4. Assessment of pollution risk to small water supplies

4.1 Raw water sources

4.1.1 Influence of microorganisms on groundwater quality

The major influence of microorganisms on groundwater quality is in terms of their persistence and mobility in the subsurface environment. Bacteria derived from manmade sources are usually eliminated in the subsurface environment through a combination of physicochemical and biological processes. However, elimination rates are specific for each particular microbial species. Figure 11 illustrates the elimination rates of various bacteria and viruses. Virus survival and migration appear to be controlled by the climate, clay content and moisture-holding capacity of the geomatrix and the specific class of virus involved.

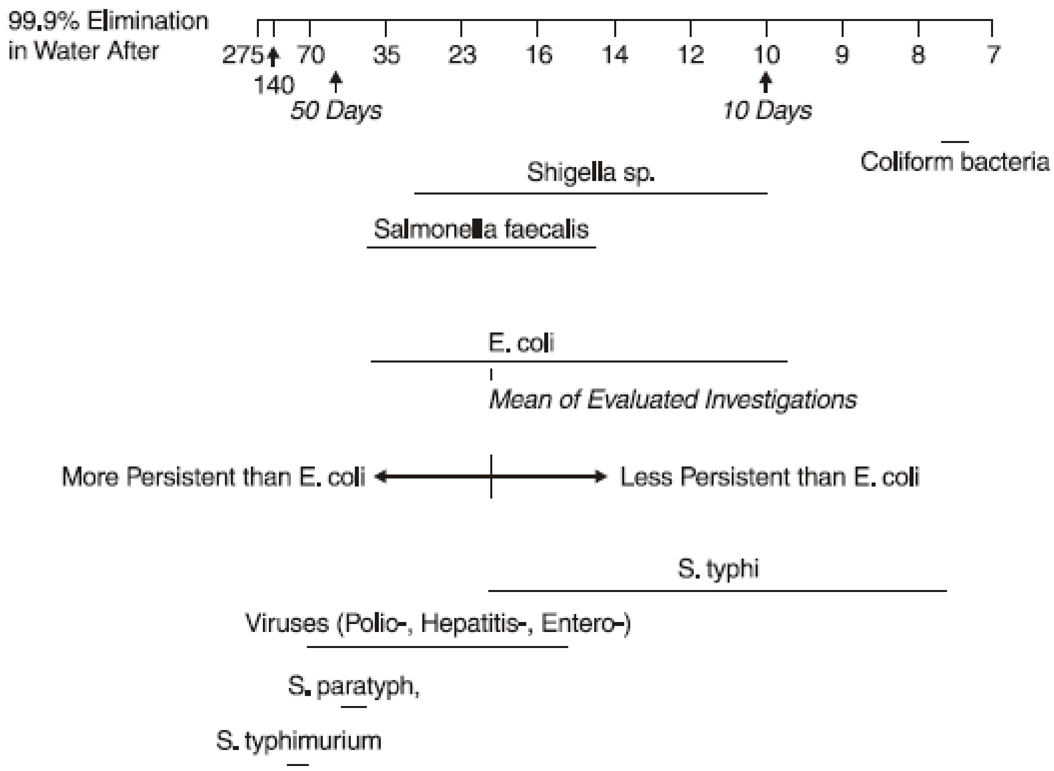

Figure 1: Elimination rates of bacteria and viruses

4.1.2 Raw water catchment

Abstraction of water from a well or borehole in an unconfined aquifer lowers the level of the water in the immediate vicinity of the abstraction point. This lowering of the water level is termed drawdown and assuming that the aquifer is homogeneous and no impermeable strata are present it will occur in a broadly circular pattern in plan view. The area of this circle is related to the hydraulic characteristics of the aquifer and the rates of abstraction and recharge. The cross-sectional shape of the drawdown is like an inverted cone with the apex being at or near the base of the well or borehole. This phenomenon is known as the cone of depression. Around each groundwater source an area is created from which water will drain towards the abstraction point. At the outermost edge of this area there will be a groundwater divide, beyond which water will bypass the source and not be drawn towards it. This divide in the flow of groundwater delineates the capture zone for the source.

It is important to distinguish between the capture zone and the cone of depression around the source. The capture zone consists of the up-gradient and down-gradient areas that will drain into the source. In the unlikely event that the water table was perfectly flat, the capture zone would be circular and would correspond to the cone of depression. However, the more common case is for the water table to be sloping due to regional groundwater gradients. In these circumstances the cone of depression and the capture zone will not correspond. This situation arises due to the hydraulic gradient of the water table downstream being dramatically changed through the action of pumping. Water will only flow towards the well where the pumping induced change in the gradient is sufficient to fully reverse the regional groundwater gradient. As pumping continues the area of the capture zone increases and this process will continue until the rate of abstraction is equalled by the recharge over the entire capture zone area. Thus the entire capture zone is known as the source catchment.

Groundwater fed springs may dry up as the water table falls during periods of low precipitation, or they may flow continuously as perennial springs with only slight variations in discharge rate throughout the year. When considering source protection the degree of protection afforded to a spring must be derived from the total spring discharge as the movement of the water through an aquifer system and issuing as a spring at any particular time is unknown. For this reason, protection zones around springs that are used as sources of supply must be derived on the basis of the total flows issuing through the spring.

4.1.3 Protection zone delineation for groundwater sources

Once the source catchment has been identified source protection zones can be delineated. These zones are required to understand the risk of contamination of groundwater being abstracted by considering how quickly potential contaminants in a given zone may reach the source. These source protection zones utilise a tripartite zonation system where the source catchments are subdivided into three roughly concentric zones. Two of these zones are determined by time of travel of the pollutant and the third by the source catchment itself. It should be noted that the shape of the zones is dictated by the characteristics of the aquifer and so in fractured rocks the zones may be elongated and stretch some distance from the source. The source protection zones are as follows[1]:

Inner zone (Zone 1) - Defined as the 50 day travel time from any point below the water table to the source. This zone has a minimum radius of 50 meters.

Outer zone (Zone 2) - Defined by a 400 day travel time from a point below the water table. The previous methodology gave an option to define SPZ2 as the minimum recharge area required to support 25% of the protected yield. This option is no longer available in defining new SPZs and instead this zone has a minimum radius of 250 or 500 meters around the source.

Total catchment (Zone 3) - Defined as the area around a source within which all groundwater recharge is presumed to be discharged at the source. In confined aquifers, the source catchment may be displaced some distance from the source. For heavily exploited aquifers, the final Source Catchment Protection Zone can be defined as the whole aquifer recharge area where the ratio of groundwater abstraction to aquifer recharge (average recharge multiplied by outcrop area) is >0.75. There is still the need to define individual source protection areas to assist operators in catchment management.

Special interest (Zone 4) - A fourth zone SPZ4 or 'Zone of Special Interest' was previously defined for some sources. SPZ4 usually represented a surface water catchment which drains into the aquifer feeding the groundwater supply (i.e. catchment draining to a disappearing stream). In the future this zone will be incorporated into one of the other zones, SPZ 1, 2 or 3, whichever is appropriate in the particular case, or become a safeguard zone.

[1] Environment Agency, 'Groundwater Source Protection Zones' from <http://apps.environment-agency.gov.uk/wiyby/37833.aspx>

4.2 Assessment of groundwater vulnerability - soil and land use factors

4.2.1 Vulnerability and risk considerations

The susceptibility of groundwater to microbiological contamination from surface or near-surface derived pollutants is greater under certain conditions than others. At any specific site, groundwater contamination depends on the natural or manmade characteristics of the site. Thus the ease with which the potential pollutant can migrate to the underlying water table or spring source depends on the physical, chemical and biological properties of the local strata. The factors that determine the vulnerability of groundwater to given pollutants or activities are as follows:

- characteristics of the overlying soil
- characteristics of the drift deposits
- nature of the solid geological strata within the unsaturated zone
- depth to groundwater
- nature of the contaminant

Land use is a critical factor and manmade structures or excavations can modify the impact of the factors listed above. Groundwater vulnerability classification is determined by the nature and quantity of material in the unsaturated zone, i.e. above the water table. In the absence of major fissures or cracks within this zone water movement is essentially slow, being confined to interconnected soil pores within an aerobic environment. However, the rate of this movement depends on the moisture content of the soil and will vary throughout the year. The overlying soil provides the potential for interception, adsorption and elimination of bacteria and viruses. Where vertical fissures occur or shattered rock comes close to the earth's surface, there is the potential for rapid flow of microorganisms to groundwater. These features reduce the ability of the soil and substrate to act as a barrier or filter.

4.2.2 Use of groundwater vulnerability maps

A methodology for classifying soils into three leaching potential classes has been developed by the Soil Survey and Land Research Centre for use in groundwater vulnerability maps. This classification also embraces all Soil Series that have been mapped to-date within the UK, with each soil series being assigned a value corresponding to the ease with which a representative pollutant could move through the soil. The mapping developed from this data may be of use when considering the potential water quality risks for a specific source.

4.2.3 Other factors that influence groundwater vulnerability

A series of site specific factors can contribute towards possible groundwater contamination but in most instances it is not possible to quantify the degree of risk. Examples of these are listed below.

- Physical disturbance of aquifers and groundwater flow. These activities lead to the disturbance of the physical barrier offered by the soil and may provide preferential pathways of water (and contaminant) movement to shallow groundwater. These include most forms of groundwater extraction, landfill operations, nearby borehole construction, any activity which interconnects naturally separate aquifers, existing or modified field drainage schemes that intercept recharge water, quarrying and gravel extraction both above and below the water table.

- Waste disposal to land. Many waste disposal practices have the potential to cause groundwater contamination. In this respect, the Environment Agency has laid down certain regulations, many of them statutory, to ensure specific objectives. For example, there will normally be objections at the planning stage to waste disposal activities that extend to or below the water table within prescribed limits of a source. However, the disposal of slurries and other wastes on agricultural land in the vicinity of a private water supply is not subject to the same regulation, although codes of good agricultural practice do exist.

- Contaminated land, being land currently or previously used in connection with specific potentially polluting activities, such as sewage treatment works, landfill sites and other waste disposal and recycling activities and waste lagoons. Also the Environment Agency will seek to protect water supplies where any of the above activities are to be found in close proximity to a water source.

- The application of liquid effluents, sludge and slurries to land. Three categories of waste are recognised, being controlled wastes (industrial effluent and sludge, both organic and inorganic in nature), sewage sludge and agriculture waste. Where the Environment Agency considers that any of these will give rise to a significant risk of polluting groundwater or surface water, there will be a presumption against spreading or compliance with existing environmental legislation. Farmers should have a waste management plan, with information relevant to suitable land available for spreading liquid effluents, sludge and slurries.

- Discharges to underground strata. Three areas of concern have been identified:

    - sewage effluent discharges including septic tank and sewage treatment plant effluents from individual properties or small housing estates

    - trade effluent discharges

    - surface water discharges that include contaminated runoff from roofs and impermeable areas such as roads, car parks, storage areas and so on.

- Diffuse pollution of groundwater. Diffuse pollution refers to pollution spread over time and space and caused by mechanisms other than local and specific discharges or events. Such pollutants are usually at much lower levels than other sources and are therefore at lower concentrations in the soil water. However, the build-up over a long period can generate potential problems. Diffuse pollution varies in character between urban and rural areas. Within the former, the two most notable examples of pollution arise from industrial sites and discharges from sewage systems. In contrast, within rural areas, the pollutant is not from an individual point discharge but arises from activities connected with intensive arable and livestock farming.

- Additional activities or developments which pose a threat to groundwater quality include miscellaneous activities such as storage of farm wastes and intensive livestock housing, graveyards and animal burial sites, sewage works and storm overflows.

4.2.4 Soil and land use factors underpinning the assessment of surface water vulnerability

In some instances, small water supplies are fed by surface waters. The role of soils in offering protection to these sources is much more limited than that described above for groundwater but nonetheless, differences in soil type will have an influence on the risk of microbiological contamination of these waters. Clearly, the soil has no role where the contaminant is deposited directly into the water body, but where a potential contaminant is deposited near to a water body there are a number of factors which affect the risk of contamination. The main factors are surface runoff which washes the contaminant into the water body and stream extension (both laterally and upslope) which entrains the contaminant.

The degree of surface flow is dependent on the intensity and duration of rainfall, the soil type, slope and land use. In general terms, high intensity rainfall, like that associated with thunderstorms, is likely to initiate overland flow in most soils as the infiltration rate of the soil is exceeded by the rainfall intensity. Low intensity rainfall over a prolonged period of time can also lead to overland flow. In both cases the soil type can have a major influence on the amount of rainfall that can be absorbed before the initiation of runoff. Soils with open, porous structures and with no slowly permeable layer will be able to absorb more than shallow soils or those with slowly permeable layers near to the soil surface. Land use can act both as an interceptor for rainfall (for example, a forest), reducing the amount that reaches the soil surface as well as providing the opportunity for the presence of potential contaminants (for example, open moorland that is grazed by domestic and wild animals).

Stream extension is the process whereby the apparent stream network as seen under dry conditions extends during rainfall, with the development of ephemeral streams and rivulets that occupy topographic hollows and are interconnected with the normal stream network. In many catchments, these streams and rivulets become dry soon after the rain has stopped. However, during rainfall the water flowing along these pathways will often be sufficiently fast and deep to entrain contaminants such as animal faeces. The occurrence of these pathways is difficult to predict from soil maps but some soil types will be more likely to behave in this way than others. During periods of rainfall, the levels of streams and rivers generally rise and may extend out beyond their normal channel to occupy their floodplain. In many small catchments, these floodplains may be only a few metres wide, but any faecal material or other potential contaminants on the surface may be entrained in the stream.