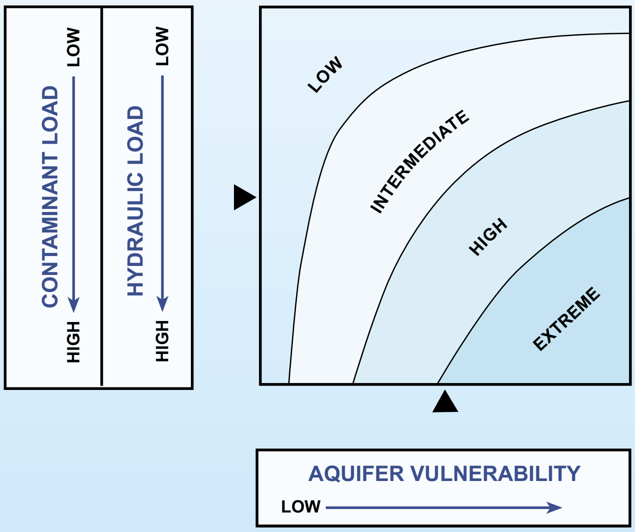
Characterising and Prioritising Groundwater Pollution Threats –

POLLUTION RISK ASSESSMENTS



Rationale

Many cities will be able to devote at least some modest resources to improving the confidence that can be placed on the diagnostic provided by the DSS. Confidence levels would be significantly increased by city-specific data which would assess on the one hand the actual hydrogeological conditions (rather than just the generic setting) and on the other the potential contaminant load from the industries and other activities actually present across the city's aquifer system information.

The human and financial resource realities present in most developing cities suggest that a **risk assessment** approach can be a cost-effective and practical way to inform those tasked with formulating policies in an aquifer protection plan. In this project we employed, as practical examples of good practice, the approach from Foster & Hirata (1988), which uses the interaction between hazard from contaminant load and aquifer vulnerability to determine the risk of pollutants reaching the aquifer (Figure 1).

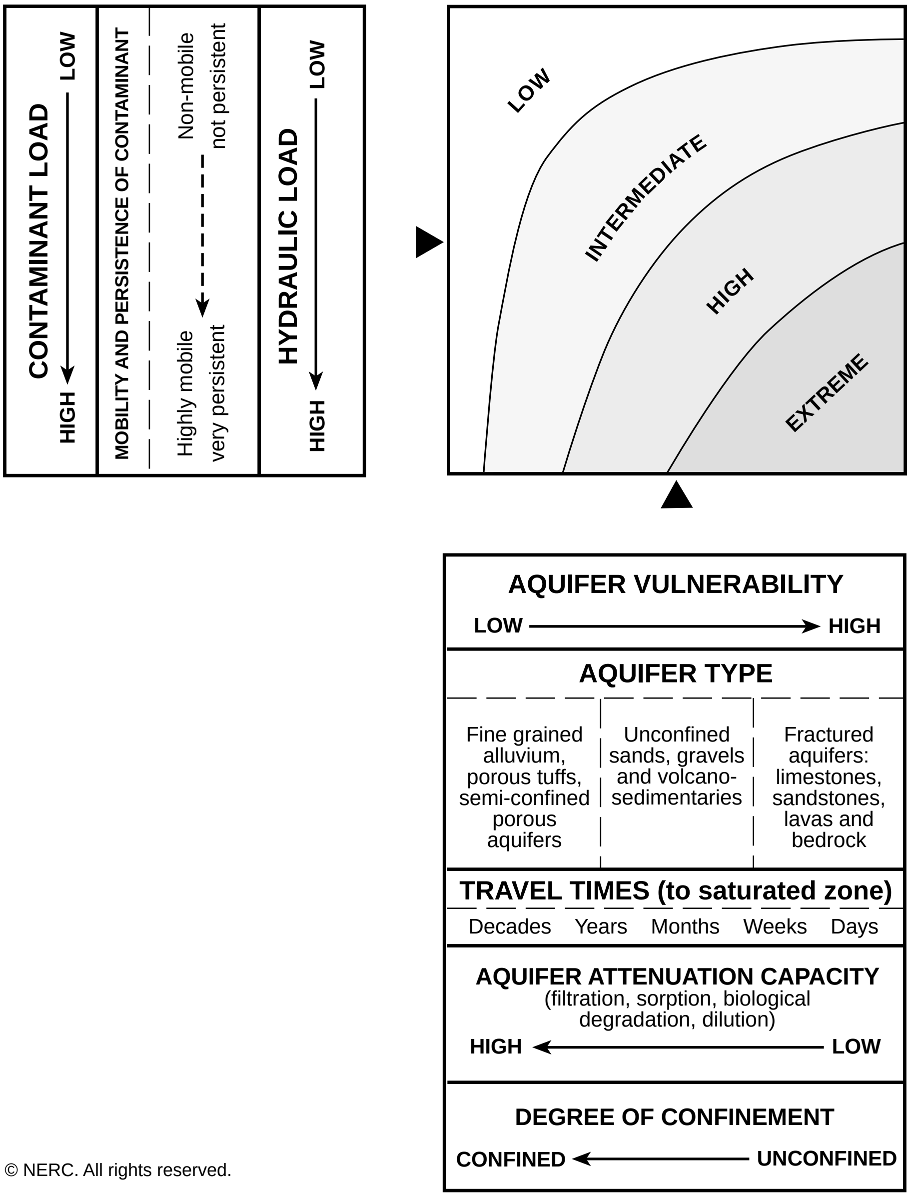


Figure 1 Conceptual scheme of groundwater pollution risk (modified from Foster and Hirata, 1988)

The risk can then be conceived as the interaction between:

- the aquifer pollution vulnerability resulting from the natural characteristics of both the aquifer and the strata separating it from the land surface and
- the contaminant load that is, will be or might be applied to the sub-surface as a result of human activity.

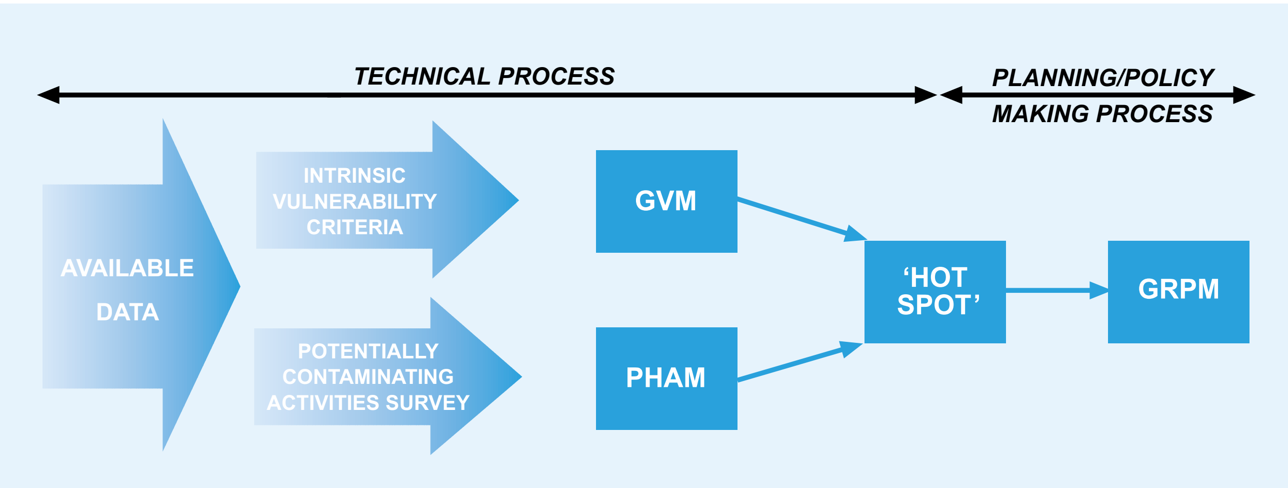
Adopting such a scheme, it is quite possible to have high contaminant load but no significant pollution risk because the aquifer's intrinsic vulnerability is low, and vice versa. As the intrinsic vulnerability relates only to the properties of the aquifer with its overlying layers, and not to the properties of the potential contaminants (because these are numerous and highly variable), the approach is most helpful when dealing with persistent mobile contaminants not readily susceptible to attenuation. As such, the scheme is necessarily a pragmatic approximation because "general vulnerability to a universal contaminant in a typical pollution scenario is a meaningless concept" (Andersen 1987).

It is important to identify at the outset settings where land zoning will be ineffective, such as vulnerable karst limestone, and risk assessments will have little value.

Role of component maps

For the purposes of developing groundwater protection and management policies, the main aids to visualisation of the assessments of aquifer vulnerability and contaminant load are maps. They feed into an Action Plan typically through a two-stage process (Figure 2):

(i) A technical stage, compiling and interpreting available information to produce practical but technically defensible assessments. This stage would usually incorporate supplemental fieldwork to supplement deficient data areas. The product would comprise simple, intelligible maps backed by a well-organised database. A concise description of methods and data sources should also be available for stakeholder reference and/or verification, not least because assumptions that will have to be made in the absence of data need to be seen to be not only rational but also requiring eventual verification.



Key map tools:

GVM	Groundwater vulnerability map
PHAM	Potentially hazardous activities map
'Hot-spot'	PHAM superimposed on GVM
GRPM	Groundwater resource protection/planning map

Figure 2 Using risk assessment maps to inform a Groundwater Management Action Plan

(ii) A policy evolution stage, in which draft(s) of policy options developed from consideration of the results of the technical stage are discussed and added to by informed stakeholders. Tools for this socio-economic stage would be the maps from stage 1 and a series of concise summaries (usually tables) that would evolve during the parallel processes of identifying/prioritising issues and analysing/informing stakeholder member groups.

As shown in Figure 2, a number of maps inform the process:

- A groundwater vulnerability map (GVM) describes the intrinsic properties of the subsurface that will either protect, or make susceptible, the groundwater system to contamination from urban activities;
- A potentially hazardous activities map (PHAM) is a first-pass approximation to an inventory and is used in conjunction with waste disposal patterns to infer nature and likely type of contaminant loading which are potentially hazardous to groundwater;
- A 'hot-spot' map comprises the superposition of the first two maps as layers, to show where inappropriate activities are currently taking place, providing a present contamination hazard, or where unplanned expansion could prejudice the resource in future;
- A groundwater resource protection/planning map (GRPM) considers the features of the aquifer vulnerability and the potentially hazardous activities component maps in the context of the city's expansion, regulatory framework and enforcement and water resource realities;
- The GRPM is a map intended for policy-making purposes and needs to be both simple and amenable to use with planning policies that may be enacted through regulatory, financial or other policy instruments.

Groundwater vulnerability assessments/maps (GVMs)

Using intrinsic vulnerability principles (NRC, 1993, Vrba & Zaporozec, 1994) the vulnerability map is formed from a number of layers (Figure 3). A parameter rating system (termed overlay and index system by some authors) was devised to make the best use of available data (Table 1). A simple relative vulnerability index is applied to each component (High/Moderate/Low/Negligible scored 3, 2, 1, 0 respectively) then a vulnerability classification based on the sum of component theme scores.

Table 1 Groundwater vulnerability mapping criteria

Example components of aquifer vulnerability used in rating system	Relative vulnerability	Vulnerability score
Depth to water table/thickness of unsaturated zone		
Presence and thickness of a low-permeability surface layer/ upper aquitard		
Presence of excavations into the upper aquitard if present		
Geology of the aquifers		
Influent reaches of rivers/canals		
Total score		

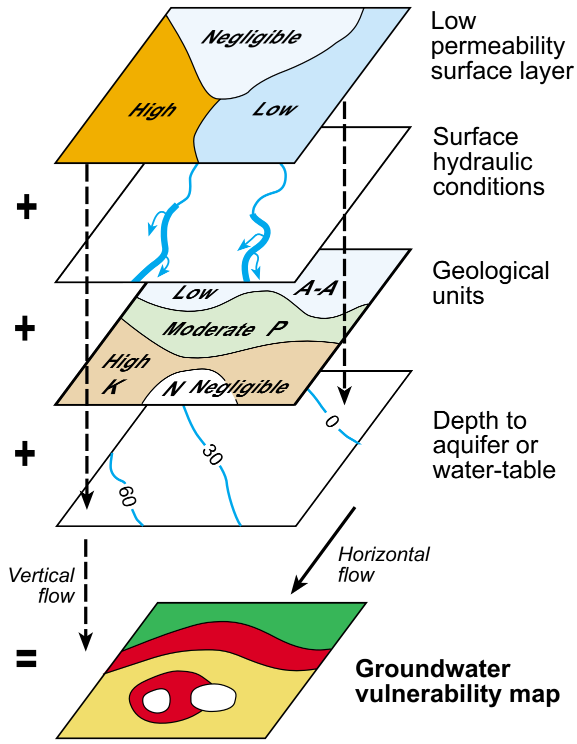


Figure 3　　Combining the layers to make the vulnerability map

Potentially hazardous activity surveys/maps (PHAMS)

The other component of the risk assessment is the estimation of likely contaminant load. At first-pass level, subsurface contaminant load can be conveniently subdivided into two classes:

(i) Diffuse/multiple point sources; these are loadings arising from the known presence of a widespread activity or urban disposal practice, usually wastewater from on-site sanitation or leaking sewers. Surveys of such sources rely for quantification on water balance/sanitation practice statistics obtained from water supply and waste disposal utilities and municipal public health departments, from which city-wide contaminant loadings can be estimated using mass-balance calculations (BGS and SAGUAPAC 1995, 1997, BGS and UAY 1994).

In practice, diffuse sources may be difficult to disentangle but it should still be possible to gain information on their role in the urban water balance. Links with the water supply/wastewater disposal utility makes assessment of both diffuse and point source loads easier because they should have information of the extent and type of wastewater arrangement in force.

(ii) Point sources; these cannot be identified without detailed field investigations and so surveys concentrate on identifying industries and other activities which generate effluent loads or handle products which would have significant potential to contaminate shallow aquifers if they entered the subsurface. Such surveys do not of course imply that every site identified is contaminating the underlying aquifer, merely that the potential exists for significant contamination of a subsurface receptor if the products of the activity are not correctly disposed. Commercial/industrial directories may be a useful source of information on potential point sources

While a wide range of human activities generate some contaminant load on aquifers, often only a few activities are responsible for the major groundwater pollution hazard. There have been many attempts to produce comprehensive lists of activities that are potential sources of groundwater pollutants, and to classify these by type. One such classification system (from Foster and Hirata, 1988) is given in Table 2.

Table 2 Classification of potentially polluting industrial types

Activity codes for industry types			
0*	Administration/retail	13	Pulp and paper
1	Iron and steel	14	Soap and detergents
2	Metal processing	15	Textile mills
3	Mechanical engineering	16	Leather tanning/processing
4	Non-ferrous metals	17	Food and beverages
5	Non-metallic minerals	18	Pesticides/herbicides
6	Petrol and gas refineries	19	Fertilisers
7	Plastic products	20	Sugar and alcohol
8	Rubber products	21	Electric power
9	Organic chemicals	22	Electric and Electronic
10	Inorganic chemicals	23	Fuel filling stations
11	Pharmaceuticals	24	Other**
12	Woodwork		

* Includes all service/tertiary activities not likely to generate a significant pollution load

** *Other* includes any activity that may be potentially polluting not covered by the other 23 codes.

'Hot-spot' Map

This map is a precursor of the groundwater resource-planning map and is produced by overlaying potentially contaminating activities on the groundwater vulnerability map. The result should be designed to provide technical information collated in a form transparent and comprehensible to stakeholders, in that groundwater protection plan discussions can be informed by a single medium such as anA4 size colour map.

Whilst 'hot-spot' maps are a very useful tool for presenting information to the non-specialist, care needs to be taken to avoid dividing the information presented into too many different classes giving a mosaic effect and confusing interpretation.

Groundwater resource protection/planning maps (GRPMs).

This develops policy zones for water quality protection using a combination of existing hot spots and aquifer vulnerability (Table 3). These zones can be used for example in a simple way to define areas for effluent-producing industry, commerce and residential use or for delineating areas around public supply installations.

Scheduling of production of the Planning Maps can be usefully linked to stakeholder mobilisation, giving an incentive to take ownership of the policies because they have been seen to be developed in discussion by all those interested.

Table 3 Policy zones for resource protection and urban planning

Policy zone classification	Example
Highly sensitive	Protection zone around public supply boreholes River protection corridors along losing river reaches or major excavations into superficial low permeability layers where the shallow aquifer would be rapidly affected by contaminated surface water
Strict	Underlying aquifer system currently susceptible to contaminated activities on land surface, or could become so in the future
Intermediate	Underlying aquifer system moderately susceptible to contaminating activities on land surface
Permissive	Underlying aquifer system not very susceptible to contaminating activities on land surface under present conditions