Assessment of Organic Pollutants in Landfill Leachate: Future Screening and Characterization

Bachelor of Science Thesis in Chemical Engineering

GUSTAV NILSSON

Department of Civil and Environmental Engineering
Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
Aerial photo of Tagene landfill[1].

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ABSTRACT

Tagene is a landfill site in Gothenburg, Sweden, owned and operated by Renova AB, mainly handling incineration residues and other incombustible wastes; producing 200 000 - 250 000 m^3 leachate annually. According to the control program for organic leachate analyses in use today, selected organic pollutants are screened for in November each year and during a characterization every third year additional organic pollutants are included as well. The aim of this study was to produce proposals to improve this control program, mainly focusing on individual organic pollutants and groups of pollutants but also a few more general organic parameters.

Pollutants where initially chosen by combining the most relevant priority pollutant lists and directives (Stockholm Convention, European Water Directive, REACH, REVAQ). From the list, based on chemical properties affecting environmental impact (POP, PBT, vPvB, R50/53, R51/53) and taking into account general presence in leachate pollutants where prioritized. The organic pollutants deemed most harmful where then further assessed based on the results of the screenings from the last five years (2008-2012), a literature study, reference values from other landfills as well as official regulations and recommendations from both national and international environmental protections agencies and chemical agencies and proposals where produced.

Organic pollutants proposed to be included in the screening at Tagene include: brominated and phosphorus flame retardants, perfluoroalkyl and polyfluoroalkyl substances, phthalates, alkylphenols and alkylphenol ethoxylates, oxygenated polycyclic aromatic hydrocarbons and dioxin-like compounds to name a few. More frequent analyses of TOC and DOC as well as characterization the bulk organic matter in the leachate are also proposed.

Keywords: Organic pollutants, landfill leachate, MSWIR, noncombustible waste, prioritizing pollutants.

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Gustav Nilsson

Abbreviations

APEs	Alkylphenol etoxhhylates
APs	Alkylphenols
BBP	Benzyl butyl phthalate
BFR	Brominated flame retardant
BOD	Biological oxygen demand
BPA	Bisphenol A
CAS	Chemical abstract service
D3	Hexamethylcyclotrisiloxane
D4	Octamethylcyclotetrasiloxane
DBP	Dibutyl phthalate
DCHA	Dicyclohexylamine
DDT	Dichlorodiphenyltrichloroethane
DEET	N,N-Diethyl-meta-toluamide
DEHP	Di-2-ethylhexyl phthalate
DEP	Diethyl phthalate
DHM	Dissolved humic matter
DIBP	Diisobutyl phthalate
DIPP	Diisopentyl phthalate
DMP	Dimethyl phthalate
DNPP	N-pentyl-isopentylphthalate
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
EO	Ethylene oxide
EPA	Environmental Protection Agency
FT-ICR	Fourier-transform ion cyclotron
GC	Gas chromatography
HCB	Hexachlorobenzene
HIX	Humification index
HMW	High molecular weight
HPLC	High performance/pressure liquid chromatography
IUPAC	International Union of Pure and Applied Chemistry
LMW	Low molecular weight
MS	Mass spectrometry
MSW	Municipal solid waste
MSWIRs	Municipal solid waste incineration residues
NMR	Nuclear magnetic resonance spectroscopy
NP	Nonylphenol
NPE	Nonylphenol ethoxylates
OCDD	Octachlorodibenzodioxin

Oxy-PAH	Oxygenated polycyclic aromatic hydrocarbon
PAH	Polycyclic aromatic hydrocarbon
PBDD	Polybrominated dibenzo-p-dioxins
PBDE	Polybrominated diphenyl ether
PBDF	Polybrominated dibenzofurans
PBT	Persistent-Bioaccumulative-Toxic
PCB	Polychlorinated Biphenyl
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PCP	Pentachlorophenol
PFAS	Polyfluorinated alkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PFOSF	Perfluorooctanesulfonyl fluoride
PFR	Phosphorus flame retardant
PNEC	Predicted no effect concentration
POPs	Persistent organic pollutants
SLF	Shredder light fraction (Shredded part of cars)
SPME	Solid phase microextraction
SVHC	Substances of very high concern
TBBPA	Tetrabromobisphenol A
TBEP	Tris(2-butoxyethyl)phosphate
TBP	Tributyl phosphate
TCEP	Tris(2-chloroethyl) phosphate
TEF/TEQ	Toxicity equivalency factor/quotient
TOC	Total organic carbon
UV	Ultraviolet
WHO	World Health Organization

1 Introduction

Municipal landfills around the world are growing in both numbers and size, simultaneously with this increasing amount of waste there is a rising environmental consciousness in the world. There is a need to know what impact these deposit sites have on the environment and will continue to have for centuries to come. Determining this is however not an easy task and the biggest problem to deal with is that no two sites are alike, different locations means different weather, soil- and bedrock compositions, operation conditions and most importantly a difference in deposited matter. The CAS REGISRTY database[2] for example contains more than 71 million different compounds (2013), with more added each year. The number of which have ended up in landfills are hard to predict and the environmental impact of these compounds is even harder, especially if taken into account the nature of the compounds when interacting with each other. Therefore standardized methods of risk assessment based on a certain number of prioritized pollutants and parameters might not be the best solution for every situation, it is however a start and something to build from.

The main way for compounds, both organic and inorganic, to exit landfills and enter the environment is through leachate. Water from precipitation and in some cases, mostly for older landfills, groundwater entering the landfill will extract substances from the waste[3]. In most developed countries this leachate is nowadays collected and either treated on site, led to a water treatment plant or a combination of both. In order to be able to properly treat the leachate it is analyzed, determining how and how often the leachate should be analyzed and what compounds should be prioritized vary between landfills, countries and a number of other parameters. Metals, salts and other inorganic pollutants are today easier to analyze and characterize than organic pollutants, mainly because more research have gone in to this field. This report will nevertheless focus on organic pollutants in leachate. Organic matter in leachate in general as well as a few emerging and prioritized pollutants from a Swedish perspective, mainly from landfills containing municipal solid waste (MSW), municipal solid waste incineration residues (MSWIRs) and other non-combustible waste are included in the study.

1.1 Background on Tagene landfill site

Tagene landfill site is one of Renova AB two landfills; since the establishment in 1974 primarily municipal solid waste incineration residues fly ash stabilized by the Bamberg-method i.e. sludge from the wet cleaning of the flue gas is mixed with the ashes and a stable "cake" is produced[4], and bottom ash/slag from Sävenäs waste incineration facility has been deposited there. Beyond the incineration residue, other material such as: unburned municipal solid waste, waste not incinerated due to downtime at Sävenäs, sewage sludge from Ryaverket waste water treatment plant owned by Gryaab, non-combustible waste (mostly construction materials), have also been deposited there. In addition to the deposition of waste, recycling and storage operations, such as fragmentation and small scale sorting of batteries, sorting and storage of recyclable metal, baling and storage of combustible waste to be burned at Sävenäs, transshipment of fine municipal waste and sorting of slag are also performed on the site[1].

The landfill produces 200 000-250 000 m^3 leachate annually, depending on precipitation. The leachate is collected in three different flows titled *L2, L3* and *L4*. The *L2 (*labeled Omr 1,2,3,5,6,7 in *Figure 1)* is the largest with 70-80% of the total leachate flow, colleting leachate from the southern part of the landfill, while *L3* (Omr 8 in *Figure 1*) and *L4* (Omr 4 in *Figure 1*) are smaller[1]. All three flows are transported in a wastewater tunnel to Ryaverket for treatment before being released back in to the environment.

Onsite treatment of the leachate has been of interest for several years and a small number of pilot studies have been carried out. The question of local treatment is now more relevant than ever because Gryaab (Ryaverket) is working with the REVAQ-certification. According to REVAQ, landfill leachate flows to waste water treatment plants can be of major concern, and have large impact on the total amount of pollutants in the sludge[5]. How and wherever the treatment is carried out in the future, characterization and screening of the leachate will continue to be a vital part of the process, a part that continuously needs to be revised and improved as our knowledge and laws progresses.

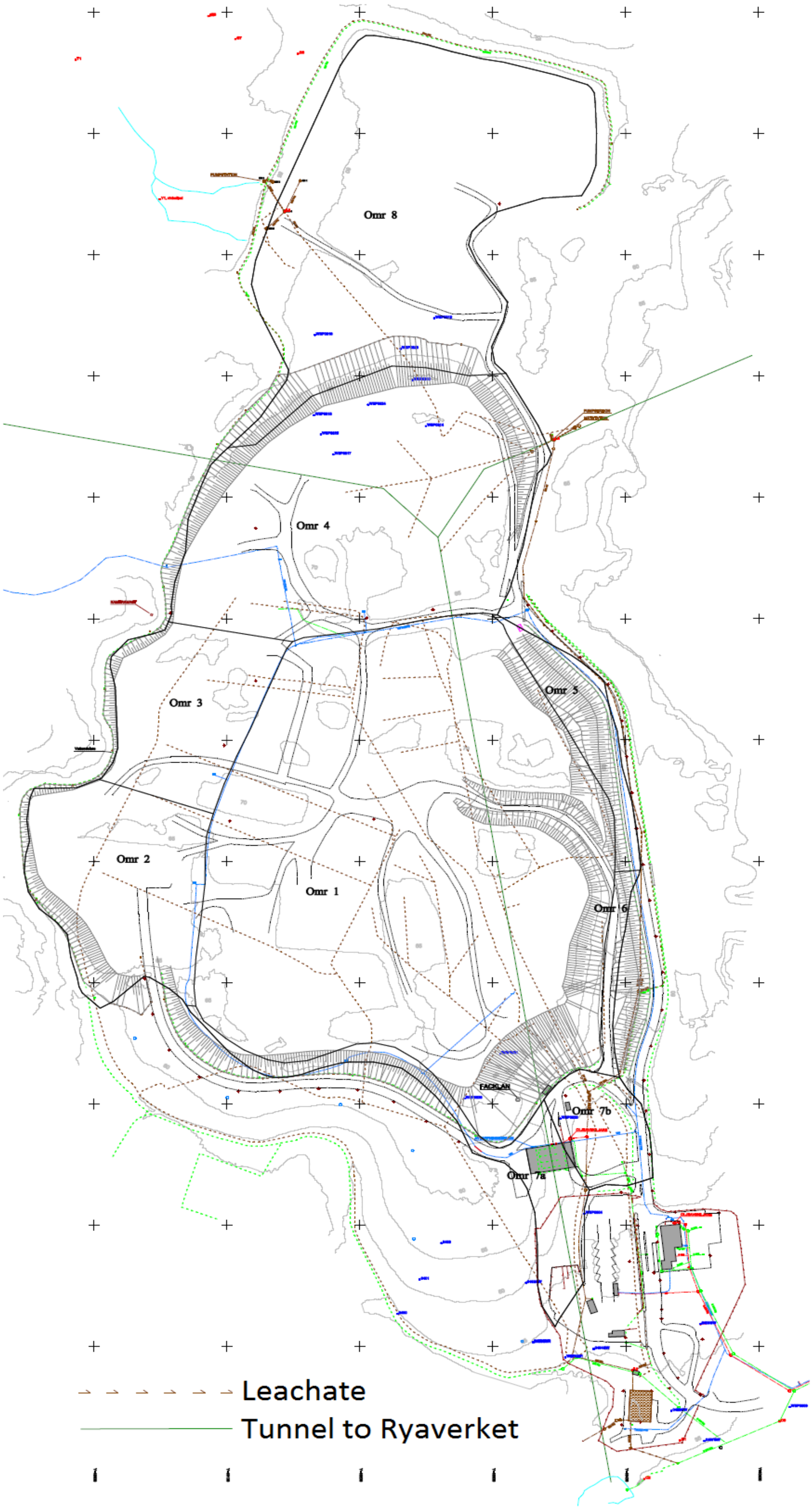


Figure 1. Map of Tagene landfill site

1.2 Aim and objectives

This project aims to compile all the analyses of organic pollutants performed on the leachate from Tagene landfill site. Based on these analyses, a literature review performed in order to provide more information and support; with regards to what is actually deposited and what operations are conducted on the landfill site, proposals for improvements in the control program will be developed. As to make sure the right compounds are being screened and that the detection limits used provides relevant information. Eventual considerations from organizations/certifications such as REVAQ and any relevant information in reports from, e.g. Swedish EPA, will also be included in the proposals for improvement, as well as other official directives, regulations and laws. Results of screenings from other landfills with similar waste deposited or landfills operating under similar conditions will be assessed and if deemed relevant used as references.

The specific objectives of the projects were to:

- perform a literature study in order to gain more information about organic pollutants in landfill leachate.
- compile all annually performed organic analyses in one spreadsheet.
- compile and summarize the identity of the deposited material as well as the activities performed on site in order to determine if any compounds not currently screened for might be found in the leachate.
- gather information and comments from organizations concerned with landfill leachate.
- gather and structure results from other landfills, if deemed relevant.
- extend the literature study in regards to eventual compounds, characteristics or prioritizations found through the work listed above.
- produce proposals to improve the control program for organic analyses used today to assess the leachate.

1.3 Methodology

The studying and reviewing of scientific literature and reports by environmental organizations is the main method used to gain information about organic pollutants in leachate, as well as examination of analyses and reports produced on behalf of Renova AB. The analyses will be compiled and structured with the spreadsheet software MS Excel.

1.4 Delimitations

- The report will only deal with organic pollutants.
- The leachate stream “L2” will primarily be focused on; the two remaining streams (L3 and L4) are given lower priority due to time constraints.
- Delimitations of the literature will be determined as the work progresses depending on what available information is deemed relevant.
- The identity of the deposited mass and the effect of the waste facility’s operations on what is leached out will not be discussed in detail, substances that may be leached out in high concentrations or substances of particularly high concern will be prioritized.

2 Laws and regulations concerning landfill leachate

The most fundamental law in Sweden affecting the subjects of concern in this report, i.e. control and analyzing of landfill leachate, is stated in chapter 26. §19 of the Swedish Environmental code (Miljöbalken)[6]:

> *”Persons who pursue an activity or take a measure that is liable to cause detriment to human health or affect the environment shall continuously plan and monitor the activities in order to combat or prevent such effects. Persons who pursue such an activity or take such a measure shall also keep themselves informed, by carrying out investigations on their own initiative or by other means, about the impact on the environment of the activity or measure. At the request of the supervisory authority, a person who pursues such an activity shall submit proposals for control programs or remedial measures to the authority. The Government or the authority appointed by the Government may issue rules concerning controls”*

The delegated legislation SFS 1998:901 §6[7], building on this law, further states that everything done to determine or prevent adverse environmental or health effects shall be documented.

These are however general laws concerning activities and operations far beyond land filling, the most specific regulation dealing with leachate from landfills are NFS 2004:10. §42[8], which states (only the parts concerning leachate are presented):

> *“Characterization of leachate from landfills containing hazardous or non hazardous waste shall be performed. In the characterization relevant parameters describing the leachates properties as well as content of substances that may have harmful effects on the environment or recipient shall be determined.”*
>
> *“That parameters established in the characterization shall be controlled every quarter and the leachate volume shall be controlled every month during the landfills operating period. Exemptions to the frequency can however be made in individual cases, though conductivity must be measured annually regardless.”*

> *"Sampling must be done separately in every place where leachate is released from the landfill."*
>
> *"Meteorological data (precipitation and evaporation) shall be measured daily during the operating period of the landfill."*

Thus there are no clearly defined parameters that must be analyzed, landfills are far too complex and varies too much between one another for it to be reasonable to force the same constraints on all of them. Therefore it is, as stated above, up to the person/people in charge to educate themselves and determine what parameters that should be used in the characterization, or delegate to people with the knowledge needed. However, since landfill leachate is such a complex and diverse source of pollutants and the knowledge about many potentially present compounds and their environmental effects are significantly lacking, it is not reasonable to demand that the risk associated with the leachate should be fully evaluated and accounted for. Chapter 2. §7 of the Swedish Environmental code[6] states:

> *The rules of consideration laid down in sections 2 to 6 shall be applicable where compliance cannot be deemed unreasonable. Particular importance shall be attached in this connection to the benefits of protective measures and other precautions in relation to their cost. The cost-benefit relationship shall also be taken into account in assessments relating to total defense activities or where a total defense measure is necessary. A decision reached in accordance with the first paragraph must not entail infringement of an environmental quality standard referred to in chapter 5.*

Where sections 2 to 6 are the general consideration rules that chapter 26. §19[6], presented above are based on.

Consequently; Work to continuously improve the knowledge about the leachate and ways to deal with the potential environmental risks associated with it and document everything done, is the extremely condensed version of the law.

3 Current control program at Tagene

The control program for leachate analyses in use today at Tagene landfill is split in to 5 different programs as described in *Table 1* below. The programs are applied to the leachate streams as described by *Table 2*. Results from 2008-2012 are found in Appendix I (In Swedish).

Beyond these annual controls a “special” program is developed and applied every third year to characterize the leachate. The parameters encompassed in the characterization are picked partly by the results from the other analysis and partly to answer any question or clarify any issues or uncertainties that may have surfaced. The parameter “chlorinated dioxins and dibenzofurans” is however always included for leachate stream L2 and L4 due to the amount of incineration residue deposited[9].

The last characterization was done 2010, beyond the parameters already mentioned it included analyzing for: additional pesticides, perfluorinated compounds, polychlorinated biphenyls (PCBs), aliphatic- (C_8-C_{35}) and aromatic (C_8-C_{35}) compounds, nitro compounds and additional chlorinated compounds, see Appendix I for full list and results (In Swedish).

Table 1. Control programs for Tagene landfill leachate analyses[9]

Label	Abbreviation	Parameters included
Onsite	S	Temperature and leachate flow
Indicator	I	pH, conductivity, chloride, color, TOC, total nitrogen, oxygen
Basic	B	suspended solids, turbidity, alkalinity, sulfate, sulfur, DOC, ammonium, nitrite and nitrate nitrogen, total phosphorus
Metal	M	sodium, potassium, calcium, magnesium, iron, manganese, aluminum, strontium, barium, copper, nickel, zinc, chromium, cobalt, lead, arsenic, cadmium and mercury
Organic	O	EOX, GC-MS screening of volatile and less volatile organic compounds (includes a number of VOCs (eg chlorobenzenes and BTEX), nonpolar aliphatic hydrocarbons, 16 PAH compounds, a number of phthalates) etc,. See Appendix I for full list of compounds (In Swedish).

Table 2. Schedule for leachate control program at Tagene landfill site[9]

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Leachate stream	*Control programs*											
L2	*S, M*	*S, I M, B*	*S, M*	*S, I M, B*	*S, M*	*S, M*	*S, M*	*S, I M, B*	*S, M*	*S, M*	*S, I, M, B, O*	*S, M*
L3		*S, I M, B*		*S, I M, B*				*S, I M, B*			*S, I, M, B, O*	
L4		*S, I M, B*		*S, I M, B*				*S, I M, B*			*S, I, M, B, O*	

4 Deposited waste and operations on site

Since the establishment in 1974 and until 2011 about 3.44 Mton of waste has been deposited in the landfill[1]. The main waste types deposited on the site are incineration residues from Sävenäs, sewage sludge from Ryaverket and incombustible municipal waste i.e. bulky wastes/construction wastes/demolition rubble. The incineration residues are received in the form of fly ash stabilized with the Bamberg- method, a practice performed to reduce the leaching capabilities of different pollutants, and as bottom ash/slag. Sewage sludge from Ryaverket is no longer deposited, the deposition stopped in the early 1980. Deposited waste is listed in *Table 3* below. No hazardous wastes have been deposited at the landfill, with the exception of asbestos.

Many parts of Tagene are currently undergoing final covering, this is done by covering the deposited waste in a geomembrane of polyethylene and over this a vegetation layer of clay >50 cm[1]. This ensures that less water will penetrate the landfill and consequently less leachate will be produced. When a landfill is undergoing covering there is a need for construction material. The material gives the landfill the correct height and slopes around it to ensure that the precipitation gets drained from the landfill. To build up the landfill to the right shape, large amounts of waste that is usually just deposited will instead be used as construction material. However since most of these types of wastes are also deposited, the exception being SLF (Shredder light fraction), and that leaching is still possible, it will all be referred to as deposited waste in the report.

Table 3. Deposited matter at Tagene landfill site[10]

Slag/bottom ash
Fly ash stabilized with the Bamber-method
Sewage sludge from Ryaverket water treatment facility
Sewage sludge from manholes and sewage drains, not from heavily congested roads
Waste from bar screens (the first step in sewage treatment)
Incombustible municipal waste from recycling stations, mostly bulky wastes/construction materials/demolition rubble.
Other incombustible wastes
Combustible solid waste not incinerated at Sävenäs due to large fractions of gravel, risks of dust explosions etc. Also combustible waste deposited due to downtime at Sävenäs, although this practice have nowadays stopped.
Residue from fragmentation of alkaline and zinc-carbon batteries
"Borrkax" – Drill cuttings/fractions from bedrock
SLF (Shredder light fraction) /ASR (automotive shredder residue)/ Fluff – Reception started in 2012, only used as construction material.
Asbestos
Latrine
Sandblasting sand
Wire
Trawls

Beyond deposition a number of other recycling and storage operations are performed on site:

- Metal is extracted (sold for recycling) from the received slag/bottom ash before it is used for construction. Annually about 125 000 ton of incineration residues are treated in this process[1][10].
- Fine municipal solid waste from waste stations are transshipped between trucks. During 2011, 16 812 ton waste passed through this process[1].
- Solid waste is sorted and baled for future incineration. During 2011, 50 668 ton wastes was baled and stored at the site before being transported to Sävenäs[1].
- Interim storage of other waste fractions.
- Dewatering of inorganic sludge, during 2011, 6690 ton inorganic sludge[1].

5 Organic Pollutants in Landfill Leachate: a Literature study

5.1 Characteristics of organics in leachate

Organic compounds are almost always present in landfills, even when only municipal solid waste incineration residues (MSWIRs) or some other non-combustible waste are deposited a measurable fraction of organic matter is still present in the leachate. Total organic carbon (TOC) and dissolved organic carbon (DOC) or dissolved organic matter (DOM), are the most common sum parameters for presenting the organic concentration. Although none of these take into account the identity of the compounds present, the information is still useful, especially DOC and DOM. A large fraction of the dissolved organic matter may not be pollutants themselves, but it has been shown that some of them possess the ability to affect the behavior of various pollutants by either sorption or by redox reactions, acting as oxidizing- or reducing agents[11-13]. Humic matter in particular have been shown to increase the leachability of hydrophobic organic pollutants from MSWIRs, highly chlorinated dioxin and dioxin-like compounds such as OCDD seem to be especially affected by dissolved humic matter (DHM)[11][14]. Increased leachability of other persistent organic pollutants (POPs) and heavy metals have also been linked to DHM concentrations[13].

Humic matter, or humus, are large (3-4 nm)[15] and stable organic compound assemblages that will not degrade naturally. They are produced by humification, a slow process in which intermediate products from organic degradation react with one another to form new molecules[16]. There is no clear chemical structure defining humic matter but it can be fractioned into three groups, humic acid soluble in dilute alkali, fulvic acid lower molecular weight, soluble in dilute alkali and acid and humin insoluble in dilute alkali and acid[14]. Separating compounds based on their solubility/hydrophobicity is useful not only for humus but for most organic compounds in leachate, and it can provide data for treatment of the leachate as well as give some insight in the organic compounds capability to react with certain pollutants by sorption. This fractioning is usually carried out by some modified version of the LC-method described by Leenheer (1981)[17]. The fact that no standardized method exist for calibration is however a problem when comparing analyzes from different sites since the results may vary a fair bit if slightly different methods have been used[18].

Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are two other basic parameters used to describe the organic content and to some extent the nature of the organic content present. BOD describes the oxygen demand for degradation of organic (and to a minor extent inorganic) compounds by biochemical and bacterial activity[19], it is usually measured over a 5 or 7 day period as BOD_5 or BOD_7. The COD measures the total oxygen demand by adding an oxidizing agent, usually potassium permanganate or potassium dichromate (COD-Mn or COD-Cr)[20]. The ratios BOD/COD, TOC/COD as well as BOD/TOC can be used to characterize the leachate in terms of biodegradability, organic to inorganic degradable components and in some cases presence of toxic substances e.g. killing bacteria, lowering BOD while COD remains unaffected[3][20-21].

One factor that has been shown to have a significant impact on the character of the DOM in landfill leachate is the age of the landfill, as time passes a number of parameters in the leachate changes, parameters affecting the preferred treatment as well as leaching of both inorganic and organic pollutants. In general the TOC and DOM decreases with age and stabilizes to a more predictable concentration from year to year, compounds with considerably high leachability are leached out early on and easily biodegradable compounds are degraded[22-23]. Degradation of organic compounds are at the highest rate shortly after deposition, resulting in high BOD and COD as well as a high ratio of BOD/COD, all of which decrease with time. The decrease of DOM is also partly due to the progress of humification, turning simple compounds in to complex more stable ones with lower leachability (mostly due to size), this does however increase DHM with time[14][24-25]. The ratio of hydrophobic to hydrophilic organic compounds has also been shown to increase with time[24-25]. The exact effect this change has on the leaching of pollutants is difficult to predict, on one hand the decrease in TOC and DOM would also decrease the leaching of pollutants but the increase in DHM might counteract this to some extent or may even begin to leach out different pollutants. New pollutants that might not have been present before but are degradation products of other compounds may also emerge with time.

Preferred treatment in terms of removing bulk organic matter is to some extent easier to determine based on the character of the leachate. Early on when BOD and COD are high, a large part of the organic matter is still biodegradable, making biochemical treatment efficient. As the BOD, COD and BOD/COD decreases so does the efficiency of the bio-treatment[23]. Simultaneously the humification progresses and the amount of DHM increases, and since the humic matter consist of organics with high molecular weights and low degradability physical-chemical methods for treatment, such as filters, becomes more useful[22]. Coagulation-flocculation, commonly used as a pre-treatment step, is another treatment method showing potential in treating leachate from older landfills[21], partly because it was found to be effective in removing hydrophobic organic matter[22], which is known to increase with time.

5.2 Selected organic pollutants

These initial groups of pollutants were chosen because they are all pollutants of concern at the present time. Many of them have a general presence in landfill leachate. Most of them are currently not screened for at Tagene or there is concern that the analyses may be inadequate for the ones that are.

5.2.1 Polycyclic aromatic hydrocarbons

PAHs or polycyclic aromatic hydrocarbons are environmental pollutants consisting of condensed aromatic rings, all in the same plane, they are as the name implies built up of carbon and hydrogen alone. Hundreds of PAHs of different molecular sizes have been identified in the environment[26], most research concerns those consisting of 2-6 aromatic rings, as they are the most common. Usually PAH are grouped into two categories, LMW (low molecular weight) PAHs, 2-3 aromatic rings and HMW (high molecular weight) PAHs, 4-6 aromatic rings[27-28]. See *Figure 2* below for two examples of PAHs, napthalene (a LMW PAH, 2 rings) and benzo(a)pyrene (a HMW PAH, 5 rings).

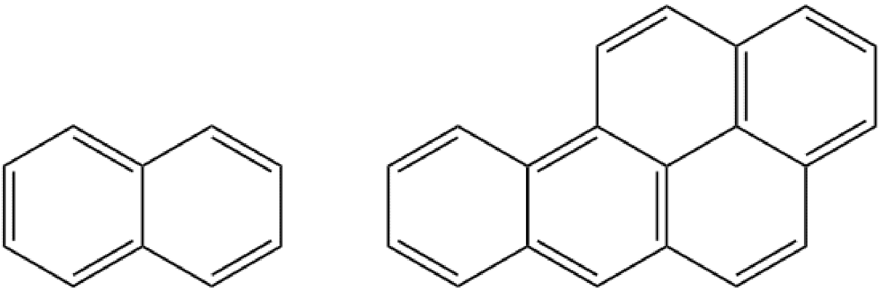


Figure 2. Structures of naphthalene and benzo(a)pyrene.

Polycyclic aromatic hydrocarbons have proven to be toxic, mutagenic as well as cancerogenic to a wide range of organisms and animals[29]. Although most organisms have the capability of transforming or degrading PAHs, many of the compounds formed are just as, or even more, hazardous as their parent PAH. The largest sources of PAHs are incomplete combustion of carbon containing materials/fuels (coal, oil, wood, waste etc)[30]. Up until the early 2000s a major source of PAHs was the HA-oils used in car tires, although the concentration is regulated now low levels of PAHs are still found in new tires [26]. Creosote-treated wood and gas stations are also sources of PAHs to varying extent[31].

The aromatic structure of the PAHs makes them stable and relatively persistent in the environment, capable of bioaccumulation and being transported long distances before degradation[26]. The LMW PAHs show relatively high water solubility while HMW PAHs are more hydrophobic[27-28], both can however be leached out of soil, but the mechanisms differ. The LMW PAHs show higher mobility and can be transported either as colloids bound to other matter or dissolved in the leachate whereas HMW PAHs are almost exclusively transported as colloids [30]. This combined with the fact that LMW PAHs are more easily degraded leads to higher ratio of HMW/LMW PAHs in soil and landfills with time [27].

Analyzing PAH content in leachate from landfills is common but usually limited to the 16 PAHs determined to be priority pollutants by the United States Environmental Protection Agency (US-EPA). However studies have more recently shown that oxygenated polycyclic hydrocarbons (oxy-PAHs), degradation products of PAHs, might be of concern as well. *Figure 3* below shows 2 examples of oxy-PAHs, anthracene-9,10-dione and benzo[a]pyrene-6,12-dione.

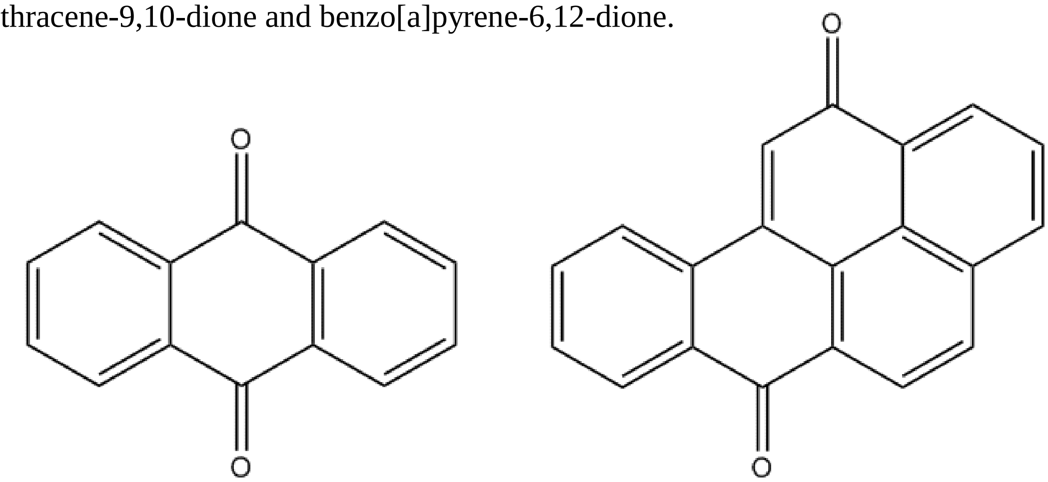


Figure 3. Structures of anthracene-9,10-dione and benzo[a]pyrene-6,12-dione

Oxygenated polycyclic aromatic hydrocarbons are created by the same processes that creates PAHs (incomplete combustion), but can also be produced in nature from degradation of PAHs by photooxidation, microbial transformation and chemical oxidation [29-30]. Determining the oxy-PAHs interaction with the environment is harder due to the fact that they can contain a number of different functional groups such as carbonyl, carboxyl, hydroxyl, coumarin and anhydride[29-30]. This in turn makes predicting oxy-PAH levels from PAH levels very difficult. Some characteristics for oxy-PAHs have however been reported. Although they are more degradable then their parent PAHs they have been shown to bioaccumulate to some extent, especially when degradation of PAHs is high[29]. Seeing as they are oxygen containing they are more polar then their parent PAHs and therefore more water soluble, giving them higher mobility in the environment, especially by leaching, the extent of the mobility increase is however unclear[29-30]. The oxy-PAHs have just as PAHs been proven to have toxic, mutagenic and cancerogenic effects on different organism and animals and, as mentioned above and in some cases they have been proven to be even more hazardous than the parent PAH[29]. Because of their increased water solubility they also present a greater threat to aquatic ecosystems than PAHs[29].

More research needs to be done on oxy-PAHs to assess the actual impact they have on the environment and what concentrations are of concern, in this respect a little more is known about the parent PAHs. In 2011 the European commission proposed a new directive for concentrations of priority substances in different surface waters, amending the last directive from 2008[32]. A few PAHs deemed as priority pollutants were included, see *Table 4* below.

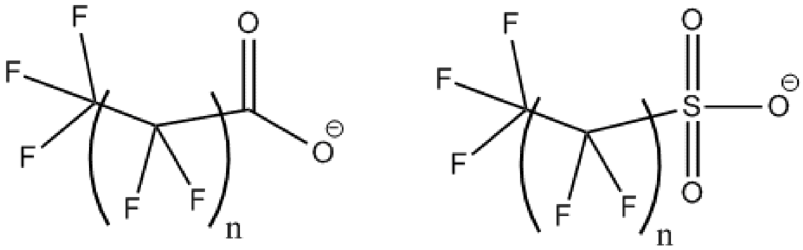
Table 4. Proposed environmental quality standard levels for selected PAHs in surface waters, by the European commission[32]. Unit (µg/l)

PAHs	Inland surface waters Annual average	Other surface waters Annual average	Inland surface waters Maximum allowable concentration	Other surface waters Maximum allowable concentration
Benzo(b)fluoranthene	0.000017	0.00017	0.017	0.017
Benzo(k)fluoranthene	0.000017	0.00017	0.017	0.017
Benzo(a)pyrene	0.000017	0.000017	0.27	0.027
Naphthalene	2	2	130	130
Anthracene	0.1	0.1	0.1	0.1
Fluoranthene	0.0063	0.0063	0.12	0.12
Benzo(g,h,i)perylene	-	-	0.0082	0.00082

5.2.2 Perfluoroalkyl and polyfluoroalkyl substances

Perfluoroalkyl and polyfluoroalkyl substances (PFASs), is the collective term describing a large class of highly fluorinated compounds, defined as containing the moiety C_nF_{2n+1}-[33]. To some extent they all present the fairly unique characteristics of being highly stable due to the strength of the C-F bond and being both hydrophobic and lipophobic[33], but the PFAS group is very diverse and encompasses hundreds, if not thousands, of different compounds with different chemical properties[34]. They are, and have been, used for numerous applications such as coating for paper, packaging, textiles etc, as part of polymers, in teflon and as surfactants to name a few[35-37]. The diverse chemical properties, the sheer number of different compounds combined with the fact that not a lot of research has been done on the environmental impact and behavior of these chemicals makes them hard to assess.

Two compounds have however been more thoroughly researched, perfluorooctanesulfonic acid (PFOS) and to some extent perfluorooctanoic acid (PFOA). The PFOS is classified as a PBT-compound (Persistent-Bioaccumulative-Toxic), in 2009 it was included in Annex B (Restriction) of the Stockholm Convention as a persistent organic pollutant, along with its salts and the compound perfluorooctane sulfonyl fluoride, PFOSF (used to make PFOS)[37]. The use of PFOS as well as PFASs that can break down to form PFOS have decreased, but not stopped completely. However the replacement chemicals used are usually other PFASs, some of which have been shown to break down to form PFOA[38]. The properties of PFOA have not been fully evaluated but recent research has shown that PFOA may fulfill the PBT-criteria as well[38]. More research is however needed in this field and it is not unreasonable to think that many of the PFASs can either by themselves or through their breakdown products pose environmental threats similar to those of PFOS and PFOA. In *Figure 4* below some of the more commonly used and consequently screened for PFASs, with structures similar to PFOS and PFOA are shown.



n=2: PFBA
n=3: PFPeA
n=4: PFHxA
n=5: PFHpA
n=6: PFOA
n=7: PFNA
n=8: PFDA
n=9: PFUnDA
n=10: PFDoDA
n=12: PFTDA

n=3: PFBS
n=5: PFHxS
n=7: PFOS
n=9: PFDS

Figure 4. Common perfluoro and perfluorosulfonic acids[34]

Due to the diverse chemical properties of the PFASs containing them all in landfills poses a significant problem and makes the leaching characteristics hard to predict. A study done on two landfills by Jonathan P et al. showed varying concentrations of different PFASs in the leachates during a 6 month period[34]. As mentioned before, no two landfills are alike, consequently the effects of the different parameters studied i.e. precipitation, temperature, amount/identity of waste etc are difficult to directly apply to other landfills but some characteristics may be transferable, such as the correlation between increase in pH and mobility of PFASs.

One thing in particular to take in to account when dealing with PFASs in landfill leachate or in any type of wastewater is the treatment. Wastewater treatment plants are optimized to degrade organic compounds, many PFASs that might degraded slowly or not at all in nature are in treatment plants rapidly degraded to smaller more stable PFASs. This means that the flow of PFOS and PFOA among others often is higher in the outlet stream of a wastewater treatment plant than in the inlet stream[39-41]. The PFOA in particular have been shown to almost completely pass through treatment plants and increase up to ten times in concentration due to breakdown of its precursors[40]. While most of the PFOS are found in the outlet stream, a significant amount is however removed from the water and found in the sludge, depending on the plant approximately 25-50% of the total PFOS have been found bond to the sludge [40-41], making the PFOS treatment more efficient than the PFOA treatment, but nevertheless insufficient. Focusing on a few priority PFASs might therefore not give the full picture of the environmental impact caused by the PFASs, depending on the treatment.

In 2011 the European commission proposed a new directive for concentrations of priority substances in different surface waters, this included purposed levels for PFOS[32]. The Swedish EPA made a similar report in 2008 that also included PFOS[42]. Both are presented in *Table 5* below.

Table 5. Proposed environmental quality standard levels for PFOS in surface waters, by the European commission and Swedish EPA [32] [42]*. Unit (µg/l)*

EU				Swedish EPA	
Inland surface waters Annual average	Other surface waters Annual average	Inland surface waters Maximum allowable concentration	Other surface waters Maximum allowable concentration	Inland surface waters	Other surface waters
0.00065	0.00013	36	7.2	30	3

5.2.3 Brominated flame retardants

Brominated flame retardants are a class of compounds encompassing about 70 different substances with widely diverse chemical properties. They are all more or less regarded as highly effective flame retardants and are therefore used in a wide range of products e.g. textiles, plastics and electronics[43]. Flame retardants are made to last as long as the product does and are therefore highly stable, not only in the product but also in the environment if allowed to get there[44].

There are a small number of different groups of brominated flame retardants, the most common historically being polybrominated diphenyl ethers (PBDEs)[43]. There are 209 possible PBDEs although not all are or have been commercially used. They are usually named BDE- followed by a number between 1 on 209, e.g. BDE-47. Or the IUPAC numerical multiplier can be used before BDE, e.g. HexaBDE, this does however cause some confusion because there are several different congeners with the same IUPAC multiplier and the commercial products named this way are technically a mixture of several different PBDEs. Four examples of BDE-congeners, BDE-47, 99, 153 and 209 are shown in *Figure 5* below:

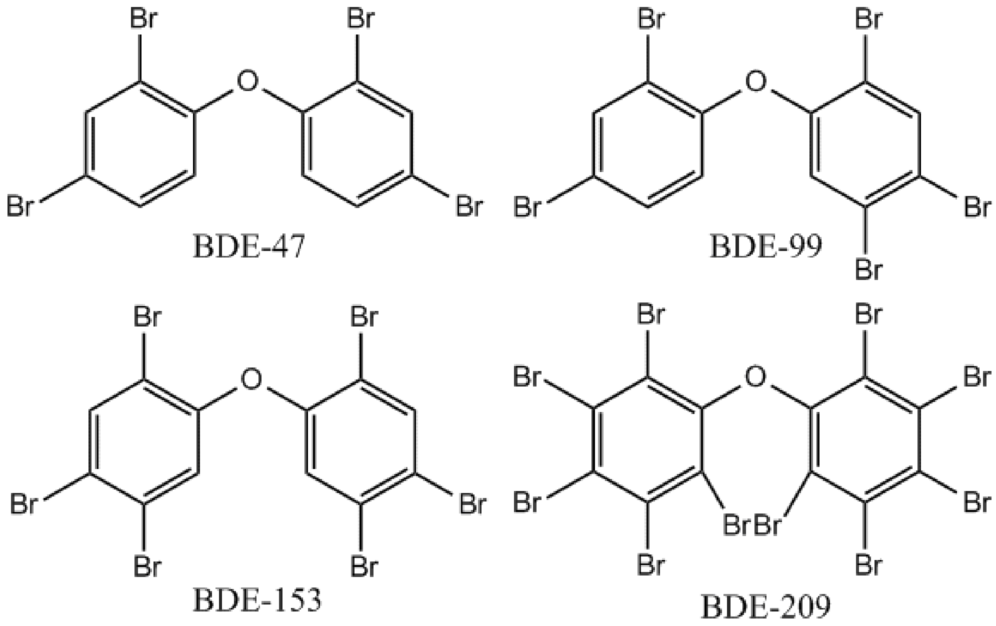


Figure 5. Structures of four different BDE-congeners.

PBDEs are highly persistent in the environment and are known to be toxic and bioaccumulate to varying degrees[43]. The only degradation pathway is through debromination i.e. one bromine is lost and replaced with hydrogen, creating a new smaller PBDE with similar chemical properties[45].

The PBDEs that have been produced in the largest scale up until now are[43]:

- commercial pentabromodiphenyl ether (PentaBDE), consisting mostly of BDE-47, a tetraBDE and BDE-99, a pentaBDE[46] [45].
- commercial octabromodiphenyl ether (OctaBDE), consisting of several different hexaBDEs and heptaBDEs[45-46].
- commercial decabromodiphenyl ether (DecaBDE), consisting almost exclusively of the fully substituted BDE-209 congener[46].

Of these, commercial PentaBDE and commercial OctaBDE are listed in Annex A (elimination) of the Stockholm Convention[45]. All PDESs are also listed in the RoHS-directive for restriction of hazardous substances in electrical and electronic equipment[47].

Two other brominated flame retardants historically produced at large scale are Tetrabromobisphenol A (TBBPA) and Hexabromocyclododecane (HBCDD or HBCD), seen in *Figure 6* below. Both have been classified as extremely toxic to the aquatic environment, persistent and possibly bioaccumulative. HBCDD do, according to Reach, qualify as a SVHC (substance of very high concern) and are under discussion in the Stockholm Convention[43-44].

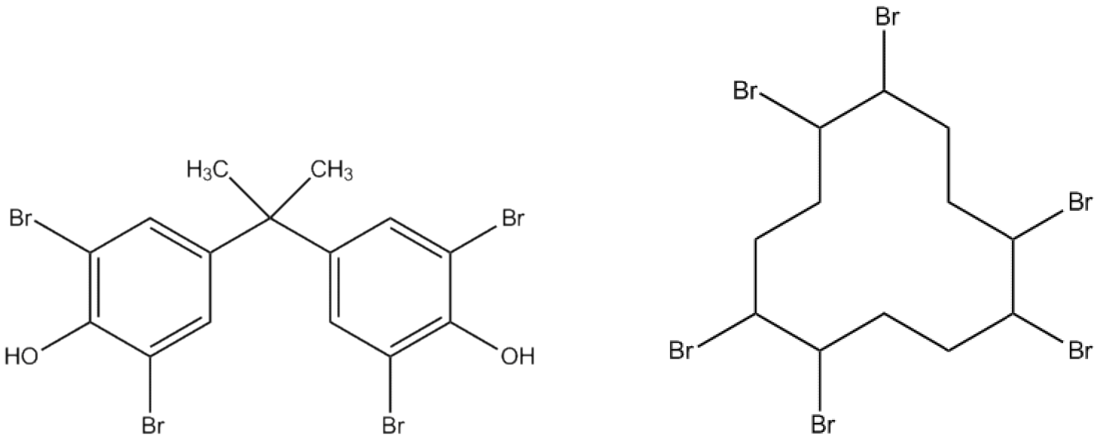


Figure 6. Structures of TBBPA and HBCDD

In 2011 the European commission proposed a new directive for concentrations of priority substances in different surface waters. In this directive some polybrominated diphenyl ethers as well as HBCDD were recognized, see *Table 6* [32].

Table 6. Proposed environmental quality standard levels for selected brominated flame retardants in surface waters, by the European commission [32]. Unit (µg/l)

Substances	Inland surface waters Annual average	Other surface waters Annual average	Inland surface waters Maximum allowable concentration	Other surface waters Maximum allowable concentration
∑ BDE-28,47,99,100,153,154	$4.9*10^{-8}$	$2.4*10^{-9}$	0.14	0.014
HBCDD	0.0016	0.0008	0.5	0.05

Brominated flames retardants are usually present to some extent in landfills due to their persistence and the large amount that have been used over the years. Even though the use has decreased and are continuing to decline it will still take time before they are no longer chemicals of concern. The main source of brominated flame retardants in landfills seems to be electronics, electrical components and crushed fragments of bulky incombustible wastes e.g. furniture[48]. But the flame retardants have also been found in varying amounts in MSWIRs, especially in the bottom fraction, indicating that although the flame retardants can be incinerated a fraction still passes through the process[49-50]. Mostly this is true for PDBEs and usually for the highly brominated congeners[50-51]. This is probably because they have been used to a greater extent lately, decaBDE was the last PDBE to be restricted under the RoHS-directive for example, and not because they are harder to incinerate.

Osako, M et al. presented some characteristics of the leaching of some brominated flame retardants in a study from 2004. The leaching of brominated flame retardants from landfills does not seem to be completely dependent on, but are highly affected by, organic matter present. The DHM in particular have been shown to increase the leachability of PBDEs. So landfills containing mostly incombustible waste and minor amounts of organics generally have lower concentrations of PBDEs in the leachate, however the concentration may still be high enough to be of concern. The TBBPA on the other hand have been found in relatively high concentrations from these types of landfills[48].

However when PBDEs are present in leachate general water treatment techniques have been shown to be efficient. Although the PBDEs hardly are broken down in water treatment facilities at all they do bind efficiently to the sludge[41][48]. For the same reasons their leachability is affected by DHM and they have the capability to bioaccumulate, the general hydrophobicity and high lipophilicity of the compounds.

5.2.4 Phthalates

Phthalates, also known as phthalic acid esters or PAEs, are di-esters of ortho-phtalic acid (*Figure 7*). They are used as plasticizers in a wide variety of polymers such as, plastics, rubber, adhesives, paint and fabrics. Consequently they are present in a many household items including furniture, clothes, electronics, construction material etc, several of which eventually ends up in landfills in one form or another, e.g. as incineration residues or just deposited[52-53].

One of the main problems with the use of phthalates, and plasticizers in general, is the fact that they are physically bond to the polymers in the material rather than being chemically bond. Physical binding is relatively weak and therefore they have a tendency to, by different means like leaching, leave the material to varying extents during the material´s life time[53-54].

Chemically the different phthalates properties varies due to the two substituents (usually aliphatic chains), bond to the ester-oxygen atoms, the polarity of the carboxyl group only truly matters when the substituents themselves are very small. Two examples of phthalates, DEHP and DBP, are shown in *Figure 7* below. The substituents can vary significantly and so does the properties of the entire compound, e.g. with a change of the aliphatic chain length from 1 to 13 carbons atoms, the vapor pressure decreases with four orders of magnitude and the K_{ow} (octanol-water partition coefficient) increases with eight orders of magnitude[55]. However, most phthalates generally exhibits high fat solubility, low water solubility and relatively low volatility[56].

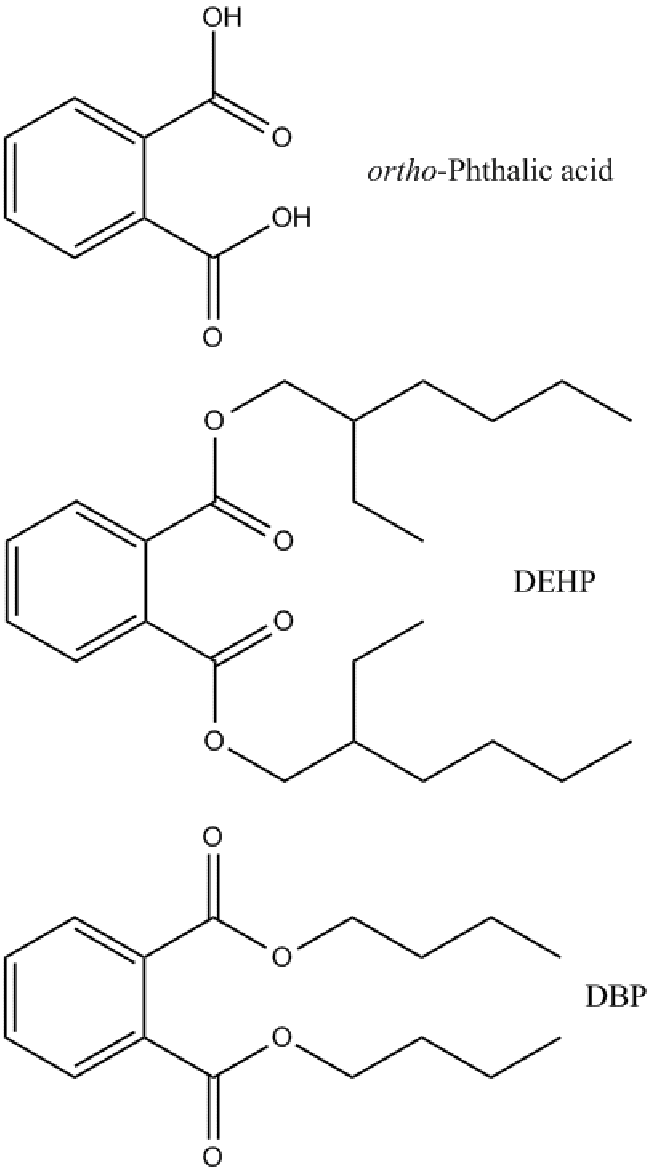


Figure 7. Structures of ortho-phthalic acids, DEHP and DBP

Phthalates does not have a very high direct toxicity, except for dibutyl phthalate (DBP) which have been shown to be extremely toxic for aquatic organisms, the main concern regarding phthalates is however that many do exhibit reproductive toxicity[53]. In response to this and due to extensive use of these compounds, the European union has restricted the use of some of the most commonly used and most environmentally concerning phthalates by putting them on the REACH candidate list for SVHCs, four of these phthalates are included in the authorization list as well:

Candidate list[57]

- Di-2-ethylhexyl phthalate (DEHP)
- N-pentyl-isopentylphthalate (DNPP)
- Dibutyl phthalate (DBP)
- Diisobutyl phthalate (DIBP)

- Benzyl butyl phthalate (BBP)
- Diisopentyl phthalate DIPP
- 1,2-Benzenedicarboxylic acid, di-C6-8-branched alkyl esters, C7-rich
- 1,2-Benzenedicarboxylic acid, di-C7-11-branched and linear alkyl esters

Authorization list[58]

- Benzyl butyl phthalate (BBP)
- Di-2-ethylhexyl phthalate (DEHP)
- Dibutyl phthalate (DBP)
- Diisobutyl phthalate (DIBP)

In 2011 the European commission proposed a new directive for concentrations of priority substances in different surface waters, DEHP was included and an annual average limit of 1.3 µg/l was proposed for all surface waters[32].

Phthalates have been shown to decompose to varying extents in nature and landfills, how fast they decompose is linked to their water solubility, which in turn depends on the identity of the substituents. The larger phthalates which generally exhibits a higher K_{ow}-value tends to be more stable while the smaller more polar phthalates, with lower K_{ow}, e.g. dimethyl phthalate, DMP, decomposes faster[54][59-60]. Hydrolysis, photolysis and volatilization have a relatively small impact of the decomposition compared to biodegradation which seems to be the main pathway for phthalates to decompose. However since biodegradation is dependent on oxygen and landfills tend to be relatively anaerobic, phthalates can persist there for a long time[54].

A study by Jonnson et al. (2003), reported that leachate concentration, from a landfill, of three smaller phthalates (DMP, DEP and DBP) decreased consistently after deposition. While the concentrations of DEHP, a larger more hydrophobic phthalate, fluctuate more and was present at a significant level long after the three others had decreased to near or below the limit of quantification[60].

Leaching of phthalates seems to be significantly dependent on DOM (dissolved organic matter) and especially HA (humic acid)[61-64]. A study by He et al. (2007), showed that the hydrogen bonding between DEHP and HA and the leaching of HA is the main route in which DEHP is leached out of landfills regardless of landfill age and DOM composition[63].

Treatment of waters polluted with phthalates can be done efficiently, since phthalates are both degradable and lipophilic. They can either be degraded or bond to the sludge extracted in water treatment facilities if suitable methods are chosen. Just as the degradation in landfills the fate varies with the individual phthalate, DEHP have been shown to bind to sludge to a greater extent while DBP are more readily degraded[41]. It should however be noted that the environmental impact of phthalate degradation products like monoesters may also be of concern, more research is however needed to assess this[65].

5.2.5 Alkylphenols and Alkylphenol ethoxylates

Alkylphenols (APs) consists of an alkyl chain, branched or straight, bond to a phenol, the chain usually has 4-12 carbon atoms (*Figure 8* below, where R is the chain). They are to a minor extent used as catalysts for curing epoxy resin, as heat stabilizers in plastic (different salts of alkylphenol) and as flame retardants (alkylphenol esters), but the main use is synthesis of alkylphenol ethoxylates (APEs)[66-67].

Alkylphenol ethoxylates are synthesized through ethoxylation of APs, a chain of ethylene oxide (EO) is bond to the oxygen atom on the AP, the chain can vary greatly in length, usually between 1-100 EO[67]. *Figure 8* below shows the simplest structure of APE, EO=1. The alkylphenol side of the molecule, built up of only carbon and hydrogen is nonpolar while the chain, containing carbon and oxygen are polar, therefore the chain length dictates the water solubility and consequently has a large impact on the environmental mobility of the compound. The fact that molecule has two distinct polarities is also what make it a potent surfactant, consequently the larger the difference is the better. Thus the most common phenols used are the ones with >8 carbon atoms, nonylphenol (C_9) being the one most used historically and as a result nonylphenol ethoxylates the most used APEs[66-67]. Nonylphenol (NP) and nonylphenol ethoxylates (NPEs) are also the compounds most frequently focused on from an environmental standpoint, risk assessments have been carried out by many researchers and organizations. It has been shown that NP, and to some extent similar APs, like octylphenol (C_8) and dodecylphenol (C_{12}), show high toxicity to aquatic organisms as well as a capability to bioaccumulate in fat tissue due to their high lipophilicity[66][68-69] . However it is not unreasonable to expect most alkylphenols and other closely related compounds to exhibit these properties to varying extents. It has also been shown that some alkylphenols are potent endocrine disruptors[66][70][73].

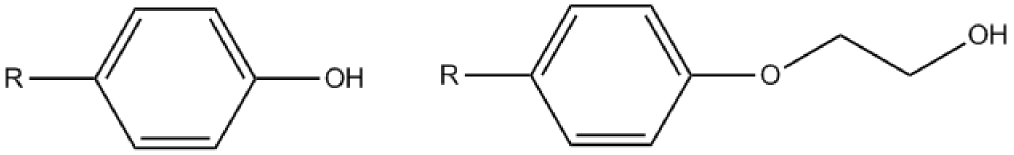


Figure 8. General structure for alkylphenols and alkylphenol ethoxylate (AP1EO)

Nonylphenol and nonylphenol ethoxylates have since 2009 been restricted in both commercial and industrial areas of use according to REACH Annex XVII[71]. The purposed concentrations of priority pollutants in surface waters by the European commission in 2011 also included levels for nonylphenol and octylphenol, *Table 7* below.

Table 7. Proposed environmental quality standard levels for selected alkylphenols in surface waters, by the European commission [32]. Unit (µg/l)

Substances	Inland surface waters Annual average	Other surface waters Annual average	Inland surface waters Maximum allowable concentration	Other surface waters Maximum allowable concentration
Nonylphenol	0.3	0.3	2	2
Octylphenol	0.1	0.01	-	-

Alkylphenol ethoxylates have been shown to readily break down in the environment, landfills, water treatment plants etc[66][68-69], the degradation products form usually consists of the parent AP or a smaller APE with EO <2. In the case of nonylphenol ethoxylates, NP, NP1EO and NP2EO are the most common degradation products, all showing aquatic toxicity, bioaccumulation- and endocrine disruption capabilities[69].

Another noteworthy thing about APs is the many different isomers possible due to the branching of the alkyl chain, NP for example has 500 different isomers[72], all showing slightly different chemical properties related to persistence, toxicity and bio accumulation. However, the exact environmental impact of these slight differences is unknown. Separating and quantifying them is also a problem since they are so similar and the fragmentation pattern analyzed by mass spectrometry (MS), the most common analytical method, is essentially the same for many of the isomers. Some progress has however been made with GCxGC/MS[70].

A comprehensive study on the occurrence of phenols in leachate from landfills was done by Kurata et al. (2007), leachate samples from 38 different municipal solid waste landfills in Japan was analyzed by targeted GC/MS. Samples was also taken at the discharge stream from the facilities treating the leachate to evaluate the treatment efficiency. Some notable things about nonylphenol and octylphenol were revealed: nonylphenol was found in all samples from all 38 sites (average: 0.65 µg/l) and octylphenol in 71% of all samples (average: 0.14 µg/l). High pH, especially >9.8 affected the leachability of phenols in general. Concentrations of octyl- and nonylphenol were mostly correlated with the deposition of incombustibles, but deposition of incineration residues was moderately correlated to the concentration as well. Conventional treatment techniques were shown to remove significant amounts of nonylphenol from the water[73]. However another study by Ahel et al. (1994), have shown that as much as 60% of the alkylphenols and alkylphenols ethoxylates entering a treatment facility are discharged[68] and the fact that some amounts passes though treatment have been proven by Ying et al. (2002), as well[69]. Thus removal of alkylphenols from wastewater seems to be dependent on what treatment techniques are employed.

6 Producing proposals to improve the control program

6.1 Methodology

In order to prioritize pollutants that might be of concern with respect to environmental impact and possible presence in leachate, a list of 154 substances and substance groups was put together. The substances where picked from the lists and criteria below:

- Pollutants listed under Annex A, B or C or being discussed for listing in the Stockholm Convention as POPs (persistent organic pollutants)[45].
- Pollutants mentioned as substances of concern in leachate or substances commonly found in leachate according to the report "Organiska riskämnen i lakvatten" by SWECO Environment[74].
- Pollutants listed as priority substances in the field of water policy in the European Water framework directive[75].
- Pollutants proposed to be included as priority substances in the European Water framework directive[32].
- Pollutants listed either under the REACH Authorization[58] or Candidate[57] list as SVHCs (Substances of very high concern).
- Pollutants fulfilling the PBT (persistent bioaccumulative toxic), vPvB (very persistent very bioaccumulative) or POP criteria according to ESIS (European chemical Substances information System) [76].
- Pollutants identified as substances of concern in the REVAQ pilot study (2012) or prioritized in the following preliminary report (2013) [41][77].

The online tool "PBT Profiler"[78], developed by the Environmental Health Analysis Center under contract to the Office of Chemical Safety and Pollution Prevention, U.S. Environmental Protection Agency, was then used to predict persistence (P), bioaccumulation (B) and toxicity (T) for compounds where experimental data from ESIS was not found. The tool uses a color grading system with green, grey, orange and red as the different levels. Only "red predictions" i.e. the worst predictions for P, B or T was noted to ensure a greater level of confidence in the potential adverse environmental impacts of the compounds. The PBT Profiler was also used to predict the percent of the pollutant that may be found in water and sediment, as they are the two most relevant medium for leaching. Partioning strongly to soil would ensure that the compounds are contained within the landfill and partioning to air, while being a pathway for exposure to the environment, is not discussed in this project.

Aquatic toxicity was also of concern so the two risk phrases below were taken into account as well[76]:

- **R50/53:** very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
- **R51/53:** toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

These compounds and parameters were then structured and assessed in MS Excel, see Appendix II for full list. The assessment and ranking of pollutants was carried out by first choosing and prioritizing between the parameters and then using the program´s sort and filter functions to generate top lists. Two lists were created based on different priority schemes in order to gain a better view of what pollutants might be most relevant. The different parameters used and their labels are seen below in *Table 8*.

Three other pollutants were chosen and discussed independent of ranking, the individual reasons for this is described below for respective compound.

Table 8. Parameters used to prioritize the selected pollutants

Labeled	Meaning	Source
Tprof	Predicted **T**oxic	PBT Profiler [78]
Bprof	Predicted **B**ioaccumulative	PBT Profiler [78]
Pprof	Predicted **P**ersistent	PBT Profiler [78]
PBT	**P**ersistent **B**ioaccumulative **T**oxic	ESIS [76]
vPvB	**V**ery **P**ersistant **v**ery **B**ioaccumualtive	ESIS [76]
POP	**P**ersistent **O**rganic **P**ollutant	ESIS [76] Stockholm Convention [45]
R50/53	Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment	ESIS [76]
R51/53	Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment	ESIS [76]
OP	**O**ften **P**resent in leachate. Found in relevant concentrations >3 times.	SWECO report [74]
MP	**M**inor **P**resence. Found in leachate in minor concentrations in some landfill leachates.	SWECO report [74]

6.2 Results and discussion

6.2.1 Prioritizing pollutants independent of general presence in landfill leachate

The first list of priority substances was created by only accounting for the chemical properties and environmental concern surrounding the individual compounds, not taking into account likely hood of finding them in landfill leachate. By prioritizing the compounds with proven adverse long term effects on the environment using the parameters and priority scheme:

POP > PBT > vPvB > Bprof > Pprof > R50/53 > R51/53 > Tprof

The list below (*Table 9*) was generated, it is not a clearly defined 1-25 top list since many of the compounds are of equal concern and no difference is made between them, but the general order still applied. As seen in the list, 15 of the 25 compounds are pesticides, many of them showing high toxicity to aquatic organisms, low water solubility and low to moderate capability of binding to or otherwise interacting with sediment. The leaching potential of these pesticides might therefore not be particularly high. This combined with the fact that most of them are nowadays regulated by e.g. the Stockholm Convention and the fact that there are no distinct sources of pesticides deposited on Tagene should make the chance of finding these compounds in high concentrations relatively low.

Table 9. List of pollutants with the highest potential to adversely affect the environment.

Compound	CAS#	Risk Phrases	%Water	%Sediment
Aldrin	309-00-2	R50/53	3	26
Chlordecone	143-50-0	R50/53		
Commercial Pentabromodiphenyl ether (Tetrabromodiphenyl ether and pentabromodiphenyl ether)	5436-43-1 32534-81-9	R50/53	4	8
DDT	50-29-3	R50/53	3	37
Dieldrin	60-57-1	R50/53	5	12
Endosulfan	115-29-7	R50/53	4	3
Endrin	72-20-8	R50/53	5	12
Heptachlor	76-44-8	R50/53	3	13
Hexachlorobenzene (HCB)	118-74-1	R50/53	4	2
Lindane	58-89-9	R50/53	7	2
Mirex	2385-85-5	R50/53	2	37
Pentachlorbenzene (PeCB)	608-93-5	R50/53	4	1
Toxaphene	8001-35-2	R50/53	3	29
Alpha Hexachlorocyclohexane	319-84-6		7	2
Beta Hexachlorocyclohexane	319-85-7		7	2
Chlordane	12789-03-6		4	8
Commercial Octabromodiphenyl ether (Hexabromodiphenyl ether and Heptabromodiphenyl ether)	36483-60-0 68928-80-3		4	7
Dicofol	115-32-2		4	6
Hexabromobiphenyl	36355-01-8		2	24
Hexachlorobuta-1,3-diene (HCBD)	87-68-3		27	2
PFOS, Its salts and PFOS-F	1763-23-1 307-35-7		2 9	19 85
Polychlorinated biphenyls (PCB)	-		-	-
Polychlorinated dibenzofurans (PCDF)	-		-	-
Polychlorinated dibenzo-p-dioxins (PCDD)	-		-	-
Anthracene oil	90640-80-5		-	-

However it is not uncommon to find some species of pesticides in landfill leacahtes[74]. In the leachate from Tagene, three pesticides: Mecoprop, Dichlorprop and Bentazone have been detected (Appendix I for full results). Mecoprop and Dichloroprop have also been detected in concentration ranges from 0.24-8 µg/l in 7 other Swedish landfills[79]. This can be attributed to the fact that these three pesticides show higher water solubility compared to the ones listed above (22-36% PBTprofiler[78]) and that these are all more or less still commonly used in households today, making the chance of them ending up in municipal landfills greater.

In the current control program for the leachate from Tagene 5 pesticides are screened for annually (Mecoprop, Dichlorprop, MCPA, 2,4-D and Bentazone) and during the characterization every third year additional selected pesticides are screened for (see Appendix I for the full list from 2010). However, during the last characterization a detection limit of 0.1 µg/l was used for all pesticides, this was probably too high to detect any of the more harmful ones from the list above (*Table 9*) since they likely would not occur in that relatively high concentration considering the circumstances. Comparing the limit of detection used for the last screening with the environmental standards in surface waters proposed by European commission, seen in *Table 10* below, it can be noted that the detection limit of 0.1 µg/l is even in the best case scenario still 1 order of magnitude too high to account for concentrations that might have adverse environmental effects (not account for dilution). Since these pesticides are persistent, all classified as either POP, PBT or vPvB, it would therefore not be unreasonable to assume that conventional wastewater treatment would not degrade them completely, so there might be a chance of them reaching the environment if they are present in the leachate. If they pass directly through a treatment plant and end up in the aquatic environment, bind to the sludge and are used as fertilizer or in the best case scenario mostly break down, is difficult to predict and probably varies between the individual compounds.

Table 10. Proposed environmental quality standard levels for selected pesticides in surface waters, by the European commission [32]. Unit (µg/l)

Pesticides	Inland surface waters Annual average	Other surface waters Annual average	Inland surface waters Maximum allowable concentration	Other surface waters Maximum allowable concentration
∑ Aldrin Dieldrin Endrin Isodrin	0.01	0.005	-	-
DDT total	0.025	0.025	-	-
Endosulfan	0.005	0.0005	-	-
Hexachlorobenzene	-	-	0.05	0.05
Dicofol	0.0013	0.000032	-	-

Consequently, the persistence of the pesticides combined with that they occur in very low concentrations may still be concerning and makes a case for them to be included in the next screening at Tagene. At least once in order to exclude them from future screenings ass the regulations now in place will ensure that environmental concentrations will not rise. On the other hand, the fact that environmental concentrations are expected to drop with each passing year and that there is no real reason for these pesticides to end up at Tagene, a landfill which mainly handles incombustibles, makes the case that these pesticides might not be the most relevant group to focus on and that commercially used pesticides, even if less toxic and persistent, should be screened for instead. This latter reasoning is strengthened below when a new list of compounds is generated by using a different priority scheme.

Apart from the pesticides, 10 other compounds/groups were found on the list, most of these being industrial chemicals which nowadays is regulated to varying extents. These are however more relevant since many of them has been found and continues to be present in leachate from other landfills, as seen below when that is factored in to the ranking.

6.2.2 Prioritizing pollutants and factoring in possible presence in landfill leachate

To produce a new list of compounds that might be more relevant i.e. contain compounds with a higher likelihood of being found in the leachate. The parameters OP (Often present) and MP (Minor presence) were prioritized before the toxicity, bioaccumulation and environmental persistence of the compounds, making the scheme:

OP > MP > POP > PBT > vPvB > Bprof > Pprof > R50/53 > R51/53 > Tprof

The list created is presented in *Table 11* below, 32 compounds/groups are presented this time (the last 10 compounds had the same predicted priority, so all were included rather than cutting of the list at 22), once again the general order still applies but it is not a clearly defined top list.

Table 11. List of pollutants previously found in landfill leachate with the highest potential to adversely affect the environment.

Compound	CAS#	Risk Phrases	%Water	%Sediment
Commercial Pentabromodiphenyl ether (Tetrabromodiphenyl ether and pentabromodiphenyl ether)	5436-43-1 32534-81-9	R50/53	4	8
Commercial Octabromodiphenyl ether (Hexabromodiphenyl ether and Heptabromodiphenyl ether)	36483-60-0 68928-80-3		4	7
PFOS, Its salts and PFOS-F	1763-23-1 307-35-7		2 9	19 86
Polychlorinated dibenzofurans (PCDF)	-			
Polychlorinated dibenzo-p-dioxins (PCDD)	-			
PAH - Anthracene	120-12-7		9	12
Octamethylcyclotetrasiloxane	556-67-2	R50/53	40	26
PAH - Phenanthrene	85-01-8		10	12
Dicyclohexylamine	101-83-7	R51/53	25	0
Nonylphenol	25154-52-3	R51/53	18	19
Octylphenol	140-66-9	R51/53	16	9
Tridemorph	24602-86-6	R51/53	13	18
Benzyl butyl phthalate (BBP)	85-68-7	R51/53	22	5
Biphenyl	92-52-4	R51/53	17	3
Dibutyl phthalate (DBP)	84-74-2	R51/53	26	1
Diphenylamine	122-39-4	R51/53	18	1
Mecoprop	93-65-2	R51/53	22	0
PAH - Naphthanlene	91-20-3	R51/53	11	1
N,N-diethyl-m-toluamide	134-62-3	R50/53	18	0
tris(2-chloroethyl) phosphate	115-96-8	R50/53	16	0
Chlorobenzene	108-90-7	R50/53	28	0
Tetrahydrothiophene	110-01-0	R50/53	32	0
3,4-bisisopropylphenol	68155-50-0		17	4
Hexamethylcyclotrisiloxane	541-05-9		47	5
Hexamethyldisiloxane	107-46-0		48	1
Myristic acid	544-63-8		26	1
N,N-dibutylformamide	761-65-9		33	0
PAH - Fluoranthene	206-44-0		8	31
PAH - Pyrene	129-00-0		8	31
Palmitic acid	57-10-3		26	1
Pentadecanoic acid	1002-84-2		26	1
Tributyl phosphate	126-73-8		27	1

Brominated flame retardants

More detailed background on brominated flame retardants is available in the initial literature study, page 18.

Found on top of this list are two commercial brominated diphenylethers (BDE), both of these are found on the first list as well, clearly showing that they are chemicals of concern. They are listed under Annex A in the Stockholm Convention since 2009[45]. However the persistence of these compounds and the fact that the regulation of them is relatively recently instated might still make the chance of finding them in landfills fairly high. Since debromination is the only pathway in which they can breakdown, i.e. heptaBDE breaks down to hexaBDE which in turn breaks down to pentaBDE etc [45], the potential environmental impact of them is significant even in low concentrations. This also makes the case for analyzing for other highly substituted congeners of BDEs, even if they by themselves are deemed slightly less hazardous to the environment. Decabromodiphenyl ether is the most prevalent example of this, together with the two already mentioned BDEs, they are historically the most commonly used brominated flame retardants[43].

While not seen on this list, other brominated flame retardants might be of concern as well and are usually analyzed for alongside the BDEs, two of the most important of these are tetrabromobisphenol A (TBBPA) and hexabromocyclododecane (HBCDD). Both have been used in significant volumes over the years and both are potent environmental pollutants.

No brominated diphenyl ethers, or any type of brominated flame retardants have been analyzed for in the leachate from Tagene, there are however reasons to do so. Known sources of brominated flame retardants are electronics, electrical components and crushed fragments of bulky wastes and the bottom fraction of municipal solid waste incineration residues (MSWIRs). Bottom ash from MSWIRs is deposited in large volumes at Tagene as well as bulky wastes, construction materials and demolition rubble[48]. With the 2012 start of deposition of SLF (Shredder light fraction from the automotive industry) a new potential source of brominated flame retardants have been introduced, this might be a potent source for numerous other pollutants for years to come as well. Since Sweden has one of the oldest car parks in Europe it would not be unreasonable to assume that the SLF produced today might come from older cars and therefore contain pollutants that nowadays have been banned in the industry, such as the discussed BDEs.

Looking at the environmental quality standards for brominated flame retardants in surface water proposed by the European commission (*Table 6 page 20*), it is clear that very low concentrations of BDEs <0.00005 ng/l (<0.002 µg/l for HBCDD), may have potential adverse effects in the aquatic environment. In a study done by Avfall

Sverige in the early 2000s, 4/9 screened Swedish landfills showed concentrations ranging from 0.0005-0.062 µg/l of BDEs in their leachate[79]. Noteworthy about this study is that the landfill showing the highest total concentration of BDEs was a landfill with relatively low TOC (62 mg/l) as well as low amounts of suspended matter (1,4 mg/l). Showing that even though the leaching of brominated flame retardants have been strongly linked to organic matter, they can still be leached out even if the TOC is low. This is significant information since the values from Tagenes leachate are fairly similar, TOC 41-46 mg/l and suspended matter: 9.5-13 mg/l. However, the identity of the TOC may have an impact of the leaching as well given that DHM (dissolved humic matter) in particular have been shown to increase leachability of numerous BDEs.

The brominated flame retardants do show very high toxicity to the aquatic environment, but since conventional water treatment techniques have proven to be efficient, this may not be the most concerning factor. The main problem in the case of Tagene however is the fact that they almost exclusively bind to the sludge in treatment plants and are hardly broken down at all, which is a problem since Ryaverket (treating the leachate from Tagene) are working with REVAQ.

Consequently, brominated flame retardants should be analyzed for at Tagene, there are potential sources, potential adverse effects if they reach the aquatic environment and even potential adverse effects if they are efficiently removed from the water bound to the sludge at Ryaverket. The most common BDE-congeners (28, 47, 99, 100, 153, 154, 209 etc) as well as TBBPA and HBCDD should probably be included in the control program. Seeing as the Environmental quality standards are set for the sum of 6 congeners (28, 47, 99, 100, 153, 154) because they all affect the environment similarly, the detection limit for each individual compound needs to be set low. As to avoid a situation where all BDEs are present but just under the detection limit, making the total concentration significant while the analyses show nothing. Also taking in to account the concentrations found in Swedish landfills (0.5-62 ng/l), the detection limits should be in the low ng/l, 0.1-1 at least.

Pesticides

Once again some pesticides are present on the list, these being Mecoprop, N,N-diethyl-m-toluamide (DEET) and Tridemorph. They are all showing higher water solubility, more than double that of the more hazardous pesticides on the list above (*Table 9 page 29*). Mecoprop have been found in the leachate from Tagene before, for 3 consecutive years in concentrations over 0.2 µg/l, while the other two have not been tested for at all. However, since Tridemorph is a fungicide nowadays mainly used at banana plantations, it is deemed toxic for reproduction and all use is prohibited in Sweden, Finland, Denmark, UK, Spain and the Netherlands since 2003, making the chance of finding it in significant concentrations at Tagene low. Banana peels in the

MSW alone, much less after incineration, is not a very potent source[80]. N,N-diethyl-m-toluamide on the other hand, is the most commonly used mosquito repellant in Sweden (~5 ton annually since 2007)[81][82], since it is widely used by the public there is a large probability that some DEET is present in municipal waste. But since almost all the municipal solid waste that is to be deposited at Tagene is incinerated the concentrations are not expected to be very high, assuming DEET breaks down during incineration. A risk assessment done by SWECO also concluded that the environmental threat of DEET in Sweden is low[82].

As concluded in the section above (page 31), screening for pesticides is relevant since they have been found in the leachate previously and even when using these new parameters (OP and MP) some pesticides are still found on the generated priority list. But since landfills are not generally big sources of pesticides, especially not from a landfill mainly handling incombustibles, the focus should most likely be on the ones still commercially used today i.e. the ones with the largest probability of actually being present in the landfill. Based on what concentrations they have been found in before and the fact that they are less harmful to the environment than the restricted ones, the detection limits used in the control program for the last 2 years (0.01-0.05 µg/l) should be sufficient.

PFOS, its salts and PFOS-F

More detailed background on perfluoroalkyl and polyfluoroalkyl substances are available in the initial literature study page 16.

The PFOS, its salts and PFOS-F are found on both lists, showing that the compounds are of clear concern. Other PFASs (perfluoroalkyl and polyfluoroalkyl substances), especially PFOA should probably be included in this group as it have been shown to have similar properties and sources and are usually analyzed for alongside PFOS[38].

A number of PFASs, including PFOS and PFOA have been analyzed for in the leachate from Tagene once before (2010), see Appendix I for detailed results. However no PFOS-salts or precursors to either PFOS or PFOA were included in the screening. Since the precursors readily break down during treatment in water treatment plants and influences the total concentration stream[39][40][41], the results from the screening may not give the full picture of the PFASs environmental impact. Also noteworthy is the fact that because of the diverse chemical properties of the different PFASs the leaching is unpredictable, studies have shown that concentrations of different PFASs in landfill leachates varies to some extent during the year[34]. This may suggest that by analyzing PFASs once every third year and during the same month every time, ensuring fairly similar conditions regarding temperature and weather, the data obtained may not be representable of the annual average leaching from Tagene.

As seen by the fact that PFASs have been detected in the leachate there are obviously PFASs sources deposited at Tagene. It is hard to pinpoint exactly what this source is, because in all likelihood there is more than one source since the compounds have been (and to a minor extent still are) used for numerous applications. To some extent all deposited waste may have some traces of PFASs due to the nature of the compounds. However, matters that stand out are the different types incombustible wastes such as demolition rubble and construction materials and the incineration residues. With the 2012 start of SLF deposition a potential new source of PFASs have been introduced as well.

Comparing the amounts of PFASs detected (Appendix I) at Tagene with the environmental standards in surface waters proposed by European commission (*Table 5 page 18*) it is apparent that the amount detected at Tagene are significant. If precursors are present the concentrations reaching the recipient may be even higher since PFASs are shown to either pass through treatment plants in the water or bind to the sludge.

Consequently, PFASs should be continued to be analyzed at Tagene, preferably more than once every third year, some precursors should ideally be included in the control program as well. Precursors can however be a problem as it stands today, which precursors to focus on is hard to determine since the identification of which compounds that might actually be precursors is not extensively evaluated, a lot of research is still needed. Two list of probable precursors of PFOS and PFOA have however been published by the Canadian EPA, see links under reference [83] and [84].

If onsite leachate treatment is implemented at Tagene, another way of analyzing precursors becomes available. That is doing a mass balance of PFOS and PFOA, over the whole treatment process, though this will not identify the individual precursors, their general presence can be determined.

The detection limits used in 2010 (100 ng/l) did detect many of the PFASs screened for, indicating that the detection limits may be sufficient, however if factoring in the proposed environmental quality standards the detection limits could be lower. Most accredited labs nowadays seem to offer detection limits around 1-25 ng/l, which should be adequate.

Phthalates

More detailed background on phthalates is available in the initial literature study page 21.

Two phthalates are seen on the list above (*Table 11*), benzyl butyl phthalate (BBP) and dibutyl phthalate (DBP). Together with two other phthalates, bis(2-ethylhexyl) phthalate (DEHP) and diisobutyl phthalate (DIBP), placing number 47 and 45 on the full list, they are listed under the REACH Authorization list as SVHCs.

There are potential sources of phthalates deposited at Tagene, the incombustible bulky waste being one of the most obvious. Six phthalates (Appendix I for full list) have been analyzed for in the leachate from Tagene for 5 consecutive years using a detection limit of 0.1 μg/l (except for DEHP using 1.0 μg/l) and apart from an isolated value of 0.22 μg/l DBP in 2009 no concentrations have been detected during the annual screenings performed according to the control program. This is somewhat surprising seeing as phthalates are commonly found in leachate, comparing to the study by Avfall Sverige[79] where phthalates were found in 4/6 landfills in ranges between 0.83-120 μg/l. This can however partially be explained because the leaching of phthalates is fairly dependent on organic matter, which coincides with the landfills leaching phthalates in the study having a TOC value >100 mg/l and the one landfill clearly leaching the most phthalates (5 different phthalates in ranges between 47-120 μg/l) having a TOC value of 490 mg/l. This also explains why DBP was the one found in Tagene, seeing as DBP is one of the smaller and more polar phthalates and therefore more water soluble and less dependent on organic matter for mobility. Also noteworthy is that the TOC and DOC concentrations were higher than "usual" during the 2009 screening, 81 and 60 mg/l respectively (Appendix I for full list).

The fact that phthalates are still present in the landfill but not leached out due to lack of organic matter during the annual screenings was confirmed in the study by Kalmykova et al. (2012), in which screening of leachate from Tagene (L2) was included. The screening for 8 phthalates were included (see Appendix I for full list and results), of which 3 were found, most notably DEHP in a concentration of 2.3 μg/l[85]. The DEHP is the most commonly found phthalate, it is also larger and more dependent on organic matter for mobility, the fact that it was leached out coincides with the DOC concentrations being 100 mg/l during the study, more than double the values measured during the annual screenings of organics for the past 3 years.

Continuing with annual screenings for phthalates at Tagene should be sufficient and the detection limits used should also be low enough to account for any potential adverse environmental effects. There are however 3 phthalates not currently screened for that might warrant being added to the control program: first of all DIBP, it is found on the priority list above and like DBP it is fairly small and mobile and might therefore be leached out. The two other phthalates are diisononylphthalate (DINP) and diisodecylphthalate (DIDP), while being slightly less harmful than the other phthalates currently screened for, they are beginning to be used more, usually as replacement chemicals for e.g. DEHP[52-53]. These two were screened for in the study by Kalmykova et al. mentioned above, though not detected, concentrations of these may rise in the future while concentrations other phthalates drop.

Alkylphenols and Alkylphenol etoxylates

More detailed background on alkylphenols and alkylphenol etoxylates is available in the initial literature study page 24.

Nonylphenol and octylphenol, the two most common alkylphenols (APs) are both found on the generated priority list. In the report by Avfall Sverige they are found in 4/5 landfills in concentrations between 0.04-14.7 μg/l[79] and according to a report by Kurata et al. (2007), nonylphenol was detected in 38/38 landfills in Japan (average 0.65 μg/l) and octylphenol in 27/38 (average 0.14 μg/l)[73]. The same study showed a strong correlation between deposition of incombustible matter and the occurrence of APs in the leachate, as well as a moderate correlation of the occurrence to the deposition of incineration residues, of which there is a large amount deposited at Tagene.

Analyzing for APs alone may not give the full picture of the concentration in leachate, since APs are commonly used to produce alkylphenol etoxylates (APEs), which can later break down to form alkylphenols again. Some of the more common APEs should therefore be screened for alongside the APs and if possible. These more common APEs usually being the smaller ones (shorter ethylene oxide chain) since the long chains tends to readily break in the environment, it is the first step of degradation.

While not included in the control program and never screened for by Renova themselves, a study by Kalmykova et al. (2012), in which portioning of a few organic pollutants were investigated a screening for a few APs and APEs in the leachate from Tagene (L2) was included[86]. Nonylphenol was found (7.3 μg/l) as well as 4-tert-butylphenol (1.5 μg/l), 4-tert-pentylphenol (0.11 μg/l) and 2 octylphenol etoxylates (0.038 and 0.84 μg/l) [85], see Appendix I for full list and results. These results confirms that some APs and APEs are indeed present in the landfill. Noteworthy about this study was that the DOC concentration was 100 mg/l, which is more than double the DOC concentrations determined during the last 3 screenings for organics at Tagene.

Consequently, screening for APs and APEs should be included in the control program at Tagene, they are potent environmental pollutants, toxic for aquatic organisms, capable of bioaccumulation and endocrine disrupting. They have been shown to be present in the leachate, they also have the potential of binding to sludge in water treatment plants and are mentioned as substances of concern in the REVAQ pilot study, this is however not discussed further due to a lack of experimental data[41].

Nonylphenol should be prioritized, closely followed by octylphenol and if possible a few nonylphenol and octylphenol etoxylates should be screened for as well. Other APs like butylphenol and pentylphenol can also be screened for, as they have been found at Tagene, however they are not environmentally prioritized as highly as nonylphenol and octylphenol, screening for their etoxylates are not prioritized either.

There is no clear priority given to the different NPEs and OPEs, some of them may also be hard to analyze. As a result, including those which the labs actually can detect and are offering analyses for are probably sufficient for now. Based on what has been detected before according to the studies above and comparing to the Environmental quality standards purposed by the European commission (*Table 7 page 25*) the detection limits should be around 0.1 μg/l for nonylphenol and nonylphenol etoxylates and approximately one order of magnitude lower for octylphenol and octylphenol etoxylates.

Polycyclic aromatic hydrocarbons

More detailed background on polycyclic aromatic hydrocarbons substances is available in the initial literature study page 14.

Five PAHs are found on the priority list (*Table 11*), these being naphthalene, anthracene, phenanthrene, fluoranthene and pyrene. Looking at the full list, 11 other PAHs are spread out between place 76 and 148 as well. Polycyclic aromatic hydrocarbons are “classic” environmental pollutants and extensive research has gone in to understanding their environmental behavior and impact and monitoring them. The annual screening for the 16 US EPA PAHs done at Tagene is somewhat of a standardized program and should be sufficient, especially when taken into account that no PAHs have been detected in the leachate from Tagene since 2009 according to analyses performed after the control program. However the ones that were detected then were relatively small and therefore more water soluble. The mobility of PAHs are strongly correlated to organic matter due to their lipophilicity and since Tagenes leachate has low TOC and DOC values there might be more PAHs contained within the landfill. This coincides with the fact that the TOC and DOC concentrations were spiking a bit (see Appendix I) in 2009 when the PAHs were detected.

While no PAHs have been detected recently by the screening performed according to the control program, the study by Kalmykova et al. (2012), mentioned in the chapter above, did also involve screening for the 16 US EPA PAHs and 4 were detected:

acenaphthene (0.03 μg/l), fluorene (0.02 μg/l), phenanthrene (0.03 μg/l) and naphthalene (0.31 μg/l). Once again these are relatively small a water soluble, naphthalene being the smallest, however it cannot be excluded that organic matter once again may have affected the leachability since the DOC concentration was found to be 100 mg/l and TOC 107 mg/l respectively[85].

Since PAHs are present to some extent in the landfill but are not leached out in high concentrations due to the lack of organics, there is also a chance that oxy-PAHs are present in the landfill, either coming from the same source as the PAHs (most likely the incineration residues) or being formed from the PAHs in the landfill. The polarity of the oxy-PAHs makes them significantly more water soluble, if they are present at Tagene they should therefore be leached out at a higher rate than the PAHs. Including some of the oxy-PAHs in the screening might therefore be warranted. Research about the environmental impacts of the oxy-PAHs is however lacking and it is difficult to assess what detection limits should be used and what concentrations that may be of concern. However due to their similarly with PAHs, using approximately the same parameters may be sufficient i.e. a detection limit of ~0.01 μg/l. The lack of data also makes it hard to determine which individual oxy-PAHs should be focused on, but since the detection limits required to detect them in the leachate might be low (they are probably not present in some orders of magnitude above PAHs), focusing on those that labs can actually detect in low concentrations should probably be prioritized.

Polychlorinated dibenzofurans, dibenzo-p-dioxins and other dioxin-like pollutants

Polychlorinated dibenzofurans (PCDFs) and dibenzo-p-dioxins (PCDDs) are unintentionally produced compounds, mostly due to incomplete combustion[45], which at Tagene would suggest that main source would be the incineration residues. They are highly persistent and linked to numerous adverse effects such as cancer, immune and enzyme disorders, birth defects and still births in a wide range of animals and organisms, including humans[45]. A few of them are consequently listed as POPs under Annex C in the Stockholm convention[45].

Dioxins and furans are usually reported by a toxic equivalency factor/quotient (TEF/TEQ) but the trend nowadays seems to be going towards reporting them on an individual basis as well[87-88]. The two most commonly used TEQs are the WHO (World health organization) TEQ and the International TEQ, I-TEQ. Toxic equivalency factors are also usually reported as upper bounds or lower bounds, which are two different ways of dealing with dioxins that are not detected. The lower bounds method deems dioxins under the detection limit as nonexistent and substitutes them as 0 in to the formula, while the upper bounds method substitutes the detection limit in to the formula, accounting for the worst case scenario, in truth the values is somewhere in between the two.

There are 7 PCDDs of the 75 possible congeners that are deemed harmful as well as 10 PCDFs of the 135 possible there. These are usually the ones focused on and they have been screened for once at Tagene (Appendix I for full results of the individual congeners), the TEQ-results are seen in *Table 12* below.

Table 12. Results from the screening of PCDDs and PCDFs at Tagene in 2010.

WHO(1998) TEQ (lower bound), only PCDD/F	pg/l	0.188
WHO(1998) TEQ (upper bound), only PCDD/F	pg/l	4.17
I-TEQ (lower bounds, only PCDD/F)	pg/l	0.295
I-TEQ (upper bounds, only PCDD/F)	pg/l	3.80

A study by Kim Y-J et al (2008), in which leachate from 12 Koreans landfills, all containing MSWIRs where screened for PCDDs and PCDFs[89]. The WHO TEQ was found to be in a range between 0.65-5.88 pg/l with an average value of 2.86 pg/l, which are comparable to the results from Tagene. In this study they also screened for dioxin-like PCBs, which is something that The Canadian EPA also proposes to be done[88]. There are 12 dioxin-like PCBs, also called co-planar PCBs, they are showing similar properties as the PCDDs and PCDFs and have been assigned dioxin TEQ values as well. They were found at an average of 0.18 pg/l WHO TEQ in the study, making their contribution to the total TEQ fairly significant. The other noteworthy thing from this study is that different compounds´ leachability was strongly correlated to organic matter, both suspended and dissolved.

The dioxin-like PCBs are also included in the Stockholm convention and along with them, hexachlorobenzene (HCB) another compound showing dioxin-like properties, also proposed to be screened for alongside the other dioxin-like compounds by The Canadian EPA[88], among others. Hexachlorobenzene was also found on the first priority list generated above. Although HCB may not be used as a pesticide anymore it is produced by the same processes (incomplete combustion) as the PCDF, PCDDs and dioxin-like PCBs[88], making it possible to be present in the leachate from Tagene. However it was not detected when screened for in 2010, but that might be because the limit of detection was 0.1 μg/l which is quite high compared to the PCDDs and PCDFs detected.

There is no official or proposed environmental quality standard for dioxin-like compounds in surface water, groundwater or leachate/wastewater available. However there is an official MCL (maximum contaminant level) for 2,3,7,8-TCDD (the dioxin both TEQ standards are based on) set for drinking water by the US EPA, this concentration being 30 pg/l. However 2,3,7,8-TCDD is a priority pollutant and the MCLG (maximum contaminant level goal) is zero[90].

Consequently, the screening for PCDDs and PCDFs should be continued as well as the screening for HCB, however a lower detection limit (comparable to the PCDD/Fs) might be necessary in the latter case. The 12 dioxin-like PCBs should also be included in the screening to account for as much as possible of the potential dioxin-like activity, once again with detection limits comparable to the PCDD/Fs. Below is a table summarizing the different PCDDs, PCDFs and PCBs of concern and their TEQs (*Table 13*). There are no official TEQ for HCB, but it has been suggested that it could be around 0.0001[91].

Table 13. PCDDs, PCDFs and PCBs of environmental concern and their respective TEQ value

Dioxins	**I-TEQ**	**WHO-TEQ**
2,3,7,8-TCDD	1	1
1,2,3,7,8-PeCDD	0.5	1
1,2,3,4,7,8-HxCDD	0.1	0.1
1,2,3,6,7,8-HxCDD	0.1	0.1
1,2,3,7,8,9-HxCDD	0.1	0.1
1,2,3,4,6,7,8-HpCDD	0.01	0.01
OCDD	0.001	0.001
Furans	**I-TEQ**	**WHO-TEQ**
2,3,7,8-TCDF	0.1	0.1
1,2,3,7,8-PeCDF	0.05	0.05
2,3,4,7,8-PeCDF	0.5	0.5
1,2,3,4,7,8-HxCDF	0.1	0.1
1,2,3,6,7,8-HxCDF	0.1	0.1
1,2,3,7,8,9-HxCDF	0.1	0.1
2,3,4,6,7,8-HxCDF	0.1	0.1
1,2,3,4,6,7,8-HpCDF	0.01	0.01
1,2,3,4,7,8,9-HpCDF	0.01	0.01
OCDF	0.001	0.0001
Dioxin-like PCBs	**I-TEQ**	**WHO-TEQ**
3,4,4',5-TCB (81)	n/a	0.0001
3,3',4,4'-TCB (77)	n/a	0.0001
20 3,3',4,4',5-PeCB (126)	n/a	0.1
3,3',4,4',5,5'-HxCB (169)	n/a	0.01
2,3,3',4,4'-PeCB (105)	n/a	0.0001
2,3,4,4',5-PeCB (114)	n/a	0.0005
2,3',4,4',5-PeCB (118)	n/a	0.0001
2',3,4,4',5-PeCB (123)	n/a	0.0001
2,3,3',4,4',5-HxCB (156)	n/a	0.0005
2,3,3',4,4',5'-HxCB (157)	n/a	0.0005
2,3',4,4',5,5'-HxCB (167)	n/a	0.00001
2,3,3',4,4',5,5'-HpCB (189)	n/a	0.0001

There is however one more factor that can be taken in to account when assessing dioxin-like activity in leachate, polybrominated dibenzofurans (PBDF) and dibenzo-p-dioxins (PBDD), compounds with the exact same structure as the PCDDs and PCDFs only the chlorine atoms are replaced with bromine. They have not been focused on from an environmental stand point much at all, the information is therefore lacking and very few reference values and guidelines are available. Though some studies are available, two in particular by Lin-Chi Wang et al. (2007 and 2010) have presented some relevant facts about the occurrence of PBDFs and PBDDs in MSWIRs: The occurrence of PBDFs and PBDDs where correlated with the occurrence of brominated flame retardants (BFRs). Although PBDD/Fs are partially formed from the incineration of BFRs[86], the major source are probably the already present PBDD/Fs in the waste products, as they are created to varying extent during the synthesis and processing of BFRs[50][86].

There are no officially determined TEQs for the PBDD/Fs, however it has been proposed that the TEQs from the PCDD/Fs should be used due to the similarity of the compounds[92]. Using this method and determining a mass balance over two waste incinerators handling mostly municipal waste it was shown that PBDD/Fs was responsible for ~4% of the total TEQ. Notable about this study was however that while PCDD/Fs partitioned mostly to fly ash, PBDD/Fs partitioned almost exclusively to bottom ash, making the TEQs in bottom comparable[50]:

- PCDD/F in Bottom ash: 0.0138–0.0787 ng I-TEQ/g
- PBDD/F in Bottom ash: 0.00811–0.0522 ng TEQ/g

Even though both bottom ash and fly ash are deposited at Tagene, the fly ash is first stabilized by the Bamberg-method, ensuring lower leachability of pollutants. This might indicate that a significant part of the PCDD/Fs found in the leachate from Tagene are actually from the bottom ash and the leaching from fly ash might not be contributing all that much to total TEQ. If this is the case there is a chance that PBDD/Fs might be leached out in significant concentrations as well. The occurrence of PBDD/Fs is as mentioned above also highly dependent on BFRs, which have not been screened for at Tagene.

Consequently, polybrominated dibenzofurans and dibenzo-p-dioxins might contribute in significant concentrations to the total dioxin-like activity in the leachate, however the research about them are still lacking. First of all BFRs should be analyzed at Tagene, seeing as this is the most significant parameter correlated with the occurrence of PBDD/Fs. But even if the BFR content is high, there are still a few arguments against analyzing for PBDD/Fs: To begin with it might be very expensive, differentiating between the fragmentation of PBDD/Fs and BFRs by GC/MS alone is hard indicating that further separation is needed before the analysis[86]. This combined with the facts that low detection limits (pg/l) might be needed and that very few labs (if any) are offering standardized analyses for PBDD/Fs, does suggest that the screening might be even more expensive then PCDD/Fs, which right now are one of the most costly leachate analyses. The TEQ values are still not experimentally confirmed, adding even more uncertainty to potential findings. However if very high concentrations of BFRs are found and PBDD/Fs are chosen to be screened for, detection limits similar to the PCDD/Fs should be used.

Siloxanes

Siloxanes is a group of organic compounds containing multiple silicon-oxygen bonds, used for a wide range of applications e.g. plastics, food related products, textiles and washing powder[93]. On this priority list three siloxanes are present, hexamethylcyclotrisiloxane (D3), hexamethyldisiloxane and octamethylcyclotetrasiloxane (D4), D4 being the one ranking the highest, it is also the most commonly used siloxane and consequently the one most focused on in terms of environmental impact.

Octamethylcyclotetrasiloxane (D4) is mostly used for the synthesis of different silicone polymers[94]. It is also used to some extent in personal care products (hair and skin care products and antiperspirants[94-95]). It is classified as toxic to aquatic organisms and possibly detrimental for fertility[94-95].

There are many possible ways for D4 to reach the environment, although personal care products as well as some silicone products have the potential of ending up in municipal landfills. Although D4 has been detected in landfill leachates >4 times in concentrations between 1-45 μg/l[74], landfills may not be a very potent source. Personal care products mostly ends up in municipal wastewater, and the industrial processes themselves releases larger amounts than the products produced[94]. Due to the nature of compound (in this case its volatility) it is also a more potent air pollutant than water, for example when released to soil 88.5% of the total mass is expected to diffuse to air[94], leaching from landfills may therefore not be the most concerning pathway for D4.

Canadian EPA concluded in 2008 that D4 may be entering the environment in concentrations that can have adverse longtime effects[94], but based on the statements above resources should probably be devoted to screening for other compounds at Tagene. The same conclusion can be applied to the two other siloxanes as well, since they are of less concern both in terms of potential concentration and individual environmental impact. They are also relatively hard to analyze[77] indicating that it might be expensive, however if cheap methods are developed in the future screening for them can be included in the control program.

Fatty Acids

Hexadecanoic acid (palmitic), pentadecanoic acid and tetradecanoic acid (myristic) are found on the list, they are all very common in landfill leachates[74] and in wastewaters in general. However, they are not deemed pollutants in this case because they are all found in significant concentrations naturally in the environment. Very high concentrations might however have adverse environmental impacts as well as affect the preferred water treatment, the mobility of other substances etc., but since this is not very relevant at Tagene where almost exclusively incombustibles are deposited this will not be studied further.

Phosphorus flame retardants

Two phosphorus flame retardants (PFRs) are found on the priority list, tris(2-chloroethyl) phosphate (TCEP) and tributyl phosphate (TBP). Tris(2-butoxyethyl)phosphate (TBEP) is found close to the end of the full list (place 141) as well. Phosphorus flame retardants are a continuously growing group of flame retardants used in wide range of products, partially because they are to varying extents replacing the more toxic and persistent brominated flame retardants (BFRs)[96]. Even though they have in many cases been deemed safer than their brominated counterparts they are not completely without environmental concern.

The phosphorus flame retardants can be divided into three different groups, inorganic, organic and halogen (almost exclusively chlorine) containing organic, the two latter being of relevance here. The organic PFRs, both with and without halogen atoms, can then be divided in three different subgroups based on their chemical structure, phosphonates, organophosphonate esters or phosphinates[96]. The fact that the PFRs encompasses such a wide range of structures and substituents makes generalizing chemical properties very hard. For example, although a majority of the PFRs are lipophilic the log K_{ow} value does vary from -9.8 to 10.6 (compared to the BFRs 4.3 to 9.9) showing that some of the PFRs are actually highly water soluble. Leaching capabilities does therefore vary significantly between different compounds, another fact contributing to this is that some of the PFRs are chemically bound to their respective product while others are physically bound[96]. A few things can however be noted:

- Chlorinated PFRs are generally more persistent in the environment[96].
- The bioconcentration factor of the non-halogenated PFRs generally increases with increasing molecular mass[96].
- Water solubility generally decreases with increasing molecular mass[96].

Tris(2-chloroethyl)phosphate or TCEP, the first PFR found on the list is an chlorinated organophosphate ester, beyond the use as a flame retardant it is also used a plasticizer or viscosity regulator in numerous polymers e.g. polyurethanes, poly resins and polyacrylates[97-98]. It is classified as persistent and toxic but does not fulfill the PBT-criteria due to the fact that it is only marginally bioaccumulative[98], TCEP has also been classified as cancerogenous and is included on the REACH authorization list as an SVHC based on this[58].

The building industry (roofing, insulation, paints etc) have historically been the largest user of TCEP, accounting for ~80% of the use in the EU, other products that might contain TCEP includes furniture, textile and carpets. The manufacturing of cars, railways and aircrafts have also reported use of TCEP[97]. However since the early 2000s no TCEP has been produced in the EU[97], although it is still imported. In 2008 for example 261.3 tones was used in Norway, 198 tones in Finland and 0.1 tones in Denmark (nothing was used in Sweden)[96]. It is to some extent also unintentionally created as an impurity in the manufacturing of other flame retardants[98].

Tris(2-chloroethyl)phosphate is not chemically bound to the polymer and diffusion from the product in question is therefore possible, this coupled with the fact that TCEP is highly water soluble (7820 mg/l at 20 ºC) makes the potential of leaching significant [97-100]. Leaching from landfills has been identified as one of the most potent pathways for TCEP to enter the environment, and it has been detected in numerous leachates[99]. According to the SWECO report it has been found in concentrations ranging from 2-23 µg/l (n=3)[74]. When in water TCEP is expected to stay there, conventional wastewater treatment plants have proven ineffective and up to 99% of total amount is expected to pass through the treatment in the water phase[98][41].

Since TCEP is of known concern and now included on the REACH authorization list, a closely related PFR, tris(2-chloro-1-methylethyl) phosphate (TCPP) have in many cases been used as a replacement chemical, however it shares many of TCEPs chemical properties and might therefore be of similar environmental concern, it is also proven to almost completely pass through water treatment[41]. In 2008, 132 tons of TCPP was used in Sweden (Norway: 42.2 tones, Denmark: 177 tones, Finland: 16429 tones)[96].

Tributyl phosphate, phosphoric acid tributyl ester or simply TBP is the second PFR found on the list, it is an alkyl phosphate ester mostly used as a flame retardant component of hydraulic fluid (primarily for aircrafts) as well as a solvent for purification of rare earth metals from ores. It is also to varying extents used as a flame retardant and plasticizer in some polymers[101]. Potential environmental releases are mainly from the industry to different water matrices (based on information from Canada)[101]. Limited data is available on the environmental effects but predictions state that TBP is not persistent or bioaccumulative and not significantly toxic to aquatic organisms in concentrations <1mg/l[96][101]. Tributyl phosphate have nonetheless been found in leachate before, according to the SWECO report >5 times in concentrations between 5-153 μg/l.

The last PFR found on the full list is tris(2-butoxyethyl)phosphate (TBEP), it has similar chemical properties and applications as TBP. However it has been identified by REVAQ as a substances of concern due to fact that it is expected to bind to sludge in significant concentrations (13%) during water treatment[77].

Screening for PFRs are currently not included in the control program at Tagene, however as there are potential sources deposited, construction material, demolition rubble, SLF and other incombustibles, screening might be warranted. In 2006 PFRs stood for 20% of total flame retardant use in Europe, BFRs for 10%[96], since this is expected to shift even more towards the PFRs, chances of finding them at Tagene is rather significant and will continue to be. Exactly which PFRs that should be focused on is hard to say because the chemical properties varies between each individual compound and along with it the leaching potential, applications and environmental impact. Not enough research have gone in to this and no clear priority list is available. However TCEP, TCPP (potent environmental pollutants historically used in large quantities and continues to be to varying extent, hard to remove from water) and TBEP (Identified by REVAQ) should probably be included. Detection limits are also hard to purpose since no reference concentrations are available, however by what concentrations have been previously found in leachate there does not seem to be a need for detection limits in the low ng/l range, rather 0.1-1.0 μg/l.

One last thing to note is that few analytical laboratories seem to be offering standardized analyses for PFRs, this might be due to that they have not been focused on very much from an environmental perspective yet, they are still somewhat overshadowed by BFRs. Maybe partially because analyzing them also may be somewhat difficult. In a study done by Brandsma et al. (2013), the coefficient of variation between most tests was shown to be 9-25%, in a few cases even higher, this based on 14 different labs in 10 different countries. However this was concluded to be due to problems with blanks and not due to matrix problems, which might suggest that the complex matrix of landfill leachates might not be a problem in itself, if the methods and analytic routines are improved which according to the study is possible[102].

Individual compounds

Dicyclohexylamine

Dicyclohexylamine (DCHA) is an amine with numerous uses, it can be seen as an industrial base chemical and it is the most commonly detected amine in the Swedish environment, it has been found in many environmental matrices as well as in landfill leachate[103]. In a screening by the Swedish EPA (2006-2007) it was found in 2/3 leachate samples (no concentrations were specified)[103] DCHA was found in leachate from 2 landfills in concentrations between 84-100 ng/l and 36-71 ng/l respectively[104]. In the report by SWECO it is found in 3 samples in concentrations between 0.5-19 μg/l[74].

It is classified as very toxic to the aquatic environment and may cause long term adverse effects[103]. Dicyclohexylamine is however relatively easily broken down[103-104] and is not deemed persistent, but possibly bio accumulative.

The most common source of DCHA is traffic, closely followed by point sources such as petroleum and plastic industries [103-104]. Dicyclohexylamine is transported through the air (the most important media for transportation of DCHA [103-104]) and is to some extent deposited in the top soil in gradient concentrations around these sources, consequently stormwater from these areas are the wastewaters with the highest concentrations of DCHA. In the screening study performed by Brorström-Lundén et al. (2011), the stormwater concentrations were more than 10 times that of the leachates, however the number of samples were rather small (storm water n=4 and leachate n=2)[104].

The PNEC (predicted no effect concentration) of DCHA is 0.16 μg/l when a safety factor of 100 is used, it is not impossible for concentrations above this to found in leachate. However there are no clear and potent sources of DCHA deposited at Tagene and since it is a pollutant strongly associated with traffic, industry and other urban activates coupled with the fact that it mostly travels through air, screening for it may not be warranted, it should at least not be prioritized. Another argument against analyzing DCHA is that very few labs (if any) are offering standardized analyses for the compounds, however if they start to do so in the future screening for DCHA can be included, reasoning about detection limits is however hard at this moment.

Diphenylamine

Diphenylamine is an aromatic compound, it is deemed "very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic enivronment" as well as "Dangerous to the environment"[76][105]. It is mainly used as an intermediate for production of other chemicals, including; antioxidants for rubber and lubricants, antiozonants for rubber, stabilizers for plastics and dyestuffs, only minor amounts are used as additives in final products[105]. According to the Swedish Chemical Agency (Kemikalieinspektionen) diphenylamine is present in 152 products in Sweden, though none of these are commercially available[106]. It is however also used to a minor extent as an additive in storage acid which some fruits are treated with.

Releases of diphenylamine to the environment are expected to mostly be from industrial processes, and even though it has been found in leachate before (2-17 µg/l, n>3)[74], the investigated landfills, unlike Tagene, all contained industrial waste. Diphenylamine has not been screened for at Tagene before, the risk of finding the compound in the leachate is still present but there are no obvious sources deposited, except for maybe SLF. However no scientific data is available to back up that this is indeed a potent source.

Just as with DCHA discussed in the chapter above, it is hard to conclude if screening is warranted. It should therefore not be prioritized but if standardized analysis are available it can be included, detection limits is however tough to purpose due to lack of data.

Chlorobenzene

Chlorobenzene also known as monochlorobenzene is a compound mainly used for synthesis of other organic substances, historically pesticides have been an important group although this has decreased due to the fact that many of them are now prohibited e.g. DDT, other chemical groups synthesized include pharmaceuticals as well as solvents[107].

Chlorobenzene is mostly released to the environment through volatilization, for example in Japan 514 tons are annually (2007) released to the air, compared to the 29 tons to water[107]. Although chlorobenzene is water soluble (500 mg/l) it is expected to slowly diffuse to air if allowed to reach the aquatic environment. However, while in the aquatic environment it has a potential (albeit low) of bioaccumulating in some organisms and it shows some direct toxicity to them as well, it is therefore labeled "Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment"[76][107].

Although landfills are not considered major sources of chlorobenzene[107] it is still commonly found in landfill leachate. According to the SWECO report it has been detected >25 time in concentration ranges of 0.1-62 µg/l[74], and in the study by Avfall Sverige it was detected in 2/4 screened landfills in concentrations between 0.11-0.4 µg/l[79].

Chlorobenzene has been screened for in the leachate from Tagene annually the last 5 years with a detection limit of 1 µg/l, but nothing has been detected thus far. Since there are no official or proposed environmental quality standards for chlorobenzene in water and landfills are not of major concern in this case, there is no need to change anything in the control program with regards to chlorobenzene.

Compounds which no conclusions can be drawn about presently

Four compounds are left on the list, tetrahydrothiophene, biphenyl, 3,4-bisisopropylphenol and N,N-dibutylformamide. Not enough relevant information about the environmental impacts, use over the past 10-15 years, leaching potential etc., of these compounds are available to draw any conclusions, they will therefore not be discussed.

6.2.3 Pollutants chosen independent of ranking on either list

Pentachlorophenol

Pentachlorophenol (PCP) has historically primarily been used as a pesticide and as a wood preservative[108][109], nowadays it is however mostly created unintentionally in different incineration and combustion processes since it is highly regulated commercially and in the industry[109]. Pentachlorophenol is being discussed for inclusion in the Stockholm convention for persistent organic pollutants as it does fulfill the POP-criteria[45], it is deemed highly toxic for the aquatic environment[109] as well as for humans[108], it is also a prioritized pollutant by REVAQ according their preliminary study[77].

Due to the polarity of the hydroxyl group PCP is relatively mobile in water alone and therefore shows potential of being leached out of landfills if present in them. In the SWECO report it has been found in landfill leachates 5 times in concentrations between 0.03-3.7 µg/l[74] and in the report by Avfall Sverige it was found in one of five screened landfills in a concentration of 0.58 µg/l[79]. Screening for PCP has been a part of the control program at Tagene since 2008, it has been found every year (except for 2010 when a detection limit of 1.0 µg/l was used instead of 0.01 µg/l) in concentrations between 0.011-0.03 µg/l (See Appendix I for complete results). The primary source is likely the MSWIRs and since the concentration has been relatively stable for the past 5 years it is not expected to change dramatically in the future either. There is consequently no need to change anything in the control program with regards to the chlorophenols, the detection limit used (0.01 μg/l) should also be sufficient, even without accounting for dilution it is still more than one order of magnitude lower than the EU environmental quality standard for surface waters of 0.4 μg/l[32].

Aliphatics C_{16}-C_{35}

Aliphatic hydrocarbons, i.e. noncyclic compounds containing only carbon and hydrogen, have a wide range of sources, both natural and anthropogenic. Some of the natural sources include deposits (crude oil, gas etc.), bacteria, planktons, insects as well as terrestrial plants. The anthropogenic sources are often loosely defined as industry, urbanization, transport etc due to the fact that aliphatics are common in petroleum based products, e.g. different fuels[110][111]. As a results aliphatics are widely spread in the environment and with landfills being a final deposition of urban waste, they likely contains at least some aliphatics.

Carbon chain lengths can be up to 64 carbons long (C_{64}) however these very large molecules are rare and not focused on from and environmental perspective. The C_{16}-C_{35} are usually defined as the larger class and the upper limit of screening. Both even and odd number of carbons are possible and generally it can be said that aliphatics with an even number of carbons are from anthropogenic sources while the odd numbers are from natural sources, however there are many exceptions to this[111].

Aliphatic hydrocarbons (C_{16}-C_{35}) are deemed priority pollutants by REVAQ according to their preliminary study[77], this is probably based on nonpolar nature of the compounds and therefore high potential to bind to sludge, the average water solubility of C_{16}-C_{35} is 0.0000025 mg/l and the Log K_{ow} is 8.8[112], as well as the fact that they are fairly common.

In a the Study by Avfall Sverige, C_{16}-C_{35} aliphatics where found in all 4 landfills screened in concentrations between 32-740 μg/l[79]. At Tagene they have been screened for once (2010), however nothing was found when using a detection limit of 0.25 μg/l (no aliphatics were found at all). This is rather surprising but can partially be explained by the low water solubility and high Log K_{ow} of the aliphatics, which indicates that organic and suspended matter would be needed for them to be efficiently leached out, none of which occurs at high concentrations at Tagene. Consequently, the chance of them being occurring inside the landfill is still reasonably high. However, one of the landfills in the study leaching out 78 μg/l of C_{16}-C_{35} aliphatics has similar TOC and suspended matter values as Tagene, contradicting this statement somewhat, but the general idea still applies. For example the landfill leaching the most aliphatics (740 μg/l) has a TOC value ten times as high as Tagene and a suspended matter value five times higher.

Screening for these aliphatics should be continued at Tagene, the fact that one analysis three years ago did not detect any aliphatics is not evidence enough to conclude that such a common group of pollutants are not present at least to some extent in the leachate. What detection limit that should be used is hard to conclude seeing as no environmental quality standards are available for water, but based on the findings in other landfills the limit of 0.25 μg/l should be sufficiently low.

Bisphenol A

Phenol, 4,4' -(1-methylethylidene)bis-, bisphenol A or BPA is a compound commonly used in plastics, rubbers and other polymers, many of which are common in commercial products, it is also to some extent used in thermo paper as receipts, tickets etc[113-115]. In recent years it has been a highly discussed chemical globally. It has been identified as toxic towards reproduction and development of many organisms, including humans. It is also endocrine disrupting well as harmful towards the environment, especially the aquatic environment [113-115]. Several low-dose studies has shown probable signs of these adverse effects as well, indicating that the amounts entering the environment today may actually be of concern. Though many of the studies have been criticized by scientists because of low reproducibility, methods used etc., the fact that numerous independent studies have shown the same results have made a lot of governments around the world react [113-114].

While in the environment BPA is expected to partition mainly to water, closely followed by soil. It is deemed persistent in soil because biodegradation which is dependent on oxygen is the main pathway for degradation and soil is typically anaerobic, in water the half-life is not expected to be long enough as to classify BPA as persistent. Bisphenol A is also showing a low to moderate capability of bioaccumulation[115]. Despite this no proposed or official environmental quality standard is available for BPA in water.

During water treatment BPA is expected to partition both to the sludge as well as to the water and pass through the treatment, it is also expected to be partially degraded, however to what extent is dependent on treatment techniques[115]. According to REVAQ it is not expected to bind to sludge in significant concentrations, this is however based on calculations and not empirical data[77].

Bisphenol A is commonly found in landfill leachate; in the screening by SWECO it was found 3 times in concentrations between 4-136 μg/l[74], in a screening of 38 Japanese landfills by Kurata et al. (2007), BPA was found in all 38 landfills in concentrations between 0.009-3600 μg/l (average: 230 μg/l, median: 1.7 μg/l). It was also mentioned in this study that this wide range of concentrations, five-six orders of magnitude, from different landfills have been seen numerous times, indicating that it is hard to predict concentrations of BPA in landfill leachates. Despite this, a correlation between the deposition of MSWIRs, particularly bottom ash, and the occurrence of BPA was found. This is significant since large quantities of bottom ash is deposited at Tagene[73].

Another comprehensive study on the leaching of BPA done by Urase and Miyashita in 2002 reviewing data from more 45 landfills presented more relevant information[116]:

- Concentrations between 26-8400 µg/l was found in leachate from municipal solid waste landfills.
- A slight correlation between TOC and leaching of BPA was found, however a major part of the leached BPA was dissolved, indicating that water alone can leach out the pollutant.
- To some extent countering the finding by Kurata, ash rich landfills leached out slightly less BPA than sites containing large amount of organics. However the sites containing more organics showed decreasing amounts of BPA in the leachate with time, while ash rich sites showed increasing amounts of BPA in the leachate with time (Tagene is deemed very old landfill in this case).

All this discussed above makes the case that BPA is likely present in the leachate from Tagene, this was confirmed by Kalmykova et al. (2012), in a study in which screening of leachate from Tagene (L2) was included. Bisphenol A was found in a concentration of 107 µg/l[85], which is significantly higher than the concentration of any other organic pollutant previously detected at Tagene. While no environmental quality standards are available it can still be assumed by just the chemical properties of BPA that this concentration is significant and may impact the environment adversely. Bisphenol A should therefore be added to the control program and screened for annually.

Also noteworthy is that the complex matrix of landfill leachates might present a problem when analyzing BPA concentrations. Two studies Deng et al. (2006) and Wang et al. (2006) in which methods for BPA detection in landfill leachates was developed showed detection limits of 18 µg/l, using a fluorescence based method[117] respectively 12.8 µg/l using SPME (solid phase microextraction)/HPLC (high performance liquid chromatography)[118]. Detection limits similar to these are still more than sufficient if the BPA concentration does not change drastically.

6.2.4 Bulk organic matter in the leachate

As mentioned, the properties of the organic matter in the leachate can heavily affect the leaching characteristics of organic pollutants[11-13] . There are a few different ways to analyze the bulk organic matter, the ones currently applied to the leachate at Tagene are TOC (total organic carbon), DOC (dissolved organic carbon), BOD_7 (biochemical oxygen demand) and suspended matter though not only organics. While giving a good view of the amounts of organic matter and in which phase it is mostly present, dissolved, colloidal or suspended, it does not say very much about the identity of the bulk organic matter, except for BOD_7 which partially describes the degradability. Partially because the BOD_7 only accounts for biodegradability, since it can also be affected by toxic substances which can potentially be present in landfill leachate, the value by itself does actually not give all that useful information[20-21]. Analyzing BOD is usually combined with analyzing COD (chemical oxygen demand), as it degrades all degradable organics (and inorganics) with an oxidizing agent, usually potassium dichromate when dealing with landfill leachate. The ratio between BOD/COD gives a better picture of the total degradability, it is also a good references value when comparing to other leachates or waters in general. A ratio around 0.3 is for example common in sewage waters (Stockholm 1990-1991)[119]. For landfills the ratio are usually lower, in a study by Avfall Sverige the COD/BOD ratio of the leachate from 6 Swedish landfills was between 0.01-0.11, average 0.06[79]. However degradability is only one parameter and it is not directly linked to leachability of pollutants. The COD_{cr} was actually included in the control program earlier, but due to it having been discussed for prohibition it was removed, this discussion is still going and including COD_{cr} again only to remove it later might therefore be a waste of resources. Also noteworthy is that the COD and TOC analyses can be sensitive to chloride in concentrations above 1000 mg/l[119], the chloride concentrations in the leachate from Tagene have for the past 3 years (2010-2012) been 4400 mg/l, 7000 mg/l and 6100 mg/l respectively. Values obtained for TOC might therefore have been affected by this and analyzing COD might not be ideal. However there are ways to deal with this and since the TOC values have been reported to a have a measurement uncertainty of just 10%, salt should not be a problem, it is however impossible to guarantee this without knowing how the lab in question dealt with this problem, consequently it is also impossible to conclude it the values obtained were too high or low, if they were indeed affected.

During the screenings of the past 3 years at Tagene, the TOC and DOC values have been very stable and relatively low, this has without a doubt contributed to the fact that most pollutants screened for have been leached out in concentrations under the detection limit (if they were leached out at all). In 2009 when the DOC and TOC values spiked, some PAHs and phthalates were detected, this was repeated once again in the study by Kalmykova et al. (2012), high TOC and DOC concentrations resulted in leaching of PAHs and phthalates[85].

As seen in the graph below (*Figure 9*) where the DOC and TOC concentrations for the past years have been plotted, there is no pattern emerging other than that DOC and TOC concentrations are related to each other. There are clear spikes and dips in concentration and since the two parameters are tested 4 times each year it is not unreasonable to think that some high spikes might have been missed (as seen by the study by Kalmykova et al. mentioned above), as well as some low dips. It is in fact somewhat unfortunate that the DOC and TOC concentrations have been so similar during each screening as it might not have given a good indication of what pollutants and in what concentrations that were actually leached out during other parts of the year. However, since there is no real pattern to the concentrations (weather and precipitation are probably parameters affecting them) it is hard to predict when sampling might be the most beneficial.

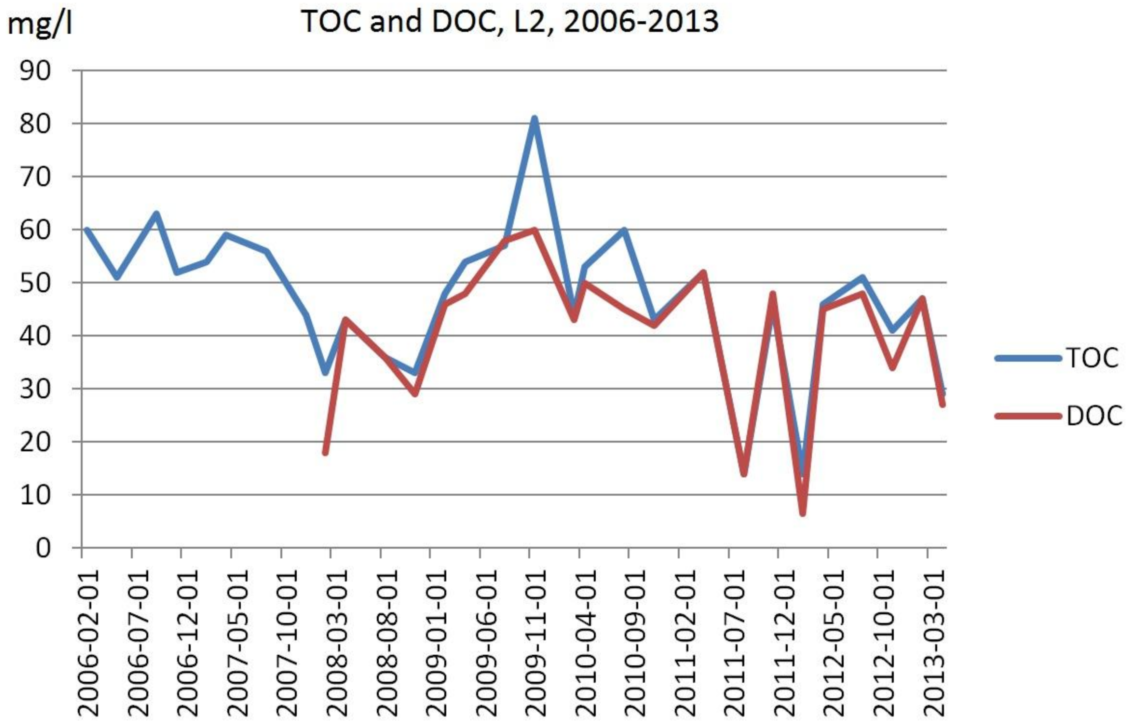


Figure 9. TOC and DOC concentrations in the leachate from Tagene, 2006-2013. (DOC has not been analyzed before 2008).

A possible solution to this can be to either analyze the TOC and DOC concentrations more frequently to establish a more reliable annual average value and see how close this is to concentrations during the past screenings, if close there might not be a problem at all and the values obtained might be representative of the annual leaching. However a lot of information about what pollutants that are actually present in the landfill could probably be obtained by running a comprehensive screening during a high spike in TOC and DOC concentrations. This does however require that TOC and DOC can be tested before the decision to run the other analyses are made, requiring either sample preservation or onsite testing of DOC and/or TOC. Consequently, running a special program during one of the dips in DOC and TOC could result in many pollutants being under the detection limit, not giving any relevant information at all, and not being representative of the average leaching. The variation of TOC and DOC during the year might also have to be factored in when calculating annual leaching of pollutants to ensure a more correct value, more data is however needed in order to apply this in practice.

Humic index

In recent years the fractioning and characterizing of organic matter in leachates and other waste waters, based on molecular weight, hydrophobicity, UV absorbance or fluorescence have moved from something that was exclusively done in research to something that is now approaching a legitimate and useful part of analyzing organics in water[120]. There are however problems with actually applying this, the fact that no standardized analysis exists and that a significant amount of research is currently going in to this field means many different techniques and analytical instrumentation are being used.

The most impressive advances have come through the use of Fourier-transform ion cyclotron (FT-ICR) mass spectrometry (MS) and homo and hetero-correlated multidimensional nuclear magnetic resonance (NMR) spectroscopy[121]. However while these instruments can provide very detailed information about the structure of the organic molecules, they do require that the different fractions of organic matter are pre-isolated[121-123], a quite labor intensive process which consequently can be assumed to be expensive. There is also an inherent problem with the larger organic molecules (humic and fulvic matter) and their supramolecular associations, since there is no clearly defined structure for them and their ionization potential can vary, techniques like MS, while still very useful for research, are resulting in irreproducible results[121], making them unsuited for annual analyses of leachates, as the values obtained might not be comparable.

These advanced methods used for research would consequently be hard to apply at Tagene, they are not standardized and therefore not widely performed by labs, they are expected to be expensive and the actual impact of the data obtained can be hard to assess without extensive knowledge of the subject. However they may very well be standardized and widely used in the future based on their potential.

For characterization of organic matter that can be applied today one of the most promising parameters to assess might be HIX (Humification index). The humification index in itself is not new, however it has never been standardized, it is a value obtained by dividing humic-like matter by non humic matter or total organic matter. While HIX can still be measured through manually fractioning the different organic fractions through a number of steps, three studies in particular have shown great results of measuring it with UV/fluorescence[123-124][126].

It is generally accepted that humic-like substances are presented by fluorescent emission peaks >380 nm and protein-like substances and other smaller organics by emission peaks <380 nm[125]. Using this, the florescence intensities of wavelength above 380 nm divided by intensities below can be used to calculate HIX. Kalbitz et al. (2000), showed there was a good correlation (>0.88) between 390/355 nm, 400/360 nm, 470/360 nm, 470/400 nm as well as with the value obtained from the fractioning method[123]. Noteworthy here is that the only sample preparation done was dilution. This was done because there is a correlation between increasing DOC/TOC and increasing HIX (the inner filtration effect) the DOC concentration must therefore be the same in each sample[121][123][126]. This dilution can however be rather hard to accurately do routinely. Tsutomu Ohno (2002) proposed a solution for this, since the inner filtration effect is proportional to concentration, diluting three or four samples to more arbitrary concentrations and extrapolating the HIX to 100% transmittance could be done. This would also result in a more standardized test with values that are comparable between studies. He also showed that a better result was obtained by using a region of emissions rather than specific wavelength and that a statistically better result was obtained by dividing by the total emission intensity. Consequently, by diluting 3-4 samples and scanning them in the emission ranges 300→345 nm and 435→480 nm (excitation 245 nm), calculating the HIX (emission intensity at 435→480 nm divided by emission intensity at 300→345 + 435→480 nm) for each sample and extrapolating the HIX value to 100% transmittance at 245 nm, a value for the relative amount of humic matter can be obtained[126].

Though this method have been tested on different water matrices during the three studies, leachate have not been studied. However using this method on leachate is probably possible, one step of sample preparation might however be needed i.e. the removal of salts, since they have been shown to affect the fluorescent properties of dissolved organic matter[121]. Although in a study by Huguet et al. (2009), this technique was used successfully on estuarine waters with varying salinity, indicating that there are acceptable salt concentrations, though not defined[127]. Ultra filtration or reverse osmosis are however recommended for the removal of salt if necessary and since the HIX is extrapolated, the results should be unaffected by any change is concentration during this step.

However this is just one example of how HIX can be determined, since the concept really is not new some labs might have methods for it (or ideas) or possibly a method for determining a similar parameter. As long as the same method is applied each time and it accounts for differences in DOC/TOC concentrations as well as compounds present in high concentrations with the ability to affect the analysis, e.g. salts, the results should be useful.

Just one HIX value (or similar parameter) by itself is however hard to get any real information out of, since humic matter is not a pollutant and there are very few reference values. Although a few minor conclusions can be drawn, high HIX value indicates that the organic particles in the leachate are larger which can for example give some insight in preferred treatment (increasing the efficiency of e.g. filters). The main advantage is gained by monitoring HIX during a period of time (years), since a change in HIX is one of the main things along with a change in DOC that can affect the leaching of a large number of organic pollutants. The effect of final cover materials for example is one thing that might affect the HIX in some way, though research about this is lacking.

6.2.5 Suggestion of organic pollutants to be included in the control program and characterization of the Tagene landfill leachates

It should be noted that due to time constraints and the sheer number of pollutants the pollutants suggested for characterization are not the only ones that might be of concern. They are however some of the most concerning and highly prioritized pollutants nowadays and they have been evaluated specifically with consideration to the Tagene landfill site. *Table 14*, summarizes the results discussed above.

Table 14. Suggestion of organic pollutants for the control program and characterization of the Tagene landfill leachate.

Pollutant/Group	Specific substances	Detection limit
Brominated flame retardants (BFRs)	BDE-congeners 28, 47, 99, 100, 153, 154, 209 TBBPA HBCDD	0.1-1 ng/l
Even lower detection limit might be warranted for the BDE-congeners, however it is unclear if it is possible in landfill leachates. Including more congeners can be done as well ideally the larger ones, these 7 listed above should however be prioritized.		
Pesticides	-	0.01-0.05 µg/l
Screening for the most common pesticides should be prioritized i.e. choosing premade analytical packages from labs should be sufficient, as evaluating and picking individual pesticides is both time consuming and probably more expensive.		
Perfluoroalkyl and polyfluoroalkyl subastances (PFASs)	PFOS, PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFDoDA, PFTDA, PFBS, PFHxS, PFDS, PFOS-F and a few precursors if possible.	1-25 ng/l
Prioritizing and analyzing precursors is hard due to lack of scientific data, the ones that can actually be analyzed by labs should therefore be prioritized. If onsite treatment is implemented at Tagene, a mass balance of PFOS and PFOA can also give insight in precursor concentration.		

<table>
<tr><td>Phthalates</td><td>DMP, DEP, DBP, BBP, DEHP, DOP, DINP, DIDP and DIBP</td><td>0.1-1 µg/l</td></tr>
<tr><td colspan="3">Some of the phthalates e.g. DEHP usually have the detection limit 1 µg/l instead of 0.1, as it is excepted to occur in higher concentrations relative the other ones. Most phthalates should however have the detection limit 0.1 µg/l.</td></tr>
<tr><td rowspan="2">Alkylphenols and alkylphenol etoxylates (APs and APEs)</td><td>Nonylphenol and a few nonylphenol etoxylates</td><td>0.1 µg/l</td></tr>
<tr><td>Octylphenol and a few octylphenol etoxylates</td><td>0.01 µg/l</td></tr>
<tr><td colspan="3">Focusing on the etoxylates the labs can detect should be sufficient until more data is available in order to prioritize. Other APs like butylphenol and pentylphenol can be included but are not as highly prioritized environmentally.</td></tr>
<tr><td>Polycyclic aromatic hydrocarbons (PAHs) and oxy-PAHs.</td><td>US-EPA PAH 16 and if possible a few oxy-PAHs</td><td>0.01 µg/l</td></tr>
<tr><td colspan="3">No clear priority can be determined for the oxy-PAHs, the detection limit needed can however be assumed to be similar, focusing on the oxy-PHAs which can be detected in that concentrations is therefore prioritized.</td></tr>
<tr><td>Dibenzofurans, dibenzo-p-dioxins and other dioxin-like pollutants</td><td>The dioxins and furans already screened for (Table 13 page 42) plus the PCBs listed in that same table as well as Hexachlorobenzene (HCB).</td><td>0.5-2 pg/l</td></tr>
<tr><td colspan="3">The detection limit for HCB can be a little higher, it should however still be comparable to the dioxin levels, the detection limit (100 000 pg/l) used in 2010 is not. Analytical methods may however be a problem here and proposing a limit without knowing what the individual labs are capable of is hard.
Analyzing for PBDD/Fs might be warranted as well, this is however dependent on potential findings of BFRs and there are a few inherent problems with analyzing them, see the discussion on page 43.</td></tr>
<tr><td>Phosphorus flame retardants (PFRs)</td><td>TCEP, TCPP and TBEP are prioritized but additional ones can be screened for as well.</td><td>0.1-1 µg/l</td></tr>
<tr><td colspan="3">Analyzing them have been and to some extent still is a problem, however this is not due to the leachate matrix and reliable methods are available.</td></tr>
<tr><td>Bisphenol A (BPA)</td><td>BPA</td><td>-</td></tr>
<tr><td colspan="3">Low detection limits in landfill leachate can be a problem, but due to the high concentrations found at Tagene even detection limits of 10-15 µg/l can be sufficient.</td></tr>
<tr><td>Aliphatics</td><td>C_{16}-C_{35}</td><td>0.25 µg/l</td></tr>
<tr><td colspan="3">Other molecular weight ranges can be included as well, but low concentrations seem to be found at Tagene and apart from by REVAQ, aliphatics are not highly prioritized water pollutants.</td></tr>
</table>

Siloxanes	-	-
Not prioritized at this moment, if cheaper more reliable methods are developed screening can however be performed. Detection limits are difficult to purpose as well, but only based on what has been previously detected, 1.0 µg/l can suffice.		
Dicyclohexylamine (DCHA)	DCHA	-
Not prioritized		
Diphenylamine	Diphenylamine	-
Not prioritized		
Fatty Acids	Hexadecanoic, pentadecanoic and tetradecanoic acid.	-
Notprioritized due significant concentrations naturally found in the environment.		
Chlorobenzene	Chlorobenzene/monochlorobenzene	1.0 µg/l
Currently included in the control program with the detection limit 1.0 µg/l.		
Pentachlorophenol	PCP	0.01 µg/l
Currently included in the control program with the detection limit 0.01 µg/l.		

7 Conclusions

- Screening of brominated and phosphorus flame retardants, alkylphenols and alkylphenol etoxylates, oxygenated polycyclic aromatic hydrocarbons, dioxin-like pollutants and bisphenol A should be included in the control program.

- Commonly used pesticides, perfluoroalkyl and polyfluoroalkyl subastances, phthalates, polycyclic aromatic hydrocarbons and dioxins, pentachlorophenol and chlorobenzene should be continued to be screened for at Tagene landfill site. Fluoroalkyl precursors and phthalates commonly used in the industry today should however be added to the control program.

- Hexachlorobenzene which is currently screened for requires a lower detection limit.

- Including COD (if possible COD_{cr}) in the control program at Tagene will give better view of the degradability of the organics (and inorganics) as well as a good value for comparison with other leachates as the BOD/COD value is very widely used. However since it is on the way of being prohibited, including it only to remove it later might be a waste of resources.

- The DOC and TOC concentrations need to be studied more and possibly analyzed before a characterization is performed. Knowing the DOC and TOC before a characterization is performed can ensure a higher chance of relevant data being obtained. Obtaining a better annual average of the DOC and TOC and factoring it in to the calculations of annual pollutant leaching is also something that can be done.

- Some type of analysis to determine humic content e.g. HIX, can provide a good "base-line" and might be a good indicator in the future if anything changes, however since this is not yet standardized there are a few inherent problems with actually doing this, it is however still possible. It should at least be kept in mind since this is sure to sooner or later be more common part of waste water characterization.

8 Questions for future research

Treating and analyzing landfill leachate is a non-ending pursuit, it can always be improved and will have to be since the composition of the leachate is ever changing. This very project could however be continued by evaluating more compounds on the compiled priority list (Appendix II), as these are that most concerning environmental pollutants today.

There are also some more specific questions that have come up during this project that needs to be answered or at least better understood:

- Which are the most important precursors of PFOS and PFOA (and PFASs in general) and how do they behave in the environment and during water treatment?
- Which are the most important alkylphenol etoxylates and how do they behave in the environment and during water treatment?
- Is there a good method for onsite analyzing of DOC and TOC?
- Is there a better parameter for relative humification or a better way of determining the HIX?
- As mentioned above, evaluation of single compounds can always be improved and more compounds can always be chosen. However at Tagene the environmental impacts and possible presence of PBDD/Fs are especially interesting since large amounts of incineration residues are deposited and the BFR content is unknown.

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10 Appendix I

Tagene avfallsanläggning - Lakvattenflöde L2
Organiska föroreningar
Analyser från Eurofins (Ospecifierat labb för 2012**)

Provtagningsdatum		**2008-11-28**	**2009-11-19**	**2010-11-27***	**2011-11-23**	**2012-11-30**	**2012****
*Karakterisering av lakvatten, utökat anatal analyser **Analyser från forskningsartikeln: *Kalmykova Y, Björklund K, Strömvall A-M, Blom L, Partitioning of polycyclic aromatic hydrocarbons, alkylphenols, bisphenol A and phthalates in landfill leachates and stormwater, Water Research, 2013; 47; 1317-1328*							
Detekterat	🟥						
Ej detekterat, under rapporteringsgränsvärde	🟩						
Analys ej utförd	▨						
Vattenflöde	**Enhet**						
Nederbörd (totalt, under aktuellt år)	mm	996	855	849	1230		
Lakvatten (totalt, under aktuellt år)	m^3	153 789	112 689	155 980	226 713		
Basanalyser	**Enhet**						
Vattentemeperatur vid provtagning	°C			16,2	18,7	4,8	
Turbiditet	FNU	1,8	400	3,1	2,5	280	
Suspenderade ämnen	mg/l	10	77	9,5	12	13	
Färgtal	mgPt/l	80	480	180	120	130	
pH	pH	8,3	8,2	8,1	8,2	8,1	
Organiska summametoder	**Enhet**						
TOC	mg/l	33	81	43	46	41	107
DOC	mg/l	29	60	42	48	34	100
BOD7	mg/l			5	6	4	
EOX	µg/l			<100	<1,0	<100	
Syre	**Enhet**						
Syre	mg/l	3,6	5,7	5,1	5,4	6	
Volatile organic compounds (EPA)	**Enhet**						
1,1,1,2-tetrakloretan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,1,1-trikloretan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,1,2-trikloretan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	

1,1,2-trikloreten	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,1-dikloretan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,1-dikloreten	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,1-diklorpropen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,2,3-triklorbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,2,3-triklorpropan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,2,4-triklorbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,2,4-trimetylbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,2-dibrometan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,2-diklorbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,2-dikloretan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,2-diklorpropan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,3,5-trimetylbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,3-diklorbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,3-diklorpropan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,3-diklorpropen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
1,4-diklorbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
2,2-diklorpropan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
2-klortoluen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
4-klortoluen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Bensen	µg/l	<0,2	<0,2	<0,2	<0,2	<0,2	
Brombensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Bromdiklormetan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Bromklormetan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Cis-1,2-dikloreten	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Dibromklormetan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Dibrommetan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Diklormetan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Etylbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Fluortriklormetan (CFC-11)	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Hexaklorbutadien (HCBD)	µg/l	<1,0	<1,0	<0,1	<1,0	<1,0	
Isopropylbensen	µg/l	<1,0	<1,0	<0,1	<1,0	<1,0	
Klorbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
m/p-xylen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Naftalen (Detektionsgräns från PAH-16)	µg/l	0,02	0,02	<0,1	<0,02	<0,02	
n-butylbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
o-xylen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
p-isopropyltoluen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Propylbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
sec-butylbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
tert-butylbensen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Tetrakloreten	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Tetraklormetan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Toluen	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Tribrommetan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	
Triklormetan	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	

PAH-16	**Enhet**						
Benzo(a)antracen	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	<0,01
Krysen	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	<0,01
Benzo(b)fluoranten	µg/l	<0,02	<0,02	<0,1			
Benzo(k)fluoranten	µg/l	<0,02	<0,02				
Benzo(b,k)fluoranten	µg/l			<0,1	<0,04	<0,04	<0,01
Benzo(a)pyren	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	<0,01
Indeno(1,2,3,c,d)pyren	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	<0,01
Dibenzo(a,h)antracen	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	<0,01
Naftalen	µg/l	0,02	0,02	<0,1	<0,02	<0,02	0,31
Acenaftylen	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	<0,01
Acenaften	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	0,03
Fluoren	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	0,02
Fenantren	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	0,03
Antracen	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	<0,01
Fluoranten	µg/l	<0,02	0,04	<0,1	<0,02	<0,02	<0,01
Pyren	µg/l	<0,02	0,02	<0,1	<0,02	<0,02	<0,01
Benzo(g,h,i)perylen	µg/l	<0,02	<0,02	<0,1	<0,02	<0,02	<0,01
Summa cancerogena PAH	µg/l	<0,02	<0,02	<0,3	<0,2	<0,2	<0,2
Summa övriga PAH	µg/l	<0,3	<0,3	<0,5	<0,3	<0,3	0,39
Summa PAH med låg molekylvikt	µg/l				<0,2	<0,2	
Summa PAH med medelhög molekylvikt	µg/l				<0,3	<0,3	
Summa PAH med hög molekylvikt	µg/l				<0,3	<0,3	

Ftalater	**Enhet**						
Dimetylftalat (DMP)	µg/l	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
Dietylftalat (DEP)	µg/l	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
Di-n-butylftalat (DBP)	µg/l	<0,1	0,22	<0,1	<0,1	<0,1	0,35
Butylbensylftalat (BBP)	µg/l	<0,1	<0,1	<0,1	<0,1	<0,1	0,57
Di-(2-etylhexyl)ftalat (DEHP)	µg/l	<1,0	<1,0	<1,0	<1,0	<1,0	2,3
Di-n-oktylftalat (DOP)	µg/l	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
Diisononylftalat (DINP)	µg/l						<1,0
Diisodecylftalat (DIDP)	µg/l						<1,0

Klorofenoler	**Enhet**						
2,3,4,5-Tetraklorfenol	µg/l	<0,01	<0,01		<0,01	<0,01	
2,3,4,6-Tetraklorfenol	µg/l	<0,01	<0,01		<0,01	<0,01	
2,3,4-Triklorfenol	µg/l	<0,01	0,04		<0,01	<0,01	
2,3,5,6-Tetraklorfenol	µg/l	<0,01	<0,01		0,012	<0,01	
2,3,5-Triklorfenol	µg/l	<0,01	<0,01		0,011	<0,01	
2,3,6-Triklorfenol	µg/l	<0,01	<0,01		<0,01	<0,01	
2,3-Diklorfenol	µg/l	<0,01	<0,01		<0,01	<0,01	
2,4,5-Trichlorophenoxyacetic acid	µg/l	<0,01	<0,01		<0,01	<0,05	
2,4,5-Triklorfenol	µg/l	<0,01	<0,01		0,024	<0,01	
2,4,6-Triklorfenol	µg/l	0,01	<0,01		0,011	<0,01	

2,4-Diklorfenol + 2,5-Diklorfenol	µg/l	<0,01	<0,01		0,028	0,39	
2,6-Diklorfenol	µg/l	<0,01	<0,01		0,016	<0,01	
2-Klorfenol	µg/l	<0,01	<0,01		<0,01	<0,01	
3,4,5-Triklorfenol	µg/l	<0,01	<0,01		<0,01	<0,01	
3,4-Diklorfenol	µg/l	<0,01	<0,01		0,013	<0,01	
3,5-Diklorfenol	µg/l	<0,01	<0,01		0,023	0,047	
3-Klorfenol	µg/l	<0,01	<0,01		<0,01	<0,01	
4-Klorfenol	µg/l	<0,01	<0,01		<0,01	<0,01	
Opolära alifatiska kolväten	mg/l	<1,1	<1,0		<1,0	<1,0	
Pentaklorfenol	µg/l	0,03	0,02	<1,0	0,014	0,011	
Summa diklorfenol	µg/l			<1,0			
Summa triklorfenol	µg/l			<1,0			
Summa Tertaklorfenol	µg/l			<1,0			
Pesticider	**Enhet**						
Bentazone	µg/l	0,07	<0,1	<0,1	0,2	0,05	
2,4-D	µg/l	<0,1	<0,1	<0,1	<0,01	<0,05	
Diklorprop-P (2,4-DP)	µg/l	0,04	<0,1	<0,1	<0,01	<0,05	
MCPA	µg/l	<0,1	<0,1	<0,1	<0,01	<0,05	
Mekoprop-P(MCPP)	µg/l	0,23	<0,1	0,24	0,21	0,24	
Atrazin	µg/l			<0,1			
Atrazin-destyl	µg/l			<0,1			
Atrazin-desispropyl	µg/l			<0,1			
Simazin	µg/l			<0,1			
Tertbutylazin	µg/l			<0,1			
Diuron	µg/l			<0,1			
1-(3,4-Diklorfenyl)urea	µg/l			<0,1			
1-(3,4-Diklorfenyl)-3-metylurea	µg/l			<0,1			
Imazapyr	µg/l			<0,1			
Linuron	µg/l			<0,1			
Cyanazin	µg/l			<0,1			
BAM (2,6-Diklorbenzamid)	µg/l			<0,1			
2,4,5-T	µg/l			<0,1			
DDT-op	µg/l			<0,1			
DDT-pp	µg/l			<0,1			
DDE-op	µg/l			<0,1			
DDE-pp	µg/l			<0,1			
alfa-HCH	µg/l			<0,1			
beta-HCH	µg/l			<0,1			
delta-HCH	µg/l			<0,1			
gamma-HCH	µg/l			<0,1			
hexaklorbensen (HCB)	µg/l			<0,1			
alfa-endosulfan	µg/l			<0,1			
beta-endosulfan	µg/l			<0,1			
sulfat-endosulfan	µg/l			<0,1			
Dieldrin	µg/l			<0,1			

Endrin	µg/l			<0,1			

Dioxiner	**Enhet**						
2,3,7,8-TCDD	pg/l			<0,72			
Summa TertaCDD				ND			
1,2,3,7,8-PeCDD	pg/l			<0,92			
Summa PentaCDD	pg/l			2,48			
1,2,3,4,7,8-HxCDD	pg/l			<1,92			
1,2,3,6,7,8-HxCDD	pg/l			<1,92			
1,2,3,7,8,9-HxCDD	pg/l			<1,92			
Summa HexaCDD	pg/l			6,21			
1,2,3,4,6,7,8-HpCDD	pg/l			11,3			
Summa HeptaCDD	pg/l			23,1			
OCDD	pg/l			112			
Summa Terta tom OktaCDD	pg/l			144			
2,3,7,8-TCDF	pg/l			<1,28			
Summa tetraCDF				ND			
1,2,3,7,8-PeCDF	pg/l			<1,72			
2,3,4,7,8-PeCDF	pg/l			<1,72			
Summa PentaCDF	pg/l			2,03			
1,2,3,4,7,8-HxCDF	pg/l			<1,6			
1,2,3,6,7,8-HxCDF	pg/l			<1,6			
2,3,4,6,7,8-HxCDF	pg/l			<1,6			
1,2,3,7,8,9-HxCDF	pg/l			<1,6			
Summa HexaCDF	pg/l			4,17			
1,2,3,4,6,7,8-HpCDF	pg/l			6,32			
1,2,3,4,7,8,9-HpCDF	pg/l			<1,52			
Summa HeptaCDF	pg/l			8,16			
OCDF	pg/l			7,13			
Summa Tetra tom OktaCDF	pg/l			21,5			
Summa Tetra tom OktaCDD/F	pg/l			165			
WHO(1998) TEQ (lower bound), only PCDD/F	pg/l			0,188			
WHO(1998) TEQ (upper bound), only PCDD/F	pg/l			4,17			
I-TEQ (lower bounds, only PCDD/F)	pg/l			0,295			
I-TEQ (upper bounds, only PCDD/F)	pg/l			3,8			

Alifater och aromater	**Enhet**						
Alifater >C8-C10	µg/l			<0,1			
Alifater >C10-C12	µg/l			<0,1			
Alifater >C12-C16	µg/l			<0,1			
Alifater >C16-C35	µg/l			<0,25			
Aromater >C8-C10	µg/l			<0,25			
Aromater >C10-C35	µg/l			<0,25			

Perflourerade ämnen	Enhet						
Perfluorbutansulfonat(PFBS)	ng/l			182			
Perfluordekansyra(PFDA)	ng/l			<100			
Perfluorheptansyra(PFHpA)	ng/l			420			
Perfluordekansulfonat(PFDS)	ng/l			<150			
Perfluordodekansyra(PFDoA)	ng/l			<100			
Perfluorhexansulfonat(PFHxS)	ng/l			254			
Perfluorhexansyra(PFHxA)	ng/l			759			
Perfluornonansyra(PFNA)	ng/l			<100			
Perfluoroktansulfonat(PFOS)	ng/l			292			
Perfluoroktansulfonamid(PFOSA)	ng/l			<100			
Perfluoroktansyra(PFOA)	ng/l			1080			
Totalt PFC exkl LOQ	ng/l			2980			
Totalt PFC inkl LOQ	ng/l			3530			
Totalt PFOS/PFOA exkl LOQ	ng/l			1370			
Totalt PFOS/PFOA inkl LOQ	ng/l			1370			

PCB	Enhet						
PCB 28	µg/l			<0,1			
PCB 52	µg/l			<0,1			
PCB 101	µg/l			<0,1			
PCB 118	µg/l			<0,1			
PCB 153	µg/l			<0,1			
PCB 153	µg/l			<0,1			
PCB 138	µg/l			<0,1			
PCB 180	µg/l			<0,1			

Nitroföreningar	Enhet						
N-nitroso-di-n-propylamin	µg/l			<0,1			
Nitrobensen	µg/l			<0,1			
Azobensen	µg/l			<0,1			
N-nitrosodifenylamin	µg/l			<0,1			
2,6-Dinitrotoluen	µg/l			<0,1			
2,4-Dinitrotoluen	µg/l			<0,1			

Övriga klorerade föreningar	Enhet						
Bis (2-kloretyl)eter	µg/l			<0,1			
Bis (2-kloroisopropyl)eter	µg/l			<0,1			
Hexakloretan	µg/l			<0,1			
Isophrone	µg/l			<0,1			
Bis(2-kloretoxy)metan	µg/l			<0,1			
2-Klornaftalen	µg/l			<0,1			
4-Klorfenylfenylether	µg/l			<0,1			
4-Bromofenylfenyleter	µg/l			<0,1			
Pentaklorbensen	µg/l			<0,1			

Alkylfenol och Alkylfenoletoxilater	**Enhet**						
iso-nonylfenol (4-nonylfenol)	µg/l						7.3
Nonylfenol monoetoxilat	µg/l						<0.1
Nonylfenoldietoxilat	µg/l						<0.1
Nonylfenoltrietoxilat	µg/l						<0.1
Nonylfenoltetraetoxilat	µg/l						<0.1
4-t-Octylfenolpentaetoxilat	µg/l						<0.1
4-t-Octylfenolhexaetoxilat	µg/l						<0.1
4-tert-Octylfenol	µg/l						0.84
4-t-Octylfenolmonoetoxilat	µg/l						0.038
4-t-Octylfenoldietoxilat	µg/l						<0.01
4-t-Octylfenoltrietoxilat	µg/l						<0.01
4-t-Octylfenoltetraetoxilat	µg/l						<0.01
4-tert-Butylfenol	µg/l						1.5
4-tert-Pentylfenol	µg/l						0.11

Bisfenol A	**Enhet**						
Bisfenol A	µg/l						107

11 Appendix II

Compiled list of prioritized pollutants

		Stockholm Convention POPs			ESIS					PBTprofiler.net					SWECO (Presence in leachate)	
Substance/Substance group	CAS#	Annex A	Annex B	Annex C	POP	R50/53	R51/53	PBT	vPvB	P	B	T	%Water	%Sediment	Often present	Minor presence
Commercial Pentabromodiphenyl ether (Tetrabromodiphenyl ether and pentabromodiphenyl ether)	5436-43-1 32534-81-9	x			x	x		x	x	x	x	x	4	8	x	
Commercial Octabromodiphenyl ether (Hexabromodiphenyl ether and Heptabromodiphenyl ether)	36483-60-0 68928-80-3	x			x			x	x	x	x	x	4	7	x	
PFOS, Its salts and PFOS-F	1763-23-1 307-35-7		x		x			x	x	x	x	x	2 9	19 86	x	
Polychlorinated dibenzofurans (PCDF)	-			x	x			x	x	x	x	x			x	
Polychlorinated dibenzo-p-dioxins (PCDD)	-			x	x			x	x	x	x	x			x	
PAH - Anthracene	120-12-7							x	x	x	x	x	9	12	x	
Octamethylcyclotetrasiloxane	556-67-2						x				x	x	40	26	x	

PAH - phenanthrene	85-01-8										x		10	12	x	
Dicyclohexylamine	101-83-7					x						x	25	0	x	
Nonylphenol	25154-52-3					x						x	18	19	x	
Octylphenol	140-66-9					x						x	16	9	x	
Tridemorph	24602-86-6					x						x	13	18	x	
Benzyl butyl phthalate (BBP)	85-68-7					x							22	5	x	
Biphenyl	92-52-4					x							17	3	x	
Dibutyl phthalate (DBP)	84-74-2					x							26	1	x	
Diphenylamine	122-39-4					x							18	1	x	
Mecoprop	93-65-2					x							22	0	x	
PAH - Naphthanlene	91-20-3					x							11	1	x	
N,N-diethyl-m-toluamide	134-62-3						x					x	18	0	x	
tris(2-chloroethyl) phosphate (TCEP)	115-96-8						x					x	16	0	x	
Chlorobenzene	108-90-7						x						28	0	x	
Tetrahydrothiophene	110-01-0						x						32	0	x	
3,4-bisisopropylphenol	68155-50-0											x	17	4	x	
Hexamethylcyclotrisiloxane	541-05-9											x	47	5	x	
Hexamethyldisiloxane	107-46-0											x	48	1	x	
Myristic acid	544-63-8											x	26	1	x	
N,N-dibutylformamide	761-65-9											x	33	0	x	
PAH - Fluoranthene	206-44-0											x	8	31	x	
PAH - Pyrene	129-00-0											x	8	31	x	
Palmitic acid	57-10-3											x	26	1	x	
Pentadecanoic acid	1002-84-2											x	26	1	x	
Tributyl phosphate (TBP)	126-73-8											x	27	1	x	
1,2-dichloropropane	78-87-5												40	0	x	

1,2-dimethoxyethane	110-71-4												46	0	x	
1,4-Dioxane	123-91-1												44	0	x	
1-Tetralone	529-34-0												26	0	x	
2-(2-butoxyethoxy)ethanol	112-34-5												30	0	x	
2,3-dimethylbutan-2-ol	594-60-5												41	0	x	
2-Decalone	4832-17-1												24	0	x	
2-ethyl-2-methyl-1,3-dioxolane	126-39-6												47	0	x	
2-methylbutan-2-ol	75-85-4												42	0	x	
3-methylbutanone	563-80-4												40	0	x	
3-methylpentan-2-one	565-61-7												37	0	x	
4-Nonylphenol, branched, ethoxylated	127087-87-0														x	
Acridine	260-94-6												18	9	x	
Bis(2-ethylhexyl) phthalate (DEHP)	117-81-7												17	19	x	
bis(2-ethylhexyl)adipate	103-23-1												24	2	x	
Bisphenol A	80-05-7												8	18	x	
Butanone	78-93-3												41	0	x	
Butylphenol	28805-86-9														x	
Camphor	76-22-2												22	0	x	
Cyanide total	-														x	
Dichlorobenzene	25321-22-6												20	0	x	
Diisobutyl phthalate (DIBP)	84-69-5												24	1	x	
Dimethyl-1,4-dioxane	25136-55-4												42	0	x	
Ethylbenzene	100-41-4												34	1	x	
Fenchone	1195-79-5												22	0	x	

Formaldehyd	50-00-0												43	0	x	
Isopropyphenazone	479-92-5												13	0	x	
m-Cresol	108-39-4												26	0	x	
Styrene	100-42-5												27	0	x	
Toluene	108-88-3												39	0	x	
Xylene	1330-20-7												34	1	x	
Lindane	58-89-9	x			x	x		x	x	x	x	x	7	2		x
Hexachlorobuta-1,3-diene (HCBD)	87-68-3				x			x	x	x	x	x	27	2		x
Hexabromocyclododecane	25637-99-4 3194-55-6							x		x	x	x	8	16		x
2,4,6-trichlorophenol	88-06-2					x							14	2		x
2,4-dichlorophenol	120-83-2					x							19	1		x
Chloroaniline	106-47-8					x							24	0		x
Benzene	71-43-2												40	0		x
Caffine	58-08-2												31	0		x
Diclofenac	15307-86-5												13	0		x
Estradiol	50-28-2												10	9		x
Oxazepam	604-75-1												15	0		x
PAH - Acenaphthene	83-32-9												12	3		x
PAH - Acenaphthylene	208-96-8												20	3		x
Phenazone	60-80-0												19	0		x
Aldrin	309-00-2	x			x	x		x	x	x	x	x	3	26		
Chlordecone	143-50-0	x			x	x		x	x	x	x	x	4	8		
DDT	50-29-3		x		x	x		x	x	x	x	x	3	37		
Dieldrin	60-57-1	x			x	x		x	x	x	x	x	5	12		
Endosulfan	115-29-7	x			x	x		x	x	x	x	x	4	3		

Endrin	72-20-8	x			x	x		x	x	x	x	x	5	12		
Heptachlor	76-44-8	x			x	x		x	x	x	x	x	3	13		
Hexachlorobenzene (HCB)	118-74-1	x		x	x	x		x	x	x	x	x	4	2		
Mirex	2385-85-5	x			x	x		x	x	x	x	x	2	37		
Pentachlorbenzene (PeCB)	608-93-5	x		x	x	x		x	x	x	x	x	4	1		
Toxaphene	8001-35-2	x			x	x		x	x	x	x	x	3	29		
Alpha Hexachlorocyclohexane	319-84-6	x			x			x	x	x	x	x	7	2		
Beta Hexachlorocyclohexane	319-85-7	x			x			x	x	x	x	x	7	2		
Chlordane	12789-03-6	x			x			x	x	x	x	x	4	8		
Dicofol	115-32-2				x			x	x	x	x	x	4	6		
Hexabromobiphenyl	36355-01-8	x			x			x	x	x	x	x	2	24		
Polychlorinated biphenyls (PCB)	-	x		x	x			x	x	x	x	x				
Pentachlorophenol	87-86-5				x	x				x		x	4	2		
Anthracene oil	90640-80-5							x	x	x	x	x				
Anthracene oil, anthracene low	90640-82-7							x	x	x	x	x				
Anthracene oil, anthracene paste	90640-81-6							x	x	x	x	x				
Anthracene oil, anthracene paste, anthracene fraction	91995-15-2							x	x	x	x	x				
Anthracene oil, anthracene paste, distn. Lights	91995-17-4							x	x	x	x	x				
Pentachlorobenzenethiol	133-49-3							x	x	x	x	x	4	3		
1,2,4trichlorobenzene	120-82-1					x		x		x	x	x	10	1		

Alkanes, C10-13, chloro (SCCP)	85535-84-8				x	x		x		x	x	x				
Nitrofen	1836-75-5					x		x		x	x	x	10	6		
1,2,3trichlorobenzene	87-61-6							x		x	x	x	10	1		
Bis(tributyltin) oxide	56-35-9							x		x	x	x				
Cyclododecane	294-62-2							x		x	x	x	63	10		
Diphenyl ether, octabromo derivative	32536-52-0							x		x	x	x	4	2		
tetramethyllead	75-74-1							x		x	x	x				
5-tert-butyl-2,4,6-trinitro-m-xylene (Musk xylene)	81-15-2					x			x	x	x		3	12		
PAH - Benzo(a)pyrene	50-32-8					x				x	x	x	2	59		
PAH - Dibenzo(a,h)anthracene	53-70-3					x				x	x	x	2	63		
PAH - Benzo(g,h,i)perylene	191-24-2									x	x	x	2	65		
PAH - Indeno(1,2,3,c,d)pyrene	193-39-5									x	x	x	2	64		
Hexabromocyclododecanes (HBCDD)	25637-99-4										x	x	8	16		
Chlorpyrifos	2921-88-2					x				x		x	6	5		
Cypermethrin	52315-07-8					x				x		x	3	23		
PAH - Benzo(a)anthracene	56-55-3					x				x		x	4	48		
PAH - Benzo(b)fluoranthene	205-99-2					x				x		x	2	58		
PAH - Benzo(k)fluoranthene	207-08-9					x				x		x	2	59		
Trifluralin	1582-09-8					x				x		x	4	7		
Acloifen	74070-46-5					x						x	9	2		
Chlorfenvinphos	470-90-6					x						x	12	1		
Dichlorvos	62-73-7					x						x	27	0		

PAH - Chrysene	218-01-9					x						x	4	48		
2,4-Dinitrotoluene (DNT)	121-14-2					x							13	0		
2-Naphthol	135-19-3					x							22	1		
Alachlor	15972-60-8					x							12	0		
Aniline	62-53-3					x							29	0		
Atrazine	1912-24-9					x							13	0		
Diuron (DCMU)	330-54-1					x							17	0		
Isoproturon	34123-59-6					x							15	0		
N-methylaniline	100-61-8					x							29	0		
Quinoxyfen	124495-18-7					x										
Simazine	122-34-9					x							14	0		
Trichlorobenzene (TCB)	120-82-1 108-70-3					x							10	1		
4,4'-Methylenedianiline (MDA)	101-77-9						x						11	1		
Carbon tetrachloride	56-23-5						x						48	0		
Tetrachloroethylene	127-18-4						x						47	0		
Trichloroethylene	79-01-6						x						52	0		
Cybutryne	28159-98-0											x	12	0		
tris(2-butoxyethyl) phosphate (TBEP)	78-51-3											x	18	1		
1,2-dichloroethane (DCA/EDC)	107-06-2												38	0		
Aliphatics C16-35	-															
Bifenox	42576-02-3												10	3		
Chlorinated naphthalenes	70776-03-3															
Dichloromethane (DCM)	75-09-2												45	0		
Diisononyl phthalate (DINP)	28553-12-0												15	2		

Di-n-Octyl Phthalate (DNOP)	117-84-0												19	11		
Ethyl benzoate	93-89-0												25	0		
PAH - Fluorene	86-73-7												19	5		
Piperidine	110-89-4												30	0		
Tris(2-carboxyethyl)phosphine	5961-85-3															
Terbutryn	886-50-0												11	0		
Trichloromethane (chloroform)	67-66-3												44	0		