Geochemical Baseline as a basis for the European Groundwater Directive

W. Mike Edmunds

Oxford Centre for Water Research

2, Mansfield Road, Oxford, OX1 3TB

For the purposes of aquifer characterisation and groundwater management there is a need for an improved understanding of the geochemical processes controlling natural water quality. Entirely natural processes may lead to a breach of existing drinking water quality limits and it is important to be able to assess whether or not pollution is taking place against the changing natural baseline. A geochemical approach is necessary to define the overall controls and reactions giving rise to the water quality and its diversity, the age distribution of groundwater, and the rates at which natural processes and changes are occurring. The extent to which pristine waters (unaffected by anthropogenic influences) are being depleted or modified by contamination must also be addressed. In this paper, a geochemical basis for a standardised Europe-wide approach is proposed, forming the basis to be used in the new Water Framework Directive and the related Groundwater Directive.

Results from 12 EU member states have been used to illustrate the baseline concept. A series of 25 reference aquifers have been studied which represent aquifer types across Europe. These have been supplemented by in-depth studies of groundwater residence times, water quality trends, applications of geochemical modelling, monitoring of quality and transfer to policy

Chemical Standards for Drinking Water and their Scientific Basis

John Fawell,

Independent Consultant, Flackwell Heath, Bucks, HP10 9EW

The basis for standards for drinking water in Europe is primarily, but not entirely, the WHO Guidelines for Drinking Water Quality. The revised standards introduced in the new EC drinking water directive represent a rationalisation of the parameters in the previous directive concentrating on the more important contaminants. This new directive was incorporated into UK law in 2001 and came in to force at the beginning of 2004, superceding the previous standards. WHO guidelines are all science based and cover naturally occurring substances, substances from industry and human habitation, substances from agriculture and substances arising from water treatment and materials in distribution. A number are of interest, for groundwater and these include arsenic, boron, fluoride, nitrate, selenium and bromate. All are based on either epidemiology or extrapolated from laboratory animal studies. Two approaches are used to extrapolate from either human or animal data; these are the application of uncertainty factors and the use of theoretical mathematical models to estimate the risk of cancer at low exposure from the risk of tumours at high exposure. However, there remain many uncertainties and controversies, and small differences in a value can have a major impact on costs and practicality.

Thresholds, Standards and Status: implementing the Water Framework Directive

T Besien[1], P A Marsland[1], S Kirk[1], D J Allen[2], D G Kinniburgh[2] and M E Stuart[2],

[1] Environment Agency

[2] British Geological Survey

This presentation discusses how pollutant thresholds may be used as part of the Water Framework Directive (WFD) and the proposed Groundwater Daughter Directive (GWDD) to assess groundwater body status. An overview of the requirements of the WFD and the proposed GWDD with respect to groundwater body chemical status is presented. A proposed approach to setting thresholds is discussed. This approach is partly based on the findings of a joint Environment Agency / British Geological Survey research study, the results of which are due to be published shortly. Following the requirements of the WFD and potentially the GWDD a potential method for setting thresholds locally within a groundwater body in order to protect relevant receptors is outlined. These receptors may include rivers, lakes, groundwater dependant terrestrial ecosystems, drinking water sources and the groundwater body itself. This receptor-based approach may therefore lead to a variety of receptor thresholds being established for a given pollutant in the body. Finally an overview of the timescales and major milestones for status assessment is discussed.

Arsenic In Groundwater: Bangladesh And Other Young Sedimentary Aquifers

Pauline L Smedley

British Geological Survey, Wallingford, Oxfordshire

High arsenic concentrations have been found in groundwaters from a number of aquifers across the world and have in several cases resulted in severe health problems as a result of long-term use for drinking water. These are most commonly manifested as skin disorders, including skin cancer, but some internal cancers and a wide range of other problems also result. Nowhere are arsenic problems more severe than in Bangladesh where most of the population relies on groundwater for potable use. Up to 35 million people in Bangladesh are estimated to be drinking water with arsenic concentrations greater than the national standard for arsenic in drinking water of 50 µg L^{-1} and some 57 million people drinking water with concentrations greater than the WHO guideline value of 10 µg L^{-1}. Mobilisation of arsenic in the Bangladesh aquifers occurs under strongly reducing conditions with release most likely related to reduction to arsenite and desorption from, and dissolution of, iron oxides in the sediments. Similar geochemical conditions have been identified in young alluvial aquifers in other parts of Asia including regions of India, China, Nepal, Vietnam and Cambodia. The style of mobilisation contrasts strongly with that in some young sedimentary aquifers in arid inland basins, including parts of south-west USA, central Mexico and Argentina. Here, arsenic mobilisation occurs under oxic, alkaline (high-pH) conditions and is likely to be linked to desorption as arsenate from iron and other oxides. The distribution and scale of arsenic problems in aquifers across the world is reviewed and the geochemical conditions in the Bangladesh aquifers described.

Increasing arsenic concentration at tubewells in the Bengal Basin – How much? How soon?

William Burgess, Mark Cuthbert[1] & Helen Cheetham[2]

Department of Earth Sciences, University College London, London WC1E 6BT

[1] currently at Birmingham University, [2] currently at The Meteorological Office

Responses to the arsenic crisis in the Bengal Basin, and estimates of impacts on health, must be alive to the question of how arsenic concentration in tubewell discharge water may change with time. Conceptual models developed for arsenic in the aquifer imply patterns of change that can be quantified using numerical models. The models illustrate how shallow hand-pumped tubewells (HTWs) are vulnerable to arsenic concentration increasing as a consequence of vertical leakage induced by pumping. The models suggest that arsenic concentration at many HTWs will rise over decades or longer, but some will remain unaffected. The maximum eventual arsenic concentration will be well in excess of the 50 ìg/l national limit but is unlikely to exceed the highest concentration currently observed at a local scale. In the absence of long-term strategic monitoring data, field evidence for these changes relies on proxy relationships between arsenic concentration and tubewell age. A linear relationship observed at regional scale (10^6 km^2; Kinniburgh and Smedley, 2001) is also apparent at village scale (10^2 km^2) in 4 out of 5 cases in a transect across the basin. In the national Bangladesh survey by DPHE/BGS fewer than 1 % of tubewells deeper than 150 m (DTWs) exceeded the national limit of 50 ìg/l. The models suggest that appearance of arsenic at DTWs after less than 10 to 15 years of pumping is only possible in the absence of an aquitard, and if sorption is negligible, or if deeper arsenic sources are present. If these conditions are discounted, appearance of arsenic at DTWs after less than 10 years of pumping suggests poor borehole grouting. This may be the explanation where environmental isotopes indicate vertical seepage from shallow arsenic source regions to deeper tubewells, but monitoring programmes should support all DTW supply schemes.

Groundwater quality problems on the Wirral – are the Victorians to blame?

Phil Merrin

United Utilities Water, Thirlmere House, Lingley Mere, Gt. Sankey, Warrington, WA5 3LP, UK

Historically, groundwater from the Triassic Sandstone aquifer has always been an important resource on the Wirral peninsula, used for both industrial and public water supply for at least the last 150 years. The Victorians constructed a number of wells and boreholes and as population growth was rapid during the 19th Century, groundwater abstraction rates increased dramatically. Of the remaining three Victorian sites United Utilities operated, Grange Pumping Station at west Kirby was marked for permanent closure in 2002 because of elevated arsenic concentrations. Prior to the site being closed, an investigation was carried out on the water quality variation within the borehole with a view to reinstating the source by either altering the pumping regime or engineering a solution within the borehole itself. Investigations identified that water quality within the borehole varied significantly with depth with arsenic concentrations in the water in excess of 1500 ìg/l. An engineering solution has since been carried out to improve water quality in the borehole so that the source can once again be used for public water supply. The results of the project will be discussed in full with possibilities for groundwater evolution on the Wirral peninsula offered as a catalyst for further research into the study of deep groundwaters in the UK and the potential impact on public water supplies.

Cryptosporidium In Groundwater – Risk Assessment And Management

Mike Packman, Chief Hydrogeologist

Southern Water, Worthing, BN13 3NX

Cryptosporidium is a protozoan parasite, which occurs in humans, many mammals, and also in birds, fish, and reptiles. The parasite multiplies in the gastrointestinal tract of an infected person, which can cause cryptosporidiosis. The oocysts are about 4 to 6 ìm in diameter, and are robust, able to survive dormant for long periods in the environment, including in water.

Water companies are required by the DWI to install continuous monitoring for cryptosporidium at all sources, (surface water and groundwater), where there is deemed to be a "significant risk" of cryptosporidium oocysts being present in the final water. This has substantial cost implications, not only for the one-off installation of monitoring equipment, but also for the daily collection and analysis of samples.

This paper describes a methodology, which has been developed by Southern Water to screen all their groundwater sources, to identify those that are at significant risk of cryptosporidium contamination. The methodology is a semi-quantitative scoring technique, developed jointly by the author, which produces a ranked list of sources covering the complete spectrum of risk and enables risk management actions to be prioritised. There is an automatic link between the risk assessment and the final categorisation, provided by the scoring system. The methodology is designed to operate with a level of information and data easily available to a water company, overcoming the problems of providing sufficient data to operate probabilistic methodologies.

Pathogen Contamination And Transport In Groundwater

Stephen Pedley

Robens Centre For Public & Environmental Health, University Of Surrey, Guildford, GU2 7XH.

Traditionally, hydrogeologists, and many public health scientists, have regarded groundwater as a microbiologically safe source of drinking water. Unlike surface waters, which are vulnerable to direct contamination from many sources, groundwater is often shielded from the immediate influence of contamination by the overlying soil and unsaturated zones. In these zones, pathogenic microorganisms have been assumed to be attenuated by the prevailing physical, chemical and biological conditions in the environment. The risk of pathogens being transported into groundwater and producing a threat to public health was, therefore, considered to be low. Consequently, many groundwater sources are used for public supply with a minimum level of treatment, normally chlorination, or with no treatment at all.

The underlying rationale for restricted dispersion in the subsurface has some merit, but it is now known that microbiological contamination of groundwater is more widespread than previously believed. Indeed, as was found with chemical contaminant studies, particularly in the 1980s, the more that is looked for, the more can be found. Previous assumptions of good microbiological quality of groundwater seem to have been based more on an absence of data rather than an absence of pathogens.

Several studies in the US and elsewhere have demonstrated the occurrence of faecal indicators and enteroviruses in groundwater. Although there may be a bias in some of the studies, created by the deliberate selection of vulnerable sites, the data show that a significant percentage, up to 70 per cent in some regions, of groundwater sources contain one or more of the microbiological indicators of faecal contamination.

This presentation will sumarise our current understanding of the microbiological contamination of groundwater and the potential consequences for public health.

Dealing With Deteriorating Groundwater Quality

Victoria Ashton and Luke de Vial

Wessex Water, Claverton Down, Bath, BA2 7WW

Groundwater, unlike surface water, is supposed to be pure. But it isn't. In the Wessex Water supply area groundwater has become contaminated with pathogens (cryptosporidium), nitrate and pesticides. Wessex has recently built three membrane plants to remove cryptosporidium and two plants to lower nitrate levels. In the next five years works to reduce pesticides at three sites and nitrate at nine sites is required. Thankfully the aquifers have remained largely free from hydrocarbon or industrial pollution.

Wessex has investigated a number of ways of predicting nitrate levels. These include allowing for the impact of varying groundwater levels in nitrate concentrations. The predictive models developed are currently being used to size the treatment plants. Wherever possible high nitrate water is blended with low nitrate water from other sources. Wessex has also investigated bio-remediation.

Pesticide levels may be caused as much by point pollution as diffuse pollution. Wessex is working with farmers around the affected sources. Improvements to the way chemicals are handled and the removal of an old sheep dip may have a significant impact on the pesticide levels reaching the abstraction points, but granular activated carbon (GAC) plants are still likely to be required at some of the sites.

Speciation And Toxicity Of Trace Elements In Ground Water: An Overview

Karen Hudson-Edwards

School of Earth Sciences, Birkbeck, University of London, London WC1E 7HX

Although most trace elements are essential, in small amounts, to the functioning of organs and biochemical processes in the human body, they become toxic and can result in a multitude of health problems if absorbed or bioaccumulated in excess. The bioavailability of trace elements is, in part, dependent on their concentrations in blood and tissues, but more importantly, on the species of the trace element. Different species have different abilities to penetrate cell membranes in their original form, or by forming complexes or chelates with proteins or other ligands. For example, lipid-soluble, organic forms of trace elements such as methyl-Hg, organo-Pb and organo-Sn can diffuse across cell membranes in lipid-rich tissues such as the brain more easily than water-soluble elements of the same molecular weight. In other cases, the ionic, inorganic ionic form of elements such as Pb(II) competes with essential elements such as Zn(II), Fe(II) and Ca(II) in many biochemical functions, leading to problems such as anaemia. Divalent trace elements such as Pb(II) can also substitute for Ca(II) in hydroxyapatite that forms bone. For some trace elements, the organometallic species are less toxic, and the oxidation state of the element dictates its potential toxicity.

Although much current research is focusing on the links between toxicity, trace elements and their species, few of these focus on the specific links between concentrations and species of trace elements in ground water, and human health. Even where studies have been carried out, the results are often conflicting. Examples will be discussed that emphasise the need for further research on trace element speciation in ground water and human health.

Bromate In Hertfordshire Groundwater

Lucy Lytton

Veolia Water Partnership, Blackwell House, Three Valleys Way, Bushey, Herts WD23 2LG. Email: lucy.lytton@veoliawater.co.uk

A drinking water standard of 10mg/l for bromate was introduced in the UK in December 2003. In anticipation of this new standard, raw water sampling was conducted by Three Valleys Water in May 2000. The concentration of bromate at one 9Ml/d abstraction from the Chalk was in excess of 100mg/l and it was immediately taken out of supply. The relevant authorities were informed and an intensive round of sampling was conducted in private and public boreholes to establish the source and the extent of the pollution. The source was identified as the site of a former chemical works, some 5 km upgradient, that had been operational from 1950 – 1980.

The impact on the water supply was retrospectively reviewed and the Health Authority conducted an epidemiological study of the affected areas. This concluded that the incidence of potentially related health problems in the receiving population was, if anything, lower than that in the general population.

A second abstraction borehole 4km downgradient from the first, has shown a bromate concentration which has risen from about half the limit during the initial sampling round to a concentration now at approximately 3 times the limit. After three years of sampling, the pattern of bromate concentration at this second site is observed to have two strong trends: an overall rise and a seasonal fluctuation, with the lowest concentrations coinciding with periods of recharge.

Analyses of water level and water quality monitoring data have highlighted deviations in flow pattern from those shown on published maps of the Hertfordshire Chalk, indicating more complex hydrogeological processes than have been previously recognised.

The approach of WaterAid to groundwater quality issues

Chris Leake

Voluntary Hydrogeological Advisor to WaterAid

Hafren Water,

WaterAid is the only UK charity dedicated exclusively to the provision of domestic water, sanitation and hygiene education to the world's poorest people. The work of the organisation is fundamental: 1.1 billion people in the world do not have access to safe water and 2.4 billion people, half the world's population, do not have adequate sanitation.

As provision of safe drinking water is one of the principle objectives of WaterAid consideration of water quality is of paramount importance to the organisation. In many of the areas in which WaterAid operate the provision of water itself is a significant challenge, consequently questions of water quality have not historically been major considerations. However recent developments, particularly the awareness of the arsenic issues in Bangladesh and West Bengal, highlighted the importance of water quality and the potential for adverse health effects. WaterAid needed to respond to these developments and therefore embarked upon a programme of raising awareness in the countries in which it works and also by formulating its own policy on water quality. The latter was developed following wide consultation, including WaterAid country representatives and governmental bodies, and was designed to be flexible enough to allow circumstances in individual countries to be accommodated.

The way in which current policies of DFiD influence WaterAid programmes will be discussed together with the relationship between the two organisations.

The raising of awareness of water quality issues within WaterAid and its partner organisations, and the development of an organisational policy has, with a relatively small amount of effort, greatly raised the profile of these issues in a very large number of people over a short period of time. This in turn will directly benefit the end users in terms of water quality and hence also greatly decrease the incidence of the effects of waterborne disease and water shortage.