Available online at www.sciencedirect.com
ScienceDirect
Mathematical and Computer Modelling 45 (2007) 766–776
MATHEMATICAL AND COMPUTER MODELLING
www.elsevier.com/locate/mcm

Use of artificial neural network simulation metamodelling to assess groundwater contamination in a road project

Eddy El Tabach[a], Laurent Lancelot[a,*], Isam Shahrour[a], Yacoub Najjar[b]

[a] Laboratoire de Mécanique de Lille (UMR CNRS 8107), University of Sciences and Technologies of Lille (USTL), Polytech'Lille – Civil Engineering Department, 59655 Villeneuve d'Ascq, France
[b] Department of Civil Engineering, Kansas State University, Manhattan, KS 66506, USA

Received 23 February 2006; received in revised form 21 July 2006; accepted 28 July 2006

Abstract

The estimation of the extent of a polluted zone after an accidental spill occurred in road transport is essential to assess the risk of water resources contamination and to design remediation plans. This paper presents a metamodel based on artificial neural networks (ANN) for estimating the depth of the contaminated zone and the volume of pollutant infiltration in the soil in a two-layer soil (a silty cover layer protecting a chalky aquifer) after a pollutant discharge at the soil surface. The ANN database is generated using USEPA NAPL-Simulator. For each case the extent of contamination is computed as a function of cover layer permeability and thickness, water table depth and soil surface–pollutant contact time. Different feedforward artificial neural networks with error backpropagation (BPNN) are trained and tested using subsets of the database, and validated on yet another subset. Their performance is compared with a metamodelling method using multilinear regression approximation. The proposed ANN metamodel is used to assess the risk for a DNAPL pollution to reach the groundwater resource underneath the road axis of a highway project in the north of France.

Keywords: Simulation metamodelling; Artificial neural networks; Accidental pollution; Trichloroethylene; Road; Transport

1. Introduction

Road accidents involving the release of toxic or hazardous materials (such as hydrocarbons and chlorinated solvents, which are non-aqueous phase liquids or NAPL) during their transportation may cause severe environmental problems. A particular attention is given to denser than water NAPLs (DNAPLs), which may reach deep into the aquifer and thus durably contaminate the groundwater. This study is concerned with the impact of a DNAPL spill on the water resource for a road project infringing a zone of drinking water catchments in the case of a road accident involving a DNAPL transporting vehicle.

The zone of study spans over several kilometers, along which soil properties vary significantly. Many numerical models simulating the transfer of NAPLs in unsaturated soils have been proposed [1–3]. Based on a precise description

* Corresponding author.
E-mail address: Laurent.Lancelot@polytech-lille.fr (L. Lancelot).

0895-7177/$ - see front matter
doi:10.1016/j.mcm.2006.07.020

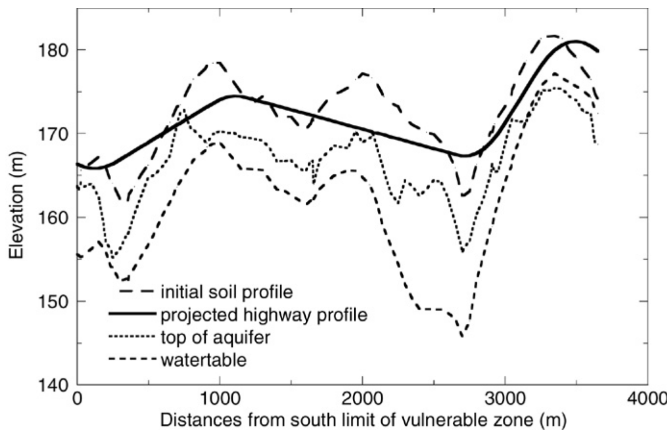

Fig. 1. Cross-section along the axis of the highway project.

of the governing mechanisms of transfer (multiphase flow, inter-phase exchanges, transport of diluted pollutant in liquid and gas phases), these models require the determination of many parameters and an intensive computational effort particularly for large three dimensional problems. If the model is to be used to study many scenarios in decision making applications, this purely mechanistic approach can prove impractical.

As an alternative, simulation metamodelling is based on the substitution of the simulation model by an approximation of the input–output relationship. Metamodelling, first proposed by Blanning [4], makes the computations much faster, allowing for more cases to be studied. This wider exploration of the input variables improves the understanding of the model, and permits us to carry out otherwise time consuming sensitivity analyses or solution optimization [5], at the cost however of a lower accuracy of the outputs. Originally based on regression methods [6,7], metamodels now use various approaches such as artificial neural networks (ANN) or kriging [8]. ANN have the advantage over regression that the form of the model need not be pre-determined. Moreover, ANN can theoretically approximate any function to any level of accuracy [9], which is very interesting when the governing physical mechanisms are highly non-linear like in pollution transfer in soils.

In this paper, a database was built with four input parameters (cover layer permeability and thickness, water table depth and soil–pollutant contact time) and the depth of contaminated soil and infiltrated pollutant quantity as output parameters, using the finite element software NAPL-Simulator [1]. Different artificial neural networks have been trained and tested on this database using the error backpropagation algorithm and cross-validation. Their performances have been analyzed and compared in statistical terms, and the optimum network has been used to predict the depth of contaminated soil in the practical case of an accidental DNAPL spill along the axis of a projected highway.

2. Problem under consideration

2.1. Presentation of the road project

The highway project crosses a valley where important drinking water resources are located.

Geological and hydrogeological surveys showed fractured carboniferous limestones overlaid with 5–15 m of silts, silty sands and silty clays, with a water table lying at 5–25 m from the soil surface, inside the fractured limestone (Fig. 1). Piezometers allowed the monitoring of water table variations with time over an almost 2 year period (September 2000 until April 2002).

Fig. 1 shows the soil profile with projected cuts and fills. In cut zones the scouring of the protective silt cover layer may increase the aquifer vulnerability during the construction phase, but these zones will be protected after the highway construction (impervious road platform, runoff retention basins). In fill zones there is a risk for vehicles to fall down from the platform during accidents and potentially cause a pollution to the unprotected natural soil, eventually threatening groundwater resources. Pollutant migration through silty cover soils should hence be thoroughly analysed in fill zones.