- nomføringer i kraftstasjoner	Forbud Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Forskrift om farlig avfall Nordsjødeklarasjonen/OSPAR ECE-protokoll (POPs) Stockholmskonvensjonen PIC-konvensjonen
Pentaklorfenol (PCP)	PCP kan forekomme i små mengder i importerte tekstiler og lær.	Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Nordsjødeklarasjonen/OSPAR PIC-konvensjonen
Enkelte tensider	Bestandel i bil- og båtpleiemidler	Nordsjødeklarasjonen/OSPAR

Prioriterte kjemikalier der utslippene skal reduseres vesentlig, senest innen 2010

Prioriterte kjemikalier	Kjente gjenværende kilder / bruksområder	Regelverk og avtaler
Bly	Metallurgisk industri, produksjon av mineralprodukter (sement, kalk, gips), blybatterier og -akkumulatorer, blyhagl, annen ammunisjon, maling og lakk, plast, glass, blåsesand, metalliske produkter, avfallsforbrenning, fiskeredsaker, fossile brenslere, kabler, seilbåter	Regulert i bensin (grense): Forskrift om helse- og miljøfarlige stoffer i motorbensin Avgift på blyholdig bensin Avløpsslam (grense): Forskrift om gjødselvarer mv. av organisk opphav Blyhagl (forbud bruksområder), visse forbindelser i maling (forbud): Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Blybatterier: Forskrift om miljøskadelige batterier Forskrift om lokal luftkvalitet Utslippstillatelser ECE-protokollen (tungmetaller) Nordsjødeklarasjonen/OSPAR
Bromerte flammehemmere	Inngår i hovedsak i elektriske og elektroniske produkter (for eksempel i PC og TV). Noe brukes også i visse typer tekstiler, plast, isolasjonsmaterialer.	Enkelte forbindelser forbudt i noen tekstiler: Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Forskrift om farlig avfall Nordsjødeklarasjonen/OSPAR
1,2 Dikloretan (EDC)	Utslipp fra plastproduksjon	Utslippstillatelser Nordsjødeklarasjonen
Dioksiner og furaner	Utslipp fra enkelte industribransjer og avfallsforbrenning (dannes ved forbrenning når klor er tilstede)	Utslippstillatelser Nordsjødeklarasjonen/OSPAR
Heksaklorbenzen (HCB)		Utslippstillatelser Nordsjødeklarasjonen /OSPAR
Kadmium	Utslipp fra enkelte industribransjer, oppladbare batterier, overflatebehandling av enkelte produkttyper, mineralgjødsel, forbrenning av oljeprodukter og kull	Regulert i fotokjemikalier (grense): Forskrift om håndtering av fotokjemikalier Avløpsslam (grense): Forskrift om gjødselvarer mv. av organisk opphav Fargestoffer i plast og maling og tilsetningsstoffer i PVC (forbud): Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Oppladbare batterier (innsamling): Forskrift om miljøskadelige batterier Utslippstillatelser ECE-protokollen (tungmetaller) Nordsjødeklarasjonen/OSPAR
Klorerte alkylbenzener (KAB)	Små utslipp fra nikkelverk (dannes i prosessstrinnet etter væske-væske ekstraksjon)	Utslippstillatelser
Kobber	Utslipp fra gruver og enkelte industribransjer, bunnstoff, treimpregnering, rør og rørdeler, metalliske produkter	Regulert i fotokjemikalier (grense): Forskrift om håndtering av fotokjemikalier Avløpsslam (grense): Forskrift om gjødselvarer mv. av organisk opphav Forskrift om regulering av forurensning fra vask og impregnering av oppdrettsnøtter Utslippstillatelser Nordsjødeklarasjonen
Krom	Utslipp fra ferrokromproduksjon, pigmenter i maling og lakk, blåsesand, korrosjonsbeskyttelse, garving av skinn	Utslippstillatelser Restriksjoner på omsetning til privat bruk Avløpsslam (grense): Forskrift om gjødselvarer mv. av organisk opphav Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier

		Nordsjødeklarasjonen
Kvikksølv	Utslipp fra industribransjer som fragmen- teringsanlegg for bilvrak, smelteverk og sekundære jernverk. Andre kilder er amalgamutslipp fra tannleger, enkelte typer måleinstrumenter, lysstoffrør og sparepærer.	Regulert i batterier (grense) : Forskrift om miljøskadelige batterier Begroingshindrende midler (forbud), termometre(forbud), emballasje (gren- se): Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Amalgam (oppsamling) og utslipp fra tannleger (rensing): Forskrift om amalgamholdig avløpsvann og amal- gamholdig avfall fra tannklinikker og tannlegekontorer Forskrift om utslipp fra krematorier Avløpsslam (grense): Forskrift om gjødselvarer mv. av organisk opphav Utslippstillatelser ECE-protokollen (tungmetaller) PIC-konvensjonen Nordsjødeklarasjonen/OSPAR
Muskforbindelser (Muxylener)	Luktstoff som blant annet brukes i ren- gjøringsmidler, toalettartikler	Nordsjødeklarasjonen/OSPAR Kosmetikkforskriften
PAH	Utslipp fra enkelte industribransjer, avfallsforbrenning, vedforbrenning og oljeprodukter (kreosot m.m.)	Krav til utforming av nye vedovner Utslippstillatelser Enkelte forbindelser (forbud) Nordsjødeklarasjonen/OSPAR
Tetrakloreten (PER)	Rensemiddel for tøy, avfettingsmiddel, laboratoriekjemikalier (stoffet kan dannes ved forbrenning av klorholdig materiale)	Avgift Nordsjødeklarasjonen
Tributyltinnforbindelser	Utslipp fra skipsverft ved sandblåsing	Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Nordsjødeklarasjonen/OSPAR Konvensjonen om forbud innen 01.01.2003 er vedtatt i den internasio- nale maritime organisasjon (IMO)
Trifenyltinnforbindelser	Utslipp fra skipsverft ved sandblåsing	Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Nordsjødeklarasjonen/OSPAR Konvensjonen om forbud innen 01.01.2003 er vedtatt i den internasio- nale maritime organisasjon (IMO)
Triklorbenzen (TCB)	Dannes ved forbrenning når klor er tilstede	Utslippstillatelser Nordsjødeklarasjonen/OSPAR
Triklloreten (TRI)	Avfettingsmiddel, løsemiddel til laborato- rieanalyser (dannes i forbrenningspro- sesser der klor er tilstede, bla. avfallsfor- brenning)	Avgift Forskrift om refusjon av avgift på trikloreten (TRI) Nordsjødeklarasjonen
SFT har i tillegg identifisert følgende stoffer som tilfredstiller kriteriesettet i Stortingsmelding 25 (2002- 2003):		
Arsen	Blyhagl, industri, olje og gassvirksomhet,	Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier Nordsjødeklarasjonen
DEHP	Mykgjører i PVC-plast, gummi, maling og lakk	OSPAR
Enkelte PFAS/PFOS forbindelser	En rekke produkter, blant annet rengjø- ringsmidler, maling, lakk, poleringsmid- ler, impregneringsmidler for tekstiler og sko	OSPAR
Høyklorerte mellomkje- dete parafiner	Mykner og brannhemmer i plast, mykner i maling, tilsatt i skjærevæsker for metal- ler	Forskrift om begrensninger i bruk m.m av enkelte farlige kjemikalier

Annex D.4. Leachate monitoring programme -Norway.

Table D.4.1. Monitoring of leachate (Snilsberg et al., 2005)

		Sigevann Kvartalsvis 1		Sigevannssediment 1 gang per år 1	
Parameter	Kort-navn	Enhet	Best. gren- se2	Enhet	Best. gren- se2
ÅRLIG PROGRAM					
Surhetsgrad	pH				
Temperatur		°C			
Ledningsevne		mS/m	1		
Suspendert stoff	SS	mg/l			
Tørrstoff innhold	TS			%w	
Korngradering					
Sporingsstoff (se omtale i kapittel 4.2.1)					
Kjemisk oksygenforbruk	KOF	mg/l	10		
Biokjemisk oksygenforbruk	BOF	mg/l	10		
Total organisk karbon	TOC	mg/l	10	mg/kg TS	1
Total nitrogen	N-tot	mg/l	0,1		
Ammonium nitrogen	NH3 / NH4+	mg/l	0,1		
Total fosfor	P-tot	mg/l	0,05		
Jern	Fe	mg/l	1	mg/kg TS	1
Mangan	Mn	mg/l	0,1	mg/kg TS	0,1
Sink	Zn	µg/l	3	mg/kg TS	3
Kobber	Cu	µg/l	1,5	mg/kg TS	1,5
Bly	Pb	µg/l	1	mg/kg TS	1
Kadmium	Cd	µg/l	0,1	mg/kg TS	0,1
Nikkel	Ni	µg/l	5	mg/kg TS	5
Krom	Cr	µg/l	1	mg/kg TS	1
Arsen	As	µg/l	2	mg/kg TS	2
Kvikksølv	Hg	µg/l	0,01	mg/kg TS	0,01
Fenoler		µg/l	0,5	mg/kg TS	0,5
Oljeforbindelser	Upolare HC	µg/l	100	mg/kg TS	100
Polysykliske aromatiske hydrokarboner	PAH16	µg/l	0,2	mg/kg TS	0,01
Monosykliske aromater	BTEX	µg/l	0,2		
Polyklorerte bifenylr	PCB7			mg/kg TS	0,002
Akutt toksisitet screening		TU			
TILLEGG HVERT 5. ÅR3					
Bred analyse av tungmetaller		µg/l		mg/kg TS	
Polybromerte difenyletere2	PBDE	µg/l	0,001	mg/kg TS	0,001
Heksabromcyklododekan2	HBDCD	µg/l	0,01	mg/kg TS	0,01
Tetrabrom bisfenol A	TBBPA	µg/l	0,005	mg/kg TS	0,005
Bisfenol A		µg/l	0,001	mg/kg TS	0,001
Alkylfenoler og -etoksilater2		µg/l	0,5	mg/kg TS	0,05
Fenoler2		µg/l	0,5	mg/kg TS	0,5

¹ I etterdriftsfasen kan hyppigheten reduseres når overvåkingen viser at utlekkingen fra deponiet har stabilisert seg.

² Analyse må gjennomføres slik at bestemmelsesgrensen ikke er dårligere enn de angitte verdiene.

¹ Best.grense=determination limit. ² Single compounds given in separate annex. Bold+underlined=included in the Pollution Inventory reporting list.

Parameter	Kort-navn	Sigevann Kvartalsvis 1		Sigevannssediment 1 gang per år1	
		Enhet	Best. gren- se2	Enhet	Best. gren- se2
Klorfenoler2		µg/l	0,5	mg/kg TS	0,5
Tinnorganiske forbindelser		µg/l	0,01	mg/kg TS	0,01
Ftalater2		µg/l	1	mg/kg TS	1
Klorbensener2		µg/l	0,5	mg/kg TS	0,5
Flyktige klorerte hydrokarbo- ner 2		µg/l	0,2		
Lineære alkylbensensulfona- ter	LAS	µg/l	20		
Fenoksysyrer2		µg/l	0,5		
Klorerte paraffiner2				mg/kg TS	0,001
Polyklorerte naftalener2				mg/kg TS	0,1
Polyklorerte dibenzodioksi- ner/furaner2				mg/kg TS	0,000001
Klorerte pesticider2				mg/kg TS	0,05
Akutt toksisitet vannplan- te/alge		TU			
Akutt toksisitet krepsdyr		TU			
Mutagenitetstest					

Annex D.5. Monitoring programme for environmental risk assessment of landfills.

Table D.5.1. Screening of leachate (SFT, 2003).

Sigevann					Kommentar
Parameter	Kort-navn	Enhhet	Best. Grense *	Tersk el-verdi **	
Karakteriserende parametre					
pH					Surhetsgrad
Ledningsevne		mS/m	1		Konduktivitet, mål for total saltinnhold
Temperatur	Temp	°C			Temperatur i sigevannet ut av deponiet
Total organisk karbon	TOC	mg/l	1	5	Mål på total organisk stoff
Kjemisk oksygenforbruk	KOF	mg/l	10		Oksygenforbrukende stoffer
Ammonium nitrogen	NH4-N	mg/l	0,1		Viktigste N forbindelse, giftig for akvatiske organismer
Klorid	Cl	mg/l	1		Ufarlig, bruker som mål på fortynningsgrad
Alkalinitet		mmol/l	0,02		Angir bufferevne, alternativ brukes innhold av HCO3 (mg/l)
Redokspotensial	Eh				Angir hvor oksisk/anoksisk sigevannet er
Suspendert stoff	SS	mg/l			Innhold av partikler i sigevannet
Biokjemisk oksygenforbruk	BOF	mg/l	10		Mål på lett nedbrytbart organisk stoff i sigevannet
Total nitrogen	N-tot	mg/l	0,1	0,5	Omfatter ammonium, organisk N, nitritt og nitrat
Total fosfor	P-tot	mg/l	0,05	0,16	Viktig næringsstoff for eutrofiering
Metaller og grunnstoff					
Jern	Fe	mg/l	1	0,2	Vanligste metall, forbruker oksygen, estetiske ulemper
Sink	Zn	µg/l	3	35	Giftig
Kobber	Cu	µg/l	1,5	2,3	Giftig
Bor	B	mg/l	0,01		
Natrium	Na	mg/l	1		Ufarlig, indikator på sigevann, mål på fortynningsgrad, må erstattes med en annen indikatorparameter (f.eks. alkalitet) ved sjønære deponier
Bly	Pb	µg/l	1	1,9	Giftig, akkumuleres i næringsskjeden
Kadmium	Cd	µg/l	0,1	0,2	Giftig, akkumuleres i næringsskjeden
Nikkel	Ni	µg/l	5	5	Giftig, allergifremmende
Krom	Cr	µg/l	1	6,3	Kan skade lever og nyrer
Mangan	Mn	mg/l	0,1	0,1	Gir smak i grunnvann, estetisk problem ved utfelling
Arsen	As	µg/l	2	2?	Giftig, akkumuleres i næringsskjeden
Kvikksølv	Hg	µg/l	0,01	0,01	Giftig
Sølv	Ag	µg/l	2		

Table D.5.1 continued

Sigevann					Kommentar
Parameter	Kort-navn	Enhet	Best. Grense *	Terskel-verdi **	
Organiske forbindelser					
Ekstraherbare organiske halogener	EOX	µg/l			vanligvis klor (EOCI)
Monosykliske aromater	BTEX	µg/l	0,2		Viktige: bensen, toluen, etylbensen, xylen,
Fenoler		µg/l	0,5		Viktige: fenol, kreosol og alkylfenol
Oljeforbindelser		µg/l	100		
Alkylfenol-etoksilater og alkylfenoler		µg/l	0,5		
Tinnorganiske forbindelser		µg/l	0,01	0,01	Viktige: tributyltinn (TBT) og trifenyltinnforbindelser
Flyktige klorerte hydrokarboner		µg/l	0,2	50	
Ftalater		µg/l	1	10	Viktige: di-2-etylhexylftalat (DEHP) og dibutylftalat,
Polysykliske aromatiske hydrokarboner	PAH	µg/l	0,2	2	Viktige: de 16 farligste forbindelsene,
Klorbensener		µg/l	0,5	10	Viktige: Heksaklorbenzen og triklorbenzen
Klorfenoler		µg/l	0,5	1	Viktige: Pentaklorfenol
Fenoksysyrer		µg/l	0,5	0,5	Viktige: MCPA, 2-4 D (pesticider)
Biologiske tester på giftighet – utslipp til overflatevann eller grunnvann					
Akutt toksisitet screening		TU			Aktuell test: Microtox
Akutt toksisitet vannplante/alge		TU			Aktuell testorganisme: <i>Selenastrum capricornutum</i>
Akutt toksisitet krepsdyr		TU			Aktuell testorganisme: <i>Daphnia magna</i>
Mutagenitetstest				hvis mutagen	Aktuell test: AMES-test, UmuC-test, SOS-chromo-test, Mutatox

Table D.5.1. Screening of leachate sediments

Sediment					Kommentar
Parameter	Kort-navn	Enhet	Krav best. grense	Terskel-verdi	
Karakteriserende parametre					
Tørrestoff	TS	Tørrestoff			
Total organisk karbon	TOC	mg/kg TS	1		Mål på total organisk stoff
Metaller og grunnstoff					
Jern	Fe	mg/kg TS	1		Vanligste metall, forbruker oksygen, estetiske ulemper
Sink	Zn	mg/kg TS	3	1875	Giftig
Kobber	Cu	mg/kg TS	1,5	375	Giftig
Kadmium	Cd	mg/kg TS	0,1	6,75	Giftig, akkumuleres i næringsskjeden
Svovel	S	mg/kg TS	0,5		Kan gi vond lukt, indikerer svovelholdig avfall (gips)
Bly	Pb	mg/kg TS	1	625	Giftig, akkumuleres i næringsskjeden
Nikkel	Ni	mg/kg TS	5	625	Giftig, allergifremmende
Krom	Cr	mg/kg TS	1		Kan skade lever og nyrer
Arsen	As	mg/kg TS	2	65	Giftig, akkumuleres i næringsskjeden
Kvikksølv	Hg	mg/kg TS	0,01	1,05	Giftig
Organiske forbindelser					
Ekstraherbare organiske halogener	EOX	mg/kg TS			vanligvis klor (EOCI)
Polyklorete bifenyler	PCB	mg/kg TS	0,002		
Alkylfenoler		mg/kg TS			
Oljeforbindelser		mg/kg TS	100		
Bromerte flammehemmere		mg/kg TS	0,002	0,005	Viktige: PBDE, PBB, TBBPA og HBCD
Klorerte paraffiner		mg/kg TS	0,005	0,005	Viktige: Høyklorete, kortkjede paraffiner
Tinnorganiske forbindelser		mg/kg TS	0,01	0,01	Viktige: tributyltinn (TBT)
Metylkvikksølv		mg/kg TS	0,01	0,03	
Fenoler		mg/kg TS	0,5	0,5	Viktige: fenol, kreosol og alkylfenol
Ftalater		mg/kg TS	1	1	Viktige: di-2-etylhexylftalat og dibutylftalat
Polysykliske aromatiske hydrokarboner	PAH	mg/kg TS	0,01	0,3	Viktige: 16 EPA-PAH
Klorbensener		mg/kg TS	0,5	0,5	Viktige: Heksaklorbenzen og triklorbenzen
Klorfenoler		mg/kg TS	0,5	0,5	Viktige: Pentaklorfenol
Polyklorete naftalener		mg/kg TS	0,1	0,1	
Klorerte pesticider		mg/kg TS	0,5	0,5	
Polyklorete dibenzodioxiner/furaner		mg/kg TS		0,00001	

Annex D.6. Sampling guidelines

A leachate sampling program must be made for all landfills licenced to emit leachate and to collect leachate. The sampling program must describe all the activities included in the monitoring; responsibilities, routines for deviations and annual reports. The sampling programme must describe:

- ❑ WHERE to sample
- ❑ WHEN to sample and analyze
- ❑ HOW to sample
- ❑ WHAT to analyze
- ❑ HOW and WHEN to report
- ❑ WHO are responsible

Here guidelines are given for detailing the sampling programme, in addition to background information on the parameters.

D.6.1 Basis for the programme layout

The programme shall be in accordance with the landfill regulations (§§14 and 15, and appendix I and III). These guidelines explain how these regulations can be met.

The regulations say that both the volume and the characterization of leachate, surface water, groundwater level and –characterization must be monitored. In these guidelines the specification on sampling leachate are supplemented with sampling of sediments in the leachate, in order to monitor emissions of compounds with low water solubility.

The programme must be adapted locally in order to monitor factual emissions and impacts, as stated in the regulations. The following information is assumed known and used as a basis for the sampling programme (see Landfill guidelines TA 1951-2003, kap5.4):

- Local groundwater is surveyed
- Soil- and groundwater upstream from the landfill is evaluated
- Local areas of specific interest are evaluated
- The risk of contamination from the leachate is evaluated, local environmental objectives
- Conditions given in permits
- Local leachate treatment
- Operational status of the landfill (active, closed)

- Landfill type (monolandfill, mixed, industrial, hazardous, ordinary, inert and so on)
- Information on specific waste types received, leaching characteristics, content etc.

D.6.2 Where to sample?

Samples must be taken of:

- Leachate, including all emission points
- Sediments in the leachate
- Groundwater, at minimum one upstream and two downstream from the landfill
- Surface water, at minimum one both up- and downstream

The following describe when and where to sample and analyze

Leachate

Sampling must be done as close as possible to the landfill to avoid dilution or chemical altering. Sampling takes place at defined emission points, e.g. from pipelines. Treated leachate should also be sampled.

Leachate sediment

Sediments in the leachate are preferably sampled at the same points as the leachate. The sediment consists of particles deposited in pipelines, in depressions, ditches and dams. Sampling should be done from the most polluted points. Sampling should focus on sediment added since the previous sampling. It is recommended to average by sampling 5-10 points and mix to one sample because the average chemical content in soils is highly variable when a small number is sampled

Groundwater

One sampling point upstream and two downstream is required. Sampling downstream should occur in the transition zone between the area that are included in the landfill and the surroundings (where background values are expected (see 5.2)).

Surface water

When leachate emit to surface water at least two points must be sampled, one upstream and one downstream the emission point.

Diffuse emissions

Eventual diffuse emissions that are not sampled by the specified program must be mapped and monitored with respect to volume and characterization.

D.6.3 When to sample and analyze?

The regulation specifies that samples must be representative for the average content since the previous sample. This means that (for relevant analyses) multiple samples must be collected and mixed before analysis. Sampling is more frequent than analysing. Mixed samples can be time- or volume proportional.

D.6.3.1 How often?

Chemical analyses and leachate volume should be measured at the following frequency:

Leachate

- Volume: monthly (operational) and 6 months (post closure)
- Composition: 4 months (operational) and 6 months (post closure)
- Sediments: 6 months
- Screening: 5 years (operational) and 10 years (post closure)

Surface water

- Volume and composition: 4 months (operational) and 6 months (post closure). More frequent if emissions are large and recipient vulnerable

Groundwater

- Level: 6 months (operational and post closure)
- Composition: 6 months (operational if there are some interests connected to the groundwater) and 12 months (no interests or post closure)

Treated leachate

- Frequency given by the amount of emissions of organic matter in the raw leachate (based on wastewater sampling guidelines). Normally one month.

These frequencies are given for the basic sampling programme. In addition there is an extended programme with usual frequency 6 months (see 3.5).

Frequency for treated leachate

Regulated parameters (e.g. COD, N, Fe) are sampled with a similar frequency as waste water, depending on the organic matter in the leachate (SFT, 2003). One personal equivalent (pe) in organic matter is 94 grams/day. The recommended sampling frequency is 6 per year for emissions equal to <1000 pe, 12 per year for 1000 – 10 000 pe and 24 per year if pe>10 000. Most norwegian landfills fall in the latter category.

A similar evaluation should also be made if the leachate is emitted without treatment and the recipients are vulnerable.

Screening

Sampling for screening are carried out as grab samples during summer, when the recipient is most vulnerable and the dilution is minimal. A procedure for screening is given in tabell 2.

D.6.3.2 How often should subsamples for composite samples be taken?

The terms grab samples, time – and volume proportional composite samples are explained in Table xx. A sampling programme can also be combinations of the different types of sampling, i.e. a strategy based on flow regimes one for low, medium, high and extreme flows.

Subsamples from leachate and surface waters:

- Operational phase: Frequency is given by the requirement of representativity. Normally once per week or 14 days

For non-composite samples the sampling and analyzing frequencies are equal. Post closure sampling do not require composite sampling.

Leachate and surface water

Minimum requirement for operational landfills are time proportional composite samples for analyses of general parameters and metals/elements (see 3.5). With 4 analyses per year this can be achieved by taking 50 ml samples every week or 100 ml samples every 14 days. Subsamples are either frozen as subsampled or frozen mixed in a larger bottle. The samples are shipped frozen to the lab. The year can be divided into winter (Dec-March), spring (April-May), summer (June-Sept) and autumn (Oct-Nov).

Volume proportional samples are often considered superior to time proportional as a basis for assessing the amount of chemicals emitted from the landfill.

The minimum requirement for the parameters BOD, suspended solids and organic compounds, and for all parameters in the post closure period,

is grab sampling at times when the concentrations are considered to be maximum.

Table x. Sampling strategies.

Grab samples	A complete sample volume is collected immediately
Mixed samples	A sample is composed of subsamples collected at some time interval, e.g. week or month
Time proportional	Composite sample of subsamples of equal volumes and time intervals.
Volume proportional	Subsamples of equal volumes but different time intervals. The subvolume must be determined according to the required total number of analyses

Continuous monitoring

Continuous monitoring is possible with electronic sensors. These are available for a number of physical (temperature, el. conductivity, redox, SS) and chemical (NH₄-N, metals, dissolved oxygen and others) parameters. Such monitoring can also provide insight in the time dependent variation in the landfill, and correlations can be made between continuous parameters and other parameters based on statistical analyses. Good quality measurements require good maintenance of the sensors, however.

D.6.4 How to sample?

Sampling methods for groundwater, sediments and water are described in a SFT-report TA720/1991, Miljøtekniske grunnundersøkelser (in Norwegian). The representativity must always be considered with an effort to maximize it.

Sampling is also described in:

Appendix xzx: Sampling protocol

Vedlegg 10: Health- environment- and safety considerations during sampling

Vedlegg 11: Sample preparations and -storage

Leachate samples

Representative samples depend on local mixing at the sampling point is adequate, ie. a turbulent stream. Some recommendations are given below, see also SFT-report TA 720/1991, kapittel 4.

Recommendations for sampling in pipelines, pumping chambers and treatment plants

Pipelines	Pipes must be big enough to support turbulence. Avoid sampling at the end of long horizontal stretches due to layering after laminar flow.
Pumping chamber	Sample between pumps and centrally in the water volume. Sample at the start up of the pumps.
Treatment plants	Good sampling points can be overflow downstream measuring channels, pumping chambers, outflow from pumps or similar where the total volume can be sampled and the mixing is good. Treatment plants can have pulses of emissions. Sampling inlet should be placed between 1/3 to 2/3 into the volume. Large constructions such as tanks, basins and pool have variable flow conditions, with both laminar and turbulent flows, and backflows, that will influence sampling. Channels are generally not preferable for sampling. Pools should be sampled at the inlet or outlet not the pool itself.

Biological sampling

Detailed instructions on sampling biological material is given in NS-EN ISO 5667-16 "Veiledning i biologisk prøving av prøver".

Preparations for sampling

Sampling must be protocolled. An example is given in appendix xxx

Time proportional sampling have fixed sampling time. Weather and run-off conditions must be analysed when taking grab samples, preferable taken at low runoff conditions. Groundwater wells must be emptied a few days before sampling.

Sample bottles

The choice of sampling bottles or other packaging depends on the parameters analysed, that the material meet the cleaning requirements (e.g. acid treatment) and sample preparations (e.g. freezing). Appendix xx gives a summary of packaging and preparations.

Sampling conditions

Local environment can pollute the sample. Wash and rinse hands before sampling, or use sterile gloves, i.e. for metals and organic parameters. Wash the bottle with the sampled liquid if possible.

Lower the bottle 10-20 cm into the volume in dams etc. and fill totally.

Temperature, pH and electrical conductivity are preferably measured in the field, not in the sampled bottle.

Prøvetakere

Manual sampling depends on the sampling point. Automatic sampling is described in NORVAR report 82/1997: Veileder for prøvetaking av avløpsvann.

Sediment is sampled by using a clean steel spoon when the sediment is easily accessible. Special sediment samplers are also available.

Health- environmental- and safety issues

Care must be taken when sampling. This is described in appendix xxx

D.6.5 What to analyze?

Analyseprogrammene er gitt i vedlegg D4.1. for sigevannsovervåking, og D.4.2. for screening av sigevannsutslipp i miljøet.

Det er gitt nyttig bakgrunnsinformasjon om parametervalg mm. i vedlegg:

- Vedlegg 2: Information on the parameters that can occur in leachate
- Vedlegg 3a: Description of the recommended parameters
- Vedlegg 3b: Background for the selection of parameters
- Vedlegg 5: Organic parameters

Det skal analyseres for organiske miljøgifter som man har fått økt kunnskap om de senere år. Videre skal det tas biologiske tester på giftighet for å få et bilde av samlet miljøeffekt av alle de stoffer sigevann fra deponier kan inneholde. Valget av parametere er basert på stoffenes miljøegenskaper, miljømyndighetenes prioriteringer og forpliktelser i internasjonale avtaler, og på kunnskap om stoffenes opptreden i deponier og sigevann. Begrunnelse for å ta med de enkelte parameterne er vist i vedlegg 3b.

Innrapporterte overvåkingsresultater vil bli brukt til å vinne erfaringer og kunnskap med faktiske utslipp og effekter av ulike stoffer. Parameterlisten vil derfor være gjenstand for videre vurderinger og revisjoner. Det kan vise seg at enkeltstoffer i liten grad påvises og dermed kan tas ut av programmet, eller at kunnskap om nye stoffer gjør at listen må suppleres.

Analyseprogrammene gjelder i utgangspunktet for alle deponier. De er imidlertid spesielt urarbeidet med tanke på avrenning fra blandede deponier. For spesialdeponier som industrideponier, deponier for farlig avfall, gruvedeponier, monodeponier kan det utarbeides egne tilpassede analyseprogram. Særlig gjelder at antall parametere kan reduseres for monodeponier, og at parametere kan tilføyes for deponier med spesielle avfallstyper. Dersom det er kjent at det er deponert farlig avfall som kan ha utlekking av forbindelser i konsentrasjoner eller mengder som kan med-

føre en helse- eller miljøfare skal de aktuelle forbindelsene og eventuelt kjente skadelige forbindelser fra nedbrytingsprosessen av disse inngå i overvåkingsprogrammet.

Screening av sigevann skal omfatte toksikologisk testing på testorganismer fra minst to ulike nivåer i næringskjeden (for eksempel alger og dafnier) som grunnlag for vurdering av miljøeffekter (se kapittel 5). I tillegg skal det gjennomføres en bakterietest, for eksempel med bakterien *Vibrio fischeri* (Microtox), som er en rask og forholdsvis rimelig test og som er egnet til overvåking av variasjoner i toksisitet.

I screening av sigevann skal det også inngå en mutagenitetstest for vurdering av utslipp av stoffer med helsemessig betenkelige egenskaper.

Tabell 2. Prosedyre ved gjennomføring av en screening av sigevann og sediment som grunnlag for utforming av overvåkingsprogram og kontroll av utslipp.

Ansvarlig	Prøvetakingen skal gjennomføres av nøytrale fagpersoner.
Tidspunktet	Tidspunktet for screening skal være i den perioden resipienten er mest sårbar for utslipp, normalt i perioden mai til august og når sigevannet er minst fortynt.
Værforhold og vannføring	Det skal ikke ha falt nedbør de siste 2 dager før prøvetakingen og det bør være en relativt tørr periode 7 dager før prøvetakingen. Vannføringen skal være lik eller mindre enn gjennomsnittlig vannføring for den aktuelle årstiden.
Prøvepunkt	Det skal tas prøver av utslippet der det antas å være mest konsentrert, det vil si utslippspunkter for sigevann.
Prøvetakingen	Prøvetakingen kan foregå som stikkprøve og skal følge de anvisninger som er gitt i veilederen.
Analysekrav	Analyselaboratorium og -metoder skal være akkrediterte og tilfredsstillende krav til (nedre) bestemmelsesgrense oppgitt i veilederen (tabell 3 og 4).
Omfang	En screening omfatter alle de typiske stoffgrupper og biologiske tester som er beskrevet i tabell 3 og 4 og omtalt i kapittel 3. Undersøkelsen kan inngå som en av de ordinære prøvene i basis eller utvidet program. For monodeponier kan analyseprogrammet tilpasses utifra beskrivelsene av avfallet (basiskarakteriseringen), samt en vurdering av muligheten for at det kan ha foregått deponering av andre typer avfall.
Funn	Funn sammenholdes mot oppgitte terskelverdier i tabell 3 og 4.
Funn < Terskelverdi	Dersom det ikke er funn over terskelverdien kan den aktuelle parameteren utgå fra overvåkingsprogrammet inntil neste screening.
Funn > Terskelverdi	Dersom terskelverdiene overstiges betyr det at sigevannet kan ha en miljøskadelig virkning. Stoffets egenskaper og fortynningsgraden i resipienten avgjør hvor skadelig virkningen er. Analysen av parameteren skal da inngå i utvidet program.

Analyseparametere i prøver av overflatevann (resipient)

For deponier med utslipp til overflatevann overvåkes karakteriserende parametere i basisprogram for sigevann. Parameterne er gitt i tabell 5.

Analyseparametere i prøver av grunnvann

For deponier med mulig utslipp til grunnvann, overvåkes indikatorparametere utenfor akseptert influensområde og oppstrøms deponiet. Dersom indikatorparameterne tilsier spredning av sigevann utenfor akseptert influensområde, overvåkes grunnvann på samme måte som sigevann. Valg av indikatorparametere gjøres på grunnlag av lokale forhold. Klor, natrium og bor er aktuelle indikatorparametere.

Feltmålinger ved prøvetaking

Ved uttak av delprøver måles temperatur, elektrisk ledningsevne, pH og sigevannsmengde i felt.

Analyse

Metaller skal analyseres som totalinnhold etter oppslutning av prøven. Oppslutning foregår ved syre- og varmebehandling av prøven på laboratoriet. Dette innebærer at alt metall i prøven inngår i analysen. Partikler skal ikke filtreres bort ettersom metaller bundet til partikler også kan ha en negativ miljøeffekt. Filtrering gir dessuten en risiko for kontaminering av prøven.

Det er flere analysemetoder for metaller. Det er viktig at det ved bestilling av analyse settes krav til (nedre) bestemmelsesgrense, som angitt i tabell 3, 4 og 5. Bestemmelsesgrensen er definert som 10x standardavvik til en blindprøve. Denne grensen er høyere enn deteksjonsgrensen da det kreves at analyseresultatet skal angis innenfor en gitt usikkerhet. For samleparametere som for eksempel PAH og ftalater gjelder kravet til bestemmelsesgrense for de enkeltforbindelsene som inngår i samleparameteren.

Spesialundersøkelser

I arbeidet med å overvåke utslipp av sigevann fra deponi kan det oppstå spesielle problemstillinger som krever mer utfyllende undersøkelser og vurderinger enn det som omfattes av den løpende overvåkingen. Dette kan f.eks gjelde i tilfelle overvåkingen tilsier at miljømål for resipienter er truet, eller at det er uoversiktelige sprednings- og fortynningsforhold i grunnvann eller åpen resipient.

I forbindelse med screening kan det være aktuelt å gjennomføre en resipientundersøkelse dersom det er betydelig utslipp av sigevann til en sårbar resipient.

Resipientundersøkelsen omfatter vanligvis kjemiske og biologiske undersøkelser i resipienten oppstrøms og nedstrøms utslippsstedet. Skisse til aktuelle undersøkelser i resipient er gitt i vedlegg 8.

D.6.6 Hydrologiske vurderinger

Utslipp fra deponier skal rapporteres som totale utslipp (kg/år). For å beregne utslippsmengder må målte konsentrasjoner i vann knyttes til beregnede vannmengder som har passert målepunktet. I dette kapitlet og i vedlegg 7 omtales strategi og metode for slik beregning.

Mange avfallsdeponier er etablert med mangelfull avskjæring av overflatevann og grunnvann, og mange har permeabelt toppdekke uten sammenhengende vegetasjon. Sigevanntmengden vil derfor kunne være stor. Måling av sigevannføring er nødvendig for å kunne foreta beregning av totale utslippsmengder. Måling av vannføring har imidlertid en rekke feilkilder, både ved installasjon av utstyr, valg av målepunkt, målemetode, vedlikehold og tilsyn.

Deponiforskriften angir veiledende hyppighet for måling av sigevanntmengde til månedlig i driftsfasen og hver sjette måned i etterdriftsfasen (se kapittel 3.3.1). Her anbefales imidlertid kontinuerlig mengdemåling av alt sigevann. Dette vil gi et langt bedre grunnlag for å beregne årlige utslipp fra deponiet. Videre må det beregnes en vannbalanse for deponiet basert på areal og værdata.

D.6.7 Vannbalanse i avfallsdeponier

Vannbalansen i et avfallsdeponi påvirkes av faktorene:

- vanninnhold i avfallet under deponering
- dannelse eller forbruk av vann i deponiet,
- inntrenging av vann fra nedbør eller grunnvann
- utstrømning av grunnvann eller sigevann
- evt. resirkulering av sigevann

Andel fremmedvann i sigevann bør være så lav som mulig, fordi dette reduserer mengden forbindelser som vaskes ut, og gjør det billigere og lettere å gjennomføre evt. rensing av sigevannet.

Nedbrytingsprosesser i deponiet medfører normalt et netto vannforbruk, men dette er lite i forhold til årlig tilført nedbør. Vanninnholdet i avfallet skal normalt være lite ved deponering, men noe vann kan presses ut ved komprimering av massene. I forhold til årlig nedbør vil også dette være lite med unntak for spesielle avfallstyper med særlig høyt vanninnhold.

I vedlegg 7 er det gitt metodebeskrivelse for utarbeidelse av vannbalanse for deponier.

D.6.8 Metoder for beregning av totale utslippsmengder

Kartlegging av avrenningsmønsteret for sigevann gjennom et år bør danne grunnlag for videre mengdemålinger. Kontinuerlig mengdemåling bør foretas med datalogger som også registrerer akkumulert vannmengde. Måleinnretningen må tåle stor skumdannelse, store variasjoner i vannmengde og et kjemisk aggressivt vann med et høyt stoffinnhold. Aktuelt utstyr kan være trykksonde og en målerenne med kjent måleprofil hvor sedimentasjonen er minimal (for eksempel H-renne). Parallelt med mengdemålingene bør det også gjøres kontinuerlig logging av ledningsevne.

Veiledende hyppighet for videre måling av sigevannsmengde er månedlig måling (i forskriften). Om kartlegging av avrenningsmønster viser små variasjoner kan dette være tilstrekkelig. I mange tilfelle vil variasjoner være store, og det vil være behov for fortsatt kontinuerlig mengdemåling.

Akkumulert vannmengde per måned/periode multipliseres med målt stoffkonsentrasjonen for perioden, som deretter summeres for alle periodene i året.

Metodene for beregning av stofftransporten med sigevann vil ha forskjellig grad av sikkerhet avhengig av tilgang på hydrologiske data, av prøvetakingsfrekvens og hvilken instrumentering som er foretatt. Bedre generell kjennskap til hvordan stoffkonsentrasjonen i sigevann påvirkes av nedbørsintensiteten vil også innvirke på hvor omfattende prøvetakingsopplegget bør være.

Erfaringstall viser at sigevannsproduksjonen fra norske deponier varierer mellom 300 og 600 mm per år og at midlere sigevannsproduksjon typisk ligger mellom 1.0 til 1.3 liter pr. sekund, eller omlag 30 000 m³ og 40 000 m³ per år, men varierer mellom 0.07 til 8 liter pr. sekund.

D.6.9 Behov for meteorologiske data

Deponiets vannbalanse kan beregnes dersom nedbør, vanninnhold, vannstand og avrenning måles over tid. For å få en kontroll av vannbalansen i deponiet bør skaffes til veie meteorologisk data som lufttemperatur, nedbør, snødybde og evt. fordampning fra en nærliggende meteorologisk stasjon eller ved direkte målinger ved deponiet.

Nedbør og nedbørvariasjoner kan med fordel måles lokalt, med en manuell eller automatisk nedbørmåler som leses av daglig. Nedbørmålere er i prinsippet et åpent kar med en veldefinert åpning. Gode nedbørmålere

leveres av ulike spesialleverandører for meteorologisk utstyr. For øvrig kan data for nedbør og fordampning hentes inn fra nærmeste meteorologiske målestasjon. Data for fordampning må vurderes lokalt utifra grad av vegetasjonsdekke.

D.6.10 Resipientvurderinger

Kriteriene er delt i to trinn:

1. Vurdering av utslipp uavhengig av resipient.
2. Resipientspesifikk risikovurdering for overflatevannresipient, grunnvann og kommunalt avløpsnett.

I første trinn sammenlignes totalmengde av utslippet mot veiledende verdier for utslipp til overflateresipient. Hensikten er å skalere utslippet uavhengig av resipientforhold.

I andre trinn tar man hensyn til resipientene og vurderer om utslippet faktisk kan gi lokale miljøskader.

Hvis verdiene i første trinn overskrides, indikerer dette normalt at sigevannet bør behandles før utslipp til overflateresipient, ettersom utslippet er så omfattende at det normalt er uønsket utifra lokale eller regionale hensyn. I tilfelle grenseverdiene ikke blir overskredet kan utslippet likevel gi lokale miljøskader. For å vurdere disse foretas den resipientspesifikke vurderingen (trinn 2).

Kriterier for overflatevann er gitt for hver av de tre forurensningskategoriene saprobiering, eutrofiering og økotoksikologiske effekter.

I vedlegg 6 presenteres metode for økotoksikologisk risikovurdering av enkeltstoffer. Metoden kan brukes for å vurdere betydningen av høye konsentrasjoner av giftige enkeltstoffer for resipienter.

Innledning

Resultater fra overvåkingen skal anvendes til å vurdere deponiets funksjon og sigevannutslippenes effekter på omgivelsene. For å vurdere miljøeffekter av sigevann trengs kriterier. I dette kapitlet gis forslag til hvordan overvåkingsresultatene kan anvendes. Inntil videre er kriteriene å betrakte som veiledende. Miljømyndighetene vil samle erfaringer med systemet over noe tid før det evt. innføres mer faste normative retningslinjer for miljøvurderingen. Et hovedmål med kriteriene som nå gis ut er å bidra til at deponieiere selv kan skalere og vurdere sine utslipp, og benytte dette i eget arbeid med å sikre at deponidriften ikke skader miljøet.

En forutsetning for å anvende kriteriene er et minstemål av kjennskap til økotoksikologisk begrepsverden og tenkemåte. Stoffet kan virke lite tilgjengelig for andre brukere, men metodene er basert på innarbeidet terminologi og metodikk. For innføring i toksikologi og økotoksikologiske undersøkelser henvises det ellers til SFT-rapportene "Kort innføring i toksikologi" (TA1756-2000), og "Økotoksikologisk undersøkelse av industriavløp" (TA 1750-2000).

For å støtte opp om de resipientespesifikke vurderingene av utslipp er det en forutsetning at det finnes kunnskap om resipientene (enten dette er overflatevann, grunnvann eller avløpsystem). Det forutsettes at man kan fastsette miljømål og grenser for hvor påvirkning kan aksepteres. Skisse til aktuelle undersøkelser i overflatevannresipient er vist i vedlegg 8.

D.6.11 Vurdering av utslipp uavhengig av resipient

På dette trinn sammenlignes målt/kalkulert utslippsmengde med veiledende grenseverdier. Vurderingen består av:

- ☐ Vurdering av saprobiering og eutrofiering. Sammenligning av målt utslipp med grenseverdier for TOC, KOF, BOF og Tot-N.
- ☐ Vurdering av økotoksikologiske effekter. Sammenligning av målt giftighet med grenseverdier for giftighetsutslipp (TEF).
- ☐ Korrigering for giftighet forårsaket av ammonium.
- ☐ Vurdering av metallinnhold. Sammenligning av målt utslipp av metaller med grenseverdier.

D.6.12 Vurdering av saprobiering og eutrofiering

Veiledende grenseverdier for utslipp av organisk materiale og næringssalter er vist i tabell 6. Grenseverdiene gjelder kun for utslipp til overflatereipient. Utslipp større enn grenseverdiene tilsier at utslippet er betydelig og at det bør vurderes rensetiltak. Ved utslipp mindre enn verdiene skal det gjøres en vurdering (trinn 2) for å avklare om utslippet likevel har lokal betydning.

Tabell 6. Veiledende grenseverdi for utslipp av organisk materiale og næringssalter fra deponier til ferskvanns- og sjøvannsresipienter. For vurderingen i trinn 1.

Parameter	Veiledende maksimalt tillatt utslippsmengde (kg/d)
TOC	150
KOF	300
BOF	150
Tot-N	50

Norge har forpliktet seg gjennom OSPAR-konvensjonen og Nordsjøavtalen til å redusere utslipp av næringssalter fra 1985 til 2005 med 50%. Det

er derfor ønskelig å begrense utslippet også uavhengig av de konkrete resipientforholdene. Sige vann fra avfallsdeponier bidrar for eksempel til 20-30% av nitrogenutslippet til vassdrag (SFT-rapport 92:23) og sige vann fra avfallsdeponier kan derfor anses å være en viktig kilde for næringssalter og organisk materiale til vassdrag.

D.6.13 Vurdering av økotoksikologiske effekter

Giftighet av utslippet beregnes på grunnlag av toksisitetmålinger utført på sige vannet.

Giftighetsutslipp (TEF) beregnes utifra målt giftighet (EC₅₀, LC₅₀ eller NOEC) og vannføring. Beregnet verdi sammenholdes med grenseverdier (tabell 7). Utslipp større enn grenseverdiene tilsier at utslippet er betydelig og at det bør vurderes rensetiltak. Ved utslipp mindre enn verdiene bør det gjøres en vurdering (trinn 2) for å avklare om utslippet likevel har lokal betydning.

Dersom de kjemiske analysene viser at sige vannet inneholder stoffer som kan antas å være toksiske kan det i tillegg foretas risikovurderinger for hver av dem. Prosedyre for økotoksikologisk risikovurdering av enkeltforbindelser er vist i vedlegg 6.

På grunnlag av målte toksisitetsdata for det aktuelle sige vannet og utslippsmengden (Q_s m³/s) beregnes verdien TEF (Toxicity Emmission factor):

$$TEF = Q_s \times \frac{100}{EC_{50}; LC_{50}; NOEC}$$

Grenseverdi for TEF i sige vann (beregnet for standard resipientscenario, dvs med en antatt vannføring på 1 m³/s i resipienten) er vist i tabell 7.

Tabell 7. Grenseverdi for TEF i sige vann (Toxicity Emmission factor).

Tilgjengelig informasjon	Maks. TEF
Laveste LC ₅₀ evt EC ₅₀ for akutt toksisitet bestemt med en art fra hver av 3 trofinivåer (bakterie, alge, krepsdyr)	0,005
En langtids-NOEC med den organismen som reagerer mest følsom i akutte toksisitetstester	0,05
Laveste langtids-NOEC bestemt med minst én alge/bakterie, ett krepsdyr	0,1

Forkortelser: se vedlegg 1.

Eksempel:

For et sige vann med vannføring 2 l/s (dvs 0.002 m³/s) er det funnet EC₅₀-verdier = 50% for alger og 60% for Daphnia. Den laveste verdien, dvs algetesten (EC₅₀=50 %) brukes til å beregne TEF:

$$TEF = 0,002 \text{ (m}^3/\text{s)} * 100/50(\%) = 0.004 \text{ (ubenevnt)}$$

Den beregnede TEF-verdien er lavere enn anbefalt maks. TEF (0,005) når tester med både alger og Daphnia er gjort. Altså er toksisiteten antatt å være akseptabel i henhold til den innledende vurdering.

Vurderinger av toksisitet knyttet til ammonium

I sigevann fra blandede deponier foreligger nitrogen i stor grad som ammonium. Ammonium er toksisk for vannlevende organismer og særlig for laksefisk. Toksisiteten skyldes hovedsakelig den ikke ioniserte formen, dvs ammoniakk (NH_3). Andelen ammoniakk øker med pH-verdien og særlig ved pH over 7.5 (tabell 8). Toksisiteten av ammonium er derfor pH-avhengig.

Tabell 8. Andel av ammoniakk ved ulike pH-verdier.

pH-verdi	Ammoniakk
7.3	1 %
8.3	10 %
8.8	25 %
9.3	50 %
9.7	75 %
10.2	90 %

I en vurdering av resultatene fra toksisitetstester er det ønskelig å skille mellom effekter som skyldes høy ammonium- og saltkonsentrasjon og effekter som forårsakes av helse- og miljøfarlige stoffer. Høye ammonium- og saltkonsentrasjoner gir en toksisk effekt i et relativt begrenset område rundt utslippspunktet i resipienten, helse- og miljøfarlige stoffer kan ha en effekt i et større område.

For å bestemme toksisiteten av organiske og uorganiske miljøgifter i sigevann med høye ammoniumkonsentrasjoner, kan man enten bruke testsystemer som er lite sensitiv mot ammonium- og saltkonsentrasjonene i sigevann (for eksempel Microtox), eller man beregner den forventede effekt forårsaket av ammonium. Ammoniumtoksisiteten for noen testorganismer som brukes i økotoksikologiske tester, er oppført i tabell 14. Toksisiteten som er forårsaket av ammonium beregnes i henhold til SFT-veileder 1750/2000 som toksiske enheter (TU):

$$\text{TU}_{\text{NH}_4} = \text{NH}_4^+ (\text{mg/l}) / \text{EC}_{50} \text{ (ammonium)}$$

Resttoksisiteten som ikke skyldes ammonium beregnes som følger:

$$\text{TU}_{\text{Rest}} = \text{TU}_{\text{Toks-test}} - \text{TU}_{\text{NH}_4}$$

Tabell 9. Toksisitet av ammonium-N (mg/l) mot ulike organismer ved ulike pH-verdier

Testorganisme	Parameter [mg/l N-NH ₄ ⁺]	Endepunkt	pH 7,0	pH 7,5	pH 8,2	pH 8,5	pH 9,0	NH ₃
Microtox (<i>Photobacterium phosphoreum</i>)	EC ₅₀	lysutsendelse/ dødelighet	4600					
Grønalge <i>Raphidocelis subcapitata</i> ⁴	NOEC	Vekst/Reprod. (72 t)	160	51	11	6	2,5	
	EC ₅₀	Vekst/Reprod. (72 t)	1600	500	110	58	24	
Krebsdyr <i>Daphnia magna</i>	NOEC	Dødelighet (24 t)		4				
	EC ₅₀			24				1,22- 1,54
Fisk <i>Salmo salar</i>	EC ₅₀	Dødelighet						0,025- 0,085

Forkortelser: se vedlegg 1.

D.6.14 Vurdering av metallinnhold

For metaller er det utarbeidet tilstandsklasser basert på konsentrasjoner i ferskvann og sjøvann (SFT-veileder 97:03 og 97:04) og en vannføring på 1 m³/s i resipienten. Disse er lagt til grunn for beregning av anbefalte maksimale utslippsmengder til ferskvanns- respektive sjøvannsresipienter. Utslipet skal ikke forverre vann- og sedimentkvaliteten i resipient betydelig (maks. fra tilstandsklasse I til III). Grenseverdiene er vist i tabell 10.

Tabell 10. Veiledende grenseverdier for utslipp av metaller fra deponier til henholdsvis ferskvanns- og sjøvannsresipienter

Parameter	Ferskvann	Sjøvann
	mengde (kg/d)	mengde (kg/d)
Kobber	0,1	0,05
Sink	1,5	0,5
Kadmium	0,005	0,05
Bly	0,1	0,01
Nikkel	0,2	0,1
Krom	0,2	0,03
Kvikksølv	0,0003	0,0003

D.6.15 Resipientspesifikk risikovurdering av utslipp til overflatevannresipient

På dette trinn foretas beregninger av fortynning og spredning av utslipp i resipient, og det vurderes om utslippet medfører uønskede effekter utenfor aksepterte influensområder.

⁴ Toksisitet av grønnaige *Selenastrum cupricomutum* er ikke kjent, men toksisiteten til grønnaige *Raphidocelis subcapitata* kan brukes som veiledende verdi

Fortynnings- og spredningsforhold beskrives (gjerne på kart). Beskrivelsen danner grunnlag for vurdering av enkeltkomponentene beskrevet nedenfor.

Videre vurdering består av:

- ❑ Vurdering av saprobiering og eutrofiering. Beregning av hvilke områder i resipienten som får en endring i tilstandsklasse (for TOC, N, P) som følge av utslippet fra deponiet. Vurdering av hvorvidt slike endringer oppstår utenfor aksepterte influensområder.
- ❑ Vurdering av økotoksikologiske effekter. Sammenligning av beregnet bidrag fra sigevann til giftighet i ulike deler av resipienten (PEC) med beregnet nulleffektkonsentrasjon (NOEC). I områder der $PEC > PNEC$ kan sigevannet gi toksiske effekter.
- ❑ Vurdering av metallinnhold. Beregning av hvilke områder i resipienten som får en endring i tilstandsklasse (for metaller) som følge av utslippet fra deponiet. Vurdering av hvorvidt slike endringer oppstår utenfor aksepterte influensområder.
- ❑ Vurdering av persistente bioakkumulerende stoffer. Korrigering av målt innhold i sigevann/sediment, og sammenligning med grenseverdier.

Den resipientespesifikke risikovurderingen utføres i prinsippet på samme måte som den innledende miljørisikovurderingen, men med den forskjellen at det blir foretatt reelle beregninger av fortynning og spredning i den aktuelle resipienten. Lokale miljømål for resipient (inkl. resipientens sårbarhet) avgjør hvor stort influensområde rundt utslippspunktet som kan aksepteres. Utslipp må deretter begrenses slik at det ikke gir effekter utover fastsatt influensområde. I disse beregningene inngår fysiske, kjemiske og biologiske målinger, samt utslippsmengder og blandingsforhold i resipienten. Influensområder som fastsettes for organisk materiale og næringssalter kan ha en annen størrelse enn influensområder som fastsettes for akseptable økotoksikologiske effekter.

Spredning/fortynning

Beregning av fortynningsforhold i resipienten kan gjøres ved hjelp av modeller som simulerer spredning og fortynning av et utslipp i ulike typer av resipienter (bekk/elv, innsjø, fjord, grunnvann). På grunnlag av beregningene bestemmes fortynningsgraden i ulike områder av resipienten. Alternativt kan fortynningsgraden måles ved analyse av en eller flere konservative parametre som kan knyttes til utslippet. Det anbefales at fortynningsforholdene beskrives på et kart. Det er viktig å ta hensyn til variasjoner i fortynningsforhold som følge av vannføring, vind eller tidevannsstrømmer slik at også de minst gunstige fortynningsforholdene blir belyst. For forhold som er tilstrekkelig dokumentert i overflateresipient anbefales at fortynningsforholdene som oppnås i 90% av tiden legges til grunn for risikovurderingen (for eksempel minstevannføringen i en resi-

pient, definert som den vannføring som overskrides i 90% av tiden på årsbasis).

D.6.16 Vurdering av saprobiering og eutrofiering i overflateresipient

Den resipientespesifikke risikovurderingen for saprobiering utføres ved å beregne konsentrasjonsøkningen av organisk materiale i resipienten som følge av utslippet. På grunnlag av en fortynnings- og spredningsanalyse beregnes i hvor store områder av resipienten som konsentrasjonen av TOC økes med 1, 2, 3, osv mg/l som følge av utslippet. For næringssalter beregnes tilsvarende tilskudd av P og N fra sigevannet i ulike deler av resipienten.

Vurderingen av miljøeffekter av organisk materiale og næringssalter gjøres med utgangspunkt i SFTs tilstandsklasser for de samme parametrene. Dersom utslippet medfører en endring i tilstandsklasser må det gjøres en lokal vurdering om dette kan aksepteres.

Eksempel:

I et sigevann er konsentrasjonene av TOC, tot. P og tot. N bestemt til henholdsvis 150, 1 og 100 mg/l. Utslippsmengden er 0,01 m³/s. Resipienten er en elv med vannføring 10 m³/s og konsentrasjonene TOC = 2 mg/l, tot. P = 5 µg/l og tot. N = 100 µg/l. Fortynningen vil gradvis øke fra utslippspunktet og til slutt bli 1000 ganger når sigevannet er fullt innblandet med elvevannet. Konsentrasjonene ved ulike fortynningsgrader er vist i figuren nedenfor. Fargeskalaen indikerer tilstandsklasser.

	Resipient	Utslipp	Fortynningsgrad				
			10 x	50 x	100 x	500 x	1000 x
TOC (mg/l)	2	150	16,8	4,96	3,48	2,30	2,15
Tot.P (µg/l)	5	1000	104,5	24,9	14,95	6,99	6,00
Tot.N (µg/l)	100	100000	10090	2098	1099	299,8	199,9

Fargeskala tilstandsklasser (samme fargekoder som i SFT-veileder 97:03)

I Meget god	II God	III Mindre god	IV Dårlig	V Meget dårlig

D.6.17 Vurdering av økotoksikologiske effekter i overflateresipient

Omfanget av eventuelle toksiske effekter av sigevannsutslipp i resipienten vurderes på grunnlag av toksisitetstester av sigevannet. Antatt null-effektskonsentrasjon (PNEC) i resipienten beregnes fra E(L)C₅₀-verdier eller NOEC-verdier fra de tester som er utført og ved bruk av sikkerhetsfaktorer som vist i tabell 17:

$$PNEC = \frac{EC_{50}; LC_{50}; NOEC}{SF}$$

Tabell 17. Sikkerhetsfaktorer (SF) for beregning av PNEC for sigevann, basert på kort-tids toksisitetstester.

Tilgjengelig informasjon	SF (PNEC)
Laveste L(E)C ₅₀ for akutt toksisitet bestemt med en art fra 3 trofinivåer (bakterie, alge, krepsdyr)	200
En langtids-NOEC med den organismen som reagerer mest følsom i akutte toksisitetstester	20
Laveste langtids-NOEC bestemt med minst én alge/bakterie, ett krepsdyr og én fisk	10

Forkortelser: se vedlegg 1.

PEC-verdier (beregnet konsentrasjon i resipienten) i ulike avstand fra utslippet fastsettes utifra målt sigevannskvalitet og forventet fortynding i resipienten. PEC beregnes eller måles dersom det er mulig på det punktet der organismene som skal beskyttes, vil eksponeres.

Risikovurderingen utføres ved å beregne forholdet mellom forventet sigevannskonsentrasjon i ulike deler av resipienten (PEC) og null-effektskonsentrasjonen (PNEC). I områder hvor PEC/PNEC >1 kan man vente at det oppstår kroniske toksiske effekter som følge av utslippet.

For toksiske komponenter i sigevannet, påvist ved den kjemiske karakteriseringen kan det gjøres PEC/PNEC-beregninger i henhold til vedlegg 6 for ulike deler av resipienten. Beregningene vil vise i hvilke områder av resipienten som PEC/PNEC er større enn 1, og hvor man således kan vente at sigevannsutslippet kan gi kronisk toksiske effekter.

På samme måte som for organisk materiale og næringssalter må det utføres en lokal vurdering av hvilken miljørisiko som kan aksepteres. Dog er det grunn til å være mer restriktiv når det gjelder toksiske effekter enn andre forurensningseffekter.

Vurdering av metallinnhold

Den resipientspesifikke risikovurderingen for metallinnhold utføres ved å beregne konsentrasjonsøkningen av metaller i resipienten som følge av utslippet. Vurderingen av miljøeffekter av metaller gjøres med utgangspunkt i SFTs tilstandsklasser for de samme parametrene.

Dersom utslippet medfører en endring i tilstandsklasser må det gjøres en lokal vurdering om dette kan aksepteres. Utslippet skal ikke forverre vann- og sedimentkvaliteten i resipient betydelig (maks. fra tilstandsklasse I til III). Som for organisk stoff og næringsstoff kan metallbelastningen i resipient presenteres på en fargeskala.

Utslipp til ferskvann			Fortynningsgrad				
Parameter	Ferskvann s-resipient	Utslipp	10x	50x	100x	500x	1000x
Kobber (µg/l)	0.5	20	2.5	0.9	0.7	0.54	0.52
Sink (µg/l)	4	600	64	16	10	5.2	4.6
Kadmium (µg/l)	0.03	20	2.03	0.43	0.23	0.07	0.05
Krom (µg/l)	0.15	600	60.15	12.15	6.15	1.35	0.75
Kvikksølv (µg/l)	0.0015	0.2	0.0215	0.0055	0.0035	0.0019	0.0017
Nikkel (µg/l)	0.4	40	4.4	1.2	0.8	0.48	0.44

Fargeskala tilstandsklasser (samme fargekoder som i SFT-veileder 97:03)

I	II	III	IV	V
God	Mindre god	Nokså dårlig	Dårlig	Meget dårlig

Vurdering av persistente, bioakkumulerbare stoffer

For stoffer som i tillegg til å være toksiske også er persistente (dvs tungt nedbrytbare) også har potensiale for akkumulering i organismer, kan skader i miljøet oppstå selv om en risikovurdering basert på toksisitet alene ikke indikerer miljøeffekter i resipienten. Dette skyldes at stoffer med slike egenskaper kan oppkonsentreres til skadelige konsentrasjoner i organismer langt fra utslippsstedet. Stoffer som er meget persistente og meget sterkt bioakkumulerende kan oppkonsentreres i næringskjeder over lang tid og er dermed en trussel for toppkonsumenter inkludert mennesket. Felles for de sterkt bioakkumulerende stoffene er at de har meget lav vannløselighet og høy affinitet til fast stoff. Det medfører at det i sigevann, som inneholder suspendert og løst organisk stoff, i hovedsak vil være knyttet til suspendert og organisk materiale. I resipienten vil en del av dette materialet sedimentere på bunnen i utslippsområdet. For noen aktuelle forbindelser i denne kategorien er det definert tilstandsklasser for sediment, som kan benyttes til å vurdere nivåer av miljøgifter knyttet til organisk materiale i sigevann.

Det beregnes totalt utslipp av de enkelte miljøgifter pr år.

Totalutslipp av tungtløselige organiske miljøgifter beregnes ved å multiplisere totalmengde organisk stoff (TOC) i sigevann (mg/d) med konsent-

rasjon av de ulike organiske forbindelsene (relatert til TOC-innhold) i sediment. Totalmengde av bioakkumulerbare stoffer skal normalt ikke overstige mengdene som er angitt i tabell 12. Beregningen foretas etter følgende formel:

$$\text{Totalutslipp} \left[\frac{\text{mg}}{\text{år}} \right] = \frac{\text{Miljøgifter i deponi} \left[\frac{\text{mg}}{\text{kg tørrstoff}} \right]}{\text{TOC-kons. i deponi} \left[\frac{\text{g}}{\text{kg tørrstoff}} \right]} \cdot \text{TOC-kons. vann} \left[\frac{\text{g}}{\text{m}^3} \right] \cdot \text{Vannmengde} \left[\frac{\text{m}^3}{\text{år}} \right]$$

Tabell 12. Veiledende grenseverdier for utslipp av miljøgifter fra deponier.

Forbindelse	Maksimalt utslipp til resipient
Σ PAH ¹⁾ (kg/år)	6
B(a)P ²⁾ (g/år)	150
HCB ³⁾ (g/år)	7,5
Σ PCB ⁴⁾ (g/år)	75
EOX ⁵⁾ (g/år)	1500
TE ⁶⁾ PCDF/D (mg/år)	0,1
Σ DDT ⁷⁾ (g/år)	7,5

- 1) PAH: Polysykliske aromatiske hydrokarboner. Gruppe tjærestoffer der en del forbindelser er potensielt kreftfremkallende (KPAH, deriblant benzo(a)pyren B(a)P. ΣPAH: sum av tri-heksasykliske forbindelser bestemt ved gasskromatografi med glasskapillarkolonne, inkluderer de 16 i EPA protokoll 8310 minus naftalen (disyklisk). Omfatter dessuten alle KPAH (gr. 2A og gr. 2B i IARC, 1987).
- 2) Se under PAH
- 3) HCB: Heksaklorbensen
- 4) PCB: Polyklorete bifenyler. Gruppe forbindelser (ulike kommersielle blandninger). ΣPCB₇= sum av de 7 enkeltforbindelsene nr. 28, 52, 101, 118, 138, 153 og 180. Enkelte PCB har dioksinliknende egenskaper
- 5) EOX: Ekstraherbart, organisk bundete halogener.
- 6) TE: Toksisitetsekvivalenter. Konsentrasjonen av dioksiner angis som TE, dvs ekvivalenter av den giftigste dioksinforbindelsen (2,3,7,8-TCDD).
- 7) DDT: Diklordifenyiltrikloretan. ΣDDT betegner sum av DDT og nedbrytningsproduktene DDE og DDD.

Konsentrasjonen av miljøgifter i sedimentert materiale eller overflatesediment vurderes ellers på grunnlag av sedimentkvalitetskriterier (SFT-veileder 97:03), miljøgiftkonsentrasjon i passive prøvetakere og biota vurderes i henhold til kvalitetskriterier for vannlevende organismer⁵ (SFT-veileder 97:03). For forbindelser som ikke er oppført i tabell 9, henvises til vedlegg 14 som inneholder veiledende sedimentkvalitetskriterier⁶. I tilfelle konsentrasjonen av bioakkumulerbare stoffer i sedimentert materiale, abiotiske eller biotiske prøvetakere overskrider grenseverdien i tilstandsklasse II (moderat forurensset) eller vannkvalitetskriterier (vedlegg 14), bør det vurderes tiltak for å redusere utslipp av partikulært og evt. løst organisk materiale med sigevann.

⁵ SPMD-konsentrasjoner kan sammenlignes med konsentrasjoner i blåskjell

⁶ I dette tilfellet må grenseverdiene omregnes som følger:

Påvisning av forurensninger i overflateresipient

Rutinemessige biologiske undersøkelser som for eksempel bestemmelse av artsdiversitet av bunndyrfauna anbefales som en kontroll av tilstanden i resipienten. Dersom slike undersøkelser indikerer uakseptable miljøeffekter som kan knyttes til utslipp av sigevann gir dette grunnlag for tiltak, selv om utførte risikovurderinger ikke har indikert uakseptabel risiko. I så tilfelle bør også grunnlaget for risikovurderingene revurderes for å identifisere feilkilder.

Enkelte biokjemiske responser i organismer kan brukes som biomarkører for eksponering til toksiske stoffer. Biomarkører beskriver "helse-tilstanden" til organismene og kan brukes til å vurdere eksponering av organismer til giftige stoffer. Undersøkelsene kan utføres på organismer som hentes fra resipienten eller som blir eksponert i bur på ulike lokaliteter. Ved at ulike biomarkører indikerer ulike typer av effekter kan de gi spesifikk informasjon om type eksponering (for eksempel tungmetaller) eller hva slags biologiske effekter (for eksempel hormonforstyrrelser) som forurensningen medfører.

For metaller og organiske miljøgifter, som i særlig grad akkumuleres i sedimenter anbefales at det utføres analyser av bunnsedimentet på ulike lokaliteter i resipienten. Konsentrasjonen av ulike stoffer kan sammenliknes med SFTs tilstandsklasser for marine sedimenter.

Vurdering av utslipp til grunnvann

Spredning av forurenset sigevann i grunnvann vurderes på grunnlag av måling av indikatorparametere oppstrøms og nedstrøms deponiet. Dersom nivå av indikatorparameter tilsier at det spres sigevann utenfor akseptert influensområde skal forholdet meldes til miljømyndigheter, og relevante tiltak settes i verk.

Dersom det er satt i gang et mer omfattende måleprogram for grunnvann vurderes innhold av organisk stoff, næringssalter, gifteffekter, miljøgifter, bioakkumulerende stoffer etter angitte kriterier og i forhold til aktuelle brukerinteresser.

Å beskytte grunnvann mot kontaminering fra sigevann har to hovedhensikter

- grunnvann kan strømme fram i dagen og forurense overflatevann
- forurenset grunnvann kan ha negative effekter for pågående og framtidig drikkevannsproduksjon eller annen bruk av grunnvann.

Spredning av sigevann i grunnvann kan påvises ved hjelp av et eller flere stoff som kan knyttes til sigevannsutslipp og som har høy mobilitet (f.eks

klor, natrium, bor). Ved hjelp av disse indikatorparametrene er det mulig å kartlegge omfanget av sigevannspåvirkningen både når det gjelder spredning og styrke. Områder der analyseresultatene for indikatorparametre er signifikant forhøyet i forhold til bakgrunnskonsentrasjonen, anses å være påvirket av sigevann.

I likhet med risikovurdering av overflateresipient bestemmes akseptable influensområder på grunnlag av miljømål for grunnvannet. Utenfor disse influensområder er sigevannspåvirkning ikke ønsket og sigevannsutslipp må hindres slik at det ikke gir negative effekter utover fastsatt influensområde.

Risikovurdering av sigevannspåvirket grunnvann foretas på grunnlag av konsentrasjon av utvalgte næringsstoffer, konsentrasjon av helse- og miljøfarlige stoffer og toksikologiske testresultater som vist i figur 3.

Figur 3. Risikovurdering av sigevannspåvirket grunnvann.

Vurdering av organisk stoff og næringssalter i grunnvann

For organisk materiale og næringssalter skal konsentrasjonene ved utkan- ten av influensområdet ligge på nivå med bakgrunnskonsentrasjonene. Ved høye konsentrasjoner av organisk materiale kan det være fare for mobilisering av bioakkumulerbare forbindelser i grunnvannet.

Vurdering av gifteffekter i grunnvann

Økotoxikologiske effekter vurderes på lik grunnlag som for overflateresipient: Med hjelp av indikatorparametere beregnes den antatte sigevannspåvirkning.

vannskonsentrasjonen i grunnvann (PEC). Den antatte null-effektkonsentrasjonen (PNEC-verdi) bestemmes på grunnlag av de toksisitetmålingene i det prøvetakingspunktet som har størst sigevannspåvirkning og de respektive sikkerhetsfaktorene.

$$PNEC = \frac{EC_{50}; LC_{50}; NOEC}{SF}$$

Det bestemmes forholdet mellom PEC og PNEC. I områder der $PEC/PNEC > 1$, kan det være fare for kroniske effekter av sigevannet. $PEC/PNEC > 1$ er derfor bare akseptabelt innenfor de definerte influensområdene. Imidlertid må man i grunnvannet ta hensyn til at miljøgifter binder i ulik grad til akvifer materialet og at spredningen av miljøgifter i grunnvannet derfor ikke er like stor som av indikatorparametere som brukes til beregningen av PEC-verdien. I de tilfellene der $PEC/PNEC > 1$ utenfor influensområdet, anbefales det å gjennomføre kroniske toksisitetstester direkte på grunnvannsprøver.

Vurdering av miljøgiftkonsentrasjoner i grunnvann

I områder der det forgår drikkevannsproduksjon er det hensiktsmessig å sammenligne miljøgiftkonsentrasjonene i prøvetakingspunktene ved utkanten av influensområdet med grenseverdiene fastsatt i drikkevannsforskriften eller egnete vannkvalitetskriterier (vedlegg 14).

Vurdering av bioakkumulerbare stoffer i grunnvann

Bioakkumulerbare stoffer er i henhold til kap. 3.2 målt enten i akvifer materiale (1-2 m under grunnvannsoverflate) eller ved hjelp av abiotiske prøvetakere (for eksempel SPMD). Konsentrasjon av bioakkumulerbare forbindelser i utkanten av influensområdet skal ikke overstige bakgrunnsnivået.

Vurdering av utstrømmende grunnvann

Det kan være aktuelt å måle organisk materiale, næringssalter, helse- og miljøfarlige stoffer, samt toksisitet i grunnvann i nærheten av en resipient som på grunnlag av de hydrogeologiske forholdene kan være påvirket av sigevannsforurenset grunnvann. Sigevannsforurenset grunnvann som når overflatevann skal behandles som utslipp av sigevann til en overflateresipient (se kap. 5.2).

Vurdering av utslipp til kommunal avløpssystem

Rensing av sigevann i kommunale renseanlegg er en mulig behandlingsløsning så lenge sigevannet ikke påvirker renseprosessen på en negativ måte eller fører til akkumulering av organiske og uorganiske miljøgifter i avløpslam i et nivå som gjør slammet uegnet til jordforbedring. Utslipp av næringssalter og organisk materiale anses ikke som et problem så lenge rensekapasiteten til renseanlegget ikke er nådd. Totalmengde av bioakkumulerbare stoffer skal ikke overstige de grenseverdiene som er formulert i tabell 12. I tillegg skal toksisiteten (målt som nitrifikasjonshemming) ikke overstige de grenseverdiene som er angitt i tabell 11.

D.6.18 Rapportering

Avviksrapportering

Dersom overvåkingen viser at sigevannsutslipp medfører betydelige skadevirkninger på miljøet skal forholdet straks meldes til forurensingsmyndigheten. Ansvarsforhold knyttet til slik meldeplikt skal gå klart fram av overvåkingsprogrammet.

Årsrapportering

Resultatene fra overvåkingsprogrammet for de enkelte avfallsdeponier skal presenteres i årlige miljørapporter som sendes forurensingsmyndigheten (FMVA) en gang i året.

Data og andre opplysninger skal presenteres i bearbeidet form i rapport som vist nedenfor og elektronisk i form av Excel regneark. Vedlegg 9 viser en prøvetakingsprotokoll som bør benyttes og vedlegges rapporten i utfylt stand sammen med originale datautskrifter fra laboratoriene. For-slag til rapportering i Excel regneark er vist i vedlegg 12.

Sammendrag

Sammendraget av de funn og resultater som er fremkommet i undersøkelsen er det viktigste i hele rapporten. Sammendraget bør være en kort og konsis, men mest mulig nyansert beskrivelse av resultatene. Det er viktig at også usikkerheten i resultatene blir nevnt i sammendraget.

Sigevannsmengde

Sigevannsmengden skal oppgis i total per år og i månedlige utslipp. Det skal gjøres en vurdering om sigevannsmengdene er reelle i forhold til nedbør og eventuelle lekkasjer. Dersom det er kontinuerlig måling av sigevann oppgis vannføringen for driftsåret i hydrogram (figur med avrenning og tid).

Nedbørdata

Nedbørdata fra nærliggende værstasjon eller fra egne målinger skal presenteres og brukes i beregning av vannbalansen.

Vannbalanse

Det skal presenteres en hydrogeologisk vannbalanse for avfallsdeponiområdet. Det skal gjøres en vurdering av mulige lekkasjer inn- og ut av området, og for betydningen av variasjoner gjennom året.

Grunnvann

Det skal presenteres forslag til akseptabelt influensområde for grunnvann omkring deponiet, inntegnet på kart sammen med plassering av brønner oppstrøms og nedstrøms deponiet. De målte parametre i grunnvann skal presenteres og vurderes.

Sigevannsdata

Følgende informasjon skal sammenstilles og presenteres sammen med de kjemiske analyse resultatene:

Prøvetaking og prøvehåndteringsmetode

Analysemetoder

Prøvepunkt

Avfallstype i deponiet eller deler av deponiet som prøven representerer

Nedbørmengde før prøvetaking (siste uke, dagen før og under prøvetaking) og prøvetakingsdato.

Prøvetakingsprotokoll og analysebevis (fra laboratoriet) bør vedlegges rapporten.

En vurdering av sigevannets innhold av forurensninger kan baseres på målte konsentrasjoner og stoffmengder. En vurdering basert på konsentrasjoner er aktuell ved vurdering av behandlingsmetoder for sigevannet og for beregning av effekter og fortynning i resipienten.

Data for utslipp fra lokale renseanlegg for sigevann skal presenteres for de konsesjonsparametre det er satt krav til. Utslippskonsentrasjoner og stoffmengde fjernet skal presenteres.

For å kunne bruke resultatene er det viktig å vite i hvilken grad de er "sanne". Derfor bør usikkerheten i test- og analyseresultatene oppgis og helst også diskuteres i rapporten. Når resultatene skal brukes er det ofte viktig å vite hvilke ledd i undersøkelsen som bidrar med den største usikkerheten.

Dersom renseanlegget ikke tilfredsstiller rensekraft skal det presenteres forslag til tiltak med fremdriftsplan.

Utslipp til resipient

Stoffutslipp skal oppgis i kg eller gram per år i tabellform. Data for de tre siste år skal vises for sammenlikning og endringen i middelerdi i forhold

til fjoråret skal vises i prosent. Konsentrasjonene skal vurderes opp mot generelle funn av sigevann (vedlegg 15) og oppgitte grenseverdier i veilederen (vedlegg 14) og evt. andre relevante grenseverdier.

Resipientens størrelse, sårbarhet, tidligere belastning, beskyttelsesverdi etc skal beskrives i forhold til vurderingen av utslippets forurensende karakter.

Endringer i miljøtilstanden for avfallsdeponiet

Endringer i utslippsmengder og konsentrasjoner skal vurderes for hvert enkelt stoff og i sammenheng. Det skal vises trendkurver for utvalgte parametre som kan ha betydning for det enkelte deponiet, for eksempel organisk materiale, NH₄-N, ledningsevne og pH. Miljøtilstanden skal vurderes for overflatevann, grunnvann og sigevann og miljømessige konsekvenser ved vesentlige endringer av utslipp.

Annex E.1. Leachate monitoring results from Sweden.

Table E.1.1. Untreated leachate from landfills in Sweden

Compounds, parameters	Unit	Min	Max	Median	Average	Samples
pH	-	6.4	9.0	7.7	7.6	27
Conductivity	mS/m	230	2700	600	740	21
Suspended solids	mg/l	1.4	2100	35	130	28
BOD ₇	mg O ₂ /l	3.0	270	16	43	26
COD _{Cr}	mg O ₂ /l	110	1400	550	660	27
TOC	mg/l	41	490	180	230	29
DOC (0.45 µm)	mg/l	37	490	160	210	27
POC	mg/l	0.0	36	2.6	6.8	24
Salinity	ppt	0.8	19	2.4	4	20
Cl ⁻	mg/l	120	4900	690	1300	29
SO ₄ ²⁻	mg/l	6.5	1900	120	310	22
F ⁻	mg/l	0.3	12	1.3	4.1	21
N-NH ⁴⁺	mg/l	0.6	870	165	230	30
N-Kjeldahl	mg/l	11	860	200	260	28
N-NO ₂ + N-NO ₃	mg/l	0.0	60	1.0	8.0	29
N-Total (N-KJ+N-NO ₃)	mg/l	15	870	200	260	30
P-PO ₄ ³⁻	mg/l	0.0	4	0.6	0.9	27
P-Total	mg/l	0.1	4	1.1	1.4	27
Organic sum parameters	mg/l					
Total extractable aliphatic compounds		0.0	5	1.0	1.6	9
Chlorinated and brominated aliphatics	µg/l					
Dichloromethane		0.0	260	0.0	9.8	27
Benzene and alkyl benzene's	µg/l					
Sum xylenes		0.0	130	0.2	9.0	31
Sum BTEX		0.0	190	1.5	16	17
Phenol and alkyl phenols	µg/l					
Phenol		0.0	10	0.0	0.7	24
sum Cresol		0.0	12	0.0	0.8	20
Sum alkylated phenols		0.0	30	0.0	4.7	17
Nonylphenol ethoxylates	µg/l					
4-nonylphenol		0.0	17	2.6	4.1	8
4-nonylphenolmonoethoxylate		0.0	15	5.4	5.3	8
PAHs	µg/l					
Sum 16 PAHs		0.0	11	0.2	2.0	30
PAHs, carcinogenic		0.0	0.3	0.0	0.04	11
Phthalates	µg/l					
DEHP		0.0	39	0.0	5.1	26
Chlorobenzenes	µg/l					
Sum chlorobenzenes		0.0	4.0	0.32	0.8	20
Chlorophenols	µg/l					
Sum chlorophenols		0.0	43	0.2	2.0	27
PCBs	µg/l					
Sum PCBs		0.0	0.04	0.0	0.005	13

Brominated flame retardants	µg/l					
Phenoxy acids	µg/l					
2-(2-Methyl-4chlorophenoxy)propionic acid (MCP (Mekoprop))		0.0	54	1.4	5.8	32
2,4-Dichlorophenoxyacetic acid (2,4-D, Dikloroprop)		0.0	8.0	0.5	1.3	30
Organic mercury compounds	ng/l					
Methyl mercury (not filtrated sample)		0.0	1.0	0.5	0.4	8
Tinorganic compounds	µg/l					
Monobutyltin		0.0	0.04	0.01	0.02	12
Dibutyltin		0.0	0.6	0.003	0.04	17
Tributyltin		0.0	0.06	0.0	0.01	17
Metals, inorganic components						
Fe	mg/l	0.2	43	2.9	6.7	27
Mg	mg/l	14	140	60	63	27
S	mg/l	2.9	750	28	120	27
Al	µg/l	26	580	150	230	27
As	µg/l	0.0	53	5.9	12	24
Cd	µg/l	0.0	3.0	0.2	0.3	26
Co	µg/l	1.7	28	9.5	9.9	27
Cr	µg/l	1.4	120	12	26	28
Cu	µg/l	1.6	80	1	19	27
Hg	µg/l	0.0	0.6	0.02	0.05	26
Mn	µg/l	130	5200	82	1400	27
Ni	µg/l	9.8	110	39	40	27
Pb	µg/l	0.0	47	3.4	6.7	27
Zn	µg/l	7.8	470	4	88	27
Toxicity, mixed leachates						
Microtox, bioluminescence inhibition						
EC50, 15 min	Vol-%	53	100	100	94	13
Green alga, Raphidocelis subcapitata growth rate inhibition						
EC50, 72 h	Vol-%	3.1	19	10	11	5
Red alga, Ceramium strictum reproduction impairment						
EC50,	Vol-%	3.6	8	5.7	5.7	2
Crustacea, Ceriodaphnia dubia lethality						
IC50, 24 h	Vol-%	0.9	7	3.8	3.8	2
Crustacea, Nitocra spinipes lethality						
IC50, 96 h	Vol-%	3.3	10	6.6	6.6	2
Zebra fish, Danio rerio lethality						
LC50, 7 d	Vol-%	1.2	3	1.5	1.9	3
Agonistic hormone activity						
Estrogenic effects in vitro, estradiol equivalents	ng/l	< 0.4	29	2.8	8.6	7
Androgenic effects in vitro, dihydrotestosterone equivalents	ng/l	< 1.0	69	27	37	6

Table E.1.2. Collection and treatment of municipal landfill leachates in Sweden (data from RVF report 2004:13).

	Number of treatment plants	Volume leachate, M m ³	Received masses of waste at the landfills. M tonnes
No treatment	Approx. 40 (mostly small landfills)	No data	No data
Collection of leachates	148	8,0	2,7
Treatment in municipal WWTP	84	4,7	1,7
Local treatment	86	3,4	1,6

Table E.1.3. Methods at local treatment plants for landfill leachates in Sweden (RVF report 2004:13). A treatment plant often have a combination of methods.

Type of treatment method	Number
Aerated ponds	86
Irrigation	34
Infiltration	28
Recirculation to landfill	29
Constructed wetland	18
Soil and/or sand filter	14
Chemical precipitation	9
Mechanical treatment	4
SBR-plant	2

Annex F.1. Summary of leachate monitoring data from the Nordic countries.

F.1.1. General parameters

Alkalinity

(meqv/l)

Mean: 14-47 Max: 60-82

Reported: Dk, N

Ref: 300-11500 (mg CaCO₃/l, or 3 - 115 mmol CaCO₃/l)

A measure of basic anions consuming acidity during neutralization. Buffer capacity (mmol/l or meqv/l as OH⁻). Sometimes given as HCO₃.

BOD (5 d, 7 d)

(mg/l)

Mean: 43-1200. Max: 270 -8300

Reported: Dk, N, S

Ref: 20-90 000

A measure of easily bichemically degradable material under aerobic conditions (mg/l). A rather imprecise measure of the total pollution potential. Also indicate potential odour problems.

COD

(mg/l)

Mean: 270-5028, Max: 640-16000

Reported: Dk, N, S

Ref: 140 – 152 000

A measure of chemically oxidising compounds (mg/l). COD_{Cr} uses dichromate which is a stronger oxidizing agent than COD_{Mn}.

Cl

(mg/l).

Mean: 203-13 000, Max: 640-100 000

Reported: Dk, N, S

Ref: 150 – 45 000

PI reporting parameter

High Cl content indicates soluble salts or easy degradable material in the waste. Highly mobile. Good indicator if natural concentrations are not high e.g. due to marine deposits.

DOC

(mg/l)

Mean: 210 Max: 490

Reported: S

Dissolved Organic Carbon (TOC on 0,45 µm filtrated samples).

Electrical conductivity

(mS/m)

Mean: 130- 3700. Max: 740-16 000

Reported: Dk, N, S

Ref: 250 - 3500

Measure of the total ionic activity (10 mS/m = 1 µS/cm).

F

(mg/l)

Mean: 4.1 Max: 12

Reported: S

PI reporting parameter

Fluoride is toxic in high concentrations.

HCO₃

(mg/l)

Mean: 163 Max: 3679

Reported: N

Ref: 610 – 7320

Bicarbonate is a major component in leachate. Mainly produced from microbially CO₂ dissolved in water. Usually measured by titration to pH 5.4. It is not known how well this method is adapted to leachate.

NH₄-N

(mg/l)

Mean: 0.11- 570, Max: 57-870

Reported: Dk, N, S

Ref: 1 – 2200

Ammonia is usually >90% of Tot-N in leachate. It can cause eutrophication, harm vegetation and be acute and chronic toxic to many aquatic species.

NO₃-N (or NO₂-N+NO₃-N)

(mg/l)

Mean: 1 – 8, Max: 60 – 375

Ref: 0.1 – 50

Usually found in low concentrations in leachate due to anoxic conditions favouring ammonia.

Tot-N

(mg/l)

Mean: 81 – 510 Max: 250 – 970

Reported: Dk, N, S

Ref: 50 - 5000

PI reporting parameter

Total nitrogen including all forms of N.

N-Kjeldahl

(mg/l)

Mean: 160- 260 Max: 860

Reported: Dk, S

Ref: 1 - 2500

Total organic N

PO₄-P

(mg/l)

Mean: 0.1- 6 Max: 1- 4

Reported: N, S

Ref: 0.1 – 30

Soluble phosphorous available for growth and eutrophication.

Tot-P

(mg/l)

Mean: 1.1 – 3.4 Max: 2.2 - 75

Reported: Dk, N, S

PI reporting parameter

Total phosphorous including all forms.

pH

(- log[H⁺])

Max: 7.4 – 9

Reported: Dk, N, S

Ref: 4.5 – 9

pH measures acidity. The solubility, speciation and toxicity of compounds often depends on pH. Mean values should be calculated on the basis of H⁺-concentrations and not the log-values and are thus not listed here.

Redox

(mV)

Mean: 39 - 55 Max: 310-410, min: -230 to -101

Reported: Dk, N

The potential for reducing or oxidizing reactions. Certain biologically induced reactions takes place at specified redox potentials. Representative measurements of reducing conditions are hard to obtain due to sample alterations.

Runoff (Q)

(m³/day)

Mean: - 118 Max: 605-1023

Reported: N, Is

Amount of leachate collected downstream landfill. Preferably reported without groundwater dilution.

Suspended Solids (SS)

(mg/l)

Mean: 98 – 130 Max: 500 – 2700

Reported: N, S

Ref: 2000 – 60 000

A measure of particles in water samples. Gravimetric filtration (usually on a Whatman 1,6 µm) and drying (105°C).

SO₄-S

(mg/l)

Mean: 5.5 – 830 Max: 242 - 2200

Reported: Dk, N

Ref: 8 – 7750

Screening parameter for e.g. demolition waste including plaster board. Sulphate is reduced to sulphide adsorbing metals. Sulphide can produce odours.

Sulfide
(mg/l)
Mean: 0.060 – 11 Max: 3.7 - 320
Reported: Dk
Ref: 8 – 7750

Sulfide is a strong odourant and metal precipitator.

Temperature
(°C)
Mean: 7.9 – Max: 17.2-24
Reported: N, Is

Leachate may have significantly elevated temperatures compared to ambient temperature due to the biological activity, especially during the aerobic phase.

TOC
(mg/l)
Mean: 85 – 230 Max: 490 - 860
Reported: N, S
Ref: 30 – 29 000

Total organic carbon is a group parameter for all organic compounds measured as C, e.g. measured by catalytic combustion to CO₂. Inorganic C is removed prior to analysis. Volatile carbon can escape analysis.

VOC (POC)
(µg/l)
Mean: 6.8 Max: 36
Reported: S

Volatile (purgable) organic carbon. Extracted from the sample by an inert gas. VOC = total carbon-total inorganic carbon-total organic carbon.

F.1.2. Elements and heavy metals

Ag
(µg/l)
Mean: 0.57 Max: 10

Reported: N

Silver is usually adsorbed to particles. Ionic Ag^+ is much more toxic to fish than Ag complexes. Fish Ag toxicity is thus higher in freshwater than in seawater.

Ag is not measured above detection limit in Norway.

Al

($\mu\text{g/l}$)

Mean: -230 Max: 580

Reported: S

The content of Al is directly dependent on pH, and is usually $<100 \mu\text{g/l}$ when $\text{pH} > 5.5$. Al can be toxic to fish in acid, humic waters when $\text{Al} > 100 \mu\text{g/l}$.

As

($\mu\text{g/l}$)

Mean: 8 - 12 Max: 53 - 62.4

Reported: N, S

Ref: 5 – 1600

PI reporting parameter

Arsenic can be acutely toxic for aquatic and terrestrial life. As(III) is more toxic than As(V). As in leachate is approx. 80% arsenate (H_2AsO_4 , HAsO_4), 10% arsenite (H_2AsO_3), the rest is methylated. Arsenic bio accumulates. Can occur at toxic levels in leachate. Sources: Brass, accumulators, cartridges, industrial processes, mines. Listed as priority compound (OBS-listen, Norway).

B

(mg/l)

Mean: 1.5 – 4100 Max: 5.8 - 4600

Reported: Dk, N

Boron is an indicator parameter for MSW leachate. An important source is soluble borate from detergents.

Ba

($\mu\text{g/l}$)

Mean: 86 – 120 Max: 120 – 310

Reported: N

Barium is toxic to some organisms (bacteria, fungi, algae) but has probably less impact on marine fauna. Occurs as Ba(II) in water, precipitates as BaSO_4 when the concentration of sulphate is high.

Cd

(µg/l)

Mean: 0.30 – 330 Max: 3.0 – 1300

Reported: Dk, N, S

Ref: 0.1 - 400

PI reporting parameter

Cadmium is toxic at low concentrations, and it bio accumulates. Sources: Batteries, accumulators, mineral fertilizers, metallurgic industry, mining, wastewater sludge, air.

Cr

(µg/l)

Mean: 6.5 - 71 Max: 40 – 654

Reported: Dk, N, S

Ref: 20 - 1600

PI reporting parameter

Chromium bio accumulates and is toxic. Cr (VI) is carcinogenic. Usually occurs as Cr (III) and Cr (VI). The latter is more soluble and toxic. Speciation depends on oxygen and pH. Oxidation and reduction is usually slow. Cr (III) as hydroxide is very soluble at pH>6. Presence of Fe or other cations can reduce solubility. Sources: Steel, cement, erosive sand, paint, industrial processes, tanneries, textile, surface treatment, wastewater. Listed as priority compound (OBS-listen, Norway).

Cu

(µg/l)

Mean: 10 - 35 Max: 62 – 3700

Reported: Dk, N, S

Ref: 5 – 10 000

PI reporting parameter

Bio accumulates in plants and are toxic to aquatic and terrestrial life. Can inhibit growth, reproduction and reduce immunity. Toxicity depends on speciation influenced by water hardness or conductivity. Sources: Wood preservatives, ship paint, mineral fertilizer, pesticides, piping and tubing. Listed as priority compound (OBS-listen, Norway).

Fe

(mg/l)

Mean: 3 - 120 Max: 7.4 – 592

Reported: Dk, N, S

Ref: 0.4 – 5500

Iron is by far the most common metal in leachate, usually as Fe²⁺. Oxidizes easily and precipitates as (Fe(OH)₃ or humic complexes, which

removes other compounds through coprecipitation. Indicator of leachate pollution, especially due to coloured precipitates.

Hg

(µg/l)

Mean: 0.03 – 8.5 Max: 0.34 – 200

Reported: Dk, N, S

Ref: 0.05-160

PI reporting parameter

Mercury occurs naturally in very low concentrations. Bioaccumulates in plants and are toxic to aquatic and terrestrial life. Toxicity is nearly the same for all species, except that young species are more vulnerable than older ones. Organic mercury is 10 to 100 times more toxic than inorganic. Inorganic mercury can be transformed to organic in nature. Sources: Batteries, dental material, thermometers, light fixtures, industry, crematorium. Listed as priority compound (OBS-listen, Norway).

Mn

(mg/l)

Mean: 1.4 – 2.0 Max: 5.2 – 760

Reported: N, S

Ref: 0.03 - 1400

A common heavy metal in leachate.

Na

Na and K are usually >30% of cations in leachate. Can be used as indicators of leachate pollution where background is not too high.

(mg/l)

Mean: 209 - 1300 Max: 796 – 3200

Reported: Dk, N

Ref: 50 - 4000

K

(mg/l)

Mean: 90-1500 Max: 306-4900

Reported: Dk, N

Ref: 10 - 2500

Ni

(µg/l)

Mean: 15 - 7300 Max: 30 – 58 000

Reported: Dk, N, S

Ref: 15 – 13 000

PI reporting parameter

Nickel shows high acute toxicity to aquatic life in lab tests. Bioavailability and toxicity is, however, strongly dependent on hardness, pH, redox, ionic strength, organic matter and Ni speciation. Sources: Batteries, steel, accumulators, catalysators, asphalt, industrial processes, burning of oil, wastewater.

Pb

(µg/l)

Mean: 5 – 130 Max: 47 – 720

Reported: Dk, N, S

Ref: 1 - 5000

PI reporting parameter

Lead species such as tetramethyl-Pb and tetraethyl-Pb are highly toxic, Pb-cromate toxic and most inorganic lead can damage health. Toxicity in water depends on hardness and salinity due to adsorption or complexing processes. Pb in leachate can increase during methanogenesis (Öman, 1991). Sources: Batteries, cables, cartridges, industry, mining, wastewater sludge, air. Listed as priority compound (OBS-listen, Norway).

Zn

(µg/l)

Mean: 88 - 970 Max: 200 – 22 000

Reported: Dk, N, S

Ref: 0.05 - 170

PI reporting parameter

Zinc is usually the second most important heavy metal in leachate. Can be toxic to aquatic life, suspected to produce genotoxic effects, zinc chromates are probably cancerogenic. Bioaccumulates. Low pH increase solubility. Sources: Batteries, ship paint, tyres, plastic, corrosion protection, industry, mining.

Ca

(mg/l)

Mean: 141-190 Max: 390-530

Reported: Dk, N

Ref: 10 - 7200

Ca and Mg are main parameters in leachate. Geochemically mobile. Can be used as indicators of leachate eg. in groundwater. Influence mobility and toxicity of heavy metals.

Mg

(mg/l)

Mean: 42-45 Max: 81-112

Reported: Dk, N

Ref: 30 – 15 000

F.1.3. Organic pollutants

Acenaphthene

PAH with high water solubility.

(µg/l)

Mean: 274. Max: 2981

Reported: N

Ref: 13.9-21.3

PI reporting parameter (as PAH)

Acenaphthylene

PAH with high water solubility.

(µg/l)

Mean: -0.6. Max: -1.0

PI reporting parameter (as PAH)

AOX

(µg/l)

Mean: 0.07 - 8.6 Max: - 800

Reported: N

PI reporting parameter

Adsorbable organic halogens expresses i.e. Cl, Br, I adsorbed to organic compounds. Usually associated to Cl-organic compounds. EOX is usually preferred for leachate due to inorganic halogens.

Alcylphenols

(µg/l)

Mean: -2.30 Max: - 11.85

Reported: N

Ref: 6.3-7

PI reporting parameter

Alcylphenols and alcylphenol-polyetoxylates (APE) are estrogenic compounds with effects e.g. in fish.

Alcylphenoletoxylates

(µg/l)

Mean: -1.50 Max: -5.6

Reported: N

Ref: 0.5 - 3

PI reporting parameter

The most common APE is nonylphenoxyethylate (NPEO) with 9 ethoxy units, degrading to nonylphenol which can be toxic and bioaccumulating in fish and mussels. Water solubility increases with ethoxy units.

B(b), B(k)-fluoranthene

PAH with low water solubility.

(µg/l)

Max: 0.15

Reported: N

PI reporting parameter (as PAH)

BDE-183

Polybrominated biphenylether. Very low water solubility.

(ng/l)

Mean: -0.02 Max: 0.17

Reported: N

PI reporting parameter (as PBDE)

BDE-154

Polybrominated biphenylether. Very low water solubility.

(ng/l)

Mean: - 0.07 Max: 0.66

Reported: N

PI reporting parameter (as PBDE)

BDE-153

Polybrominated biphenylether. Very low water solubility.

(ng/l)

Mean: -0.11 Max: 0.66

Reported: N

PI reporting parameter (as PBDE)

BDE-100

Polybrominated biphenylether. Low water solubility.

(ng/l)

Mean: -0.20 Max: - 1.06

Reported: N

PI reporting parameter (as PBDE)

BDE-99

Polybrominated biphenylether. Low water solubility.

(ng/l)

Mean: - 1.00 Max: 3.51

Reported: N

PI reporting parameter (as PBDE)

BDE-47

Polybrominated binphenylether. Moderate water solubility.

(ng/l)

Mean: - 0.90 Max: 4.88

Reported: N

PI reporting parameter (as PBDE)

BDE-28

Polybrominated binphenylether. Moderate water solubility.

(ng/l)

Mean: - 0.05 Max: 0.20

Reported: N

PI reporting parameter (as PBDE)

Benzene

Monocyclic aromatic hydrocarbon. Benzene is very toxic to some aquatic species

(µg/l)

Mean: 0.083 - 3.9 Max: 0.31 - 710

Reported: Dk, N

Ref: 0.2 - 1630

PI reporting parameter

Brominated flame retardants

Brominated flame retardants consists of many compounds e.g. polybrominated diphenyleter (PBDE), hexabromocyclododecan (HBCD), brominated bisphenol A (TBBPA). HBCD is increasing in bird eggs. PBDE is measured in relatively high concentrations in fish. TBBPA is also estrogenic.

(µg/l)

Mean: - 4.8 Max: - 18.6

Reported: N

PI reporting parameter (as PBDE, TBBA, HBCD)

Benzo(a)pyrene

PAH with very low water solubility.

(µg/l)

Max: 10.9

Reported: N

PI reporting parameter (as PAH)

Benzo(ghi)perylene

PAH.

(µg/l)

Max: 5.5

Reported: N

PI reporting parameter (as PAH)

Bentazone

Herbicide with high water solubility and no anaerobic degradation. Frequently found in groundwater.

(µg/l)

Max: 0.53

Reported: N

Ref: 0.3 – 4.0

BTEX

Monocyclic aromatic hydrocarbon.

Benzene, toluene, ethylbenzene and xylenes (dimethylbenzene)+styrene.

(µg/l)

Mean: 15.7 – 21.9 Max: 190 - 1400

Reported: N, S

Chlorobenzenes

One or more Cl attached to the benzene ring. Water solubility decrease with the number of Cl attached.

(µg/l)

Mean: 0.30 – 0.8 Max: 0.45 – 14.4

Reported: N, S

Ref: 0.1 – 110

Chlorinated hydrocarbons

Volatile Cl-organic compounds (e.g. tetrachlorethene, trichlorethene, vinylchloride) have been measured in groundwater polluted with leachate. Several are genotoxic (trichlorethene, vinylchloride). Overlaps the parameter chlorobenzenes

(µg/l). Max: 0.5

Chlorinated paraffins

Short chain chlorinated paraffins (SCCP) are very toxic to aquatic organisms, bioaccumulating, persistent and carcinogenic.

(ng/l)

Mean: - 105 Max: 614

Reported: N

PI reporting parameter

Chloroform

(µg/l)

Mean: 0.05 Max:

Reported: Dk

PI reporting parameter

Chlorophenol

(µg/l)

Mean: 0.3 Max: 12

Reported: N

PI reporting parameter

4-CPP (what is this)?

(µg/l)

Mean: -160 Max: 3.8- 170

Reported: Dk

2-M-6-CPP

(µg/l)

Mean: 2.5 Max: 3

Reported: Dk

Cresole

(µg/l)

Mean: 0.1 Max:

Reported: Dk

2,4-D

Herbicide.

(µg/l)

Mean: 0.14-1.2 Max: 1.20

Reported: Dk

Dichlobenil/dichlorbenzamide

Herbicide.

(µg/l)

Mean: 0.2-0.9 Max: 1-1.4

Reported: Dk

Dichlorethane

Solvent

(µg/l)

Mean: 0.59

Reported: N

PI reporting parameter

Dichlorethene

Solvent

(µg/l)

Mean: 1.6 Max: 5

Reported: N

Dichlorprop

Herbicide.

(µg/l)

Mean: 0.13-0.4 Max: 1.6 - 24

Reported: Dk, N

Dinoseb

Herbicide,

(µg/l)

Mean: 0.1-0.13 Max:

Reported: Dk

Dioxane

(µg/l)

Mean: 12

Reported: N

DNOC

Pesticide

(µg/l)

Mean: 0.1-0.13 Max:

Reported: Dk

Ethyl(ene)benzene

Monocyclic aromatic hydrocarbon.

(µg/l)

Mean: 0.063-2.10 Max: 34

Reported: Dk, N

Fluoranthene

PAH. Medium solubility.

(µg/l)

Mean: -125. Max: -212

PI reporting parameter (as PAH)

MCPA

Herbicide.

(µg/l)

Mean: 0.13-0.3 Max: 0.4

Reported: Dk

PI reporting parameter

Mechlorprop

Herbicide,

(µg/l)

Mean: 0.1-3.5 Max: 1.2-10
Reported: Dk

Methyl-phenols
(µg/l)
Mean: 1.3-2.2 Max: 2.1-3.7
Reported: Dk

Naphtalene
(µg/l)
Mean: 0.27-0.55 Max: 2.2
Reported: Dk

Oil in water
(µg/l)
Mean: -35 Max: -650
Reported: N

Phenol
(µg/l)
Mean: 0.31 Max: 1.6
Reported: Dk

Phenoxyacids
Group of herbicides
(µg/l)
Mean: 240 - 510 Max: 2200
Reported: Dk

Phtalate, sum
placticiser
(µg/l)
Mean: 3.6 Max: 250
Reported: N

Simazine
Herbicide,
(µg/l)
Mean: 0.13 Max:
Reported: Dk
PI reporting parameter

Tetrachloromethane
(µg/l)
Mean: 0.038 Max:

Reported: Dk

Tetrachloroethylene

(µg/l)

Mean: 0.05 Max:

Reported: Dk

PI reporting parameter

Toluene

(µg/l)

Mean: 0.08 Max:

Reported: Dk

PI reporting parameter

1,1,1-Trichloroethane

(µg/l)

Mean: 0.038 Max:

Reported: Dk

PI reporting parameter

Trichloroethylene

(µg/l)

Mean: 0.038 Max:

Reported: Dk

PI reporting parameter

m+p-xylene

(µg/l)

Mean: 0.16 Max: 0.5

Reported: Dk

o-xylene

(µg/l)

Mean: 0.12 Max:

Reported: Dk

Xylenole

(µg/l)

Mean: 0.1 Max:

Reported: Dk

Toxicology and microbiology

Microtox EC10 15 mins

(Vol-%)

Reported: Min 15 Max: 21 Mean: 17

Reported in: N

Microtox EC20 15 mins

(Vol-%)

Reported: Min 28 Max: 43 Mean: 34

Reported in: N

Microtox EC50 15 mins

(Vol-%)

Reported: Min 3-53 Max: 101 Mean: 55-94

Reported in: N, S

Pseudokirchneriella subcapitata EC50

(Vol-%)

Reported: Min 14 Max: 71 Mean: 21

Reported in: N

Pseudokirchneriella subcapitata EC50 72 hours

(Vol-%)

Reported: Min 14 Max: 14 Mean: 14

Reported in: N

Scenedesmus subspicatus 72 hours

(Vol-%)

Reported: Min 13 Max: 101 Mean: 36

Reported in: N

Skeletonema EC50

(Vol-%)

Reported: Min 1 Max: 63 Mean: 3

Reported in: N

Green alga, Raphidocelis subcapitata growth rate inhibition EC50 72 hours

(Vol-%)

Reported: Min 3 Max: 19 Mean: 11

Reported in: S

Red alga, Ceramium strictum reproduction impairment EC50

(Vol-%)

Reported: Min 4 Max: 8 Mean: 6

Reported in: S

Crustacea, Ceriodaphnia dubia, lethality, IC50 24 hours

(Vol-%)

Reported: Min 1 Max: 7 Mean: 4

Reported in: S

Crustacea, *Nitocra spinipes*, lethality, IC50 96 hours

(Vol-%)

Reported: Min 3 Max: 10 Mean: 7

Reported in: S

Zebra fish, *Danio rerio*, lethality LC50 7 days

(Vol-%)

Reported: Min 1 Max: 3 Mean: 2

Reported in: S

Microtox is a bacteriological test based on bio-luminiscence often used for screening of acute aquatic toxicity. The test measures the inhibition of light emission. The test seems to have equal sensitivity to acute tests based on crustacean and fish, but appear to be more sensitive to complex compounds such as chlorinated benzenes, phenols and ethanols, and less sensitive to pesticides and heavy metals.

Green algae have high ecological relevance since they are primary producers and the main food source for a number of salt- and freshwater species. Algae are less sensitive to ammonia than crustacean and fish.

Red algae are also primary producers. The test focus on one step in the reproduction and the effect variable is the number of developed cystocarps.

*The crustacea *Daphnia magna* is a water flea feeding on algae and bacteria and are a primary food source for a number of species. The acute toxicity is measured after 24 and 48 hours of exposure, and chronic toxicity on reproduction after 7 days.*

Acute toxicity can be measured on fish measuring spawn survival after 72 hours to 7 days.

F.1.4. Isotopes and tracers

No isotope- or tracer studies have been reported from the Nordic countries.

F.1.5. Leachate sediments

Dry matter

Dry matter (DM) is the weight of the dried sediment.
(weight-% of total weight)

Min: Max:

Reported:

TOC

Total organic carbon
(weight-% of dry matter)

Min: 0.07 Max: 34

Reported: N

BOD

Biochemical oxygen demand
(mg/kg)

Min: Max: 345

Reported: N

Fe

Total iron
(mg/kg DM)

Min: 13500 Max: 368 000

Reported: N

S

Total sulphur
(mg/kg)

Min: 470 Max: 62 302

Reported: N

Sulphate

Most common S compound and odour potential
(mg/kg)

Min: 8500 Max: 24000

Reported: N

Dry matter

Dry matter is the weight of the dried sediment.
(weight-%)

Min: Max:

Reported:

As

Arsen

(µg/kg)

Min: 2.82 Max: 45

Reported: N

Cd

(µg/kg)

Min: 0.15 Max: 3

Reported: N

Cr

(µg/kg)

Min: 11.4 Max: 130

Reported: N

Cu

(µg/kg)

Min: 8 Max: 242

Reported: N

Ni

(µg/kg)

Min: 5.5 Max: 69

Reported: N

Zn

Abundant in leachate

(µg/kg)

Min: 137 Max: 22691

Reported: N

Hg

(µg/kg)

Min: 0.03 Max: 63

Reported: N

Pb

(µg/kg)

Min: 3.5 Max: 111

Reported: N

BDE

(Poly)brominated binphenylether.

Hormonally active and lipophile compounds. Accumulates in sediments.
Often ordered according to bromination.

(µg/kg)

Min: 0.05 Max: 76

Reported: N

alfa-HBCD

(µg/kg)

Min: 100 Max:

Reported: N

Annex F.2. Comparison of limit values

	DK	N	D	EU1	EU2
	*	**	***	****	*****
General parameters (mg/l)					
Cl	150			460	46 000
Sulphate	250			1500	
NVOC	3	5 ^a	200 ^k	160 ^h	1160 ^a
Tot N (– nitrat)	1 + b	0.5 ^b	70		1160 ^b
NH4	0,5 + b				
Tot-P		0.16	3		
Metals and elements (µg/l)					
Fe		200			
As	8	2	100	60	0.13
Ba				4000	
Pb	10	1.9			0.5
Cd	2	0.2	100	20	0.02
Cr	25	6.3	500	100	0.5
Cr VI	1		100		
Cu	100	2.3	500	600	0.5
Hg		0.01	50	2	3.0
Mo	20			200	
Mn		0.1			
Ni	10	5	1000	120	0.5
Zn	100	35		1200	0.5
Organic pollutants (µg/l)					
AOX			500		0.02
Chlorinated solvents (-vinylchlorid)	1	50 ^c			0.02
Chlorinated benzene		10			
DEHP	1				0.02
1,2-dibrommethane	0,01				0.02 ⁱ
PAH	0,2				0.11
MTBE	5				0.02
Hydrocarbons, total	9		1000		
			0		
Pentachlorophenol	<detec- table	1 ^d			1.2
PesticideS					
Total	0,5	0.5 ^e			
Single	0,1				
Chlorinated	0,03				0.01 ^j
Phenoles	0,5			0.3 ^f	
PAH		2			0.11
Phtalater (-DEHP)	10	10			
Tin organic		0.01			0.11
Vinylchlorid	0,2				

* DK=maximum allowed concentrations in groundwater as basis for risk assessment, <http://www.retsinfo.dk/> **
N=environmental risk assessment threshold values. *** Requirements for leachate emissions in Germany (Federal Ministry
for the Environment, Nature Conservation and Nuclear Safety, Germany, 2004). ****Council Decision 2003/33/EC limit
values from percolation test defining inert waste.*****Pollution Inventory leachate reporting values assuming average
Q=118 m³/d (Robinson & Knox, 2003) ^a as TOC ^bas Tot-N ^cvolatile chlorinated hydrocarbons ^dChlorinated phenols
^ephenoxy acids ^fphenol index ^hDOC ⁱ as PBDE ^kas aldrin ^las COD

Annex G.1.

Leachate sampling substances and threshold values in the UK (Robinson % Knox, 2003)

Parameter	Unit	Reporting threshold	Measured in the Nordic countries µg/l	Equivalent discharge at max. C m3/year ^a
aniline	kg	1		
aldrin	g	0,5		
AOX	kg	1000	0.07-800	1,25E+06
atrazine	g	60		
azinphos methyl	g	4		
azinphos ethyl	g	0,5		
benzene	kg	1	0.08 – 1400 ^b	7,14E+02
benzyl butyl phtalate (BBP)	kg	1		
biphenyl	kg	1		
brominated diphenyleters - tot as Br	kg	1	0.02 – 4.9 ^c	2,04E+05
ter-butyl methyl ether (MTBE)	kg	1		
carbon tetrachloride	g	250		
chlorides total as Cl	kg	2 000 000	200 – 100 000	2,00E+07
chlorinated paraffins c18-c28	kg	1	105 – 614 ^d	1,63E+03
chlorinated paraffins c14-c17	kg	1		
chlorinated paraffins c10-c13	kg	1		
Chloroform	kg	4	0.05	8,00E+07
chloronitrotoluenes	kg	1		
4-chloro-3-methylphenol	kg	1		
2-chlorophenol	kg	1	0.3 – 12	8,33E+04
chlorfenvinphos	g	10		
chlorpyrifos	kg	1		
cyanides total as CN	kg	50		
cypermethrin	kg	0,05		
2,4-D non ester	kg	1	1.2	8,33E+05
2,4-D ester	g	400		
DEHP	kg	1	250	4,00E+03
DDT total	g	0,5		
demeton	g	200		
Diazinon	g	10		
1,2 dichloroetane	kg	2	0.6	3,33E+06
dichloromethane	kg	10		
2,4-dichlorophenol	kg	1		
dichlorphos	g	0,5		
Dieldrin	g	2,5		
dimethoate	g	400		
Diuron	kg	0,08		
endosulfan	g	0,5		
Endrin	g	0,5		
fenitrothion	g	0,5		
Fenthion	g	0,5		
fluorides total as F	kg	2000		
hexachlorobenzene	g	20		
hexabromocyclohexane (HBCD)	kg	1		
hexachlorocyclohexane	g	20		
hexachlorobutadiene	g	4		
Isodrin	g	0,5		
isoproturon	kg	0,08		
linuron	g	800		
malathion	g	0,5		
MCPA	kg	1	0.1 – 0.4	2,50E+06
mecoprop	kg	1	230	4,35E+03
4,4-methylene dianiline	kg	1		
mevinphos	g	8		

naphtalene	kg	1		
nitrogen total N	kg	50 000		
nonylphenol etoxylate	kg	1		
nonylphenols	kg	1		
octylphenols	kg	1		
ocyl phenol etoxilates	kg	100		
omethoate	g	4		
organic tin compounds total as Sn	kg	50		
PAH - 6	kg	5		
parathion	g	0,5		
parathion methyl	g	1,5		
pentachlorophenol	g	50		
permethrin	g	10		
PCB	g	2		
phosphorous total P	kg	500		
propetamphos	kg	0,01		
propylene oxide	kg	1		
simazine	g	80		
tetra bromo-bisphenol a (TBBPA)	kg	1		
tetrachloroethylene	kg	9		
TOC	kg	50 000		
toluene	kg	1	0.08 – 1400 ^b	7,14E+02
triazophos	g	2		
tributyl tin compounds	g	5		
trichlorobenzene all isomers	g	40		
1,1,1-trichloroethane	g	200		
1,1,2-trichloroethane	g	200		
trichloroethylene	kg	11		
xylens	kg	1		
As	kg	6		
Cd	kg	1		
Cr	kg	20		
Cu	kg	20		
Pb	kg	20		
Hg	g	130		
Ni	kg	20		
Zn	kg	20		

^a Calculated from the reporting limit and the maximum concentration measured. Normal annual leachate volumes are 50 000 m³ – 200 000 m³. If the calculated equivalent leachate volume is lower than these volumes it is likely the compound is emitted in the PI sense.

^b As BTEX ^c As BDE ^d For all chlorinated paraffins

Annex G.2.

Requirements for leachate emissions in Germany (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany, 2004).

Parameter	Unit	Limit ^a
COD	mg/l	200
BOD5	mg/l	20
Tot-N (NH4-N + NO3-N)	mg/l	70
Tot-P	mg/l	3
Tot-hydrocarbons	mg/l	10
NO2-N	mg/l	2
Toxicity to fish eggs (Tegg)		2
AOX	mg/l	0.5
Hg	mg/l	0.05
Cd	mg/l	0.1
Cr	mg/l	0.5
Cr (VI)	mg/l	0.1
Ni	mg/l	1
Cu	mg/l	0.5
As	mg/l	0.1
CN, easily released	mg/l	0.2
Sulphide	mg/l	1

^a Qualified random sample or 2-hour mixed sample

Annex G.3.

Annex II of the Council Decision. Co=first eluate (max. Value) of a percolation test at L/S = 0.1 l/kg).

Parameter	Co (percolation test) mg/l
As	0.06
Ba	4
Cd	0.02
Cr total	0.1
Cu	0.6
Hg	0.0002
Mo	0.2
Ni	0.12
Pb	0.15
Sb	0.1
Se	0.04
Zn	1.2
Cl	460
F	2.5
SO4	1500
Phenol index	0.3
DOC	160
TDS	-

http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_011/l_01120030116en00270049.pdf

Annex G.4. Isotopes and tracer studies

Isotopes can be used to differentiate sources to water and water pollutants. No isotope data have, however, been reported from the participating countries.

Robinson (1995) reported relatively high values of tritium (^3H). These findings are speculated to arise from landfilling of fluorescence paint from signs etc. Inert waste: 4

Table 8 summarizes experiences with isotope measurements in leachate compared to other water types. It seems possible that leachate can produce clear signals as e.g. tritium and ^{13}C (inorganic carbon), and possibly other signals too. There is a clear lack of data of isotopes in leachate from the Nordic countries.

Table 8. Isotope measurements *

Compound	Unit	Leachate	Rain	Groundwater	River	Bog gases	Half-life (years)
Tritium (^3H)	TU	0 to 39 000 ^{a, b}	10 to 50	100 to 400 ^a			12.4
$\delta^2\text{H}$ (methane)	(‰)	-304		-241		-294	
$\delta^2\text{H}$ (waste)	(‰)	-400 to -30		-241			
$\delta^{18}\text{O}/^{16}\text{O}$	(‰)	-20 to + 40 ^e	-4 to -19 ^d	-7 to -15			Stable
$\delta^{13}\text{C}$ (organic)	(‰)	-27		-27			Stable
$\delta^{13}\text{C}$ (inorganic)	(‰)	2.27 to 16.11		-19.55 to 20.3	-	3..8	Stable
$\delta^{13}\text{C}$ (methane) _c	(‰)	-52.7 to -53.3		-72.6	15.09	-76	Stable
$\delta^{13}\text{C}$ (waste)	(‰)	-32 to -21		-72.6			Stable
^{14}C (inorganic) ^b	% mC	121		93			5435
$\delta^{34}\text{S}$ ($\text{SO}_4\text{-S}$)	(‰)			-3 to 9.1			Stable
$\delta^{15}\text{N}$ ($\text{NH}_4\text{-N}$)	(‰)	22.31 to 27.42			-2.71	-2.71	Stable

* TU=Tritium units = $1\ ^3\text{H}$ per $10^{18}\ \text{H}^+$ = 0.12 bequerel/l. van Breukelen et al., 2003; North et al., 2004, ^a Robinson, 1995, 1996, ^b Kerfoot et al., 2003, Waldron et al., 1996. %mC=percent modern carbon. ^c Increases during methanogenesis ^d Halvorsen, 1994. ^e in waste fractions (carbohydrates, lipids, amino acids, phenylpropanes), Schulten & Gleixner, 1999.