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Aquifer analogs as a tool for improved site characterization in groundwater remediation projects

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Resumo

A falta de informações sobre as reais heterogeneidades dos aquíferos dificulta o entendimento integral do transporte e do destino de contaminantes nas águas subterrâneas. Devido a limitações de ordem prática, modelos conceituais baseados nos métodos de investigação comumente usados não retratam exatamente as heterogeneidades do aquífero, as quais decisivamente afetam a dispersão dos contaminantes e o sucesso dos projetos de remediação. Um aquífero análogo de um dos reservatórios de água subterrânea mais importantes da Europa Central foi usado para investigar os efeitos de heterogeneidades físicas e químicas no destino de um contaminante orgânico típico em diversas escalas e em alta resolução. Os resultados deste estudo fornecem uma compreensão integral sobre o transporte de contaminantes em subsuperfície, levando-se em consideração as condições ambientais locais, e demonstram como hipóteses simplificadas podem impedir que modelos matemáticos forneçam previsões corretas.

Abstract

The lack of information about true aquifer heterogeneities represents a challenge for a complete understanding of the transport and fate of groundwater contaminants. Due to practical constraints, conceptual site models based on the commonly used investigation methods do not precisely depict aquifer heterogeneities, which decisively affect the spreading of contaminants and the success of clean-up projects. A high-resolution aquifer analog of one of the most important groundwater reservoirs in Central Europe is used to help investigate the effects of realistic multi-scale physical and chemical heterogeneities on the fate of a common organic contaminant. The results of this study provide an integral understanding of subsurface contaminant transport while taking into consideration the local environmental conditions, and demonstrating how simplified assumptions can prevent the use of mathematical models for correct predictions.

Key words

Aquifer analog, contaminant transport, Guarani aquifer system

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1 – Introduction

Through intensive industrial and manufacturing activities, pollutants (e.g. hydrocarbons, chlorinated solvents, metals, pesticides) are released into the subsurface environment and their concentration in soil, sediments and groundwater often exceeds the human and ecotoxicity thresholds. Numerous remediation technologies have been developed to tackle groundwater contamination, but they mostly rely on conceptual site models based on restricted point data (e.g. borehole cores, monitoring wells). Even if advanced geophysical and geostatistical methods are additionally applied, neither the small-scale aquifer heterogeneities nor the physical and chemical parameters can be satisfactorily captured. As a result this leads to an inefficient remediation design and unreliable groundwater management. Hence, alternative aquifer characterization techniques are required to improve our conceptualization of the subsurface environment. A successful alternative approach and validated method to reproduce a high-resolution subsurface image is the use of aquifer analogs [1, 2, 3, 4, 5, 6]. Such geological analogs provide a benchmark to test the applicability of simulation techniques [7, 8, 9].

This work utilizes a high-resolution aquifer analog consisting of highly heterogeneous fluvial deposits in SW-Germany in order to investigate the effects of true aquifer heterogeneities on contaminant transport. This numerical experiment provides a unique opportunity to assess the contaminants' behavior under realistic conditions versus simplified assumption made due to the restricted availability of subsurface data in practice, or due to the employment of analytical models.

2 – Aquifer Analog Study

The aquifer analog study employs a high-resolution aquifer analog of the size of 16m x 7m [5, 6], representing a sediment body of unconsolidated gravel bed deposits, which are of a fluvial and glaciofluvial origin. Litho-, hydrofacies and architectural elements were determined, rasterized and implemented in a numerical (finite differences) model. Additionally, a data-base was set up that connects the numerical grid cells with facies-based physical and chemical properties, derived from Heinz et al. [3], Kostic et al. [10] and Kleineidam et al. [11]. Focus is placed on the individual facies-specific organic carbon content, which is the most sensitive parameter for sorption of organic contaminants [e.g. 12, 13, 14] and highly relevant for contaminant plume propagation.

3 - Results

The outcome of the numerical simulations shows differences for contaminant concentrations and arrival times compared to an analytical solution if physical and chemical aquifer parameters are correctly represented. Specifically, the simulation under close-to-reality conditions enables the assessment of prediction errors for contaminant concentrations and arrival times, which occur if common practice methods and average values for aquifer parameters are applied. Further, the results expose the importance to apply the appropriate sorption mechanism in the prediction of contaminant arrival times under the consideration of the local groundwater flow parameters. Especially, in highly permeable aquifers the use of the correct sorption mechanism can significantly increase prediction accuracy.

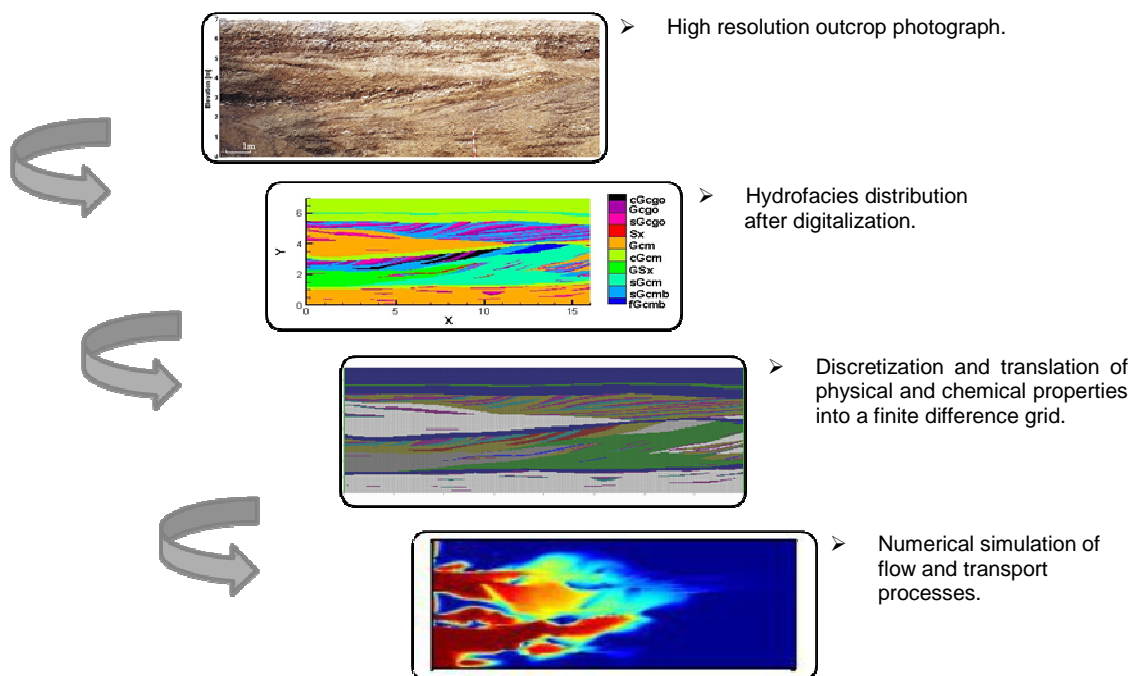


Figure 1. Schematic overview of aquifer analog construction and modeling [15].

4 - Conclusion

In conclusion, the study gives proof of the use of aquifer analogs as a practical tool to support field data interpretation and to develop appropriate conceptual site models. These models are one of the most important factors in controlling the efficiency of remediation projects [16]. Thus, the use of aquifer analogs is beneficial for decision making authorities, environmental consultants and practitioners. The results of this study also strongly motivated the creation of an international project, including Brazilian, German and Swiss institutions, for the construction of aquifer analogs in the Guarani aquifer system from 2011 on.

5 - References

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