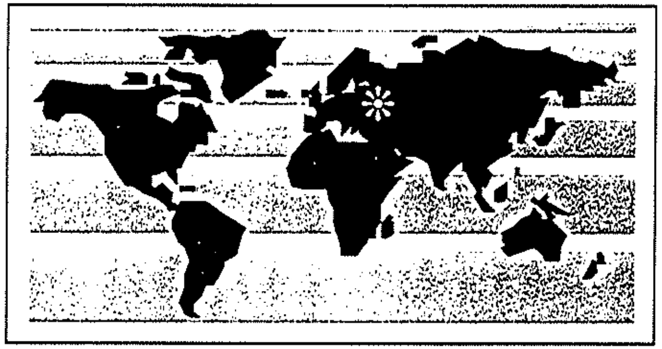
International Symposium on Environmental Contamination in Central and Eastern Europe

"A Forum for Technology Transfer"



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Section 6: Modeling and Computer Applications

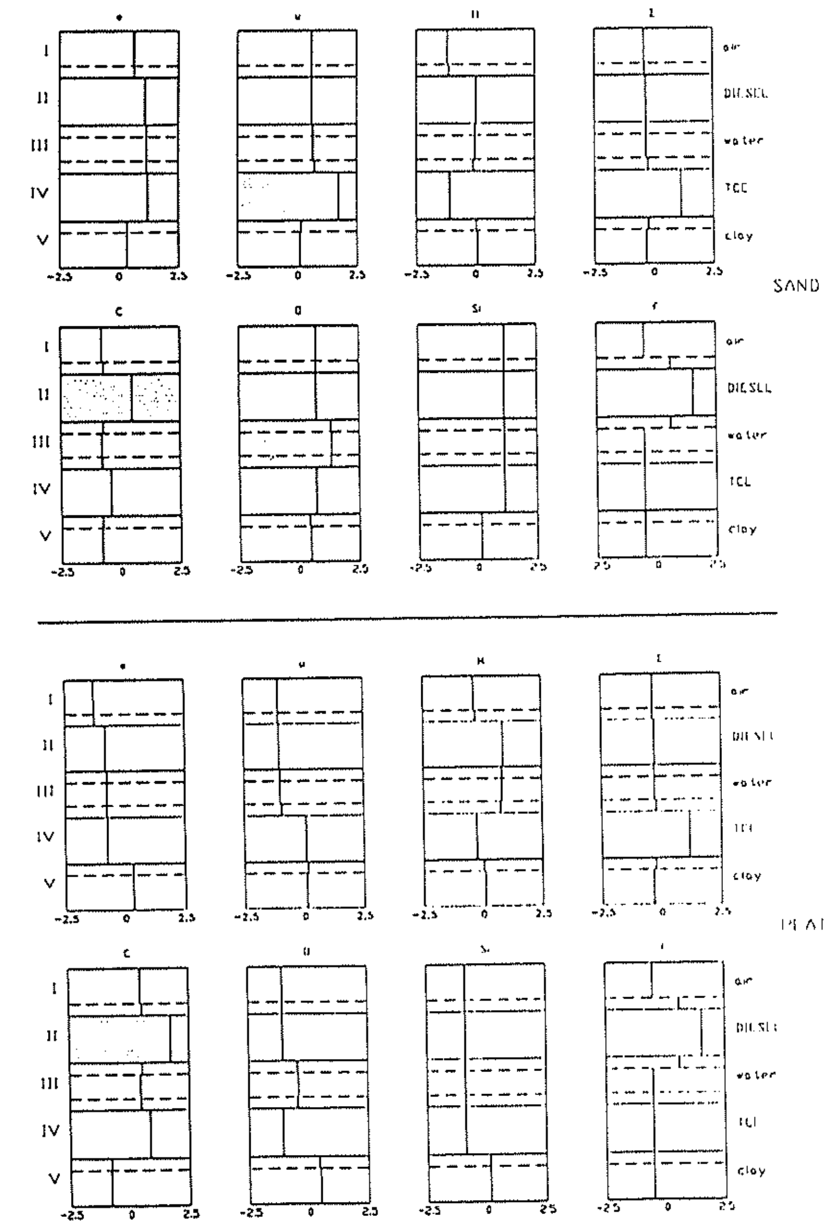

Figure 5 Standardized results in sand soil (top) and peat soil (bottom).

MODELLING AND OPTIMIZATION OF AN HYDROGEOLOGICAL SYSTEM TO PREVENT GROUNDWATER POLLUTION FROM A LEAKY LANDFILL

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Abstract

Numerical simulations of the groundwater flow and contamination in a confined sandstone aquifer underlying a leaky landfill, have turned out very helpful in the choice of the prevention means to be taken. The geometry of a buried impervious wall and the scheme of the associated pumping system are optimized using a Finite Element code. The results of this study are illustrated, commented and analyzed with an eye to the further applications of this method to other cases. This consistent way to make use of all the available data, provides undoubtedly a very good tool to advise the decision-makers facing this kind of environmental problems.

Introduction

The main environmental concerns for the selection of a site in view of waste dumping are : (1) the pollution risk of the groundwater aquifers; (2) the slopes stability and any modification of the natural conditions induced by the dump site; (3) the landscape aspect; (4) the different nuisances as odors,rats,papers and eventually truck traffic. The two first problems are more fundamental and depend principally on the geological and hydrogeological conditions. The others are function of the landfill setting and operating conditions and consequently in normal cases, it is easier to palliate them .

The risk of pollution of the groundwater is linked to the leakage of the infiltration water through the waste products. As an exemple, in Belgium, the annual average rainfall is about 750 mm (or 750 liter/m2), and in a normal vegetal environment the evapotranspiration can be estimated to 550 mm/year by plants roots and transpiration. Another part is immediately driven away by the surface runoff and only the water left is really infiltrated into the aquifers.

These values are reliable for a natural ground covered with normal vegetation but are not representative of an active dump or disposal site. In this last case, no vegetation is present and the surface runoff is very weak. After evaporation, the remaining water infiltrates and percolates through the waste products and,of course, becomes highly polluted. For a closed disposal site with a restored vegetal cover, a mean percolating volume of about 2000 m3/km2/year is estimated and can be reduced to few hundreds if the dump has been covered previously by an impervious geotextile (Monjoie, 1990).

The percolating water is to be collected in integrality to avoid the pollution of the groundwater. If the actual volume of collected water does not reach the approximations mentioned here above, the landfill is certainly leaking and is likely provoking a pollution of the aquifers. That is the reason why it is very important that the potential landfill sites would be characterized by a satisfying imperviousness. Naturally impervious sites are often small valleys or vales in

impervious layers consisting of shales or clays, where the imperviousness is ensured by the impervious substratum and the superficial drainage by the altered colluvial mantel. The polluted water are collected downwards in the valley where they can be directed to an adequate treatment.
Embankments over an impervious substratum (figure 1) are another possibility, but a draining trench cutting the superficial layers or the colluvial mantel is then necessary to collect the percolating water. This drainage can also be extended upwards by superficial drains ensuring a better collect of the percolates under the embankments contributing, by this way, to the consolidation and to the stabilization of the waste products .

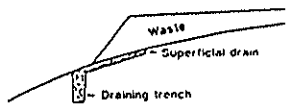

Fig.1 Waste disposal in embankment with an underlying superficial drain and a draining deep trench located downwards.

The old open-pit sites, except maybe the clay-pit sites, do not present the required characteristics of natural imperviousness. A sand-pit on a shaly substratum or abandoned quarries in a limestone or sandstone context can rarely be considered as totally (laterally and/or vertically) impervious. These sites can be improved, however, by artificial means. The impermeability system consists most often in using impervious geomembranes (or geo-textiles). But in case of awaited differential compactions or rock instabilities, a thick additional clayey bedding is recommended. In fissured limestones and chalks or in calcareous sandstones, where aquifers are very productive but also highly vulnerable, despite these precautions, it is still not recommendable to place a disposal site for waste products. Even for the dump of inert waste products, the choice of such a site can be done at the unavoidable condition that all the percolating water could be collected adequately (by pumping wells or underlying galleries), considering the case of accidental spill of other products than those which were prescribed (figure 2) [1].
Unfortunately, many disposal sites have been chosen previously, without taking into account all these recommendations. The cost of cleaning up the most severe cases of induced contamination can be estimated to millions of dollars. Choices have to be made between the measures to be taken in order to improve and eventually to restore the groundwater quality. As mentioned by Fetter [2], there are mainly two broad categories of remedial measures: one must either remove or isolate the source on one hand, and pump and treat the groundwater on the other hand. Various types of remedial measures can be developed and the use of models should provide the opportunity to compare the different alternatives for their effectiveness.

Case study

The case described here is relevant to the optimization of the geometry of an impervious slurry wall and of the associated pumping, in order to isolate the contaminated zone of an aquifer underlying a leaky landfill. The landfill is an old open-pit in calcareous sandstones. The calcareous sandstones are underlain by a thick marl layer of very low hydraulic conductivity which is a very effective impervious layer through which the polluted water can probably not leak more deeply. Moreover, the piezometric levels of the underlying confined aquifer are higher than those of the superficial aquifer. In these conditions, only the water table aquifer is polluted by the percolating water from the landfill deposits. It shows a gradient mostly directed westwards (figure 3), to join in the western part, an alluvial aquifer which is also contaminated.
The organic compounds found in the content of the polluted water are not of high toxicity and concentrations in heavy metals are still lower than the legal standards for industrial water in Belgium.

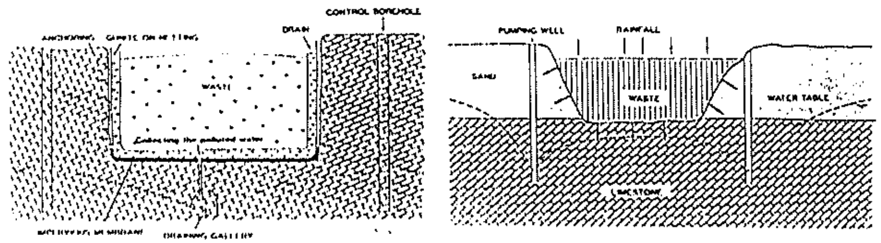

Fig.2 Adequate collecting systems for waste disposals sites located in unpropitious geological conditions (from Monjoie [1]).

However, a collecting system and the treatment of the polluted water have been prescribed. Fourteen boreholes have been drilled and equipped as piezometers in the upper sandstone aquifer and in the alluvial aquifer. The electrical conductivity, the temperature and the pH of the water are continuously measured. Water samples have been taken and analyzed to determine the pollutants contents. Hydraulic conductivity values of the aquifer have been determined by five pumping tests using in each case the other holes as piezometers. The transmissivity defined as the product T = K.e , with e being the saturated thickness has been found in different zones of the studied area.

Data and conditions of the model

A groundwater flow model using the Finite Element Method ([3],[4],[5],[6] and many others) has been elaborated on basis of all the collected data. The program used is running on IBM PC-386. A 2D approach is realized considering that the aquifer thickness (i.e. the saturated thickness) is implicitly taken into account in the transmissivity value affected at each element of the meshing network [7]. Of course, this vertical integration introduces a non linearity of the transmissivity, solved numerically by successive iterations on its value [8]. The finite element discretization (figure 4) includes the whole landfill zone and is prolonged on the different sides in order to carry the boundary conditions forward from the main stressed area [9]. The lateral boundary conditions are prescribed piezometric heads, as no lateral impervious boundaries can be found in this hydrogeological environment. The marl layer is assumed as the impervious basement of the model. Infiltration due to the rainfall is taken to a maximum value of 600 mm/year in agreement with the hydrological studies in the region. The infiltrating water leaking through the waste deposits is the pollution source. The calibration of the model ([10],[11] and [12] has been completed step by step and it has taken more than 40 runs to obtain reliable results compared to the measured piezometric levels. Corresponding to the calibrated piezometric map, six zones with different transmissivity values comprised between 0.001 and 0.00002 m2/s have been distinguished.

Results of the model

Many simulations have been completed varying the wall geometry and the pumping scheme. Only some of the results are summarized in the following lines :
A) The simulation is realized with the impervious wall as described before (figure 4) and a total pumping of 450 m3/day corresponding to 120 m3 day in both boreholes B5 and B1, 100 m3/day in B8 and 25 m3/d in B10 and B11. An additional pumping of 60 m3/d is localized at the node 424 of the discretized mesh (figure 4). The computed piezometric map (figure 5) shows that near the southern boundary of the model, some streamlines not converging to the pumping wells can be drawn. In this case, it is then possible that after the vertical leakage through the landfill, the

polluted water joining the aquifer would not be collected by the pumping system. For the next runs, this pumping scheme is changed in order to avoid such a situation.

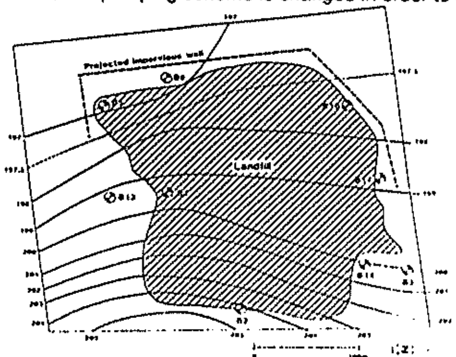

Fig.3 Measured piezometric map of the aquifer in the zone of the studied landfill site.

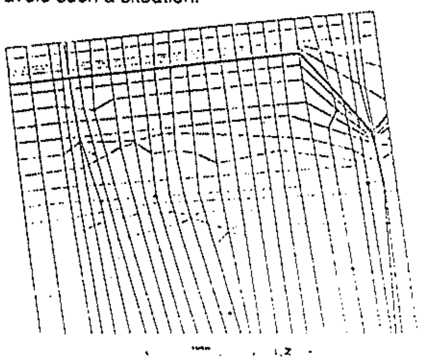

Fig.4 Finite element discretization of the studied area

B) With a total withdrawal of 475 m3/d, corresponding to 200 m3/d in B1, 150 m3/d in B5, 100 m3/d in B13 and 25 m3/d in B12, the second simulation shows clearly a better situation (figure 6) than in (A). No streamline can be drawn under the disposal site without being directed to the pumping wells. This scheme which consists in concentrating the main values of pumping on B5 and B1, located in the high permeability zone, is apparently propitious to collect the maximum of polluted water.

C) With another geometry of the wall and a withdrawal concentrated on B5 (300 m3/d), B1 (150 m3/d) and B11 (25 m3/d), the computed piezometry (figure 7) is also propitious for collecting the contaminated water. However for the same order of pumping, the total length of the wall is increased in comparison of the solution (B).

D) The wall is prolonged eastwards (figure 8) closing nearly completely the high permeability zone located near the boreholes B13 and B1. The pumping scheme can be limited to 200 m3/d in B5, 125 m3/d in B1 and 25 m3/d in B11 (figure 8) keeping an acceptable solution for the collect of the contaminated water. It is shown that this prolongation of the wall allow to pump less in the wells.

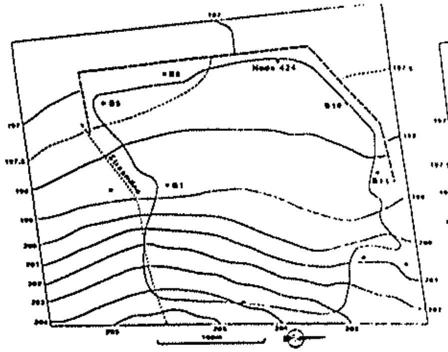

Fig.5 Results of the run (A), some streamlines passing under the landfill can escape from the pumping wells.

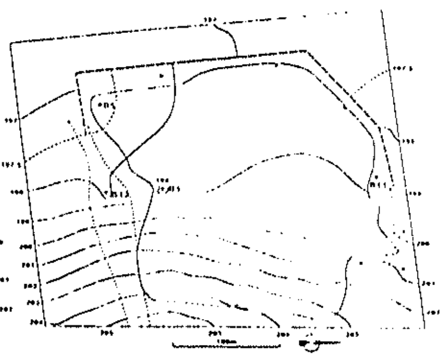

Fig 6 Results of the run (B)

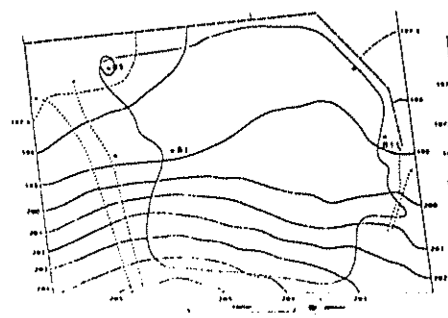

Fig.7 Results of the run (C).

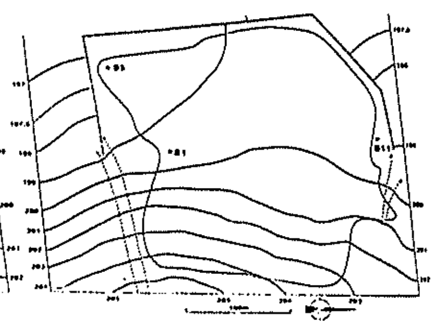

Fig.8 Results of the run (D).

Conclusions

Even if this model is limited to steady conditions and does not take into account the eventual diffusion of pollutant, the results give a good idea of the situation. On basis of the different pumping schemes and the wall geometries that have been simulated, general trends can be deduced : (1) it will be necessary to pump about 450 to 500 m3/d; (2) the optimal pumping scheme depends strongly on the chosen geometry of the wall and conversely. Of course, additional data would lead to more accurate results, but the results shown here above, bring the necessary information that decision-makers need before to begin the important remedial works. In this sense, we can consider that this modelling exercise was particularly beneficent as the task remaining now consists in choosing between two or three collecting system, considering from that moment only the financial aspect.

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