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Validation of a sulfide soil landfill numerical model

Validation d'un modèle numérique de décharge pour sols sulfurés

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ABSTRACT: Due to their silty texture and high organic content, sulfide soils are typically unsuitable for use as a foundation for construction projects. In most cases, excavation and replacement with other construction materials are needed to ensure the structural integrity of building or infrastructure. Landfills are commonly used for the disposal of excavated sulfide soil. Because of the chemical properties of these soils and the risk of acidification, these landfills need to be kept saturated to limit oxygen diffusion. However, the long-term behaviour of these landfills is not yet fully understood, highlighting the need for further research to investigate the fluctuation of the degree of saturation in the soil, under different conditions. This study examined the effect of seasons on the degree of saturation in sulfide soil landfills and its effect on oxygen transport. The objective of the current study was to validate a numerical model of a sulfide soil embankment, done using SEEP/W software, with data from the monitoring of a sulfide soil landfill, in Northern Sweden. A one-dimensional numerical model of the landfill was created using laboratory measurements of hydraulic conductivity and water retention capacity. This model was then validated by comparing it with data from installed sensors. The numerical model accurately predicted the degree of saturation changes over time in the landfilled soil. These findings allow engineers to optimize design and predict long-term performance under different environmental conditions. The study highlights the importance of numerical modelling in predicting long-term hydrological behaviour and offers valuable insights into sulfide soil landfill behaviour.

RÉSUMÉ: En raison de leur texture limoneuse et de leur forte teneur en matière organique, les sols sulfurés sont généralement inadaptés dans les fondations des projets de construction. Dans la plupart des cas, il est nécessaire de les remplacer par d'autres matériaux de construction pour garantir l'intégrité structurelle des bâtiments ou des infrastructures. Les sols sulfurés excavés sont couramment mis en décharges. En raison de leur propriétés chimiques et du risque d'acidification, il est nécessaire de maintenir ces décharges saturées pour limiter la diffusion de l'oxygène. Cependant, le comportement à long terme de ces décharges n'est pas encore pleinement compris, soulignant la nécessité de recherches supplémentaires pour étudier leurs fluctuations du degré de saturation dans différentes conditions. Cette étude a examiné l'effet de la consolidation et des saisons sur le degré de saturation des décharges de sol sulfuré, avec un accent particulier sur le transport de l'oxygène. L'objectif de cette étude était de valider numériquement un modèle de digue en sol sulfuré en utilisant le logiciel SEEP/W, avec des données provenant d'une installation de capteurs dans une décharge de sol sulfuré, dans le nord de la Suède.Un modèle numérique unidimensionnel de la décharge de sols a été créé en utilisant des mesures de laboratoire de la conductivité hydraulique et de la capacité de rétention d'eau. Ce modèle a ensuite été validé en le comparant aux données des capteurs installés.L'étude a montré que le modèle numérique prédisait avec précision les variations du degré de saturation au fil du temps dans le sol. Ces résultats permettent aux ingénieurs d'optimiser la conception des digues et d'en prédire les performances à long terme dans différentes conditions environnementales. L'étude met en évidence l'importance de la modélisation numérique pour prédire le comportement hydrologique à long terme et offre des informations précieuses sur le comportement des décharges de sol sulfuré.

Keywords: Sulfide soil landfill; numerical modelling; SEEP/W; saturation degree; oxygen transport.

1 INTRODUCTION

Sulfide soil contains high concentrations of mainly iron sulfides (e.g., pyrite). These minerals naturally occur in certain geological formations found worldwide, including tropical regions, Australia, and coastal areas of Sweden and Finland. Disturbing these soils through excavation or construction exposes the sulfide minerals to oxygen, leading to oxidation. This can create acidic conditions, lowering soil pH which leads to dissolved sulfate and metals released into water bodies, impacting aquatic life and infrastructure.

Sulfide soils are often silty and water-rich, and pose risks of settlement, soil failure, and frost heave in cold regions. Therefore, they are often excavated and replaced with more construction-suitable soil types. The urbanization and construction of infrastructure in sulfide soil regions in sweden have heightened the demand for soil management alternatives e.g. disposal. Due to the soil's chemical properties, its disposal is complex, requiring measures to prevent oxidation and acidification. Hence, these soils must be deposited while remaining saturated to prevent environmental hazards.

Creating optimal conditions for sulfide soil is expensive and restricts landfill capacity. To expand landfill capacity and prevent oxidation, it is vital to understand the hydrological properties of sulfide and silty soils in unsaturated conditions. Some software, including one-dimensional (1-D) and two-dimensional (2-D) flow models, have been employed to help in the design and evaluation of soil covers such as VADOSE/W and SEEP/W(Song & Yanful, 2008). SEEP/W has been commonly used to simulate water infiltration in unsaturated systems e.g. (Aubertin et al., 2009; Bréard Lanoix, Pabst, & Aubertin, 2017; Bussière, Aubertin, & Chapuis, 2003; Cifuentes, Aubertin, Chapuis, Bussière, & Molson, 2006; Fala, 2003; Gwendoline, Bruno, Pabst, Émilie, & Roy, 2020; Martin, 2003).

This study aims to predict the behaviour of sulfide soil landfills under various conditions and identify short and long-term influencing parameters by validating a numerical model using SEEPW with on-site measurement data.

2 MATERIAL AND METHODS

2.1 Description of test plots

The test area is a sulfide soil landfill where fresh soil was recently deposited. A 60 cm layer of till covers the entire site, while the depth of the sulfide soil deposition exceeds 3 metres (Figure 1).

2.2 Field measurements

The installation of sensors for measuring temperature, water matric potential (WP), and volumetric water content (VWC), was carried out in the sulfide soil layer and cover in May 2022. Table 1 lists the depth of installation of instrumentation. It is important to note that additional sensors were installed in this case study; however, the data from these additional sensors has not been presented in this paper.

2.3 Finite element modelling

Hydrogeological numerical simulation was conducted using SEEP/W 2021. The sulfide soil landfill analyzed in this study is composed of two primary layers (cover and sulfide soil) based on the test plot. Specifically, the cover layer surface is represented as a distinct 60 cm layer with a finer mesh to reduce convergence challenges when modelling infiltration events into the arid ground, and to incorporate the impact of surface drying and desiccation.

In this study, the measured data from sensors were employed to verify the numerical model. The initial case was the same as the test plot case to verify the performance of the numerical model.

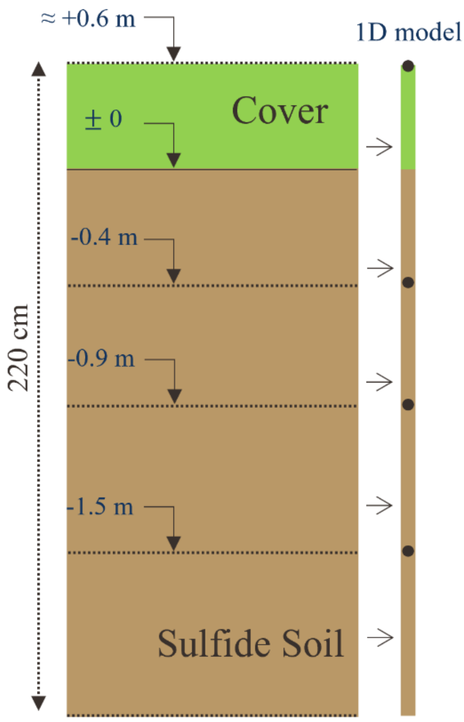

Figure 1. Soil layers and 1D model.

Table 1. Sensor installation position.

Layer	Depth (m)	Monitoring points	Sensors
Cover	≈ +0.6	Point 1	VWC & WP
	+0.1	-	
Sulfide soil	-0.1	-	
	-0.4	Point 2	VWC
	-0.9	Point 3	VWC
	-1.5	Point 4	WP

2.4 Input data

When conducting simulations of soil layers using SEEP/W software, it is essential to ensure that all necessary input data is included in the model. These input data including material properties, boundary conditions, and initial conditions are critical to the accuracy and reliability of the simulation results.

2.5 Material properties

The material properties of the soil layers must be accurately defined, including soil water characteristics curve (SWCC), and hydraulic conductivity. These parameters will play a significant role in determining the flow of water within the sulfide soil layers. The SWCs of material including air entry value (AEV) were derived from a pressure plate test conducted in the laboratory for the material used for the test plot. The SWCCs were fitted with theoretical curves using Van Genutchen model.

The saturated hydraulic conductivity (HC) was measured using permeability tests. The results then were used to predict unsaturated hydraulic conductivity using SEEP/w. The unsaturated hydraulic conductivity function is challenging to measure directly, and prediction methods are commonly used instead. In this study, Van Genutchen model was used to estimate unsaturated hydraulic conductivity of soil as a function of matric suction. The material properties used in the numerical modelling are summarized in Table 2.

Table 2. material properties.

Soil	Porosity	AEV (kPa)	HC (m/s)
Cover	0.3	50	10^{-7}
Sulfide soil	0.4	20	$5e10^{-7}$

2.6 Boundary and initial condition

The boundary and initial conditions must be properly defined to provide a comprehensive understanding of the water flow into and out of the soil layers. A Land Climate Interaction (LCI) boundary condition was applied to the top of the domain. The LCI boundary condition requires weather information, including air temperature, relative humidity, wind speed, and precipitation, which is essential for calculating infiltration and flux in the system caused by rainfall, snowmelt, evaporation, etc. This data was obtained from the Swedish Meteorological Institute website using a weather station at Umeå airport from May 2022 to September 2023. The bottom boundary was considered an open boundary condition, representing both inflow and outflow of water, depending on the local hydraulic gradients and other boundary conditions. The initial water table level was set at the cover surface level, and all soil layers were considered fully saturated at the first step of the simulation. This assumption was based on the water level measured at the site and measurements from samples taken from the site. The saturation water content was determined based on the maximum and minimum density of the soil at the site.

3 RESULTS

The study presents data collected between May 2022 and September 2023, which were used to evaluate the validation of a numerical model simulation for a sulfide soil landfill. The data consist of soil layer temperature, volumetric water content, and water flux in the soil layers. To compare the simulation results with measured data, three sensors were selected at points 1, 2 and 3 for volumetric water content and temperature and two sensors (point 1 and 4) for water flux to compare results from the numerical model and landfill case study, as indicated in *Table 1*.

In Figure 2, a comparison is made between temperatures in different soil layers and the air temperature. Notably, the temperature in the soil layers did not drop below freezing, despite sub-zero air temperatures during the winter. This phenomenon is attributed to the insulating effect of snow covering the soil surface, which prevents the soil layers from freezing. This observation is crucial when considering the potential impact of frost depth on the hydraulic conductivity of the soil layers and water flow. Figure 3 presents a comparison between measured and numerically calculated volumetric water content. Initially, differences in the results were observed due to sensor placement in disturbed soil following the excavation of a ditch in the soil layers to be able to install sensors. This led to significant fluctuations in soil volumetric water content.

Over time, the system reestablished equilibrium, and the results of the numerical model began to align with the observed trend. It is shown that during winter when the soil surface was covered by snow the soil layers, including sulfide soil remained saturated.

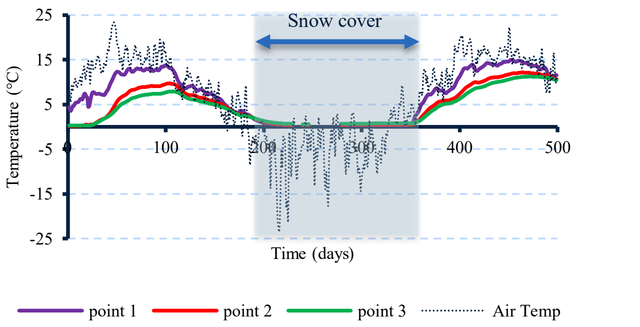

Figure 2. Comparing soil layer temperatures to air temperature.

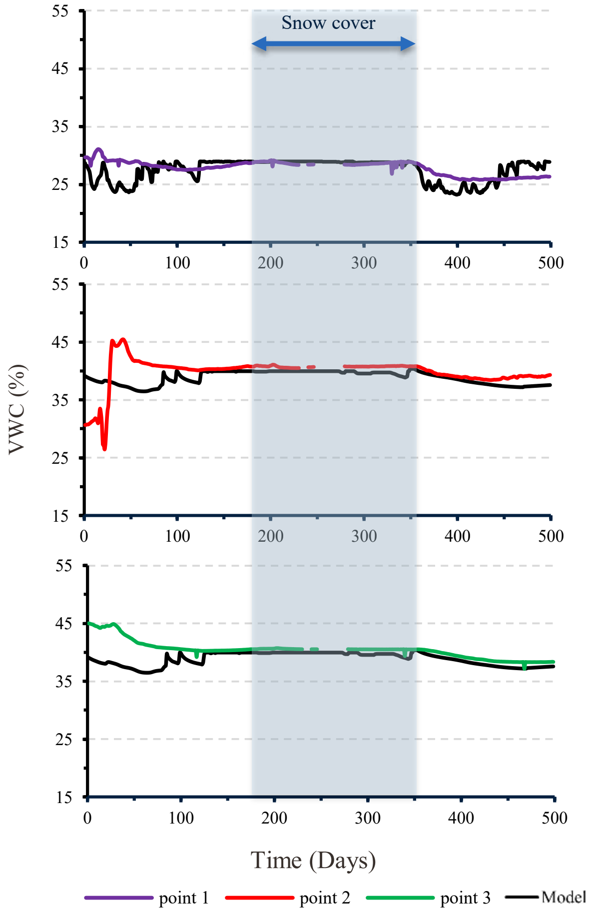

Figure 3. comparison measured and predicted VWC.

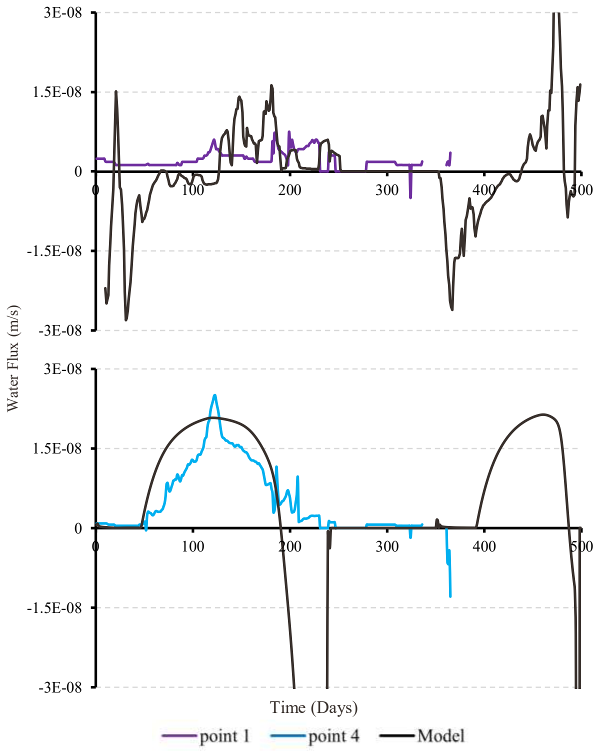

Figure 4. comparison measured and predicted water flux.

Figure 4 provides a depiction of water flux at specific points within the soil layers. These graphs are based on data recorded by water potential sensors. Unfortunately, these sensors only collected data for approximately 400 days, and not for the entire monitoring period until September 2023. Fluctuations in water potential reflect the dynamic movement of water into and out of a system. An increase in water potential signifies water entering or becoming more available within the system, often due to factors like rainfall, irrigation, or root water uptake. Latter is not the case in this specific case. Conversely, a decrease in water potential indicates water leaving the system, through processes such as evaporation, transpiration, or drainage. Water flux based on water potential can be calculated using Darcy's Law, where the flux equals the product of hydraulic conductivity and the negative gradient of water potential, providing a straightforward method for comparison between software outputs and calculated water flux values.

Water movement direction is indicated by positive or negative flux values in this paper. Positive flux signifies water moving towards the surface, such as during summer from days 0 to 200 due to higher temperatures and evaporation. With lower temperatures and autumn precipitation starting from day 120 to 200, the positive flux decreases, indicating slower water flow towards the surface and less water exiting the system. Negative flux denotes water moving away from the surface, potentially due to precipitation and snow melting in the springtime beginning from day 400. During the snow season, roughly between days 250 to 350, the flux is zero, likely due to snow covering the soil surface and preventing water from entering or leaving the system. Initial discrepancies between measured and predicted data may result from soil disturbance during sensor installation, but consistency improves over time, particularly between days 50 and 200.

At Point 4, there is a negative flux predicted just before the snow season, which is not reflected in the measured data. Similarly, there is negative flux occurring between approximately after snow season, which is also not found in the predicted data. In summary, differences exist between the measured data and the results of the numerical modelling.

These differences can be explained by the position of the water table and its fluctuations. However, it's important to note that the available data on water table fluctuation at the site is limited and hasn't been integrated into the model. Additionally, the properties of the soil are closely related to its density and water retention capacity. For this specific soil, further tests are necessary to measure its water retention capacity and hydraulic conductivity at various densities. The changes in density over the monitoring period are also unknown. To enhance the accuracy of the model's predictions, it is beneficial to determine the consolidation properties of this soil and assess potential changes over the monitoring period.

Finally, it's crucial to acknowledge that the climate data used in this model is not specific to the site. Differences in temperature, precipitation, and other climate variables may introduce variations that impact the modelling results.

4 CONCLUSION

This study aimed to validate a numerical model for a sulfide soil landfill, with the objective of enhancing understanding of water movement and seepage in sulfide soil layers. The goal was to predict the behavior of these soil layers over an extended period. The numerical model successfully predicted the volumetric water content in various layers of the sulfide soil landfill. Additionally, the study compared the results of water flux from both measured and predicted data.

This comparison revealed that, although the prediction results came close to estimating the flux in the soil layers, disparities between the measured and improved data were evident. These differences may be attributed to inaccuracies in material properties, climate data, and the fluctuations of the water table under real conditions. To enhance prediction accuracy, it is essential to define more precise boundary and initial conditions for the model.

Continuing this research requires obtaining more comprehensive data on the material properties of sulfide soils in general, including their consolidation properties. Furthermore, accurate data on the density of soil layers at the specific landfill site is necessary, which can be acquired through borehole sampling. In addition, identifying the parameters that influence the saturation degree of sulfide soil landfills and quantifying the impact of each parameter through numerical analysis is crucial for further advancements in this field.

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REFERENCES

Aubertin, M., Cifuentes, E., Apithy, S., Bussière, B., Molson, J., & Chapuis, R. (2009). Analyses of water diversion along inclined covers with capillary barrier effects. *Canadian Geotechnical Journal, 46*(10), 1146-1164, https://doi.org/10.1139/T09-050.

Bréard Lanoix, M., Pabst, T., & Aubertin, M. (2017). Characterization of the hydrogeological properties of a sand layer placed on an experimental waste rock pile, In: *70th Canadian Geotechnical Conference (GeoOttawa 2017)*, Ottawa, Canada,.

Bussière, B., Aubertin, M., & Chapuis, R. P. (2003). The behavior of inclined covers used as oxygen barriers. *Canadian Geotechnical Journal, 40*(3), 512-535, https://doi.org/10.1139/t03-001.

Cifuentes, E., Aubertin, M., Chapuis, R., Bussière, B., & Molson, J. (2006). Analyses of water diversion length of inclined, layered soil covers.

Fala, O. (2003). *Étude des écoulements non saturés dans les haldes à stériles à l'aide de simulations numériques*: National Library of Canada= Bibliothèque nationale du Canada, Ottawa.

Gwendoline, H., Bruno, B., Pabst, T., Émilie, B., & Roy, P. (2020). Influence of climate change on the ability of a cover with capillary barrier effects to control acid generation. *Hydrogeology Journal, 28*(2), 763-779, https://doi.org/10.1007/s10040-019-02084-y.

Martin, V. (2003). *Étude des propriétés non saturées des stériles miniers*: École polytechnique de Montréal.

Song, Q., & Yanful, E. K. (2008). Monitoring and modeling of sand-bentonite cover for ARD mitigation. *Water, air, and soil pollution, 190*(1-4), 65-85, https://doi.org/10.1007/s11270-007-9581-z.

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