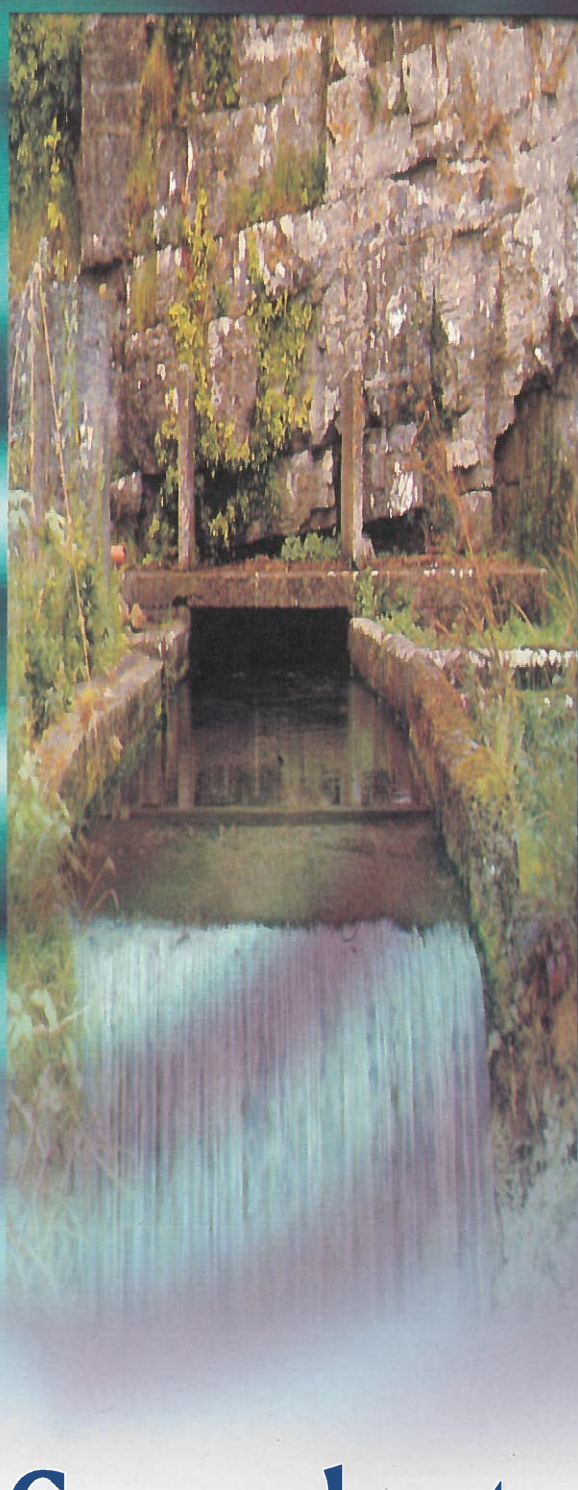




Groundwater Protection Schemes

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Department of the Environment and Local Government
Environmental Protection Agency
Geological Survey of Ireland



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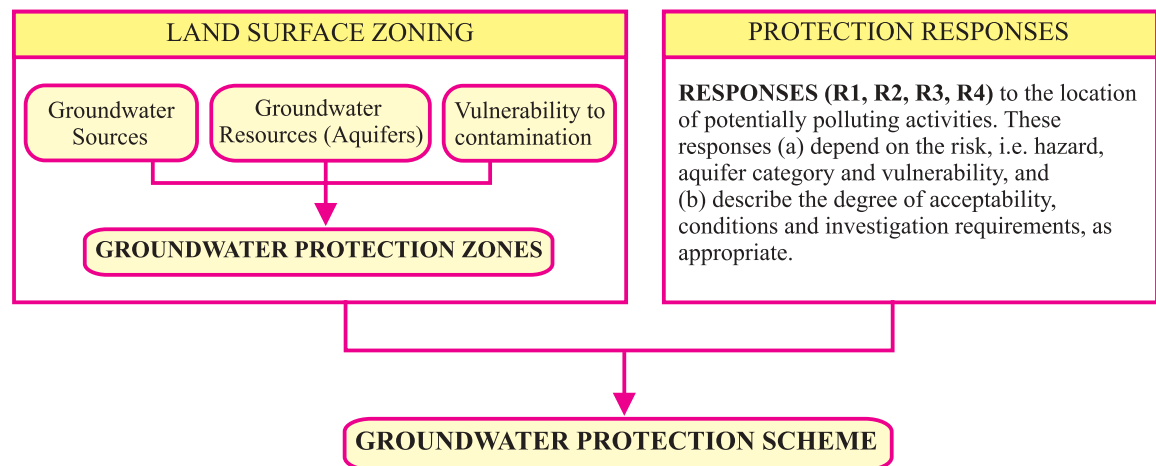
Executive Summary

Groundwater is an important natural resource which supplies some 20-25% of drinking water in Ireland and is important in maintaining wetlands and river flows through dry periods. Groundwater in Ireland is protected under European Community and national legislation, and local authorities and the Environmental Protection Agency (EPA) are responsible for enforcing this legislation. A practical and effective means of protecting groundwater and preventing pollution is through the use of a Groundwater Protection Scheme. The Geological Survey of Ireland (GSI), the Department of Environment and Local Government (DoELG) and the EPA have jointly developed a methodology for the preparation of Groundwater Protection Schemes, as outlined in this document.

A Groundwater Protection Scheme provides guidelines for the planning and licensing authorities in carrying out their functions, and a framework to assist in decision-making on the location, nature and control of developments and activities in order to protect groundwater. Use of a scheme will help to ensure that within the planning and licensing processes due regard is taken of the need to maintain the beneficial use of groundwater.

A Groundwater Protection Scheme aims to maintain the quantity and quality of groundwater, and in some cases improve it, by applying a risk assessment-based approach to groundwater protection and sustainable development. In this way it helps public authorities to meet their responsibility to protect groundwater. This would include planning authorities which have a major function in the development and control of land use and the built environment.

Two main components are integrated to produce a Groundwater Protection Scheme: (a) land surface zoning; and (b) groundwater protection responses for potentially polluting activities.



Summary of Components of a Groundwater Protection Scheme

The land surface zoning is presented on a Groundwater Protection Map which delineates land areas in terms of groundwater vulnerability to pollution and groundwater potential and is compiled by combining an Aquifer Map and a Groundwater Vulnerability Map. These, in turn, are derived from a series of primary maps: bedrock and subsoil geology, depth to bedrock, and hydrogeological data.

Groundwater protection responses for the different zones indicate the acceptability of a particular activity with respect to the potential hazard, aquifer category or source protection area, and groundwater vulnerability. The responses outline the design and construction conditions and investigation requirements which may be appropriate. Responses have been developed for potential hazards such as landfills, on-site wastewater treatment systems (septic tanks) and landspreading of organic wastes. These responses are published separately (DoELG / EPA / GSI, 1999).

A scheme also provides for the delineation of Source Protection Areas around significant groundwater supply sources. These areas are subdivided into Inner and Outer protection areas, based on the 100 day time of travel and the catchment area respectively, and the associated vulnerability is superimposed on these sub-divisions, to give Source Protection Zones.

All zones delineated under a scheme should be regarded as provisional. Site specific investigations may provide information that enables the zonation to be improved.

A scheme can also be used pro-actively: for example, to identify suitable sites for potentially polluting developments by avoiding, where possible, the main aquifers and vulnerable areas; or to locate water supply sources by identifying the best aquifers and avoiding the most vulnerable areas.

Detailed bedrock maps will soon be available for the whole country, but detailed subsoil maps will not be available for a number of years. In the absence of adequate mapping it is not possible to produce a comprehensive Groundwater Protection Scheme for every county. However, interim measures can be developed which apply the same concepts and principles. Thus a local authority can determine an appropriate groundwater protection response for a particular activity if they have site specific information on the vulnerability and aquifer classification.

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1. Introduction

The primary responsibility for groundwater protection rests with any person who is carrying out an activity that poses a threat to groundwater. The protection of groundwater quality from the impact of human activities is a high priority because:

- groundwater is an important source of water for industry, agriculture and drinking water;
- groundwater moves slowly through the ground and so the impact of human activities lasts for a relatively long time;
- groundwater may be difficult to clean up, even when the source of pollution is removed;
- groundwater provides baseflow to surface water systems and accordingly its quality influences the amenity and recreational value of surface water and its potential use for water supply purposes;
- unlike surface water where flow is in defined channels, groundwater is present everywhere;
- agricultural, industrial and other human activities are posing increasing risks to groundwater quality;
- EU legislation and national regulations require that pollution must be prevented (as part of sustainable groundwater quality management).

The most practical and effective means of protecting groundwater and preventing pollution, for land-use planners and water resources managers, is through the use of groundwater protection schemes.

Since the mid 1980s, a number of local authorities – Offaly, Wexford, north Cork, Galway and Louth – have been successfully using groundwater protection schemes. These are based on a relatively simple scheme proposed by the Geological Survey of Ireland in the early 1980s and appropriate to the available hydrogeological information and planning needs of that time. Now a more comprehensive scheme, using a greater geological and hydrogeological input, is required to enable better and more defensible decision-making in land-use planning and environmental protection.

The level of available geological and hydrogeological information on which to base a groundwater protection scheme varies from area to area at present. Where the information is adequate, a comprehensive scheme, based on hydrogeological concepts, is achievable. As adequate geological information, particularly on subsoils, is not available for a significant proportion of the country at present, it will not be possible to produce comprehensive groundwater protection schemes for every local authority area in the short term. However, the concept and principles of a Groundwater Protection Scheme can still be used as a basis for decision-making regarding groundwater protection. Interim groundwater protection measures are recommended pending a comprehensive scheme, reflecting the precautionary principle for environmental protection.

A scheme consists of two closely interlinked components: (i) **land surface** (groundwater protection) **zones**, based on hydrogeological concepts and information particularly regarding aquifers and vulnerability; and (ii) **groundwater protection responses** for potentially polluting activities, which give guidelines on the acceptability of the activities, investigation requirements and, where appropriate, the likely planning or licensing controls.

A groundwater protection scheme enables regulatory authorities to take account of: (a) the potential risks to groundwater resources and sources; and (b) geological and hydrogeological factors, when considering the control and location of potentially polluting activities. In practice its use needs a realistic and flexible approach. The groundwater protection zone maps have limitations because they generalise (according to data availability) variable and complex geological and hydrogeological conditions. Therefore, a scheme provides a technical framework to assist in decision-making on the location and nature of developments and activities with the view to ensuring the protection of groundwater. It is not prescriptive and decisions may need to be qualified by site-specific considerations.

2. Background Factors and Key Principles

2.1 Groundwater: An Important Resource

Groundwater is a major natural resource in Ireland providing between 20% and 25% of drinking water supplies. In certain counties, particularly in the midlands, the proportion is much greater, e.g. north Cork 90%, Roscommon 86%, Offaly 60%, Laois 54%, and Kilkenny 52%. In rural areas not served by public or group water schemes, groundwater is usually the only source of supply and there are many thousands of wells and springs (at least 100,000) in use. Many industries, especially food processing industries such as creameries and meat factories, have their own water supply, often from groundwater. There are vast groundwater resources available and which are unused for water supply at present.

2.2 Groundwater: a Resource at Risk

Groundwater is a resource which is under increasing risk from human activities, for the following reasons:

- since groundwater flow and contaminant transport are neither readily observed nor easily measured, and both processes are generally slow, there can be a lack of awareness or, in some instances, complacency among decision-makers about the risks of groundwater contamination;
- contamination of wells and springs is occurring;
- there is widespread application of domestic, agricultural and industrial effluents to the ground;
- the quantities of domestic and industrial wastes are increasing, and landfill is the principle disposal route;
- there has been a significant increase in the application of inorganic fertilizers to agricultural land and in the usage of pesticides since the 1960s;
- greater volumes of road traffic and more storage of fuels/chemicals; and
- chemicals of increasing diversity and often high toxicity are being manufactured, distributed and used for a wide range of purposes.

The main threat to groundwater is posed by: (a) point contamination sources; e.g. farmyard wastes (mainly silage effluent and soiled water), septic tank effluent, sinking streams, leakages, spillages, pesticides used for non-agricultural purposes and leachate from waste disposal sites; and (b) diffuse sources; e.g. spreading of fertilizers (organic and inorganic) and pesticides. While point sources have caused most of the contamination problems identified to-date, there is evidence that diffuse sources are increasingly impacting on groundwater.

2.3 Groundwater Contamination Prevention

Prevention of groundwater contamination is of critical importance and must be a key aim for the following reasons:

- Once groundwater contamination occurs, the consequences last far longer than surface water contamination (months, years and sometimes decades) because groundwater moves slowly. Remediation is frequently not practical or is very expensive. Also, it is both impractical and a poor environmental strategy to provide comprehensive treatment

to remove certain pollutants, such as pesticides and other trace organics. It is therefore preferable to prevent or reduce the risk of groundwater contamination than to deal with its consequences.

- Groundwater is an important resource in Ireland, used for drinking water, industry and agriculture, and should be protected for present and future usage.
- Groundwater provides the baseflow (i.e. the water which feeds rivers year-round, and upon which flood flows are superimposed) to surface water systems, many of which are used for water supply and recreational purposes. In many rivers, more than 50% of the annual flow is derived from groundwater and more significantly, in low flow periods in summer, more than 90% is groundwater. If groundwater becomes contaminated surface water quality can also be affected and so the protection of groundwater resources is an important aspect of sustaining surface water quality.
- Contaminated drinking water is a health hazard and once contamination has occurred, drilling of new wells is expensive and in some cases not practical. Consequently “prevention is better than cure”.
- It is an offence to pollute groundwater under the Local Government (Water Pollution) Acts of 1977 and 1990.

2.4 Groundwater Protection Through Land-use Planning: a Means of Preventing Contamination

There are a number of ways of preventing contamination, such as improved well siting, design and construction and better design and management of potential contamination sources. However, one of the most effective ways is utilising groundwater protection schemes as part of the planning process.

Land-use planning (including environmental impact assessment), integrated pollution control licensing, waste licensing, water quality management planning, water pollution legislation, etc., are the main methods used in Ireland for balancing the need to protect the environment with the need for development. However, land-use planning is a dynamic process with social, economic and environmental interests and impacts influencing to varying degrees the use of land and water. In a rural area, farming, housing, industry, tourism, conservation, waste disposal, water supply, etc., are potentially interactive and conflicting and may compete for priority. How does groundwater (and groundwater pollution prevention) fit into this complex and difficult situation, particularly as it is a resource that is underground and for many people is “out of sight, out of mind”? Groundwater protection schemes enable planning and other regulatory authorities to take account of both geological and hydrogeological factors in locating developments; consequently they are an essential means of preventing groundwater pollution. The schemes should be formally adopted by planning authorities in their development plans.

2.5 Environmental Principles

The Government's environmental policy incorporates the following principles, which are taken from Sustainable Development: A Strategy for Ireland (DoE, 1997).

- **Sustainable Development**

The Government's strategy for sustainable development seeks to ensure that economy and society in Ireland can develop to their full potential within a well protected environment, and with responsibility towards present and future generations and the wider international community.

- **Precautionary Principle**

The precautionary principle requires that emphasis should be placed on dealing with the causes, rather than the results, of environmental damage and that, where significant evidence of environmental risk exists, appropriate action should be taken even in the absence of conclusive scientific proof of cause.

- **Polluter Pays Principle**

Its objective is to allocate correctly the costs of pollution, consumption of energy and environmental resources, and production and disposal of waste to the responsible polluters and consumer, rather than to society at large or future generations; in turn, this provides an incentive to reduce pollution and consumption.

These principles are the basis for a groundwater protection scheme as outlined herein. Also, the concept of risk and the requirement to take account of the risk of contamination to groundwater from potentially polluting activities have been integrated into the scheme.

2.6 European Union Policy

In 1980 the European Commission adopted a Groundwater Directive (80/68/EEC) which was aimed largely at the control of discharges of specified substances to groundwater. The Directive applies to a restricted range of substances which could pose a serious threat to groundwater quality, through direct discharge, waste disposal operations or other activities on or in the ground.

The need for further action to avoid long term deterioration of the quality of freshwater resources was recognised by the participants at the Ministerial Seminar on groundwater held in The Hague in November 1991. The final declaration stated that:

- groundwater is a natural resource with both ecological and economic value, which is of vital importance for sustaining life, health, agriculture and the integrity of ecosystems;
- groundwater resources are limited and should be protected on a sustainable basis; and
- it is essential to protect groundwater resources from overexploitation, adverse changes in hydrological systems resulting from human activities, and pollution, many forms of which can produce irreversible damage.

The declaration stresses that the objective of sustainability should be implemented through an integrated approach, which means that:

- surface water and groundwater should be managed as a whole, paying equal attention to both quality and quantity aspects;
- all interaction with soil and atmosphere should be taken into account; and
- water management policies should be integrated within the wider environmental framework as well as with other policies dealing with human activities such as agriculture, industry, energy, transport and tourism.

At present an EU proposal for a Council Directive establishing a framework for Community action in the field of water policy is being prepared to enable sustainable use of water (including groundwater) as part of integrated management and protection of water resources. At Member State level, national action programmes, incorporating groundwater protection policies, will be required.

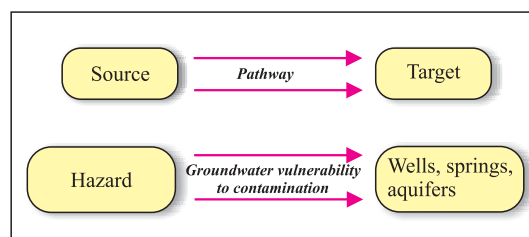
2.7 Risk and Risk Management: a Framework for Groundwater Protection Schemes

Risk can be defined as the likelihood or expected frequency of a specified adverse consequence. Applied to groundwater, it expresses the likelihood of contamination arising from potentially polluting sources or activities (called the **hazard**). A hazard presents a risk when it is likely to affect something of value (the **target**, which in this case is groundwater). It is the combination of the probability of the hazard occurring and its consequences that is the basis of **risk assessment**.

$$\text{RISK} = \text{PROBABILITY OF AN EVENT} \times \text{CONSEQUENTIAL DAMAGE}$$

Protection, like risk, is a relative concept in the sense that there is an implied degree of protection (absolute protection is not possible). An increasing level of protection is equivalent to reducing the risk of damage to the protected quantity, e.g. groundwater. Moreover, choosing the appropriate level of protection necessarily involves placing a relative value on the protected quantity.

Groundwater protection schemes are usually based on the concepts of groundwater contamination risk and risk management. In the past, these concepts were in the background, often implicit, sometimes intuitive factors. However, with the language and thought-processes associated with risk and risk assessment becoming more common, relating a groundwater protection scheme to these concepts allows consistent application of a protection policy and encourages a rigorous and systematic approach. The conventional source-pathway-target model for environmental management can be applied to groundwater risk management:



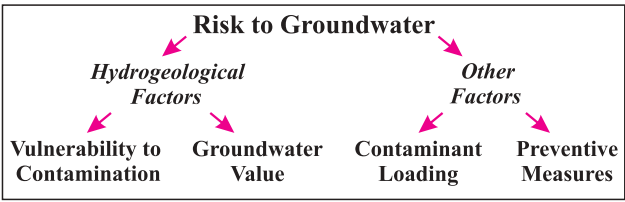
The **risk** of contamination of groundwater depends on three elements:

- (i) the **hazard** afforded by a potentially polluting activity;
- (ii) the **vulnerability** of groundwater to contamination;
- (iii) the potential **consequences** of a contamination event.

Risk management is based on analysis of these three elements followed by a **response** to the risk. This response includes the assessment and selection of options and the **implementation of measures** to prevent or minimise the consequences and probability of a contamination event.

The **hazard** depends on the potential **contaminant loading**. The natural **vulnerability** of the groundwater dictates the **likelihood of contamination** if a contamination event occurs. The **consequences** to the target depends on the **value** of the groundwater, which is normally indicated by the aquifer category (regionally important, locally important or poor) and the proximity to an important groundwater abstraction source (a public supply well, for instance). **Preventive measures** may include, for instance: control of land-use practices and in particular directing developments towards lower risk areas; suitable building codes that take account of the vulnerability and value of the groundwater; lining of landfill sites; installation of monitoring networks; specific operational practices. Consequently, assessing the risk of contamination to groundwater is complex. It encompasses geological and hydrogeological factors and factors that relate to the potentially polluting activity. The geological and hydrogeological factors are

the vulnerability to contamination and the relative importance or value of the groundwater resource. The factors that relate to the potentially polluting activity are the contaminant loading and the preventive measures.



A conceptual model of the relationship between these factors is given in Figure 1, where septic tank effluent is taken as the hazard. A groundwater protection scheme as outlined here integrates these factors and in the process serves to focus attention on the higher risk areas and activities, and provides a logical structure within which contaminant control measures can be selected.

To some extent, exposure of groundwater to a hazard can be minimised by engineering measures (for example, use of landfill liners). However, in most cases, a significant element of the total exposure to the hazard will depend on the natural geological and hydrogeological conditions, which properly determine the vulnerability or the sensitivity of the groundwater to contamination. Engineering measures may be required in some situations to reduce the risk further.

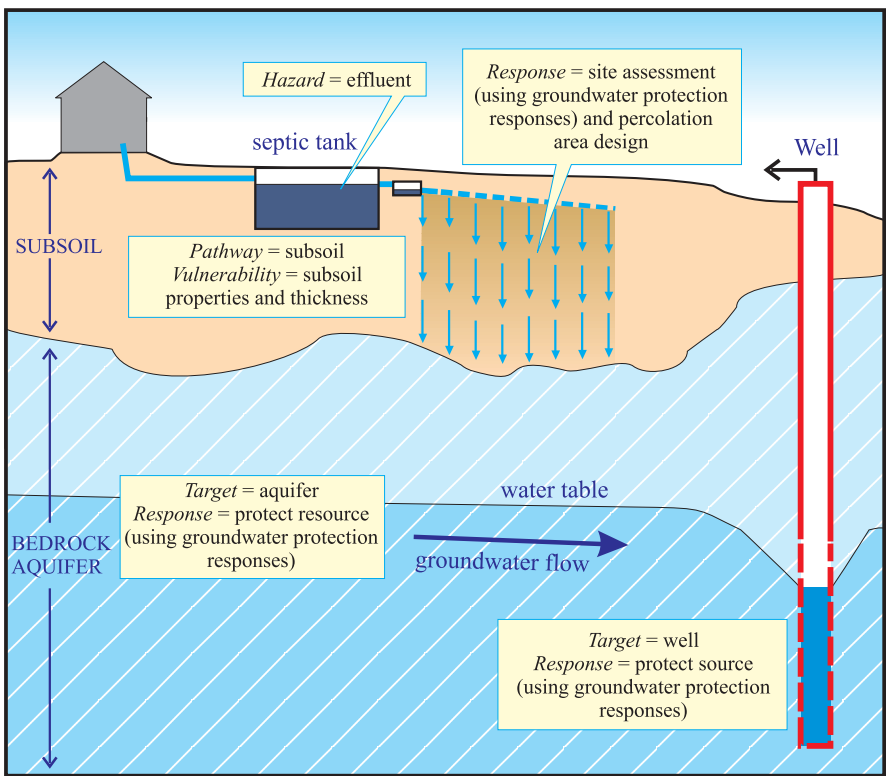


Figure 1. Schematic diagram showing how the elements of risk are applied to groundwater protection

2.8 Objectives of a Groundwater Protection Scheme

The overall aim of a scheme is to preserve the quality of groundwater, particularly for abstraction purposes, for the benefit of present and future generations.

The principal objectives, which are interrelated, are as follows:

- to assist public authorities to meet their statutory responsibilities for the protection and conservation of groundwater resources;
- to provide geological and hydrogeological information for the regulatory process, so that developments can be located and controlled in an environmentally acceptable way; and
- to integrate the factors associated with the risk of contamination, focus attention on the higher risk areas and activities, and provide a logical structure within which control measures can be selected.

A scheme provides a framework for decision-making and guidelines for the public authorities in carrying out their functions. As groundwater protection decisions are often complex, sometimes requiring detailed geological and hydrogeological information, a scheme requires flexibility to take account of site-specific considerations.

2.9 How a Groundwater Protection Scheme Works

There are **two main components** of a groundwater protection scheme (Figure 2):

- **Land surface zoning**, which encompasses the hydrogeological elements of risk.
- **Groundwater protection responses for potentially polluting activities**, which encompass both the contaminant loading element of risk and planning/preventative measures as a response to the risk.

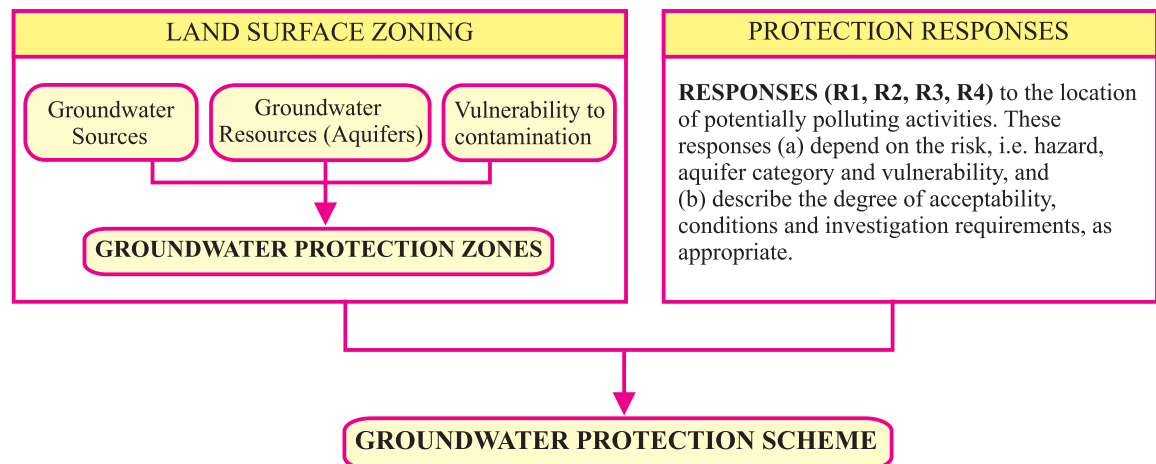


Figure 2. Summary of Components of a Groundwater Protection Scheme

Land surface zoning provides the general framework for a groundwater protection scheme. The outcome is a map, which divides any chosen area into a number of groundwater protection zones according to the degree of protection required. The quality and level of sophistication of the land surface zoning map usually depends on the data and resources (time, money and staff) available, and on the degree of hydrogeological analysis used. Delineation of protection zones based on 'adequate' hydrogeological information and analysis is recommended as a defensible basis for planning and development decisions.

There are three main hydrogeological elements to land surface zoning:

- Division of the entire land surface according to the **vulnerability** of the underlying groundwater to contamination. This requires production of a vulnerability map showing four vulnerability categories.
- Delineation of **areas surrounding groundwater sources** (usually public supply sources); these are termed source protection areas.
- Delineation of areas according to the value of the groundwater resources or **aquifer category**: these are termed resource protection areas.

These three elements are integrated together to give maps showing **groundwater protection zones**; source protection zones and resource protection zones.

The location and management of potentially polluting activities in each groundwater protection zone is by means of a **groundwater protection response matrix** for each activity or group of activities, which describes: (i) the degree of acceptability of each activity; (ii) the conditions to be applied; and, in some instances (iii) the investigations that may be necessary prior to decision-making.

While the two components (the protection zone maps and the groundwater protection responses) are different, they are incorporated together and closely interlinked in a scheme.

3. Land Surface Zoning for Groundwater Protection

3.1 Information and Mapping Requirements for Land Surface Zoning

The **groundwater resources protection zone map** is a land-use planning map, and therefore is the most useful map for the decision-making process. It is the ultimate or final map as it is obtained by combining the **aquifer** and **vulnerability maps**. The **aquifer map** boundaries, in turn, are based on the **bedrock map** boundaries and the **aquifer categories** are obtained from an assessment of the available **hydrogeological data**. The **vulnerability map** is based on the **subsoils map**, together with an assessment of relevant **hydrogeological data**, in particular indications of permeability and karstification. This is illustrated in Figure 3.

Similarly, the **source protection zone maps** result from combining **vulnerability** and **source protection area maps**. The **source protection areas** are based largely on assessments of **hydrogeological data**. This is illustrated in Figure 4.

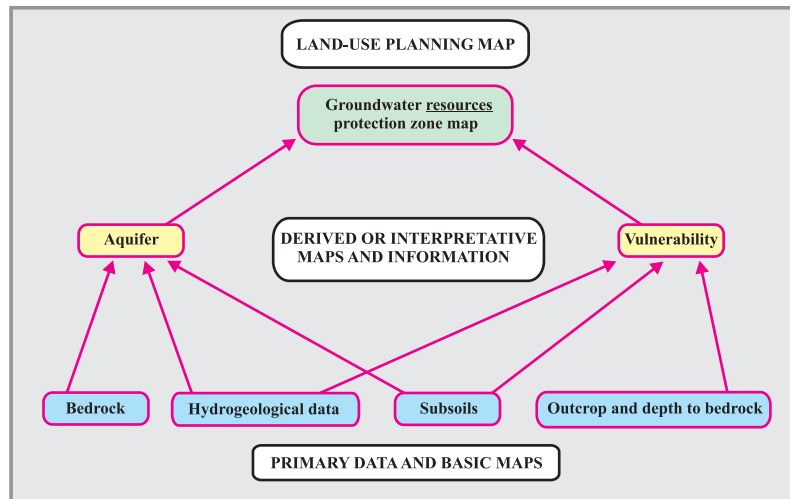


Figure 3. Conceptual framework for production of groundwater resource protection zones, indicating information needs and links

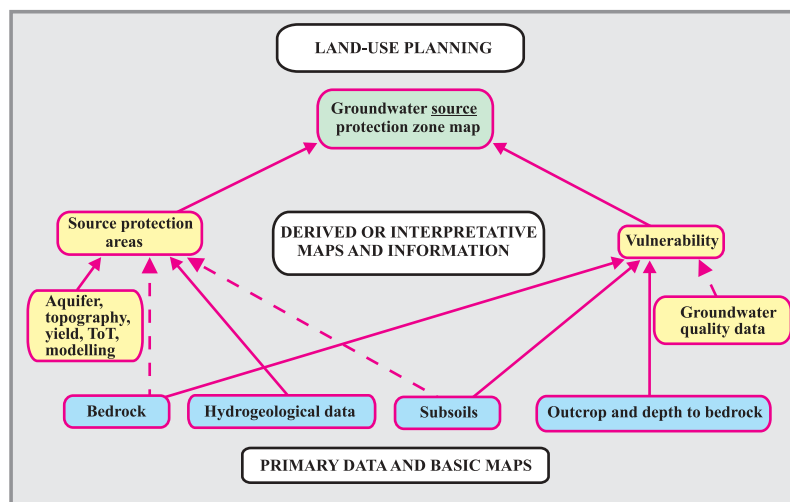


Figure 4. Conceptual framework for production of groundwater source protection zones, indicating information needs and links

3.2 Vulnerability Categories

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

The vulnerability of groundwater depends on: (i) the time of travel of infiltrating water (and contaminants); (ii) the relative quantity of contaminants that can reach the groundwater; and (iii) the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate. As all groundwater is hydrologically connected to the land surface, it is the effectiveness of this connection that determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is considered to be more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. The travel time, attenuation capacity and quantity of contaminants are a function of the following natural geological and hydrogeological attributes of any area:

- (i) the subsoils that overlie the groundwater;
- (ii) the type of recharge - whether point or diffuse; and
- (iii) the thickness of the unsaturated zone through which the contaminant moves.

In general, little attenuation of contaminants occurs in the bedrock in Ireland because flow is almost wholly via fissures. Consequently, the subsoils (sands, gravels, glacial tills (or boulder clays), peat, lake and alluvial silts and clays), are the single most important natural feature influencing groundwater vulnerability and groundwater contamination prevention. Groundwater is most at risk where the subsoils are absent or thin and, in areas of karstic limestone, where surface streams sink underground at swallow holes.

The geological and hydrogeological characteristics can be examined and mapped, thereby providing a groundwater vulnerability assessment for any area or site. Four groundwater vulnerability categories are used in the scheme - **extreme (E)**, **high (H)**, **moderate (M)** and **low (L)**. The hydrogeological basis for these categories is summarised in Table 1 and further details can be obtained from the GSI. The ratings are based on pragmatic judgements, experience and available technical and scientific information. However, provided the limitations are appreciated, vulnerability assessments are essential when considering the location of potentially polluting activities. As groundwater is considered to be present everywhere in Ireland, the vulnerability concept is applied to the entire land surface. The ranking of vulnerability does not take into consideration the biologically-active soil zone, as contaminants from point sources are usually discharged below this zone, often at depths of at least 1m. However, the groundwater protection responses take account of the point of discharge for each activity.

Vulnerability maps are an important part of groundwater protection schemes and are an essential element in the decision-making on the location of potentially polluting activities. Firstly, the vulnerability rating for an area indicates, and is a measure of, the likelihood of contamination. Secondly, the vulnerability map helps to ensure that a groundwater protection scheme is not unnecessarily restrictive on human economic activity. Thirdly, the vulnerability map helps in the choice of preventative measures and enables developments, which have a significant potential to contaminate, to be located in areas of lower vulnerability.

In summary, the entire land surface is divided into four vulnerability categories - extreme (**E**), high (**H**), moderate (**M**) and low (**L**) - based on the geological and hydrogeological factors described above. This subdivision is shown on a groundwater vulnerability map. The map shows the vulnerability of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1-2 m below the ground surface. Where contaminants are released at significantly different depths, there will be a need to determine groundwater vulnerability using site-specific data. The characteristics of individual contaminants are not taken into account.

Vulnerability Rating	Hydrogeological Conditions				
	Subsoil Permeability (Type) and Thickness			Unsaturated Zone	Karst Features
	High permeability (sand/gravel)	Moderate permeability (e.g. Sandy subsoil)	Low permeability (e.g. Clayey subsoil, clay, peat)	(Sand/gravel aquifers only)	(<30 m radius)
Extreme (E)	0 - 3.0m	0 - 3.0m	0 - 3.0m	0 - 3.0m	-
High (H)	> 3.0m	3.0 - 10.0m	3.0 - 5.0m	> 3.0m	N/A
Moderate (M)	N/A	> 10.0m	5.0 - 10.0m	N/A	N/A
Low (L)	N/A	N/A	> 10.0m	N/A	N/A
Notes: (1) N/A = not applicable. (2) Precise permeability values cannot be given at present. (3) Release point of contaminants is assumed to be 1-2 m below ground surface.					

Table 1. Vulnerability Mapping Guidelines

3.3 Source Protection Zones

Groundwater sources, particularly public, group scheme and industrial supplies, are of critical importance in many regions. Consequently, the objective of source protection zones is to provide protection by placing tighter controls on activities within all or part of the zone of contribution (ZOC) of the source.

There are two main elements to source protection land surface zoning:

- Areas surrounding individual groundwater sources; these are termed source protection areas (SPAs)
- Division of the SPAs on the basis of the vulnerability of the underlying groundwater to contamination.

These elements are integrated to give the source protection zones.

3.3.1 Delineation of Source Protection Areas

Two source protection areas are recommended for delineation:

- Inner Protection Area (**SI**);
- Outer Protection Area (**SO**), encompassing the remainder of the source catchment area or ZOC.

In delineating the inner (SI) and outer (SO) protection areas, there are two broad approaches: first, using arbitrary fixed radii, which do not incorporate hydrogeological considerations; and secondly, a scientific approach using hydrogeological information and analysis, in particular the hydrogeological characteristics of the aquifer, the direction of groundwater flow, the pumping rate and the recharge.

Where the hydrogeological information is poor and/or where time and resources are limited, the simple zonation approach using the arbitrary fixed radius method is a good first step that requires little technical expertise. However, it can both over- and under-protect. It usually over-protects on the downgradient side of the source and may under-protect on the upgradient side, particularly in karst areas. It is particularly inappropriate in the case of springs where there is no part of the downgradient side in the ZOC. Also, the lack of a scientific basis reduces its defensibility as a method.

There are several hydrogeological methods for delineating SPAs. They vary in complexity, cost and the level of data and hydrogeological analysis required. Four methods, in order of increasing technical sophistication, are used by the GSI:

- (i) calculated fixed radius;
- (ii) analytical methods;
- (iii) hydrogeological mapping; and
- (iv) numerical modelling.

Each method has limitations. Even with relatively good hydrogeological data, the heterogeneity of Irish aquifers will generally prevent the delineation of definitive SPA boundaries. Consequently, the boundaries must be seen as a guide for decision-making, which can be reappraised in the light of new knowledge or changed circumstances.

3.3.1.1 Inner Protection Area (SI)

This area is designed to protect against the effects of human activities that might have an immediate effect on the source and, in particular, against microbial pollution. The area is defined by a 100-day time of travel (TOT) from any point below the water table to the source. (The TOT varies significantly between regulatory agencies in different countries. The 100-day limit is chosen for Ireland as a relatively conservative limit to allow for the heterogeneous nature of Irish aquifers and to reduce the risk of pollution from bacteria and viruses, which in some circumstances can live longer than 50 days in groundwater.) In karst areas, it will not usually be feasible to delineate 100-day TOT boundaries, as there are large variations in permeability, high flow velocities and a low level of predictability. In these areas, the total catchment area of the source will frequently be classed as SI.

If it is necessary to use the arbitrary fixed radius method, a distance of 300m is normally used. A semi-circular area is used for springs. The distance may be increased for sources in karst aquifers and reduced in granular aquifers and around low yielding sources.

3.3.1.2 Outer Protection Area (SO)

This area covers the remainder of the ZOC (or complete catchment area) of the groundwater source. It is defined as the area needed to support an abstraction from long-term groundwater recharge i.e. the proportion of effective rainfall that infiltrates to the water table. The abstraction rate used in delineating the zone will depend on the views and recommendations of the source owner. A factor of safety can be taken into account whereby the maximum daily abstraction rate is increased (typically by 50%) to allow for possible future increases in abstraction and for expansion of the ZOC in dry periods. In order to take account of the heterogeneity of many Irish aquifers and possible errors in estimating the groundwater flow direction, a variation in the flow direction (typically $\pm 10-20^\circ$) is frequently included as a safety margin in delineating the ZOC.

A conceptual model of the ZOC and the 100-day TOT boundary is given in Figure 5.

If the arbitrary fixed radius method is used, a distance of 1000m is recommended with, in some instances, variations in karst aquifers and around springs and low-yielding wells.

The boundaries of the SPAs are based on the horizontal flow of water to the source and, in the case particularly of the Inner Protection Area, on the time of travel in the aquifer. Consequently, the vertical movement of a water particle or contaminant from the land surface to the water table is not taken into account. This vertical movement is a critical factor in contaminant attenuation, contaminant flow velocities and in dictating the likelihood of contamination. It can be taken into account by mapping the groundwater vulnerability to contamination.

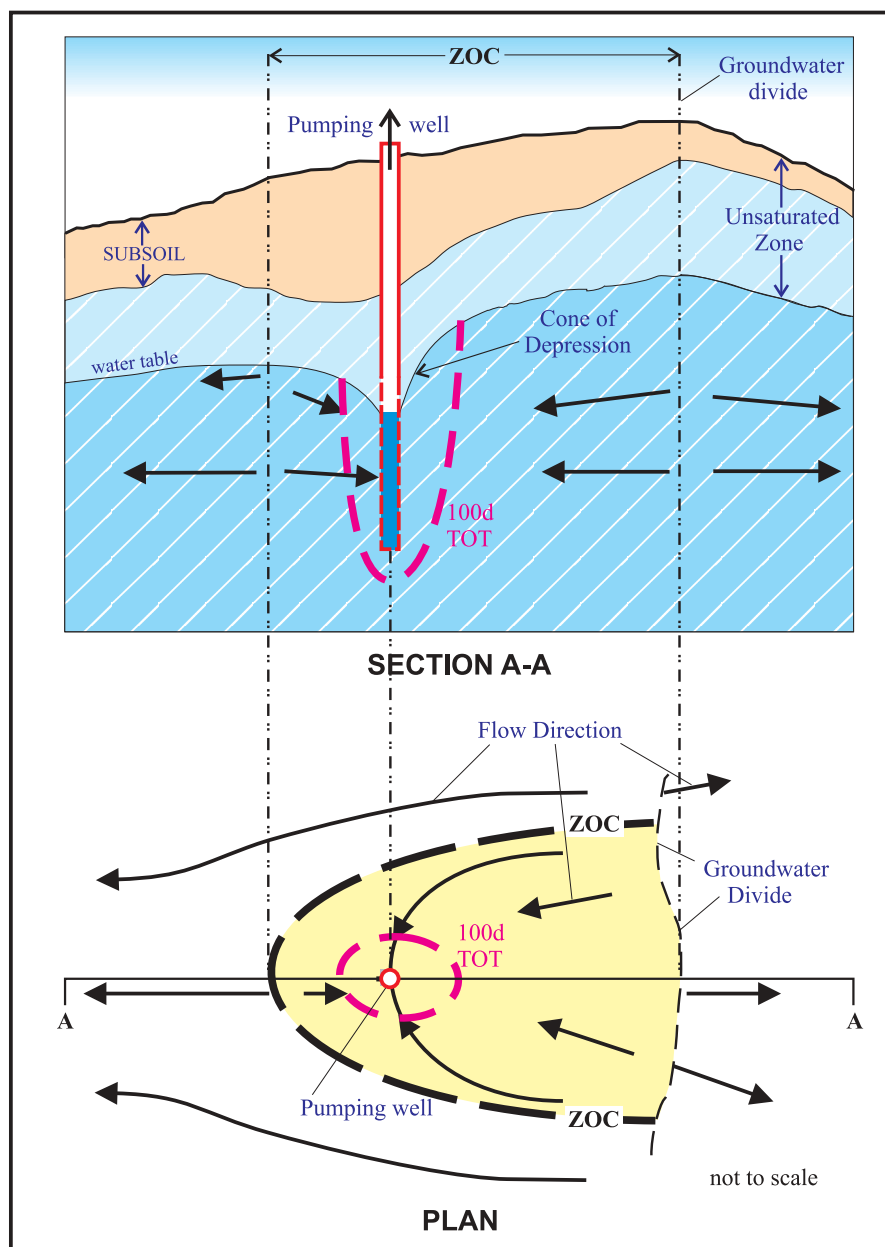


Figure 5. Conceptual Model of the Zone of Contribution (ZOC) at a Pumping Well (adapted from US EPA, 1987)

3.3.2 Delineation of Source Protection Zones

The matrix in Table 2 below gives the result of integrating the two elements of land surface zoning (SPAs and vulnerability categories) – a possible total of eight source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SO/H**, which represents an Outer Source Protection area where the groundwater is highly vulnerable to contamination. The recommended map scale is 1:10,560 (or 1:10,000 if available), though a smaller scale may be appropriate for large springs.

VULNERABILITY RATING	SOURCE PROTECTION ZONE	
	Inner (SI)	Outer (SO)
Extreme (E)	SI/E	SO/E
High (H)	SI/H	SO/H
Moderate (M)	SI/M	SO/M
Low (L)	SI/L	SO/L

Table 2. Matrix of Source Protection Zones

All of the hydrogeological settings represented by the zones may not be present around each groundwater source. The integration of the SPAs and the vulnerability ratings is illustrated in Figure 6.

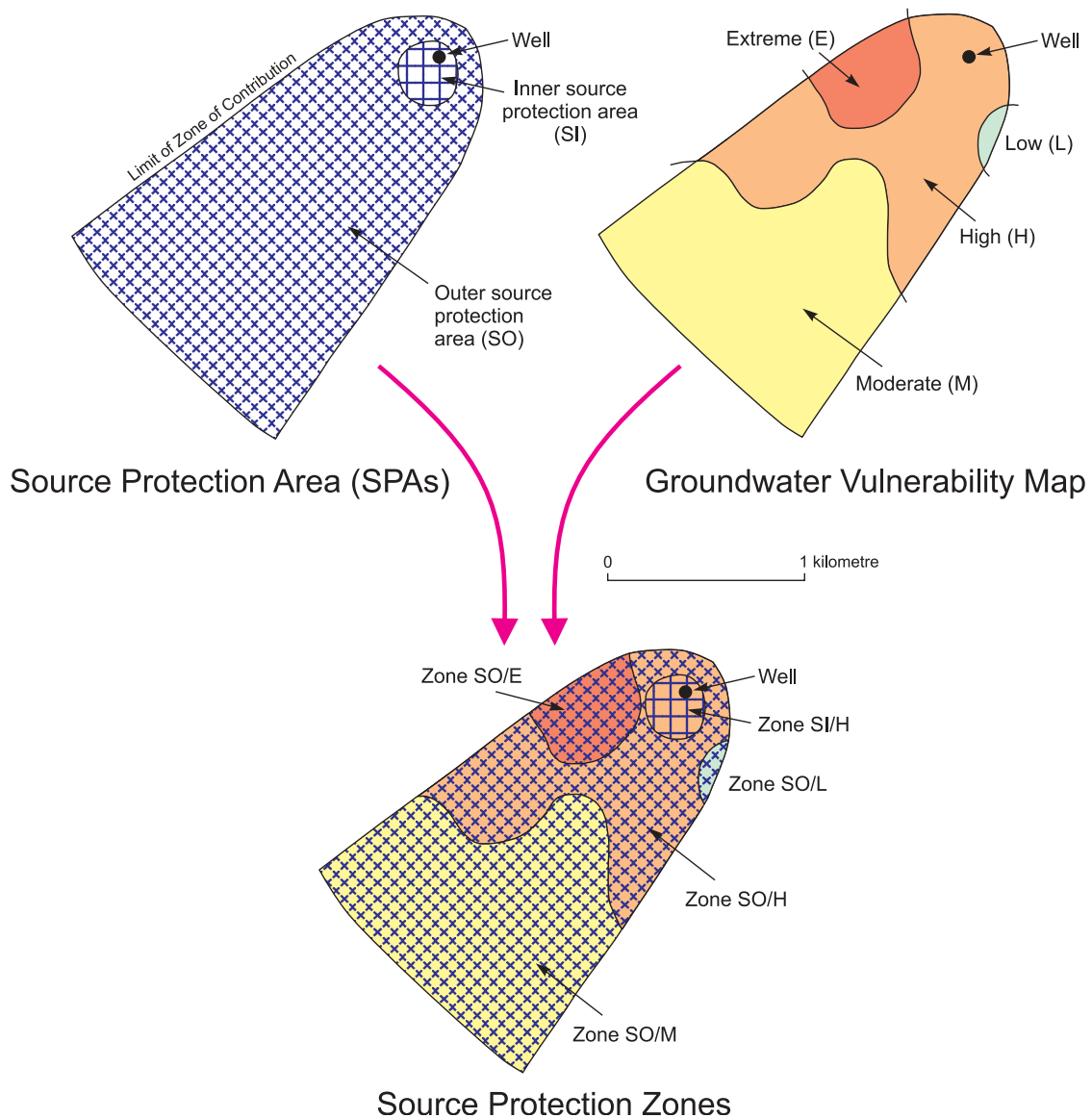


Figure 6. Delineation of source protection zones around a public supply well from the integration of the source protection area map and the vulnerability map.

3.4 Resource Protection Zones

For any region, the area outside the SPAs can be subdivided, based on the value of the resource and the hydrogeological characteristics, into eight aquifer categories:

Regionally Important (R) Aquifers

- (i) Karstified aquifers (**Rk**)
- (ii) Fissured bedrock aquifers (**Rf**)
- (iii) Extensive sand/gravel aquifers (**Rg**)

Locally Important (L) Aquifers

- (i) Sand/gravel (**Lg**)
- (ii) Bedrock which is Generally Moderately Productive (**Lm**)
- (iii) Bedrock which is Moderately Productive only in Local Zones (**L1**)

Poor (P) Aquifers

- (i) Bedrock which is Generally Unproductive except for Local Zones (**P1**)
- (ii) Bedrock which is Generally Unproductive (**Pu**)

These aquifer categories are shown on an aquifer map, which can be used not only as an element of a groundwater protection scheme but also for groundwater development purposes.

The matrix in Table 3 below gives the result of integrating the two regional elements of land surface zoning (vulnerability categories and resource protection areas) – a possible total of 24 resource protection zones. In practice this is achieved by superimposing the vulnerability map on the aquifer map. Each zone is represented by a code e.g. **Rf/M**, which represents areas of regionally important fissured aquifers where the groundwater is moderately vulnerable to contamination. In land surface zoning for groundwater protection purposes, regionally important sand/gravel (**Rg**) and fissured aquifers (**Rf**) are zoned together, as are locally important sand/gravel (**Lg**) and bedrock which is moderately productive (**Lm**). All of the hydrogeological settings represented by the zones may not be present in each local authority area.

VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf/Rg	Lm/Lg	L1	P1	Pu
Extreme (E)	Rk/E	Rf/E	Lm/E	L1/E	P1/E	Pu/E
High (H)	Rk/H	Rf/H	Lm/H	L1/H	P1/H	Pu/H
Moderate (M)	Rk/M	Rf/M	Lm/M	L1/M	P1/M	Pu/M
Low (L)	Rk/L	Rf/L	Lm/L	L1/L	P1/L	Pu/L

Table 3. Matrix of Resource Protection Zones

3.5 Flexibility, Limitations and Uncertainty

The land surface zoning is only as good as the information which is used in its compilation (geological mapping, hydrogeological assessment, etc.) and these are subject to revision as new information is produced. Therefore a scheme must be flexible and allow for regular revision.

Uncertainty is an inherent element in drawing geological boundaries and there is a degree of generalisation because of the map scales used. Therefore the scheme is not intended to give sufficient information for site-specific decisions. Also, where site specific data received by a regulatory body in the future are at variance with the maps, this does not undermine a scheme, but rather provides an opportunity to improve it.

4. Groundwater Protection Responses

4.1 Introduction

The location and management of potentially polluting activities in each groundwater protection zone is by means of a **groundwater protection response matrix** for each activity or group of activities. The level of response depends on the different elements of risk: the vulnerability, the value of the groundwater (with sources being more valuable than resources and regionally important aquifers more valuable than locally important and so on) and the contaminant loading. By consulting a **Response Matrix**, it can be seen: (a) whether such a development is likely to be acceptable on that site; (b) what kind of further investigations may be necessary to reach a final decision; and (c) what planning or licensing conditions may be necessary for that development. The groundwater protection responses are a means of ensuring that good environmental practices are followed.

Four levels of response (**R**) to the risk of a potentially polluting activity are proposed:

- R1** Acceptable subject to normal good practice.
- R2^{a,b,c,...}** Acceptable in principle, subject to conditions in note a,b,c, etc. (The number and content of the notes may vary depending on the zone and the activity).
- R3^{m,n,o,...}** Not acceptable in principle; some exceptions may be allowed subject to the conditions in note m,n,o, etc.
- R4** Not acceptable.

4.2 Integration of Groundwater Protection Zones and Responses

The integration of the groundwater protection zones and the groundwater protection responses is the final stage in the production of a groundwater protection scheme. The approach is illustrated for a hypothetical potentially polluting activity in the matrix in Table 4 below:

VULNERABILITY RATING	SOURCE PROTECTION		RESOURCE PROTECTION						
			Regionally Imp.		Locally Imp.		Poor Aquifers		
	Inner	Outer	Rk	Rf/Rg	Lm/Lg	Ll	Pl	Pu	
Extreme (E)	R4	R4	R4	R4	R3 ^m	R2 ^d	R2 ^c	R2 ^b	
High (H)	R4	R4	R4	R3 ^m	R3 ⁿ	R2 ^c	R2 ^b	R2 ⁿ	
Moderate (M)	R4	R3	R3 ^m	R2 ^d	R2 ^c	R2 ^b	R2 ⁿ	R1	
Low (L)	R3 ^m	R3 ^o	R2 ^d	R2 ^c	R2 ^b	R2 ⁿ	R1	R1	
→ → → → → → → → → →									

Table 4. Groundwater Protection Responses for a hypothetical activity

The matrix encompasses both the geological/hydrogeological and the contaminant loading aspects of risk assessment. In general, the arrows (→↓) indicate directions of decreasing risk, with ↓ showing the **decreasing likelihood of contamination** and → showing the direction of **decreasing consequence**. The **contaminant loading** aspect of risk is indicated by the activity type in the table title.

The **response** to the risk of groundwater contamination is given by the response category allocated to each zone and by the site investigations and/or controls and/or protective measures described in notes a, b, c, d, m, n and o.

It is advisable to map existing hazards in the higher risk areas, particularly in zones of contribution of significant water supply sources. This would involve conducting a survey of the area and preparing an inventory of hazards. This may be followed by further site inspections, monitoring and a requirement for operational modifications, mitigation measures and perhaps even closure, as deemed necessary. New potential sources of contamination can be controlled at the planning or licensing stage, with monitoring required in some instances. In all cases the control measures and response category depend on the potential contaminant loading, the groundwater vulnerability and the groundwater value.

In considering a scheme, it is essential to remember that: (a) a scheme is intended to provide guidelines to assist decision-making on the location and nature of developments and activities with a view to ensuring the protection of groundwater; and (b) delineation of the groundwater protection zones is dependent on the data available and site specific data may be required to clarify requirements in some instances. It is intended that the statutory authorities should apply a scheme in decision-making on the basis that the best available data are being used. The onus is then on a developer to provide new information which would enable the zonation to be altered and improved and, in certain circumstances, the planning or regulatory response to be changed.

4.3 Use of a Scheme

The use of a scheme is dependent on the availability of the groundwater protection responses for different activities. Currently draft responses have been developed for three potentially polluting activities: landspreading of organic wastes, single house systems and landfills. Additional responses for other potentially polluting activities will be developed in the future.

5. Interim Measures for Groundwater Protection

5.1 Introduction

For a significant proportion of the country, the currently available geological and hydrogeological information is inadequate to enable a comprehensive scheme as described in the previous sections to be prepared in the short term. Until sufficient information is available for all areas, statutory authorities need an interim scheme which combines **the principles of a groundwater protection scheme with the best available hydrogeological information, to form a defensible basis for decision-making regarding groundwater protection**. In order to achieve this, interim land surface zoning and groundwater protection measures will be required.

In general, it should be possible to ascertain the aquifer category for a given locality (allowing for some uncertainty in the location of geological boundaries). However, the vulnerability rating will normally require site specific information.

Because the Interim Measures lack certain elements, particularly vulnerability maps, they will be less efficient in the evaluation of proposed developments or activities: site investigations will need to be more extensive, decision-making will be slower, and planning may be more restrictive. Authorities should aim to complete and implement a comprehensive groundwater protection scheme as soon as practicable.

5.2 Factors Influencing the Choice of Interim Measures

Interim Measures for the protection of groundwater should:

- (i) make the best use of the information that is readily available, (e.g. aquifer maps);
- (ii) protect the groundwater with the greater value, i.e. significant groundwater supply sources and regionally important aquifers;
- (iii) protect the most vulnerable groundwater;
- (iv) to take account of the proposed EU Framework Directive on Water.

The priorities that follow from these factors are:

- delineating source protection zones around wells and springs;
- delineating aquifer categories;
- mapping the extremely vulnerable areas, particularly on regionally important aquifers.

5.3 Information Needs

5.3.1 Interim Source Protection Zones

To delineate protection zones around significant groundwater sources, additional information is usually needed on the following:

- water levels and groundwater gradients near the sources;
- pumping test data for wells, or flow measurements for springs;
- vulnerability maps for the zones of contribution (ZOCs).

Where the hydrogeological information is poor and/or where time and resources are limited, a simple zoning approach using (a) the arbitrary fixed radius method, or preferably (b) simplified variable shapes, is a good first step, requiring little technical expertise, which allows initial delineation of source protection areas. However, as far as practicable, source protection zones should be delineated by hydrogeological methods. In many cases, some additional work will be necessary, usually involving: (a) estimating groundwater gradients near sources; (b) carrying out a short pumping test (on wells); (c) measuring outflows (of springs); and (d) carrying out vulnerability mapping in the ZOCs. For source protection zone delineation, the areas concerned are relatively small, and mapping should typically take less than one week.

5.3.2 Interim Resource Protection Zones

To delineate resource protection zones, good subsoils and depth-to-bedrock maps, which are required for the production of vulnerability maps, may be unavailable. Without adequate maps of subsoils and depth-to-bedrock, production of a regional vulnerability map requires undertaking a substantial mapping programme (typically two years per county). However, in the interim, the vulnerability rating of a particular site or small area can be ascertained by site investigations, e.g. by trial pitting and drilling. Also, existing information in the Geological Survey, while not sufficient to enable a regional vulnerability map to be drawn, may help to indicate the likely rating of a site. Therefore, sufficient information to enable the vulnerability rating of any given site can be obtained relatively quickly, and should be requested from developers by the planning and regulatory bodies.

Aquifer maps are not available for all areas at present, but sufficient information on the bedrock geology is already available for most areas and should be available for all areas by the end of 1999 as a basis for delineating bedrock aquifer boundaries. There is insufficient subsoil information to enable the boundaries of sand/gravel aquifers to be delineated precisely, but in most areas the presence of gravel aquifers can be indicated. At present, as a short term measure, the GSI can give a provisional aquifer category designation for any area. However, in order to give a more definitive evaluation, assessment of all available hydrogeological data for a local authority area, together with some pumping tests on public supply wells, is required.

In contrast to the situation regarding vulnerability ratings, aquifer categories cannot be determined solely by site investigations data. In view of the variability in the hydrogeological characteristics of Irish aquifers, a regional approach is required.

5.4 Applying Interim Measures

Interim Measures can be implemented on a phased basis. The following order of priorities is suggested:

- (i) source protection zone delineation;
- (ii) aquifer mapping;
- (iii) delineation of extremely vulnerable areas;
- (iv) subsoil and vulnerability mapping on regionally important aquifers;
- (v) subsoil mapping in the remaining areas.

In delineating protection zones, priority should be given to the larger sources and those at greater risk, either due to the presence of potential hazards nearby or to the vulnerability.

While a provisional aquifer category can be assigned to any area at present, it is advisable to undertake a full assessment of the available hydrogeological data before producing an aquifer map.

In the absence of a comprehensive scheme, more investigation will be necessary to assess the vulnerability and the relative value of particular aquifers.

In assessing the impact of a proposed development in an area outside the ZOCs of groundwater supplies, an interim groundwater protection zone can be obtained by: (a) contacting the GSI for a provisional aquifer category; and (b) undertaking a site investigation to determine the vulnerability rating. **From this information the groundwater protection zone for any location (Table 3) and the associated groundwater protection responses (Table 4) can be determined. Consequently, the response for any particular activity at any site and the appropriate control measures can be implemented.**

5.5 Summary

Interim Measures for the protection of groundwater should include:

- Delineation of source protection areas around significant groundwater supply sources, using the best practicable method.
- Vulnerability mapping around significant groundwater supply sources, so that source protection zones can be delineated.
- Delineation of Resource Protection Areas, using the available aquifer maps.
- Delineation of extremely vulnerable areas.
- Evaluation of vulnerability for any given site proposed for a potentially polluting activity, based on site investigation data supplied by the developer.
- Implementation of groundwater protection responses, based on the above information.
- Plans to undertake the remaining elements of a comprehensive groundwater protection scheme.

References

Department of the Environment, 1997. Sustainable Development: a Strategy for Ireland. Government Publications, Dublin.

US EPA, 1987. Guidelines for delineation of wellhead protection areas. Office of Groundwater Protection, US Environmental Protection Agency.

Glossary

AQUIFER: any stratum or combination of strata that stores or transmits groundwater. (Local Government (Water Pollution) Act, 1990). *More commonly:* A permeable geological stratum or formation that can both store and transmit water in significant quantities.

Confined Aquifer: An aquifer in which the groundwater is overlain by impermeable geological strata; confined groundwater is generally subject to pressure greater than atmosphere.

Unconfined Aquifer: An aquifer where the water table is exposed to the atmosphere through openings in the overlying material.

Granular Aquifer: An aquifer composed of discrete grains of material (usually sand and/or gravel) in which groundwater flows through the spaces (pores) between the grains (intergranular flow). Such an aquifer is said to have a **primary** porosity and permeability, as contrasted with **secondary** porosity and permeability which results from fracturing, etc. Flow through a granular aquifer is said to be **intergranular flow**.

Poor Aquifer: An aquifer which is normally capable of yielding only sufficient water from wells or springs to supply single houses, small farms or small group water schemes. These can be sub divided into: Bedrock aquifers which are generally unproductive except for local zones (Pl) and Bedrock aquifers which are generally unproductive (Pu).

Locally Important Aquifer: An aquifer which is moderately productive, i.e. capable of yielding enough water to boreholes or springs to supply villages, small towns or factories. These are divided into: Sand/gravel aquifers (Lg); Bedrock aquifers which are generally moderately productive (Lm); and Bedrock aquifers which are moderately productive only in local zones (LI).

Regionally Important Aquifer: An aquifer which is sufficiently productive to be able to yield enough water to boreholes or springs to supply major regional water schemes. These are divided into: extensive sand/gravel aquifers (Rg); karst aquifers (Rk); and fissured aquifers (Rf).

ATTENUATION: The process of diminishing contaminant concentrations in groundwater, due to filtration, biodegradation, dilution, sorption, volatilisation and other processes. Breakdown or dilution of a contaminant in water.

BASEFLOW: That part of the flow in a stream which is not attributable to direct runoff from precipitation or snowmelt, usually sustained by groundwater discharge. That part of a stream discharge derived from groundwater seeping into the stream.

CONTAMINANT LOADING: The amount (volume and concentration) of a contaminant discharged to soil or groundwater.

CONTAMINANT TRANSPORT: The transport of a contaminant through topsoil, subsoil or bedrock.

DOWN-GRADIENT: The direction in which groundwater or surface water flows (also referred to as down-slope). Opposite of up-gradient.

ECOLOGY: The study of the relationships among organisms and the relationship between them and their physical environment.

FISSURE: Natural crack in rock which allows rapid water movement.

GROUNDWATER: That part of the subsurface water that is in the saturated zone, i.e. below the water table.

GROUNDWATER PROTECTION RESPONSE: Control measures, conditions or precautions recommended as a response to the acceptability of an activity within a groundwater protection zone.

GROUNDWATER PROTECTION SCHEME: A scheme comprising two main components: a land surface zoning map which encompass the hydrogeological elements of risk and a groundwater protection response for different activities.

GROUNDWATER PROTECTION ZONES: Zones delineated by integrating aquifer categories or source protection areas and associated vulnerability ratings. The zones are shown on a map, each zone being identified by a code e.g. SO/H (outer source area with a high vulnerability) or Rk/E (regionally important aquifer with an extreme vulnerability). Groundwater protection responses are assigned to these zones for different potentially polluting activities.

GROUNDWATER SOURCE: A source of water supply which depends on groundwater, usually a well (dug well or borehole) or a spring, occasionally an infiltration gallery.

HAZARD: In this context, a potential source of pollution.

KARST FEATURE: Landscape feature which results from karstification (solution of limestone) such as a turlough, swallow hole, cave, etc.

KARST: Type of topography characterised by closed depressions or sink holes and an absence of surface drainage, resulting from underground solution of rocks and diversion of surface waters to underground routes. It is formed in limestone, dolomite, gypsum and other soluble rocks as a result of solution of these materials and associated processes of subsurface drainage, cave formation and collapse.

LANDFILL: A site used for the deposit of waste on to or under land.

PERMEABILITY: The ability of a medium to transmit fluids under a potential gradient (units = $L^3/t/L^2$ or L/t). Measure of a soil or rock's capacity to transmit water.

POINT (POLLUTION) SOURCE: Any discernible, confined, or discrete conveyance from which pollutants are or may be discharged, including (but not limited to) pipes, ditches, channels, tunnels, conduits, wells, containers, slatted sheds and animal rearing sheds.

RECHARGE: The addition of water to the zone of saturation; also, the amount of water added.

SATURATED ZONE: The zone below the water table in which all pores and fissures are full of water.

SOURCE PROTECTION AREA (SPA): The catchment area around a groundwater source which contributes water to that source (Zone of Contribution), divided into two areas; the Inner Protection Area (SI) and the Outer Protection Area (SO).

The **SI** is designed to protect the source against the effects of human activities that may have an immediate effect on the source, in particular in relation to microbiological pollution. It is defined by a 100-day time of travel (TOT) from any point below the water table to the source.

The **SO** covers the remainder of the zone of contribution of the groundwater source.

SUBSOIL: The material between the topsoil and the bedrock.

SWALLOW HOLE: A small steep depression caused in karst topography by the dissolution and collapse of subterranean caverns in carbonate formations.

TIME OF TRAVEL (TOT): The time required for a contaminant to move in the saturated zone from a specific point to a well. It is the average linear velocity of flowing groundwater using Darcy's Law.

$V = k/n_e \cdot dh/dx$, where:

n_e = effective porosity,

k = permeability

dh/dx = groundwater gradient

UNSATURATED ZONE: The zone between the land surface and the water table, in which pores and fissures are only partially filled with water. Also known as the vadose zone.

VULNERABILITY: A term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

WATER TABLE: The uppermost level of saturation in an aquifer at which the pressure is atmospheric.

ZONE OF CONTRIBUTION (ZOC): The area surrounding a pumped well that encompasses all areas or features that supply groundwater recharge to the well. It is defined as the area required to support an abstraction from long-term groundwater recharge.



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