EuroGeo4 Paper number 090

SUPERIOR SOLUTIONS WITH GEOSYNTHETICS IN LANDFILL CAPPING APPLICATIONS

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Abstract: Many waste material disposal regulations call for the construction of a so-called "composite-seal" as the standard system for closing municipal and hazardous waste landfills. Such composite seals have proven to be excellent at the base of landfills and have been transferred with only minor technical modifications for use as caps on landfill top surfaces. However, since the mid-1990s, implementation of such standard systems have been increasingly rejected and replaced in favor of alternative structures; this was the result of experience gained in research investigations, lysimeters and excavations.

These alternative structures have increasingly replaced individual system components of the standard seal (e.g. the mineral drainage layer or the compacted clay liner found in conventional structures) with modern, high-performance geosynthetic components. A review of laboratory and field investigations performed over the last 20 years makes it obvious that alternative geosynthetic products (manufactured under high-quality, closely-monitored conditions) often afford better functionality and efficiency than the corresponding mineral components called for in standard systems. Furthermore, these geosynthetics are economically superior often to mineral components by several magnitudes. With regard to overall reduction in carbon dioxide emissions the geosynthetic seals are the preferred answer to climate change concerns.

This is why HDPE geomembranes as convection barriers, geosynthetic clay liners as convection retardants and geosynthetic drainage elements are now increasingly used in surface capping systems.

The paper will depict the development of state-of-the-art technology for the referenced geosynthetics and explain the essential application fundamentals in view of long-term behaviour.

Keywords: landfill, capping systems, geosynthetics, long-term behaviour

INTRODUCTION

Geosynthetic Functions in Landfills

Sealing

Acting as liquid and gas barriers, geomembranes have become a fundamental component in landfill engineering, due to the greater need for groundwater protection. High density polyethylene (HDPE) geomembranes, specifically those with a certificate from governmental side, and a thickness of more than 1.5 mm, in some countries up to 2.5 mm, are mostly used.

In regions where local soils are not suitable for the construction of hydraulic barriers, geosynthetic clay liners (GCLs) can be used to protect the hydrogeological resources by providing an effective barrier against potential risks to the environment. Typical compacted clay liners (CCL) are difficult as well as expensive to build. A geosynthetic clay liner can replace or augment the typical CCL in most designs to minimize the thickness of the sealing system as well as the costs of installation. To be able to judge the sealing properties of a GCL and a CCL, a comparison of the permeability, under consideration of the permittivity (k/d-value), can be worked out. A comparison of the permittivity considers the hydraulic conductivity (k_f-value [m/s]) as well as the effective thickness of the sealing system. Additionally a comparison of the flow rate under consideration of the effective hydraulic head (if drainage is directly on top) can be used.

Protection

Geomembranes, structures, coated material as well as related construction elements must often be protected from potential mechanical damage. Without suitable protection, damage may occur by sharp-edged objects such as stones, from the unevenness of the subsoil or even by the cover material. Mechanically bonded needle-punched non-wovens and even composite materials manufactured from polypropylene (PP) are normally used for protection layers. Specific to non-woven geotextiles, the protection function is directly related to the thickness and mass per unit area, the heavier and thicker non-woven provides better protection.

Drainage

Drainage materials are required for the surface collection of precipitation, the subsurface collection and diverting of groundwater, as well as the general collection of fluids and gases and their diverting into a drainage system. Drainage systems are typically designed with individual material layer or in combination with other components to create pre-formed composite drainage elements. Composite drainage elements consist of at least one filter layer and one drainage layer. The filter layer is required to enable the flow and diversion of fluids to a collection point without the build-up of pressure. Single and multiple component geosynthetic drainage systems, mainly made with polypropylene, often replace the conventional thick mineral drainage layer for liquid or gas collection. The long-term transmissivity [m²/s] gives comparable values about the discharge capacity.

Separation

As a separation layer, geotextiles are used to prevent adjacent soil layers or fill material from intermixing. Synthetic non-wovens that exhibit an elongation capacity are the materials of choice in most applications. The selection of a suitable product depends upon the base course grain size and the operational loads to be expected.

Filtration

In filtration applications non-woven geotextiles are employed to retain soil particles while allowing the vertical passage of liquids through the filter media. Two aspects of filtration should be considered when designing. The mechanical filter efficiency (does the fabric have sufficient soil retention capacity) and the hydraulic filter efficiency (does water divert without a hydraulic pressure build-up). As with mineral filter layers, the geotextile pore size distribution and geotextile thickness directly benefits the long-term mechanical and hydraulic efficiency of the filter.

The US Environmental Protection Agency (EPA) Federal Regulations (US RCRA, 2002) and the European Council Directive on the landfill of Waste describe prescriptive cross sections for hazardous and non-hazardous waste landfill base lining and capping systems. Figure 1 shows the design requirements of the EU Directive. These regulations are minimum standards for the European countries. Many European countries have introduced even higher standards. The sealing components of these systems consist of a mineral layer and a geosynthetic layer.

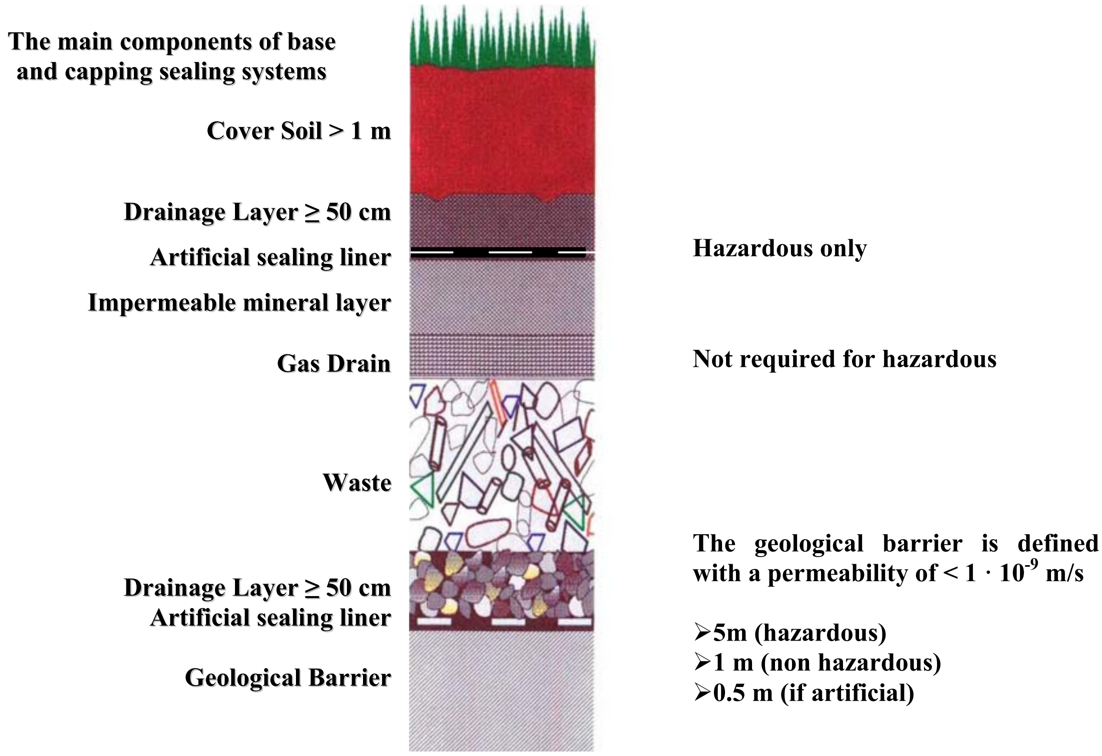

Figure 1. EU Directive, state-of-practice of base and capping sealing systems

In the EU Directive the permeability of the necessary geological barrier is described with $k < 1 \times 10^{-9}$ m/s and a thickness of at least 1.0 m. The HDPE geomembrane should have at least a thickness of 2.0 mm (80 mils). A leachate collection layer of 0.50 m must be installed on top the sealing components. State-of-practice is to install a protection layer, normally a needle punched non-woven with not less than 800 g/m², between the HDPE membrane and the leachate collection layer. The waste is dumped directly on the leachate collection layer.

For the US-EPA Directive for non hazardous landfill base lining systems the regulations for the mineral layer is different to in the EU-directive. There is no need for a geological barrier. The requirement is to install a compacted clay liner in a thickness of 0.60 m with a permeability of $k < 1 \times 10^{-9}$ m/s.

The geosynthetic lining component in this system is a 1.5 mm (60 mils) HDPE geomembrane, which is covered with a leachate collection layer of 0.30 m thickness and a permeability $k > 10^{-4}$ m/s. Before dumping the waste the regulations requirement is to install a filter soil layer over the leachate collection layer.

Landfill Capping

Technically equivalent cost-efficient alternatives can be obtained with complete geosynthetic solutions. In recent years it has become apparent that mineral sealing system can become compromised if settlements of the waste body appear. The settlements result in unacceptable deformations of the CCL that can lead to a permeable CCL even with elongations << 1%. The most serious problem for a top liner is the desiccation (less critical for a geological barrier). The results and the end of the quotation of the status-workshop "Desiccation behaviour of mineral sealing layers in landfill surface sealing systems" (2002) of the German Geotechnical Society is given in the following: "However, it has to be pointed out that in spite of the realisation of the causes and the existing empirical experiences no definite recommendations can be given at the moment for the long-term functional design of landfill surface sealing systems with mineral sealing layers." This statement is still valid also in 2008.

For sealing applications multidirectional shear strength transmitting needle-punched GCLs can replace difficult to build compacted clay liners in non-hazardous landfill as well as hazardous landfill cover system (Figures 2 and 3). Due to their excellent multi-axial strain behaviour, needle punched GCLs retain their sealing capability under high elongation, differential settlement conditions of landfill capping systems. Steep slope applications up to 2.5h:1v are possible with needle-punched non-wovens as the carrier and cover components of these GCLs.

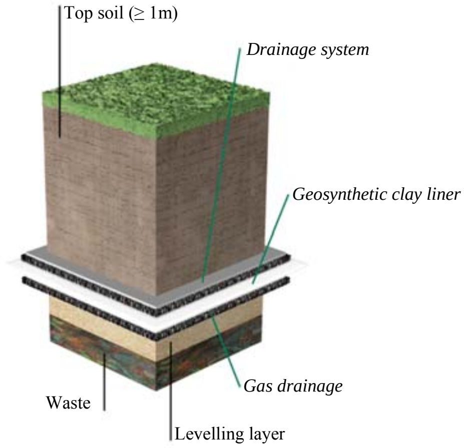

Figure 2. EU directive equivalent capping system (non hazardous)

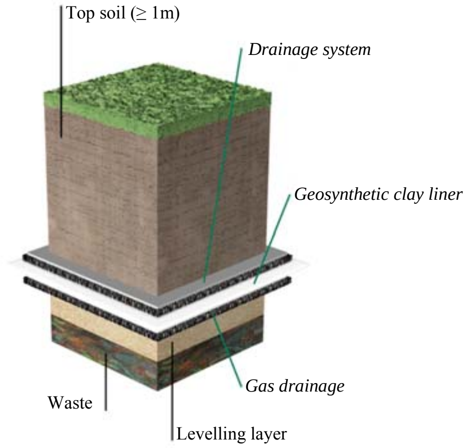

Figure 3. US-EPA directive equivalent capping system (non hazardous)

Geosynthetic clay liners / bentonite mats

Factory-made, shear force transmitting geosynthetic clay liners (needle-punched bentonite mats) have been available for 20 years as substitutes for mineral sealings made in accordance with geoengineering methods. The first positive assessments of installation experience using bentonite mats as the only sealing element in sealing systems on landfill surfaces are based on excavations undertaken in 1990 (on the Grabow landfill; Heerten 2004). From these beginnings, a national and particularly an international widespread use of needle-punched geosynthetic clay liners developed to replace mineral sealings made in line with geotechnical methods in basal and surface sealing systems for landfills.

In the second half of the 1990s extensive tests in the form of 8 excavations in 7 different landfill surface sealing systems were carried out to acquire evidence of self-healing following wet and dry cycles. The bentonite weight per unit area of the excavated products was between 3 kg/m² and 5 kg/m². The products had been subjected to stress under field conditions over 15 to 72 months. The layer covering the bentonite mats was between 0.4 m and 1.0 m. The samples were taken from regions in Germany where the average annual rainfall was stated to be approximately 600 mm/year to approximately 1200 mm/year by the German Meteorological Office. Regarding normal stress factors such as ion exchange, frost, drought and root penetration, all of the samples were subject to stress typical for the respective region and installed systems.

The excavations were carried out and monitored by independent experts with great care so as not to cause any damage to the samples. Permeation tests as per ASTM D 5887 were carried out in tri-axial cells in which water flowing in and flowing out could be measured separately. By taking separate measurements it was possible to differentiate the saturation phase of the stationary flow phase and avoid misinterpretations.

Additional irrigation tests in a lysimeter unit at the University of Essen (Maile 1997) and X-ray tests at TÜV Nord allowed the self-healing process following rewetting and time-dependent improvements in the sealing effect to be presented almost up to the initial value as a "self-healing function".

In 1998, a special-purpose lysimeter unit comprising 6 single lysimeters was built to provide additional evidence of the existing long-term sealing effect under field conditions. It has been in continuous operation since then, supported scientifically and technically by independent experts again (Blümel *et al.* 2003).

Evaluation of the measured results shows very clearly the differences between dry periods in the summer and wet periods in the winter. Figure 4 shows as an example of a lysimeter the corresponding degree of efficiency of a standard bentonite mat and the system efficiency of the whole set-up regarding the existing sealing effect.

The reduced efficiency of the bentonite mat in each summer through desiccation is clearly evident. It is however compensated by summer evapotranspiration from the vegetation layer so that a high level of approximately 98 – 99 % efficiency is retained. It is equally clear that this is followed in each winter by an improvement in efficiency levels which repeatedly achieve the levels of the previous year. As an ion exchange has taken place (exchange of sodium ions for calcium ions in sodium bentonite) in the bentonite layer of the GCL installed in the lysimeter 2 to 3 years after installation, the results document that there is no reason to fear a reduction in efficiency or sealing effect of the system following an ion exchange in surface sealing system with comparable set-ups even after alternating dry and wet cycles (Reuter 2005).

In contrast, comparable research strategies and results proving the efficiency of compacted clay liners (CCLs) are still missing.

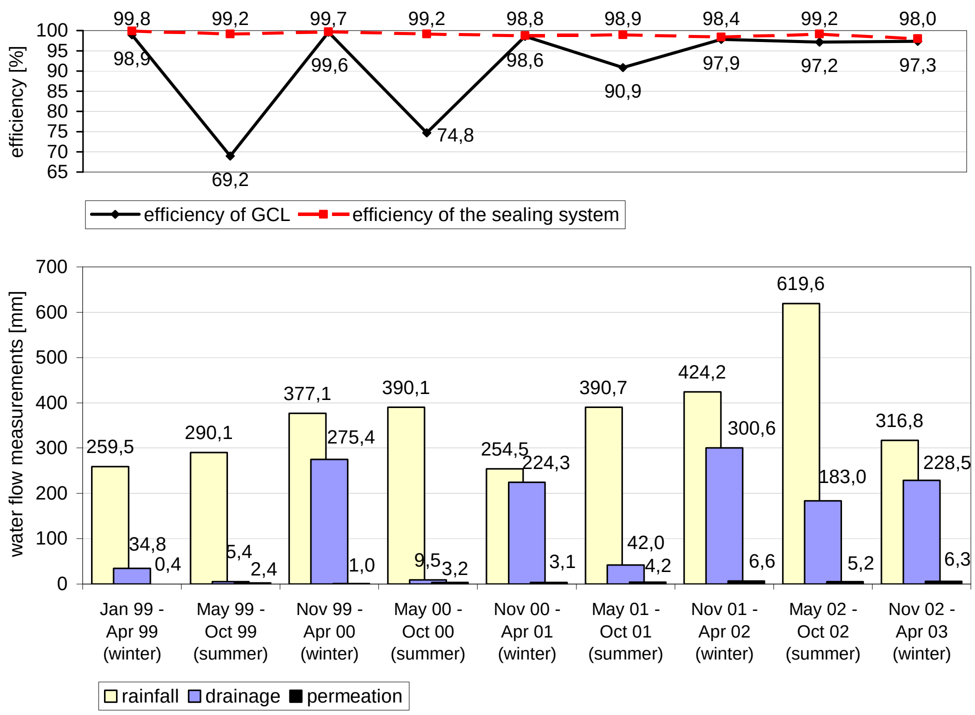

Figure 4. Lysimeter 3 – the impact of summer and winter cycles on the sealing effect of single-layer standard bentonite mats.

In 2000, the Federal Institute for Materials Research and Testing (BAM), Berlin was commissioned to carry out research and development projects regarding the "long-term shear strength of bentonite mats" in order to generate evidence of aging stability of geotextile components and long-term shear force transmission on embankments of a landfill sealing system. After developing and implementing the relevant long-term creep tests in accordance with the long-time established long-term stability testing of geomembranes, in 2003 BAM were able to produce report on the long-term shear force strength of GCL bentonite mats containing the following core statement:

> "Samples of bentonite mats in long-term creep tests at 80°C showed extraordinarily long run times, the minimum creep time of 365 days was clearly exceeded and so far there were no failures in any of the tests. An Arrhenius extrapolation of run times achieved so far shows a lower limit in functional time at 15°C of 200 years."

The tests were continued. No failures have been observed and creep time has, in the meantime, been extrapolated for the GCL to more than 400 years.

Geomembranes

The physical requirements and chemical resistance of HDPE geomembranes for landfill caps are comparable to those needed in landfill basal linings because of the aggressiveness of landfill gas condensate. HDPE geomembranes have been successfully tested for their resistance to many chemical environments and are considered suitable for landfill sealing systems in covers and caps.

Structured or textured HDPE geomembranes are used to increase shear force transmission between the adjacent components under more challenging conditions to ensure long term stability.

Geomembranes must be protected from mechanical damage by cover material or any underlying source. If using a mineral drainage layer mechanically bonded PP non-woven made of crimped staple fibres are often installed rather than a sand protection layer. To avoid significant geomembrane deformation during installation and to ensure long-term protection, needle-punched non-woven geotextile with a minimum mass per unit area of 800 g/m² are recommended.

Geosynthetic Drainage Systems

When used in combination with a HDPE geomembrane, geosynthetic drainage composites not only fulfil the filter and drainage function, but also act as a protection layer for the geomembrane. The drainage geocomposite as a protection and drainage system also prevents deformation in the HDPE geomembrane (see Table. 1).

In landfill caps, geosynthetic drainage systems can effectively transmit and direct the percolated rainwater to a collection or drainage point. Proper drainage minimises the standing water build-up on the sealing element, increases liner efficiency and improve the capping system stability.

State-of-practise geosynthetic drainage systems consist of three individual layers made of following components:

1. filter non-woven – protects the drainage layer from clogging,
2. drainage layer – transmits the water in the filter level,
3. filter/protection non-woven – serves as filter or separation layer to the mineral component or protection layer for the HDPE geomembranes

The composite bonding of the three layers into one ensures the uniform shear force transmission within the drainage system. Due to the uniform bonding, some geosynthetic drainage composites are also suitable for the use in steep slopes. After establishing a testing strategy also for geosynthetic drainage systems BAM (Berlin) has certified some products for the application in final covers of landfills in Germany.

Table 1. Mass per unit area of geotextiles or drainage composites as protection layer in consideration of the height of the waste and the cover soil in Germany

Height of cover soil	Mass per unit area non-woven	Mass per unit area drainage composite
Up to 1.0m	> 800 g/m^2	> 1.000 g/m^2
Up to 1.5m	> 1.200 g/m^2	> 1.000 g/m^2

The stable structure of the core layer of some drainage geocomposite provides the long-term drainage performance of these products. Drainage geocomposite can also be used as the gas venting and protection layer beneath the liner capping system.

Needle punched bonded non-woven filter geotextiles prevent the passage of soil particles from the vegetation layer into the drainage layer. The requirements on the filtration and separation layer are dependant upon the recommendations of the Geotechnics of Landfills and Contaminated Sites Working Group (GDA, 1997). Above all, the long-term permittivity of the geotextile filtration layer must be ensured to prevent the pressure build-up above the drainage layer that could compromise the liner system stability.

With hydraulic and mechanical filter properties defined by the Guideline of the Research Association for Roads and Traffic (FGSV, 1994) and by using a geotextile of at least robustness class 3, the long-term efficiency of the geotextile filter is ensured.

Temporary covers, which are installed during landfill operations and until the main settlements of the waste body have occurred, can minimize precipitation infiltration and reduce gas emissions, when applied prior to the final or temporary seal. A 1.5 mm thick HDPE geomembrane is ideal for this application.

Geosynthetic drainage systems (GDS) have been in use for many years as long-term drainage of rainwater and artesian water in landfills, construction work, tunnel and bridge building, areas where GDS has replaced conventional mineral building materials, thereby protecting natural resources and the environment. For example, just one truck is required to transport a quantity of GDS which would be required for draining an area of approximately 3,500 m² to surface-seal a landfill. As a contrast, around 65 trucks would be required to transport a mineral drainage layer (30 cm of gravel) to drain an area of about 3,500 m² to surface-seal a landfill. Figures 5 and 6 show the easy installation of GDS.

Figure 5. Shear strength transferring drainage geocomposite

Figure 6. Drainage geocomposite on placement top of a GCL

Information regarding selection and dimensioning can be found in a variety of publications. Today, GDS is state-of-the-art.

Experience gained from excavations and a test site

In 1999, the authors in cooperation with tBU (Institut für textile Bau- und Umwelttechnik GmbH) and the Technical University of Munich (Prüfamt für Grundbau, Bodenmechanik und Felsmechanik) carried out 6 excavations in different landfills where GDS had been installed. Further, during the course of the Bay Forrest Research Project F 58 (F) 1999, a large-scale lysimeter unit was set up at the landfill in Kienberg where a variety of drainage layers had been installed. Investigations of the GDS were carried out by the tBU and some by the TU Munich. The GDS had been subjected to stress and strain for a duration of between 2 and 12 years in the landfill cover sealing systems.

The aim of the excavations was to confirm what had been determined in laboratory investigations. Furthermore, an overall impression of GDS, which had been in service for many years, was sought. All of the cases involved GDS comprising a random-fiber non-woven drainage core, with mechanically bonded filter non-woven attached to both sides.

In order to determine long-term drainage capacity of a GDS, something must be known about the expected long-term thickness of the product used. Creep tests carried out in the lab document a dimension of 5-6 mm for the investigated GDS long-term thicknesses. Surprisingly, all thickness measurements of the explored GDS types lay in the region of 6-9 mm, thus quite a few millimetres, but a high percentage more than the results of laboratory creep tests had shown. The results of the excavations show that the laboratory values lie on the safe side and can be used to measure the water drainage capacity in the end situation.

The GDS samples which were dug out were also subjected to long-term stress and strain in a pressure creep test under 20 kN/m² in order to supplement the knowledge gained so far and to investigate future creep behavior of the samples, which, in some cases, had already been 12 years in service. The long-term pressure creep tests and extrapolated long-term prognoses show that even after several years of pre-stress, no difference could be recognized between samples which were as good as new and such as had been subjected to stress and strain over many years. In lab tests, the drainage capacity was determined at hydraulic gradients of i=1.0 and i=0.1. In all cases, the results lay higher than the values that had been expected after dimensioning.

In addition the properties of the separating and filter geotextile that keep the drainage core free of soil sediments in the long term are also significant factors. For this purpose, the geotextile used (mechanically bonded non-woven) must as a filter lead in and drain off rainwater pressure-free into the drainage core, whereby the geotextile must retain the soil without becoming clogged up with fine particles. The long-term permeability of the non-woven is given – as per current regulations – when the permeability of the factor-new non-woven reduced by factor 50-100 is more permeable than the soil to be filtered. It could be proved by means of the excavated samples that permeability had only been decreased by a factor 3 to 8 (in one case a factor of 23). This shows that the prescribed reductions fall distinctly short of the filter regulations for non-wovens and that the filtration long-term behaviour is in accordance with existing design approaches for needle-punched non-woven geotextiles.

Table 2. Hydraulic properties of filter geotextiles

Excavations	**BL**	**OB**	**ER**	**BU**	**WI**	**VI**
Water permeability coefficient (at 20 kPa) k_v [10^{-4} m/s] - practically new / with soil deposits	23 / 3.1	23 / 1.0	40 / 7.7	61 / 2.0	61 / 9.2	23 / 5.8
Actual decrease $-k_v$ [10^{-4} m/s]	7.4	23	5.4	3.1	6.6	3.9
Soil deposits in non-woven [g/m²]	521	39	483	672	1021	136

Excavation locations of operating landfills in Germany:
BL Bleicherode
OB Oberhausen
ER Erbenschwang
BU Burgau
WI Bischofswiesen-Winkl
VI Vinstedt

During the investigations carried out at the Kienberg landfill one of the most outstanding facts to emerge from the series of observations is that even the most heavy discharges of water such as those experienced during the flooding in Bavaria at Whitsun 1999 (rainfall between May 20, 1999 and May 22 1999 was 61.4 mm) into the drainage layer no significant differences to mineral drainage layers (30 cm with 8/32 mm gravel) were determined. This can be seen in the example of measurements made during the Whitsun flooding (Figure 7). The recorded measurements show almost identical drainage capacities in both mineral and geosynthetic drainage layers (GDS).

To investigate the filter and drainage efficiency on the Kienberg landfill, the results from two test sites were compared with each other. A geosynthetic drain mat was installed in test site I. It consisted of a three-dimensional 600 g/m² seepage layer encased with a 300 g/m² filter non-woven layer on each side. A 30 cm thick gravel drainage layer (8/32 mm with k = 1-10^{-2} m/s) was installed in test site IV plus a non-woven (300g/m²) as filter layer between the gravel drainage and the vegetation layer.

The report of the results shows that GDS in comparison with the 30 cm gravel drainage is not only equivalent but far more efficient. It turned out that the tested GDS exhibited a very high reserve capacity that far exceeds the German recommendations even during extremely short-term hydraulic loading.

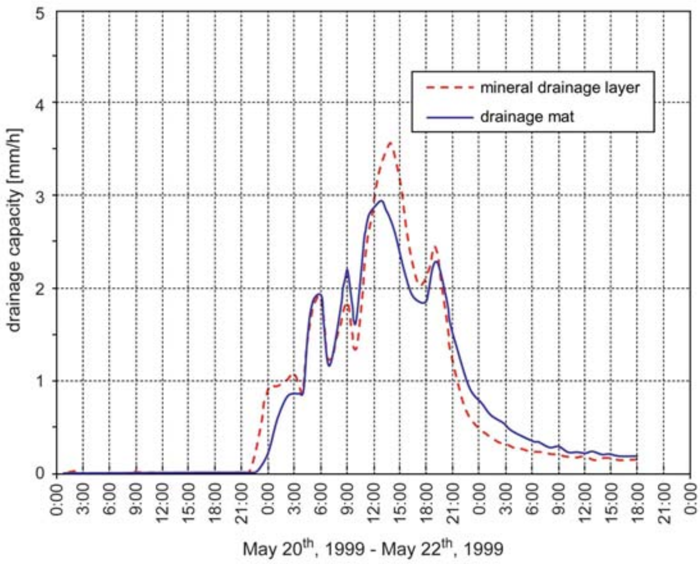

Figure 7. Volume of run-off on site with geosynthetic drainage layer (GDS) compared with mineral drainage layer (Bavaria, landfill Kienberg, May 1999)

CONCLUSION

Geosynthetic clay liners and geosynthetic drainage composites are increasingly used in landfill surface sealing systems (cappings). An application history of nearly 20 years is given, and based on monitoring, excavation and lysimeter investigation much positive performance data are presented. The results show a superior or at least equal efficiency of geosynthetic clay liners or geosynthetic drainage composites compared to a construction built with classic soil materials in accordance with the requirements of the Landfill Regulations established in the EU. Considering the economical and ecological advantages of the geosynthetic solution the base and surface sealing systems with components like geomembranes, geosynthetic clay liners and geosynthetic drainage systems should be the preferred solution.

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