Project supported by Inno-MT

Sustainable management of leachate from landfills

Towards assessment of the duration of the aftercare period at a landfill

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Content

Annex A
Request for data from Skaarup Landfill as input for estimation of the duration of the aftercare period ("Wish list")

1. Background and objectives

Using the landfill site Waste Centre Skårup at RenoSyd I/S in Skanderborg, Denmark as an example, a pilot project has been carried out under Innovation Network Environmental Technology (Inno-MT) with the overall objective to create the basis for reducing the consumption of resources, the environmental impacts and the costs associated with the operation and aftercare of a landfill site by applying new and innovative solutions for waste water treatment and landfill management.

The three main goals of the pilot project have been:

A. To assess and describe the content and methodology of a decision support tool for short and long term management of leachate from landfilled waste. For a given landfill site, the tool should assist in:

   1. Development of fact-supported estimates of the duration of the aftercare period based on site-specific input and various assumptions;

   2. Development of environmentally and economically optimal management strategies and technologies for the landfilled waste and the produced leachate with specific focus on a shortening of the aftercare period;

B. To identify suitable combinations of treatment technologies for the leachate through testing at pilot and laboratory scale. The treatment technologies must be flexible and able to adjust to the varying quantities and qualities of the leachate, and the treated leachate should comply with existing and expected future discharge criteria with specific focus on problematic substances.

C. To identify new technological measures and strategies to influence and accelerate those stabilizing processes which in a landfill can contribute to shorten the aftercare period. The efforts, including partial or full recirculation of treated leachate, will be focused on improving the percolation of water within the landfilled waste, attempting to accelerate the leaching and degradation/removal of the problematic substance.

The results of the pilot project should form the basis of a proposal for a more comprehensive project, possibly with international participation, aiming at further development of the above mention decision support tool to be marketed and applied in Denmark and internationally.

The project participants are Renosyd i/s, DHI, Grundfos Biobooster, Dansk Affaldsforening and UltraAqua.

The following deliverables were foreseen:

1. A listing of the expected quality criteria discharge of treated leachate into receiving waters with particular focus on existing and expected future water quality criteria with respect to microorganic pollutants.

2. Characterisation of leachate and initial testing and development of selected leachate treatment technologies. Based on the results of these initial activities,

one or more full scale leachate treatment concepts or scenarios shall be drafted and roughly priced. Characterization, testing and development of concepts/scenarios shall be based on a specific Danish landfill (Skårup), which is rather typical of many landfills in Denmark and the rest of Europe (the market is both Danish and international).

3. Initial investigations at Skårup Landfill focusing on the hydraulic conditions within the landfill including the feasibility of recirculating leachate to possibly reduce the aftercare period.

4. A description of content and methodology of a decision support tool which for a given landfill can assist in selection of suitable options for forecasting of the aftercare duration, selection of a flexible and modular treatment technology, and selection of an optimal strategy and optimal technology that can enhance the stabilizing processes within the landfilled waste.

5. An attempt at identifying both other Danish and European potential cooperation partners and possible source of funding for a more comprehensive R&D project to further develop the products of this project and adjust them to an international market.

Practically, the project has consisted of two parts, where one part (leachate treatment) primarily has consisted of activities related to treatment of the currently produced (and future) leachate, whereas the other part primarily has comprised activities related to description, prediction and reduction of the duration of the aftercare period, i.e. the period during which monitoring, collection and treatment of leachate will still be required.

This report presents the results the project activities related to the assessment of the aftercare period. The activities in this part of the project has been carried out by RenoSyd i/s, DHI and Dansk Affaldsforening.

It should, however, be noted that it has not been possible to achieve the intended objectives related to assessment/prediction of the duration of the aftercare period within the framework of the project. Compared to many other landfills, the activities at Skårup Landfill are actually quite well documented in reports, applications, descriptions and permits etc., but much of the information required for the assessment of the duration of the aftercare period cannot be readily elucidated from all these sources of data. This is mainly due to the fact that the landfill has been operated as a sequence of cells from 1980 until today (a new cell was constructed when the old cell was filled to capacity) receiving many different types of waste, and in particular that the leachate streams collected from most of the stages are mixed either in the leachate collection system or in the pipeline transporting the leachate to the municipal wastewater treatment plant. In addition, the available water balance calculations for the landfill does not address the individual stages or units/cells and hence it is only possible to describe the composition of the leachate as a function of time (or the liquid to solid ratio – L/S) in a very crude manner that combines several types of leachate of different ages in one single description. This is not very helpful in assessing the future development in leachate quality. Only from the last two cells is it possible to collect leachate separately.

In order to investigate whether or not it might be possible to assess the duration of the aftercare period for at least the older cells at Skaarup Landfill, it is recommended that efforts should be made to collect some the information that is currently lacking, in particular more cell-specific information. It should be considered if it would be possible somehow to adjust the existing leachate drainage system in such a manner that leachate production can be monitored for individual cells or groups of individual cells for Cell 1 to 4, and the leachate monitoring programme should be changed to ensure that the analytical programme proposed in Annex A is carried out at least once a year for all cells and currently twice a year for Cells 5 and 6.

2. Framework and principles for decisions on the discontinuation of the aftercare at landfills

2.1. Existing regulation

Currently there are no concise, operational criteria defining when the aftercare of a landfill can be stopped, i.e. when collection and treatment of leachate, monitoring of the quantity of leachate and the quality of leachate and groundwater, and maintenance of the environmental protection systems are no longer necessary. As seen below, the existing rules are expressed in very general formulations.

The Danish Statutory Order no. 1049 on landfills of 28 August 2013 (BEK 1049/2013) §27 states: "The inspecting authority shall determine when the aftercare of the landfill or cell can be considered completed and no further active management of the landfill or the cell will be required". In Annex 2 to the Statutory Order aftercare is addressed as follows: "The permit must include the requirement that operation, maintenance, monitoring and control of the environmental protection systems at the landfill shall continue for as long as the landfill is considered a hazard to the surroundings." Similarly to the Landfill Directive (1999/31/EC), the Statutory Order does not provide any concrete or even guiding information about the criteria that must be fulfilled before the aftercare can be ended and management become dependent only on passive measures.

2.2 Operational criteria for ending of the aftercare

This section outlines a methodology and provides some proposals that may help setting more concrete and operational criteria for cessation of the aftercare, and allows the operator of a landfill to demonstrate that the flux of contaminants to the environment would be (and remain) acceptable under the assumptions of, inter alia:

- no active management of the landfill;
- failure of all engineered environmental protection systems;
- attainment of hydraulic equilibrium (see below);
- no functioning gas or leachate management systems.

The condition in BEK 1049/2013 that the aftercare (i.e. "maintenance and monitoring of the environmental protection systems of a landfill" – including monitoring, collection and treatment of leachate and monitoring of groundwater and surface water quality) must continue for as long as the landfill "is considered a danger to the surrounding environment" can and should be reformulated in terms of more specific conditions for ending the aftercare. It should be changed from a vaguely defined requirement of an evaluation to be made by the authorities to express concrete criteria the fulfilment of which the operator shall demonstrate. Subsequently, the authorities should check that the criteria are indeed fulfilled, and if they are, acknowledge that aftercare is no longer required at the landfill. As far as the management of leachate is concerned this could, for example, be expressed as follows: *The aftercare at a landfill (with respect to leachate manage-*

ment) may be discontinued when the operator has demonstrated to the authorities that the landfill without active environmental protection systems cannot at any time after cessation of the after-care cause a number water quality criteria (to be specified) to be exceeded at a given distance downstream of the landfill site. Although more concrete than the existing text in the regulation, it would be necessary to supplement with a number of more specific technical descriptions and explanations in order for the conditions to appear reasonably clear and transparent. This would on the one hand provide the operators with information on what is expected of them and allow them to – at the earliest possible time – adjust and optimize design and operation to fulfil the criteria as soon as possible and shorten the aftercare period, and on the other hand allow for a reasonably uniform enforcement of aftercare cessation regulation across the country.

With respect to the requirements of the source term (of contaminants) and the condition of the landfilled waste ("final storage quality" or "end status") which could be set at a generic level to allow the discontinuation of the aftercare at a landfill, different options which vary with respect to environmental safety and sustainability may be envisaged.

Table 2.1 Various possible definitions of "final storage quality" (where the aftercare of a landfill can be discontinued) in terms of quality and quantity of leachate.

Type	**Character of the contamination potential**	**Potential release of contaminating substances to soil and water**	**Necessary stability of passive environmental protection systems**
A	Total and remaining equilibrium between potentially contaminating substances in the landfilled waste and outside the landfill (same concentration in the leachate and the groundwater)	No gradient for transport of contaminating substances between the landfill and the surroundings	Not important
B	The level of concentration of potentially contaminating substances in the leachate is (and will remain) acceptable in the surroundings	Release/seepage of leachate to the surrounding groundwater or surface water will not lead to unacceptable impacts, regardless of the amount of leachate produced	Less important
C	The flux of potentially contaminating substances is (and will remain) acceptable in the surroundings	Release/seepage of leachate to the surrounding groundwater or surface water will not lead to unacceptable impacts if the flux does not exceed a given (site-specific) value	Long term stability of passive measures to reduce infiltration may be required

For an end status of type A there will be no impact on the environment from leachate, and for an end status of type B, the impact will always be acceptable regardless of the amount leachate produced and released. In these cases there will be no need of passive environmental protection measures such as infiltration-reducing covers that would limit the amount of leachate produced and released. Assessment of the transport and fate of the released substances will not be necessary since the water quality criteria will be met everywhere. It must, however, be anticipated that attaining a state corresponding to type A or type B will take a very long time for most landfills. The most (or the only) realistic and applicable definition of the end status/final storage quality should therefore be based on type C, where the flux (i.e. the amount released per unit time) and not the concentration of a contaminant is assessed in relation to the impact on the surroundings, and where the effect of attenuation/dilution in soil, aquifers and surface waters upstream of the point of reference (or point of compliance, POC) is accounted for.

This definition of the end status for a landfill or the principle behind it has already been acknowledged and applied indirectly in European (and Danish) landfill regulation, since the calculation of the leaching based waste acceptance criteria (WAC) in EU Council Decision 2003/33/EC and BEK 1049/2013 are based on modelling of flux and retention/dilution (attenuation) of the regulated contaminants. The requirement that the flux must not again increase to an unacceptable level after the landfill has attained end status/final storage quality means that the effect of a possible “bathtub effect” which may cause an increased leaching of the upper parts of the landfill (see below) must be assessed and taken into account.

When the Danish leaching WAC for landfills in BEK 1049/2013 were calculated (see Hjelmar et al., 2009), the Danish EPA defined a number of so-called primary ground water quality criteria which should always be complied with in the groundwater at a distance of 100 m downstream of the landfill (and hence also further downstream). The point of reference where the primary ground water quality criteria should be complied with is referred to as the “point of compliance” or “POC”. The purpose of these scenario-based calculations was to establish the maximum source strength of a number of substances that would always comply with the primary quality criteria in the groundwater at the downstream POC under the specific conditions pertaining to the scenarios defined for the calculations. The maximum source strength (flux) for a given substance and a given category of landfill (for inert, mineral and hazardous waste, located near the coast or inland) was subsequently converted to the result of an equilibrium-based leaching test (a batch or column leaching test) at various values of L/S (in particular L/S = 2 l/kg and L/S = 10 l/kg). This means that in principle the groundwater between the landfill and the POC has been “written off” – at least for some time – while the groundwater downstream of the POC can be expected to have an acceptable quality (at least as far as impacts from the landfill are concerned). The principle in the risk-based scenario calculations is shown in Figure 2.1 which also shows the source-transport-receptor chain upon which the assessment of the impact on the groundwater at the POC is based.

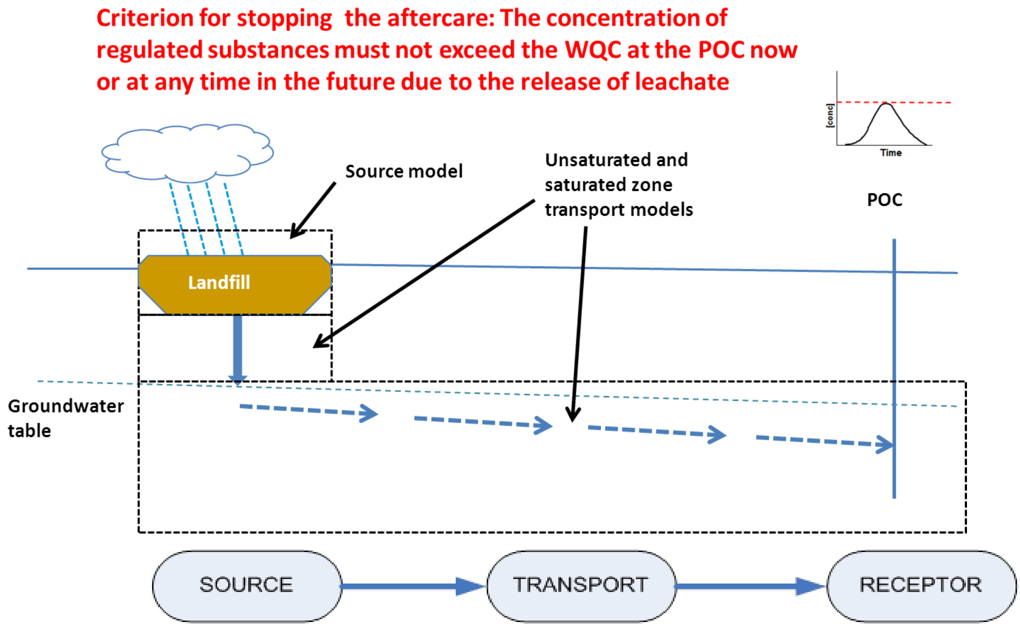

Figure 2.1: Cross section showing the principle of a scenario based impact/risk assessment for groundwater downstream of a landfill. A series of three coupled model describing the source and transport (through the unsaturated and saturated zones) of substances from the landfill to the POC for assessment of the impact or calculation of WAC.

Figure 2.2 shows how the impact assessment can be expanded to include surface water.

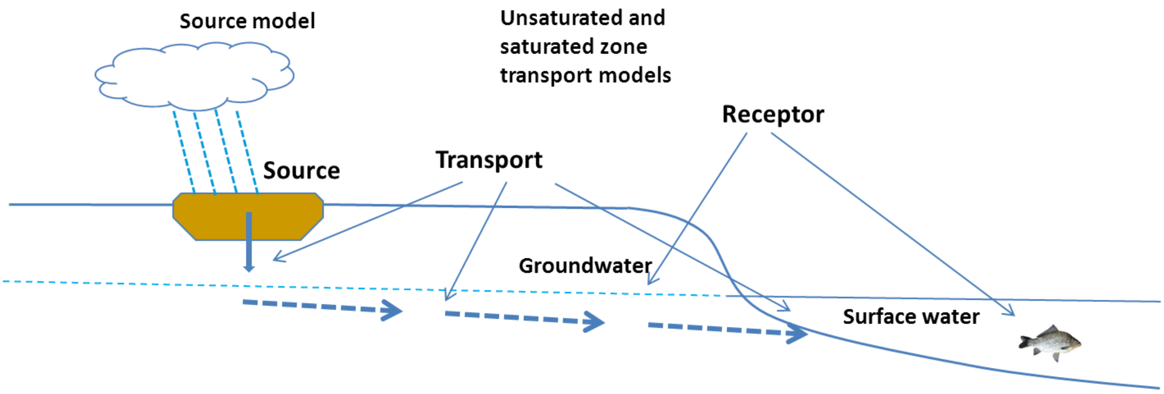

Figure 2.2: If supplemented with a surface water dilution/transport model, the groundwater quality impact assessment may be extended to include surface water quality.

The assumptions made in the calculation of the WAC and the installation of the prescribed environmental protection systems should, when the WACs are complied with, ensure that the groundwater quality (the primary groundwater quality criteria, GWQC) will not be exceeded at the POC, not only during the period when the environmental protection systems can be expected to be intact (including the aftercare period), but also in all future after the end of the aftercare period. The source term applied in the scenario calculations is based on the assumption that the source strength will decrease with time and in such a way that the primary GWQC will still be complied with when and after the active environmental protection systems and measures (including leachate collection and treatment) fail or are deliberately discontinued.

It is worth noting that for some of the substances present in the leachate a concentration peak at the POC may be expected occur a long time after the leachate has been released from a landfill due to attenuation in soil and groundwater. For some substances such as e.g. Cu and Pb this time lag may constitute several thousand years. Since it is the flux and not just the concentration of a substance that is determining the source strength, the concentration of a substance in the leachate at the source does not necessarily have to comply with the groundwater (or surface water) quality criterion at the time when the aftercare is terminated. Instead, it should be demonstrated beyond doubt that the flux and its expected future development are such that the attenuation in the soil and groundwater between the landfill and the POC is sufficient to ensure present and future compliance with downstream groundwater or surface water quality criteria at the POC.

If it is accepted that the area between the landfill and the POC is effectively “part of the landfill”, it would seem reasonable to apply the same POC and the same primary groundwater quality criteria as those used when calculating the leaching WAC listed in BEK 1049/2013, possibly supplemented with additional substances and updated as appropriate, when assessing if the aftercare can be discontinued. For landfills located near (upstream of) fresh or marine surface water bodies the primary water quality criteria will have to be adjusted to the actual conditions.

When assessing the compliance of the release of the leachate with the primary quality criteria at the POC, future compliance must also be ensured. It is, in particular, necessary to ensure that a so-called “bath-tub effect” (see Figure 2.3) will not lead to non-compliance when the leachate is no longer collected and managed. When pumping of the leachate ceases, the level of leachate within the landfill may rise until a new hydraulic equilibrium is established, i.e. the amount of infiltrating precipitation is equaled by the leachate leaking through bottom and side liners or flowing over the sides. If parts of the landfilled waste that have not previously been in much contact with water/leachate become saturated under these conditions, the composition of the leachate may change substantially compared to its composition when compliance with the primary quality criteria at the POC was first established. In such cases it may be necessary to resume collection of the leachate while maintaining the new leachate head corresponding to the new hydraulic equilibrium until such time that compatibility can again be achieved. In practice, this may prolong the aftercare period by several years.

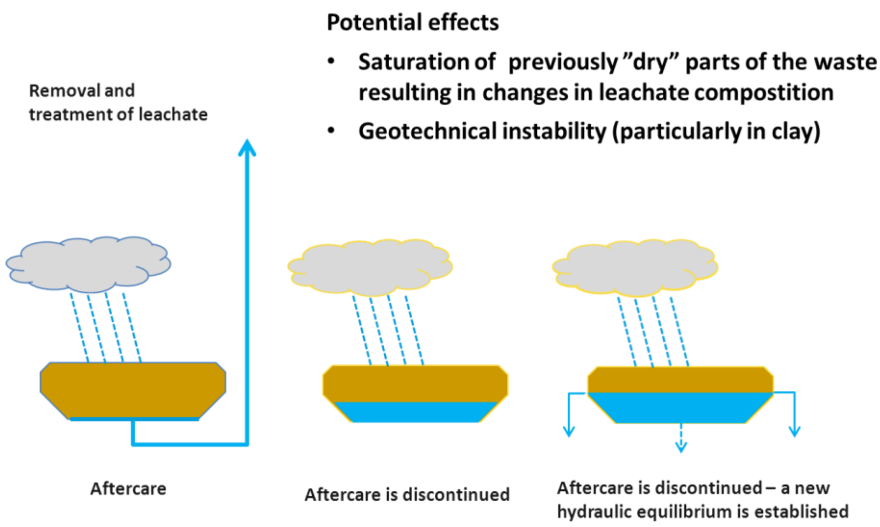

Figure 2.3: Illustration of the "bathtub effect" which may occur after leachate collection and removal have stopped.

2.3 A proposal for a procedure to determine if the aftercare can be ended for a landfill

The flow sheet in 2.4 illustrates the main principles of a decision process which for a given landfill may be used to determine whether or not the aftercare can be ended from the perspective of discharge and impact of leachate.

The assessment consists of three main elements:

- Determination of the source strength, including a possible "bath tub effect"
- Determination of the transport of substances of concern from the landfill to the POC
- Determination of the impact on groundwater/surface water at the POC

The assessment of the source strength (as a function of time), the transport of substances and the effect at the POC will generally require the performance of computer-based model calculations. The transport calculations will normally involve 3D modelling and account for sorption/dilution/attenuation in the unsaturated and saturated zones.

To prevent spending unnecessary or wasted major efforts – e.g. when a landfill turns out to be far from the point where the aftercare can be ended – it is proposed to apply a stepwise procedure in the assessment, starting with simple and conservative assumptions and immediately available data and gradually include more sophisticated modelling solutions and/or improved data. As far as the **transport** of substances is concerned, it would be possible to start out with a simple solution which could be conservative (e.g. with limited or no retention of substances in the soil and aquifer) and thus represent a "worst case" transport scenario, and move on to more sophisticated, better supported and more realistic modelling if necessary (i.e. if the water quality criteria at the POC are not met). Although some things in the landscape and the surrounding environment may change over time, the substance transport model to be applied can essentially be set up (and improved) at any time during planning, operation or aftercare of the landfill.

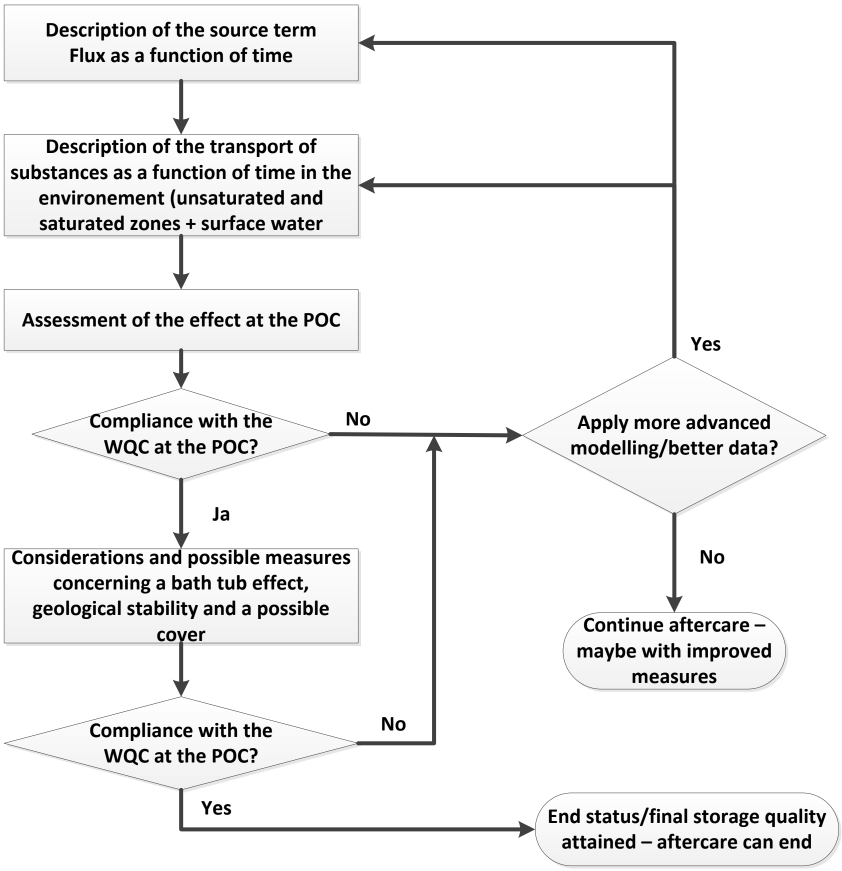

Figure 2.2: Flow sheet showing the main processes and issues that should be considered when deciding if the aftercare can be ended at a landfill.

For the **source** term, it is less clear what can be regarded as conservative and “worst case”. The optimal sequence of steps in the assessment of the source strength is more likely to reflect the availability of data and the actual conditions at the landfill and, not the least, the point in time at which the assessment is carried out (the planning phase, the operation phase or late in the after-care phase) than a gradually decreasing degree of conservatism. The quality, accuracy and availability of data may be expected to be better for a landfill that is already in the aftercare phase than for a landfill still in the planning or operation phase. Until good data are available and the potential consequences of a possible “bath tub effect” have been evaluated, only rough assess-ments of the remaining duration of the aftercare period are likely to be possible.

The most challenging task is therefore to get a reliable source term description for a given landfill. Due to the general lack of desired data and the often poor quality of the data that are available, a simple historic description of the quantity and quality of the leachate as function of time from the start of the operation period of a landfill to the time of assessment may at best be difficult and often impossible to derive, let alone a reliable prediction of the source term over the next several decades. The landfill operators have not been required to collect the necessary data of sufficient quality because until quite recently little thought was given to the determination of the duration of the aftercare period and how to possibly influence it. The situation is further complicated by the fact that controlled landfills have only existed for 35 to 45 years and seldom been subject to systematic gathering of information, and by the fact that many landfills are constructed in overlapping stages over long periods of time, and that the leachate from different stages are often mixed prior to registration of quantity and quality. At the same landfill, some stages may be in the aftercare phase while others are still in operation.

The source term for a landfill is a flux consisting of a combination of the water balance and a description of the composition of the leachate as a function of time. For a given substance, i, the flux, $M_i(t)$, from a landfill unit may be described as a function of time:

$M_i(t) = C_i(t) \times Q(t)$, where

$C_i(t)$ is the concentration of substance i in the leachate as a function of time, and

$Q(t)$ is the quantity of leachate produced as a function of time.

If the landfill unit or landfill site under assessment consists of cells or areas containing different types of waste and/or parts which have been established in stages at different times causing the water balances (and concentration profiles) to differ significantly from each other, it will be necessary to describe the combined source term as sum of parallel sources (which may also have to assessed individually):

$M_i(t) = \sum (M_{ij}(t) = \sum (C_{ij}(t) \times Q_j(t))$, where j varies from 1 to n, and n = the no. of different areas

The first task of an attempt at assessing the aftercare conditions at a specific landfill is therefore to collect and compile current and historical data on the design and operation of the landfill with the aim to be able to develop appropriate combinations of water balances and leachate composition as a function of time, and to be able to estimate future developments, in particular of the leachate composition as a function of time. Modelling and assessment of the transport of substances and the impact at the POC will further require information on the geography, geology and hydrogeology of the surroundings as well as the nature and water quality requirements of the receptors (downstream groundwater and/or surface water bodies).

3. Description of the Skårup Landfill site

3.1 General description

Waste Management Centre Skårup is owned and operated by RenoSyd i/s and is located at 75 Oddervej in the postal district 8660 Skanderborg in Denmark. The landfill has been placed in a hilly, former gravel quarrying area between Skanderborg and Gjesing. The site is located in an area classified as suitable for extraction of potable groundwater. The landfill site consists of 10 stages of which the first, Stage 1, was established and approved together with Stage 2 in 1979 and taken into use in 1980. Stages 3 to 9 was originally approved in 1985, and so far stages 3 to 6 has been taken into use. Later permits have been issued with time limits or as additions to the existing permits. In addition to mixed waste, the landfill has earlier received municipal solid waste incinerator (MSWI) fly ash and bottom ash for disposal in a specific part of Stage 1 and later at the eastern part of Stage 2, part 2. Stages 3 and 5 has also received asbestos. On 10 June 2010 Waste Management Centre Skårup was granted permission to take Stage 6 into use by the authorities at Environmental Centre Århus. Currently only Stage/Cell 6 is in operation.

As shown in Figure 3.1, the landfill is located approximately 650 to 1200 m North East of Skanderborg Lake which is the ultimate receptor of any leachate leaking into the groundwater. Miljøcenter Århus (2009) also indicates that a small stream North West of the site may also be a potential receptor. The stream discharges into Skanderborg Lake.

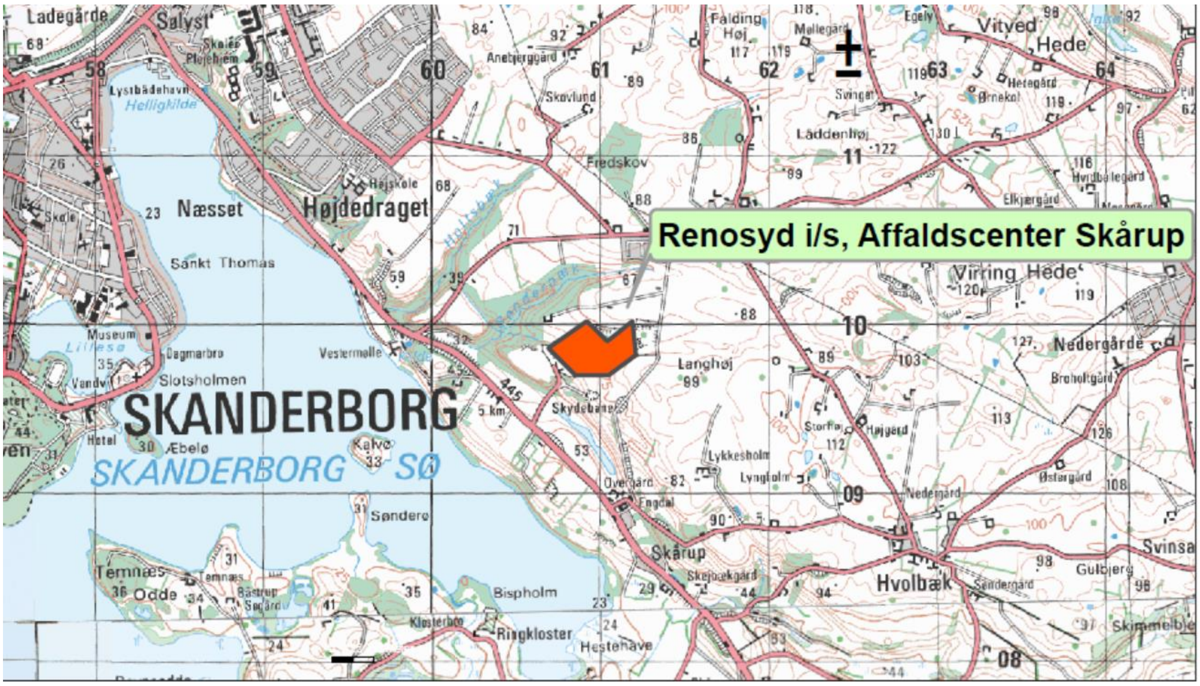

Figure 3.1: Location of the Skårup Landfill close to Skanderborg Lake.

3.2 Information required and collected on Skårup Landfill

A "wish list" of information considered necessary to support the source term assessment was drawn up. The main points on the list which is shown in full in Annex A are summarized below:

- Detailed information on the design of each landfill stage/unit/cell
- Detailed information on the operation of the landfill (per unit/cell)
- Details on the type and location of the waste placed in each unit/cell, including waste characterization data
- Leachate production data/water balance data for each single unit/cell
- Detailed and appropriate leachate quality data separately for each unit/cell (time series)
- Information on gas production

A large amount of information was provided by Renosyd i/s. This information has been stored in a data file by Dansk Affaldsforening, and many of the data sources are listed under the references. Particularly useful information was obtained from the time series of leachate analyses and amounts and types of landfilled waste provided by Renosyd and from the decision: "Afgørelse om overgangsplan og revurdering for Affaldscenter Skårup, Oddervej 75, Skanderborg" (Miljøcenter Århus, 2009). The latter provides an excellent overview of the history and general conditions for the landfill. An extensive hydrogeological study assessing the risk to groundwater extraction was carried out in 1998 (Carl Bro, 1998). This was later supplemented by other studies and may at a later time be used in the possible development of descriptions/modeling of the transport of contaminants from the source to the receptor. In 2013. Rambøll (2013) carried out water balance calculations for the entire site (all cells) for 2010, 2011 and 2012. The calculated volumes of leachate showed a significant deviation from the collected volume of leachate (58 %) in 2012, and unfortunately the subdivision in different parts of the site was based on topography rather than individual cells, except for Stage 6 (the cell currently in operation). These data would therefore require further scrutiny and treatment before they would become useful in a source term assessment.

Compared to many other landfills, the activities at Skårup Landfill are actually quite well documented in reports, applications, descriptions and permits etc., but unfortunately very little of the information can be referred to separate or specific cells, and therefore the information required for the assessment of the duration of the aftercare period cannot be readily elucidated from all these sources of data. This is mainly due to the fact that the landfill has been operated as a sequence of cells from 1980 until today (a new cell was constructed when the old cell was filled to capacity) receiving many different types of waste, and in particular that the leachate streams collected from most of the stages are mixed either in the leachate collection system or in the pipeline transporting the leachate to the municipal wastewater treatment plant. Currently, the leachate streams from Stage 1 to Stage 4 are collected in the same system, whereas the leachate streams from Stage 5 and Stage 6 are collected separately. However, all three streams are then mixed and pumped through a pipeline to the wastewater treatment plant. As already mentioned, the available water balance calculations and the annually collected volumes of leachate for the landfill does not address the individual stages or units/cells and hence it is only possible to describe the composition of the leachate as a function of time (or the liquid to solid ratio – L/S) in a very crude manner that combines several types of leachate of different ages in one single description. This is not very helpful in assessing the future development in leachate quality. Only from the last two cells is it possible to collect leachate separately, but the leachate from these cells is still young and quite far from the point where cessation of the aftercare can be considered (one of them, Stage 6, is still in operation and the other, Stage 5, was closed only a few years ago).

Despite extensive efforts to extract useful information from the comprehensive collection of information obtained from RenoSyd, it has become clear the main objective of the project – to assess the duration of the aftercare period at Skaarup Landfill - cannot be fulfilled on the basis of this material alone and within the relatively short time allocated for the project. However, the data have now been evaluated and stored and may become useful at a later time, if more appropriate new data can collected from the landfill site, and a more comprehensive data treatment can be carried out.

It serves no purpose to attempt to carry out calculations on the presently available data material (e.g. leachate composition as a function of time). Instead, some examples of the information collected are presented in the following.

3.3 Overview examples of the information collected

Figure 3.2 shows a plan of the various stages at Skaarup landfill. The total surface area of Stages 1 through 6 (filled up and active stages) is approximately 92,000 m^2.

Figure 3.2: Map showing all stages of Skaarup Landfill. Future stages (7 – 10) are located at the North Eastern corner of the area (from Miljøcenter Århus, 2009).

Table 3.1 shows the surface areas of the individual stages/cells and the volumes of waste deposited in each of the closed and active cells (no waste was placed in cell 4A). The table also shows the remaining disposal capacities of cell 6 and the future cells as well as the years when each of the cells was started and closed, respectively. Table 3.2 shows the main types of waste that has been deposited in each of the various cells at Skaarup Landfill.

Table 3.1: Information on surface area, deposited waste, remaining capacity and starting and closing time for the individual landfill cells at Skaarup Landfill (based on Miljøcenter Århus, 2009)..

Stage	Area	Amount of waste		Capacity	Active period	
	m2	m3	t	m3	Start	Closed
1	10,000	45,000			1980	1981
2.1	12,500	52,000			1981	1983
2.2	12,500	53,000			1983	1985
3	9,000	69,900			1985	1986
3A	6,000				1986	1987
4	7,200	57,000			1987	1991
4.A	10,000	-				
5	12,700	159,035			1991	2009
6	11,000	62,535		170,500	2009	-
7				130,000		
8				120,000		
9				130,000		
10				70,000		

Table 3.2: Overview of the main types of waste placed in each of the various cells at Skaarup Landfill (information provided by Renosyd i/s).

Stage	Active period		Types of waste placed in landfill
	Start	Closed	
1	1980	1981	C&D waste, soil, yard waste, industrial waste, sludge, household waste, fly ash
2.1	1981	1983	C&D waste, soil, yard waste, industrial waste, sludge, household waste, fly ash
2.2	1983	1985	C&D waste, soil, yard waste, industrial waste, sludge, household waste, fly ash
3	1985	1986	Asbestos, soil, yard waste, industrial waste, non-combustible large waste, sludge, IBA
3A	1986	1987	Asbestos, soil, yard waste, industrial waste, non-comb. large waste, sludge, unsort. waste, IBA
4	1987	1991	Asbestos, soil, yard waste, industrial waste, non-comb. large waste, sludge, unsort. waste, C&D waste, oil-pollute soil, asphalt, road sweepings, sand and screening debris, IBA
4.A			
5	1991	2009	Asbestos, soil, yard waste, industrial waste, non-comb. large waste, sludge, unsort. waste, C&D waste, oil-pollute soil, asphalt, road sweepings, sand and screening debris, batteries, IBA
6	2009	-	Asbestos, C&D waste, soil&rocks, slightly cont. soil, IBA, fly ash, mixed waste, sludge, sand and screeing debris

Table 3.3 shows the types of bottom liners, the top cover and the activities currently carried out on the surface of each of the landfill cells. It is noteworthy that very few of the cells have been equipped with a top cover, and that various waste management activities are carried out on top of all of cells.

Figure 3.3 shows the leachate collection system at Skaarup Landfill, including the sampling points for leachate from Cell 5, Cell 6 and the combined leachate from Cells 1 to 4, 5 and 6.

Table 3.3: Overview of bottom liners, top covers and activities on the top of each of the cells at Skaarup Landfill. Source: Miljøcenter Århus (2009) and information from RenoSyd i/s (2014).

Stage	Active period			Bottom liner	Top cover	Activity on top of the cells
	Start	Closed				
1	1980	1981			None	Composting
2.1	1981	1983		1 + 2-3 m clay	None	Storage of sludge, metal + comp.
2.2	1983	1985			None	Storage of baled waste, sorting of IBA
3	1985	1986		0.5 m compacted clay	0.8 m clay+ 0.3 m sc	Storage of compost and metal
3A	1986	1987			None	Storage of waste suited for incineration
4	1987	1991			0.8 m clay+ 0.3 m sc	Storage
4.A					None	Sorting
5	1991	2009		0.6 m compacted clay	None	Storage
6	2009	-		0.5 m clay + HDPE liner	None	Treatment of sulfide containing leachate

Figure 3.3: Overview of the leachate collection system at Skaarup Landfill, including the sampling points for leachate from Cell 5, Cell 6 and the combined leachate from Cells 1 to 4, 5 and 6.

Figure 3.4 shows the total annual amounts (in tonnes) of waste landfilled at Skaarup Landfill from 1980 to 2012 as well as the total annual amount of leachate collected from the landfiil. The information in these graphs is based on the records kept by RenoSyd (included in the data file stored at Dansk Affaldsforening). Figure 3.5 shows the data in Figure 3.4 accumulated over time, i.e. accumulated total amounts of waste landfilled and accumulated total amounts of leachate collected at Skaarup Landfill from 1980 to 2012.

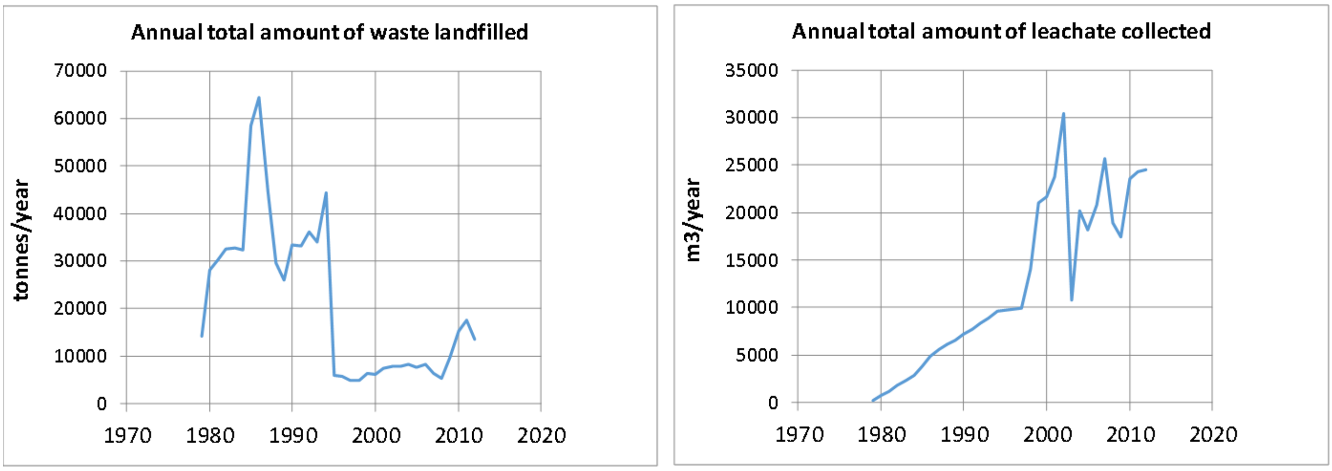

Figure 3.4: Annual amounts of waste landfilled and leachate collected from 1980 to 2012 at Skaarup Landfill.

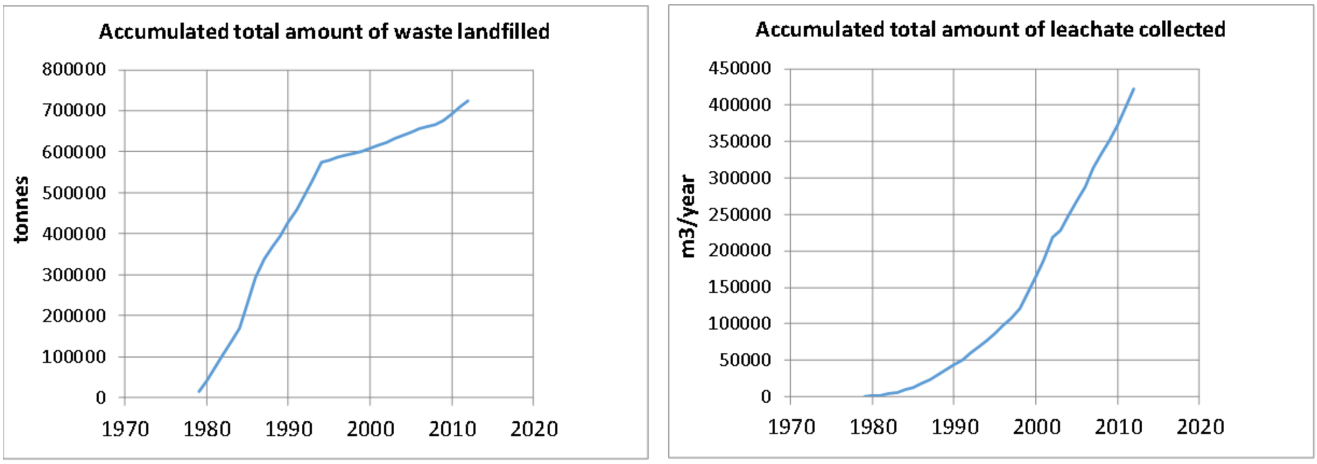

Figure 3.5: Accumulated total amounts of waste landfilled and leachate collected from 1980 to 2012 at Skaarup landfill.

According to Miljøcenter Århus (2009) the leachate production rate during the period 1998 to 2007 from the cells 1, 2.1, 2.2, 3, 3A, 4, 4A and 5 with a total surface area of 79,900 m^2 varied between a low of 10,750 m^3 (in 2003) and a high of 25,700 m^3 (in 2007), corresponding to 135 mm and 322 mm, respectively. Figure 3.6 shows the significant variation in leachate production during that period (can also be seen from Figure 3.4).

In Figure 3.7, the annual amounts of waste landfilled and the annual amounts of leachate collected have been combined to produce a graph showing the accumulated overall liquid to solid ratio, L/S, as a function of time.

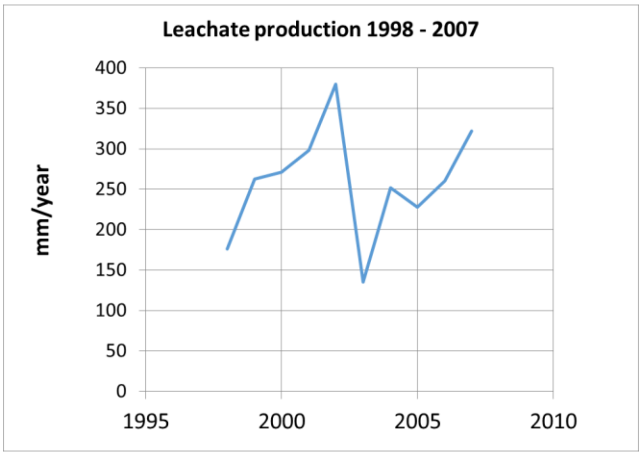

Figure 3.6: Leachate production in mm/year for the period of 1998 to 2007 at Skaarup Landfill.

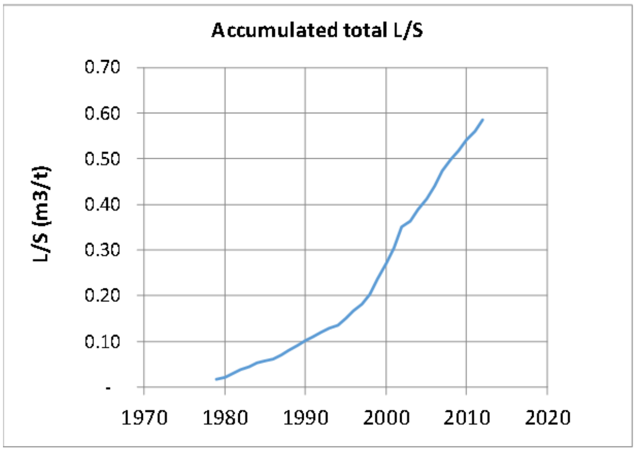

Figure 3.7: Accumulated overall L/S as a function of time for the leachate produced at Skaarup Landfill.

From Figure 3.7 it can be seen that the overall L/S value has reached a value of approximately 5.8 l/kg or m^3/tonnes. Obviously, this is a very crude measure, since it is a mixture covering higher L/S values for the earlier cells and much lower L/S values for the recent and current cells. More information will be required to provide more accurate estimates for cells 1 to 4. For cells 5 and 6, estimates can be carried out but they will be low. It is generally assumed that L/S values at least between 2 and 5 (or even higher) will be necessary before it can be considered to end the after-care.

Table 3.4 shows some examples of the composition of three types of leachate that are monitored: Mixed leachate from all cells and leachate sampled separately from Cell 5 and Cell 6. For comparison, expected environmental standards or criteria for groundwater and inland surface water quality for some of the substances are shown in Table 3.5. It can be seen that even for the mixed leachate, a dilution or attenuation of ammonia of 180 times is required to reach the inland surface water quality criterion. In its current state (reduced), the concentration levels of trace elements/heavy metals seems to be less problematic. However, much more specific information will be required to perform an actual assessment of the expected duration of the aftercare period for the various cells. Some attenuation will occur during transport of the substances from the source (the landfill) to the receptor (e.g. Skanderborg Lake), and it must be ensured that there are no valuable groundwater resources along the transport path. At the lake, an initial dilution of approximately 10 times may generally be assumed. Because of the lack of cell-specific leachate information, improving measures such as targeted recycling schemes (other than those possibly already practiced at Cell 6) has not been considered.

Table 3.4: Selected results of chemical analyses of leachate from Skaarup Landfill sampled on 8 October 2013.

Parameter	Unit	Mixed leachate	Stage/unit 5	Stage/unit 6
pH	-	7.8	8.1	8.6
Cl	mg/l	910	730	1700
SO4	mg/l	200	1700	2200
Na	mg/l	590	1000	1500
K	mg/l	470	600	2600
NH3	mg/l	180	100	130
NVOC	mg/l	120	130	210
BOD5	mgO/l	28	21	270
As	µg/l	12	15	400
Cr	µg/l	10	14	53
Cu	µg/l	11	25	2.4
Ni	µg/l	24	29	160

Table 3.5: Environmental quality standards.

Parameter	Unit	Groundwater	Inland surface waters
Chloride	mg/l	150[a]	15[b]
Sulfate	mg/l	250[a]	20[b]
As	µg/l	8[c]	4,3[d]
Cr (tot)	µg/l	25[c]	3,4
Cu	µg/l	100[c]	1[d]
Ni	µg/l	10[c]	2,3[d]
DOC/NVOC	mg/l	3[a]	3
Ammonia-N	mg/l		1[e]

a: Values used in calculations of the WAC for landfilling in BEK nr. 1049/2013.

b: Proposal: 1/10 of the groundwater quality criteria. No Danish criteria exist.

c: From ”Liste over kvalitetskriterier i relation til forurenet jord og kvalitetskriterier for drikkevand” (Miljøstyrelsen, 2014a).

d: From ”Bekendtgørelse nr. 1022 af 25. august 2010 om miljøkvalitetskrav for vandområder og krav til udledning af forurenende stoffer til vandløb, søer eller havet.”

e: Quality criterion set by local authorities.

4. Recommendations

In order to investigate whether or not it might be possible to assess the duration of the aftercare period for at least the older cells at Skaarup Landfill, efforts should be made to collect some the information that is currently lacking, in particular more cell-specific information. It should be considered if it would be possible somehow to adjust the existing leachate drainage system in such a manner that leachate production can be monitored for individual cells or groups of individual cells for Cell 1 to 4, and the leachate monitoring programme should be changed to ensure that the analytical programme proposed in Annex A is carried out at least once a year for all cells and currently twice a year for Cells 5 and 6.

5. References

Miljøcenter Århus (2009): Afgørelse om overgangsplan og revurdering for Affaldscenter Skårup, Oddervej 75, Skanderborg.

Miljøgodkendelse for deponering af affald på Skårup Losseplads, Århus Amt, 1979.

Lokalplan nr. 006 for en kontrolleret losseplads ved Skårup, Skanderborg Kommune, 1979.

Tillæg nr. 1 miljøgodkendelse – godkendelse af slagge/flyveaskedepot på etape 1, 31.03.1981

Godkendelse af 0,5 ha yderligere til 2. etape. (Ulovligt udgravet), 04.03.1982

Godkendelse af nedlæggelse af vejeanlæg + ændret registrering af affald, 09.03.1983

Godkendelse af udvidelse på 3 %. (Ulovligt udgravet), 13.04.1983

Godkendelse af slagge/flyveaskedepot på østlig del af etape 2 del 22. 22.02.1985

Tillæg nr. 2 til miljøgodkendelse godkendelse af etaperne 3-9. 25.03.1985

Specialdepot asbestaffald 08.07.1986

Godkendelse af mellemdeponi for slagger på østlige del af etape 2 del 2, 16.07.1987

Godkendelse af sorteringsanlæg for slagge, 17.08.1987

Indvinding af grus og ler, forøge gravedybde samt fredningsdeklaration, 05.11.1987

Accept af arealudvidelse, 09.06.1988

Godkendelse af knuseanlæg samt mellemdeponi for byggeaffald28.06.1988

Godkendelse af ændring af areal og fyldhøjde, 26.09.1988

Godkendelse af semimobilt forsorteringsanlæg, 28.12.1989

Tillæg nr. 3 til miljøgodkendelse mobil knuser, 26.11.1985

Miljøstyrelsens afgørelse – stadfæstelse af godkendelser af 22.02.1985 og 25.03.1985, 06.06.1986

Midlertidigt oplag af genbrugsmaterialer, 30.10.1987

Miljøstyrelsens afgørelse – tilladelse til mellemdeponi af brændbart affald, 28.03.1988

Godkendelse af knuseanlæg samt mellemdeponi for byggeaffald, 28.06.1988

Godkendelse af kompostering af haveaffald, depot for træaffald samt flytning af mobil knuser, 17.10.1990

Godkendelse til deponering af forurenet jord, 13.12.1990

Godkendelse af øget deponeringsdybde og recirkulering af perkolat, 03.01.1991

Godkendelse af semimobilt forsorteringsanlæg, 11.04.1991

Århus Amt Miljøkontoret, 1992. Teknisk rapport. Grundvandsforhold i Skanderborgområdet.

Godkendelse af mellemlager for kemikalieaffald, 24.02.1992

Godkendelse af depot for restprodukter fra røggasrensning, 01.09.1992

Vedrørende revision af kontrolprogram – tillæg til miljøgodkendelse 3.11.1992

Vilkårsændringer vedrørende retableringsbetingelserne jf godk. 26.09.1988, 22.06.1993

Godkendelse af mellemlager for kemikalieaffald,16.05.1994

Forlængelse af godkendelse af depot for restprodukt fra røggasrensning, 19.12.1995

Rapport for miljøtekniske undersøgelser, Skårup Losseplads, Skanderborg Kommune, jour.nr. 8-76-5-745-3-93, Carl Bro A/S for Århus Amt, oktober 1997.

Teknisk resumérapport, affaldsdepot og kontrolleret losseplads, Skårup Losseplads, Skanderborg Kommune, Carl Bro A/S for Århus Amt, februar 1998

Godkendelse af deponering af eternitplader og mellemdepot for letjern, 17.08.2000

Miljøansøgning for aktiviteter på Skårup Losseplads, I/S RENO SYD/COWI, 2000.

Supplement til miljøansøgning for aktiviteter på Skårup Losseplads, I/S RENO SYD/COWI, 2000.

Korrektion til miljøgodkendelse af 17. august 2000 mellemdepot for letjern, 28.06.2001

Tillæg til miljøgodkendelse af mellemlagre af forbrændingsegnet affald, balleteret affald, olie- og kemikalieaffald og klinisk risikoaffald, 03.07.2001

Tillæg til miljøgodkendelse – kompostering af haveaffald på dele af etaperne 1, 2.1, 2.2 og 3, 08.08.2002

Tillæg til miljøgodkendelse af midlertidigt mellemlager af slam fra renseanlæg, 08.04.2002

Indberetning af oplysninger til klassificering af Skårup Miljøanlæg, I/S RENOSYD, februar 2002.

Miljøstyrelsens afgørelse af klager over 3 tillæg til miljøgodk. af 28.06.2001, 03.07.2001 og 08.04.2002, 02.05.2003

Et års forlængelse af miljøgodkendelse til kompostering af haveaffald på dele af etaperne 1, 2.1, 2.2 og 3, 23.06.2004

Tillæg til miljøgodkendelse af mellemlagre af forbrændingsegnet affald og klinisk risikoaffald, 22.12.2004

Tillæg til miljøgodkendelse – et halvt års forlængelse til mellemlager for slam fra renseanlæg, 26.04.2005

Tillæg til miljøgodkendelse – et halvt års forlængelse til kompostering af haveaffald samt til mellemlagre af forbrændingsegnet affald og klinisk affald,14.06.2005

Udvidelse af mellemlager af forbrændingsslagge, 29.06.2005

Tillæg til miljøgodkendelse – et års forlængelse til kompostering af haveaffald samt til midlertidig mellemlagre af slam fra renseanlæg, forbrændingsegnet affald og klinisk affald, 25.10.2005

Tillæg til miljøgodkendelse – et års forlængelse af udvidelse af mellemlager af forbrændingsslagge, 27.06.2006

Tillæg til miljøgodkendelse – et års forlængelse til kompostering af haveaffald samt til midlertidig mellemlagre af slam fra renseanlæg, forbrændingsegnet affald og klinisk risikoaffald, 25.10.2006

Tilladelse til udvidelse af driftstiden i ugerne 19-22, 2007 for balletering af forbrændingsegnet affald, 15.05.2007

Afgørelse om at dobbeltindpakket og mærket knust asbest ikke skal klassificeres som farligt affald, 05.07.2007

Forlængelse af miljøgodkendelse af udvidelse af mellemlager af forbrændingsslagge, 18.07.2007

Tillæg til miljøgodkendelse – et års forlængelse til kompostering af haveaffald samt til midlertidig mellemlagre af slam fra renseanlæg, forbrændingsegnet affald og klinisk risikoaffald, 12.09.2007

Geoteknisk Rapport nr. 1, Skårup Losseplads, Etape 6, Grontmij/Carl Bro, juli 2007.

Skitseprojekt, Skårup Losseplads, Etape 6, Grontmij/Carl Bro, November 2007

Forlængelse af mellemlager af forbrændingsegnet slagger, Tillæg til miljøgodkendelse vedr. udvidet driftstid og modtagelse af lettere forurenet jord, 20.06.2008

Tilladelse til afledning af spildevand § 28, 13.05.2008

Forlængelse af mellemlager af forbrændingsegnet slagger, 30.10.2008

Forlængelse af miljøgodkendelse af kompostering a haveaffald samt miljøgodkendelse til midlertidige mellemlagre af forbrændingsegnet affald og klinisk risikoaffald, 30.10.2008

Forlængelse af miljøgodkendelse af kompostering a haveaffald samt miljøgodkendelse til midlertidige mellemlagre af forbrændingsegnet affald og klinisk risikoaffald, 22.07.2009

Forlængelse af mellemlager af forbrændingsegnet slagger, 22.07.2009

Annex A

Request for data from Skaarup Landfill as input for estimation of the duration of the aftercare period ("Wish list")

Leachate data and other information should to the extent possible be reported on the basis of single cells or units with separate monitoring and sampling points. Under all circumstances, data should be referred to the relevant landfill compartments and operation periods.

In addition to data, a general historical description of the development of the landfill from its start until now is desired, supported by maps, applications, permits, risk assessments and geological/hydrogeological investigations. The following more specified information should also be supplied:

Landfill design (per unit/cell)

- Overfladeareal (både ved toppen og ved bund/bundmembran, hvis de afviger væsentligt fra hinanden)
- Surface area (both at the top and at the bottom liner if they are significantly different)
- Average height
- Type of bottom liner (details should be described)
- Type of top cover (details should be described)
- Design of draining system for leachate
- Design and location of sampling and monitoring points for leachate
- Design and location of systems for collection and application/combustion of gas
- Design and location of surface drains

Operation

- Specification of time periods when the various waste types were deposited (with specification of cells/units and main waste types)
- Landfilling methods applied (vertically (backfilling), horizontally in layers (approximate thickness), daily cover (if used, with what?), compaction, etc.)
- Indication of the periods/points in time when completed units were covered

The waste (per unit/cell)

- Typer af affald modtaget/deponeret
- Types of waste received/landfilled
- Annual amounts of each type of waste landfilled during the operation period (in tonnes and or cubic meters)
- All available information on the physical and chemical properties of the waste, including composition and leaching properties
- The origin of the waste (particularly if all or a large part of the waste was produced by the same company/institution)

Quantity of leachate/water balances (per unit/cell)

- The amount of leachate produced/collected as a function of time (e.g. on a monthly basis (preferred) or on an annual basis over the entire lifetime of the unit/cell) – please indicate how the data were assessed/measured/calculated
- Monthly (preferred) or annual data on local precipitation and temperature (the origin of the data should be indicated – at the landfill or from a nearby weather station or other)
- Information on observed or suspected leakages or other unintended occurrences that may influence the amount of leachate measured
- Information on all water flows that are monitored within the landfill area
- Information on all water balance calculations that may have been carried out for the landfill
- Information on how collected leachate is managed

Leachate quality (per unit/cell)

- Prøvetagningsstedet og dets indretning
- Location and design of leachate sampling points
- Sampling methods (pumping, random sampling, flow proportional sampling?)
- Date for each sampling
- Pre-treatment of leachate samples (filtration/no filtration, in-situ/on-site measurements, etc.)
- Who carries out the sampling?
- Which laboratory performs the chemical analyses
- Results of leachate analyses and the analytical methods used (see also proposal for basic analytical programme for leachate below)
- Temperature of the leachate when sampled

Leachate data in excel format are preferred, possibly supplemented with information on analytical methods and possibly with copy of the original reports from the chemical analytical laboratories attached.

Gas production (per unit/cell)

- Opsamlet gasmængde per måned eller år
- Amount of gas collected per month or year
- Available information on the composition of the gas
- Management of the gas after collection

In addition, information is desired on all relevant studies and projects which over time have been carried out in relation to the landfill.

Proposal for chemical analytical programme for the leachate (at least once a year)

pH, conductivity, redox potential, chloride, fluoride, sulfate, HCO_3^-, NVOC/DOC, benzene, toluene, xylenes and ethyl benzene, hydrocarbons, PAH (sum of 4), phenols, Al, Si, Ca, Mg, Ti, Fe, Mn, Na, K, As, Ba, Cd, Cr, Hg, Mo, Ni, Pb, Sb, Se, V and Zn.

The parameters shown in bold are not included in Table 2.3 in Statutory Order No. 1049/2013 on landfills (BEK 1049/2013). If possible, it would be useful to carry out the analyses for chloride, fluoride, sulfate, DOC, Al, Si, Ca, Mg, Ti, Fe, Mn, Na, K, As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, V and Zn both before and after filtration (0.45 micron filter), at least a few times.