MODEL-BASED ASSESSMENT AND OPTIMIZATION OF MANAGEMENT STRATEGIES AT A GERMAN CONTAMINATED SITE

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Resumo

Um plano de gerenciamento foi proposto para controlar a contaminação das águas subterrâneas em uma fábrica de recuperação de metal na Alemanha. Uma avaliação e otimização das estratégias propostas foi realizada por meio de um modelo numérico de fluxo de água subterrânea e de uma inovadora técnica de otimização computadorizada. Os trabalhos de otimização melhoraram consideravelmente o arranjo proposto para os poços de bombeamento, permitindo uma redução significativa do número necessário de poços e de suas vazões, assim como uma captura separada de plumas de contaminação distintas. Simulações transientes ainda demonstraram a possibilidade de se reduzir significativamente às taxas de vazão durante os meses de verão alemão. A estratégia otimizada de gerenciamento da área contaminada pode levar a uma expressiva redução de custos.

Abstract

A site management plan was proposed to control the groundwater contamination at a German metal recovery plant. A model-based assessment and optimization of the proposed strategies was carried out with a numerical groundwater flow model and an innovative model-based optimization technique. The optimization work considerably improved the pumping wells arrangement, allowing a significant reduction of the required number of wells and of their extraction rates, as well as a separated capture of distinct plumes. Transient simulations have also shown that a significant withdrawal reduction may be possible during the German summer months. The optimized contaminated site management strategy can led to expressive cost reductions.

Key words

Contaminated Site Management, Optimization, Modeling

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1 – INTRODUCTION

At a German metal recovery plant, past production activities and word war impacts caused the contamination of the local unconsolidated Quaternary aquifer. The proposed contaminated site management plan assumes that the polluted area (approx. 200,000 m^2) can be entirely secured through the installation of a subsurface physical barrier, allied to pump and treat measures inside the enclosed area. The recommended strategy is therefore a permanent protection measure, supported by clean-up actions.

In addition to the groundwater recharge by rainfall, it is assumed that lateral and vertical groundwater inflow will occur at the enclosed area, through the (not completely impermeable) cut-off wall and the underlying aquitard, respectively. Hence, existing remediation wells are to be complemented by numerous new ones. Moreover, due to the predicted cut-off wall slight seepage, extraction wells should be additionally installed to ensure, through groundwater abstraction, that the hydraulic gradient along the physical barrier is toward the enclosed area.

In this work, a model-based assessment and optimization of the proposed contaminated site management strategies was carried out. Firstly, a steady-state numerical groundwater flow model was developed, calibrated and applied to evaluate the planned interventions. Secondly, innovative model-based optimization techniques were employed to assist the selection of the optimal site management option. Ultimately, transient simulations were carried out to evaluate the management options during distinct seasonal periods.

2 – MATERIALS AND METHODS

The computer program MODFLOW-NWT [1], a standalone version of three-dimensional finite difference code MODFLOW-2005 [2], was selected to simulate the site groundwater flow regime. The post-processing module MODPATH [3], designed to calculate three-dimensional flow paths based on the MODFLOW outputs, was employed to evaluate the hydraulic control of the site source zones.

MODFLOW-NWT and MODPATH were then coupled with an optimization module based on the so-called Evolutionary Algorithms [4] (Figure 1). In this optimization module, each variant of the site well system is represented as an individual. Each individual is characterized by a set of properties, for example, the coordinates and the pumping rate of individual wells. The suitability (fitness) of a variant of the problem posed is derived from an evaluation of the simulation results (groundwater model and particle tracking). The

fitness function can be freely defined, i.e., incorporated variables calculation are problem-specific defined. From the relationship between the properties and the fitness of the individuals (variants) of a generation (population), the optimization module always determine new generations to individuals (i.e. wells configurations) with optimal fitness.

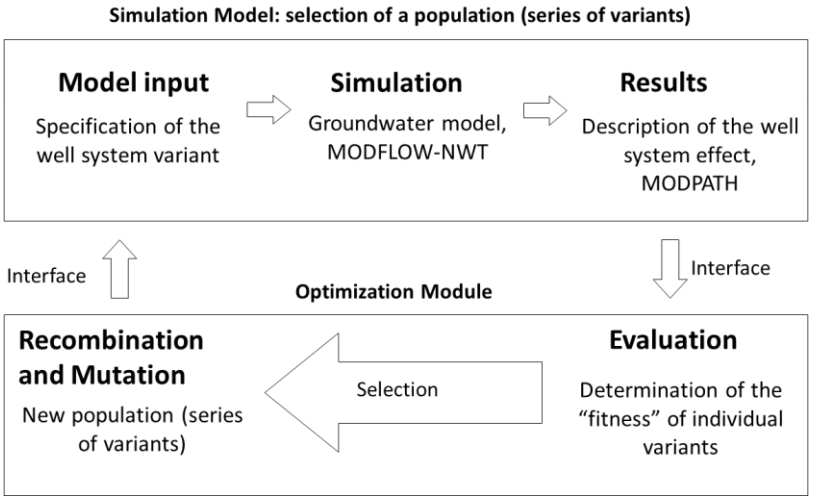

Figure 1. Scheme of the Optimization-Simulation System.

Hydro GeoAnalyst and Visual MODFLOW were used to assist the model setup and the visualization of the optimization results, respectively.

3 – SITE HYDROGEOLOGY

From the top to the bottom, 6 geologic units were considered in the site groundwater flow model: (1) fine to medium sand (Weichsel glaciation); (2) calcareous coarse silt to fine sand (loss, Weichsel glaciation); (3) fine to coarse sand (river terrace, Weichsel glaciation); (4) clay, silt and sand (moraine, Saale glaciation); (5) weathered marlstone (upper Cretaceous); (6) non-weathered marlstone (upper Cretaceous)

Units 1 and 2 comprise two independent contaminated Quaternary porous aquifers, separated by an aquitard formed by unit 3. Localized discontinuities in this aquitard generate hydraulic windows connecting the upper (unit 1) and lower (unit 2) Quaternary aquifers. Units 4 and 5 comprise the underlying aquitard of the contaminated aquifers. Unit 6 composes a regional fractured Cretaceous aquifer that partially feeds the contaminated Quaternary aquifers at the site.

The planned cut-off wall will advance from the ground surface until the first 2 m of the weathered marlstone horizon (unit 5). Given that the thickness of the Quaternary aquifer is not homogenous, the physical barrier depth will vary from ca. 10 to 14 m. Moreover, at the

upper aquifer, a drain will be constructed along the up streamed cut-off wall external face, in order to minimized groundwater level rises there.

4 – RESULTS AND DISCUSSIONS

The proposed physical barrier and the pumping wells quantity, position and extraction rates were examined considering the two essential aspects of the planned site management actions: (i) the hydraulic capture of the three delineated source zone areas and (ii) the minimization of groundwater leakage from the enclosed area to the surroundings areas. According to the modeling results, the proposed site management measures can indeed control the spreading of contaminants towards the site neighboring areas. However, the suggested well configuration will probably generate a mixing of distinct contaminant plumes, what can negatively affect the pump and treat performance.

For all examined prediction cases, the mathematical optimization carried out in this study was able to significantly improve the well configurations, in comparison with the proposed site management plan. The optimized arrangement of the pumping wells allows not only a reduction of the required number of wells and of their extraction rates (e.g., approx. 60% for the remediation wells), but also the separated hydraulic capture of distinct contaminants plumes. The latter is considerably beneficial for the design and operation of on-site contaminated groundwater treatment plants. The executed transient simulations have additionally shown that during the German summer months of June to October, significant groundwater withdrawal reductions should also be possible.

The optimized site management strategy can led to substantial cost reductions.

5 – REFERENCES

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