

Criteria For Risk Evaluation In Groundwater Management Projects: A Comparative Study

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Abstract. Environmental protection criteria in the decision making process on the choice of a drainage system at a construction site in the city of Basel are presented here.

A comparative quantitative evaluation between two drainage systems was possible focusing on the definition of equivalence criteria for aquifer protection and on the design of measures that guarantee the same safety level with respect to the above-mentioned criteria.

The criteria discussed in this article are based on the hydraulic characteristics of the groundwater system, as they result from two-dimensional groundwater simulations in the area of the project.

1. Introduction

Although groundwater modelling has become a standard instrument in the engineering practice in almost all decision making processes for groundwater management purposes, the criteria for risk evaluation have to be studied and defined for the specific case involved. In the environmental impact assessment studies related to underground construction, the influence of the project on the groundwater flow has to be evaluated. Pumping wells at the construction site draw down the water table to the prescribed levels allowing dry conditions for workers and for building operations. The cone of depression strongly modifies the quantity and the quality of the groundwater. Criteria for groundwater risk evaluation based on the hydraulic characteristics of the groundwater system and on the patterns of the flow domain are discussed. A project case and two possible drainage systems are presented here. The comparative study shows the role of the quantity and the quality of the groundwater in decision-making processes on the choice between two drainage systems at the construction site.

2. Project

The project is located in Switzerland and deals with the construction of a Highway which crosses a highly urbanised quarter of Basel where industrial and commercial areas coexist. The project is portioned in several stretches. We refer here to a road stretch which includes the construction of a tunnel at the intersection between two road axes. There the required water table drawdown and the big extension of the drained area make the study of the drainage system a key part in the realisation of the project. Two important aspects are related to the design of the drainage system: safety conditions at

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the construction site and groundwater protection during the construction phase.

Two drainage systems are compared for aquifer protection purposes. In one case the pumping system is open, i.e., the walls at the construction site do not close up the zone in which the water level has to be drawn down by the pumping wells (open drainage system). In the other case a part of the drained area is completely closed by an impermeable barrier system plugged in the ground down to the bottom of the aquifer (partially closed drainage system). In this case the pumping activity within the protected area has no influence on the regional groundwater flow (only local effects due to the presence of the barriers). Thus, in this case, only the drainage system of the open drained area is considered for the impact evaluation on the quantity and quality of the regional groundwater system.

3. Area: geographical and hydro-geological characteristics

The project area is a quarter of Basel on the left-hand side of the Rhine, where industrial and commercial activities co-exist in a highly urbanised zone of the city. In this area there are several groundwater users with their pumping and recharging wells, some probable contaminated areas and a monitoring system with piezometers to measure the water table levels on a regular base. Information concerning the contaminated area (location, extension, contaminants) and the pumping activities of the groundwater users are protected data.

The main groundwater direction is South West-North East. An important hydrological component is the Rhine, which acts like a receiving stream. Along the riverbank close to the construction site there is a wall, driven down to the bottom of the aquifer. A part of the ground water flowing to the Rhine is blocked and cannot find there a free exit into the river because the coastal wall acts like an impermeable barrier. Thus the groundwater flux is divided into two parts: one flowing along the wall in the North direction and the other one flowing along the wall in the South direction, both at the end flowing out into the river (Fig.1a).

4. Model

A two-dimensional groundwater model is made using a program (ASM) based on the finite difference method. The model domain is defined through boundary conditions: a potential flow line at the inflow boundary (first order boundary condition), leakage condition (third order boundary condition) at the outflow boundary, simulating the interaction between the Rhine and the ground water, and two streamlines (second order boundary conditions) laterally (Fig.1b).

The model domain is discretized into cells 30m×30m. The mesh size in the construction area is refined into cells 5m×10m. The aquifer bottom was calculated using an interpolation code (krigging) and the data from borehole profiles available in the databank of the Kantonsgeologie (Geologisch-Paläontologisches Institut der Uni Basel).

Mean values of the pumping rates and of the recharging rates for the wells in the model area are derived from the data delivered from AUE (Amt für Umwelt und Energie) and inserted in the corresponding model cells. A mean value was also used for the water level in the Rhine. The leakage coefficient was treated like a calibration parameter.

The hydraulic conductivity of the zones involved is estimated from pumping test data. These values cannot always be considered as representative values for the zone surrounding the wells. This is the case of pumping tests in industrial areas where foundation of destroyed buildings still lay in the underground together with foundations, canals, tubes, inspection tunnels and other underground structures related to the existing industrial processes. Thus the first estimation values are adjusted during the calibration work for a better match between the observed groundwater level and the calculated levels at the observation points.

Underground structures which reduce the flow infiltration surface vertically are considered in the two-dimensional model using a fictive value of the hydraulic conductivity in the corresponding cells. For these a reduction of the hydraulic conductivity proportional to the reduction of the infiltration area is calculated. Underground structures which penetrate down to the aquifer bottom (like the walls at the construction site and the bank wall on the Rhine) are represented with impermeable cells.

The drained area at the construction site is simulated in the model with cells having constant hydraulic head. The walls and the drained area at the construction site are shown in Fig.2a for the open drainage system and in Fig.2b for the partially closed.

It has to be noticed that the geometry of linear structures, like underground tubes or inspection tunnels can be represented with rectangular mesh cells only in a approximate way.

Numerical groundwater simulations are carried out for stationary conditions using monthly mean values. Groundwater potential lines (blue lines) and the catchment area (red lines) are shown for the two drainage systems in Fig.3a and 3b. Results show that both drainage systems have a strong impact on the groundwater regime. It is clear that the cone of depression due to the pumping wells at the construction site involves changes on the groundwater flow. It is also evident that the bigger the pumping rate is, the greater is the cone of depression and the impact of the construction phase on the groundwater regime.

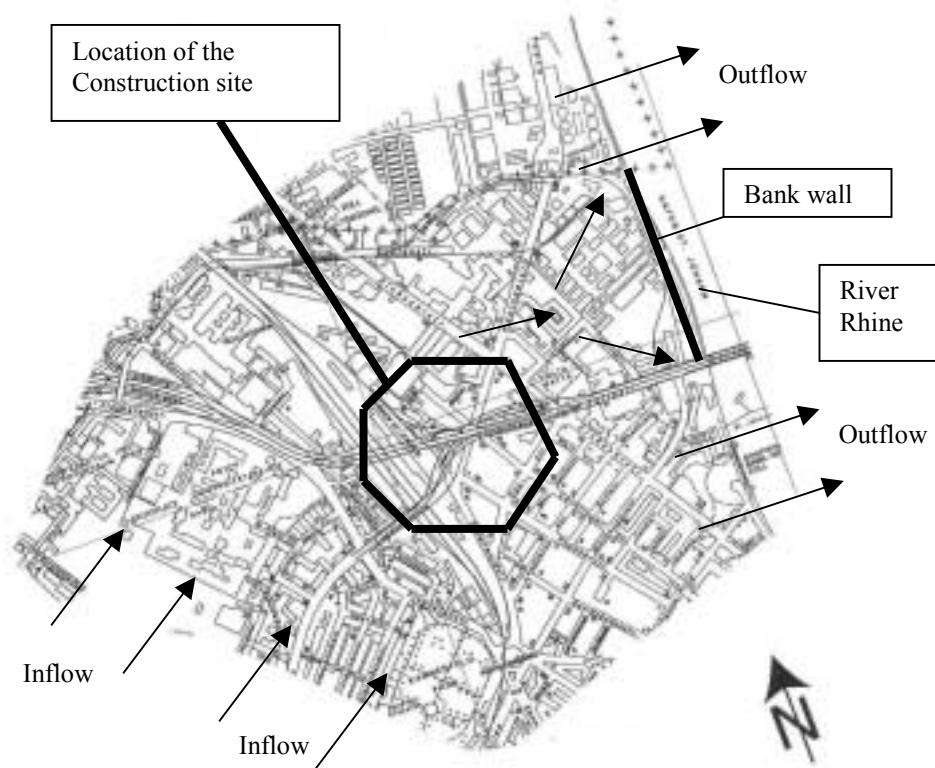


Fig.1a - Project area

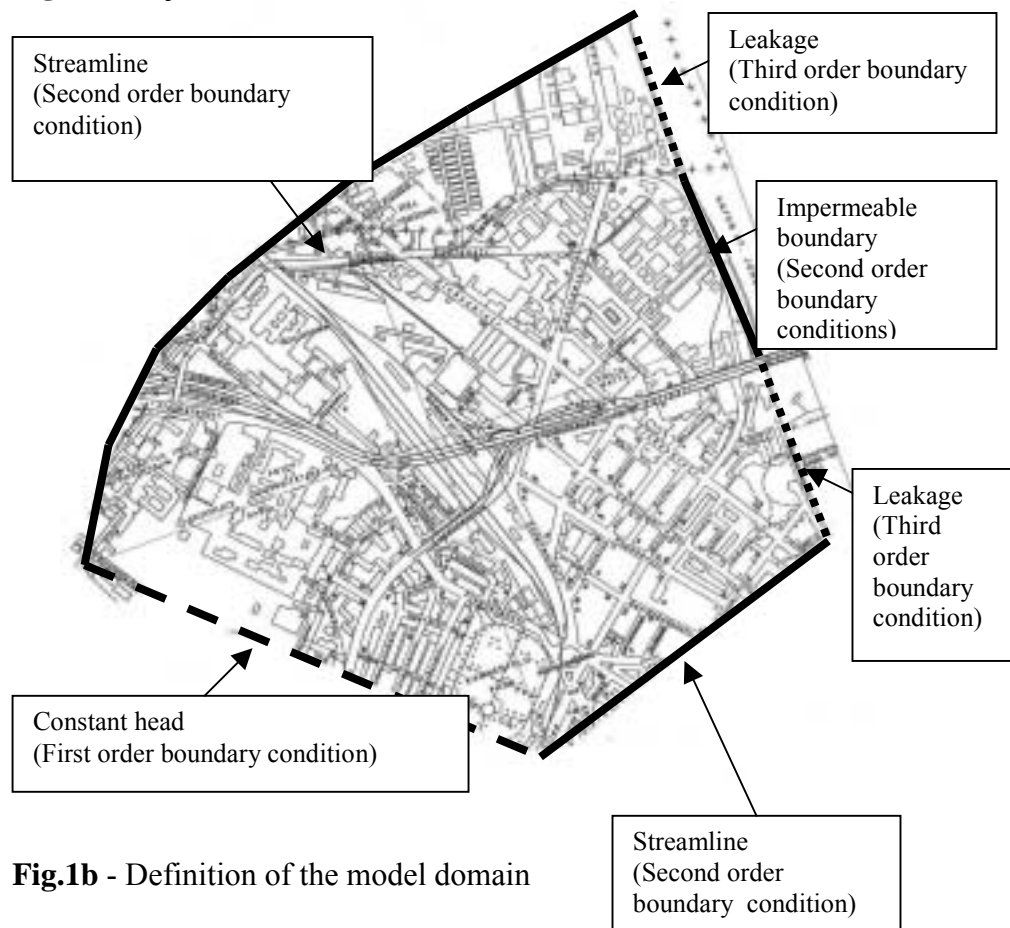
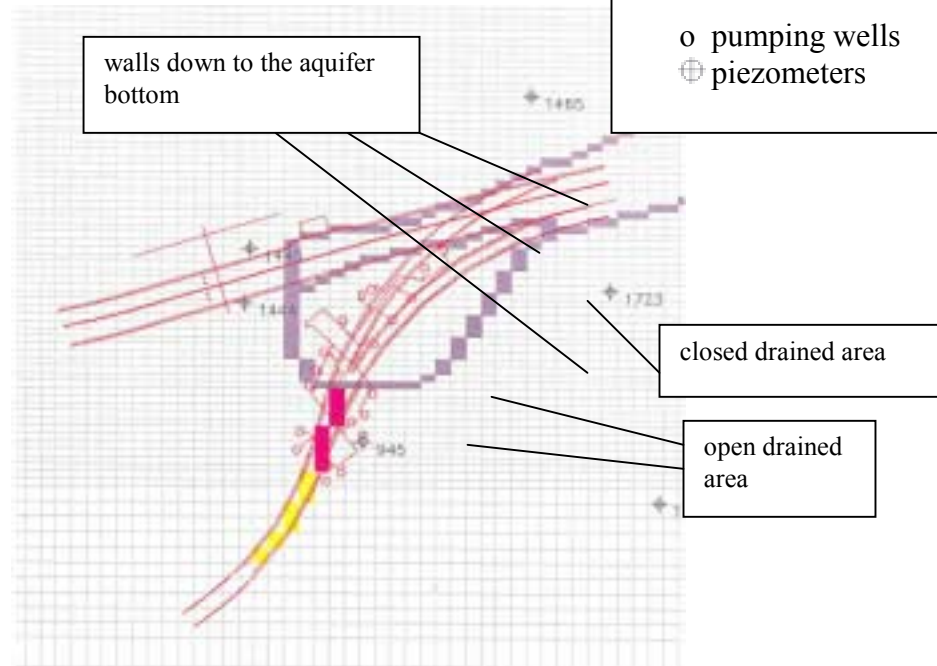
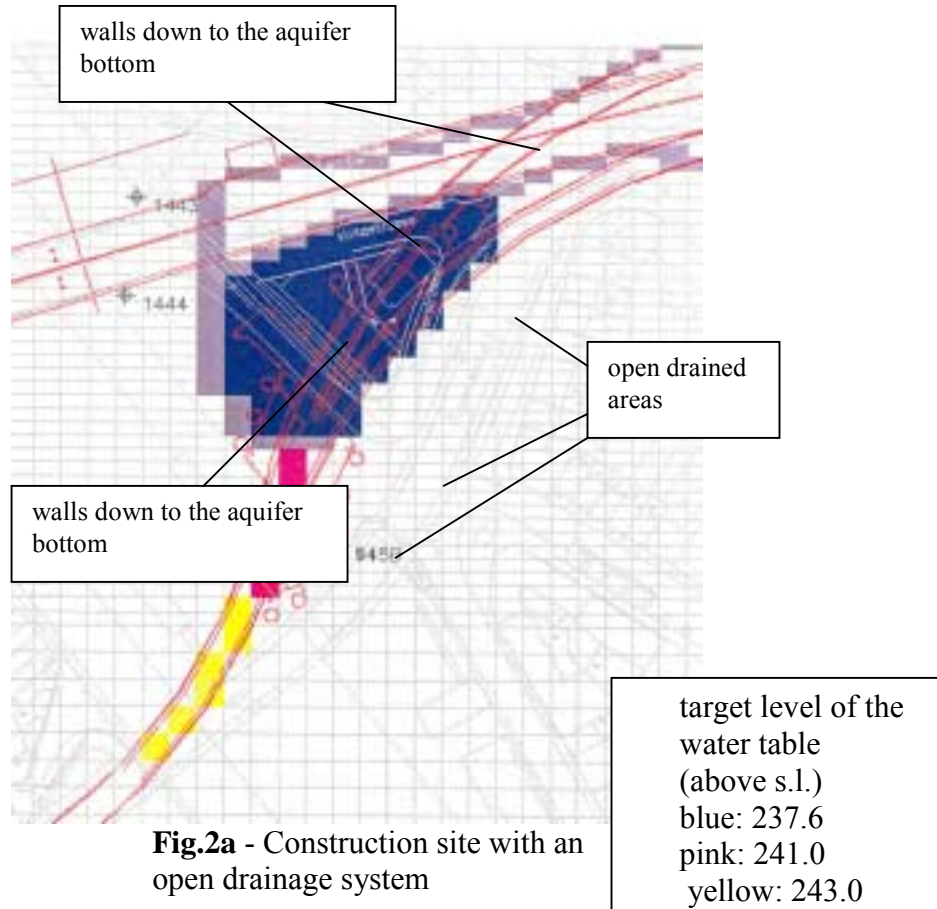


Fig.1b - Definition of the model domain



5. Procedure in the decision making process

The question then is how the two scenarios can be compared and the difference between them be quantified.

Instead of answering this question which involves comparative criteria, another procedure was followed.

The main question was split into two problems:

- to define equivalence criteria in the context of aquifer protection
- and to find measures able to convert the two scenarios into solutions which offer the same safety level according to the equivalence criteria previously defined.

Safety level (or risk degree) in the context of aquifer protection includes two aspects: the quantity and the quality of the groundwater. The groundwater withdraw strongly modifies the quantity and the direction of the natural water fluxes on a local and on a regional scale. In particular, low water table levels can create a risk for the other wells in the area, since the required pumping rate there can only be guaranteed if a prescribed hydraulic head is available.

Changes in the flow field represent also a risk for the quality of water. Contaminated zones which are at rest in undisturbed conditions could be moved because of the higher hydraulic gradients due to pumping. Changes in the local flow velocity at contaminated sites could cause the spreading of a polluted plume.

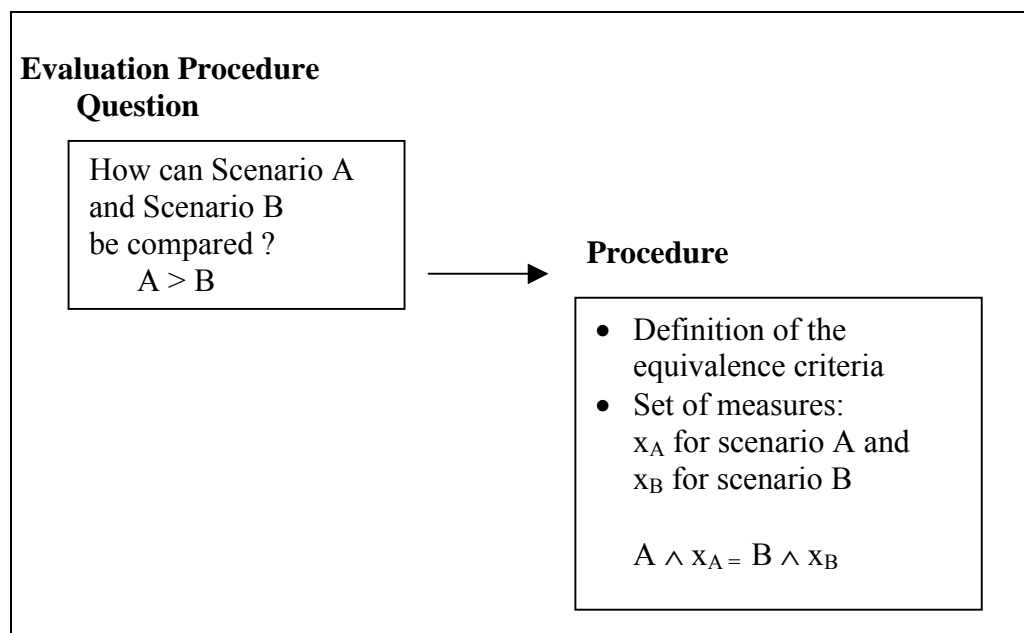


Fig.4 - Decision making procedure on the choice between two scenarios

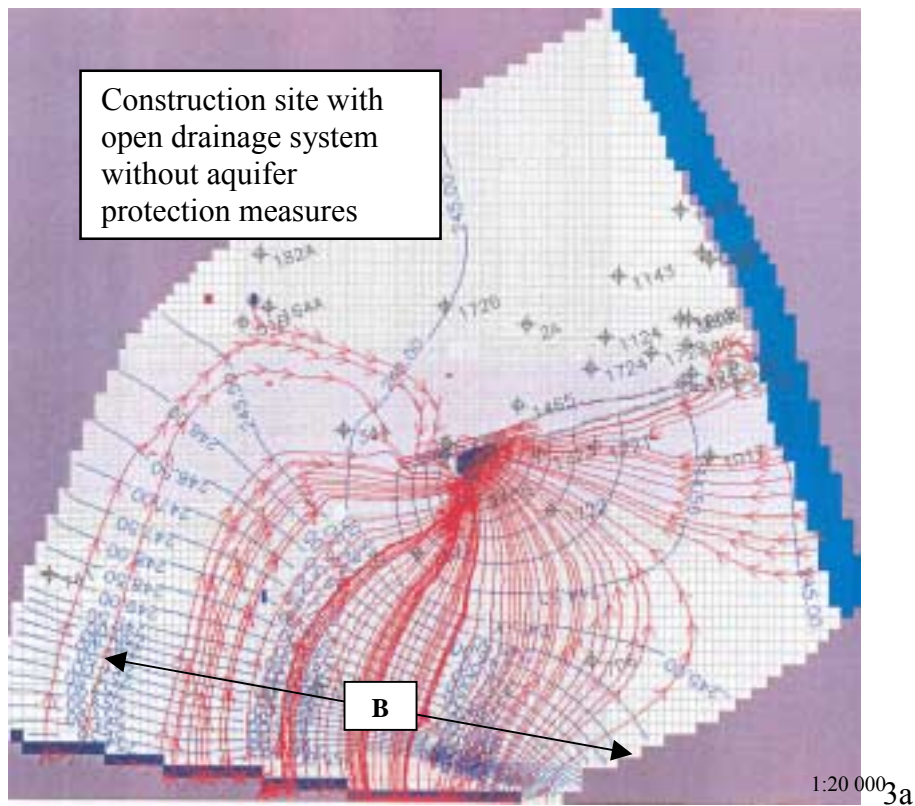
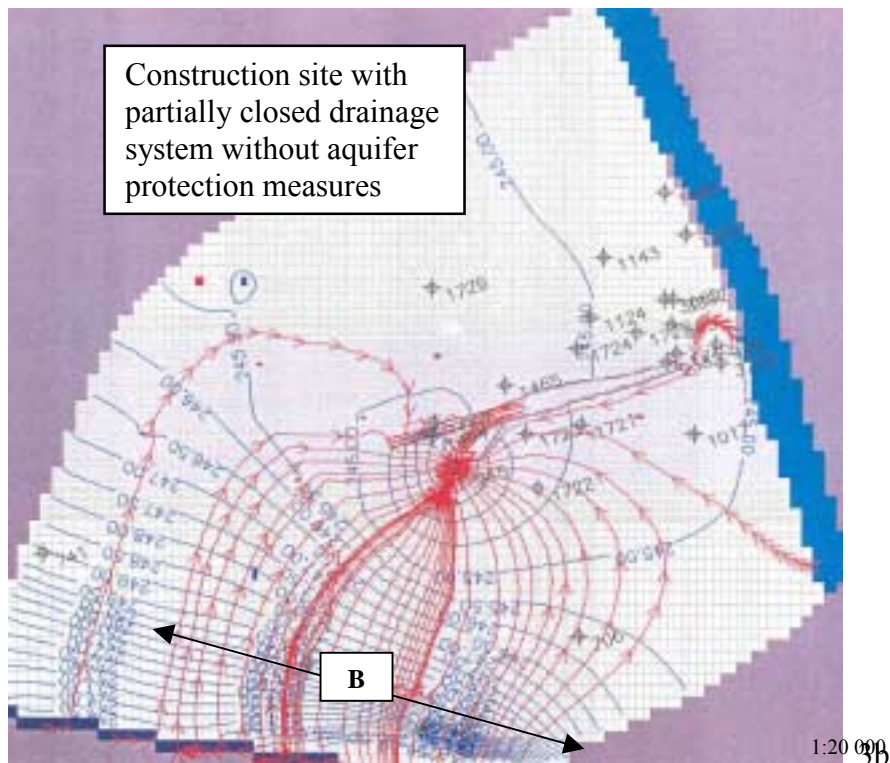


Fig.3a, b - Potential flow lines (blue lines) and catchment area (red lines).
 Time interval: (→) 3 months
 B= Width of the catchment area



5.1 Equivalence criteria for impact evaluation

Many criteria based on different parameters can be considered:

- the width of the catchment area of the drainage system
- the water level in the pumping wells of the groundwater users
- the water velocity under probable contaminated zones
- the piezometer head difference at the two sites of the road axes
- the displacement of the water divide behind the bank wall
- the inflow from the Rhine in the aquifer
- and others

The first three criteria are chosen for the analysis of the scenarios related to the drainage systems. The choice of the first three criteria can be explained out of the following considerations. The catchment area is the inflow area for the pumping wells system. The width of the catchment area shows the impact of the drained area on the flow field on a regional scale. The water table levels give information on the water stored (eventually available) in the aquifer. At the exploitation points, the aquifer drawdown below a prescribed level means additional costs for the groundwater users who are obliged to get water from the water supply system of the city to satisfy their needs. The water velocity under contaminated areas strongly influence the velocity of the contaminant and thus the spreading of the transport process. The catchment area, the groundwater levels and the flow velocity depend on the hydrological conditions. For the impact evaluation two groundwater flow regime (high flow and low flow, annual values) are investigated (C. Miracapillo and P. Huggenberger, 2001). The pictures in Fig.3, 6, 7 and 8 refer to high flow conditions.

5.2 Aquifer protection measures

Hydraulic measures to reduce the environmental risk are studied. The installation of a certain number of recharging wells all around the construction site upstream from the pumping wells is considered (Fig.5). Numerical simulations are carried out. It is found that the catchment area of the open drainage system with 6 recharging wells is similar to the one of the partially closed drainage system with 3 recharging wells. Fig.6a and 6b show that the width of the catchment area in the two cases is the same. The flow velocities in some areas which could be contaminated have in the two cases the same values (Fig.7), with the exception are the areas n.1 and n.2, which are located in the north part of the model domain.

Comparison of the groundwater levels between the two cases shows lower levels for the partially closed drainage system with 3 recharging wells than for the open drainage system with 6 recharging wells. Thus an additional recharging well (RW**) is included in the partially closed drainage system. In conclusion the impact on the aquifer of pumping and recharging wells in the two cases (open drainage system + 6 recharging wells and partially closed drainage system 4 recharging wells) can be considered, at the end, equivalent with respect to the criteria previously defined.

Thus, the two project cases with the corresponding (different but equivalent) hydraulic systems, can be submitted to comparative studies concerning other

problematic (noise, traffic, etc.) and to the cost analysis for decision-making purposes on the choice of the project solution.

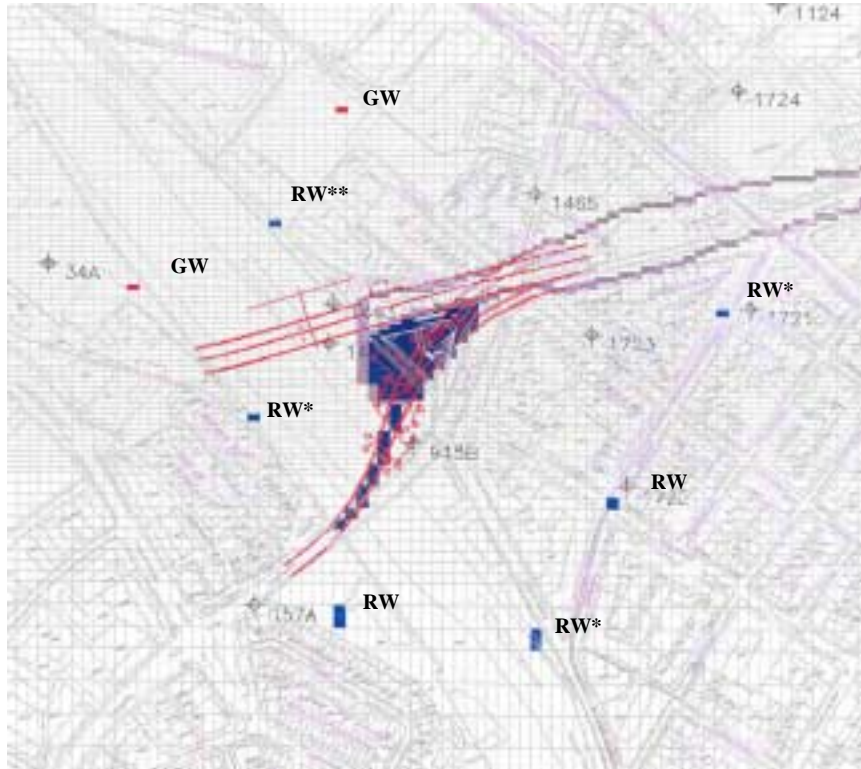


Fig.5 - Location of the recharging wells around the construction site

GW = Ground water users

⊕ = Piezometer

RW = Recharging wells for both drainage systems

RW* = Additional recharging wells for the open drainage system

(RW** is included, at the end of the study, also in the partially drainage system)

6. Conclusions

Numerical models are suitable to simulate different project cases on a regional scale, since it is possible to consider source and sink terms, different kinds of heterogeneity and, if necessary, a complex geometry of the flow domain. In this particular case, several hydraulic components and structural elements, which play an important role on the distribution of the potential lines and on the water budget, can be considered. At the same time, some aspects related to the “artificial” heterogeneity of the aquifer, due to the land use and to the urban and industrial development, affect the validity of the results of the numerical simulations.

The influence of these aspects on the accuracy of the numerical results is not evaluated. It is, in fact, realistic to assume that these approximations affect in the same way the result accuracy of both scenarios, without limiting the validity of the comparative study.

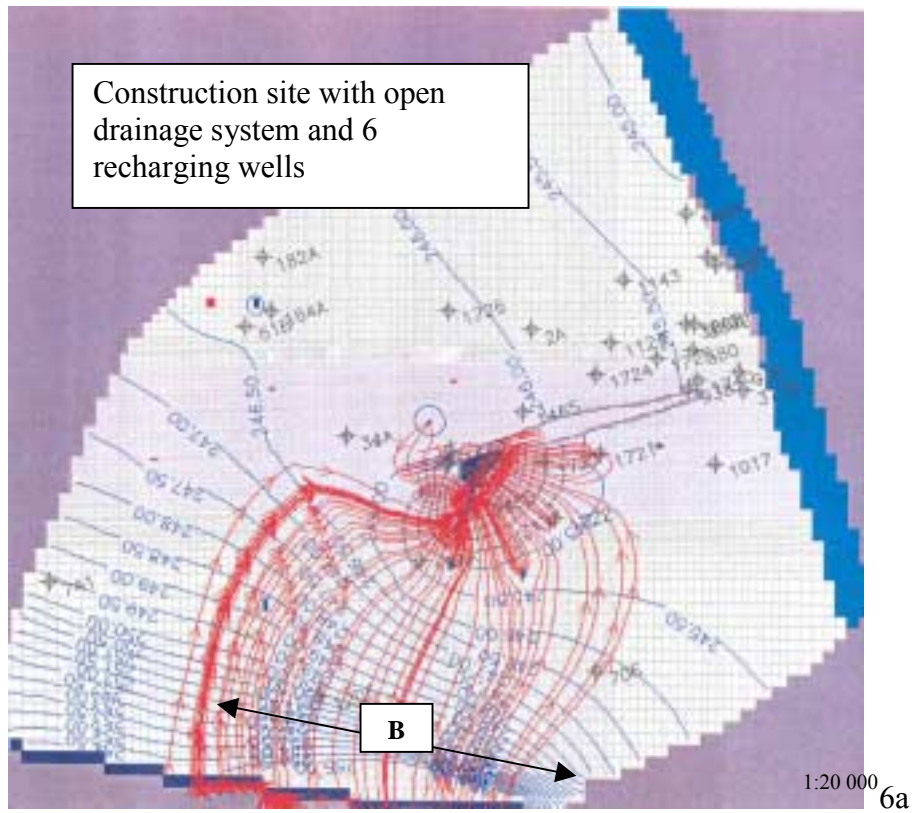
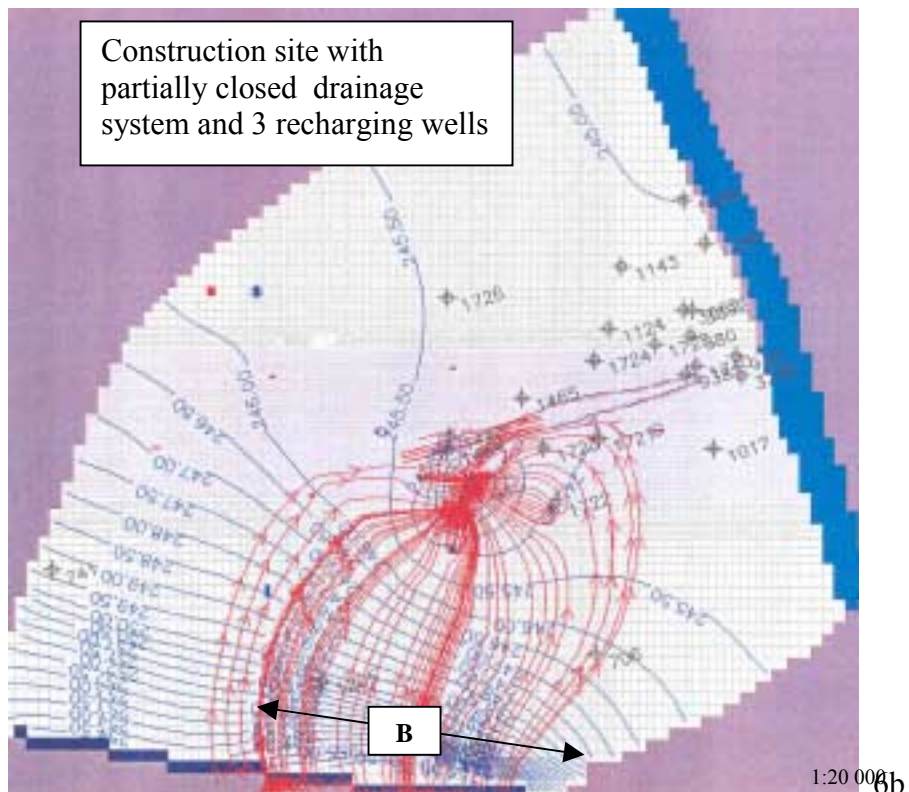


Fig.6a, b - Potential flow lines (blue lines) and catchment area (red lines).
Time interval: (→) 3 months
B= Width of the catchment area



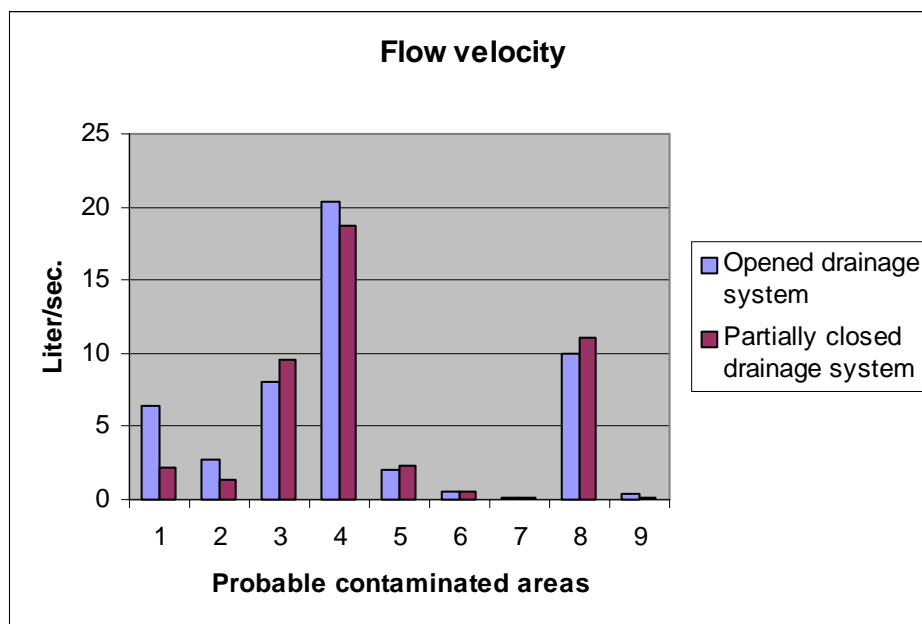


Fig.7 – Flow velocities (l/s) in probable contaminated areas

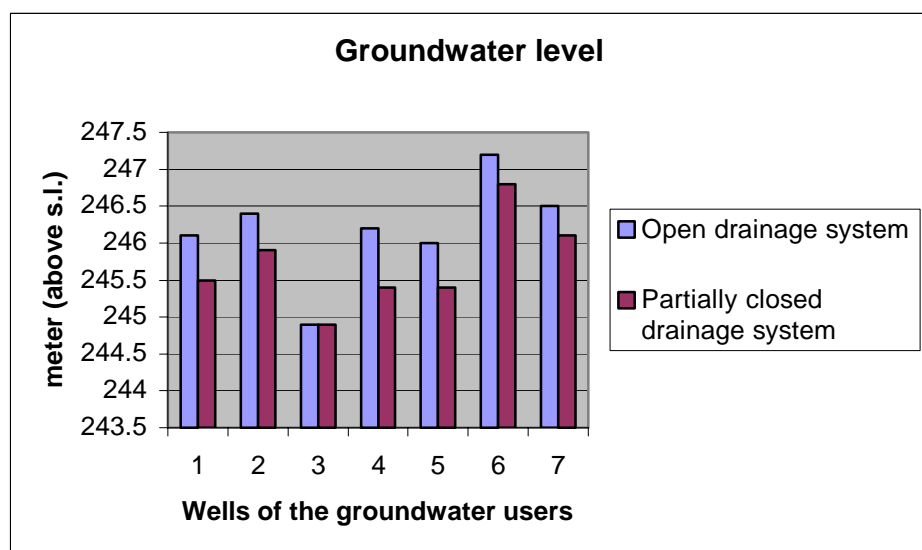


Fig.8 – Water table levels (m) at the wells location

The key points of the comparative study are the definition of equivalent safety criteria for groundwater protection (based on the flow patterns and on the characteristics of the hydraulic system) and the design of measures, in order to satisfy the equivalence criteria previously defined. This procedure has demonstrated that it is easy, cost efficient, flexible, reliable, and, generally speaking, suitable in preliminary environmental studies.

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