GROUNDWATER PROTECTION STRATEGY : IS EUROPEAN EXPERIENCE RELEVANT TO LATIN AMERICA?

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Abstract - The current approach to groundwater protection in Europe is outlined by specific reference to the scientific concepts and practical development of the British land-surface zoning strategy. The limitations of the concepts and difficulties of strategy implementation are also discussed, and its relevance to Latin America assessed.

GENERAL BACKGROUND

STATUS OF GROUNDWATER PROTECTION IN EUROPE

- During the 1990s the European Commission (EC) has strengthened its message on the need for more systematic attention to the protection of groundwater, given the major role this resource plays in the public water-supply of many member states of the European Union (EU) and the rather widespread evidence of a significant threat of contamination from agricultural, industrial and other activities. This followed earlier directives to prevent List 1 and limit List 2 substances reaching groundwater (80/68EC), to reduce the maximum permissible concentrations of some contaminants in drinking water (80/778/EC) and to control the pollution of groundwater by nitrate from agricultural sources (91/676/EC).

- Diffuse pollution from agriculture is probably the most serious threat to groundwater in the EU, on account of the proportion of the resource and the number of sources potentially affected. Most European countries also recognise a major problem associated with (much past and some present) industrial and urban development. Most systematic surveys of point-source groundwater pollution reveal that the severest concerns are associated with synthetic organic contamination (Table 1).

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- The issuing of the more recent EC groundwater action plan and draft (comprehensive water) directive prompted the British government to review and consolidate groundwater protection strategies nationally. The rationale and framework of the British strategy is described below. Although the EC allows a significant degree of subsidiarity in areas of environmental policy, most EU member states have taken (or are taking) a broadly comparable approach on this issue.

CONTAMINANT GROUP*	**FREQUENCY OF OCCURRENCE BY SEVERITY CLASS****				
	A	B	C	D	E
Metals (As, Cu, Cr)	11	67	124	**155**	61
Other Inorganic (NH_4, SO_4, CN)	15	41	63	**85**	31
Chlorinated Solvents (TCE, PCE, TCA)	86	**89**	76	37	9
Hydrocarbon Fuels	22	69	**137**	111	29
Phenolic Compounds	7	23	**43**	42	8
Other Organics (BTEX, PAHs, PCBs)	19	79	**112**	93	25
Landfill Leachate (NH_4, Cl, DOC)	5	49	102	**163**	78

* examples of commonest contaminant species within group given

** the severity classes grade from high significance to groundwater resources (A) to moderate significance (C) and low significance (E)

Table 1: Frequency and severity of occurrence of contaminant types for all recently identified point sources of groundwater pollution in England & Wales (EA, 1997)

RATIONALE OF BRITISH PROTECTION STRATEGY

- Most groundwater resources originate either directly, or indirectly, as excess rainfall infiltrating the land surface. Activities at the land surface thus influence, and can threaten, the quality of groundwater recharge, and to be proactive in protecting groundwater we need to incorporate hydrogeological considerations into land-use planning. In theory it is possible to manage land entirely in the interest of groundwater gathering, but in practice it is generally necessary to define protection strategies which, while they constrain land-use, accept trade-offs between competing interests.

- Simplification of hydrogeological interpretations must be accepted if we are to communicate effectively and to achieve this. Simple guide maps (with relatively few zones) and robust matrices (indicating what activities are acceptable in each zone with a given design level) are needed (Foster & Skinner 1995). It is necessary to resist the temptation to set up too many zones, since this is not practicable, reduces understanding and risks losing credibility.

- Instead of applying universal controls over land use and effluent discharge to the ground, it is more cost-effective (and less prejudicial to economic development) to utilize the natural contaminant attenuation capacity of the strata overlying the saturated aquifer, which varies with the geology. This is the basic idea underlying the concept of aquifer pollution vulnerability.

- Moreover, if potable use comprises only part of the total available groundwater resource, then it may not be cost-effective to protect all parts of the aquifer equally. A sensible balance also needs to be struck between the protection of groundwater resources (aquifers as a whole) and specific sources (boreholes, wells and springs). The logical development for the latter is to superimpose definition of source protection areas (SPAs) around existing (and designated future) sites of potable water-supply (Figure 1).

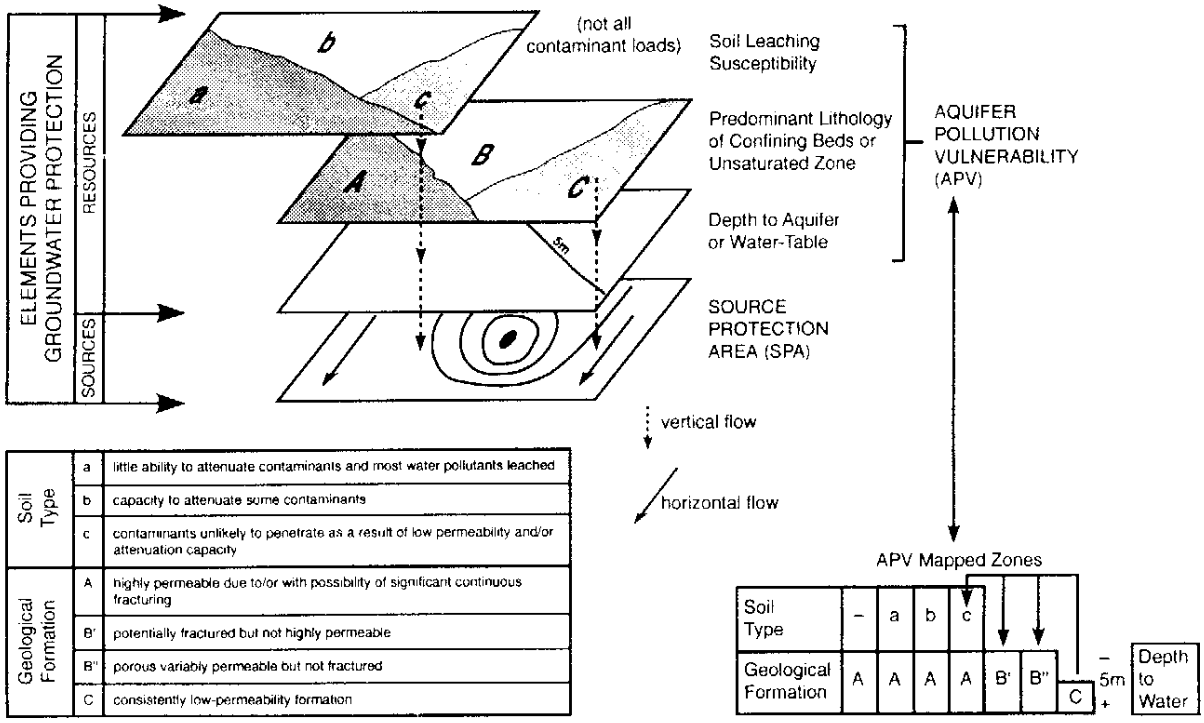

Figure 1 : **Elements of British groundwater protection policy and aquifer vulnerability scheme** (Foster & Skinner, 1995)

Figure 1 : Elements of British groundwater protection policy and aquifer vulnerability scheme (Foster & Skinner, 1995)

- These approaches are viewed as preceding (but being complementary to) site-specific groundwater pollution risk assessments, using the (pollution) source-pathway-receptor (groundwater source) model.

MAPPING OF AQUIFER POLLUTION VULNERABILITY

DEVELOPMENT OF VULNERABILITY CONCEPT

- The term 'vulnerability' began to be used in hydrogeology from the 1970s, with the implication of relative susceptibility of aquifers to anthropogenic pollution. Foster (1987) suggested that it was necessary and logical to define aquifer pollution vulnerability as 'the intrinsic characteristics of the strata separating the saturated aquifer from the immediately-overlying land surface which determine its sensitivity to being adversely affected by a surface applied contaminant load', in effect a function of:

* the inaccessibility of the saturated zone, in a hydraulic sense, to the penetration of pollutants,

* the attenuation capacity of the strata overlying the saturated zone, as a result of contaminant retention or reaction.

- Groundwater pollution risk could then be defined as the probability that the uppermost part of an aquifer will become contaminated to an unacceptable level by activities on the land surface, and will be the result of the interaction between the intrinsic vulnerability and the contaminant loading applied at the location concerned (Foster & Hirata, 1988; Adams & Foster 1992). These authors also considered that vulnerability mapping was worth pursuing for land-use planning and environmental impact assessment (provided its definition was clear and its limitations understood), that inventories of subsurface contaminant load were of high priority and that both could be implemented on a GIS-compatible basis.

- Recently two major professional working groups have reviewed and pronounced upon the applicability of the vulnerability concept (NRC, 1993; IAH, 1994). Both came out in favour of its usefulness, but neither succeeded in producing a precise definition of vulnerability.

- Some workers, most notably the US group who developed the DRASTIC vulnerability index (Aller et al, 1987), consider that a factor representing the natural mobility and persistence of pollutants in the saturated zone should be included, but this is considered illogical since it does not view vulnerability maps from the perspective of planning and controlling activities at the land surface. It is considered far preferable for vulnerability to be a statement about the intrinsic characteristics of the strata (vadose zone or confining beds) separating the saturated aquifer from the land surface, thus providing an indication of the impact of land-use decisions at that point on the immediately-underlying groundwater.

LIMITATIONS OF CONCEPT

- Subsurface water flow and contaminant transport are complex processes, in particular the degree of attenuation will vary significantly with type of contaminant and pollution process in any given situation. Thus a 'general (integrated) intrinsic vulnerability to a universal contaminant in a typical pollution scenario' has no validity in rigorous scientific terms (Foster & Hirata, 1988), and viewed academically vulnerability mapping would be better carried out for individual contaminant groups in specific situations.

- The more practical way forward for general planning purposes, however, is to use integrated vulnerability maps, but make every effort to spell out adequate 'health warnings' against their misuse (Foster & Hirata, 1988). Such warnings have been elegantly expressed in the recent US review (NRC, 1993) in the form of three laws of groundwater vulnerability: first - 'all groundwater is to some degree vulnerable', second - 'uncertainty is inherent in all vulnerability assessments', third - 'there is risk that the obvious may be obscured and the subtle indistinguishable'. The latter is especially true of the more complex systems of vulnerability assessment, such as DRASTIC.

THE BRITISH APPROACH

- The aquifer pollution vulnerability system currently adopted in Britain classifies (by lithology and thickness) the predominant strata above the saturated aquifer as the principal indicator of pollution vulnerability. Only a few major classes are recognized (Figure 1).

- In deciding the criteria for lithological classification there was concern that (as in DRASTIC) too much emphasis might inadvertently be placed on average vadose zone time-lag, and vulnerability would then become more a measure of when (as opposed to if and which) pollutants reach the aquifer (Foster & Skinner, 1995). Thus greatest emphasis was put upon the likelihood of well-developed fracturing being present (rather than the thickness and porosity of the strata involved), since this is considered the most critical factor increasing vulnerability and reducing the chance of contaminant elimination, especially given that hydraulic surcharging is present in many pollution scenarios.

- In terms of final vulnerability class, this scheme produces similar results to the earlier GOD vulnerability index (Foster, 1987), but on balance it was considered preferable not to use indexation, because of the danger of obscuring the basic hydrogeological data on which estimates are based.

- A particularly important aspect of both schemes is clear interpretation of the classes of relative vulnerability established (Table 2). In this way it is possible to overcome many (if not all) the objections to the use of integrated vulnerability in groundwater protection policies.

VULNERABILITY CLASS	DEFINITION
Extreme	under rapid influence of surface water and vulnerable to most water pollutants (including protozoa and colloid-attached species) with relatively rapid impact in many pollution scenarios
High	vulnerable to many pollutants, except those highly absorbed or readily transformed, in many pollution scenarios
Moderate	vulnerable to some pollutants but only when continuously discharged/ leached
Low	only vulnerable to conservative pollutants in long-term when continuously and widely discharged/leached
Negligible	confining beds present with no significant groundwater flow

Table 2: Significance of integrated relative classes of intrinsic aquifer pollution vulnerability (Foster, 1998)

- A novel element of the new British approach, is the way the soil zone is incorporated. Soils are classified into three categories by relative susceptibility to leaching and in areas of high hydrogeological vulnerability are taken as modifying the overall vulnerability ranking (Figure 1). Since in urban areas, in particular, the soil is often removed during construction or the subsurface pollutant load is applied below its base, the soil zone is assumed to be absent.

DELINEATION OF SOURCE PROTECTION AREAS

BASIS FOR DEFINITION

- Source protection (called wellhead protection in the US) is also an essential part of groundwater protection. It provides the special vigilance against pollution, in respect of water destined for sensitive human uses, primarily for reticulated public supplies. As a concept it is long established, being part of legal codes in some European countries for over 100 years. However, increasing hydrogeological knowledge and changes in the nature of threats to groundwater mean that the concept has had to evolve.

- Source protection areas (SPAs), also known as zones (SPZs), are defined in relation to the saturated-zone flow characteristics of the aquifer in the proximity of the source concerned. They defend against contaminants which decay with time, where subsurface residence time appears to be the best measure of protection, and against non-degradable contaminants, where flowpath-dependent dilution must be identified.

- Current British practice (Adams & Foster, 1992; NRA, 1992; Foster & Skinner, 1995) is based primarily upon two zones:

* Catchment Area: the capture zone of the source defined in area by water balance considerations and in geometry by groundwater flowpaths.

* Microbiological Protection Zone: defined by the mean 50-day saturated zone travel time, based upon pathogen decay criteria.

LIMITATIONS OF CONCEPT

- The source protection area concept is a simple and powerful one, which is readily understood by land-use planners and others who need to make the often-difficult public decisions generated by groundwater protection policies. However, challenges can be posed by those who demand either greater protection or less restriction.

- In Britain, source protection zones are currently defined on the basis of the licensed yield and the average recharge rate, which between them set the catchment area. There are a number of hydrogeological situations where this simple approach is open to question. For example the annual variation of catchment area may be very large in karstic and other low-storage aquifers, suggesting that the maximum (rather than average) catchment area might be more appropriate. Small sources (with yields of less than 0.5 Ml/d) also present special problems.

- The 50-day travel time zone to protect against microbiological contamination is generally not thought to be excessively conservative, since there is plenty of evidence suggesting substantially longer subsurface survival for some pathogenic organisms, although rarely involving actual transport to groundwater sources. Any criticism that zones are too big, therefore, focuses on the use of only saturated aquifer transport to calculate zone geometry, which in cases of very thick vadose zones of unconsolidated strata is not unreasonable.

- The most serious limitation of the SPA concept arises when aquifers are subject to heavy pumping. If this is all for public supply then zones can be amalgamated and simplified, but if a significant proportion is for less sensitive uses and/or for seasonally-variable demands (such as industrial cooling or agricultural irrigation), interference between pumping wells produces excessively complex and unstable SPAs (Figure 2). The presence of surface watercourses gaining from natural aquifer discharge produces similar complications (Foster & Skinner, 1995)

- Perhaps the greatest concern is the lack of precision of SPAs in areas of hydrogeological complexity and/or uncertainty. Land-use planners who are used to maps which follow physical surface features are uncomfortable with protection zones which lack the same permanence and which can vary, either if hydrogeological knowledge or circumstance change.

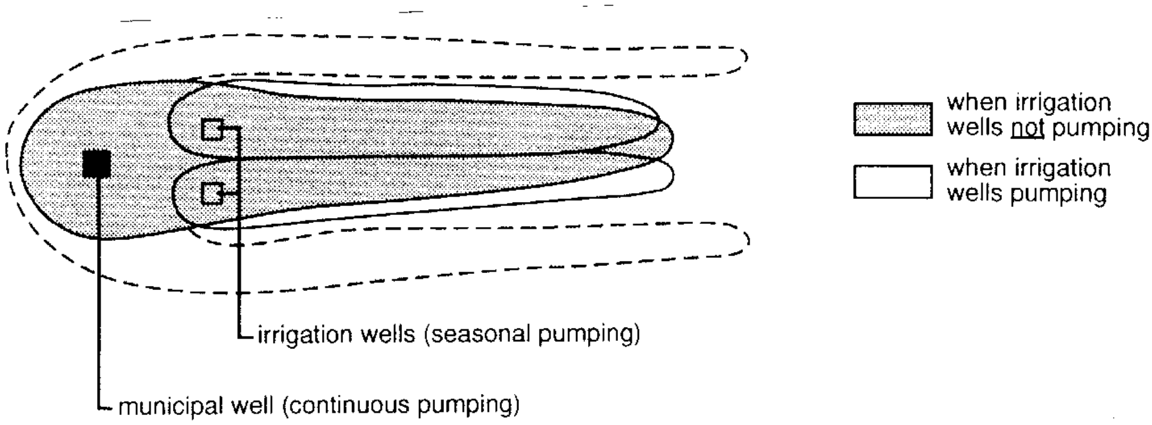

Figure 2 : Unstable groundwater source protection area caused by seasonal pumping of irrigation wells (Foster & Skinner, 1995)

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THE BRITISH APPROACH

- SPAs can be best defined where data availability is good and readily used to establish a regional groundwater flow model with robust boundary conditions. Flowpath-defined source protection zones can be confidently derived using steady-state two-dimensional model codes; FLOWPATH having proved to be a robust and practical tool in many hydrogeological environments. Where hydrogeological complexity is greater, and data availability justify, the MODFLOW-MODPATH-MODELCAD programme suite shows promise.

- Where there is more uncertainty over the most critical variables affecting zone geometry (recharge rate, hydraulic conductivity and effective porosity), best estimate and credible limit values for each factor are made and all combinations which achieve acceptable hydraulic head distributions are used to compile:

* Best-Estimate Catchment Area: the only zone to satisfy the groundwater balance.
* Zone of Confidence (ZOC): defined by the overlap of all plausible combinations.
* Zone of Uncertainty (ZOU): formed by the boundaries of all plausible combinations.

- Although the ZOC is the area of greatest confidence, it will not normally be of sufficient area alone to provide adequate protection to the source. However, in Britain it is used for controls on soil nitrate leaching to groundwater, where it has been the basis for compensation paid to farmers for restrictions on nitrogen use. It is argued that concentrating control measures in a limited, but confidently-defined zone, gives a more certain return on the public funds expended (Foster & Skinner, 1995).

- In order to deal with situations where lack of data and aquifer heterogeneity combine to make modelling inappropriate, a suite of manual techniques are used to provide the best-estimate protection zones. Groundwater environments where these have been most commonly applied are in karstic or semi-karstic aquifers, situations where seasonably-variable spring discharges are the dominant sinks, and in hard-rock aquifers. The general principle employed is that any zone is better than no zone at all, and that even a circular (or in the case of springs, semi-circular) zone will be declared to provide a precautionary marker that more investigation will be required if threatening land-use change or other activity is proposed.

APPLICABILITY AND DIFFICULTIES OF STRATEGY

RELEVANCE TO LATIN AMERICA

- The combination of pollution vulnerability zones and source protection areas provides a credible and defensible framework for the control of potentially-polluting activities through land-use planning and a logical basis for assessing groundwater pollution risks from existing installations and practices. It will assist regulatory and planning agencies in prioritising actions in this respect and also help promote public understanding of the need for groundwater protection.

- Given the even greater pressure on national, provincial and municipal agencies concerned with groundwater in Latin America, any approach which helps prioritise expenditure and harmonise activity on investigation, monitoring and mitigation must be of direct relevance.

- The approach adopted also allows fairly flexible adaptation to local circumstances. It has been successfully used in a number of locations in the Latin American-Caribbean region, such as Barbados (Chilton et al, 1990) and Chile (Muñoz et al, 1997). The fact that it aims to make best use of available hydrogeological data, but does not require highly detailed knowledge of contaminant transport in the given local groundwater system, must also be an advantage.

- A further factor generally favouring the overall philosophy of groundwater protection (instead of water treatment at point-of-use) in Latin America is that the prevailing WHO drinking water guidelines are far better justified and more realistic to achieve through protection than the corresponding (highly idealistic) EC guidelines. Moreover, the cost advantage of aquifer protection over water-supply treatment is greater because of the generally higher cost of the latter.

PROBLEMS WITH PRACTICAL IMPLEMENTATION

- A number of limitations of the two basic concepts advocated for land-surface zoning have been discussed in the corresponding sections above. These limitations serve to reduce the confidence and precision with which the methods can be applied, but not to invalidate the approach. However, some related EC policies have tended to conflict with groundwater protection strategies and lead to some illogical outcomes (Foster, 1998).

- There have also been significant obstacles to the implementation of protection measures on the ground including:

* effecting changes in agricultural regime (as opposed to refining best management practice for existing cropping and husbandry) in high-vulnerability source protection areas, especially where intensive monocultures have become established

* lack of understanding of the transport and persistence of certain contaminants in some subsoil profiles and aquifer types, which has lead to very large uncertainties in the mapping of vulnerability zones and protection areas

* making sensible and confident use of natural contaminant attenuation capacity in the saturated zone of aquifers, given the nature of EC directives and scientific uncertainty over the processes involved

* dealing technically, financially and legally with the legacy of past industrial pollution, which should only be attempted where there is risk to important water sources.

- It also has to be recognised that shallow groundwater in urban areas is often likely to be contaminated, as a result of the legacy of past activities, and may continue to be significantly polluted in the absence of comprehensive mains sewerage. However, there is an urgent need to control the loading of persistent contaminants, which may be transferred to deeper (generally less vulnerable) aquifers in the longer term.

- The following type of action needs to be taken in the interest of protection of potable groundwater supplies (Foster et al, 1998):

* restricting the density of residential development served by in-situ sanitation
* selectively prioritising mains sewerage extension to source protection areas of high aquifer vulnerability
* improving the location and quality of wastewater discharge from main sewerage systems after consideration of the potential impacts on periurban and downstream municipal wellfields
* special handling of chemicals and effluents at any industrial sites located in source protection areas and/or areas of high aquifer vulnerability.

- In urban situations of extreme aquifer vulnerability it will be necessary to delineate source protection areas as total conservation zones and avoid most forms of economic development within them. This will only be possible in some periurban situations, whilst elsewhere it may be unavoidable to dedicate areas of the subsurface for waste disposal, prohibiting the abstraction of potable or sensitive groundwater supplies.

- The detailed implementation of groundwater protection policy on the ground will, of necessity, vary quite widely with hydrogeological and socioeconomic diversity. Raising awareness and broadening participation will always be critical factors and various approaches may be useful including:

* municipality-sponsored local interest groups, which can be most effective for achieving the necessary consensus
* operational involvement and financial investment of major water users, which is an essential complement to the efforts of the regulatory agency
* some type of groundwater forum involving all relevant stakeholders at regional/national level can also be useful for policy refinement, to create favourable conditions for policy implementation and for mobilising research funding to reduce costly areas of hydrogeological uncertainty.

- Much care is needed when dealing with the media so as not to provoke overreaction to groundwater pollution threats amongst water consumers and the politicians representing them. This will normally divert investment into water-supply treatment and/or the purchase of bottled water, resulting in more overall expenditure on water, but less investment in aquifer protection.

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