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PROTECTION AREAS A SPECIAL CASE OF GROUNDWATER PROTECTION

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ABSTRACT

It is obvious, the scientific and empirical basis to delimit protection areas have to be improved and complemented. Moreover we have to see, even with a much broader knowledge of the determinating parameters we often will fail, to establish protection areas preventing wells in every case from damage. By means of some examples I would like to point out:

- The difficulties to get valuable permeability coefficients, conductivity and flow patterns as well as unequivocal and significant results of tracer tests allowing to delimit protection areas.
- The fact we don't master the propagation of harmful pollutants as nitrates, pesticides, sometimes mineral oils, too, and so on with such an area.
- The impossibility to include in protection areas the drainage basins of streams, recharching the aquifer by influent seepage.
- The difficulties in dimensioning and in taking the necessary precautions within protection areas in karstic regions.

These examples prove, to avoid damages, protection areas have to be supported by an efficient groundwater protection also in the catchment area. That asks with high priority for a better knowledge, too.

INTRODUCTION

In 1978 the meeting of the International Association of Hydrogeologists (IAH) "Drinking-water protection areas for groundwater" in Basle showed the urgency to improve the scientific bases for the dimensioning of protection areas. It was

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proposed to form a temporary working group of IAH with the following objectives (KLECZKOWSKI & BLAU 1980):

- Beside the elimination processes of epidemiologically relevant organisms, till now considered as the most important criteria for dimensioning (DVGW 1975, EIDG. AMT FUER UMWELTSCHUTZ (AFU) 1977, VAN WAEGENINGH 1977), the chemical and physical processes underground have to be treated with equal priority.
- The actually available knowledge has to be evaluated completely and critically. The emerging conclusions have to be drawn in cooperation with representatives from the fields of hygienes, bacteriology, chemistry, physics and hydraulics. Gaps of knowledge are to be pointed out and the appropriate research suggested.
- Proposals for the erection and development of data banks on pollutants and cases of damage have to be made.

In near future to dispose of dimensioning criterias, taking into account a great deal of the numerous determining factors and their interactions, is very important for the health of the population and for an economic drinking and industrial water exploitation. In view of this the IAH Council decided in January 1981 to support the proposed working group and to prove with UNESCO, if the elaborated program could be integrated in the International Hydrological Program (IHP) 3rd phase (1984-1989). Since 1979, entrusted by the research association (GFR), a team leaded by Prof. G. Matthes (University of Kiel) has been working at the problems of "Survival of bacteria and viruses underground depending on biological and geochemical conditions" (MATTHES & PEKDEGER ; in press). A collaboration with this team is planned. It is obvious, the financial resources of the working group will not allow pure research. Therefore it is to be hoped, a collaboration[2] with other research teams and specialists will be possible.

PROTECTION AREAS A SPECIAL CASE OF GROUNDWATER PROTECTION

Not only my collaboration by creating the Swiss guidelines (AFU 1977), but also ten years of experience with determinations of protection areas in unconsolidated and consolidated rocks have convinced me, the problem of a sufficient protection of our production wells could not be solved only by such areas. Our knowledge of the permeability variations in the unsaturated and the hydraulic conditions in the saturated zone, the possible spreading of insoluble or only partially soluble pollutants, the lapse of biological, chemical and physical processes, their interactions and so on will never be good enough, to determine

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protection areas preventing wells in every case from damage or allowing to start decontamination in time. Even if it would theoretically be possible to take into account all the determinating factors, in practice very often the money to get them will lack. We additionally need a very good protection and control of the water bearing formation and their catchment areas. You may oppose, in most countries the protection of groundwater and its inflows has been secured by laws. That is true. But for economical reasons we have to store, transport, manipulate and use a lot of harmful materials. In spite of all precautions some pollutions on local or regional scale cannot be avoided. By means of some experimental results I shall try to explain where I see the main difficulties to get determining values to define protection areas beyond all doubt.

EVALUATION OF PERMEABILITY COEFFICIENTS AND SUBSURFACE FLOW PATTERNS

In the lower part of the Emme valley, 20 km northeast from Berne, some years ago we started with the determination of the groundwater resources available for the water supply. The aquifer is build up by sandy, rarely silty gravel with some cobbles and boulders, sometimes alternating with clean, rarely silty or clayey sands and cobble beds. Usually the gravel is not consolidated. The stratification proves that there are floodplain deposits of a meandering river. Average coefficients of permeability k: 3.5 to $11.0 \cdot 10^{-3}$ m/s; average porosity: 17%; average groundwater flow velocities: 4 to 42 m/d; average thickness of the aquifer: 25 m; aquiclude: molassic sandstones and marls. Replenishment of the aquifer: essentially by infiltration of surface water (Emme river and its tributaries); the seepage of precipitations adds only a few % (BLAU, WERNER & MITARBEITER; in press). The interesting first results induced us to build up a test area, where we are studying the fundamental problems of in situ measurements in cased-in boreholes and screen pipes (4 to 6 inches in diameter) of significant values of the horizontal permeability. Complementary to the field investigations groundwater motion and head distribution near a well are studied by a halfcylindrical model. Beside this goal we will try to show by a model study, how to evaluate economically the safe yield in heterogeneous unconsolidated gravelly aquifers, being very important for water supply in Switzerland.[3]

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[3] These investigations, we realize in cooperation with the Federal Institute of Technology (FIT) in Zürich, are approved and financially supported by the Swiss National Research Foundation within the scope of the national research program "Water economy". Direction: Prof. E. Trüeb, FIT, Zürich and the author; realization: A. Werner and collaborators, consulting engineers, Burgdorf. I acknowledge the help of all my collaborators as well as the support of the National research foundation.

Up till now our investigations have clearly shown the following facts, being important to estimate the values we need to determine protection areas:

1. Pumping and recharging tests often used in casings, are influenced by more factors as supposed till now. The effects of some, e.g. the non-Darcy flow near the borehole, the influence of the drilling-system, can be estimated by more extensive test methods. To get reliable values of the permeability remains difficult. For pumping tests in screen pipes we have to propose a new method of determination. The vertical head distribution is measured by narrow piezometer pipes fixed in- or outside the screen tube. The vertical flow in the tube is determined by a highly sensitive flowmeter. The average horizontal permeabilities and their vertical variations can be calculated by superposing head and flow states during or without pumping. This method is qualified to replace the pumping tests in casings. The values obtained are considerably higher than those got conventionally. Comparing these values with permeability coefficients, calculated upon datas out of pumping tests with high withdrawals or out of tracer tests, we ascertain, they represent the conditions in the aquifer in a significant manner giving more details of the flow pattern than conventional tests. The multilayered aquifer, till now considered as quasi-homogeneous, has to be divided in 3 parts. We find in the center of the test area approximatively the following situation: an upper part, 10 m thick, $k \sim 9 \cdot 10^{-3}$ m/s, a medium section 7 m thick, $k \sim 1 \cdot 10^{-3}$ m/s and a lower part, 4 m thick, $k \sim 6 \cdot 10^{-3}$ m/s. As flowmeter measurements proved the different piezometric potentials are producing a flow out from the upper part into the lower one.[4] Within the scope of our consideration we have to draw the following conclusions: to estimate the inflow situation of a well, we have to know the vertical and horizontal variations of permeability. Only this allows us to some extent, to judge the risks of the propagation of pollutants, depending on initial quantities, concentrations and inflow situations. It is obvious, additionally we have to consider the possible dispersion of harmful substances (see e.g. DRACOS 1965, FRIED 1975, ZILLIOX in KLECZKOWSKI & BLAU 1980: 130). The permeability coefficients have to be determined by methods of which the results permit to evaluate significant values. Some of the conventional ones are of no use.

2. We are using a twodimensional numerical model with finite elements (TROESCH 1975) to simulate the groundwater flow. Its calibration under steady state conditions[5] has been rather difficult. We didn't succeed with a "trial

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[4] This part of the investigations is realized within the scope of a thesis by P. Hufschmied (Promotor: Prof. E. Trüeb FIT Zürich). I acknowledge his reliable work.

[5] This year we will start calibration under nonsteady state conditions; see WEA 8o/81

and error" technique in determining the permeability distribution of the aquifer allowing to approach the calculated groundwater potentials to the measured levels. Only the indirect determination of the permeability distribution with a "stream tape" technique combined with our model gave satisfactory results. We have to draw the following conclusions: The conformity of measured and calculated equipotential lines does neither prove that the calculated or suggested flows are conform to the natural ones, nor the permeability distribution is according to the conditions in the aquifer. Only with a direct gauging of the most important flows you will get better results. As in practice very often you are not able to determine all the flows, it will be necessary to measure a sufficient number of permeability and storage coefficients, too. That means: Disposing of a simulation model you have to assure, if the flow and permeability patterns are not ambiguous. Only if that can be denied in all probability, you will be allowed to determine the permeability and velocity values you need to calculate protection areas and to estimate the possible danger of an inflow of harmful pollutants.

MEAN PORE VELOCITIES OF GROUNDWATER DETERMINED BY TRACERS

To determine among other things the mean pore velocities of groundwater, we carried out quite a lot of tracer tests with salt (NaCl), fluorescein (or another dye), apathogenic bacteria and viruses. The results have always been similar. As an example we consider the test realized in the Aare valley, southeast from Berne, in the alluvial, very permeable ($k \sim 2.5 \cdot 10^{-2}$ m/s) aquifer, groundwater flow unconfined, built up by unconsolidated clean gravel with some sand. As tracers were used fluorescein, Streptokokkus faecalis, Serratia marcescens, Bacillus pumilus, Bacillus subtilis and polio viruses. The experimental set-up consisted of an injection well I, an observation well O_1, 45 m downstream, and 3 other ones (O_3-O_2-O_4), 90 m downstream, lying at a right angle to the flow direction. All of the wells penetrated completely. As the results are published (MARTI et al. 1979), I select those being important for this consideration. The contents of tracers in the samples retrieved in the wells O_1 and O_2 in the upper (u) and the lower part (l) of the aquifer, allow to compute the following maximum mean pore velocities (max. v):

	max. v m/d			
	I - O_{1u}	I - O_{1l}	I - O_{2u}	I - O_{2l}
Fluorescein	720	>1080	216	288
Strept. faecalis	216	x	192	312
Bac. subtilis	108	48	168	168
Serr. marcescens	192	x	216	288

Bacillus pumilus, the viruses and the x marked tracers were not detected. These results raise some questions. In our aquifers we often see, the longer the distance, we are taking into account, the lower the mean pore velocity is. This is certainly a consequence of the "puff-pastry" like structures of our unconsolidated water bearing formations. But can we explain by that the enormous difference of the velocities determined with fluorescein between I - O_1 and I - O_2? In hydraulic considerations there is often postulated to chose a medium velocity corresponding to the point when 50% of the dye has passed (see e.g. KAESS 1970, AFU 1977). By hygienic reasons some scientists prefer, in determinating protection areas, to use the maximum mean pore velocity (e.g. RICHTER 1974, REHSE 1977). But what happens when the bacteria are travelling faster than the dye (compare the values of Strept. faecalis)? Till now we are missing a critical, comprehensive discussion about all these questions from the hydraulic, hydrogeologic and hygienic point of view. The scope of free judgement and therewith the danger for errors are too large.

PROPAGATION OF HARMFUL POLLUTANTS

1. Danger of mineral oil propagation. - In a narrow valley, its brook is tributary to the Emme, we find a small confined aquifer built up by sandy gravel, 3.5 m thick, average permeability coefficient $7.5 \cdot 10^{-4}$ m/s, porosity 22%, average gradient of the groundwater 5‰, aquiclude: molassic sandstones. The confining layers consist of sands, silts (sometimes clayey) and peat. The aquifer was exploited only by one production well with a capacity of about 5 l/s, serving for the water supply of a children's home. Last year suddenly a film of mineral oil could be observed in the well. Our investigations showed that more than 1.2 km of the valley, 200 - 300 m broad, upstream the well was polluted. Following the oscillating groundwater level, the oil smeared the upper part of the aquifer. The numerous gas-chromatographic analysis indicated in all probability that this was an insulation oil, perhaps a little bit altered underground by chemical, physical and biological processes. The collected datas of a few soil tests and some observations of excavations, reported by inhabitants, referred, the pleistocene filling of the valley was very heterogeneous. In the upper part of the valley, in addition to the gravel, there are sands and silts forming the aquifer. The residual saturation of insulation oils in sandy gravel lies close to 10 l/m^3.[6] The order of magnitude of spilt oil amounts to some tenthousand liters.

[6]According to Dr. F. Schwille, Bundesanstalt für Gewässerkunde, Koblenz (GFR), whom I thank very much for his informations.

As a matter of fact according to the hydraulic and hydrogeological situation we have to see, neither relying on the Swiss (AFU 1977) nor on the German guidelines (DVGW 1975) we could prevent the establishment of a transformer plant 1.2 km upstream the well. If a large quantity of insulation oil is percolating unobserved or not announced, damage will occur in certain cases some years later. This damage points to another difficulty. By creating the Swiss guidelines, for a long time we have discussed, if it would not be useful to ask with the determination of a protection area a provident estimation, by a numerical model simulation, of the development as well as the steady final form of the propagation of a possible mineral oil spill, as proposed by SCHIEGG (1977). For the general case we renounced, seeing the difficulties to determine significantly all the parameters necessary for the calculation. In the discussed case we have to agree, it will never be possible in consideration of the heterogeneous structur of the aquifer, to build up a simulation model reflecting in a valuable manner the natural situation.[7]

2. Other pollutants, for examples nitrates and pesticides. - It is out of discussion the problem of the increasing nitrate contents of the groundwater almost all over the world, cannot be solved with protection areas. Some preventive measures within these areas may help a little bit (see TRUEB 1980), but to return to tolerable concentrations we will be forced to take the necessary precautions in all the catchment area. I fear, to protect sufficiently our groundwater production wells for the drinking-water supply against pesticides and their degradation products, means to ask for the same measures: protection of the exploitable water bearing formations as a whole. The Swiss list of plant protectives 1979/1980 (EIDG. GESUNDHEITSAMT et al. 1980) forbids the use of some protectives, containing certain particular harmful active ingredients. Discussions about protectives used in agriculture and herbicides used by railway companies to protect embankments have clearly proved, our knowledge of the behaviour underground of these pollutants is not sufficient to treat finally the question of adequate protection measures.

RECHARGE BY INFLUENT SEEPAGE OF STREAMS

Some years ago the simulation with dyes of a severe fish poisoning proved as byproduct we didn't expect a considerable seepage of the Aare river between Thun and Berne into the alluvial gravelly aquifer, being very important for the local and regional drinking-water supply. In 1978 this tracer test was repeated

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[7] I thank Prof. Th. Dracos for the possibilities to discuss this oil spill.

with fluorescein in the scope of the investigations of our most important aquifers (KELLERHALS & TROEHLER 1978). With the tracer test isotopic analysis of the $^{18}O/^{16}O$ ratio were carried out. Samples withdrawn in wells distributed over the whole valley, about 25 km long and 1.5 to 3 km broad, showed, the part of recharged water lied between 0 and 90%, but very often it was higher than 50%. The seepage water reached a lot of important wells in a few hours. The fact that the most of the water supplies distribute the pumped groundwater without any treatment all the time proves the very good purification effect during the passage through the biological very active river bottom and the gravel. Difficulties never arrived although the sewage plants didn't yet work some years ago.
Similar conditions we found in the Emme valley (see above). Northeast from our test area we determined an average recharge by influent seepage of the Emme of 1.2 m^3/s, an amount of 34% of the total groundwater runoff. No quality problems, too. It is obvious, a certain risk by seepage of harmful pollutants cannot be denied. Therefore a comprehensive protection concept of wells, withdrawing naturally or induced recharged water, should include protection of the whole or at least of the most significant part of the drainage basin of the river. The necessary preventive measures should be retained in the legal proceedings to establish a protection area. In Switzerland it cannot be realized practically. The owners of production wells, having to prevail the prescriptions in the protection zones, are not able to limit other interests and to survey industries, agriculture, traffic and so on in such large areas. In the scope of water protection in general the responsible department of the administration has to require limitations and measures being necessary.

PROTECTION AREAS IN KARST

The meeting in Basle mentioned above showed clearly all the problems of protection areas in Karst: insufficient purification of water underground, high flow velocities, long travelling distances of pollutants, very large areas, disproportion of required measures to the problem, questionable realizability and so on. The problems of procedure, necessary investigations, cost-benefit ratio and economic consequences were discussed by BURGER (1977), CRAMPON (1974). To look for possible solutions we have to consider the two extremes: No special protection in the catchment areas of wells and springs - severe limitation of landuse with all the economic consequences and preventing measures in the whole catchment area, extensive investigations of the inflow conditions. The practicable solution lies in between: Special preventing measures in the whole area are necessary, but we have to tolerate limitated risks caused by actions required to inhabit a region being economically self-dependent. We know, a lot of tracer tests, chemical and isotopic analysis (see e.g. KIRALY & MULLER 1979) proved it, it is very difficult to delimit exactly catchment areas in Karst. Again we have to point out the importance of the groundwater protection in general.

SUMMARY STATEMENTS

As proposed at the IAH meeting in Basle (KLECZKOWSKI & BLAU 1980), the scientific and empirical bases to delimit protection areas have to be improved and completed as soon as possible. Let's hope RICHTER's opinion (1974), that all determination methods for protection areas are more or less "rules of thumb", is exaggerated. But as a matter of fact it will rarely be possible to delimit protection areas beyond all doubt. To avoid damages they have to be supported by an efficient groundwater protection and control within the whole catchment area. To get this goal we have to deepen our knowledge of determining aquifer and hydraulic parameters, of spreading and elimination of harmful pollutants and their degradation products in water, in saturated and unsaturated rocks.

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