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Protecting groundwater supplies through a Water Safety Plan approach

● With an estimated two billion people around the world dependent upon groundwater resources, managing pollution and risks relating to the use of such resources for drinking water is a necessary undertaking. In this article, **BOB BREACH, RICARDO HIRATA** and **JOSE VIEIRA** outline a proactive Water Safety Plan approach to ensure the safety of supplies.

The launch in 2004 of the third edition of the World Health Organization (WHO) guidelines for drinking water quality[1] jointly with the IWA Bonn Charter for Safe Drinking Water[2] marked the culmination of a major shift in worldwide advice on how to manage drinking water quality. This redressed the balance of effort away from reliance solely on end product testing towards a more proactive risk-based approach known as a Water Safety Plan (WSP). A WSP is endorsed by WHO[3] as the most effective means to consistently ensure the safety of drinking water supplies through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer. This article briefly summarises an approach to developing a WSP for groundwater catchments. (More detailed technical information is given in Foster et al[4] and in Foster and Skinner[5]).

The importance of groundwater for drinking water supply

Groundwater is an integral part of the water cycle and inextricably linked to surface water and aquatic ecosystems. It is being exploited extensively in all countries, and in some areas represents the only water available for human uses, particularly those in peripheral urban areas or in remote rural settlements. In large parts of the world it is also vital for use in agriculture. However, groundwater exploitation is often carried out in an unplanned and uncontrolled way. The increase in the number of aquifers and wells degraded by pollution highlights a major concern that without proper management this vitally important resource will be in real danger.

Groundwater plays an important and sometimes fundamental role for water supply. No comprehensive statistics exist on the population dependent upon groundwater, but, for example, it is estimated that more than two billion people are dependent directly or indirectly upon groundwater for potable supplies. This includes 12 of 23 megacities (>10 million inhabitants) in the world[6].

Understanding groundwater characteristics

The characteristics of different groundwater catchments vary considerably, including the response to different polluting activities or events, the time taken for pollution to impact at the water abstraction point, and the ease with which pollution prevention can be realistically carried out. Additionally, the pathways by which pollutants move from the pollution source to the abstraction point can be complex and need to be fully understood before the risks can be fully assessed and effective mitigation options pursued.

Passage of water through the soil layer and underlying rock strata to the water table can attenuate some but not all types of pollution and thus treatment for groundwater tends to be simpler than for surface water. Deep groundwater typically has a much slower response to polluting activities on the surface, often many years. However, for some shallow or fissured groundwater sources the response can be much faster, sometimes as little as a few days. All of these factors and others need to be taken into account when developing a catchment WSP. The phrase ' know your catchment' is a vital one for any water supplier.

The need for groundwater protection

A WSP is underpinned by the so-called multi barrier approach, which is based on having in place a number of eparate barriers to hazards that may be present in raw water. This means that if one barrier fails for any reason then the other barriers can still prevent or minimise contamination of the final water supplied to consumers[7]. The multi barrier approach can cover all aspects of water quality management including catchment protection, water treatment, and management of the distribution network. However, protection of raw water sources should be seen as the first and sometimes the

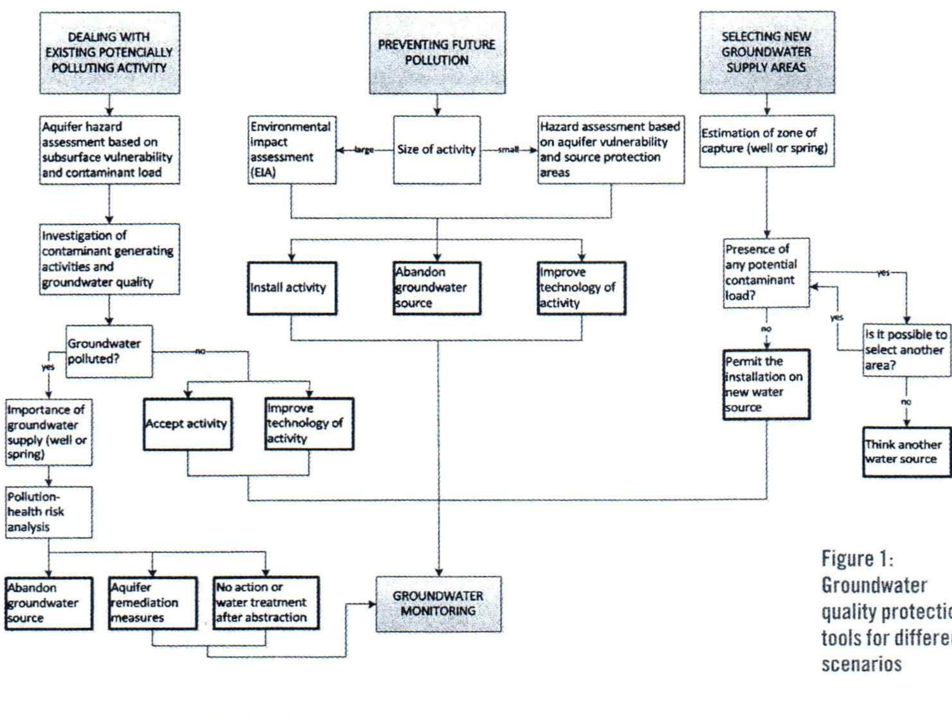

Figure 1: Groundwater quality protection tools for different scenarios

most important barrier to prevent microbial and / or chemical contamination of drinking water. This is particularly true for all types of groundwater water supply sources.

In the absence of direct contamination, groundwater from deep and confined aquifers is usually microbially safe and chemically stable and thus water treatment can be relatively simple. However, even deep aquifers can over time be contaminated by pollution arising from industry, urban development, oil storage and transport, and poor management of agricultural and other land use. Shallow or unconfined aquifers can be subject to more rapid contamination from discharges or seepages associated with agricultural practices (e.g., pathogens, nitrates and pesticides), on-site sanitation and sewerage (pathogens and nitrates) and industrial wastes. If such water supply sources also have relatively limited treatment then there is a much higher risk of contamination passing into the distribution network.

Once subsurface or groundwater pollution has occurred it is usually very expensive and sometimes impractical to implement remedial action at an economic cost. The exception may be those fast response aquifers where removal of the hazard or hazardous activity can result in reduction of groundwater contamination in a relatively short timescale. The primary aim of groundwater protection should therefore be focused on prevention of those activities which might result in an unacceptable subsurface contaminating pollution load, either across the whole aquifer or within the capture zone for public supply sources.

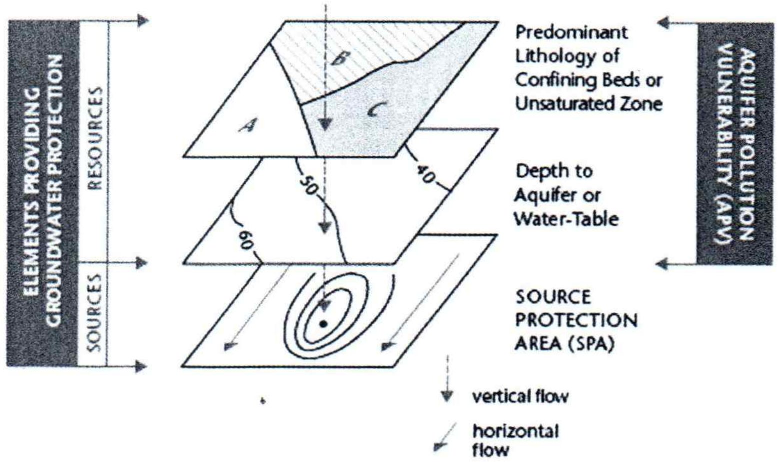

Figure 2: Components of groundwater pollution hazard assessment used for land surface zoning (Foster et al., 2002)

Working in partnership

Understanding catchment characteristics and / or activities potentially impacting on raw water quality and availability is thus of paramount importance for ensuring drinking water safety. However, successful integrated water resources management requires the commitment and cooperation of all institutions and organisations that are directly or indirectly responsible for drinking water source protection within the catchment.

Although water suppliers do not normally have powers or the responsibility to directly control activities within the catchment, it is essential that they work closely with relevant agencies and land users to identify ways that groundwater pollution risks can be managed most cost effectively. There are a wide range of catchment stakeholders with whom water suppliers may need to develop such partnerships. They can include national and regional Governments, regulatory authorities and catchment management agencies, as well as those many different land users carrying out activities within the catchment, which could pose a pollution risk. The institutional arrangements and legislative framework for managing catchments will vary considerably between countries and this will impact on the way in which such partnerships can be developed. It also means that partnerships often need to be developed at both national / regional and local levels.

Strategies for control of groundwater pollution

Implementing groundwater pollution prevention measures is a complex task. A step by step approach for dealing with different groundwater pollution scenarios is given in Figure 1. There are two interrelated but independent strategies, which focus on the protection of:

- Groundwater resources (aquifers) as a whole
- Groundwater sources – those parts of the aquifers where the resource is exploited for water supply or other purposes

While both approaches are complementary, the emphasis placed on one or the other will depend on local hydrogeological conditions, the extent to which groundwater resources have been developed and exploited, and a range of other broader socioeconomic factors.

There are four main interrelated catchment protection tools, which can be used to control groundwater pollution risks:

- Mapping overall aquifer pollution vulnerability
- Quantifying the potential subsurface contaminant load
- Implementing source protection

Table 1: Typical hazards and hazardous activities potentially impacting groundwater

Source	Hazard or hazardous activity
Natural	A wide range of potential hazards can arise naturally from the geology of the aquifer.
Surface water infiltration	Inadequate wellhead protection, uncased or inadequately cased bores, surface water influence on groundwater can all lead to ingress of microbial and other pollutants from surface water. This can be exacerbated in adverse weather conditions.
Human wastes	Sewage from septic tanks, cess pits and latrines, or land disposal of sewage effluent and sludges can create both microbial and chemical hazards.
Solid waste facilities	Inadequate disposal of solid waste is responsible for a significant number of cases of groundwater pollution and can comprise a complex and wide range of polluting substances.
Farming and land use	Animal wastes, nutrients, and/or pesticides derived from a range of agricultural activities can pose serious problems in many areas.
Mining and mineral extraction	Exploration for mineral and petroleum resources and the subsequent operation of a mining site and supporting infrastructure can give rise to a range of potential water pollution hazards.
Industry	The range of contamination hazards from industrial is potentially very large. As well as potential toxicity, many industrial substances can also give rise to cause unacceptable tastes and odours in drinking water.
Fuel transport and storage	Losses from fuel storage and transport present a common source of groundwater contamination.
Urban development	As well as microbial pollution from human wastes, urban development, particularly in less affluent countries can be a significant source of nitrate groundwater pollution.

areas (SPAs), which define the zone of capture of boreholes, wells and springs
- Placing controls or restrictions on hazards or hazardous activities within defined areas of the catchment

In developing a WSP, ideally the whole aquifer should be considered for protection. However, in some situations it may not be economic or practicable to do so. For example, it may not be cost effective to protect the whole aquifer if only a small amount of it is used as water source. In such situations it would suffice to define the groundwater capture zone of specific water sources, and assess their pollution vulnerability and subsurface contaminant load. Conversely, in those areas with a large number of significant groundwater abstractions, whole aquifer strategies should be adopted.

The responsibility for implementing each strategy may vary. Aquifer pollution vulnerability assessment is a management tool used as part of land use planning to protect strategic aquifers. Depending on the size of the aquifer, these are therefore usually the responsibility of regional or national authorities. These are complemented by implementation of source protection areas around important wells or springs used for public supply, which are the responsibility of local catchment managers and water suppliers.

Whole aquifer strategies, including pollution vulnerability mapping, are more universally applicable, since they endeavour to achieve a degree of protection for the entire groundwater resource and for all groundwater users. SPAs are more suitable for part of the aquifer body. In both cases, they would commence with aquifer pollution vulnerability mapping, followed by SPA definition for specific water wells or springs. These would be followed by the identification, localisation and classification of potential contaminant loads (PCL). The interaction between these two elements with PCL permits the aquifer pollution hazard or SPA hazard definition, respectively (Figure 2).

Mapping overall groundwater pollution vulnerability

The concept of aquifer vulnerability is related to the intrinsic characteristics of the strata, which separate the aquifer saturated zone from the land surface. These characteristics determine the risk of the aquifer being adversely affected by a surface-applied contaminant load. Vulnerability is determined by: a hydraulic assessment of likelihood that the pollutants will reach the saturated zone; and an estimate of the extent to which pollutants will be attenuated by physiochemical retention or reaction during passage through the strata overlying the saturated zone.

Groundwater source protection areas

The delineation of groundwater SPAs is an essential element in the protection of drinking water sources from contamination. SPAs have to take into account two different types of contaminants: those that decay with time, where subsurface residence time is the best measure of protection; and non-degradable contaminants, where flowpath-dependent dilution must be provided.

The proximity of a land use activity to a groundwater source is a key factor influencing the contamination hazard it poses. The pollution threat will depend on whether the activity is located within the capture zone of the water supply source, and the horizontal flow time in the aquifer from the location of the activity to the abstraction point (Figure 3). SPAs are therefore normally divided into four zones:
- Zone A – The operational area immediately adjacent to the well head or borehole
- Zone B – The inner catchment area representing approximately 50 day travel time to the abstraction, which is normally considered the minimum necessary for degradation of microbiological pollutants
- Zone C – the intermediate area representing approximately 300-500 day travel time to the abstraction
- Zone D – the whole source capture zone

Assessing subsurface pollution load and restriction of potentially polluting activities

A key step in implementing a groundwater protection strategy is to undertake a detailed survey of the aquifer catchment or source protection area to identify those hazards or hazardous activities that have the potential to cause groundwater pollution. In doing so it is important to take into account whether generation of a subsurface contamination load is a direct result of the hazard (e.g. septic tanks) or whether the load might be generated accidentally (e.g. due to spillage)[8]. It is also important to understand whether any hazardous activities have taken place in the past, since polluting processes or activities which ceased some years before can be still generating a subsurface contaminant load by leaching from contaminated soil.

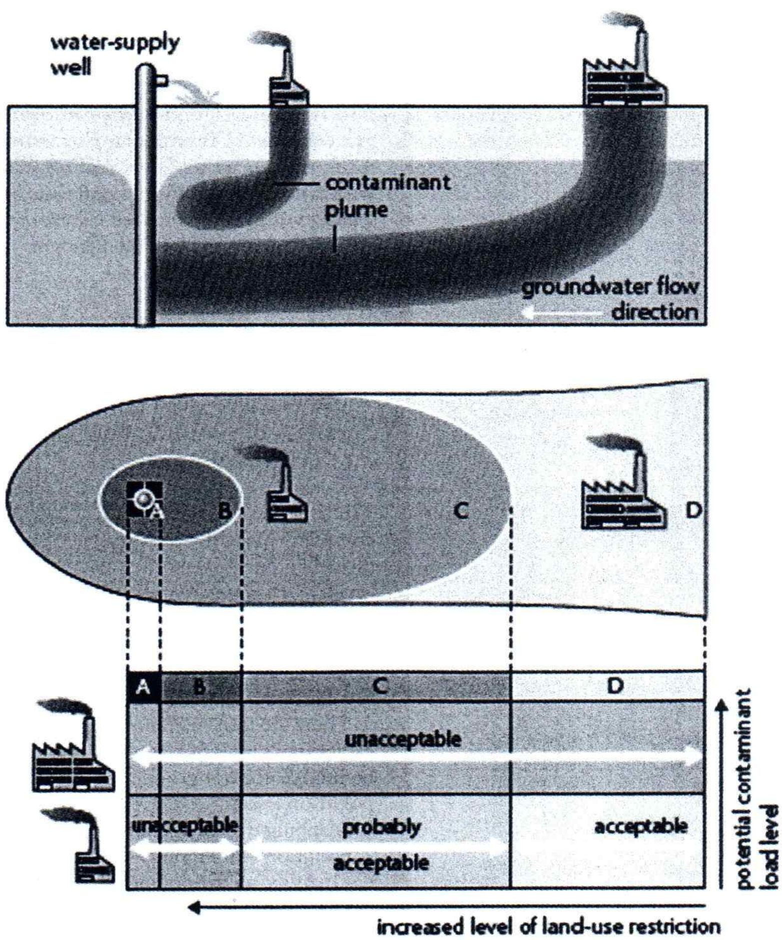

Figure 3: Diagram showing different levels of source protection areas, with land use restrictions (Foster et al. 2002)

Drinking Water Quality Management from Catchment to Consumer

A Practical Guide for Utilities Based on Water Safety Plans

Editor: Bob Breach

The Bonn Network is a global group of water suppliers who have adopted the Bonn Charter for Safe Drinking Water. The network was originally established to develop and share best practice in drinking water quality management. 'Drinking Water Quality Management from Catchment to Consumer' is a best practice book that brings together the experience of network members to provide a practical guide to help utilities worldwide to develop improved water quality management. It is based on the principles of the Bonn Charter and Water Safety Plans and is intended to complement and support other relevant publications, particularly the WHO Water Safety Plan Manual.

This emphasis is on practical information 'by operators for operators', learning from the experience of a range of water suppliers across the world.

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The classification of potentially polluting activities by their spatial distribution provides a direct and visual impression of the type of groundwater contamination threat they pose and the approach to control measures that are likely to be required. This allows measures to be implemented to control the hazard or hazardous activity. This might be secured though adoption of voluntary codes of best practice but typically may require statutory control and enforcement. Typical hazards and hazardous events that can have an impact on groundwater quality are summarised in Table 1. The most serious risk to water supplies normally arises from pathogenic organisms derived from human and animal wastes and this needs particular emphasis. More information on chemical hazards is available in Thompson et al[9]. ●

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