# Water balance and efficiency of landfill covers with layers of dredged material

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**Abstract**
Since 1995/1996 the water balances and the long-term performance of a 4 m thick landfill cover system with a barrier of dewatered dredged material have been measured in-situ in a large-scale lysimeter (test field) on a landfill in Hamburg, Germany. The lysimeter is integrated in the landfill cover and was built in the same way to obtain representative measurement results. For more than 12 years until the end of data evaluation in November 2007, the whole cover system performed well. The average discharge below the barrier is 16 mm/yr and nearly constant all over the year with a slight seasonal pattern. Reasons for the good performance are the large thickness of the barrier, the large thickness and load of the layers above, the "slow" lateral drainage layer and the root barrier that smoothes the inflow into the drainage layer. The measurements will be continued.

**Key Words**
Landfill cover systems, water flow, liner performance, liner leakage.

**Introduction**
The operation of the port of Hamburg requires a continuous dredging of the river Elbe and the harbour basins. A part of the dredged material is contaminated with heavy metals and organic pollutants and has to be deposited in a landfill after being processed in a technical plant called METHA. The mineral barrier of the landfill cover system has been constructed with dredged material. Due to the inexperience of using dredged material in a cover and its the relatively unfavourable material properties (high organic content, high water content, high shrinkage potential) the water balance and the long-term efficiency of the landfill cover system have been investigated in a research project starting in 1995. The extensive measurement program of the research phase, carried out until 1999/2000 by the Institute of Soil Science, was largely reduced in the subsequent monitoring phase, carried out by HPA. About 12 years of measurement from 1995/1996 to November 2007 are now evaluated.

**Methods**
*Layer design and construction of the test fields*
In 1995 two lysimeters (test fields) were constructed on the northern slope of the Francop landfill site, each 10 m wide and 50 m long in slope direction (inclination of 8 %). The "standard design field" FS has the standard cover design of the Francop site with the following layer sequence (Figure 1):

1. Vegetation of grasses and perennial weeds
2. 1.2 m top soil of loamy material, the uppermost 0.1 m being rich in humus
3. 0.3 m root barrier of compacted loamy material
4. 1.0 m lateral drainage layer of sand from dredged material
5. 1.5 m barrier of dredged material
6. a collection pan for the percolation water of the barrier

The construction of test fields was carried out by the same machinery, the same soils and the same quality assurance as the cover of the whole site in order to study cover systems with representative construction quality.

*Measurement program*
The measurement program comprises meteorological parameters (precipitation, air temperature, etc.), discharges from all layers (surface runoff, interflow on the root barrier, lateral drainage, discharge below the liner), soil hydrological data (matric potential with tensiometers, soil moisture with TDR), physical, chemical and mineralogical soil properties and water chemical properties (ions like $Cl^-$, $SO_4^{2-}$ etc.).

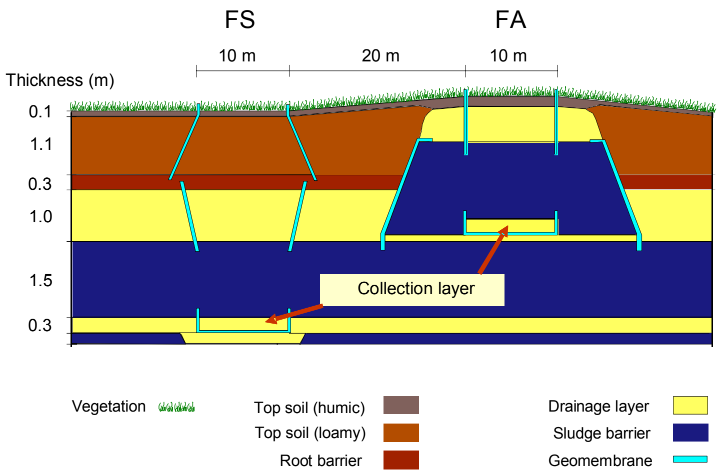


**Figure 1. Layer design of the test fields.**

## Results

The measurements on the standard design field FS from 1996 to 2007 led to the following main results (Figure 2):

- The annual surface runoff usually was very small (a few mm per year) except for the first year 1996 (28 mm) when the canopy of the vegetation was not yet closed and the years 2002 and 2007 when large amounts of the surface runoff were caused by particular extensive rainfalls.
- The average annual interflow on the root barrier was 28 mm/yr and had a relatively broad range of values (4 to 76 mm/yr). Like surface runoff also the discharge on the root barrier was largely related to particular extensive rainfall events.
- The annual discharge below the barrier was 16 mm/yr and relatively constant over the years. The daily discharge rates were nearly constant over the year. However, they show a slight seasonal pattern with maximum values in late summer and autumn and minimum values in late winter and spring which can be explained by temperature-dependent water movement.
- The largest annual discharge was lateral drainage. It largely depends on the inflow into the drainage layer which is mainly determined by precipitation and evapotranspiration. Other values (surface runoff, interflow on the root barrier, changes in water storage of the upper layers) are only of minor importance. The time series of the daily lateral drainage shows the pattern typical for drainage layers. Peaks of lateral drainage occurred as a reaction to large inflow / precipitation events followed by exponential decreases of the flow rates when the inflow into the drainage layer stopped.
- The time lags between the surface runoff, interflow on the root barrier and lateral drainage were relatively small and indicated that the discharges reacted almost immediately (often within a few hours) after a precipitation event.
- The water chemical analyses of the very mobile chloride ion ($Cl^-$) over time indicate that no fresh water has percolated the barrier until now. The percolation rate is so slow that still only pore water is discharged.

## Conclusions

The study allows the following conclusions:

- The barrier of processed dredged material has performed well for more than 12 years since construction. Though the material has a high risk of crack formation due to dewatering, no continuous cracks have occurred until now. This is likely caused by several reasons:
  1. the large thickness of the barrier (1.5 m in contrast to the minimum requirement of the German regulations for landfills of 0.5 m);
  2. the large thickness and the large load of 2.5 m sand and soil above the barrier;
  3. the “slow” lateral drainage layer on the barrier, which keeps its surface wet all over the year; and
  4. the root barrier on the lateral drainage layer, which probably smoothes the inflow into the drainage layer.

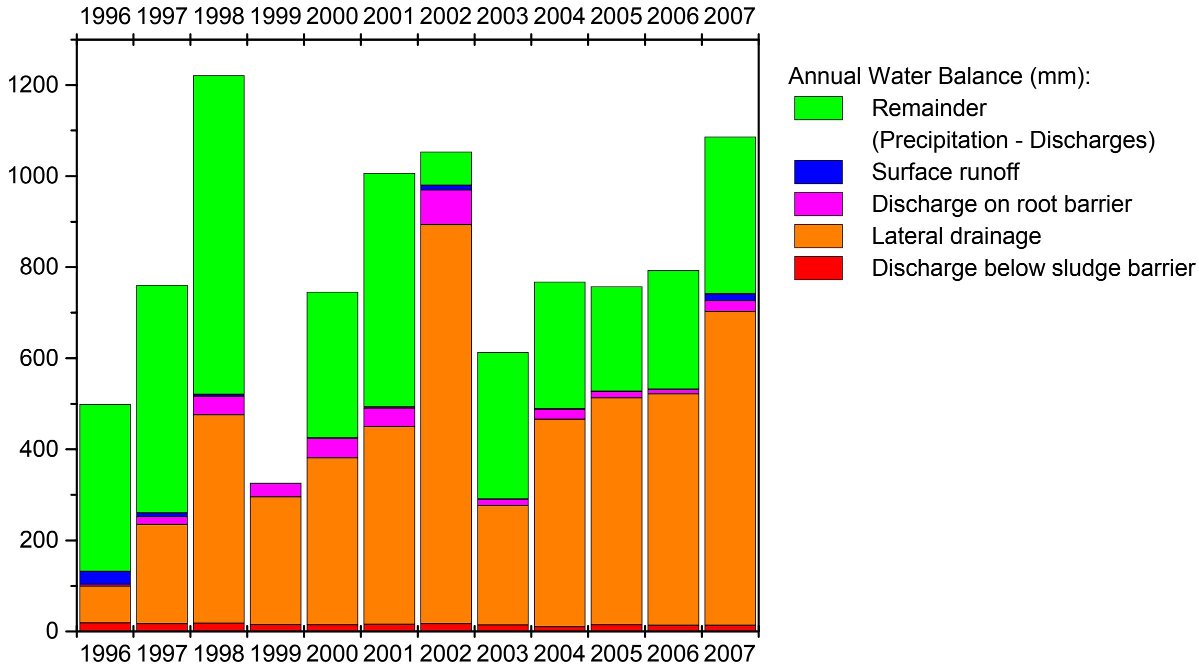


**Figure 2. Annual water balances (mm/yr) of test field FS (2007 incomplete: until 17.11.2007).**

- The lateral drainage layer made of medium sand has also performed well for more than 12 years. Its small saturated hydraulic conductivity ($0.7 \times 10^{-4}$ m/s, a factor of 14 smaller than the minimum requirement according to the German regulations) is compensated by a much higher thickness. Lateral drainage occurred all over the year. Therefore, it is reasonable to assume that the surface of the barrier was kept wet all over the year.

The whole 4 m thick cover system has performed well. However, due to the materials used and the slow biological, mechanical and hydrological processes the water balance and discharge measurements will be continued.

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