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Long term monitoring of leachate flux into drainage pipes of MSW landfills

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Abstract

The measurement of leachate quality and quantity is an essential part of the monitoring of landfills in the different phases during their lifespan. These measurements allow the evaluation of the decomposition processes in the landfill and the efficiency of technical installations for the reduction of the leachate generation. Normally the measurements are made at the outlet of larger sections of the landfill or at the overall landfill. An identification of smaller parts with different biological or hydraulic behaviour within the landfill section is not possible in that case. In the framework of a long-term research project concerning the monitoring of landfills, different devices for small-scale identification of the leachate discharge were developed at the Technical University of Braunschweig. The device allows a measurement of the leachate discharge inside a single drainage pipe having a length up to 375 m. The measurements showed the influence of changes in operation. It was found that the discharge in the pipes and the efficiency of the drainage system was strongly influenced by deformations and torsion of the high-density polyethylene pipes and unequal settlements of the subsoil. The discharge of leachate in the drainage system was, as expected, very non-uniform and in parts the leachate was not flowing inside the pipes, but rather in the surrounding gravel layer. Furthermore, large differences in leachate quality may occur, whereas the differences in discharge volume are small. With the developed system it is possible to control the efficiency and the functioning of top cover systems for landfills.

Keywords

Landfills, monitoring, long-term emissions, leachate, aftercare

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Introduction

Landfills are constructions which must show functional safety over several generations because the deposited waste materials are likely to cause a hazard to the environment at large and to human health in particular. Determination of leachate volumes and qualities is therefore an important element during the monitoring of landfills in the different phases of their operation. These measurements are important in terms of the following activities.

- The evaluation of the decomposition processes in the landfill and the determination of the necessary phase of leachate collection and treatment.
- Establishing a data basis for the prognosis of the long-term behaviour of the landfill and for the verification and adaptation of the models.
- The survey of the efficiency of the technical installations (e.g. top cover systems) for the reduction of leachate generation.
- Monitoring the leachate distribution during recirculation.

The measurements are the basis for the evaluation of the long-term risk potential of the landfill. Furthermore the landfill directives require that the results obtained from monitoring have to be compared with the calculations made to evaluate the future emission behaviour. The prognosis for the emissions is made by models which should take into account all processes leading to a generation of leachate or by extrapolating the existing data. In any case the quality of the prognosis is decisively dependent on the quality of the measured data. Very often the leachate emissions are only determined at a few points, and often in short-time intervals and these values are assumed to be representative for the landfill, which might have a surface area of several hectares.

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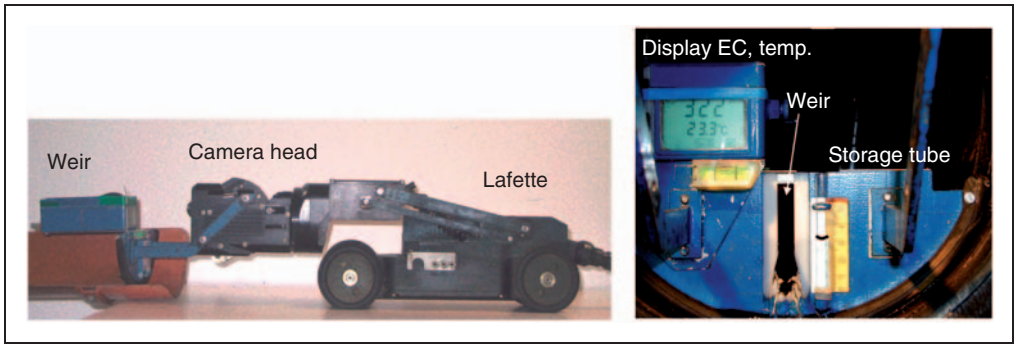

Figure 1. Camera lafette with weir (left); view through the camera on the weir (right).

A lot of measurements on landfills had been made in recent years with a view towards the optimization of degradation processes in landfills and the closely connected distribution of water in landfills, especially after leachate recirculation (e.g. Chang & Gagnard 1995, Döberl et al. 2002, Rosqvist et al. 2007). Most of these investigations had the above-mentioned disadvantages or they give only qualitative information about leachate distribution. The optimal system would be one which uses the installed technical equipment and which allows monitoring of leachate resulting from small sub-areas of the landfill in defined time intervals.

Different measuring devices for the improvement of the prognosis for the leachate at the landfill base have been developed at the Leichtweiss Institute within a research project funded by the Deutsche Forschungsgemeinschaft.

One of the new measuring devices for the determination of leachate influx to the drainage pipe is introduced in detail and the results from practical use demonstrate the capability of this method.

Methods and investigated site

For the measurement of the leachate outflow on a small scale two different measurement systems were developed. One system was installed at the outlet of a single drainage pipe and the outflow volume was registered continuously. With this system the catchment area was reduced from several hectares for the whole landfill to a maximum of about 12 000 m^2 for a single pipe (according to German regulations: maximum length 400 m, maximum distance between two pipes 30 m). The system, which is not considered herein (more details in: Ziehmann & Collins 2001, Münnich et al. 2005), allowed an observation of changes in landfill operation (temporary closure of waste disposal, re-uptake of disposal, installation of top cover systems, etc.) and of climatic influences on long-term leachate generation. Even then, the catchment area might be too large for a detailed examination, because the mass of waste disposed of in the area might be very high (e.g. about 500 000 t at a landfill height of 40 m) and, furthermore, the MSW showed a large variability in its physical and biochemical properties.

For the determination of the influx of leachate into the drainage pipe a measurement device was developed on the basis of a commercially available camera system, which is commonly used for the inspection of drainage pipes. A spillway weir was installed on the camera head, which can be moved in all directions (Figure 1). The placement of the weir and the required temporary sealing of the leachate flow in the pipe can be controlled by the movement of the camera head. After the measurement it can be controlled if a bypass-flow of leachate has occurred through the slots of the pipe.

A supplementary data transfer cable was not necessary because almost the entire spillway weir was visible through the camera. The height of the impounded water is measured over a storage tube with a millimetre scale, which is also readable through the camera. In addition a sensor for electrical conductivity and temperature is installed on the weir to identify changes in leachate quality. The efficiency of the camera carriage is only reduced very minimally by the installation of the spillway weir.

By lowering the weir the rubber seal is pressed against the bottom of the pipe and the free flow of leachate in the pipe is completely cut off. The construction of the rubber seal allows a closure of deformed pipes with variations up to 5–7 mm from the circular profile of the pipe. The lowering of the weir induces a backwatering of leachate, whose height can be read off at the storage tube, which has a millimetre scale on the side. The maximum height of the overfall is 50 mm, which corresponds to a flow-rate of between 13 and 7 L min^{-1} depending on the type of weir. In addition the temperature and the electrical conductivity are determined in the leachate. The volume of leachate is calculated with the help of a calibration curve. The disadvantage is that these data are stored automatically. The position of the camera lafette inside the drainage pipe is measured with the odometer of the supply cable.

Starting from the measured results and the known geometry of the landfill base, a surface-specific calculation of discharge can be made. The total length of the drainage pipe can be divided into parts of different lengths by changing the measuring point distances. Thus the specific collection

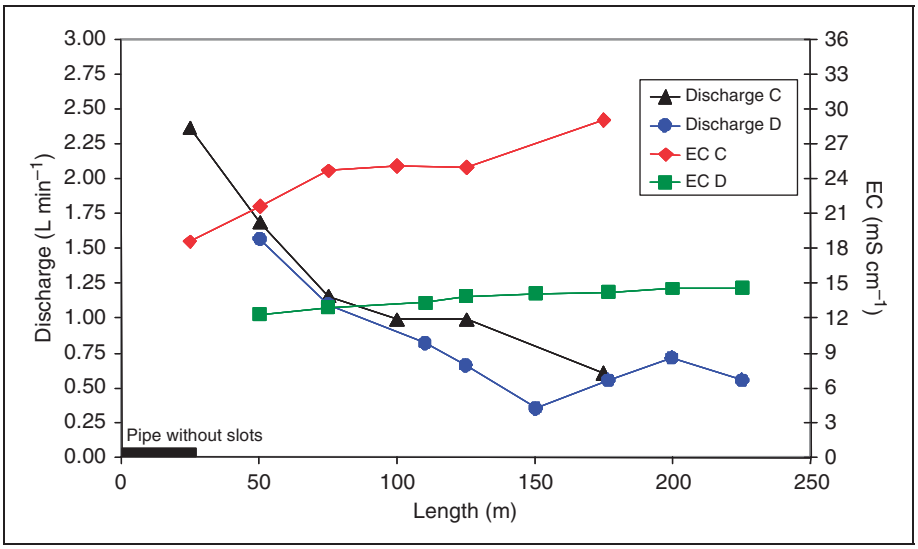

Figure 2. Results from monitoring in two adjacent pipes.

area can be adapted to the conditions present at the actual landfill.

The measurements of the influx of leachate to the drainage pipes were made at a landfill in Germany. The specific landfill area was in operation from mid-1994 until May 2005 and only non-treated fresh MSW was deposited. After the phase of disposal a combination of high-density polyethylene-foil and soil material was installed as top cover system on the surface. The base liner system and the drainage system were built according to the German landfill ordinances. The maximum height of deposited waste is about 55 m above the base liner system. In some areas of the landfill a leachate recirculation over shafts is performed and surface water, which had not been in contact with waste, is infiltrated into the drainage system in known areas.

The measurements were performed in seven adjointed pipes of a sub-area of the landfill. The distance between the pipes was 30 m, the length was from 294 m up to a maximum of 364 m. The inside diameter of the drainage pipes was 290 mm and outside diameter was 400 mm. The angle for the identification of the non-slotted area amounted to 120°; meaning that, from a backwatering of about 7.25 cm on, the leachate was flowing back through the drainage openings into the surrounding gravel layer. In the area of the lead-throughs of the outer slope, over a length of about 20–24 m the pipes had no opening on the surface. The mean slope of the pipes was from 1.3 to 1.4% when the measurements were started.

Results from monitoring

In the period from 2000 to 2009 *in situ* measurements were conducted at regular intervals. The distance in the pipes between the two measurements points was variable; that is, it was adapted to the special conditions of each pipe. In any case an attempt was made to limit the maximum distance to 25 m, but in some parts this was not practicable because of high local settlement of the liner system with backwatering and high deformations of the pipes, which made sealing of the pipe impossible.

The direct results of the monitoring are shown in Figure 2 for two pipes C and D, lying at a distance of 30 m.

The only similarity in the discharge behaviour in both pipes was, as to be expected, the increase in discharge volume over the distance in the direction of the outlet, whereas the total volume in pipe C was much larger than in pipe D. The steep curve progression in the section from 25 m up to 75 m in pipe C shows that in the region of the slope the discharge volume increased strongly. The monitoring in the adjacent pipe D showed in part a different behaviour. The total discharge volume was obviously lower and in the section between 150 and 200 m the discharge volume in the pipe was decreasing. It is to be expected that in this section the base liner had no imperfection which allowed any volume of leachate to be infiltrated into the underlying natural soil. The reason for this decrease was that the leachate was not flowing inside the pipe but in the surrounding gravel layer. Such by-passes are a result of unequal settlement of the pipes, deformations and torsions or poor fitting of the pipes.

The quality of the leachate – determined as EC – was different in the two pipes, although in both pipes the values decreased in the direction towards the outlet. The leachate in the border area of the landfill was less loaded in comparison with the central area, a possible reason for that might be the age of the waste, which was higher in the peripheral zone The values in pipe C were much higher and also the decrease was stronger in comparison with pipe D.

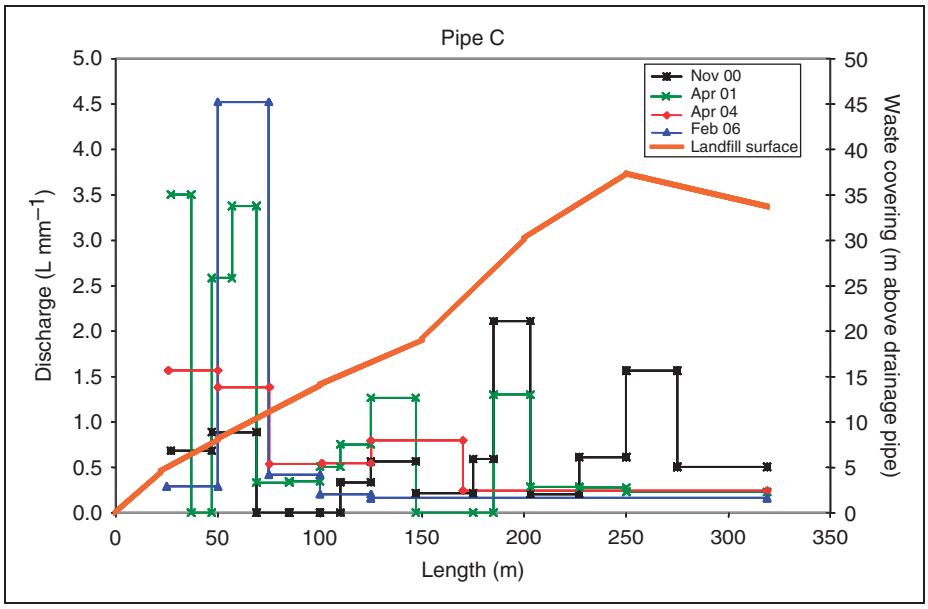

Figure 3. Discharge rate along the pipe C for different dates.

The temperatures in the leachate, which is not shown in the figure, were similar in both pipes. The expected curve progression with smaller values at the outlet, which were caused by the smaller vertical cover of waste and the related higher heat loss, was distinguishable.

The repetitions of the measurements at different dates point out that the areas with high influx volumes to the pipes were changing along the flow path. In Figure 3 the results of four measurements made in the interval from November 2000 up to February 2006 in pipe C are shown. A similar behaviour was also observed for the rest of the pipes. In this figure the discharge rate, which was calculated from the measured leachate volume, the distance between two measurements points and the horizontal distance of 30 m between the two pipes is shown. It becomes obvious that in the first years most of the discharge occurred in the zone from about 150 m on. In the following years the influx to the pipe was more and more relocated towards the outlet, in the zone between 25 m up to about 75 m. As other monitoring measurements did not give any hints that this occurrence was a result of bad spots in the top cover system caused by rainwater that infiltrated the landfill, it has to be assumed that the leachate in the zone ahead was not flowing in the pipe but in the surrounding gravel layer.

Furthermore the curves show that due to the ongoing deformation of the pipe the measurement of the leachate volume had no longer been possible beyond 175 m since 2004 and beyond 125 m since 2006.

Figure 4 shows the spatial distribution of the leachate discharge at the landfill base for two different dates. The line of sight is from the maximum height of the base liner to the outlet of the drainage pipe.

On both dates it can be seen that most of the leachate was flowing in the lower area of the landfill, near the outlet of the pipes. It is also obvious that even at this small scale some large differences in the leachate volumes existed. Noticeable are the very high discharge volumes on the right side of the areas looked at in the drain pipe at 180 m. In this area the surface run-off from other landfill areas was infiltrating. Whereas in 2003 a continuous increase of discharge volume up to 2 L min^{-1} at the outlet could be observed in nearly all drainage pipes, the discharge distribution in 2009 was quite different in this area of the landfill. The recirculation of leachate near the centre of the landfill area caused a strong increase in discharge along the drainage pipe in the region of 225 to 175 m. In the remaining length of the pipe up to the outlet the increase in discharge was only caused by rainfall and/or biochemical and physical processes and it was of the same order as in the areas which were not influenced by the recirculation. The distribution of discharge at the landfill base showed that although the hydraulic behaviour was anisotropic [the horizontal permeability was much higher than the vertica (Khandbilvardi et al., 1992, Hudson et al. 1999, Münnich et al. 2005)] the spatial spreading of injected leachate was small.

For a better interpretation of the observed differences in the discharge along the flow path in the pipe and the increase near the outer slope, the settlement of the pipes was determined with a hydrostatic profile system developed at the Leichtweiss-Institute (Bauer et al. 2005). In some pipes the local settlement was so high that the required minimum slope of 1% no longer existed. Especially in pipe C the settlement had led to a slope which was opposite to the flow direction of the leachate. The settlement was so great that leachate entered the slots of the pipe and flowed back into the gravel layer. These settlement measurements were consistent with the measurement of the specific leachate discharge. With the help of the camera it was possible to distinguish areas

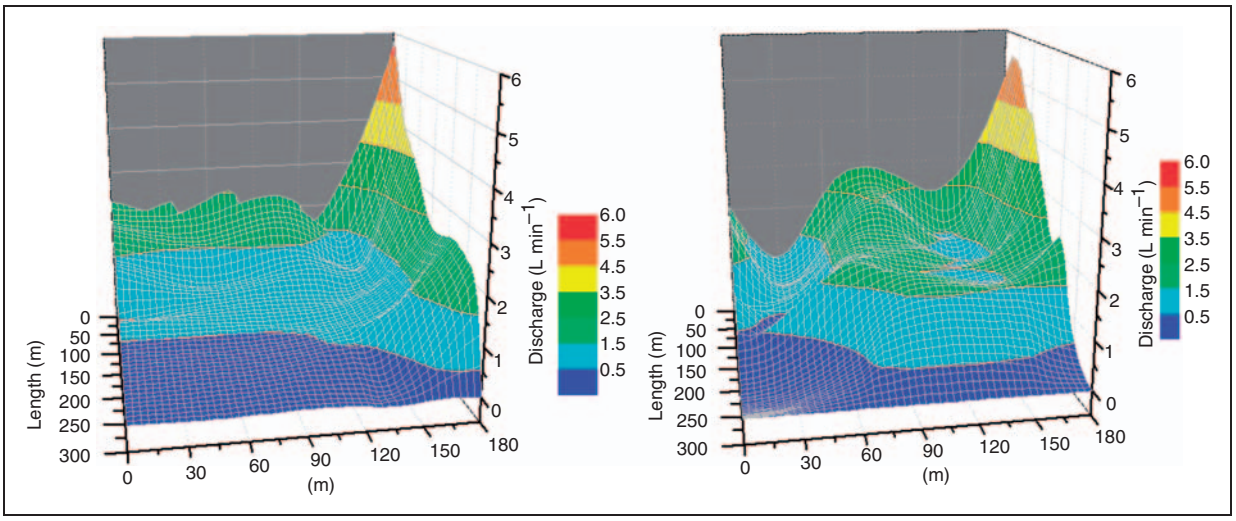

Figure 4. Distribution of leachate discharge at the landfill base, June 2003 (left) and June 2009 (right).

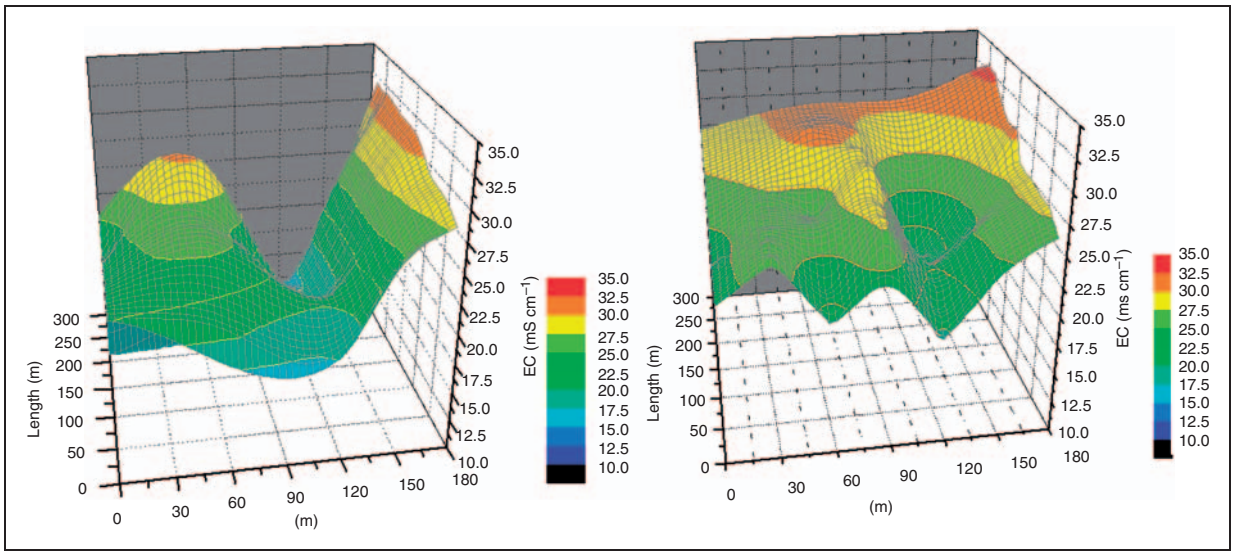

Figure 5. Distribution of EC in leachate at the landfill base, June 2003 (left) and June 2009 (right).

where torsion of the pipes had occurred, so that even with low water levels in the pipe the leachate was flowing back through the slots into the drainage layer. High local settlement and backwatering of leachate in the area near the outer landfill slope may lead to slope stability problems.

The quality of the leachate was also related to the volume. In Figure 5 the distribution of the electrical conductivity (EC) in the leachate is shown for the same measurement dates as before. The line of sight in these graphs was from the outlet to the maximum height of the landfill base.

The results show that in the area where surface water was infiltrated (area at 180 m) the EC was very high. This might on one hand be the result of intensified leaching by applying water to the waste or on the other hand because the surface water had been in contact with waste before being infiltrated. Furthermore, the leachate in other areas showed large differences in the values, which could not directly be related to differences in the discharge volume. This was especially significant in 2003, when the differences in discharge volume were small on the left side of the landfill, whereas the concentrations in leachate showed large differences.

The distribution of temperature showed only slight differences over the investigated areas. Higher values could be observed near the area of recirculation, but a spreading over large areas was not recognizable. The lowest values were measured in the older part of the landfill area and in the direction of the slope, where the height of deposited waste was lower and therefore the losses of energy over the surface higher.

Conclusions

Up to now the raster for the monitoring of leachate discharge volume of landfills is rather rough. Very often only the inflow volume to the purification plant is measured. For the required prognosis of the long-term behaviour of the landfill the assumption of a constant discharge rate over all of the base of the landfill is not sufficient. At the Leichtweiss-Institute a measurement device was developed to determine the discharge volume inside the drainage pipes. This system allowed a reduction of the observed catchment area of leachate discharge from several hectares to about $30\,m^2$ The system is described herein and the results of *in situ* measurement are presented. The results are summarized in the following items.

- The leachate discharge along the flow path in the pipes was as expected very unequal, and the areas with increased/decreased discharge volumes were changing temporarily. These well known effects, which hav been described in the past by many authors, are caused by the heterogeneity and the distinct dual porosity of the waste. The temporal changes in zones with different discharges are influenced by changes in operation (e.g. temporary or final covering, leachate recirculation) but also by degradation of the waste. The time until the leachate discharge ceased completely after the construction of the final top-cover system cannot be stated precisely at the moment. Therefore the monitoring in drainage pipes is important for the identification of these different areas and also for the control of the functioning of the cover system.
- In some areas discharge did not occur in the pipe, but in the surrounding gravel layer. This by-pass flow was caused by unequal settlement of the base liner, deformation and torsion of the pipes. In both cases leachate flowed back out from the pipe in the gravel. This effect is not critical as long as the gravel layer shows high permeability and is not influenced by clogging caused by biochemical effects.
- At the outer slope of the landfill an increasing discharge to the pipes could be observed with time. A backwatering of high volumes in this area may cause problems in view of slope stability.
- Especially in the areas of the high slope, settlement and/or uplift of the pipes could be observed. These two last points are closely interconnected. As the slope of the drainage pipes has – at least in Germany – to be controlled at regular intervals, it is known from practice that most of the landfills have areas where the pipes have a slope contrary to the flow direction and therefore areas in which backwatering occurs.
- The horizontal flow of leachate was not very distinctive; namely, although the distance between two pipes was only 30 m most of the recirculated leachate flowed in the pipes directly beneath the area of infiltration. The situation might be different, if during operation a daily soil cover is applied on the landfill surface. In this case the horizontal spreading of leachate might become more important. This different anisotropic behaviour must be taken into account if the often recommended (e.g. MPCA 2009) vertical wells or lances are used in practice for the recirculation of leachate.
- In addition, the leachate impact – in this case characterized by the electrical conductivity – may diverge on a small spatial and time scale. Leachate quality is the most important parameter in view of the determination of the duration of the aftercare phase for landfills. The experience from practice shows that there are considerable differences in leachate quality over short distances (e.g. Sormunen et al. 2008). As a result of dilution and degradation the concentrations in leachate at the base of the landfill are often lower than in the saturated waste body above. Analyses of the leachate quality only at the outlet of a single pipe may therefore not describe the real risk of potential groundwater contamination.
- The temperature in leachate at the landfill base showed only slight differences in the different areas and changed only slowly with time. The temperature in leachate at the base is always lower than in the waste body itself, but the often determined temperatures at the outlet of the drainage are – depending on the landfill construction – often even lower. The determination of the temperature allows the identification of 'hot spots'.

The implementation of monitoring systems for measuring the spatial distribution of the leachate discharge at the landfill base facilitates, in combination with settlement measurements of the drainage layer, a better understanding of the long-term behaviour in the different phases of the landfill and gives a better data base for the required prognosis.

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