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Pollution and pollutant transport in the geosphere: An introduction to the symposium

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ZUSAMMENFASSUNG

Die Umweltforschung in den Erdwissenschaften beschäftigt sich mit der Geosphäre, d. h. (1) mit Wasser und Sedimenten von Flüssen, Seen und Ozeanen und (2) mit wasser-ungesättigten und -gesättigten Bereichen von Böden und darunterliegenden untiefen Gesteinsformationen. An Standorten wo Abfall-Lager oder tiefliegende Tunnels geplant sind oder Minen existieren, werden auch tiefere Formationen miteinbezogen. In den vergangenen Jahren sind Erdwissenschafter immer mehr mit Umweltverschmutzung in ihren klassischen Arbeitsgebieten konfrontiert worden (Grundwasser, Erz-, Erdöl-, Kies-, Ton- und Zementrohstoff-Lager). Die wichtigsten umweltverschmutzenden Faktoren sind chemische und radioaktive Substanzen sowie Mikroorganismen. Bedeutende Transportprozesse sind physikalischer (z. B. Fliessen, Diffusion), chemischer (Lösung, Ausfällung, Sorption) und mikrobiologischer Natur (Transformationsprozesse). In der Praxis der Raumplanung muss eine schonende Nutzung der Umwelt gewährleistet sein, und sie muss auf klaren wissenschaftlichen Kriterien basieren. Heute können die anstehenden Umweltprobleme nur durch den Einsatz von interdisziplinären Arbeitsgruppen mit vertieften Kenntnissen in Erdwissenschaften, Hydrologie, Chemie, Biologie, Physik und Ingenieur-Wissenschaften gelöst werden; der Erdwissenschafter muss dabei seine fachspezifischen Kenntnisse einbringen. Dieses Symposium vereinigte in der Schweiz zum ersten Mal Erdwissenschafter, Bodenkundler, Physiker und Chemiker, um anstehende Umweltprobleme der Geosphäre darzustellen und zu diskutieren.

ABSTRACT

Environmental research in earth sciences is focused on the geosphere, i.e. (1) waters and sediments of rivers, lakes and oceans, and (2) soils and underlying shallow rock formations, both water-unsaturated and -saturated. The subsurface is studied down to greater depths at sites where waste repositories or tunnels are planned and mining activities exist. In recent years, earth scientists have become more and more involved in pollution problems related to their classical field of interest, e.g. groundwater, ore deposits, or petroleum and non-metal natural deposits (gravel, clay, cement precursors). Major pollutants include chemical substances, radioactive isotopes and microorganisms. Mechanisms which govern the transport of pollutants are of physical, chemical (dissolution, precipitation, adsorption), or microbiological (transformation) nature. Land-use planning must reflect a sustainable development and sound scientific criteria. Today's environmental pollution requires working teams with an interdisciplinary background in earth sciences, hydrology, chemistry, biology, physics as well as engineering. This symposium brought together for the first time in Switzerland earth and soil scientists, physicists and chemists, to present and discuss environmental issues concerning the geosphere.

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1. Introduction

Problems of environmental pollution have been tackled by interdisciplinary teams for the last twenty years (Stumm 1985). The contribution and participation of earth scientists in such teams becomes more and more important and a new branch of "environmetal geology" is about to be established. This symposium has been organized as a forum for those already working in this branch of applied geology and to encourage others to become involved.

Earth scientists are trained in geologic mapping and detailed mineralogical and petrographical studies. They contribute to environmental pollution problems with the development of models of the structure and the composition of the subsurface, normally not accessible for direct observation. Based on their knowledge of the earth's history (i.e. the evolution in time), they are asked today to extrapolate this knowledge to the future, to predict long term effects of subsurface pollution. In the perialpine belt of Europe, this is only possible for relatively short time spans, due to the complex subsurface structure and the proximity of alpine glaciers. Furthermore, earth scientists have a specific knowledge about the nature of minerals and rocks and their interaction with natural and polluted fluids (Fig. 1). Figure 1 shows the transport paths of polluted fluids in the subsurface. The term geosphere used in this symposium involves (1) the water and sediment part of rivers, lakes and oceans, and (2) the water-unsaturated and -saturated part of soils, consolidated and unconsolidated formations. At sites where waste repositories and deep seated tunnel constructions are planned and mining activities exist, the subsurface is studied down to greater depths, i.e. 1,000 to 3,000 m.

Today's anthropogenic pollution of the atmosphere and of surface waters is well known to a general public. In the case of the geosphere, however, only few people are aware of the pollution risk to the same extent. There are various land uses with an enhanced risk of subsurface pollution. Sources of pollution include agriculture, sylviculture, mineral extraction, domestic, commercial and industrial activities, and final disposal of wastes (Fig. 2). Considering the impact of agricultural fertilizers on soil, of wastes disposal sites or of spills of non-aqueous phase liquids during transportation and use, on the groundwater and aquifers, there is a clear need for a quality management of land use (e.g. Hartmann & Michel 1992). Land-use conflicts require decisions (e.g. protection, monitoring, risk and environmental impact assessments). The management practices must reflect a sustainable development and sound scientific principles. Natural fluids in the subsurface (soil gas, interstitial and ground waters) act as conveyor belts for pollutants (Fetter 1993, Hutzinger 1990, 1991, Russo & Dagan 1993, Yong et al. 1992). The extent of this environmental pollution requires both earth and soil scientists with an interdisciplinary background in hydrology, chemistry and biology as well as engineering. These scientists must have a thorough understanding of the physics and the chemistry of the interactions between the surfaces of rocks, soil materials and the fluids.

2. Pollutants

There are, in general terms, three types of pollutants (Fig. 3; Jackson 1982, Fetter 1993): (1) chemical, (2) radioactive and (3) microbial.

Chemical pollutants are the most widespread of all pollutants: e.g. nitrates and organic micropollutants derived from agricultural and sylvicultural fertilizers, toxic halogenated

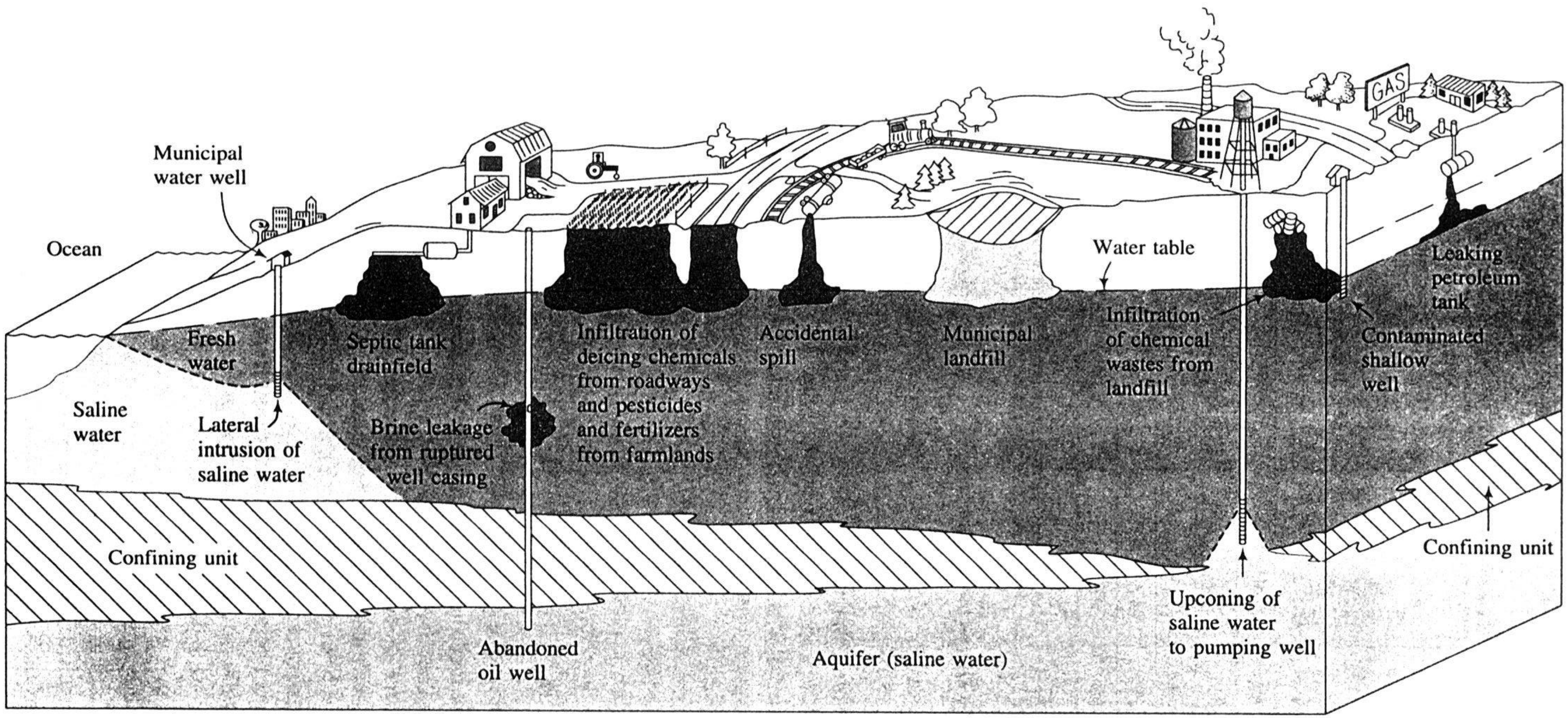

Fig. 1. This figure originally entitled "Mechanisms of ground-water contamination" by FETTER (1993) illustrates very well the upper part of the geosphere and its major pollution sources (reprinted with permission from "Contaminant hydrogeology" by C.W. Fetter, Copyright ©1993 by Macmillan College Publishing Company Inc. New York).

organic compounds and heavy metals disposed of at waste-disposal sites, and phosphorus or heavy metals from sewage sludges and outlets of sewage-treatment plants. Rivers with considerable amounts of treated waste waters which flow on well-permeable aquifers can lose waters into these aquifers and thus pollute the ground water. Figure 2 gives the situation in the U.S.; it is probably also valid for the countries of Western Europe.

Perhaps the most toxic long-term pollutants which environmental earth scientists must deal with today are the *radioactive wastes* that have been produced since World War II. Because of their toxicity, they have been the subject of considerable research. In fact much of what is known concerning the transport and attenuation of pollutants in aquifers is due to hydrogeological research using radioactive tracers or investigations of radioactive waste-disposal sites. The dispersion of ^{137}Cs fallout after the nuclear tests of the fifties and after the Chernobyl accident in 1987 is so widespread that the presence or absence of it is used to identify the age, e.g. of lake sediments. Cs in solution is essentially immobile because of its strong sorption to solid surfaces, but other radioactive pollutants are more toxic such as e.g. plutonium, or more mobile such as tritium.

While chemical and radioactive pollutants have come to public attention during the present century, *microbial pollutants* of fecal origin were the major preoccupation of the public health agencies in Europe and America during the 1800's and still are in the less developed countries. In today's industrialized countries, bacteria of fecal origin are no longer of a problem; rather microorganisms have become of interest for the remediation of polluted parts of the geosphere, under optimal conditions. This practice might, however, result in a new microbiological danger for the subsurface.

Hence we have identified criteria for determining those substances that constitute the most serious pollutants in subsurface fluids and rocks – *toxicity and mobility*. The pollutants of greatest concern for the fluid phases are those which are both toxic and mobile, and those of concern for the solid phase are the ones with irreversible sorption mechanisms (cf. review in chapt. 9 of Sigg & Stumm 1994).

3. Fluid-rock interaction

Geosphere fluids interact with the surfaces of the rock and mineral particles in aquifers and lake sediments, and the subsurface biota. These interactions may be intense, depending on the grain size of the geological material, the water flow velocity and various biogeochemical factors. The mobility of pollutants in the subsurface is controlled by their interaction with the fluid and with the solid materials of rocks. Considering the mobility of pollutants dissolved in fluids, we need to know the average fluid velocity and the distribution of velocities as well as the retardation of the pollutant relative to the fluid. Transport processes of pollutants in the various fluids of the subsurface environment can be subdivided into processes related to the flow of water (e.g. advection, hydromechanical dispersion, molecular and matrix diffusion), and interactions between the pollutant and the solids. Such interactions are (1) reversible processes related to the retardation of pollutants relative to the flowing fluid, such as electrostatic sorption on mineral surfaces or on organic matter, hydrophobic bonding, solubility control, ion-exchange phenomena, and (2) irreversible processes (e.g. chemisorption) or transformation processes (biotic or abiotic) leading to the disappearance of a pollutant.

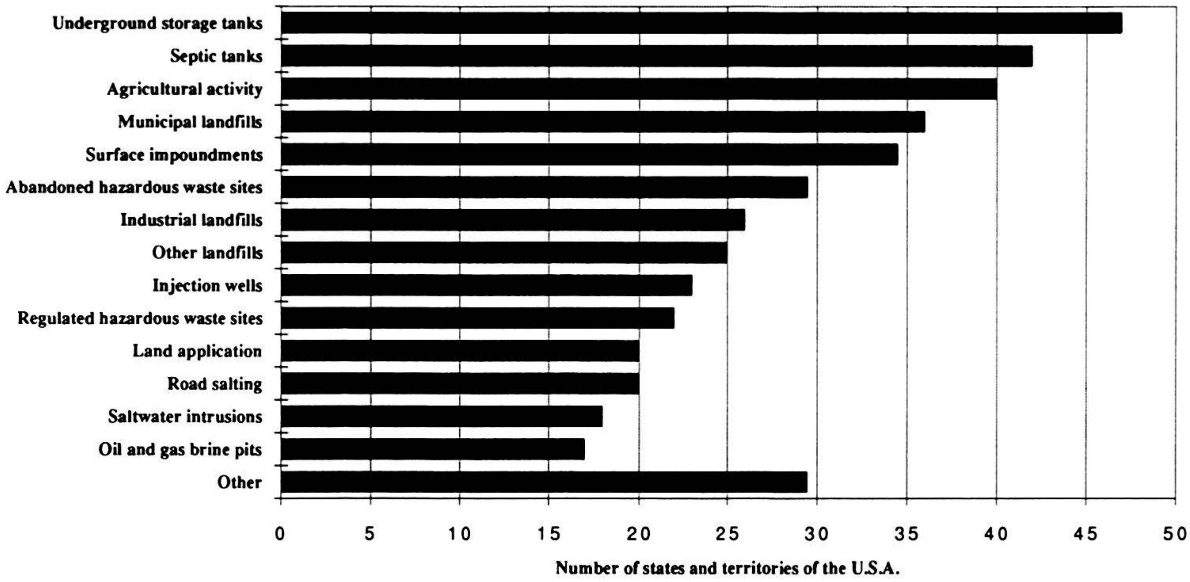

Fig. 2. Typical pollution sources for the geosphere. Data source: National Water Quality Inventory, 1988 Report to the U.S. Congress, Environmental Protection Agency, 1990.

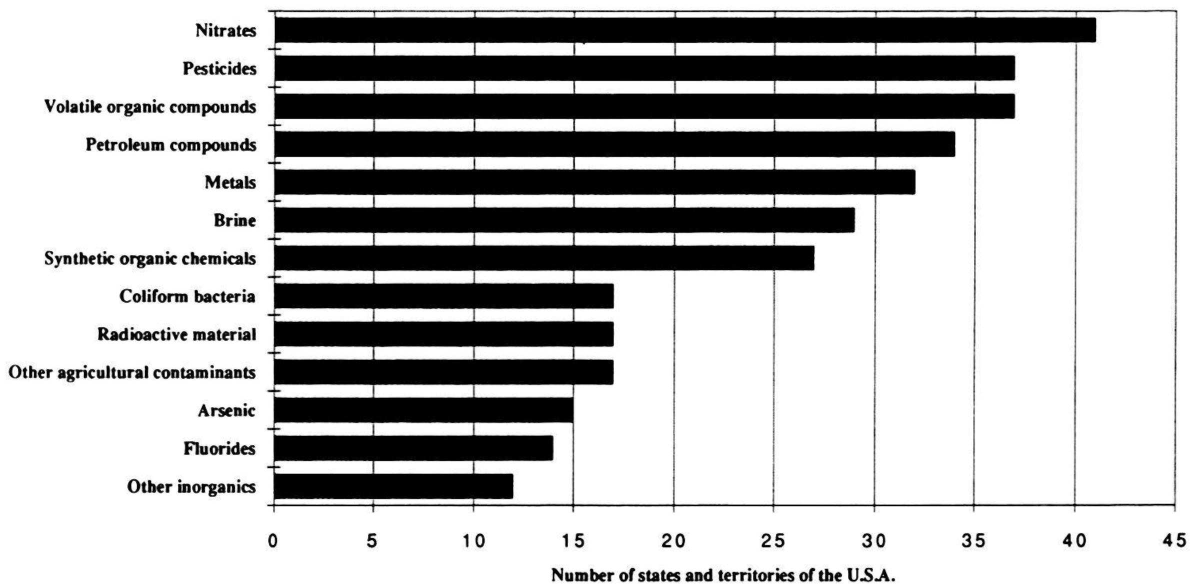

Fig. 3. Potential pollutants of water. Data source: National Water Quality Inventory, 1988 Report to the U.S. Congress, Environmental Protection Agency, 1990.

Pollutant transport in the geosphere is mainly solute transport. Colloid-facilitated transport, the flow of non-aqueous-phase liquids (NAPLs) or polluted soil air play a role in special cases. Transport phenomena involving two or more fluid phases are important in soils and in many superficial "anthropogenic sediments" at wastes-disposal sites.

4. Field oberservations versus laboratory measurements and modeling

Information about natural and anthropogenic input of a pollutant (sources, fluxes, concentrations) as well as the structure and the dynamics of a given natural system can be gathered from field observations. Laboratory studies are necessary for the investigation of individual processes of marker compounds. The results of laboratory studies must be incorporated into mathematical models. Such models serve to calibrate the laboratory results. Once calibrated, the model should be able to predict the environmental behavior and the fate of a pollutant in the geosphere (Stumm et al. 1983; Jackson & Hoehn 1987). This could, however, not be verified to date, in most cases. One of the major problems of adapting models to field situations is the change of scale of many parameters such as grain size, hydraulic conductivity, surface area and surface properties of the solid phase. In laboratory systems, these parameters show relatively small spatial variabilities. The scaling-up of these parameters in the models from the laboratory to a field situation often leads to results which do not agree with field observations. This is partly because natural subsurface environments are by far more heterogeneous than laboratory systems. Therefore, a combination of laboratory, field and modeling work is necessary for a better understanding of transport processes in the geosphere.

5. Geosphere pollution risks in Switzerland

The perialpine belts of Switzerland (Mittelland, Sottoceneri) belong to the most densely populated areas in Europe. The high population density and industrialization of the area have led to severe land use conflicts because the various land uses exhibit an enhanced pollution potential for water, soil and air. Most shallow geological formations of this region consist of unconsolidated granular material of a high porosity (e.g. lake sediments) or of a high hydraulic conductivity (e.g. aquifers of glaciofluvial outwash). Therefore, a good protection strategy abandons pollutants before they are used, rather than try to clean up polluted sediments and waters.

Lakes are generally the habitat for aquatic biota, mainly fish, and serve for recreation purposes. Lake water is a drinking-water resource, especially for metropolitan areas (e.g. Stuttgart, Zürich). Lake sediments are threatened e.g. by heavy metals, phosphorus and metabolites of detergents. For such substances, lake sediments act as a sink. Excess phophorus leads to an eutrophication of lakes. Lake biota are threatened by organotin compounds of anti-foulings for boats. Phosphorus and organotin compounds have recently been banned.

Ground waters are the main source of drinking-water (Hoehn & Bundi 1983; Hartmann & Michel 1992; Blau 1992). Aquifers are threatened mainly by agricultural fertilizers, accidents, spills, and leakages of various chemicals from industrial activities. Here, the tendency is to reduce the use of solute chemical pollutants in the contributing area of drinking-water wells and springs (Hoehn et al. 1994). A specific danger for ground waters is the unknown number and the unknown pollution risk of polluted sites (old landfills without liners and covers, abandoned facilities; see Arneth et al. 1986). The starting point for an improvement of this situation is to file the sites concerned depending on their pollution risk.

6. Topics presented at the symposium

During the symposium, problems related to the geosphere were adressed by around forty oral and poster presentations. Some of them have been submitted for publication and are presented as follows:

Methods important in environmental research: the first paper of this series by *Alexander & McKinley* discusses critically the use of chemical distribution coefficients in pollution studies. *Bensimon et al.* present the analytical method of induced coupled plasma connected with a mass spectrometer (ICP-MS) as a means to analyse ultratraces of compounds in natural and polluted fluids. This series ends with a review by *Stipp,* written especially for earth scientists, of the relatively new field of techniques to explore material surfaces, which gives new insights on the exact role and nature of pollutants.

Processes in the ocean and in lakes: the study of *Gendre et al.* on coprostanol, an organic tracer compound of human activity, along the coast of the Islands of Mauritius opens the discussion on this topic series. It is followed by the paper of *Span et al.* on the phosphorus content of sediments and water, in various peripheral lakes of the Alps. The study by *Thunus et al.* deals with a model for the transport and sedimentation of suspended particles in Lake Neuchâtel. The paper of *Thomas* on the history and possible sources of pollutants in Lake Ontario, one of the larger lakes of North America, demonstrates that long-term monitoring is necessary to completely assess the extent of pollution in complex natural systems.

Fluid composition and behavior in soils and shallow aquifers: the paper by *Atteia* discusses the behavior of soil fluids and their influence on trace element distributions in different types of soil. *Biaggi et al.* present a model of nitrate distribution and circulation based on a large number of measurements in an extensively used agricultural environment. *Kozel & Zwahlen* address the problems related to pesticide pollution of aquifers. The paper of *Surbeck* deals with natural radionuclides such as radium, uranium and thorium in drinking water, as pollutants or as useful tracer elements.

Waste disposal, landfill and former mining activities: The paper of *Löw & Guyonnet* considers release processes of pollutants from different types of waste repositories and discusses critically the use of bulk hydraulic properties. *Geiger & Schulin* summarize the knowledge on exposure of living beings to heavy metals from soils. *Martinson* presents field and laboratory data on leachates from one of the larger toxic waste repositories in Switzerland. Two papers deal with heavy metal pollution by former mining activities: *Bondietti et al.* report on a case of arsenic and cadmium pollution in the vicinity of a former gold mine, and *Pfeifer et al.* about a case of small scale uranium pollution by exploration work and natural rock fall.

Finally, the paper of *Romer* is dedicated to a field situated between the geosphere and the atmosphere, where only a few earth scientist work: the consequences on man of the *atmospheric pollution* by dust particles. The paper deals with asbestos-type fibrous particles in human lungs.

7. Concluding remarks

Most studies of this symposium were dedicated to one single compartment of the geosphere. More inter-compartment studies will, however, be necessary in the future in order to fully assess pollution and its influence on the future of our planet. The sustainable development of the geosphere in a given region requires quality management strategies and decisions for the protection (Baccini & Brunner 1991). The natural properties of soil, rocks and fluids are compared with quality requirements for the various beneficial uses. Pollution in industrialized countries raises the question of better management strategies and decisions for better protection and survey of the geosphere. Whatever the nature of pollution, it is seldom reversible because of the high cost of decontamination. A good strategy is, therefore, that of protection. Protection of systems such as the ground water is set on the basis of a law and the necessary technical ordinances (e.g. on water protection, or on wastes). It includes land-use restrictions, the set-up of quality standards, and monitoring. Strategies for the clean-up of polluted sites must be established. Due to the high expenses, each case of a pollution must be treated as an individual, and no "cook-book recipes" can be formulated.

Concerning the future of environmental practice and research in Switzerland, the funding of projects has unfortunately become difficult, after a few years of growing interest of the industry and governmental agencies in environmental questions. This fact should, however, not discourage the earth scientists to become active in this challenging direction of earth and related natural sciences.

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REFERENCES

Arneth, J.-D., Kerndorff, H., Brill, V., Schleyer, R., Milde, G. & Friesel, P. 1986: Leitfaden für die Aussonderung grundwassergefährdender Problemstandorte bei Altablagerungen. WaBoLu Hefte 5/1986.

Baccini, P. & Brunner, P. 1991: Metabolism of the anthroposphere. Springer, Berlin.

Blau, R. V. 1992: Nutzungs- und Schutzkonzepte – Grundlagen für die Trinkwassergewinnung aus Grundwasservorkommen. Gas-Wasser-Abwasser 72 (4), 248–252.

Fetter, C. W. 1993: Contaminant hydrogeology. Macmillan, New York.

Jackson, R. E. 1982: The contamination and protection of aquifers. Nature and Resources 18 (3), 1–5.

Jackson, R. E. & Hoehn, E. 1987: A review of processes affecting the fate of contaminants in groundwater. Water Poll. Res. J. Canada 22 (1), 1–20.

Hartmann, D. & Michel, P. 1992: Grundwasserschutz in der Schweiz. Gas-Wasser-Abwasser 72 (3), 167–173.

Hoehn, E. & Bundi, U. 1983: Gefährdung und Schutz des Grundwassers in der Schweiz. Schweiz. Ing. Arch. 104 (4), 33–41.

Hoehn, E., Blau, R., Hartmann, D., Kanz, W., Leuenberger, H., Matousek, F. & Zumstein, J. 1994: Der Zuströmbereich als Element eines zeitgemässen Grundwasserschutzes, Gas-Wasser-Abwasser 74, 187–193.

HUTZINGER, O. ed. 1990: The natural environment and the biogeochemical cycles. The handbook of environmental chemistry. Volume 1, part E. Springer, Berlin.
– ed. 1991: Water pollution. The handbook of environmental chemistry. Volume 5, part A. Springer, Berlin.
RUSSO, D. & DAGAN, G. eds. 1993: Water flow and solute transport in soils. Springer, Berlin.
SIGG, L. & STUMM, W. 1994: Aquatische Chemie, eine Einführung in die Chemie wässriger Lösungen und natürlicher Gewässer. Verlag Fachvereine, Zürich, 3rd ed.
STUMM, W. 1985: Globale chemische Kreisläufe und ihre Beeinflussung durch die Zivilisation – Die Gefährdung von Wasser, Wald und Luft. Vortragsreihe «panta rhei», Bd. 5, Hans-Erni-Stiftung, Luzern.
STUMM, W., SCHWARZENBACH, R. P. & SIGG, L. 1983: Von der Umweltanalytik zur Ökotoxikologie – ein Plädoyer für mehr Konzepte und weniger Routinemessungen. Angew. Chemie 95, 345–355.
YONG, R. N., MOHAMED, A. M. O. & WARKENTIN, B. P. 1992: Principles of contaminant transport in soils. Elsevier, Amsterdam.

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