National Groundwater and Contaminated Land Centre

Microbiological Contaminants in Groundwater

Environment Agency

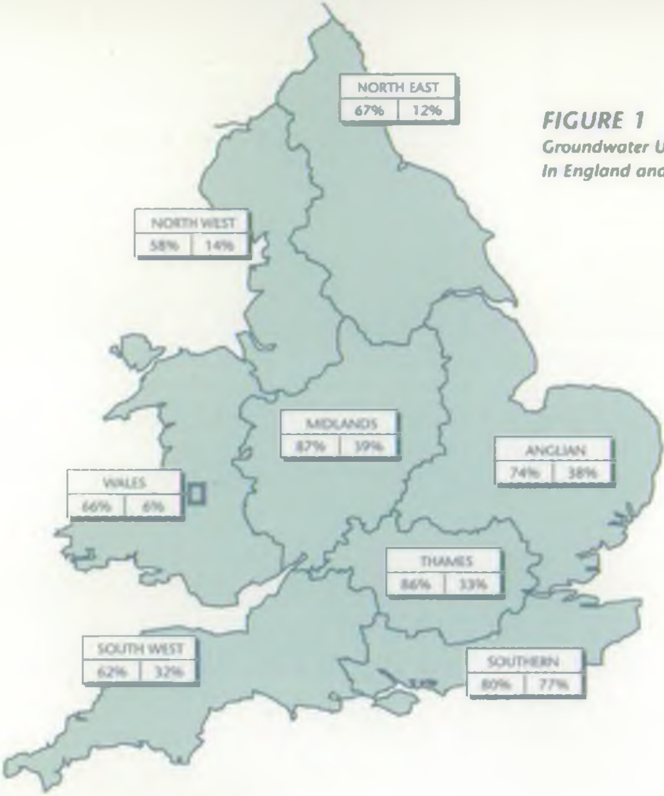


FIGURE 1
Groundwater Use For Public Supply In England and Wales (1994).

Groundwater Contamination

A groundwater contaminant may be defined as any solute, non-aqueous phase liquid, or particle that enters groundwater as a consequence of natural processes or the activities of man. Contamination of groundwater can come from a wide range of sources. Listed below are just some of the possible sources of microbial contamination in groundwater.

- Underground storage tanks
- Septic tanks
- Agricultural activities especially farm waste sites
- Municipal landfills
- Abandoned hazardous waste sites
- Sewage sludge handling
- Recharge from rivers containing sewage effluent
- Leaking sewers

A further list of potential sources of groundwater contamination has been compiled by the Agency as part of its published "Policy and Practice for the Protection of Groundwater."

Microbiological Contaminants in Groundwater

Groundwater is an important natural resource worldwide. More than half the water supplied for public use, in Europe and the United States is groundwater. Figures for England and Wales show that around 30% of drinking water supplies are taken from groundwater sources. This figure rises to 77% in parts of southern and eastern England. Traditionally, groundwater has been perceived as having two advantages over surface water. Firstly, it is attractive in terms of capital investment because development can progress in stages with rising water demand. Secondly, it is much less vulnerable to pollution. However, there is a significant body of evidence to suggest that the latter advantage is being eroded due to the increasing number of point and diffuse sources of pollution arising from urban, industrial and agricultural activities. Moreover, contaminated aquifers may be difficult to restore to their original status, due to the complex interactions between the physical,chemical and biological properties of aquifers and the pollutants.

Due to changes in industrial, agricultural and domestic requirements demands on groundwater have increased. Concerns about unforeseen contamination have heightened as a result. Awareness of the contamination of groundwater usually only occurs after substantial concentrations of a particular contaminant, chemical or microbial, has entered the aquifer system.

There is little published work on groundwater microbiology (both indigenous and introduced populations) in the UK and even less on the role of indigenous microbes on groundwater quality and health. Most of the information here has come from North America, and thus by its very nature may not be directly relevant to the UK. However it serves as a good basis to understand the effects of microbiological contaminants on groundwater.

Escherichia coli ATCC® 25922

Microbial contamination

Microbes are organisms that are too small to be clearly perceived by the unaided human eye. They include protozoa, many algae, fungi, bacteria and viruses. The role of microbial contaminants of groundwater in the transmission of disease has been well established by epidemiological investigations of waterborne disease outbreaks dating back to the first realisations in Victorian times, that micro-organisms could cause disease. Groundwater, whilst it is usually of high quality both chemically and microbiologically, is vulnerable to contamination from human activity or natural processes.

Recently, there has been renewed concern regarding the microbiological quality of water in UK aquifers, both now and for the future, as pressures on the environment increase. Many people in rural areas rely on private boreholes and wells which may be particularly vulnerable to microbial pollution in view of the uncertain level of disinfection which these receive.

Indigenous Microbiological Activity in Aquifers

Most aquifers provide all the requirements necessary for microbial growth and may sustain an indigenous microbial population. However, the availability of nutrients (carbon, nitrogen, phosphorus and sulphur) and energy sources will control the extent of microbial growth and activity. In unpolluted areas such nutrients must be obtained from the groundwater itself or via dissolution of compounds from the rock matrix. Environmental conditions such as pH, temperature, pressure, redox etc. all influence microbial growth and activity. In their turn, microbial processes can influence geochemistry and water quality of the groundwater. For example, microbial production of acids may increase the dissolution of metals from the aquifer rock, Currently, there is little information on microbiological compositions and activities in UK aquifers.

Salmonella enteritidis ATCC® 13076

Pathogens in Aquifers

Pathogens are organisms that are capable of causing disease, although not all isolates of a pathogen will cause disease. The degree to which a pathogen causes disease is termed virulence. It would therefore require few cells of a highly virulent strain to cause disease in a susceptible host, whilst many cells of a low virulence strain would be required to have a similar impact on its host. Waterborne diseases of concern in the UK can originate from protozoa such as ***Cryptosporidium parvum, Giardia lamblia*** and bacteria such as Legionell or Vibrio species or from enteric and other viruses. The presence of enteric bacteria and enteric viruses in raw groundwater samples is also a cause for concern. The custom of applying precautionary disinfection to all public water supplies in the UK means that reported cases of contamination are uncommon. However, it should be noted that there are many thousands of private water sources in England and Wales, most of which are groundwater-based and provide supplies with minimal or no treatment. Waterborne outbreaks in public supplies are usually associated with a physical breakdown of the treatment processes used, and in private supplies they are typically due to contamination of untreated groundwater supplies with animal or human waste.

Most waterborne infections originate from the gut of humans or animals. Treated sewage effluent contains high numbers of microorganisms, including pathogens. Most treated sewage effluent in the UK is discharged into surface water, but in some parts of the UK rivers are in direct contact with underlying aquifers and this can provide a pathway for the contamination of groundwater. Sewage sludge application to land, particularly if untreated is another activity with potential to pollute groundwater both chemically and microbiologically.

The common way to protect water supplies from these organisms is to have effective sanitation, and sewage treatment systems, together with an effective drinking water treatment and distribution system. It is generally the

Legionella pneumophilia ATCC® 33153
grown on Oxoid Legionella Selective Medium

case that pathogens entering an aquifer will die off naturally over time and as the water flows through the aquifer. For untreated potable supplies it is therefore essential that sources of microbiological pollution into groundwater such as septic tanks are sufficiently remote to allow this self-purification process to occur. It is also important that the structures supplying the potable water are carefully maintained and constructed.

The ideal way to detect the presence of waterborne pathogens would be to analyse the water for the presence of specific organisms of concern. However, this may be difficult or in some cases impossible with todays technology. Hence, indicator bacteria (coliforms) are used as a warning of possible contamination and as an index of water quality deterioration. Some coliform bacteria are intimately associated with the human and animal gut (hence the name from colon - large intestine). However, the coliform group is large and diverse, some strains can be associated with plant material and therefore high levels of total coliforms may not be a true indication of contamination. A more precise test is to look for the bacteria ***Escherichia coli***, an organism which is normally present in mammalian faeces. However, it is now generally agreed that these tests are of limited value as universal pathogen indicators in groundwater. New protocols are required to identify both indigenous populations and the risks from contaminant organisms hazardous to health.

Cryptosporidiosis

Cryptosporidiosis is caused by the protozoan Cryptosporidium found in man, mammals, birds, fish and reptiles. The only species known to infect both man and livestock is ***Cryptosporidium parvum***. An animal infected by this parasite can excrete oocysts in very large numbers (1010 daily) for up to 14 days. These spore-like oocysts are tiny and very resistant to adverse conditions in the environment, being able to survive dormant but viable for months in clean water or moist soil. They are similarly very resistant to standard

chlorination disinfection regimes used in the treatment of raw waters for drinking water supplies. While most oocysts in the environment originate from agricultural sources and wastewater discharges, contamination of surface waters can also arise from infected riverine wildlife. Recently it has been shown that some groundwaters may also be at risk from Cryptosporidium. In response to an outbreak of Cryptosporidiosis in north west London and Hertfordshire in March 1997 a group of experts under the chairmanship of Prof. Ian Bouchier was reconvened, at the behest of the UK Government, to consider and report on the outbreak. A report was published in November 1998 and was the third report from such an expert group, others having been published in 1990 and 1995 under the chairmanship of Sir John Badenoch.

The Bouchier report made the following recommendations (amongst others):

1.2.13 Water utilities should systematically assess and rank the potential risk of groundwater contamination by Cryptosporidium by application of a tripartite approach, which assesses source, catchment and hydrogeological factors.

1.2.14 Continued use should be made of existing national groundwater vulnerability maps and source protection zoning schemes to assess risk of contamination with Cryptosporidium.

1.2.15 For Cryptosporidium risk assessment, a fourth classification of "extreme vulnerability" is recommended for use with vulnerability maps and zoning schemes.

Bovine Spongiform Encephalopathy

Bovine Spongiform Encephalopathy (BSE) is one of a class of diseases called Transmissible Spongiform Encephalopathies (TSEs) which occur in several animal species. As part of its responsibility for the regulation and management of waste disposal in England and Wales, the Environment Agency has carried out several assessments to quantify the risks of BSE infection being transmitted to humans as a result of disposal of the cattle-derived waste material.

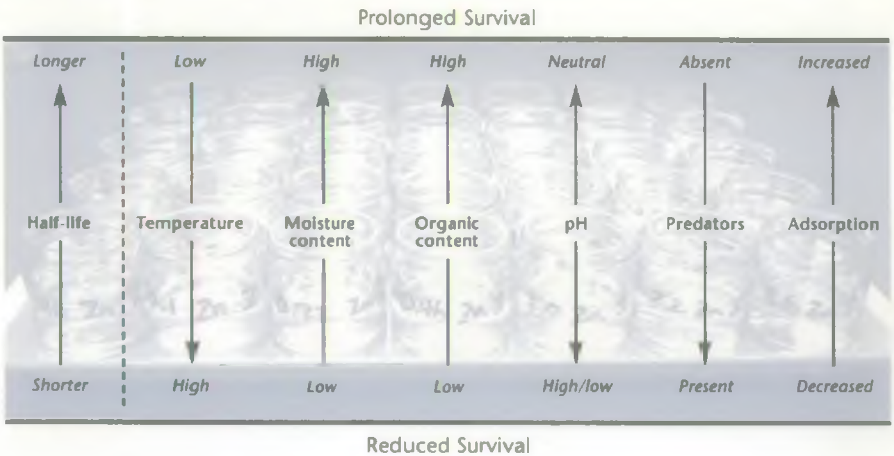
The Agency broadly concluded that for the disposal options considered (incineration, and landfilling of carcasses and rendered products), the risk of human infection by the BSE agent is extremely small.

Antibiotic Resistant Organisms in Aquifers

The widespread use of antibiotics in medicine and in agriculture has introduced a major selection pressure upon microorganisms. This has led to an increase in the occurrence of antibiotic resistant organisms. The presence of bacteria with multiple antibiotic resistance (chiefly coliforms) in drinking water is well documented and normal water treatment processes are thought to be less effective against these resistant organisms. The entry of such resistant organisms into groundwater may provide a reservoir of resistance, difficult to detect and remote from any possible remedy.

Factors Affecting Movement and Fate of Microbiological Contaminants in the Subsurface

Figure 2

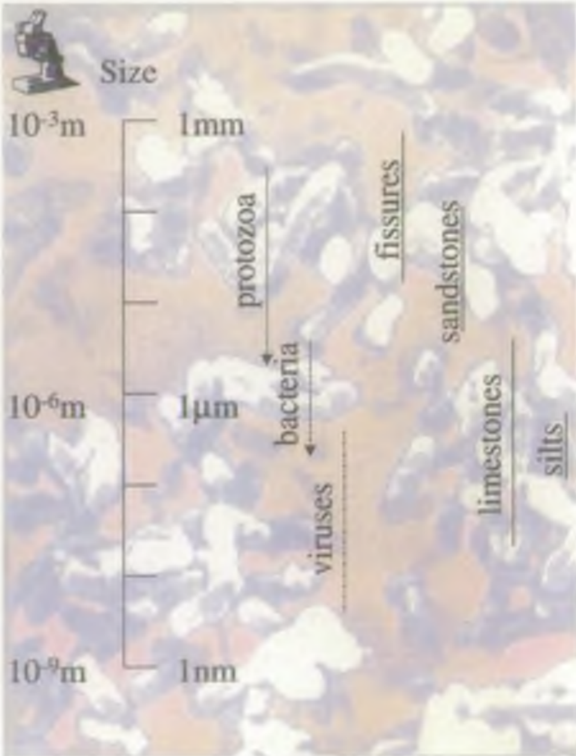


Factors affecting microbe survival

The transport of microbes within the subsurface by groundwater is affected by a number of processes which can be divided into two types: those that are related to the characteristics of the organism (e.g. size, shape, activity) or those such as temperature and moisture content which are related to the environment in which they are located (groundwater, aquifer and soil). A comparison of organism sizes and the likely subsurface transport routes is shown in Figure 3. Obviously, organisms can only pass through aquifer spaces which are physically larger than the organism itself.

In many cases there is interrelation between the environmental and organism factors, and the processes cannot be treated in isolation. In addition, a large number of factors including temperature, type of organism, water chemistry, organic content of soil and presence of other predatory organisms can influence the persistence of microbes. An indication of how these affect microbe survival is shown in Figure 2. The most critical factors are usually temperature and

Figure 3



moisture content. A key point is that there is a relationship between survival time of a microbe and the travel time between source of contamination and abstraction point. If the survival time of the pathogenic microbe is greater than the travel time, then the potential risk to health is greater. The corollary of this is that if the survival time is less than the travel time then there will be minimal risk to health by microbial infection.

Septic Tanks and Package Treatment Plants (PTPs)

A potential source of microbiological contamination of groundwater is from the disposal of treated sewage effluent. In the UK most houses are connected to the public sewerage system. The sewage is treated at sewage works and the effluent disposed to a surface watercourse. If a property is not connected to the main sewer then there are several alternatives for wastewater disposal. These include Package Treatment Plants (PTP), which can be operated to a similar standard as a full-scale sewage treatment plant. Conditions imposed on the effluent discharged to surface water depend largely on the volume of effluent discharged and the size of the receiving watercourse. Septic tanks have no moving parts and require very little maintenance or attention from trained personnel but they cannot treat the sewage to the same degree as a well operated PTP. The risk to groundwater depends on the effluent itself, the effectiveness of the soakaway, and on the aquifer properties. Cesspools act as a storage tank for sewage and do not discharge the sewage to the ground. If properly

Septic tanks may be constructed of glass fibre, thermoplastics or precast concrete
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constructed and maintained, cesspools should not pose any risk to groundwater.

Although the usage of PTPs, septic tanks and cesspools in the U.K. is not extensive in terms of the volume of wastewater handled, the potential for groundwater contamination is clear and the misuse of septic tanks is evident from discussions with the manufacturers. A detailed understanding of the removal of microbes or pathogens by septic tanks and PTPs is required to estimate the microbiological loading on the ground, and potentially on underlying groundwater resources, however, the published literature is very limited.

There are a number of guidance documents on the building and

operation of septic tanks and PTP's. These include BS 6297:1983 'Design and installation of small sewage treatment works and cesspools'. BS 6297 deals with the design and installation of sewage treatment works suitable for discharges from domestic and industrial communities ranging from single households up to about 1000 population-equivalent. CIRIA have also produced a series of leaflets giving basic information on the installation and maintenance of these systems.

Bioremediation

The UK has a 200-year history of industrial development, but a shorter history of effective control of the chemicals used in these industries. A wide range of chemicals may therefore be present in groundwater for which very little data exists. The problem is exacerbated by the rapid increase in the number of potential pollutants. Little data exists for the release of total toxic chemicals into the environment. Many of these chemicals will become associated with the hydrological cycle from where they may be eventually transported into groundwater systems. Bioremediation, sometimes referred to as biorestoration, is a managed or natural process in which microbiological processes are used to degrade or transform contaminants to less toxic or non-toxic forms. It is a complex process which must be based on an understanding of a wide range of factors including microbiology, biochemistry, metabolic processes, structure and function of natural microbiological communities, chemistry of the pollutants, physiochemical interactions between microbes, contaminant and aquifer matrix. Bioremediation processes can alter the physical and chemical characteristics of groundwater, and accurate risk assessment is required to ensure the environment is adequately protected. Recently, the potential to utilise the natural microbial populations of aquifers to degrade man-made pollution has received increasing attention. This "natural attenuation" approach may provide the only possible method for treating some instances of groundwater pollution.

Using the Policy and Practice for the Protection of Groundwater to Assess Microbiological Risk to Groundwater

Figure 4

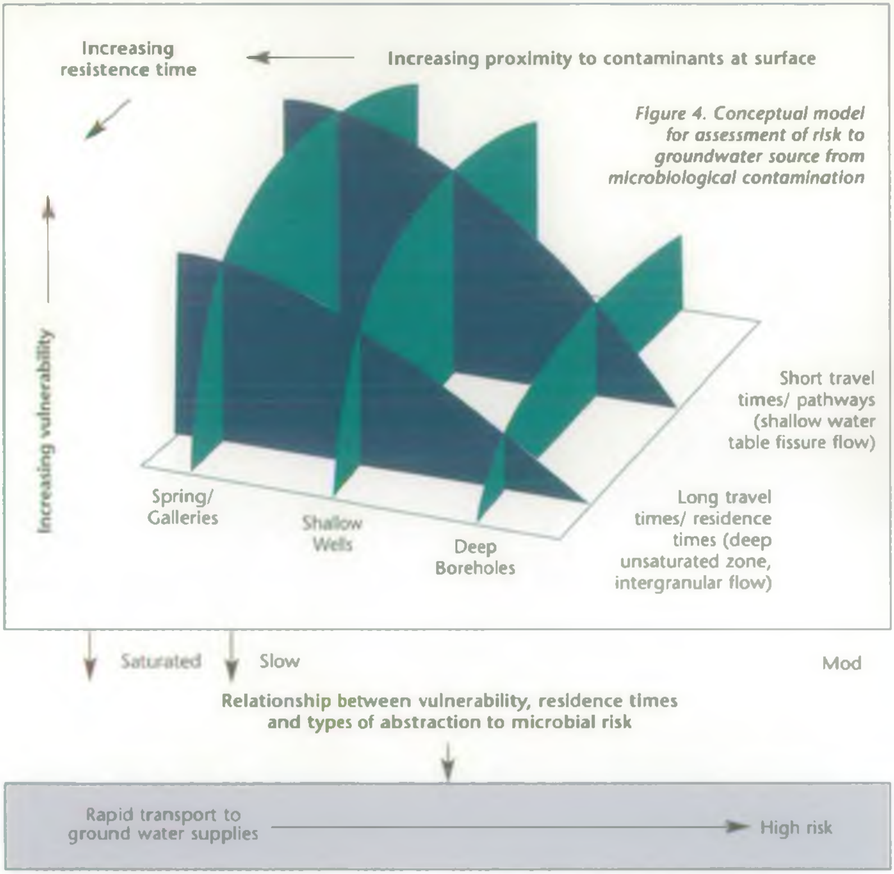

Figure 4. Conceptual model for assessment of risk to groundwater source from microbiological contamination

The guidance document Policy and Practice for the Protection of Groundwater (PPPG), produced by the Environment Agency, sets out the policy in England and Wales on groundwater protection. There are a number of factors that favour pollutant attenuation (nature of the soil cover, presence of drift, depth of unsaturated zone etc) but for microbes perhaps the key element is that of travel/survival time. Any process that extends the residence time of water before it is abstracted from an aquifer

reduces the risk from pathogens. The corollary is that any structure that draws from shallow flow cycles, which is likely to contain water that has had a short travel time since recharge, has a higher pollution risk than one drawing on long residence-time waters. Figure 4 demonstrates the conceptual relationship.

Using short travel times/pathways as a prime criterion, many spring systems and abandoned mine workings, most infiltration galleries, catchpit systems and some shallow wells would be more likely to encounter microbial pollution problems than deep wells/boreholes. In addition, some wells with horizontal tunnels (or adits) off the main shaft can inadvertently induce and favour rapid downward leakage of recent, potentially contaminated water.

Summary

The realisation that groundwater quality and microbiology are intrinsically linked is still a relatively recent one. The potential sources of microbial contamination to groundwater are many and varied. However the available literature on the fate of introduced and indigenous microbes in UK aquifers is extremely limited. An assessment of the indigenous microbial activities and populations is required to be able to assess fully the impact of human activity on groundwater quality in terms of microbial load.

Acknowledgements

Microbial growth plates reprinted with kind permission of Unipath Ltd.

Sources of Further Information

Environment Agency Pollution Prevention Guidance notes PPG1 to PPG22 obtained from the Environment Agency.
Fax: (0118) 953 5419.

Septic tanks and small sewage treatment works: a guide to current practice and common problems.
CIRIA Technical Note 146.

Septic tank systems: a regulators guide (1998). CIRIA leaflet SP144/BT.

Sterritt, R. M. & Lester, J. N. (1988). Microbiology for environmental and public health engineers. Publisher E & F. N. Spon. ISBN 0 419 12770 4.

Bouchier et a (1998)
Crypto sporadium in water supplies
Drinking Water Inspectorate

Technical information

This booklet was prepared in part from an Environment Agency R&D report:

R&D Technical Report P139 - A Review of the Microbiological Contaminants in Groundwater

Copies of this document are available from the Regional Information Centre (Library) and externally from the Foundation for Water Research
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