THE ECONOMIC DIMENSION OF AQUIFER PROTECTION - OR PUTTING A PRICE ON GROUNDWATER POLLUTION

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ABSTRACT

The protection of aquifers used as a source of potable water-supply needs to be placed on a sounder economic basis. Processes generating groundwater pollution risk can usefully be classified in terms of their net economic benefit or cost to society. In this context it is important to put a realistic price on the damages stemming from groundwater pollution. This should include an allowance for aquifer restoration or for threatment of all affected groundwater supplies, where such measures are feasible, or for the loss of groundwater resources where they have to be abandoned. A theoretical framework for this purpose is presented and the factors involved are critically reviewed. It is concluded that (a) the marginal cost-benefit ratio for specific increments or components of the polluting activity is much more relevant than the overall figure, and (b) the time horizon and discount rate selected for economic assessment are especially critical in the case of groundwater pollution. Damages are also likely to fluctuate widely with site and scenario as a result of variation in local hydrogeological conditions, water-supply and waste disposal options.

1 INTRODUCTION

1.1 Background to groundwater pollution problems

In recent years concern has been growing about the frequency, extent and consequences of groundwater pollution incidents. Aquifer contamination is often slow to become fully apparent in groundwater supplies, but is very persistent. Aquifer restoration is always expensive and often impracticable.

Among activities generating major groundwater pollution risk are the ground disposal of industrial effluents and residues, the spillage or leakage of industrial chemicals during their use, storage or transportation, the intensification of agricultural cultivation, and the infiltration of urban wastewaters by a variety of routes.

The pollution of potable groundwater supplies constitutes an involuntary health risk to the general public. Individual contaminants causing the most common problems include nitrates, some halogenated organic compounds in widespread use as solvents and disinfectants, and certain heavy metals notably hexavalent chromium.

Concern about groundwater pollution is not restricted to the older industrialised nations. It has spread to those developing nations experiencing rapid urban, industrial or agricultural expansion, and is becoming especially serious because of their greater dependence on groundwater for potable supplies and on unsewered sanitation and soakway drainage.

1.2 Need for economic appraisal

More attention is beginning to be given to aquifer protection. However, for more rapid and systematic progress in this respect to be achieved, it will be necessary to demonstrate that groundwater pollution control is a cost-effective policy and to concentrate available funds for this purpose where they are likely to reap the maximum benefit to society. Economic evaluation of groundwater contamination is further required to determine appropriate costs, so that the "polluter-pays-principle" can be pursued more consistently.

Economic assessment should also give a clearer appreciation of the differing implications of groundwater pollution for industrialised and developing nations.

2 ECONOMIC ASSESSMENT OF GROUNDWATER POLLUTION

2.1 Classification of polluting activities

The net benefit (NB) of an uncontrolled activity (a) generating a groundwater pollution risk is expressed by:

$$NB_a = GB_a - D_a \tag{1}$$

where GB is the gross benefit to the private and/or public sector of the activity involved and D the damages consequent upon groundwater pollution. In qualitative terms, it is both possible and helpful to classify polluting activities by their relative gross benefit and pollution damage (Fig. 1).

Three rather arbitrary, but significant, divisions are recognised. The first has been termed "regrettable ignorance". Practices falling into this division have high risk of causing major pollution damages, provide little economic return in gross benefit terms and require control through public education and legal enforcement. They include such practices as disposal of polluted wastes to disused wells and of spent oils and solvents to soakaway drainage. At the other end of the scale "sound practice" has the opposite implication.

A rather large intermediate group falls between these two extremes and activities within this group are classified as ranging from "operational

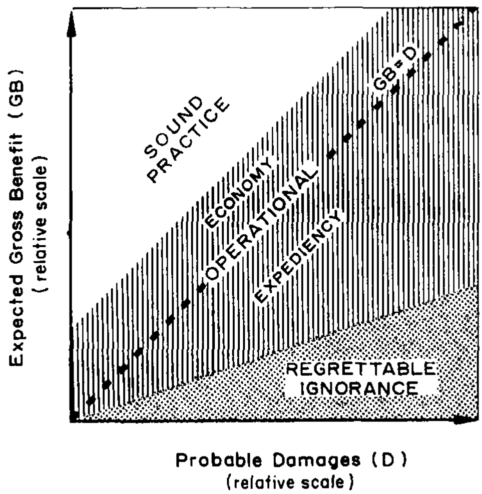


Fig.1. Qualitative classification of groundwater polluting activities on economic criteria.

expediency" to "operational economy". Such activities require detailed cost-benefit analysis and, if economically justified, appropriate control measures should be enforced. An example is excessive application during land disposal of wastewater, sludge or slurry. Whether this represents gross expediency or reasonable economy in operational practice will depend, to considerable degree, on the pollution vulnerability of local aquifers and the composition of effluent involved.

It is stressed that different components of, or processes within, a single activity may fall within widely separate divisions. For example, the unsewered option for basic sanitation is accepted sound practice, which under appropriate conditions does not result in significant deterioration in groundwater quality. However, its use in high-density urbanisations, and in areas underlain by fissured aquifers with shallow groundwater table, needs careful consideration, because of the high risk of groundwater pollution. Moreover, such operational practices as the degreasing of septic tanks and cesspits with halogenated highly-toxic solvents represent a major hazard to adjacent shallow water-supply boreholes and wells.

2.2 Estimation of pollution damages

The expected damages (D) of an uncontrolled polluting activity can be estimated from the following equation (Raucher, 1983):

$$D = p\,[q(C_{ws} + C_{gwr}) + (1 - q)\,C_{health}] \qquad (2)$$

where p and q respectively are the probability of groundwater pollution occurring and of detection and remedial action before the contaminated water is consumed; both expressed on the scale 0-1.

The probability of groundwater pollution is equivalent to the risk of groundwater pollution, which can be assessed (Foster, 1987) through the interaction between:

(a) the natural aquifer pollution vulnerability as determined by a set of intrinsic characteristics, and

(b) the subsurface contaminant load generated by the polluting activity or process concerned.

This risk will inevitably be site and scenario specific, and can in practice prove difficult to quantify, because of the potential significance of rather detailed factors. It should also be noted that the probability of aquifer pollution will normally be somewhat higher than that of contamination of an individual water-supply drawn from the aquifer. To this extent, equation (2) could be considered to require expansion.

The probability of detecting pollution will depend primarily upon the comprehensiveness of routine sampling and analytical programmes, and secondarily on the complexity of the local groundwater flow regime. High probabilities can normally be expected in those industrialised nations where increasing emphasis is being placed on environmental quality control. Low values are likely in developing nations, because of generally infrequent monitoring of groundwater quality for only a restricted range of determinands and lack of technical and financial resources to take remedial action.

The expected damages can include up to three components:

(a) C_{ws} the cost of developing alternative water-supply sources,

(b) C_{gwr} the cost of pollution containment and aquifer restoration or treatment of all affected groundwater supplies, where such measures are feasible, or of loss in option value as a result of the abandonment of groundwater resources,

(c) C_{health} the cost in terms of impact on human health resulting from the deterioration in drinking water quality.

Values of C_{ws} are relatively straightforward to estimate. In the case of a typical municipal water-supply borehole yielding 2-10,000 m^3/d, most of the cost of development of an alternative source (for substitution or blending) will be associated with the capital investment for water pipelines to link the new source into the existing distribution system. The total cost will commonly fall in the range US$2-6 million over the initial 20 years, unless an alternative groundwater source cannot be located within a few kilometres distance.

It is more difficult to estimate and to generalize a range of values on C_{gwr}, because of relatively limited international experience to date. A wider range of treatment systems (including sorption columns, ion exchange resins and membrane processes) are becoming more readily available and economically attractive for groundwater sources. Where treatment to remove chemical contaminants is feasible, the total sum is likely to be similar to that for development of alternative groundwater sources, but revenue costs will form a much larger proportion of the total. The elimination of microbiological contaminants from groundwater can, however, generally be achieved much more cheaply.

Restoration is almost always a protracted process, especially if this is left mainly to natural dilution and degradation processes. In the few instances where pollution containment and clean-up in an aquifer seriously contaminated by persistent toxic chemicals has been attempted, costs have tended to exceed US$10 million, and even then potable quality has not always been restored.

These cost components are often ignored in site-by-site evaluation of the damage of groundwater pollution and the value of groundwater protection. In the long-term this omission must be questioned in consequence of the persistent or even irreversible nature of most groundwater pollution and the aggregate effect of numerous individually-small pollution incidents. Alternatively some realistic value should be put on the loss of fresh groundwater resources.

Those situations in which $C_{ws} + C_{gwr}$ are likely to be highest will be associated with:

(a) diffuse pollution sources which can affect numerous groundwater sources and thereby a large population,

(b) the more vulnerable aquifers with high risk of groundwater pollution,

(c) incidents which involve persistent hazardous chemicals, and pollutants which cannot be removed by conventional water treatment,

(d) locations where an alternative water-supply will be very costly to develop.

The quantification of C_{health} remains subject to major scientific uncertainty (Hunt & Farrell, 1987) and conceptual conflict. Such costs are likely to vary widely with contaminant type and other factors, and potentially could be very large in some instances. One proposed method of evaluation (Shechter, 1985) considers the product of three factors:

(a) the dose-response of the contaminant concerned in terms of increased human fatality or morbidity,

(b) the size of the population affected,

(c) the economic value of life.

The latter factor can be taken as the average productive or purchasing capacity of the population affected or preferably the national GNP per capita, since this raises less questions of social equity.

Adopting this approach, a groundwater source providing 5,000 m^2/d and polluted by a contaminant reducing the average life expectancy of the population served by 1 year, would cause long-term damages of the order of US$2 million/ annum for both industrialised and developing nations in the Americas, using reasonable water use, life expectancy and GNP per capita figures, but without including medical costs expended by the population in response to problems or fears of ill-health.

In some cases, health costs will be incurred even after pollution has been detected but before remedial measures can be taken. The occurrence of health problems may even be the first indication that pollution has taken place. In such instances a further expansion of equation (2) is required to include a component of C_{health} under the q term. This would also need to include medical costs incurred as a result of the fear of pollution effects.

2.3 Simplified formula for pollution damages

Although such a situation will only be achieved in the more environmentally -conscious of the developed nations, it may be reasonable to assume that q = 1 and $C_{health} = 0$. In effect, this is saying that all groundwater pollution will be detected, that appropriate corrective action will be taken before the contaminant concentration exceeds the WHO guideline value and that no measurable health effects will be suffered from drinking water with concentrations below that value. In this were the case:

$$D = p\,(C_{ws} + C_{gwr}) \qquad (3)$$

where p is the probability that the contaminant under consideration will exceed the WHO guideline value in the groundwater supply concerned.

In most senses, this is a much simpler and more equitable approach to the evaluation of groundwater pollution damages, always assuming that a realistic value for C_{gwr} is included.

2.4 Importance of marginal cost-benefit analysis

An inevitable consequence of this approach is to make the economic analysis of groundwater polluting activities extremely sensitive to marginal increases in contaminant load as the guideline value is approached, since this will be the point at which the bulk of the costs consequent upon groundwater pollution will then be incurred. Below this value damages would be regarded as negligible (that is, D=0).

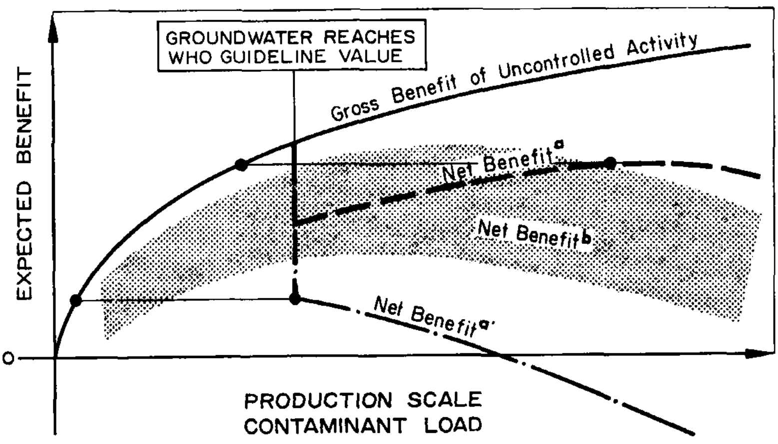
Appraisal of the marginal cost/benefit of progressive increments of, or specific components within, the polluting activity is generally a much more realistic basis for the economic analysis of groundwater pollution than dealing with overall figures for the entire activity. Thus equations (1) and (3) respectively are better written as follows:

$$MNB = MGB - MD \qquad (1a)$$

$$MD = p(MC_{ws} + MC_{gwr}) \qquad (3a)$$

The increment could be in the scale of pollution generation by an individual unit or equally in the number of polluting units within a given area. In situations where the groundwater resource has to be abandoned, however, the analysis of marginal cost-benefit becomes irrelevant because additional pollution incurs no further damages.

In many instances an increment of the polluting activity will be reached (or a component of the polluting activity will be identified) for which MGB < MD, that is the net benefit to society (MNB) will be negative. A typical scenario is illustrated (Fig. 2) in which an increment in the production scale or contaminant load is reached for which the net benefit after deducting C_{ws} or $(C_{ws} + C_{gwr})$ reaches a maximum. Since D = 0 until the WHO guideline value is exceeded, an equal or higher net benefit could well have been obtained at a lower level of production.



a: for $D = C_{ws}$
a': for $D = C_{ws} + C_{gwr}$
b: range for $D = C_{protect}$, implemented at early stage

Fig. 2. Hypothetical relationships between expected benefit and increasing scale of production for a typical groundwater polluting activity. (All benefits refer to money value in year 1 of activity but are not discounted).

It is these critical increments or components of the polluting activity, which most urgently need to be identified and controlled. They include such practices as:

(a) excessive and/or grossly-mistimed application of fertilisers and some pesticides in agricultural crop cultivation, and the progressive conversion of grassland and woodland to arable cultivation,

(b) in industry the additional cost involved in recovery programmes to avoid excessive loading of oils and solvents in effluents discharged to the ground, in locating a safe site for the land disposal of solid residues, in providing linings for some effluent lagoons, and in regular integrity tests and maintenance of subsurface tanks used for the storage of hazardous chemicals.

3 ECONOMICS OF AQUIFER PROTECTION

3.1 Theoretical basis of protection policies

Groundwater pollution risk is a consequence of subsurface contaminant load. Even in a highly vulnerable aquifer, there is no risk of pollution until a contaminant load is applied. The basis of all groundwater pollution control policies is to eliminate, or to reduce to a tolerable level, the subsurface contaminant load generated by a given polluting activity (Foster, 1987). This can be attempted over the entire recharge area of aquifers or in more restricted (special protection) areas.

Aquifer protection is, in effect, incurring a cost $C_{protect}$ to reduce the probability (or risk) of groundwater pollution from p to p^-. In essence, it is a question of "pay now" rather than "pay later".

Additional security may also be achieved by increasing the probability of detection from q to q^+ by improving monitoring at a cost $C_{monitor}$.

The protection policy will be justified when:

$$MC_{protect}^{(p\ to\ p-)} + MC_{monitor}^{(q\ to\ q^+)} \qquad MD_{(p-\ to\ p)} + MD_{(q+\ to\ q)}$$

Problems are likely to be encountered, however, in the accurate estimation of p, p^- and $MD_{(p^-\ to\ p)}$ in actual field situations. Nevertheless, there is a growing body of experience, which demonstrates the economy of sensibly-devised groundwater protection policies, especially if the cost of aquifer restoration or loss of groundwater resources is realistically priced in the cost-benefit analysis (Fig. 2).

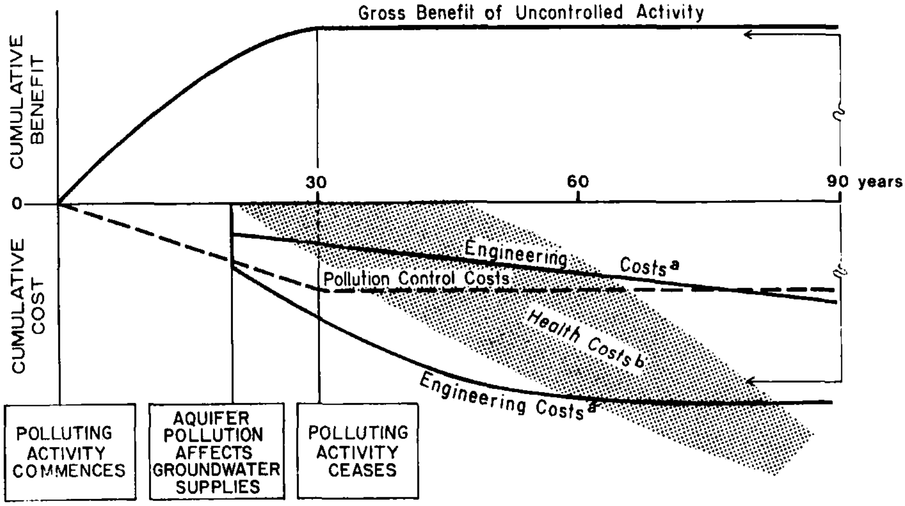
3.2 Significance of time horizon

The calculation of net benefit has to be made over a defined time horizon, normally discounting future costs and benefits to present value at a defined "discount rate". This is, in practice, generally equivalent to the predicted average interest rate net of inflation. In many economic studies in the engineering sector, the time horizon is fixed rather arbitrarily at 20 years, and the discount rate at 2-5% for industrialised nations and 10-15% for developing economies.

Calculation of the cost of groundwater pollution and the benefit of groundwater protection can be very sensitive to the selection of these two economic parameters. This is due to a number of distinct reasons most of which are unique to the case of groundwater:

(a) in many instances the passage of persistent pollutants through the unsaturated zone and the advance of pollution plumes in aquifers can take years or even decades, thus damages take a long time to become apparent and may continue to affect an increasing number of water-supply boreholes (and the population served by them) with time,

(b) in the long-term there may be greater probability of groundwater pollution occurring as a result of deterioration of pipelines, tanks, impermeable liners, etc., and perhaps also greater likelihood of pollution detection,



a: minimum for water-supply modifications if feasible
a': for water-supply treatment or aquifer restoration if feasible
b: possible range depending on whether pollutant is pathogenic or acutely toxic, or exhibits long-term chronic toxicity such as carcinogenic or mutagenic effects

Fig. 3. Hypothetical illustration of the importance of selection of time horizon in the economic evaluation of groundwater pollution and aquifer protection. (Benefits and costs refer to money value in year 1 of activity but are not discounted).

(c) aquifer restoration is invariably a long-term operation, moreover treatment of groundwater supplies once contaminated will be needed almost in perpetuity,

(d) although some groundwater contaminants are pathogenic or acutely toxic, many pollutants have chronic carcinogenic and/or mutagenic effects, and will take years or generations to fully affect the exposed population.

Some of these points related to the time horizon in economic calculations are illustrated in Fig. 3. Not uncommonly the costs of pollution control appear the greatest in the short-to-medium term, but in the long run may represent the most economic option.

The time at which corrective action is taken in respect of groundwater pollution, also influences the economic analysis of various potential remedial measures. This is true in the case of diffuse pollution from intensification of agricultural cultivation. If land-use controls in special protection areas are implemented at an early stage, they are usually found to be economically attractive, especially in the case of relatively small groundwater sources. Once serious pollution problems exist, however, treatment of water-supplies will normally be favoured on economic grounds, since the benefits of enforcing agricultural restrictions will not be realised for many years in terms of improvements of groundwater quality.

4 CONCLUSIONS

(a) Groundwater polluting activities should be evaluated and classified in terms of their net benefit to society after deducting realistic damages consequent upon aquifer pollution.

(b) The cost of aquifer restoration or long-term treatment of all affected groundwater supplies should be included in this estimate of damages, if either are feasible, and where sources have to be abandoned an allowance for loss of groundwater resources should be added to the cost of development of alternative supplies.

(c) The quantification of certain factors in the estimation of pollution damages will often prove difficult, but the outcome of cost-benefit analysis is always likely to be sensitive to local hydrogeological conditions, water-supply and waste-disposal options.

(d) The time horizon selected for economic analysis will generally be critical to the evaluation of costs of groundwater pollution and the benefits of groundwater protection.

(e) Marginal, rather than overall, cost-benefit analysis is the better indicator of priorities for groundwater pollution control.

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