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# Use of numerical modelling when designing a full-scale field test of landfill top covers

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## ABSTRACT

Landfill closures typically include cover systems with a low-permeable barrier to limit the flow of water to and from the waste to minimize contamination of the surrounding environment. Commonly the low-permeable barrier in the top cover consists of compacted clays and/or geomembranes. An ongoing full-scale pilot test in southern Norway examines the performance of landfill low-permeable barriers, sometimes called sealing layers, constructed of two different recycled clayey soils compared to a traditionally used dry crust clay. Four test cells have been constructed with a top cover consisting of a coarse protection layer overlying a sealing layer. A lysimeter lies at the base to collect and measure the water which percolates through the entire top cover. By modelling the seepage through a simplification of the pilot test top cover, this paper investigates how 2D numerical hydrogeological modelling may be used to inform the design and/or construction of top cover pilot tests in temperate climates. It assesses the effect of sealing layer inclination, thickness and saturated hydraulic conductivity, as well as how detailed, as-built cross-section models compare to simple column models. Saturated hydraulic conductivity was found to be the most important feature when varied within a realistic range. Further, it asserts that 2D modelling may provide an efficient way to assess the consequences of deviations from designed geometry. Simple column models were found to be as suitable for this as more detailed cross-section models.

*Keywords: numerical model, sealing layer, field test, landfill, top cover, temperate climate*

## 1 INTRODUCTION

Safe landfill closures involve installing cover systems to limit the flow of water to and from the waste to reduce leachates and groundwater contamination. Traditionally, the low-permeable barrier in such cover systems consists of compacted natural clays. In Norway, dry crust clays are typically used. However, dry crust clay is often in short supply because it is frequently used for other applications (e.g. in road embankments) and must therefore usually be bought from construction projects. If materials, which are normally considered as waste, could be recycled and used in the sealing layer, it would both save the deposit operator large costs and contribute to reducing society's generation of waste.

As part of a larger R&D project (earthresQue, 2023) investigating potential applications of different waste and surplus materials, an ongoing full-scale pilot test at a landfill site in southern Norway examines the performance of landfill sealing layers constructed of two different recycled plastic soils. These are: a cement-stabilized clay (CSC) and a press filter residual (PFR) from a soil washing plant. Prior to the construction of the test cells, numerical hydrogeological modelling using the software Seep/W by GeoStudio Int. was carried out to inform their design and instrumentation. Hydraulic conductivity values were based on laboratory results from earlier compaction tests on the same materials. In addition to analytical calculations, simple analyses were performed with a 2D model to approximate the percolation rates and thereby to inform a sufficient lysimeter area and necessary tipping bucket measurement resolution. However, the exact saturated conductivity of the different sealing layers could not be predicted beforehand. Furthermore, because of both practical purposes and unforeseen challenges arising in the field, the final sealing layer geometries differed moderately from design. These deviations from as-built properties were not considered for the initial analyses. While the saturated conductivity is known to greatly influence sealing layer performances, little is currently known about the impact that moderate variations in layer thickness and surface inclination may have on the performance of such top cover test cells with limited width. This study is a continuation of the initial analyses. Its purpose is both to (a) quantify how the mentioned as-built differences may influence the performance of a sealing layer in temperate regions, and to (b) investigate the usefulness of theoretical 2D numerical models to inform the design of similar top cover field tests. Hence, this paper aims to answer the following practical questions:

1) In order to make an accurate prediction of the cumulative percolation over a one-year-long period, how important is it to know the as-built sealing layer inclination, thickness and saturated conductivity?
2) How may a 2D model be useful when designing top cover test cells?
3) How detailed does the 2D model have to be in order to provide useful simulation results?

## 2 FULL-SCALE PILOT TEST

Prior to the construction of the full-scale pilot test, the properties of the particular cement-stabilized clay (CSC) and press filter residual (PFR) were carefully assessed by a field compaction test as well as relevant laboratory tests carried out on both disturbed and undisturbed samples. The results from that study are presented by the companion paper by Ritter et al. (2023). Both the CSC and PFR were found to have potential as material for geological landfill barriers, and especially as sealing layers in the top cover for deposits of inert waste. As a result, a full-scale pilot test was initiated to compare these alternative materials with dry crust clay and further quantify their field performance. The test site will be operational for several years before being disassembled.

For the full-scale pilot test, a test area has been established on top of a 4 m high pile of coarse waste material. Similar to other waste at the landfill site, the pile has been compacted. At the top of the pile, a rectangular area of 240 m$^2$ has been divided into four consecutive sections, which hereafter are called test cells. Each cell has a particular sealing layer with a thickness between 50-70 cm and its own lysimeter below, see the cross-section in Figure 1. The entire test area is covered by a permeable protection layer of 1.8 m crushed limestone to prevent cracking of the sealing layer by frost or desiccation. The layer thicknesses replicate design recommendations for the particular landfill, considering the types of waste, the required permeability and the local climate.

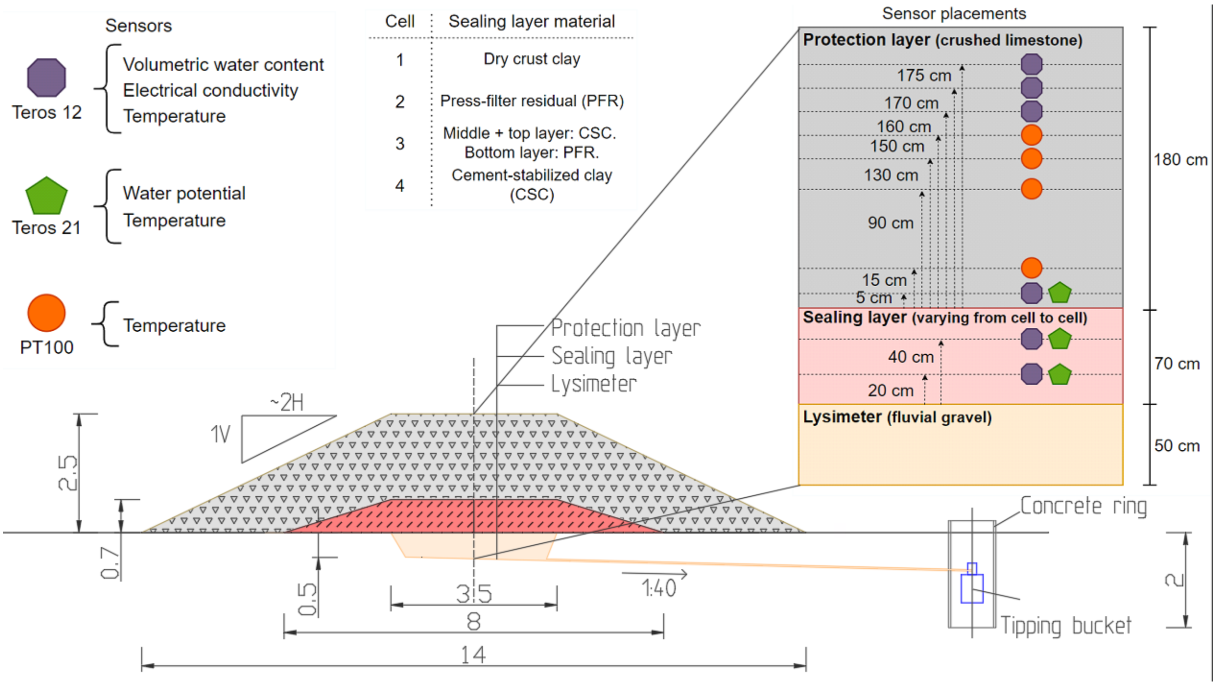

*Figure 1. Cross-section drawing of an as-built test cell with idealistic geometry and dimensions. The instrumentation set-up is included. Dimensions for the top cover are in meters.*

The lysimeters collect and measures the infiltrated water in tipping buckets. These measurements may be used to estimate the hydraulic conductivity. The test cells are also instrumented for measurements of volumetric water content, electrical conductivity, water potential and temperature at several depths (see Figure 1).

Figure 2 shows the test area during the construction of the lysimeters, which consist of excavated trenches covered with an impermeable 1.5 mm HDPE geomembrane and filled with a poorly graded fluvial gravel. Through an inclined pipe, the concrete rings on the left-hand side are connected to a drain at the base of the lysimeter. The drain is connected and sealed to the impermeable geomembrane, ensuring all percolated water is transferred to the pipe. Figure 3 shows the test area during the sealing layer construction. A permeable class 3 geotextile is placed above the lysimeters to prevent migration of soil from the sealing layer to the gravel. The sealing layer was constructed as one continuous layer covering all four lysimeters, with different materials above each of them. It was compacted in three turns to achieve a designed thickness of around 60 cm with a relatively homogeneous density. For each turn, approximately 35 cm of loose masses were laid out and compacted with 10-12 passes of a Cat D6 bulldozer (Caterpillar, 2023). The same procedure was followed two more times. All materials were compacted at natural water contents up to 5 %-points higher than their optimum. The water contents were 27-30% for the dry crust clay, around 30% for the CSC, and 32-36% for the PFR. See Ritter et al. (2023) for compaction curves of the CSC and PFR.

After the bulldozer-compaction at the third layer, 4-6 passes were made with a 13-ton rolling machine for a further compaction and to smoothen the surface. Remaining irregularities were smoothened by an excavator using its bucket.

***Figure 2.*** *Construction of lysimeters. The embedded picture shows the drain during a percolation test after the geomembrane was laid out.*

***Figure 3.*** *Compaction of the first of three layers (left). Sealing layer surface upon finalization (right).*

Following finalization of the sealing layer, the in-situ properties were documented by a Troxler nuclear gauge (Troxler, 2009) and 72 mm tube samples were retrieved from the sealing layer of each cell. Furthermore, a concrete ring was placed at the sealing layer surface positioned directly above each lysimeter, instrumented, and subsequently filled with crushed limestone constituting the protection layer. Finally, crushed limestone was applied over the entire test area according to design. After each construction step, DGPS readings were made along the extents and on top of the sealing and protection layer.

## 3 NUMERICAL MODEL AND SIMULATIONS

The numerical modelling of water flow through the top cover was performed with the finite-element software Seep/W 2019 developed by GeoSlope Int. (now Seequent). The software has many applications, where one is simulating infiltration through geological landfill barriers.

### 3.1 Model construction

Models were not made to approximate the specific geometrical and material properties of each cell, but rather to being representative averages of all cells. Table 1 describes the key differences and main purposes of the models. Based on the gathered coordinates from the layer surfaces, two cross-section and four column models were constructed with different sealing layer geometries, explained further in the section below. Two of the column model geometries were simulated with different $k_{sat}$ values, explained in Section 3.2.

***Table 1.*** *Overview of the models included in this study, and which feature they were mainly included to assess. *Models from which the simulation results are presented in charts in Chapter 4.*

| **Model abbr.** | **Model** | **Sealing layer thickness, left-right (cm), inclination** | **$k_{sat}$ (m/s)** | **Main purpose – to assess the influence of** |
|---|---|---|---|---|
| CS-F | *Cross-section, flat | 70 – 70, - | 1e-8 | *Inclination, model complexity |
| CS-I | *Cross-section, inclined | 70 – 50, 1:17.5 | 1e-8 | |
| CO-F-1 | *Column, flat | 70 – 70, - | 1e-8 | |
| CO-I-1 | *Column, inclined | 70 – 64, 1:16.7 | 1e-8 | |
| CO-F-2 | Column, flat | 70 – 70, - | 1e-9 | Saturated conductivity |
| CO-I-2 | Column, inclined | 60 – 54, 1:16.7 | 1e-8 | Sealing layer thickness |
| CO-I-3 | Column, inclined | 60 – 54, 1:16.7 | 1e-9 | Saturated conductivity |
| CO-I-4 | Column, inclined | 80 – 74, 1:16.7 | 1e-8 | Sealing layer thickness |

Figure 4 shows a sketch of the cross-section model CS-I and the corresponding column model CO-I-1. The cross-section models are considered as the main models. The column models are a simplification of these, being 1 m broad "columns" replicating the center of the test cells. A mesh size of 0.1 m was used for the column models, and 0.15-0.3 m for the cross-section models. Figure 5 compares the cross-section model geometries with the as-built geometries based on DGPS measurements across each cell.

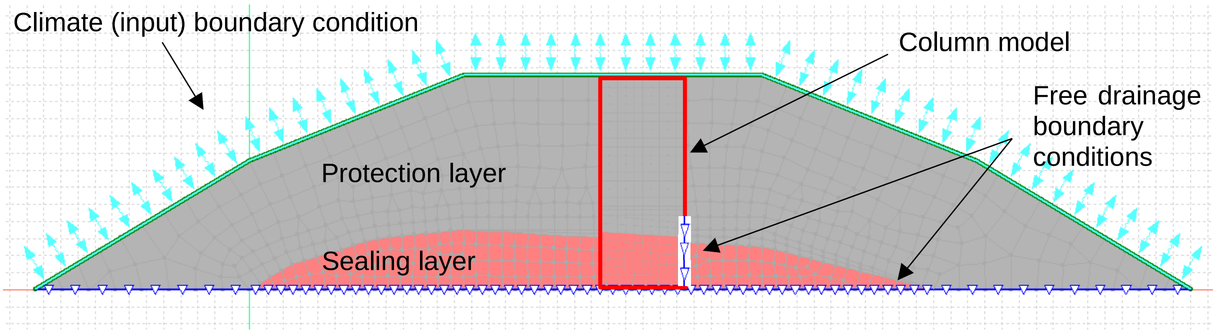

***Figure 4.*** *Model geometries and transient boundary conditions for CS-I. The corresponding CO-I-1 model with boundary conditions is included on top of the cross-section in the red frame.*

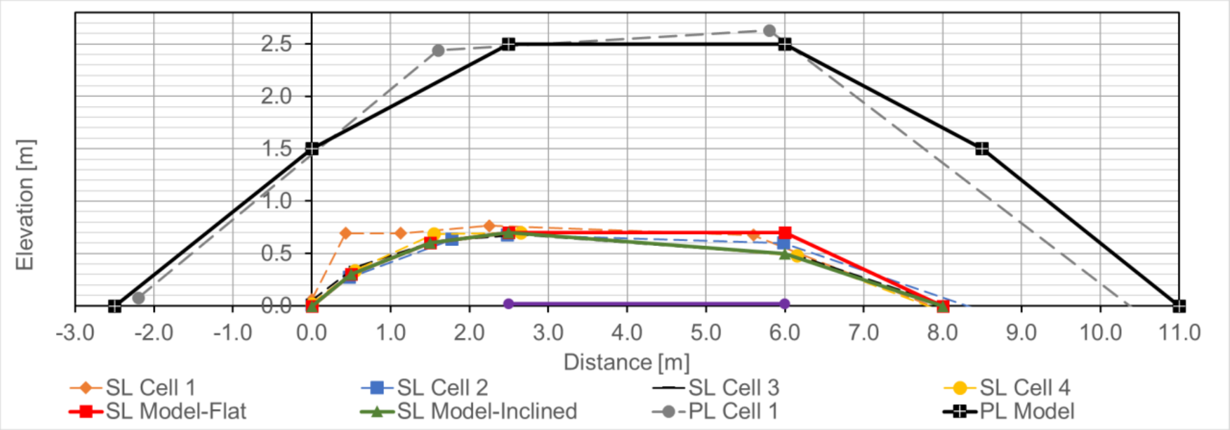

***Figure 5.*** *As-built and model geometries of the top cover including sealing (SL) and protection layer (PL). The purple line (2.5 to 6 m) shows where the percolation was evaluated, representing the lysimeter.*

### 3.2 Material properties

The CSC soil used in the pilot test came from a construction project, whereas the PFR soil came from a soil washing plant. Both may be considered as silty clays according to the Unified Soil Classification System (USCS). The CSC is considerably less homogeneous compared to the PFR regarding grain size distribution, plasticity and especially hydraulic conductivity. The properties of both materials are discussed in more detail by Ritter et al. (2023).

A wet period followed the sealing layer compaction before the protection layer was applied. At the time the modelling was performed it was therefore believed that the saturation degree in field was between 0.9 and 1, which was then replicated in the models. Thus, it was considered that modelling it as saturated would be accurately enough for the purpose of the study, where the aim was not to predict the exact performance of the cells, but to investigate some of the factors which may influence it. Therefore, only the saturated hydraulic conductivity $k_{sat}$ and volumetric water content $\theta_s$ needed to be provided for the model sealing layer. Based on Troxler results, $\theta_s$ was set to 0.5. $k_{sat}$ values were decided based on results from permeability tests in oedometer cells (Ritter et al., 2023). When compacted at 40 kPa, which represents the top cover application, the CSC and PFR exhibited on average saturated hydraulic conductivities between 1e-8 and 1e-9 m/s. The sealing layer was therefore modelled with both these values, intended to cover the likely range of conductivities for both materials. $k_{sat}$ was considered to be isotropic, i.e. $k_{vertical} = k_{horizontal}$.

Because the protection layer is likely to be far from fully saturated, it was modelled by considering unsaturated flow. Hence, in addition to $k_{sat}$ = 1e-4 m/s and $\theta_s$ = 0.6, the material model required a soil water retention curve (SWRC) as input. A "gravel" example SWRC was used. The van Genuchten equation (van Genuchten, 1980) was used to approximate its $k_{\underline{u}}$ function based on the SWRC. Figure 6 presents the SWRC (left) and the unsaturated hydraulic conductivity functions (right). The use of a sample SWRC curve as well as modelling the flow through the sealing layer as saturated are discussed in Chapter 5.

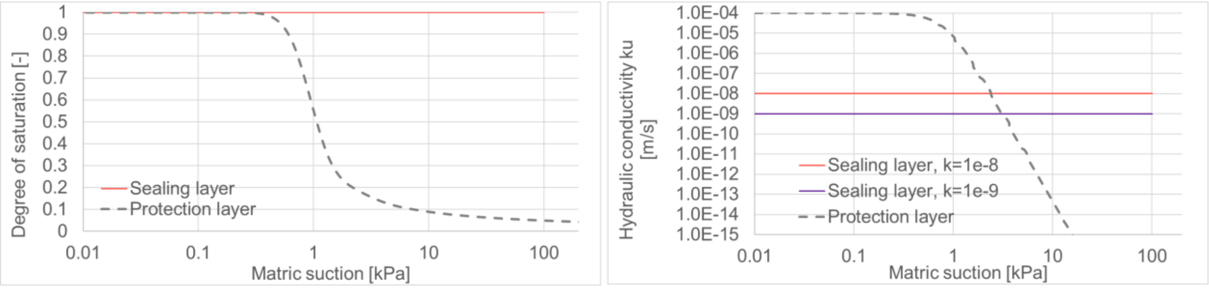

***Figure 6.*** *Hydraulic functions applied to the sealing layer material. Soil water retention curve (left). Unsaturated hydraulic conductivity $k_u$ (right).*

### 3.3 Simulations and boundary conditions

All simulations were run over a 365-day long period. Each model was simulated with a steady-state phase to set initial conditions (volumetric water content/saturation degree) and a transient phase where a climate data set from the landfill site was given as input. The initial conditions were simulated by a water table 0.5 m above the base, which initiated a saturation degree of close to 1 at the boundary between the protection layer and the sealing layer. The protection layer was almost completely desaturated. This is discussed as a limitation in Section 5.4.

In the transient phase, the land-climate data set was applied to the entire protection layer surface. It included data of precipitation, temperature, wind speed and relative humidity registered at the site by a Lufft smart weather sensor (Lufft, 2023) over a one-year period from 20th of October 2020 to 20th of October 2021. Solar radiation based on latitude and albedo based on snow cover from January to February was given as input to model the evaporation more precisely. The landfill site is located in southern Norway, a region with temperate climate. The average temperature through the year was 8.2°C, with 48 days with average temperatures below 0 °C. Only 12 days had average temperatures above 20°C. 172 of the simulated 365 days had precipitation. 18 of the precipitation days had snow (temperatures below 0), and the snow accounts for 31 mm of the total 973 mm. Snow melt was not calculated, thus it is only the 942 mm of rainwater which is considered as water input.

A potential seepage face boundary was applied to the entire base of the model, allowing free drainage across it. Both materials which underlies the sealing and protection layer (an alluvial gravel and a coarse waste material) should be sufficiently permeable to drain the percolating water rapidly. Thus, there will not be any water pressure build-up at the boundary and no water will move laterally along the base. The base drainage conditions should therefore be modelled realistically. To allow runoff in the column models, a potential seepage face was also applied to the right edge of the sealing layer as well as 30 cm up into the protection layer, as shown in Figure 4. An evaluation of simulation results from the cross-section models showed that the lateral flow above the sealing layer surface occurred only in the lower part of the protection layer. Thus, the entire right boundary did not have to allow seepage.

## 4 RESULTS

### 4.1 Water balance over the entire period

For all simulations, the water balance over the entire period was assessed. Figure 7 presents the water balance for the cross-section models (CS-F and CS-I) and their corresponding column models (CO-F-1 and CO-I-1). Their sealing layer was modelled saturated with a $k$ of 1e-8 m/s. For the column models, the rainfall and net infiltration was calculated over the entire top, and the percolation over the entire base area. For the cross-section models, rainfall and net infiltration was only calculated over the flat 3.5 m surface of the protection layer, whereas the percolation was calculated over the 3.5 m part of the base corresponding to the lysimeter width. An evaluation of the simulation flow pattern indicated that the hydraulic gradient guided the flow towards the sides through the entire simulation period. Thus, no water ingress from the sloped parts of the protection layer flowed towards the lysimeter. For the column model results, the runoff from the sealing layer surface was extracted by evaluating the water flow across the side boundary where seepage was allowed. For the cross-section models, it was difficult to separate the runoff that came from the top and slopes of the protection layer. The runoff from the various models is thus not specifically shown in Figure 7 but correspond to the difference between the net infiltration curve and the percolation curves.

As there is no vegetative layer on top of the test cell, the calculated evaporation is small and accounts for about 3.5% of the rainfall. The data indicate that the sealing layer have an almost constant percolation rate. This seems to be caused by the saturated flow in the sealing layer, as well as the low degree of saturation in the protection layer, resulting in a low unsaturated hydraulic conductivity which again causes the water input to the sealing layer to be distributed over time. For the four simulations presented in Figure 7, the final cumulative percolation corresponds to between 27 and 33% of the entire rainfall. The cumulative percolation results from all simulations are also presented in Section 4.2.

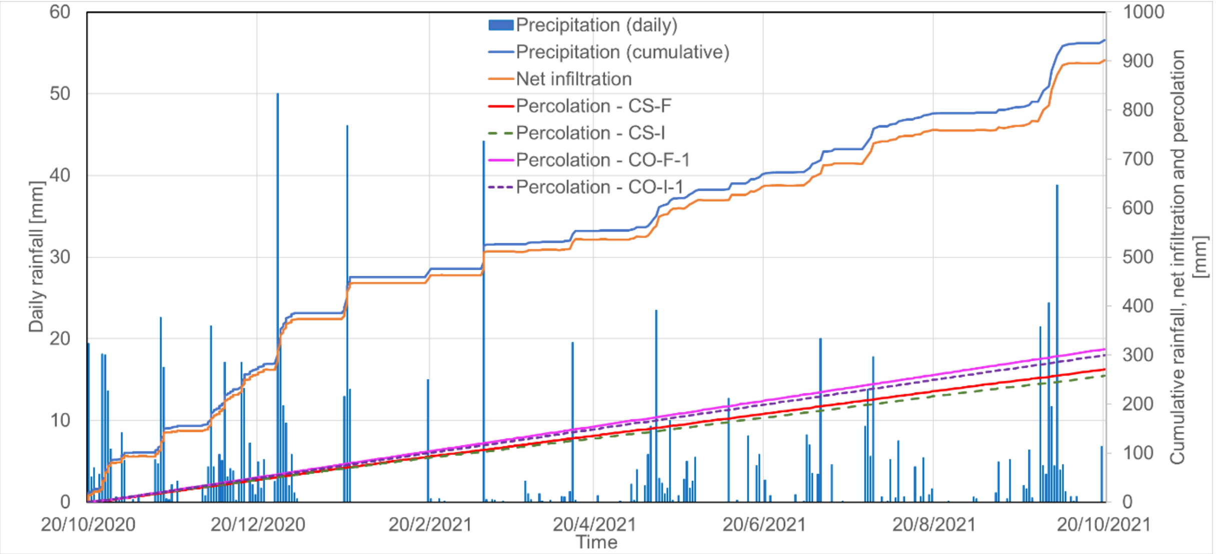

***Figure 7.*** *Water input and output. Left axis shows cumulative values of rainfall, net infiltration and percolation calculated with four of the models. Right axis shows daily rainfall rates.*

## 4.2 Cumulative percolation

Cumulative percolation results are presented in Figure 8 for the same four models as were presented in Figure 7. The apparent initial delay in the curves is caused by the slow-moving wetting front downward in the protection layer. Looking at the percolation response throughout the simulated period, although there are distinct differences in leaked volumes, all models clearly produce the same overall trends. It is evident that the cumulative percolation, which is presented as percentage of the experienced rainfall, decreases upon notable rainfalls, whereas it increases during dried periods. To a certain degree, this may be explained by the percolation of rainwater being distributed over several days, thus causing a slight smoothening of the response. However, what's probably more important is that when more water is gathered at the sealing layer surface, as in wet periods, a larger part of the water drains towards the sides than when there is no ponding as in drier periods. Nevertheless, the total amount of rainfall increases more in wet than in dry periods.

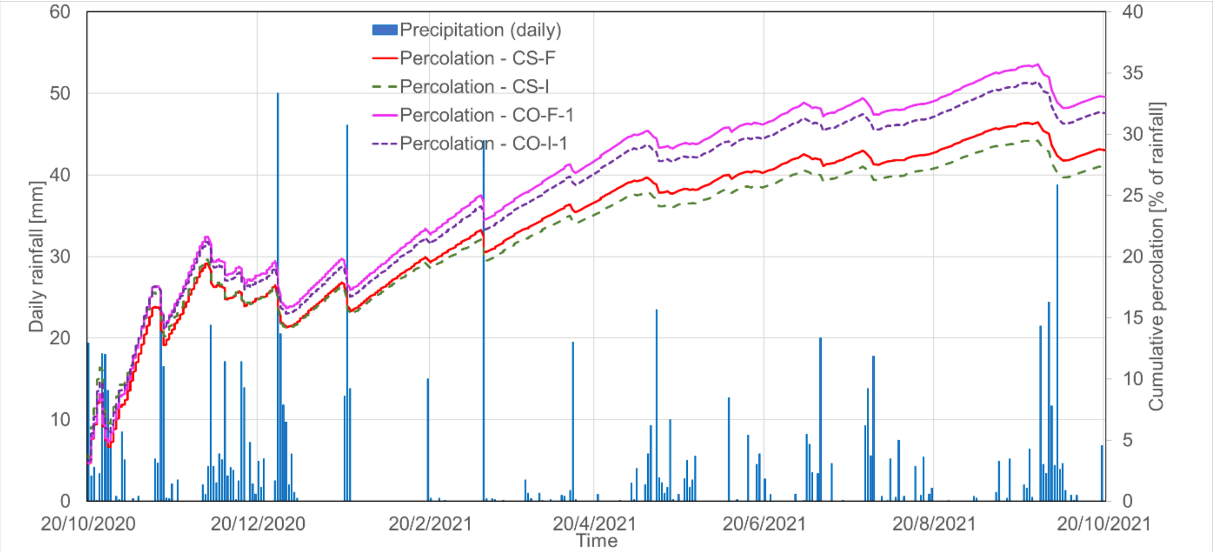

***Figure 8.*** *Cumulated percolation as percentage of the cumulated rainfall. Daily rainfall on the right axis.*

Table 2 presents the cumulative percolation values calculated with all models which were assessed in this study. As shown in the table, the saturated hydraulic conductivity $k_{sat}$ affects the results by 163% when adjusting it between 1e-8 and 1e-9 m/s (CO-F-1 vs. CO-F-2 and CO-I-2 vs. CO-I-3). Equivalently, a factor of ten decrease in $k_{sat}$ causes a factor of ten decrease in cumulative percolation. This appears as a natural consequence of the sealing layer being modelled as fully saturated.

The column models consistently produced higher percolation rates than the cross-section models. Within each model type, the influence of the sealing layer inclination was around 4-5%. Comparatively, the differences between the corresponding column and cross-section models were 14% for the flat and 15% for the inclined. There is no effect of adjusting the sealing layer thickness within the range of 60-80 cm.

***Table 2.*** *Cumulative percolation results. *Results presented in Figures 7 and 8.*

| Model abbr. | Model | Sealing layer thickness, left-right (cm), inclination | $k_{sat}$ (m/s) | Cumulative percolation (mm) | Cumulative percolation (% of rainfall) |
|---|---|---|---|---|---|
| CS-F | *Cross-section, flat | 70 – 70, - | 1e-8 | 270.7 | 28.7 |
| CS-I | *Cross-section, inclined | 70 – 50, 1:17.5 | 1e-8 | 257.5 | 27.3 |
| CO-F-1 | *Column, flat | 70 – 70, - | 1e-8 | 311.7 | 33.1 |
| CO-I-1 | *Column, inclined | 70 – 64, 1:16.7 | 1e-8 | 299.3 | 31.8 |
| CO-F-2 | Column, flat | 70 – 70, - | 1e-9 | 31.4 | 3.3 |
| CO-I-2 | Column, inclined | 60 – 54, 1:16.7 | 1e-8 | 298.6 | 31.7 |
| CO-I-3 | Column, inclined | 60 – 54, 1:16.7 | 1e-9 | 30.0 | 3.2 |
| CO-I-4 | Column, inclined | 80 – 74, 1:16.7 | 1e-8 | 299.4 | 31.8 |

## 5 DISCUSSION

### 5.1 Influence of geometry, material properties and model complexity

The influence of the geometry of the sealing layer was studied by adjusting (1) its surface inclination, (2) its thickness and (3) the complexity of its surface (2D cross-section vs. 2D column). When attempting to make rough predictions of the performance of the sealing layers, the simulation results indicate that the first two factors are not important.

The difference in results between the cross-section and column models (factor 3), however, are considerable, and may be of importance depending on the purpose of the modeller. It is not fully understood what causes the column models to admit more percolation than the cross-section models. Despite the difference in lateral extent of the sealing layer above the lysimeter (3.5 vs 1 m), the most prominent difference appears to be how the runoff is modelled. In the cross-section models it is caused by a hydraulic gradient induced by flow conditions and distant boundary conditions, while in the column models it is caused by the close-by free drainage boundary conditions. How this difference affects the runoff is not discussed here, but it is a question that would be interesting to study further.

### 5.2 Necessary knowledge of as-built properties

The simulation results appear to indicate that when modelling to predict percolation, if the top cover test cells are constructed with moderate differences from the geometrical design, the deviations are of minor importance. The difference in results from the various cross-section and column models are governed by the saturated hydraulic conductivity. At field conditions, where the sealing layer may be partially saturated, the retention properties of the sealing layer will affect the percolation. The modelling of the saturated flow through the sealing layer is a limitation of this paper and is further discussed in Section 5.4 along with the SWRC of the protection layer.

As $k_{sat}$ are of major importance to the seepage through the sealing layer, if there is some uncertainty associated with the value, a sensitivity analysis should be performed if the model outputs are to be used in decision-making of any kind. By varying $k_{sat}$ within a realistic range of values one may determine the lower and upper bound of percolation. However, for this study, where the laboratory-measured hydraulic values varied with more than a power of ten, the difference in estimated percolation will be so large that some decisions may be difficult to make regardless.

### 5.3 Usefulness of the models in relation to design of top cover test cells

Studies such as this may be used to inform the construction of top cover test cells. By doing a sensitivity analysis on the sealing layer geometry, the importance of constructing the test cells to be identical and according to design is visualised. For this study, the simulation results imply that moderate variations in the surface inclination and thickness of the constructed sealing layer will have little effect on its performance. Such findings may prove useful during the construction phase, as they will help the engineers and machine operators to focus on the important aspects and not use time on avoiding or correcting deviances which will not have a notable effect on the sealing capability.

To directly assess the importance of the test cell sizes, a comparison of different cross-section models is required. Also, although the results have not been compared with percolation measurements yet, it seems likely that the cross-section models will provide the most accurate prediction of percolation. However, the column models appear to simulate the difference in sealing layer geometry and saturated conductivity as well as the cross-section models. Thus, for assessments of the possible effect of sealing layer inclination, thickness and saturated conductivity, a column model should suffice. Further, for most practical purposes, simulations with a column model should predict the water balance components accurately enough compared to a corresponding cross-section model. The time it will take to set up a reasonable column model will also be much less than it will take to decide on the geometry of the cross-section, making the model and updating it if the design is suddenly altered. In addition, the cross-section model would require a larger and more complex mesh, so that the necessary running time of the simulations will become longer.

### 5.4 Limitations and assumptions

There are multiple limitations to this study. The aim of the study was to look at how modelling could be used to inform the construction of field test top cover cells, not to make precise predictions of the percolation. However, for these studies to come to full use, the percolation volumes need to be predicted reasonably. Thus, although it is impossible to know what the field conditions will be exactly, it is still a limitation.

In this study, the actual initial saturation degree in the entire top cover could have been approximated more realistically. In field, the sealing layers are partially saturated. Under such conditions, the SWRC of the various sealing layer materials will decrease their conductivity notably. By itself, this would lead to less percolation than what is modelled. However, there are especially two other assumptions which also have a notable effect on the water flow. First, the saturation degree in the protection layer is likely modelled to be lower than it is in the field. A higher saturation degree will lead to higher conductivity and faster water infiltration towards the sealing layer. Thus, the water input to the sealing layer will be less evenly distributed with time than it is in the simulations. Second, the chosen "gravel" SWRC is not scientifically based. If the crushed limestone is finer than the example gravel, it will presumably have a higher air-entry value and the SWRC would shift towards higher suctions. The hydraulic conductivity would be lower, thus delaying the downward water flow after rainfall events. It is not known what the total effect of a potential deviation from these three assumptions will be. What is clear however, is that it is beneficial to be able to make reasonable predictions of the various SWRC and initial degrees of saturations also for the purpose of informing construction of field test top covers.

The smooth surface of the sealing layer (assuming no ponding) and the homogeneity of the sealing layer materials are other rough assumptions that might affect the influence of the studied sealing layer features.

The discussed assumptions and simplifications may have a notable impact on how well one will be able to model the exact performance of the sealing layers. As argued, they may also have an impact on sensitivity studies on the sealing layer features. However, if the initial conditions and the material properties are approximated well, 2D modelling may prove to be an effective tool to assess the sensitivity of a top cover to the sealing layer inclination, thickness and conductivity. Such sensitivity studies may be useful to inform the design and construction of both top cover pilot tests and final full-scale top covers.

## 6 CONCLUSION

The overall aim of the study was to assess whether and how 2D cross-section and column models may be utilized to predict the performance of a sealing layer before construction. The key aspects in this regard were (1) how characteristics that are likely to not become exactly as designed, may influence the percolation rates, and (2) whether a simplified column model would provide similar output as a cross-section model with as-built geometry. The influence of the sealing layer inclination, thickness and saturated hydraulic conductivity were investigated through a one-year long simulation period with weather input from the landfill site. Furthermore, the difference in simulation results between column- and cross-section models were assessed. The study found that for a test area with minor sealing layer width, during fully saturated conditions in the sealing layer:

- The saturated hydraulic conductivity $k_{sat}$ is of major importance. A tenfold decrease of $k_{sat}$ essentially results in a tenfold decrease in cumulative percolation.
- Within the assessed range, the inclination and thickness of the sealing layer is of little importance. Due to the short width of the sealing layer, ponded water is easily drained sideways even when the surface is flat.

A simple 2D model geometry may prove sufficient for predicting cumulative percolation rates of a top cover test cell. The percolation rates are far more sensitive to variations of the saturated hydraulic conductivity within the realistic range than they are to natural variations in model geometry and complexity. The minor influence of sealing layer thickness and inclination, and medium influence of model complexity, suggests that 2D modelling may serve as an effective tool to make preliminary predictions on the response of a designed top cover. It is beneficial to have estimated the SWRC of the materials and to have predicted the initial degree of saturation in both the sealing and protection layer.

This study is the first step towards obtaining a model with the aim of accurately predicting the performance of the four top cover test cells. The models regarded here will in the future be calibrated against saturation degrees within the top cover. Pressure plate tests are currently performed and will be used to estimate the SWRC of the sealing layer materials. Simulations will then be performed with recent weather data and the simulated percolation will be compared to measured percolation.

## 7 ACKNOWLEDGEMENTS

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