

Sustainable Groundwater Management Concepts & Tools

Briefing Note Series Note 8

Groundwater Quality Protection defining strategy and setting priorities 2004

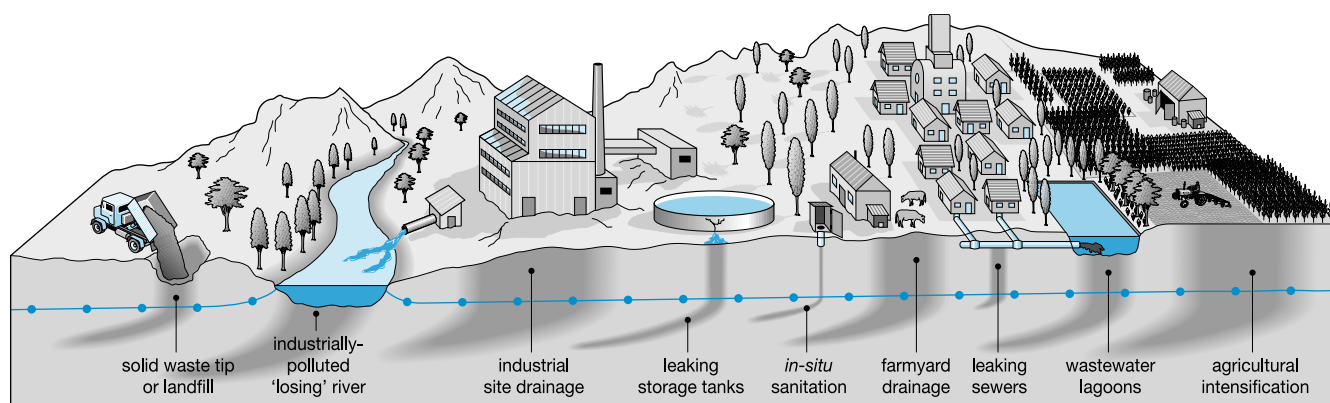
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Why do groundwater supplies merit protection?

- Groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both the urban and rural environment. It thus plays a fundamental (but often little appreciated) role in human well-being, as well as that of some aquatic and terrestrial ecosystems.
- For municipal water supply, high and stable raw-water quality is a prerequisite, and one best met by protected groundwater sources. Recourse to treatment processes (beyond precautionary disinfection) in the achievement of this end should be a last resort, because of their technical complexity and financial cost, and the operational burden they impose.
- However, all too widely in the past groundwater resources have, in effect, been 'abandoned to chance'. And all too often those exploiting such resources for the provision of potable water supply have taken no action to protect water quality.
- Worldwide, aquifers (geological formations containing usable groundwater resources) are experiencing an increasing threat of pollution from urbanization, industrial development, agricultural activities and mining enterprises. Thus proactive campaigns and practical actions to protect the natural (generally

Figure 1: Land-use activities commonly generating a groundwater pollution threat



excellent) quality of groundwater are widely required, and can be justified on both broad environmental-sustainability and narrower economic-benefit criteria.

- In some cases it may take many years or decades before the impact of a pollution episode by a persistent contaminant becomes fully apparent in groundwater supplies abstracted from deeper wells. This can lead to complacency over the pollution threat. But the real implication is that once groundwater quality has become obviously polluted, large volumes of aquifer are usually involved. Thus clean-up measures nearly always have a high economic cost and are often technically problematic.

How do aquifers become polluted?

- The pollution of aquifers occurs if the subsurface contaminant load generated by man-made discharges and leachates (from urban, industrial, agricultural and mining activities) is inadequately controlled, and (in certain components) exceeds the natural attenuation capacity of the underlying soils and strata (Figure-1).
- Natural subsoil profiles actively attenuate many water pollutants and have long been considered potentially effective for the safe disposal of human excreta and domestic wastewater. The auto-elimination of contaminants during subsurface transport in the vadose (or unsaturated) zone is the result of biochemical degradation and chemical reaction, but contaminant retardation (due to sorption on the surfaces of clay minerals and/or organic matter) is also of importance, since it greatly increases the time available for processes resulting in contaminant elimination.
- However, not all subsoil profiles and underlying strata are equally effective in contaminant attenuation. Concern about groundwater pollution relates primarily to the so-called phreatic (unconfined) aquifers,

Table 1: Common groundwater contaminants and associated pollution sources

POLLUTION SOURCE	TYPE OF CONTAMINANT
Agricultural Activity	nitrates; ammonium; pesticides; fecal organisms
<i>In-situ</i> Sanitation	nitrates; fecal organisms; trace synthetic hydrocarbons
Gasoline Filling Stations & Garages	benzene; other aromatic hydrocarbons; phenols; some halogenated hydrocarbons
Solid Waste Disposal	ammonium; salinity; some halogenated hydrocarbons; heavy metals
Metal Industries	trichloroethylene; tetrachloroethylene; other halogenated hydrocarbons; heavy metals; phenols; cyanide
Painting and Enamel Works	alkylbenzene; tetrachloroethylene; other halogenated hydrocarbons; metals; some aromatic hydrocarbons
Timber Industry	pentachlorophenol; some aromatic hydrocarbons
Dry Cleaning	trichloroethylene; tetrachloroethylene
Pesticide Manufacture	various halogenated hydrocarbons; phenols; arsenic
Sewage Sludge Disposal	nitrates; various halogenated hydrocarbons; lead; zinc
Leather Tanneries	chromium; various halogenated hydrocarbons; phenols
Oil and Gas Exploration/Extraction	salinity (sodium chloride); aromatic hydrocarbons
Metalliferous and Coal Mining	acidity; various heavy metals; iron; sulphates

especially where their vadose zone is thin and their water-table shallow, but may also arise even where aquifers are semi-confined, if the confining aquitards are relatively thin and permeable.

- An idea of the more common types of activity capable of causing significant groundwater pollution hazard can be gained from Table 1. It is important to recognize that these depart widely from the activities and compounds most commonly polluting surface water bodies. This is the result of the very different factors controlling the mobility and persistence of contaminants in the subsurface, due to the presence of the aquifer matrix and the much slower rates of biodegradation (consequent upon the low levels of organic carbon, the much reduced populations of bacteria and the constraints on diffusion of oxygen).
- It is also important to stress that certain industrial and agricultural practices (and specific incremental processes within such practices) often present disproportionately large threats to groundwater quality. Thus sharply-focused and well-tuned pollution control measures can produce major benefits for relatively modest cost.

How can groundwater pollution hazard be assessed?

- Groundwater pollution hazard assessments are needed for clearer appreciation of the actions needed to protect groundwater quality, and should become an essential component of *environmental best-practice*. The logical definition of groundwater pollution hazard (Table 2) is the interaction between the aquifer pollution vulnerability and the contaminant load that is, will be or might be, applied on the subsurface environment as a result of human activity at the land surface. Adopting such a scheme, we can have high vulnerability but no pollution hazard, because of the absence of a significant subsurface contaminant load. Moreover, contaminant load can be controlled or modified, but aquifer vulnerability is essentially fixed by the natural hydrogeological setting.
- Aquifer pollution vulnerability is, in effect, the inverse of 'the pollutant assimilation capacity of a receiving water body' in the jargon of river quality management. It can be assessed from the hydrogeological characteristics of the overlying vadose zone or confining beds. Indexation of these characteristics (Figure 2) permits the generation of an overall vulnerability index which can be readily mapped. On such maps the results of surveys of potential subsurface contaminant load can be superimposed to

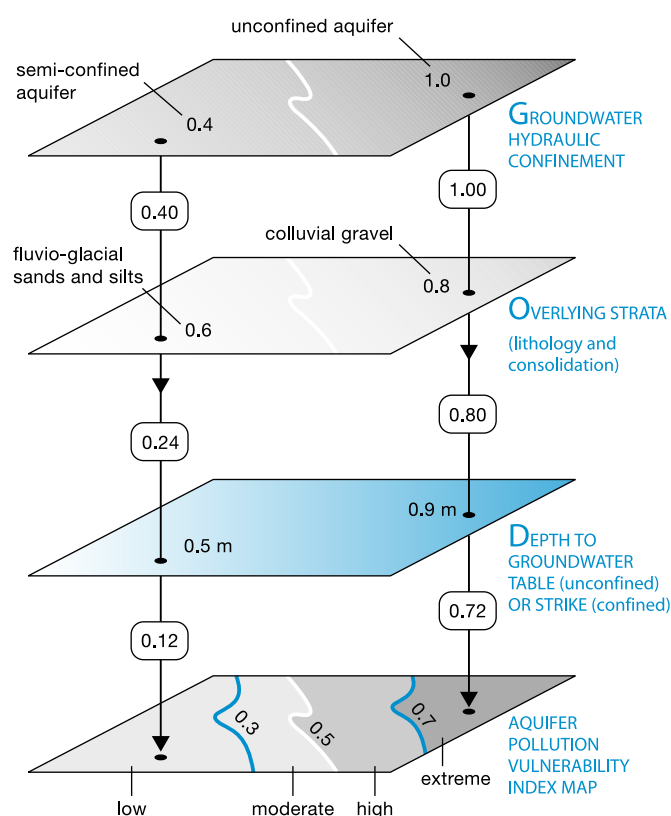
Table 2: Definition of common terms relating to groundwater pollution

TERM	DEFINITION
Aquifer Pollution Vulnerability	sensitivity to contamination, determined by the natural intrinsic characteristics of the geological strata forming the overlying confining beds or vadose zone of the aquifer concerned
Groundwater Pollution Hazard	probability that groundwater in an aquifer will become polluted to concentrations above WHO drinking-water guidelines when a given subsurface contaminant load is generated at the land surface
Groundwater Pollution Risk	threat posed by this hazard to human health due to pollution of a specific groundwater supply source or to an ecosystem due to pollution of a specific natural aquifer discharge

facilitate the assessment of groundwater pollution hazard.

- Whether this hazard will result in a threat to a public-supply source depends primarily on its location with respect to the groundwater sources (and their flow-zones and capture areas), and secondarily on the mobility of the contaminant(s) concerned within the local groundwater flow regime. A number of areas and zones should normally be defined (Figure 3), using hydrogeological data on the local groundwater flow regime. Various analytical and numerical models are available to facilitate their delineation.
- The scales at which the survey, mapping and analyses of the various components needed to assess groundwater pollution hazard are undertaken will vary with the main focus of the work—water-supply protection or aquifer resource protection.
- Groundwater pollution hazard assessments should prompt municipal authorities or environmental regulators to take both preventive actions (to avoid future pollution) and corrective actions (to control the pollution threat posed by existing and past activities).

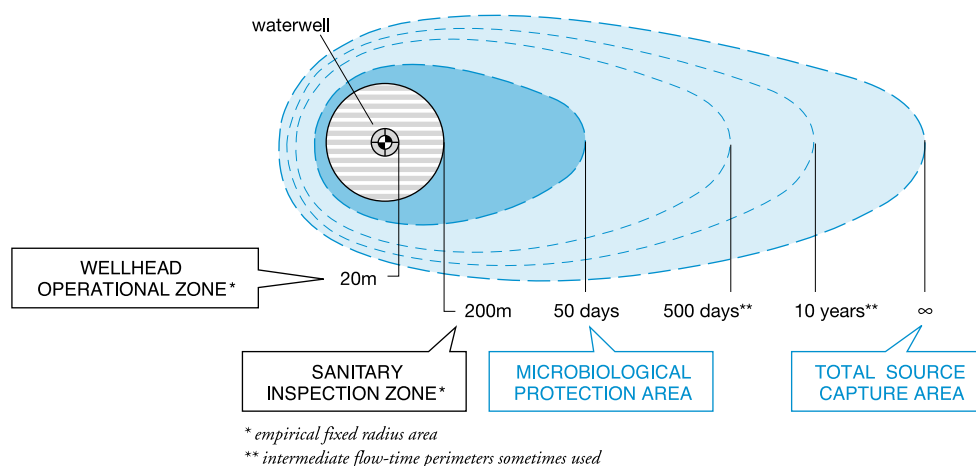
Figure 2: Generation of an aquifer pollution vulnerability map using the GOD methodology based on hydrogeological characteristics of the overlying vadose zone or confining beds



What does groundwater pollution protection involve?

- To protect aquifers against pollution it is essential to constrain land-use, effluent discharge and waste disposal practices. However, in practice it is necessary to define groundwater protection strategies that accept trade-offs between competing interests. Thus instead of applying universal controls over land use and effluent discharge, it is more cost-effective (and less prejudicial to economic development) to utilize the natural contaminant attenuation capacity of the strata overlying the aquifer, when defining the level of control required to protect groundwater quality.
- Simple and robust zones (based on aquifer pollution vulnerability and source protection perimeters) need to be established, with matrices that indicate what activities are possible where at an acceptable risk to groundwater. Groundwater protection zoning also has a key role in setting priorities for groundwater quality monitoring, environmental audit of industrial premises, pollution control within the agricultural advisory system, determining priorities for the clean-up of historically-contaminated land, and in public education generally. All of these activities are essential components of a sustainable strategy for groundwater quality protection.
- A sensible balance needs to be struck between the protection of groundwater resources (aquifers as a whole) and specific sources (boreholes, wells and springs). While both approaches to groundwater

Figure 3: Idealized scheme of surface sanitary zones and groundwater flow perimeters for the protection of a waterwell in an unconfined aquifer



pollution control are complementary, the emphasis placed on one or other (in a given area) will depend on the resource development situation and on the prevailing hydrogeological conditions.

- If potable use comprises only a minor part of the available groundwater resource, then it may not be cost-effective to protect all parts of an aquifer equally. Source-oriented strategies will then be appropriate, working at scales in the range 1:25,000–100,000 and:
 - delineating groundwater source protection (capture) areas and flow-time perimeters
 - assessing aquifer pollution vulnerability and subsurface contaminant load in the areas so defined.
 This approach is best suited to relatively uniform, unconsolidated, aquifers exploited only by a small number of high-yielding municipal water-supply boreholes with stable pumping regimes. It cannot be so readily applied where there are a very large and rapidly growing number of individual abstractions, which render consideration of individual sources and establishment of fixed areas impracticable.
- Aquifer-oriented strategies are more universally applicable, since they endeavor to achieve a degree of protection for the entire groundwater resource and for all groundwater users. They involve aquifer pollution vulnerability mapping over more extensive areas (including one or more important aquifers) working at a scale of 1:100,000, or greater if the interest is limited to general information and planning purposes. Such mapping would normally be followed by an inventory of subsurface contaminant load at more detailed scale, at least in the more vulnerable areas.

Who should promote groundwater pollution protection?

- The ultimate responsibility for groundwater pollution protection must lie with the relevant agency of national or local government. But given their responsibility to conform with codes of sound engineering practice, an obligation also exists on water-service companies to be proactive in undertaking (or promoting) pollution hazard assessments for all their groundwater sources.
- A technical guide has been produced by GW-MATE for professional groundwater specialists, environmental engineers and scientists, who are called upon to undertake groundwater pollution hazard assessments for water-service utilities, and to develop pollution protection strategies for environmental

agencies and municipal authorities (including those concerned with land-use planning, effluent discharge and waste disposal control).

- The assessment procedure proposed is highly complementary to other groundwater investigation, evaluation and management actions. It is designed to be undertaken relatively rapidly, and to utilize data that has already been collected for other purposes or that can readily be collected at field level. Following the methodology presented, it should be possible for an appropriate team to complete a groundwater resource and supply pollution hazard assessment within 2–12 months, depending on the size and complexity of the area under consideration.
- The procedures for groundwater pollution hazard assessment presented constitute an effective vehicle for initiating the involvement of relevant stakeholders (including water-user interests and potential groundwater polluters). They provide a sound basis for forceful representations to be made to the local environmental and water resource regulator for implementation of the necessary pollution control and aquifer protection measures. Even where no adequate pollution control legislation or agency exists, it will normally be possible to put pressure on the local government or municipal authority to take protective action under decree in the greater interest of the local population.

Further Reading

- Alley, W.M., ed. 1993. *Regional Groundwater Quality*. Van Nostrand Reinhold. New York, USA.
- Clarke, R., Lawrence, A. and Foster, S. 1996. *Groundwater—a Threatened Resource*. UNEP Environment Library 15.
- Foster, S., Chilton, J., Moench, M., Cardy, F. and Schiffler, M. 2000. *Groundwater in Rural Development: Facing the Challenges of Supply and Resource Sustainability*. World Bank Technical Paper 463. Washington, D.C., USA.
- Foster, S., Hirata, R., Gomes, D., D'Elia, M. and Paris, M. 2002. *Groundwater Quality Protection: a Guide for Water Utilities, Municipal Authorities and Environment Agencies*. World Bank Publication. Washington, D.C., USA.
- Foster, S., Lawrence, A. and Morris, B. 1997. *Groundwater in Urban Development: Assessing Management Needs and Formulating Policy Strategies*. World Bank Technical Paper 390. Washington, D.C., USA.
- Kovar, K. and Krasny, J. 1995. *Groundwater Quality: Remediation and Protection*. IAHS Publication 225, IAHS Press. Wallingford, UK.

Publication Arrangements

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