ECONOMIC ASPECTS OF GROUNDWATER PROTECTION

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ABSTRACT

Economic criteria of groundwater protection have not yet been firmly established. The economics of groundwater protection should be based on the fact that prevention of pollution is always less expensive than aquifer reclamation which is a costly, long-term and technologically demanding process with unpredictable results. The consequences of groundwater pollution and depletion observed during the last few decades in various countries are producing undesirable economic, social and ecological impacts on their populations and on national or regional development. It is emphasized that the establishment and implementation of a consistent groundwater protection strategy and policy, the creation of a management structure for groundwater resources protection, and the design and operation of groundwater monitoring programmes are the decisive factors for economical groundwater resources protection and conservation. Financial assessment of remedial and restrictive measures to combat groundwater pollution, as part of the comprehensive groundwater protection and reclamation programmes, is being discussed and analysed.

1 INTRODUCTION

Groundwater is a geological agent and a vitally important resource for man and natural environment.

In the past, low demands for groundwater, of which there seemed to be an abundance, led to a "philosophy" that groundwater was an inexhaustible resource. The attitude was the same in respect to groundwater quality. It was not taken into account that aquifer pollution and depletion was a hidden and long-term process and that their response was delayed.

The dream that groundwater is an invulnerable and safe source of water came to an end during the 1950s. The consequences of groundwater pollution and depletion observed during the last few decades in several countries, produce adverse economic, social and ecological effects on the population. Enormous financial resources are required for the treatment of polluted groundwater for drinking purposes and for the transport of water over long distances to regions in which aquifers have been polluted or depleted.

Almost all financial means invested into groundwater projects were usually channelled towards groundwater resources development. Since the 1960s, in several countries, the finances invested into groundwater protection and aquifer reclamation have accounted for over 50 per cent of the expenditures flowing into groundwater projects, and have had an increasing trend.

The focal point of groundwater protection economy lies in the sphere of preventive protection of all usable national groundwater resources. No matter how much we develop the technologies for polluted aquifer restoration or cut their prices, there still remain financial and social losses caused by the poor management and inadequate control of groundwater resources, the absence of competent legislature and regulations, etc. When a governmental organizational structure and mechanism is in operation in a country, responsible for integrated planning, development and protection of water resources, and when the principle, so frequently proclaimed by governments, that no economic development shall take place which would cause deterioration of ecological conditions and environmental damage to population is adhered to, there are preconditions for gradually reducing the adverse impacts on groundwater resources. Undoubtedly, this will be the most significant economic and social benefit derived from the national policy and strategy in water resources protection. Groundwater protection is always less expensive than aquifer reclamation - a long-term, costly and technologically demanding process with unpredictable results. The cost factor of groundwater protection has different values from the view points of decision-makers, planners, environmental and water scientists, polluters or groundwater users. An objective economic and social analysis of the costs-benefits of groundwater protection will therefore always be questionable.

2 ECONOMIC BENEFITS OF GROUNDWATER PROTECTION STRATEGY AND POLICY

Groundwater strategy and policy as a basis for maintaining the economic and social value of groundwater resources must take into consideration that the polluters will not treat effluents voluntarily because the treatment is costly, and the users will not reduce the volume of abstracted groundwater unless they are forced to by legislative measures and unless laws and regulations on groundwater protection are strictly applied.

The groundwater protection strategy and policy are based on the assumptions that:

. groundwater is a source of drinking water;
. the volume of utilizable groundwater resources over the national territory should be known, or at least a qualified estimate of it;
. systematic protection of groundwater is less costly than the reclamation of polluted or depleted aquifers;
. the degree of groundwater protection varies within the national territory;
. the technical and financial requirements will be great for comprehensive protection of groundwater resources in areas with irreplaceable or valuable resources, smaller for overall protection of less vulnerable or valuable groundwater and insignificant for low-intensity protection of groundwater having little value or naturally well protected.

2.1 Groundwater protection strategy

The principal objective of a groundwater protection strategy is to preserve the natural quality of groundwater, particularly for drinking purposes, for the benefit of the present and future generations´ health. This requires the creation of an organizational structure capable of the implementation and enforcement of comprehensive strategy and policy leading to legislation that regulates the management and control of efficient groundwater protection and conservation programmes. A governmental office for groundwater protection, established within the ministry or agency responsible for the protection of total environment, and the delegation of authority to state and regional offices are therefore strongly recommended.

The main aims of a groundwater protection strategy include:

. to define the value of the groundwater resources with a view to national interests and needs;
. to define the criteria for groundwater protection management and delegate the implementation of decisions to the relevant governmental authorities;
. to obtain governmental financial support for the establishment and operation of groundwater protection programmes;

- to assess the cost-effectiveness of aquifer protection and reclamation;
- to establish the legal and institutional basis, regulatory statutes and standards for groundwater protection;
- to establish a control system and an effluent charging system on the polluter-pays principle;
- to provide technical guidelines for the activities related to groundwater protection and reclamation;
- to support and coordinate research programmes for the development of methods of groundwater protection and technologies for detection and elimination of subsurface pollution;
- to inform and educate the general public about groundwater protection programmes.

The government´s financial support for the implementation of the programmes designed within a national, state or regional groundwater protection strategy depends on the significance of groundwater resources for the national development, the extent of human impact on groundwater system, and, above all, the financial possibilities of the government in question. In highly industrialized countries, the financial expenditures on the protection of the environment, including groundwater resources, accounts for 7 to 12 per cent of the governments´ annual budget.

Collection and distribution of the financial resources obtained from the charges for the failure to observe the laws and regulations for groundwater protection are also part of the protection strategy. However, fines and charges do not constitute the goal of groundwater protection strategies,but rather a temporary tool at a time when the management and control system of groundwater protection is still underdeveloped or when financial means are not available for the installation of waste treatment technologies. A well developed effluent charging system can bring financial resources to the government, which, in turn, can be invested into groundwater protection programmes.

2.2 Groundwater protection policy

Not all groundwater resources must be protected to the same level since they are all not of the same value or vulnerability. To protect all groundwater resources to the same degree would be unbearable in terms of economy, useless in terms of hydrogeology, and unrealistic in terms of management and control.

The criteria for defining a groundwater protection policy depend on:

. the value of groundwater and its vulnerability;
. the volume of rationally utilizable groundwater resources;
. the current and expected demands for water resources in a given region;
. implementation of effective legislation related to groundwater protection and pollution.

The classification of groundwater resources by these criteria is always complicated and questionable, and requires good knowledge of the hydrogeological, economic and social aspects of the studied area.

A good example of comprehensive groundwater protection policies is the USA in which three classes of groundwater are defined (EPA, 1984). The relations between the level of protection and the related financial costs are expressed in Table 1.

Another example of groundwater protection policy is Czechoslovakia, in which the most valuable groundwater resource occurs in the Czech Cretaceous Basin, covering some 15,000 square kilometres; 7 $m^3 \cdot s^{-1}$ of groundwater are being pumped to public water supplies. The groundwater protection policy, based on a good level of knowledge about the hydrogeological system and its vulnerability, is reflected in the pragmatic approach to the protection of groundwater resources. Simplified figures show that only about 20 per cent of groundwater in this basin require complex, comprehensive and financially demanding protection (land acquisition, restriction of agricultural activities, and intensive monitoring activities). The demands on the protection of the remaining groundwater are markedly lower in terms of hydrogeology and economy.

2.3 Implementation of groundwater protection strategy and policy

Both development and protection of groundwater resources should be considered integral parts of national water management plans, and must be dealt with simultaneously. Reconnaissance, investigation, pilot studies, planning, evaluation and economic assessment of usable groundwater resources should always precede their abstraction. The criteria for groundwater quality protection should always be examined and determined simultaneously with the individual steps of the groundwater development process.

TABLE 1

Classes of groundwater in USA compiled according to EPA data (1984).

Class		Basic criteria	Level of groundwater protection	Financial requirements for groundwater protection	Remarks
I	Special groundwater	Highly vulnerable, irreplacable or ecologically vital	Extremely high	High - in some areas costs on land acquisition and economic losses due to restriction of human activities must be considered	Significant water resources
II	Current and potential sources of drinking water and waters having other beneficial uses	All other groundwater use or available for drinking or other purposes	High to moderate - prevention of contamination based on technology of remedies rather than through restrictions	Reasonable - expensive remedial measures of aquifer restoration applied only exceptionally	Majority of usable groundwater in USA
III	Groundwater not considered potential sources of drinking water and of limited beneficial use	Heavily saline or heavily contaminated	Usually low - migration to class I or II groundwater or discharge to surface water must be precluded	Usually low - occasional costs on clean-up activities may be required	Limited beneficial use

The strategy of groundwater resources protection should also be interrelated with the protection of the remaining components of the hydrological cycle, land use planning and abstraction of other natural resources, with a view to their rational development and better allocation.

Legislative measures based on Water and Environment Acts are essential for implementing comprehensive and financially efficient groundwater protection strategy and policy. Special attention should be devoted to the regulations concerning the licences and permits for groundwater utilization and abstraction, to prevent depletion of groundwater resources. Regulations for groundwater quality protection should determine first of all the responsibility of polluters and their penalization, and the prohibition or permission system for the discharge of wastes. Within the regulations, various economic advantages should be established in order to prevent groundwater pollution, such as tax benefits, or low-interest loans for the construction of treatment plant or industrial plants introducing dry and waste-free technologies, financial assistance by the government to the construction of closed water circulation systems, multirecycling processes in the industrial sector, etc. Bonuses for farming activities which do not use inorganic fertilizers should be also provided.

The timely establishment of priorities, preferences and potential conflicts in the development of a national or regional economy requires the formulation and implementation of policies and strategies focused, among other things, on:

. coordinated development of natural resources, including groundwater;
. assessment of and control over the effects of natural resources utilization, including groundwater, in the economic, social and ecologic spheres;
. preventive protection of groundwater resources as the most effective, and financially the least expensive method of water protection.

3 ECONOMIC CRITERIA FOR GROUNDWATER PROTECTION MANAGEMENT

Groundwater protection management is a complex process whose economic criteria cannot be formulated with finality. Two categories of groundwater protection management can be considered:

- Overall protection of groundwater resources on the national or regional scale;

- Comprehensive protection around public water supplies.

The financial requirements on groundwater protection management vary depending on the natural conditions and the intensity and kind of anthropogeneous activities. Groundwater protection management cannot be implemented or operating effectively, if we do not have at least the basic knowledge about the properties of the groundwater system.

3.1 Overall protection of groundwater resources

is based on the assumption that all effectively accessible groundwater resources are, or will be, tapped for drinking or other purposes, and therefore their protection is desirable. Under water management plans, national and regional governments and water authorities should therefore bear the responsibility for, and financially support the protection of, the as yet unexploited groundwater resources.

Implementation of overall protection of groundwater resources calls for the following activities and related expenditures:

. investigation of the hydrogeological system and determination of its vulnerability;
. identification, inventory and assessment of the existing and potential pollution sources;
. monitoring of quantitative and qualitative parameters of the hydrogeological system;
. control over groundwater resources protection.

(i) The basic information about hydrogeological system in the countries in which hydrogeological investigations have been carried out is known, and there is no need for financial funds for complementary investigation. Expenditures include above all labour costs of experienced personnel for determining the vulnerability of and overall protection principles for the groundwater system. The costs on investigating one square kilometre of a given hydrogeological system usually mount to tens, or hundreds at the most of US dollars.

In regions in which knowledge of the hydrogeological system is scarce or nil, field and underground (boreholes) investigation should be carried out. The expenditures related with such investigation depend on the complexity of the groundwater system. The costs amount to some hundreds to thousands of US dollars per sq. km, depending on the level of overall protection to be attained or required.

(ii) Field trips and data collection and analysis are realized for identification, inventory and risk assessment of the principal existing and potential polluters and pollution sources. The expenditures covering the labour costs of various levels of scientific expertise and costs on transport facilities can be estimated at tens, exceptionally hundreds, of US dollars per sq. km of protected area.

(iii) The monitoring programme is an important item in the budget for overall groundwater protection. Construction costs on the design of a monitoring network may be significant when monitoring boreholes are not available or when the existing boreholes do not meet the criteria for segment testing, sampling of the hydrogeological system´s vertical profile, or separate monitoring of individual aquifers. Costs per one metre of a monitoring borehole having the above parametres, which cover screening, testing and written and graphic evaluation may be estimated at US dollars 150 to 300, depending on the depth, diameter, material of screening and rock composition. Estimated operational costs covering sampling (once a year), transport facilities and expenditures on laboratory analysis and maintenance of the monitoring borehole, per monitoring station, amount to US $ 100 to 200 annually.

(iv) Control measures within overall groundwater protection management are related with the establishment and implementation of regular control over:

. the principal existing and potential sources of pollution;
. exploitation of groundwater resources;
. operation of monitoring networks;
. observation of laws and regulations for groundwater protection.

The costs related with control measures are usually included in the control activities of national and regional water authorities responsible for water resources protection. In the sum of total costs on overall groundwater protection, those on control activities, constitute only a small portion.

3.2 <u>Comprehensive protection around public water supplies</u>

The groundwater resources utilized for public drinking water supplies are protected by protection zones, referred to as wellhead protection areas in the USA, usually delineated in two or three degrees. The main purpose of groundwater protection zone delineation is to protect drinking water supply wells or wellfields from pollution and depletion and provide the population with water which meets the standards for drinking water. In several countries wellhead protection is part of groundwater protection policy and strategy programmes, and is based on the relevant legislation.

Comprehensive protection of public water supply wells requires:

- cooperation between national, regional and local water authorities;
- establishment of a general concept of groundwater management in protection zones;
- implementation of technical, institutional, legislative and control measures and regulations;
- the granting of governmental financial funds for monitoring activities and establishment of criteria for their allotment;

3.2.1 Costs related with groundwater protection zone delineation

The costs of the techniques and methods employed for delineating groundwater protection zones of water supply wells depend primarily on: aquifer complexity and vulnerability; properties of the unsaturated zone; kinds, quantities and properties of potential pollutants and their distance from wells or wellfield; pumping rate and drawdown depth of water table in wells; and size of population dependent on water supply systems.

(i) First degree groundwater protection zones. These protect the well and its immediate environment from mechanical damage and direct pollution. Their extent is usually small - several tens of square metres at the maximum. They are excluded from agricultural use and other human activities. The cost on delineating these protection zones is low, in the order of tens to hundreds of US dollars, as there is no need for high-level professional expertise or hydrogeological investigation. The acquisition costs of the land included in the first degree protection zone varies in different countries and regions. However, owing to the small extent of these zones, the cost of land acquisition is negligible

(ii) Second and third degree groundwater protection zones. These zones are extensive (several hundreds of square metres to several square kilometres) and include the discharge areas, the cones of depression (zone of influence) around pumping wells, the recharge and contribution areas and other vulnerable areas of a given water supply system.

In several European countries, the second degree zones cover areas having a delay or residence time of 50 to 60 days. It should be emphasized that the delay time has been determined so as to protect water supply wells from the risk of groundwater microbial contamination, but it may become inadequate for certain chemical contaminants.

The third degree zone protects groundwater quality in water supply wells from persistent chemical contaminants. It is the most extensive zone, but restrictive measures are lower. Van Waegeningh (1985) recommends 10 to 25-year residence time.

In general, the level of restrictions and prohibitions in groundwater protection zones decreases with the distance from a well or wellfield. The second and third degree protection zones cover significant portions of land, frequently with fertile and cultivated soil. For this reason the overprotection of water supply wells is not desirable because restrictive measures or exclusion of soil from farming activities lead to economic losses. On the other hand, the underprotection of wells and wellfields may cause groundwater pollution requiring long-term and costly remedial actions.

(iii) Benefits of groundwater protection zones. Protection zones should be delineated by means of a complex of up-to-date methods and techniques to minimize the degree of uncertainity in their definition. Protection zones should be as small as possible but a large as necessary (Van Waegeningh, 1985, Foster, 1987, EPA, 1987). Expressed in financial terms, higher input costs on accurate protection zone delineation lead to reduced operational costs on well and wellfield protection. Since the operation of water supply systems is always long-term, the operational costs involved in their protection should be as low as possible. A sophisticated approach to protection zone definition should be therefore preferred.

The Guidelines for Delineation of Wellhead Protection Areas in USA (EPA, 1987) provide good examples of potential costs related with the simplest to the most complex delineation methods. Estimates of potential costs (Table 2) consider labour costs and the level of technical expertise required for each of the methods applied. Potential overhead costs include the use of data-collecting equipment, computer hardware and software and report prepara-

TABLE 2

Costs of delineation associated with various WHPA methods (after EPA, 1987).

Methods	Manhours required per well	Level of expertise[+]	Cost per well	Potential overhead costs
Arbitrary fixed radii	1 - 5	1	US $ 10 - 50	Low
Calculated fixed radii	1 - 10	2	US $ 13 - 125	Low
Simplified variable shapes	1 - 10	2	US $ 13 - 125	Low - medium
Analytical methods	2 - 20	3	US $ 30 - 300	Medium
Hydrogeologic mapping	4 - 40	3	US $ 60 - 600	Medium - high
Numerical modelling	10 - 200[+]	4	US $ 175 - 3500	High

[+] Hourly wages per level of expertise assumed to be (based on NWWA, 1985):

1. Non technical	US $ 10.00
2. Junior hydrogeologist/geologist	US $ 12.50
3. Mid-level hydrogeologist/ /modeller	US $ 15.00
4. Senior hydrogeologist/modeller	US $ 17.50

tion; some of these items are already available, thereby reducing overhead costs.

However, in many cases the delineation costs must be expected to be markedly higher, especially when the criteria cannot be exactly defined and additional techniques (such as boreholes, pumping tests, field measurements, trace tests) must be applied because of a lack of data and information on the aquifer system and potential contaminant sources. Considering in such a case the need for drilling and screening of only one additional borehole (with an average depth of 20 metres), a pumping test and groundwater sampling and analysis, the cost of delineation will be two or three times higher (US $ 7,000 to 10,500 per one well) than as listed in Table 2 for the most expensive method.

Examples of pollution of public water-works in many countries show that the capital and operational costs on water supply wells protection are always lower than treatment of low-quality water when protection of wells is not adequate. In extreme cases polluted wells must be abandoned. Additional costs on the construction of alternative water supply wells are then generated. The effect of distributing lower-quality groundwater on human health cannot be expressed numerically as yet, but it must be considered, too, as intangible costs. Cost/benefit studies should therefore include the social, environmental and financial value of groundwater resources.

In regions with population concentrated in urban and rural areas and with suitable hydrogeological conditions, it is more effective to establish centralized water supply systems. For these systems, the total extent of protection zones with restrictive measures will be smaller than in the case of individual public wells, as will operational costs on wellfield protection management. The tangible and intangible costs related with the consequences of restrictive measures in groundwater protection zones influence the economy of a given region.

It is desirable to establish and implement internationally unified concepts and guidelines for protection zones delineation, as an important scientific and economic task in groundwater protection management.

4 COSTS AND BENEFITS OF GROUNDWATER MONITORING PROGRAMMES

Groundwater monitoring as one of the effective methods of groundwater protection and conservation is a technically and financially demanding process (Everett, 1983, EPA, 1985, Vrba, 1987). It is therefore generally accepted that a monitoring programme is only beneficial if the results it yields are applied. The benefits derived from the financial means expended are always compared with the value of the information obtained. Monitoring programmes are advantageous in the economic respect, in comparison with the costs expended on the rehabilitation of anthropogeneous damage to the groundwater system when a monitoring network is not in operation and the warning signal is lacking that aquifer pollution or depletion is setting in.

4.1 Integration and coordination of monitoring programmes - a scientifically and financially desirable task

A groundwater monitoring programme is governed mainly by monitoring objectives, the extent of the territory to be monitored and the effects in time and space of natural processes and human impacts on the hydrogeological system. International (GEMS - Global Environmental Monitoring System), national (state), regional (provincial) and local (site specific) monitoring programmes and networks are in operation at different levels throughout the world.

The integration and coordination of groundwater monitoring programmes with surface water, precipitation, evaporation and soil monitoring networks is recommended, because there exist interrelations and immediate and/or retarded influences between the above mentioned components (Table 3). The conjunctive design of monitoring networks and the multiple use of monitoring stations help to reduce the budget on the design and operation of monitoring networks.

The monitoring budget includes input costs on the network design and construction and the costs on its operation, maintenance and management. Advance costs into national monitoring networks as a part of national groundwater protection policy and strategy, usually without immediate financial returns, require a morally mature society and a far-thinking governmental mechanism. On the other hand, the financial return of expenditures on local and site specific monitoring programmes is generally quick because the polluters and users of water need the data to anticipate or alleviate environmental problems, thereby reducing the financial consequences, fines and legal prosecution.

TABLE 3

Scheme of integration, interrelation and coordination of groundwater quality programme.

	Groundwater quality programme	Integration	Interrelation	Coordination
Separate	Local	Groundwater quantity monitoring programme		
	Regional	Groundwater quantity monitoring programme	Precipitation - surface water monitoring programme	Atmosphere - soil monitoring programme
Interconnected	National	Groundwater quantity monitoring programme	Precipitation - surface water monitoring programme	Atmosphere - soil monitoring programme
	International	Groundwater quantity monitoring programme	Precipitation - surface water monitoring programme	

4.2 <u>Groundwater quality monitoring - financially demanding programme</u>

Groundwater quality monitoring is a financially demanding programme and one of the most important activities in groundwater protection and quality conservation (Van Duyvanbooden, 1986, Vrba, 1986, 1987).

An essential aspect of groundwater quality monitoring is the acquisition of data, covering sampling techniques and frequencies, and selection of parametres to be monitored. Special requirements are placed on the construction of monitoring wells because separate sampling of the hydrogeological system´s vertical profile is always preferred to mixed samples which are not appropriate for the study of groundwater quality variations and contaminant hydrogeology problems. Routine monitoring of the unsaturated zone should be part of the monitoring activity, particularly when studying the impact of diffuse pollution.

(i) <u>National monitoring programme</u> is a costly process in terms of the capital costs on establishing a monitoring network as well as the operational costs on the monitoring activity. The value and vulnerability of aquifers play the decisive role in the design of a national network. From the financial and technical points of view, a biannual sampling frequency of a national monitoring network is considered to be the maximum; normally one-year sampling intervals are implemented. Financially demanding automatic data acquisition systems are installed for pilot monitoring stations only.

Examples of national monitoring programmes may be given for the the Netherlands, Czechoslovakia and Denmark (Table 4).

(ii) Regional monitoring programmes provide data for the regional strategy and policy of conjuctive use of water resources and determination of impacts of diffuse pollution sources on the water system. The design of a monitoring network should be flexible. The sampling is more frequent (four times a year and more per station). The extent of the variables analyzed is adapted to regional circumstances.

Construction costs per well of a monitoring network are analogous to those in a national network; however, the network density is greater. Operational costs are higher, because of the more frequent sampling. Laboratory costs per analysis are lower as a smaller number of components are usually analyzed. Operational costs of US $ 600 to 800 per station annually are a realistic estimate.

(iii) Site specific monitoring networks are usually related to point pollution sources. The duration of their operation is variable, and may range from months to years. A great density of sampling points and a hidh sampling frequency of selected variables, depending on the kind and properties of existing and/or potential pollutants are required. Monitoring wells are mostly situated close to the pollution sources, and are often used for remedial actions. Operational costs of site specific monitoring networks are high and are covered by the polluters.

Remote sensing techniques as fast and cost-effective monitoring methods are being successfully employed in the site specific monitoring activity.

4.3 Statistical evaluation of groundwater quality monitoring data

The purposes underlying the use of statistical operations are to optimize the design of monitoring networks, the sampling frequency, the number of parameters and variables monitored, etc., thereby reducing the costs on monitoring while preserving the value of the information obtained. The following example well presents the utilizability of statistical analysis for sampling frequency determination.

The results of a five-year regional monitoring programme for

TABLE 4.

Examples of national groundwater quality monitoring networks.

Country	Establishment of network	Number and density of monitoring stations	Kind of aquifer and tested segments	Monitoring frequency	Monitoring parametres	Construction cost per monitoring well	Operational cost per well per year
The Netherlands	1978 - 1984	370 wells one per hundred square kilometres	Shallow aquifer segments: 10 m, 15 m and 25 m	Once a year	19 parametres and occasionally certain organic pollutants	US $ 3,500 per 25 m deep well	
Czechoslovakia, Czech section	Operation started in 1985	180 wells for shallow aquifers 98 wells for deeper aquifers 44 springs total:322	Shallow aquifer: one segment Deeper aquifers: 2 or 3 segments	Twice a year Deeper aquifers once a year	22 parametres and occasionally certain organic pollutants	US $ 200-300 per metre of monitoring well	US $ 200 - 250
Denmark	In preparation	150 wells-one per hundred square kilometres	Each station two or three boreholes with two to three sampling depths	Two to six times a year	Drinking water standards parametres, heavy metals and organic micropollutants		

optimizing farming activities and groundwater quality of a shallow aquifer in central Bohemia indicate that the sampling frequency for some macrocomponents (K, SO_4, Cl) may be reduced to an interval of one year. However, the optimum interval for NH_4 and NO_3 is one month or less (Table 5). The operational costs on groundwater sampling include above all the expenses on the transport of sampling technology and manpower to the sampling point, the installation of pumps, short-term pumping prior to sampling and, to a substantially smaller extent, the costs of water analysis. Optimization of the sampling frequency with a view to the fact that the sampling interval for NH_4 and NO_3 is one month, will therefore not lead to any marked savings in the operational costs on the monitoring activity in this case.

TABLE 5

Statistical evaluation of the frequency of monitoring certain chemical components (after Skořepa, 1986).

Chemical components		Na	K	NH_4	Mg	Ca	Cl	NO_3	HCO_3	SO_4
Sampling interval (months)		The difference between average annual value obtained at selected intervals and values obtained at one-month interval of sampling (in per cent)								
2	Mean error	4.2	2.6	39.6	5.5	1.4	1.1	12.0	4.0	2.5
mth.	Max.er.	15.0	6.5	80.7	11.8	3.3	1.7	2.2	12.7	6.6
4	Mean error	5.3	4.1	100.1	6.8	3.9	3.8	19.1	5.3	2.8
mth.	Max.er.	22.9	9.8	463.9	15.1	8.2	21.4	51.0	21.9	7.6
6	Mean error	7.7	7.9	91.9	10.2	4.4	5.8	26.2	7.8	5.1
mth.	Max.er.	47.8	22.2	431.0	41.9	16.7	35.7	69.6	59.1	16.0

5 ECONOMIC ASPECTS OF GROUNDWATER POLLUTION

No generally valid figures can be established on the cost of scientific, managerial and technological activities related with the implementation of anti-pollution projects because each pollution episode is highly individual in its nature and in the parameters of the groundwater environment within which it occurs and which it affects.

The most important factors which affect the technology and economy of anti-pollution projects is the extent of pollution, the kind of pollutants and the degree of the groundwater system´s vulnerability to pollution.

5.1 Site specific pollution

Site specific pollution, also referred to as local or point pollution, is related with accidental or hidden, surface or underground spills or leakages of effluents, some of which may be hazardous or toxic.

Leakages from petrol and other chemical storage tanks and adverse impact of liquid and solid wastes disposed of in landfills and surface impoundments are listed the most frequently as causes of site specific groundwater pollution.

(i) Surface spills of pollutants: immediate action is the most effective and less expensive. The pollutant is still on the surface or close under the surface, and its removal, as well as excavation of polluted soil or weathered rock must be carried out immediately. The costs (in the order of hundreds or thousands of US dollars) depend on the quantity of the polluted material to be removed, the distance over which this material must be transported to the treatment facilities, and on the method of its liquidation.

(ii) Underground spills of pollutant: These are the most frequent causes of groundwater pollution. The restoration of aquifers is always a long-term (years), costly and technologically demanding process.

In terms of economy and technology, total costs on remedial measures can be broken down to the following steps:

The costs of pollution identification covers the activities related with the determination of the probable quantity of pollutant leaked, identification of the pollution point and delineation of the pollution plume. The use of quick, relatively inexpensive remote sensing methods for identifying the extent of the pollution plume is always preferred to the drilling of numerous expensive boreholes. The stage of pollution identification is short (one to two months), and the least expensive in the process of the remedial measures applied (thousands to tens of thousands of US dollars).

Construction costs cover the installation of all facilities essential for pollutant removal from the underground. Specially screened wells are drilled around the pollution source as well as at the front of the pollution plume to protect the unpolluted part of the aquifer or water supply. Impermeable barriers and, in the case of high groundwater levels, drains or trenches are other methods of remedial measures. A unit for the treatment of the

TABLE 6

Costs on techniques applied on aquifer´s restoration.

Kind of pollutant	Technique of clean up operation	Maximum operational costs for treatment of 1 m^3 water in US $	Costs on 1 m well in US $	Effectiveness of clean up process - residual concentration in $mg.l^{-1}$	Times of clean up-operation W = weeks M = months Y = years	Complexity of rehabilitat. processes S = simple C = complicated VC = very complicated
Aviation kerosene	Scavenge pumping + treatment through expanded perlite + stripping	2.25	100 - 300	4 - 2	Y	S
	Scavenge pumping + treatment through sucking and expanded perlite	2.00	100 - 300	4	Y	S
	Microbial degradation	0.01	100 - 300	n . 0 .0.1	Y	C
	Hydroxiring	-	-	n . 0 .0.1	Y	C
Petrol	Scavenge pumping + treatment through expanded perlite + stripping	2.50	200 - 300	3 - 5	Y	C
	Scavenge pumping + treatment (expanded perlite and activated carbon)	3.00	200 - 300	0.1	Y	C
Heavy fuel oil	Pumping + treatment through gravitational separator	1.25	200 - 300	2 - 1	Y	C
	Pumping + treatment through sucking and gravitational separator	1.00	200 - 300	2 - 1	M - Y	S
Organic chlorinated solvents	Pumping + treatment through activated carbon + stripping	3.00	200 - 400	1 ug . l^{-1}	Y	C

TABLE 7

Site specific pollution - examples from USA and Czechoslovakia.

Locality	Kind of contaminant	Origin of contamination	Construction costs in millions US $	Operational costs	Total costs	Time of clean up operation	Remarks
Nashua N. H. USA (after Josephson, 1983)	Volatile organic solvents	Leakage from abandoned pit	Monitoring and abstraction wells and treatment facilities 2.4	Depending on kind of chemicals and their concentration US $ 0.22 - 2.52/1000 gal. treated	For the completed project US $ 10 million	Several years - started in 1980	Costs per well US $ 400 - 3000 depending on depth costs for sampling and analysis US $ 200 - 1500 per sample
Prague international airport (after Švoma and Houzim, 1984) and unpublished data	Oil hydrocarbons aviation - kerosene	Spill from kerosene storage tanks	Monitoring and abstraction wells and treatment facilities 2.0	Depending on time of clean up operation US $ 0.1 - 4.5/1000 l treated	For the completed project US $ 10 million - alternative water supply for nearby village not included	Several years - started in 1973	Costs per 1 m of well US $ 200 - 300 scientific expertise and lab analysis 20 % of total costs

polluted water pumped is installed. The construction costs may range from hundreds of thousands to, perhaps, millions of US dollars when an impermeable barrier is constructed over the whole thickness of the aquifer into the impermeable bedrock and completed with a leachate collection system.

Operational costs include those related with the monitoring and restoration of aquifers, mainly scavenge pumping of polluted water which must be treated immediately because regulations do not permit discharge of polluted water over the surface. The most complicated and costly process is the removal of residual pollution; it is accelerated by way of artificially recharging the aquifer. Operational costs also include maintenance, energy and labour costs, those on monitoring activities and field and laboratory analysis. Operational costs account for a substantial part of total costs on remedial measures, and amount to hundreds of thousands to millions of US dollars, depending on the time needed for aquifer restoration.

All of the above steps in aquifer reclamation must also include the costs on scientific personnel with a high level of expertise and experience in the design, supervision, control and evaluation of remedial measures. These costs usually account for 20 to 30 per cent of total outlays on remedial measures.

Potential overhead costs may be extremely high when the pollution affects the public water supply to such an extent than an alternative drinking water source must be temporarily or permanently obtained, or when the water treatment plant must be complemented with an adequate treatment unit for pollution elimination.

The average costs of the techniques applied in the clean up of the most typical groundwater pollutants produced by industry are expressed in Table 6 .

Table 7 informs well about the cost factor involved in the process of aquifer rehabilitation polluted by organic solvents (USA) and oil hydrocarbons (Czechoslovakia).

5.2 Diffuse pollution

Diffuse pollution, also referred to as non-point pollution of groundwater, is usually related with agricultural activity, above all the consequences of massive fertilizer and pesticide application or irrigation return flow.

Anti pollution programmes are concerned chiefly with the pollution of aquifers by nitrogen compounds. At current fertilizer management practices nitrogen input significantly exceed nitrogen uptake. Data from many regions of the world show that only about 50 per cent of the fertilizer nitrogen applied is removed with grain production, while 30 per cent or more are nitrogen losses to water system. This poor management produces impact on water quality and leads to low economic efficiency of farming production. Due to the great areal extent of diffuse nitrate pollution, the application of the "isolate-source-policy" and subsurface clean-up techniques is ineffective. The protective measures leading to improvement of groundwater quality is to manage and control the nitrogen input to the plant-soil-groundwater system. These can be achieved by restricting or prohibiting farming activities in vulnerable areas or by changing agricultural practices (selection of suitable fertilizers and determination of doses, times and techniques of their application, selection of suitable plants and determination of the rotation system) and activities (regulations between animal production and extension of the farmland). The choice between the two alternatives is based mainly on economic, social and ecological factors. In the decision-making process, the importance of groundwater resources and agricultural production for a given region should be evaluated with respect to the strategy and policy of economic development in a given region, and the priorities and preferences between integrated land use planning and groundwater protection management should be established. In regions where water supply depends on irreplaceable groundwater resources only, less intensive agricultural production and control over all farming activities, especially in vulnerable areas of the hydrogeological system, should be strongly recommended.

From the economic point of view, intensive agricultural production may be allowed in regions abounding in water resources, provided the financial profit derived from this production will be higher than expenditures on alternative water supplies in the event the existing sources are polluted. However, from the ecological point of view and that of the public opinion, to sacrifice water for profits from soil is not acceptable. In spite of the two systems, the economic and the physical ones, being independent of each other, their mutual relations must be coordinated and integrated with the objective of achieving benefits from soil and water utilization while conserving the quality of the environment.

In any case, we should expect the economic and social benefits (reduced water treatment costs and impact on human health, etc.), gained through stringent control over water quality, to cause the agricultural sector losses due to restrictions on its production. The preference of public interests (protection of public water supplies) will therefore have direct financial impact on the producer (farmer). The losses caused to farmers should be analyzed and compensated for by financial funds created for this purpose within national or regional economies.

The distribution of the benefits and costs between the water and agricultural sectors, integrated land use planning and groundwater protection management is the key factor in the strategy of effective soil and water resources utilization.

5.2.1 Examples of conflicts of interests between the agricultural and water sectors

Economic Measures against Leaching Losses of Nitrogen in Sweden are reported by Bring (1987). In Sweden, quality bonus payments for protein content in wheat and barley have been introduced. The result of these regulations is the farmers´ interest in attaining high yields with the protein content above the standard to receive the bonus. This requires increased input of nitrogen fertilizers which, in turn, leads to increased nitrogen leaching to the water system. With a view to environmental protection in Sweden, fertilization rates over 100 N kg/ha are not desirable as yields and the protein content do not increase significantly above this dosage, in contrast to nitrogen leaching which increases strongly. The relations between fertilization, harvest and nitrogen leaching on experimental plots have been evaluated and the so-called business economic optimum and environmental economic optimum have been established. Brink concludes that leaching will decrease if the protein bonus is abolished, the price of nitrogen increased and grain prices reduced.

Czechoslovak experience, based on several years of research on 20 to 30-ha plots, suggest that in second degree groundwater protection zones delineated in shallow unconfined aquifers where restriction of farming activities is implemented, cereal yields reach only about 75 per cent (3.5 t/ha/year) in comparison with farmland cultivated at full intensity. Assuming the average extent of the groundwater protection zone around a well to be approximately five hectares, the annual yield losses per protected well amount to US $ 1,375 (an equivalent of US $ 220 per tonne of wheat). Summarizing the average costs of comprehensive protection of water supply wells we obtain the following figures:

Labour cost on groundwater protection zone delineation per well	US $ 3,500
operational cost on groundwater quality monitoring of selected compounds per year as related with well protection area	US $ 8,000
yield losses (5 ha/well/year)	US $ 1,375
potential overhead costs per well	US $ 3,000
Total	US $ 15,875
of which annual operational costs are approx.	US $ 9,500

The operational costs of a conventional water treatment plant, following from the non-delineation of protection zones, inadequate protection management and subsequent groundwater quality deterioration, can be estimated at US $ 0.03 per cubic metre of water, i.e. some US $ 23,350 annually for a well yielding 50 l/s and operating 12 hours a day.

The capital costs of constructing a conventional treatment plant with a capacity of 0.5 m^3/s can be estimated at US $ 1.5 million, depending on prices in different countries.

A simplified example illustrates well the economic advantages of preventive groundwater protection in comparison with water treatment costs. Economic losses due to lower cereal production are not significant.

6 CONCLUSIONS

It has been illustrated on examples that groundwater protection is a less expensive process than rehabilitation of polluted ground water. However, groundwater protection should not be perceived as an isolated action but rather a long-term programme controlled and supported by Governments and their institutions. It is only this concept of groundwater resources protection which can be effective not merely from the economic, but also from the social and ecological points of view.

Assessment of social consequences of using low-quality groundwater has so far not been part of the cost/benefit analysis. The illness and death rates, impacts on human psychology, lower working abilities, migration of population, alimentary diseases, etc. should be included in the cost/benefits studies. In this field, however, data are available only exceptionally. Sometimes these damages are included into the intangible factors and not expressed in financial terms.

In the sphere of ecology, the effects of groundwater pollution are usually manifest with a delay, indirectly, and are frequently difficult to identify. Polluted groundwater affects many plant and animal species and the soil and rock system. In these cases, too, effects of polluted groundwater on the sphere of ecology are so far rarely included in the cost/benefit analysis.

The initial step in the economy of groundwater protection and conservation is the creation of a governmental organizational structure responsible for the establishment and implementation of a strategy and policy leading to legislature, management and control of groundwater resources.

(i) Within groundwater protection strategy and policy, decision should be made about the level of groundwater protection and the related financial costs, depending on the significance of groundwater resources for national, regional or local development. The cost/benefit analysis of protective, restrictive and remedial measures must be carried out, and adequate financial funds for implementing these measures should be secured. Effectiveness of aquifer reclamation should be observed in the frame of anti-pollution programmes.

(ii) Legislative measures based on Water and Environment Acts are essential for economy in groundwater protection and conservation. Special attention should be devoted to the regulations concerning the licences and permits for groundwater quality conservation. Regulations for groundwater quality protection should determine first of all the responsibility of polluters, rules of their penalization, and the prohibition or permission system for the discharge and burial of wastes. Within the anti-pollution regulations, various advantages could be established, such as tax benefits or low-interest loans, endowment,bonuses, etc. In the case of polluted water supplies, it is not the population which is to be financially afflicted. The financial responsibility for securing alternative supplies is borne by the polluter and the government regulations, particularly by well developed charging system. Legislative measures should include not only protection of groundwater supplies but also that of potential groundwater resources.

(iii) Groundwater protection management should be focused on overall preventive protection of groundwater resources over the whole national territory, and on comprehensive protection around groundwater public supplies. The conflicts and restrictive measures produced by protection of groundwater resources must be identified and analyzed from the economic and social points of view. The task of decision-makers is to choose a suitable strategy in defining priorities and preferences, with respect to national or regional development and to find balance between environmental protection policy and economic incentives. The monitoring activity significantly supports the groundwater protection management. The benefits derived from the financial means expended on monitoring should always be compared with the value of the information obtained. Statistical methods help to optimize the relations between monitoring costs and information losses. However, it is still difficult to express the value of groundwater monitoring data in financial terms and economic criteria.

(iv) Control should be extended particularly over the observance of legislative measures and regulations, and over the protection management process and monitoring activity. A groundwater protection programme is demanding in terms of technology, human energy and financial funds, and therefore control over the whole programme is desirable. A functioning control system completes the process of groundwater protection; it should guarantee that measures for pollution prevention are implemented and observed. In such a case, the benefits in the economic, social and ecologic spheres will be attained.

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