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FIELD TESTS ON PROPAGATION OF CONSERVATIVE TRACERS IN FLUVIOGLACIAL GRAVELS OF UPPER BAVARIA

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ABSTRACT

Tracer experiments performed in fluvioglazial gravels indicate that migration and dispersion processes in the groundwater are frequently influenced: by fabric of the sediment, by special hydraulic boundary conditions and even by groundwater level fluctuations. In detail the findings are:

- In aquifers which are homogeneous consistent values for the groundwater flow velocity are measured;
- dispersivities from field studies correlate very well with laboratory experiments; if distances between injection and detection points are considered; this relation is mainly due to bedding structures existing in otherwise homogeneous aquifers; by comparing the effects on tracer propagation parallel and perpendicular to bedding this effect is to be seen;
- deviations from dispersivity-distance-relation for fluvioglacial gravels occure under special hydraulic and geologic boundary conditions; deviations usually fit higher dispersivities than expected;
- transverse dispersion increases strongly under the influence of inhomogeneities in the unsaturated as well as in the saturated zone;
- transverse dispersion is small in homogeneous aquifers; in gravels the transverse dispersion coefficients were found to be about 10 - 20 times smaller than the longitudinal dispersion coefficients;
- hydraulic influences, like oscillating movements of the groundwater in connection with changes of the groundwater level and the geometrie of potential field , cause additional dispersion of the tracer plume. These represent a dispersion process which is superimposed on the normal hydrodynamic dispersion and may lead to higher or lower dispersivities than expected.

INTRODUCTION

Moraineous and fluvioglacial gravels were deposited in Alpine valleys and in the foreland of the Alps by the pleistocean glaciations. These gravels have grain size distributions similar to that of a Fuller mixture with a maximum grain diameter of about 20 mm. They comprise all over Southern Germany, and in particular in Bavaria the most important aquifers.

The quaternary gravels have hydraulic conductivities between 10^{-3} and $3 \cdot 10^{-2}$ m/s, their effective porosity lies between 10 and 20 % and mean velocities range from 10 - 40 m/d (ref. 1). To estimate the possible influences of contaminants on these groundwater resources as well as the propagation of contaminants in the groundwater, a number of tracer experiments with instantaneous line injections were performed, taking special account of the geologic and hydraulic boundary conditions. The principle goal of the investigations was to determine the groundwater velocity, the path of groundwater flow and the extent of dispersion.

^{82}Br, in the chemical form bromide, was used, which is one of the most reliable tracers for groundwater experiments. Combined experiments with ^{82}Br and the fluorescent dye tracers uranine (di-sodium-fluoresceine, C.I.• 45 350) and eosin (C.I.* 45 380) demonstrated a similar tracer behaviour for all the coarse grained aquifers of concern.

In some cases the detection of the fluorescent dye tracers was performed directly in the field with recording filter fluorometers (TURNER 111 and PERKIN-ELMER 1000). But mainly water samples were taken, which were analysed for content of fluorescent dye tracers in the laboratory (PERKIN-ELMER 203, AMINCO SPF 500). With a special scan procedure the two fluorescent dyes could be detected side by side in the same sample (ref. 2). The detection limits are $2 \cdot 10^{-12}$ g/ml for uranine and 10^{-11} g/ml for eosine.

RESULTS

Oberau field

8 tracer injections were made into the aquifer at different sites in the field during a period without artificial groundwater extraction. In the observation points tracer passage curves were obtained (Fig. 1). From the tracer passage curves, mean flow velocities and dispersion coefficients were derived and dispersivities were calculated. In addition, observations on the width of the tracer path as a function of distance were made.

The flow velocities are uniform in the range of 20 - 25 m/d and agree with values calculated on the basis of hydraulic conductivity, porosity and hydraulic gradients.

• Colour index

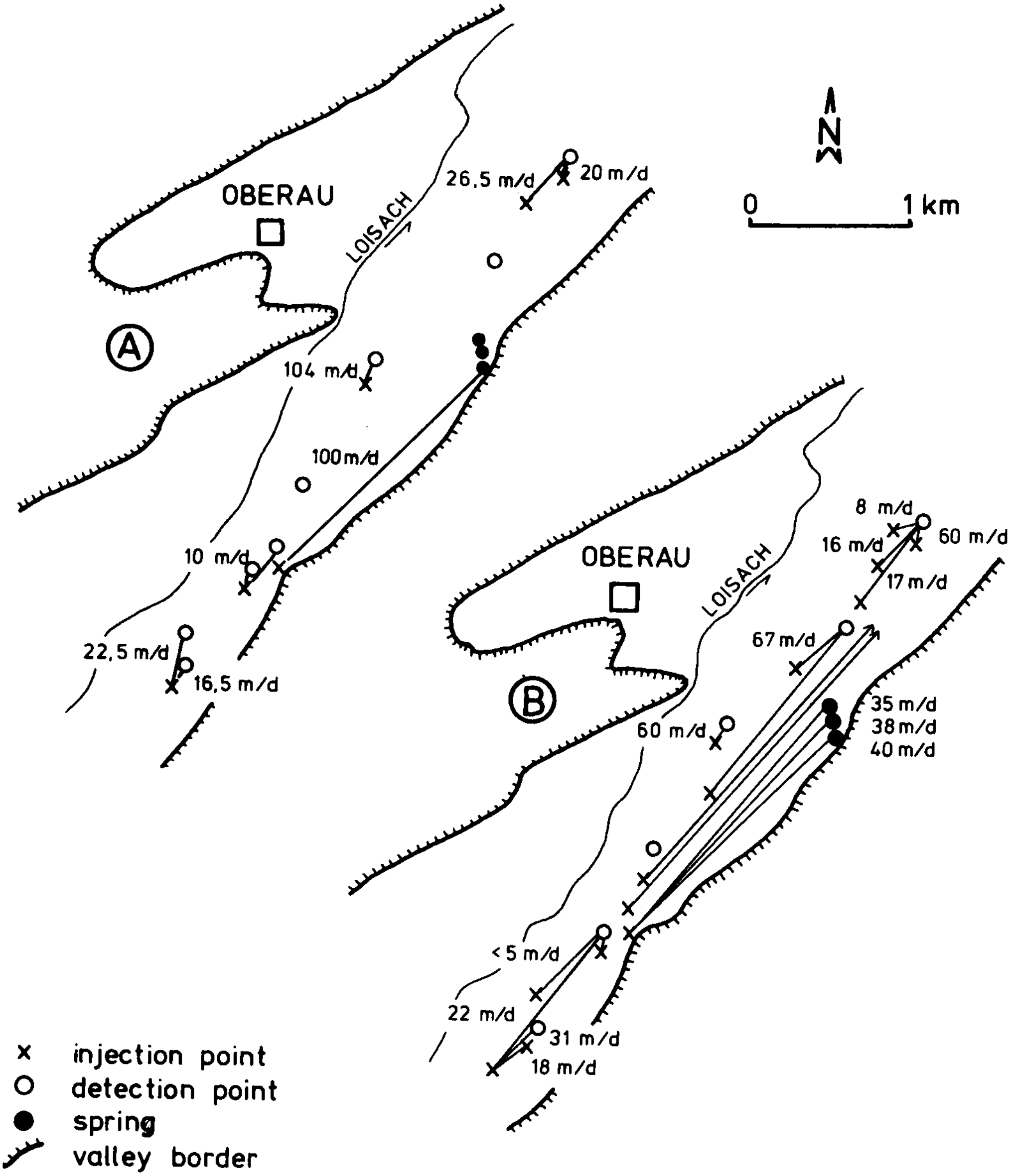

Fig. 1. Mean flow velocities in the investigation area of Oberau/Bavarian Alps
A. without groundwater discharge B. with groundwater discharge from 6 wells.

The calculated dispersivities vary between 4 m and 20 m depending on distance between injection and detection well (Fig. 2). Higher dispersivities than expected are met, if groundwater flow is influenced by geologic interfaces; this was the case for two experiments.

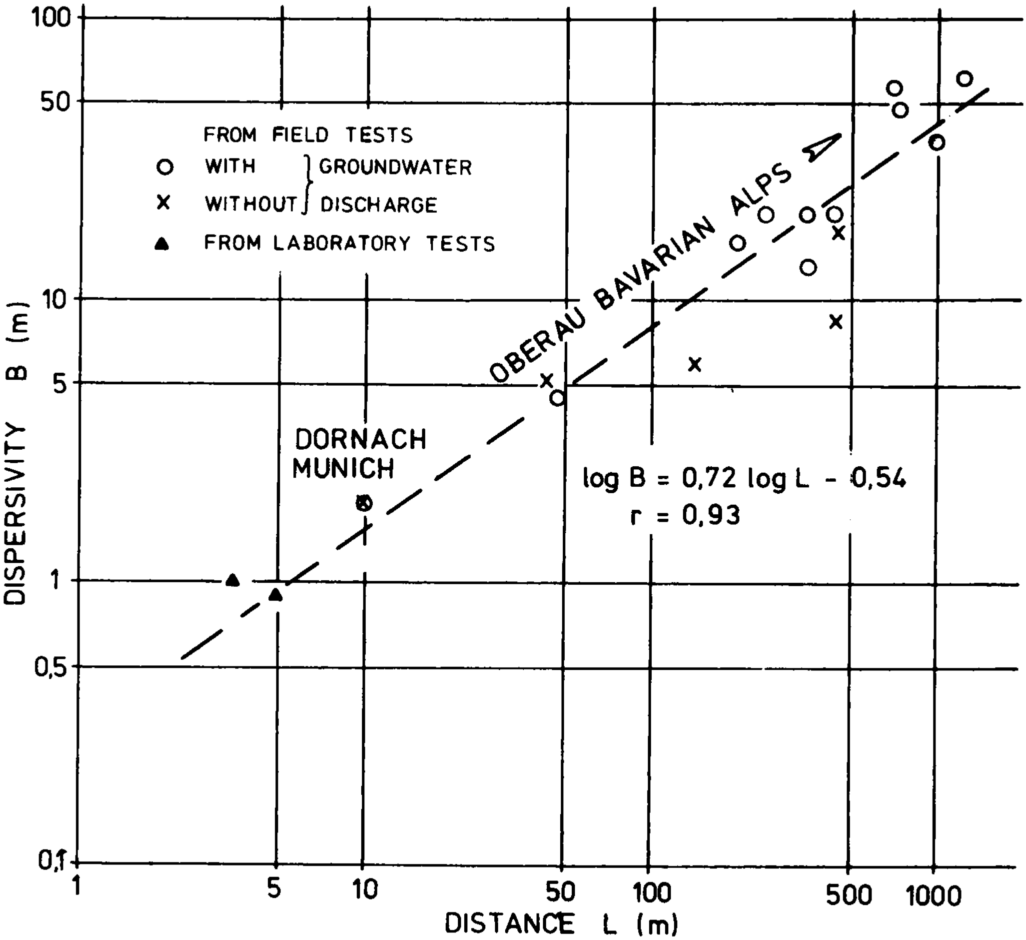

Fig. 2. Dispersivity in its relation to distance between injection and detection point. Laboratory results are from ref. 3.

The grouping of piezometers was not dense enough for a detailed analysis of the lateral dispersion; however the results indicated that the tracer moved in bands with a width of about 10 % of the length of flow path (Fig. 3).

During a pumping test with a pumping rate of 2.5 m^3/s out of the 6 production wells some more tracer tests were performed in the same region. As expected, at distances lower than 60 m to the production well increased groundwater velocities were registrated. In areas extending to greater distances from the production wells groundwater velocities however were in the same range as in the experiments without groundwater extraction (Fig.1).

The flow velocities are calculated from the distance between tracer injection point and observation point. However in the vicinity of a production well the actual flow paths can strongly deviate from the direct line between the two points, introducing a possible deviation from these measured values (Fig. 4). Because of the transverse dispersion the tracer plume will be distributed in this case over stream lines with strongly differing flow velocities and flow paths of different length, before the streamlines again join together in the well; the pure hydrodynamic dispersion is thus superimposed by dispersion effects which have their origin in the geometry of the potential field. The distortion of the potential field influences the shape of the tracer passage curve (Fig. 4) and as a result the dispersivities deviate to lightly higher values from the scheme in figure 2.

Calculated dispersivities are plotted in Fig. 2 against test distances. As expected these values fit very well with the dispersivities from foregoing experiments if the tracer propagation is not disturbed by the above mentioned hydraulic discontinuities. This correlation between dispersivities and test distances is also valid for other areas with fluvioglazial gravels in Bavaria (ref. 3) and it includes at its lower end results of laboratory experiments on columns (ref. 3). This relation seems to give a good explanation for the well known discrepancy between dispersivities from laboratory experiments and field tests. This discrepancy seems mainly to be a matter of scale. In laboratory research on dispersion is mainly concerned with influences of texture; field experiments include beside texture also fabric properties of the aquifer, that are the more homogeneous the longer the test distances are. Main influences on tracer propatation is due to bedding.

The width of the tracer band in groundwater is about 10 % of the length of the flow path, since groundwater flows parallel to bedding; this is equivalent to an opening angle of the tracer cone of about 5°. However, the transverse propagations get more important in seepage water that has to flow perpendicular to the bedding.

Some tracer tests were performed in a creek (Kuhflucht) with a mean discharge

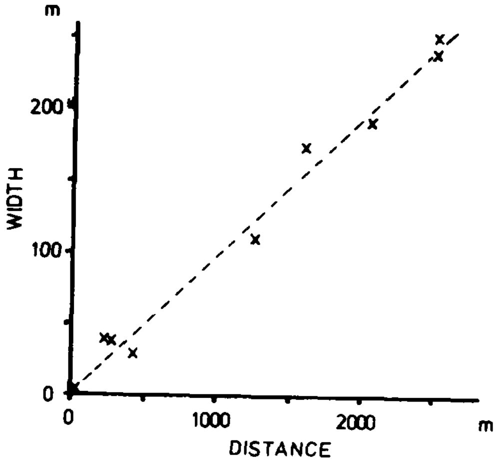

Fig. 3. The width of the tracer plume as a function of travel distance. The lateral borders are drawn with the detection limit of fluorescein (0.002 mg/m^3).

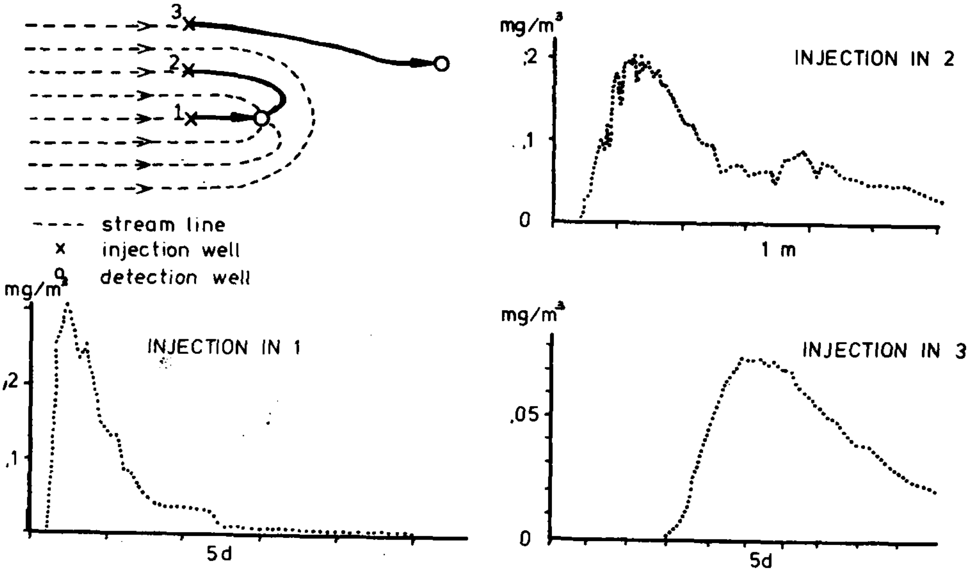

Fig. 4. The flow field around a discharge well and the different tracer passages in dependence of the position of injection point within the flow field.

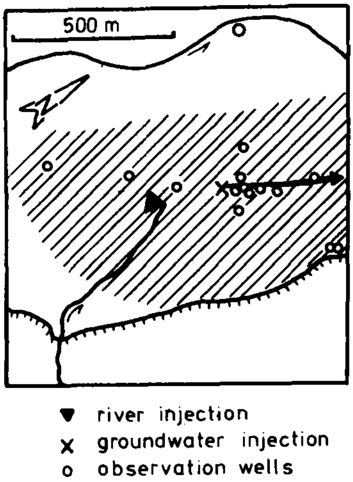

Fig. 5. Tracer distribution in groundwater caused by a punctual tracing of a river infiltration 12 m above groundwater level (hatched area) and of groundwater (arrow).

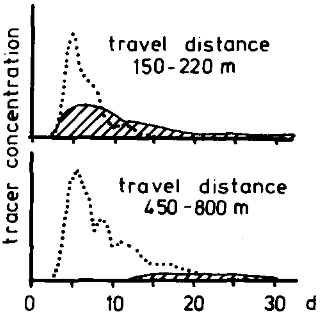

Fig. 6. Examples for tracer passages from groundwater and infiltration tracer test.

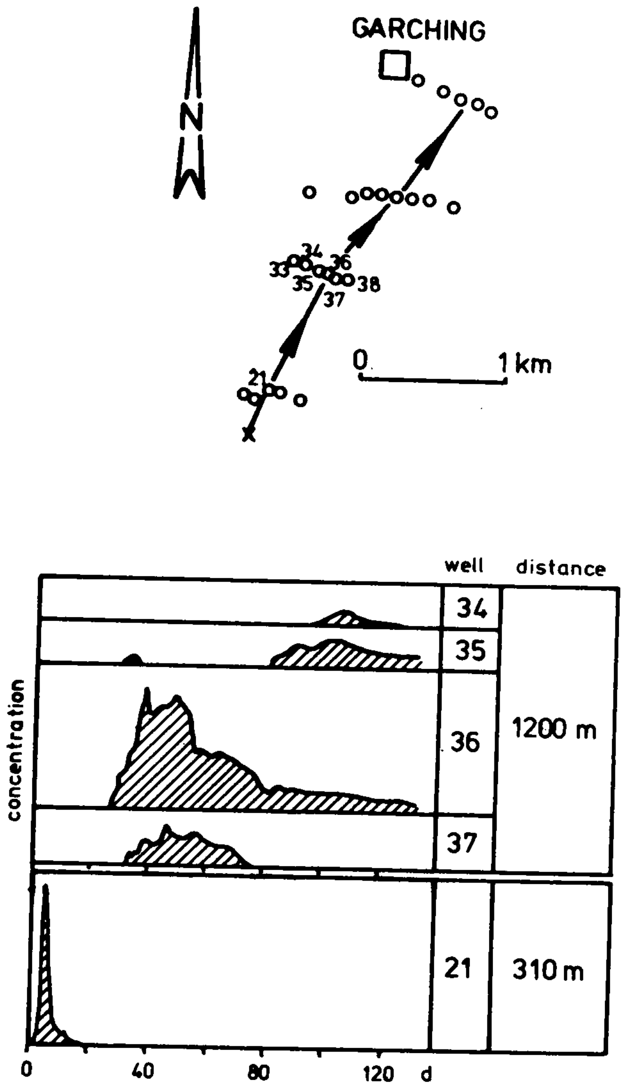

Fig. 7. Tracer test north of Munich. The test site with its injection (x) and observation wells and the tracer passage in the wells of the first and second row.

of 0.3 m^3/s, all of which infiltrates to groundwater (ref.4). This river infiltration was traced pointwise and instantaneously.

It was not possible to observe the tracer migration in the unsaturated zone, but in the groundwater using the many wells in the vicinity of injection point.

The mean velocity of seepage water was 20 - 30 m/d and very similar to the mean velocity of the groundwater. In contrast to a directly injected tracer, tracer added to seepage water appears in the groundwater in a wide spread area around the injection locality (Fig. 5). This wide spread tracer propagation is due to bedding in the creek fan sediments. In the bedding layers, transverse propagation of the tracer becomes very important; the opening angle of this tracer cone is on the order of 100 - 140°.

If we compare the results from tracer propagation parallel with that vertical to bedding, we have to state very rough differences in the shape of tracer passage curves (Fig. 6) which are due to the influence of bedding on dispersion.

North of Munich

The measured tracer passage curves are given in Fig. 7. From these mean velocities of 23 - 25 m/d were calculated. The observation of the dispersion of the pointwise injected tracer provided, among other things, the information: the tracer plume does not only migrate in the main flow direction (NNE); but an oscillating motion in the transverse direction is superimposed which is caused by changes in the groundwater level. A few days after the tracer injection the groundwater level increased as a consequence of high precipitation and the whole groundwater body together with the tracer plume was shifted to the west. Such a shifting of the tracer plume makes the evaluation of tracer passage in an observation well to calculate dispersion coefficient and flow velocity rather difficult. Such effects influence the evaluation of longitudinal and transverse dispersion.

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