Groundwater Pollution (GPoll)

An ESF scientific programme

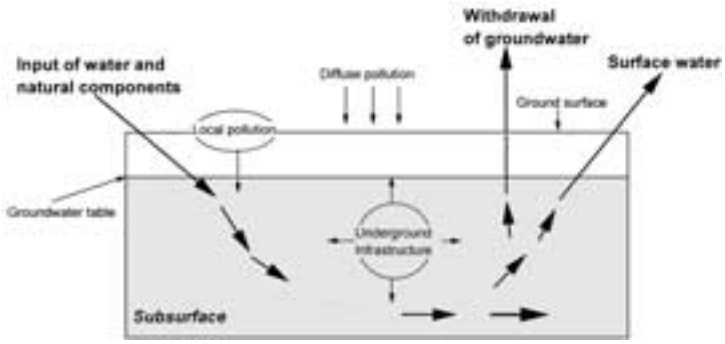
A *clean and safe source of drinking water is regarded by the United Nations as a fundamental human right. Many European countries depend on groundwater for drinking water supplies. As this water becomes increasingly polluted, they are faced with two options: Develop increasingly complex and expensive methods of cleaning the water or risk the consequences to human health of drinking polluted water. Groundwater pollution is, of course, also of concern in environmental terms.*

GPoll is a long-term programme that initiates and promotes multinational, multidisciplinary research on pollution of groundwater by toxic chemicals, metals, pathogenic organisms, radionuclides and by excess nutrients. It focuses on the fate of pollution in groundwater systems because of their significance for human and environmental health. The research has urgency because of the sharp increases in the incidence of pollution-related disorders and the increasingly conspicuous damage caused by pollution to natural ecosystems. However, most of the groundwater participates in the hydrological cycle although the residence time may vary from months to centuries. The processes causing groundwater pollution may, therefore, often only become apparent over the long term. Hence, the programme includes planning for long-term research and monitoring.

European collaboration provides added value, partly because pollution is international, and also because environmental problems require interdisciplinary research. No single country can provide all of the necessary expertise and therefore international cooperation is essential between centres of excellence in different subject areas. One aim of GPoll is to encourage the best scientists from widely different disciplines to engage in environmental research, and to cooperate internationally.

GPoll's emphasis is on fundamental and strategic research that has potential for use in maintaining clean water supplies. Determining whether prevention of a specified kind of pollution is urgent, requires research on the fate and impact of the pollutant, or mixture of pollutants. Only then will we have a basis for remedial measures to degrade, immobilise or contain them.

The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.



Input of water from the surface to the subsurface generates groundwater. Groundwater may receive pollutants from three principally different sources. More than 50-70% of the drinking water in Europe is drawn from the subsurface. The quality of such drinking water reflects the many different processes and possible pollutants groundwater meets during its flow underground.

Sources and classes of groundwater pollutants

Pollution enters the groundwater system from different sources. A convenient way to distinguish these sources is:

- **Diffuse pollution** is the input from different sources including the atmosphere and from agricultural use of fertilisers and crop protecting chemicals.

- **Local pollution** enters from point sources including industrial sites and waste dumps.

- **Subsurface infrastructure pollution** includes sources like storage facilities, tunnels and pipelines.

The fate of the pollution in the groundwater system determines to a large extent the quality of the groundwater resources used by man and surface ecosystems. Our current knowledge of the subsurface processes that occur in the groundwater is insufficient to predict the fate of most pollutants. One of GPoll's purposes is to identify a research agenda to ensure the sustainable use of groundwater supplies. The suggestions for research address processes in the subsurface based on input of water, input of pollutants, geochemical properties of the subsurface, and biogeochemical activities therein.

Priority pollutants to be considered are:

- Agrochemicals including fertilisers and pesticides;
- Hormones and antibiotics;
- Fuels and other solvents;
- Metals including radionuclides;
- Microorganisms and viruses.

Aims and objectives

An interdisciplinary approach

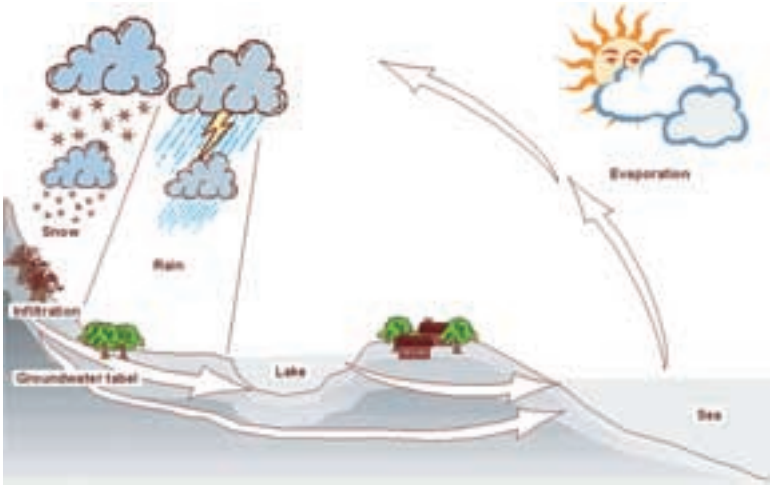
The complexity of natural systems requires interdisciplinary research as well as a combination of different scales of investigations. If parameters obtained from simplified systems, like e.g. batch experiments, do not match field observations, *they should not be used to generate models*. The complexity of the field situation should be scaled down to experimental set-ups in order to define parameters matching the system dominating processes. The field investigations as well as the experiments have to be designed in close co-operation of different scientific groups as e.g. geologists, geochemists, biologists and modellers. This target can be achieved by an appropriate funding of interdisciplinary research activities including analysis and detection, physical transport, chemical transformation and immobilisation and biotransformation.

1. Analysis and detection

Uncontrolled use of organic compounds lead to the occurrence of a new generation of pollutants in the surface and groundwater, such as antibiotics, hormones and halogenated hydrocarbons. To be able to reliably investigate this kind of pollution at low concentrations, new methodologies need to be developed. Representative sampling is the basis of any accurate determination of concentration or transformation of these compounds. Interaction of pollutants with solid surfaces is of special concern for their distribution in the subsurface environment. Due to the lack of standardisation of analytical methodology, misleading results can be obtained. To assess the impact of metals on the environment, special attention should be paid to their speciation. Molecular microbial diagnostics needs intensive further development if we want to know who is doing what in the ongoing subsurface microbial processes and which are the dominant organisms. To detect existing pollution, the limits and the direction of its spreading and the location and extension of its source, sensitive, accurate, quick and cheaper methods have to be developed.

2. Physical Transport

The relevance of scale and heterogeneity to the conceptualisation and parameterisation of porous media and to an appropriate up-scaling and down-scaling of its models must be further researched by means of the appropriate physical models of these media as well as *in-situ* to be fully understood. To properly understand and forecast pollution propagation, media characterisation and parameterisation must be made with respect to the mass transport. Media characterisation with this respect is still uncertain in very heterogeneous, fractured and karstic rocks. Rock parameter acquisition, relevance and representativeness have still to be improved at the general level. Flow and mass transport, governing pollution propagation in the groundwater, are dependent on physical, chemical and biological processes. An appropriate coupling of these processes must be achieved as well as a better understanding of process and/or reaction dynamics. Further, the role of suspended matter transported in groundwater as a pollution carrier must be investigated and incorporated.



The hydrological cycle is driven by the sun and gravitation. Not more than 10% of the precipitation over Europe fall directly to lakes and rivers, a part (10-40%) is captured by the vegetation as interception whereas the main part of the rain and snow infiltrate into the ground. Runoff from surface water systems is generally transported much faster than the transport of water through the ground. Residence times of water in the ground can be from days to hundreds of years and longer. That is why groundwater in many cases reacts slowly on pollution.

Chemical transformation and immobilisation

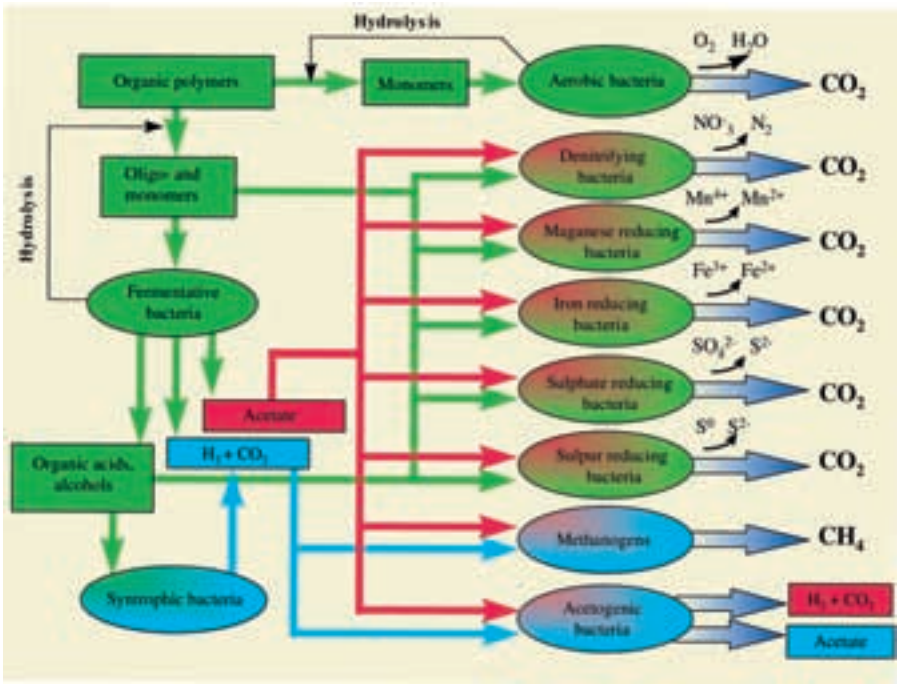
Pollution of groundwater is the result of a redistribution of elements or components leading to unacceptable concentration levels. A detailed understanding of the transport is therefore needed for the analysis and prediction of a particular case of groundwater pollution. The physical transport of pollutants in subterranean systems to the groundwater, e.g. from a point source or a diffuse source, is directly dependent on the speciation, i.e. the chemical state of the particular element or compound. The speciation, and any change of it, is determined by the over-all biogeosphere processes that govern the hydrochemistry and the transport route. Parameters of particular importance are pH, the redox potential, particularly the presence of redox sensitive elements (Fe, S, As, Se as well as O, N) and the presence of complexing ligands. The transport of a trace metal depends on the speciation of the solution which is continuously determined by the composition of the aqueous phase. Of particular importance is the formation of stable complexes with organic acids (notably humic substances and other polycarboxylic acids). The trace component is distributed between a stationary solid phase, mobile suspended solid phases and the mobile aquatic phase through adsorption/desorption processes.

Biotransformation

Organic compounds mainly of anthropogenic origin make up a wide spectrum of pollutants identified in soil and groundwater. They belong to almost all varieties of substituted and unsubstituted aliphatic and aromatic compounds. Biotransformation of such compounds, either intrinsic or facilitated, is one way of preventing the polluting compounds from reaching target organisms which would react on their toxicity or resulting in water not accepted for use for drinking or irrigation. Thus, efforts are taken to study and utilise biotransformation in order to remediate soils and groundwaters. There are several cases reported, where successful biotransformation of polluted areas has occurred. A challenge is to study and decide if a polluted area should be left for natural attenuation or if it should be subjected to more active remediation measures. The primary source of pollution should always be tracked and eliminated if possible.

The chemical structure of an organic pollutant giving its physical properties will form the background for its aptitude to be degraded. Organic pollutants of anthropogenic origin, i.e. new compounds synthesised by man as well as petroleum products of different refinery grades, are in analogy with their naturally formed cousins dependent on a row of parameters among which are:

- Ability to function as a substrate i.e. as carbon and/or energy source or as electron acceptor.



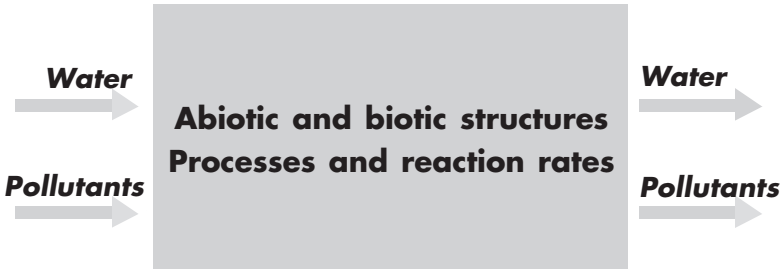
Biodegradation of organic pollutants in groundwater can occur via a number of different metabolic pathways, characterised by the principal electron acceptor in the carbon oxidation reaction. A range of compounds that may occur in groundwater are formed or consumed by microbes.

- Suitability for co-metabolic transformation.
- Toxicity to microorganisms.
- Solubility in water – concentration levels.
- Sorption features.

Upon these compound specific properties microorganisms able to transform the compound will need nutrients and electron donors or acceptors and a suitable physical-chemical environment e.g. appropriate pH and redox conditions. A combination of the above features will govern the fate of a certain compound or group of compounds in relation to biotransformation. This means that the kinetics and thus the degree of persistence of a compound will be determined by these properties. In order to assess the extent of biotransformation of a compound or a mixture of compounds polluting a groundwater basin a row of parameters has to be studied.

Bioprocesses in the subsurface

A basic approach for understanding groundwater pollution bioprocesses is to consider processes in a small-scale representative cell (scaled down box) taken from the subsurface system. This approach allows scientists to consider a multitude of cases ranging from heavily polluted point sources to processes related to diffuse pollution and covering both well understood reaction mechanisms and descriptive rate measurements.



The small scale box for study of subsurface processes.

The processes in the grey box are governed by the input parameters water and polluting chemicals, the characteristics of the abiotic matrix, and the microbial activity. In addition to the development of molecular diagnostics to determine the nature of the dominant organisms, the need for an appropriate physiological characterisation of the microbiological potential relevant to the prevailing micro-environmental status is central. In particular atten-

tion should be paid to the generally low temperature of the subsurface environment, the often oligotrophic nature of the organisms involved, and the distribution of pollutants between the aqueous and solid phases in the system. The small-scale boxes may be considered as suitable experimental systems that can provide relevant information at the laboratory scale. They may take the shape of aquifer microcosms e.g. sediment columns.

If sufficient information of representative cells of the subsurface system has been generated, the next challenge is to upscale the processes in both time and space. The quality of upscaling is strongly dependent on the understanding of the small-scale processes and the scale-dependent heterogeneity of the system. A priority list of research needs with respect to subsurface bioprocesses are:

- Encourage inter- and multidisciplinary collaboration in hydrobiogeochemistry through workshops and fellowships.
- Development and use of suitable laboratory systems (small-scale boxes) to study processes under relevant boundary conditions.
- Development and use of molecular diagnostic techniques for the characterisation of the biological agents.
- Studies of the biological potential, natural attenuation, under field conditions.
- Build and manage a European GPoll database containing pertinent physical, chemical and biological data.

Activities

Fellowships

GPoll fellowships have enabled talented scientists to spend up to six months in a foreign laboratory, exploiting new techniques and facilities and strengthening collaboration. Groups of fellowships facilitate international cooperation to build on new discoveries in a flexible and opportunistic way. To date 55 fellowships have been awarded by GPoll, 25 Short Visits (SV) and 30 Collaborative Research Projects (CRP).

Some of the topics dealt with are:

- *Solid phase enhanced direct spectrofluorimetric determination of polychlorinated biphenyls (PCB's) in groundwater* (Manuel Algarral Gonzalez, Spain)
- *Composition of humic substances along their movement in groundwaters and ability to interact with xenobiotica* (Linda Eglite, Latvia)
- *Transport of groundwater bacteria in heterogeneous aquifer predicted by up-scaling of sorption from laboratory to field* (Lina Ekere, Sweden)
- *Modelling of ground water pollution in mining districts* (Sergey A. Galchenko, Russia)
- *The assessment of phytoremediation in contaminated mine-soils as a new technique to prevent groundwater pollution* (Petra Kidd, United Kingdom)
- *Characterisation of humic substances and their effect on ferrous iron oxidation and* in situ *biremediation of chlorophenol-polluted groundwater* (Jörg Langwaldt, Finland)
- *Multisensor systems on the basis of new thin-film sensors for detection of toxic pollutants and radionuclides in the groundwaters* (Ioulia Mourzina, Russia)
- *A field and modelling study of the Estonian wetlands as natural remediation systems of groundwater pollution* (Erik Puura, Sweden)
- *Molecular analysis of natural bacterial populations in groundwater of uranium wastes* (Galina Radeva, Bulgaria)

- *A study of geological structures in karst for understanding the underground water drainage and possible paths for pollution in groundwater* (Stanka Sebela, Slovenia)

- *Biogechemical transport modelling of nitrate in a porous pleistocene aquifer* (Teodora Szocs, Hungary)

- *Groundwater pollution by contaminant transport from soil to fractured rock* (Kai Witthüser, Germany)

Workshops

International GPoll workshops have reviewed recent discoveries, practical advances and emerging themes in particular scientific areas, developed initiative for international collaboration.

- *Prospective terrestrial environment and groundwater pollution*, 15-18 November 1998, Göteborg, Sweden

- *Ground layer as a geochemical barrier for propagation of groundwater pollutants*, 23-25 June 1999, Moscow, Russia

- *Groundwater pollution in Karst – preserving water quality in Karst systems*, 4-6 November 1999, Ljubljana, Slovenia

- *Attenuation of groundwater pollution by bank filtration*, 15-17 June 2000, Dresden, Germany

- *Groundwater pollution in areas of groundwater overexploitation*, 10-13 September 2000, St. Petersburg, Russia

- In-situ *reactive barriers versus pump-and-treat for groundwater remediation*, 18-19 October 2001, Berlin, Germany

- *Analysis, toxicity and biodegradation of organic pollutants in groundwater from contaminated land, landfills and sediments*, November 2001, Barcelona, Spain

Symposium

GPoll cosponsored *GROUNDWATER 2000*, held in Copenhagen, Denmark 6-8 June 2000. GPoll funded travel grants for eight young scientists from 6 GPoll member countries and funded eight invited speakers from 7 GPoll member countries. GPoll also organised a very appreciated poster evaluation procedure with prizes for 3 winning posters. Almost 300 delegates representing 36 countries world-wide participated in the conference.

Summer school

GPoll will sponsor a summer school on *Buffer Zones for Water Pollution Control* which will be held in Ghent, Belgium on 29 August-7 September 2001.

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For the latest information on this programme consult the *GPoll* home page:
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Cover picture:
Courtesy of Grundfos A/S Denmark.
Many European citizens depend on groundwater for drinking.

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