# Guidance on Requirements for ‘Prior Investigation’ and Monitoring (including ‘Requisite Surveillance of Groundwater’) for Activities Authorised under the Groundwater Regulations 1998

Entec UK Limited

R&D Technical Report P2-174/TR

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**Statement of Use**
This report provides guidance on prior investigation and monitoring in connection with the implementation of the Groundwater Directive (80/68/EEC) and particularly with reference to the Groundwater Regulations, 1998. It is provided primarily as internal guidance to the Environment Agency, but will also be available to operators and practitioners affected by the Regulations. The document will be used in conjunction with the Environment Agency's Groundwater Regulations Process Manual to assist in the specification of investigatory work for and assessment of authorisations under the Groundwater Regulations, and the specification of monitoring required under those regulations. Protocols derived from this R&D work are likely to be incorporated into the Groundwater Regulations Process Manual in due course. The principles contained in this document are also likely to find application in other circumstances where compliance with the Groundwater Directive is necessary.

**Key words:**
Groundwater Regulations, prior investigation, monitoring, requisite surveillance, land spreading, soakaways, risk assessment

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# EXECUTIVE SUMMARY

The Groundwater Regulations (SI 1998, Nº 2746) place a duty on the Environment Agency in England and Wales to protect groundwater by:

- Prohibiting discharges of ***List I*** substances to groundwater (below the water table) (Regulation 4);
- Preventing pollution of groundwater by ***List II*** substances (Regulation 5).

Except for licensed landfill sites, and certain exempt activities that constitute beneficial use, all deliberate disposals of listed substances onto or into land that might lead to a discharge to groundwater (in the saturated zone), require an ***authorisation*** under the Groundwater Regulations.

Applications for authorisations must be accompanied by the results of a '***prior investigation***' and assessed on its findings. Once approved, the Environment Agency (the '*Agency*') must ensure that the authorised disposal is subject to '***requisite surveillance of groundwater***'.

A broad framework for prior investigation is set out in this document. It has four levels of assessment:

- **Level 1**: Initial screening procedure for assessing applications related to land spreading;
- **Level 2**: A conservative quantitative screening tool for assessing land spreading and initial assessment of soakaways;
- **Level 3**: Quantitative risk assessment based on site specific data and representation of processes which will control the fate and transport of contaminants through the soil and unsaturated zone;
- **Level 4**: Assessment of dilution at the water table (for List 2 substances only).

From Level 1 to Level 3, the assessment becomes successively less conservative, but information requirements increase. This means that information requirements are kept in proportion to the risks associated with each activity and so low-risk sites are rapidly and cost-effectively screened out. The data requirements for each level are identified and described.

This report provides background information on the processes and parameters that can affect the movement of contaminants through the soil and unsaturated zone. An understanding of these processes is key to appropriate use of the four levels of assessment.

For the four levels of assessment, the report first briefly describes the Environment Agency's initial screening procedures for land spreading of sheep dip and other chemicals such as waste pesticides. Details are then provided of a Level 2 quantitative screening tool that has been developed specifically for this project. This Level 2 tool conservatively quantifies the breakthrough of contaminants at the base of the soil zone. It also predicts the amount of contaminant remaining in the soil to ensure the disposal operation does not lead to the long term derogation of soil/land quality. For subsequent levels of assessment, guidance is given on the general approach to the use of less conservative quantitative methods (Level 3, e.g. the P20 methodology) or to the calculation of dilution at the water table (Level 4).

A strategy for monitoring (the activity) and requisite surveillance of groundwater is outlined.

*As part of Conditions of Authorisation*

i) Record keeping by the applicant, requirement of Groundwater Regulations;

ii) Monitoring of the discharge. Dependent on activity and risk;

iii) Monitoring (requisite surveillance) of groundwater (e.g. boreholes or groundwater discharges such as springs, river baseflow). Dependent on activity and risk.

*As part of Enforcement by the Environment Agency*

iv) Site visits by the Environment Agency to verify details of the application and compliance with the technical measures required by the authorisation, including requisite surveillance.

*As part of an overall management strategy by the Environment Agency*

v) Strategic monitoring of groundwater (e.g. boreholes or groundwater discharges such as springs, river baseflow). The objective of this monitoring should be to provide confirmation that the overall assessment process and management strategy is appropriate (i.e. protects groundwater as a whole from the discharge of effluents containing listed substances, rather than directed to monitoring at the sites of specific authorisations, see Section 4.6).

Each application should be evaluated to determine whether requisite surveillance is required in addition to monitoring of the discharge (specified as part of the authorisation) and to site inspection by the Environment Agency. Requisite surveillance by the applicant is considered to be warranted where:

- Level 1 Screening indicates high risk. The Level 1 high risk threshold should be reviewed based on applying the Level 2 and Level 3 methodology to a range of applications;
- Activities with high loading (hydraulic loading of greater than 30 $m^3$/ha/d and chemical loading score of greater than 20, Level 1). This threshold should be reviewed based on applying the Level 2 and Level 3 methodology to a range of applications to determine the risk associated with different Level 1 screening scores;
- Discharge is to soakaway, except where the applicant is able to demonstrate that the activity represents a low risk to groundwater;
- Area of spreading used for a single spreading event exceeds 4 ha (this is intended to identify larger applications where the hydraulic/chemical loading is sufficient to require spreading over a larger area).

In general, requisite surveillance is unlikely to be warranted for the majority of applications as the assessment procedure has been designed to screen out activities that would give rise to a risk of the discharge of List I substances at the water table or of pollution by groundwater from List II substances.

It is considered that additional groundwater monitoring should be undertaken by the Environment Agency to confirm that the assessment procedure is appropriate and whether these activities result in an impact on groundwater quality. In view of the large number of applications, any such monitoring should be carefully targeted, and guidance is given in this report on identifying cases where monitoring could be implemented.

Note:

It is intended that the Level 2 Screening Tool Spreadsheet referred to in this document will be available electronically by downloading from the Environment Agency's website:

www.environment-agency.gov.uk

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# GLOSSARY

| | |
|---|---|
| Absorption | The incorporation of a chemical within a solid or liquid. |
| Adsorption | The attachment of a chemical to the surface of a solid or liquid. |
| Advection | Mass transport caused by the bulk movement of flowing groundwater. |
| Anaerobic/Anoxic groundwater | Groundwater that contains oxygen in concentrations less than about 0.5 mg/l. |
| Aquifer | A permeable geological stratum or formation that is capable of both storing and transmitting water in significant amounts. |
| Artificial recharge | Water which is deliberately discharged to groundwater for the purposes of groundwater management. |
| Authorisation, regulation 1(2) | An authorisation under regulation 18 (disposal or tipping) or 19 (a conditional notice for control of other activities) of the Groundwater Regulations 1998, a discharge consent under section 85 of the Water Resources Act 1991 or Part II Control of Pollution Act 1974 (Scotland), or an authorisation under Part I of the Environmental Protection Act 1990 (IPC authorisation). |
| Attenuation | Reduction in contaminant concentration through biological, chemical and physical processes as it passes through a medium. |
| Biodegradation | The transformation of a substance or chemical by micro-organisms, resulting in a change in chemical mass within the environment. |
| Catabolism | Biodegradation process where the degraded molecule is utilised as a nutrient or energy source. |
| Cation Exchange Capacity (CEC) | The capacity of a material to attract cations (e.g. $Na^+$, $Ca^{2+}$, $NH_4^+$) from pore water and exchange them for other cations held by electrostatic forces on negatively charged clay-mineral surfaces. This process affects the transport of ions in solution and is particularly important for ammonium ($NH_4^+$). |
| COGAP-W | Code of Good Agricultural Practice for Water (MAFF). |
| Conservative pollutants | Pollutants which can move readily through the aquifer with little reaction with the rock matrix and which are unaffected by biodegradation (e.g. chloride). |
| Controlled waters | Defined by Water Resources Act 1991, Part III, Section 104. All rivers, canals, lakes, ground waters, estuaries and coastal waters to three nautical miles from the shore. |

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| Daughter product (or breakdown products) | A compound that results directly from the biodegradation of another. For example *cis*-1,2-dichloroethene (*cis*-1,2-DCE) is commonly a daughter product of trichloroethene (TCE). |
| Diffusion | Migration of substances by natural movement of their particles. |
| Dilution | Reduction in concentration brought about by the addition of water. |
| Direct discharge, regulation 1(2) | The introduction into groundwater of any substance in list I or II without percolation through the ground or subsoil. |
| Dispersion | Irregular spreading of solutes due to aquifer heterogeneities at pore-grain scale (mechanical dispersion) or at field scale (macroscopic dispersion). |
| Dispersivity | A property that quantifies the physical dispersion of a solute being transported in a porous medium (dimension L). |
| Free phase contamination | Product (e.g. gasoline, diesel) which is present in its original (undissolved) state and at a high saturation. May also include coal tars. |
| Groundwater | All water which is below the surface of the ground, in the saturation zone, and in direct contact with the ground or subsoil. |
| Ground waters (s104,WRA,1991) | Any waters contained in underground strata. |
| Henry's Law Constant | Coefficient that represents the equilibrium partitioning factor between a solute in the water and vapour phases (unitless). |
| HOST | **H**ydrology **O**f **S**oil **T**ypes: a hydrologically based classification of the soils in the United Kingdom. |
| Hydraulic conductivity | A coefficient of proportionality describing the rate at which water can move through a permeable medium. The density and kinematic viscosity of the water must be considered in determining hydraulic conductivity (dimension $LT^{-1}$). |
| Hydraulic gradient | The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head. |
| Hydraulic head | The sum of the elevation head, the pressure head, and the velocity head at a given point in the aquifer. |
| Indirect discharge, regulation 1(2) | The introduction into groundwater of any substance in List I or II after percolation through the ground or subsoil. |
| Intergranular | Occurring between the grains of a rock or soil. |

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| List I and List II substances (see Appendix C). | Those substances listed in the Annex to Directive 80/68/EEC and repeated in the Schedule to the Groundwater Regulations, 1998 (SI 1998 N$^{\underline{o}}$ 2746). Detailed classification of substances is undertaken by JAGDAG (Joint Agency Groundwater Directive Advisory Group). |
| MORECS | Meteorological Office Rainfall and Evaporation Calculation System. |
| NSRI | **N**ational **S**oil **R**esources **I**nstitute formerly known as the **S**oil **S**urvey and **L**and **R**esearch **C**entre (SSLRC) |
| Oxic/aerobic | Groundwater that contains oxygen in concentrations greater than about 0.5 milligram per litre (mg/l). |
| Partition coefficient | In a heterogeneous system of two or more phases in equilibrium, the ratio of the activities (or less accurately the concentrations) of the same molecular species in the phases is a constant at constant temperature. |
| Pathway | A route along which a particle of water, substance or contaminant moves through the environment and comes into contact with or otherwise affects a receptor. |
| Permeability | General measure of the ability of a medium to transmit a fluid. More specifically measured by hydraulic conductivity and intrinsic permeability (*q.v.*). |
| Permanently unsuitable for other uses | Groundwater that in the opinion of the Environment Agency (as the responsible body), for reasons of quality and/or quantity cannot be used for other purposes (particularly domestic and agricultural use), either at present or in the future. |
| Pollution of groundwater | The discharge by man, directly or indirectly, of substances or energy into groundwater, the results of which are such as to endanger human health or water supplies, harm living resources and the aquatic ecosystem or interfere with other legitimate uses of water (Groundwater Directive, 80/68/EEC). |
| Pollution (Environmental Protection Act, 1990) | Pollution of the environment due to the release (into any environmental medium) from any process of substances which are capable of causing harm to man or any other living organism supported by the environment. |
| Porosity | The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment. |
| Prior investigation, (Regulation 7) | Examination undertaken prior to authorisation to determine the hydrogeological conditions of the area concerned, the possible purifying powers of the soil and subsoil, the risk of pollution and the potential alteration of the quality of the groundwater from the discharge. It should also establish whether the discharge of substances into groundwater is a satisfactory solution from the point of view of the environment. |

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| Receptor | An entity (e.g. human, animal, water, vegetable, building, air) which is vulnerable to the adverse effects of a hazardous substance or agent. |
| Recharge | The amount of water of meteoric origin that reaches the water table (can be calculated as precipitation less evapotranspiration, runoff and increase in soil storage). |
| Requisite surveillance (Regulation 8) | Investigation in the form of monitoring of groundwater, which is considered necessary by the Environment Agency to determine whether the authorised activity affects the quantity and quality of the groundwater, and/or to ensure that the necessary technical precautions are effective in preventing the entry of List I substances and pollution by List II substances. |
| Retardation | A measure of the reduction in solute velocity relative to the velocity of the advecting groundwater caused by processes such as adsorption. |
| Risk | A term used to denote the probability of suffering harm from a hazard and embodies both likelihood and consequence. |
| SAC | **S**pecial **A**rea of **C**onservation |
| Saturated zone | The zone in which the voids of the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer. |
| Soakaway | A restricted and well defined area of ground that is used for the rapid transmission of liquids (normally water) to the subsurface environment. |
| Source | The point, area or origin where a hazardous substance or agent (e.g. a contaminant that is capable of causing harm) may enter the natural system. |
| Source Protection Zone (SPZ) | An area designated around a groundwater source, the maximum extent of which is the catchment area for the source and within which there are limits to the processes and activities that can occur within that area. |
| Sorption | Absorption and adsorption considered jointly. |
| SSLRC | **S**oil **S**urvey and **L**and **R**esearch **C**entre (now part of NSRI). |
| SSSI | **S**ite of **S**pecial **S**cientific **I**nterest. |
| SUDS | **S**ustainable **U**rban **D**rainage **S**ystems. |
| Swale | A grass-lined channel with shallow side slopes in which infiltration occurs along its length, but which also acts as a conveyance channel. |
| Target concentration | Derived chemical concentration at compliance point. |

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| Unsaturated zone | The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched groundwater may exist in the unsaturated zone. Also called zone of aeration and vadose zone. |

# LIST OF SYMBOLS

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**Parameters**

| **Symbol** | **Units** | **Description** |
|---|---|---|
| A | $m^2$ | Area of land spreading or soakaway. |
| $A_c$ | $m^2$ | Catchment area to soakaway. |
| AR | $m^3$/ha/day | Application Rate. |
| $A_{gw}$ | $m^2$ | Groundwater catchment area estimated from groundwater contour maps or for unconfined aquifers approximated to the surface water catchment. |
| $a_v$ | m | Dispersivity. |
| b | m | Saturated depth of aquifer beneath the site. |
| $b_{mz}$ | m | Depth of groundwater mixing zone. |
| BFI | fraction | Fraction of HER to recharge. |
| $C_{max}$ | mg/l | Peak concentration at base of assessed zone (soil or unsaturated). |
| $C_0$ | mg/l | Starting concentration applied to land or discharged to soakaway. |
| $C_t$ | mg/kg/yr | Average soil concentration after one year. |
| D | $m^2$/s | Hydrodynamic dispersion. |
| $D^*$ | $m^2$/s | Mechanical dispersion. |
| $D_d$ | $m^2$/s | Molecular diffusion coefficient through medium. |
| $D_w$ | $m^2$/s | Molecular diffusion coefficient in water. |
| $f_{oc}$ | fraction | Fraction of soil organic carbon. |
| HER | mm/yr | Effective rainfall. |
| I | mm/yr | Infiltration rate (over site or recharge area). |
| i | m/m | The hydraulic gradient. |
| $K_d$ | l/kg | Soil/water distribution ratio. |
| $K_{oc}$ | l/kg | Organic carbon/water distribution ratio. |
| K | m/day | Hydraulic conductivity of the strata. |
| $M_o$ | mg/$m^2$/yr | Total mass loaded to soil per year. |
| $M_t$ | mg/$m^2$/yr | Mass remaining in soil after one year (365¼days). |
| N | No/yr | Number of applications per year. |
| n | fraction | Effective porosity. |
| $Q_{gw}$ | $m^3$/day | Estimated groundwater flow beneath the site. |
| $R_f$ | fraction | Retardation factor. |
| $T_{½}$ | Days | Soil degradation half-life. |
| $T_r$ | Days | Retarded travel time. |
| $T_T$ | Days | Total retarded travel time. |

| | | |
|---|---|---|
| $T_{lag}$ | Days | Minimum number of days with SMD following application. |
| $T_u$ | Days | Unretarded travel time. |
| $v$ | m/s | Groundwater velocity. |
| $w$ | m | Width of the site perpendicular to the flow direction. |
| $z$ | m | Thickness of soil. |
| $\rho$ | g/cm$^3$ | Soil bulk density. |
| $\theta_w$ | fraction | Mobile moisture content. |
| $\theta_a$ | fraction | Air filled porosity. |
| $\tau$ | fraction | Tortuosity of medium. |
| $\lambda$ | days$^{-1}$ | Decay rate = 0.693/*T½*. |

# 1. INTRODUCTION

## 1.1 Background

The Groundwater Regulations 1998 (GWR) complete the transposition of the EC Groundwater Directive (80/68/EEC) into UK legislation. They are applicable to a wide range of activities involving List I and II substances where there is a potential risk to groundwater.

Dependent on the nature of the activity, it can fall within a system of authorisations, or notices and adherence to approved Codes of Practice. However, for all deliberate disposals of listed substances onto or into land that might lead to a discharge to groundwater (the saturated zone), and which are not covered by the Waste Management Licensing Regulations 1994 or Radioactive Substances Act 1993, an ***authorisation*** under the Groundwater Regulations is required.

Applications for authorisations must be accompanied by the results of a "***prior investigation***" and assessed on its findings. Once approved, the Environment Agency (the "*Agency*") must ensure that the authorised disposal is subject to "***requisite surveillance of groundwater***". The same requirements are necessary via the other means of implementation of the Groundwater Directive such as Water Resources Act discharge consents, IPC authorisations and the forthcoming authorisations under the IPPC regime. All of these are considered as authorisations for the purposes of the GWR.

In the year April 1999 to March 2000, over 12 000 applications for authorisations were received by the Agency. Over 90% of these were from agriculture related to the disposal of waste sheep dip or pesticide washings. More applications are expected in the future from agriculture and industry and there is also a requirement to review each of the authorisations every four years.

To help assess these applications, the Agency has developed initial screening procedures, but a significant proportion of those screened fall into a "grey" zone requiring further evaluation. Furthermore, a wide range of non-agricultural activities are not covered by the existing screening tool. Some of these, particularly large industrial or treated sewage effluent discharges, could require site investigation and detailed risk assessment. There is therefore a need for methods to examine the entire range of applications and to allow further evaluation of some of the initial screened applications.

Given the wide range of potential activities and risks to groundwater to be assessed, as part of an authorisation, the technical requirements for prior investigation and monitoring/requisite surveillance vary enormously. Regardless of the size, type or location of each activity, the technical requirements all need to fall within the same conceptual framework. The scope and cost of these requirements also needs to be proportional to the size, scale and risks from each activity.

## 1.2 Purpose of this Report

Against this background, the Agency commissioned this research and development project to prepare good practice technical guidance on *prior investigation* and *requisite surveillance of groundwater* for activities authorised under the GWR and on monitoring generally to support the Agency's operations in connection with these regulations.

The technical guidance outlined in this present report is based on a ***risk assessment*** approach incorporating a ***source-pathway-receptor*** analysis, with groundwater being the main receptor of concern, although with some reference to land and soil quality or conservation.

The overall methodology for prior investigation is a tiered approach incorporating the Agency's initial qualitative screening procedures, followed by subsequent levels of quantitative assessment. At successive levels, the assessment becomes less conservative, but information requirements increase. This means that information requirements are kept in proportion to the risks associated with each activity and so low-risk sites are rapidly screened out cost-effectively.

Guidance is provided on determining the degree of monitoring and requisite surveillance that should be specified in granting an authorisation, and the role of the Environment Agency in ensuring that the conditions of the authorisation are followed.

## 1.3 Scope of Guidance

This guidance is produced for the assessment of deliberate disposals to land including land spreading and soakaways and should be used in conjunction with the manual for the Groundwater Regulations Process. It is not intended for the assessment of landfill sites, but the general risk-based approach is compatible.

Background information on processes is provided, but not in detail as the focus of this guidance is on the general framework behind prior investigation and requisite surveillance and not the detail of the science.

## 1.4 Target Audience

The target audience for this guidance is primarily Agency staff assessing the acceptability of submitted proposals and specifying monitoring requirements. However, this guidance is also publicly accessible and could be used by a combination of applicants, operators and consultants acting on behalf of landowners on whose land the authorised disposal is to take place.

## 1.5 Definition of Terms

Key terms used in this report are defined below:

***Authorisation****, regulation 1(2)* - an authorisation under regulation 18 (disposal or tipping) or 19 (a conditional notice for control of other activities) of the Groundwater Regulations 1998, a discharge consent under section 88 of the Water Resources Act 1991 or Part II Control of Pollution Act 1974 (Scotland), or an authorisation under Part I of the Environmental Protection Act 1990 (IPC authorisation).

***Pollution****, regulation 1(2*) - the discharge by man, either directly or indirectly, of substances or energy into groundwater, the results of which are such as to endanger human health or water supplies, harm living resources and the aquatic ecosystem or interfere with other legitimate uses of water. In addition to this definition given in the Regulations, pollution of groundwater resources may generally be considered to result when the quality is affected to the extent that the water is rendered unfit for its original use.

***Prior Investigation****, regulation 7* - an examination undertaken prior to authorisation to determine the hydrogeological conditions of the area concerned, the possible purifying powers of the soil and subsoil, the risk of pollution and the potential alteration of the quality of the groundwater from the discharge. It should also establish whether the discharge of substances into groundwater is a satisfactory solution from the point of view of the environment. Prior investigation is intended to help identify any necessary technical precautions to prevent pollution from potential discharges/disposals.

***Requisite Surveillance*** - that investigation in the form of monitoring of groundwater which is considered necessary by the Environment Agency to determine whether the given activity affects the quantity and quality of the groundwater, and/or to ensure that the necessary technical precautions are effective in preventing the entry of List I substances into groundwater and pollution by List II substances.

***Soil*** – that earth material that has been so modified and acted upon by physical, chemical and biological agents that it will support rooted plants.

***Groundwater**, regulation 1(2)* - all water which is below the surface of the ground in the saturation zone (below the water table) and in direct contact with the ground or subsoil.

## 1.6 Relationship to Other Procedures

This document provides technical guidance on prior investigation and requisite surveillance of groundwater for activities authorised under the Groundwater Regulations, 1998. Guidance on the interpretation of these regulations is given in the DETR document 'Guidance on the Groundwater Regulations, 1998'(DETR, 2001).

The Environment Agency has already developed initial screening procedures to deal with applications for land spreading for sheep dip and applications for land spreading of other listed substances. These tools are described in Environment Agency's Process Manual. The Process Manual also includes the following guidance:

*Section 6.2 Framework for Technical Assessments and Prior Investigations for Regulation 18 Authorisations.*

*Section 6.3 Initial technical screening system for applications for land spreading of sheep dip.*

*Section 6.4 Initial technical screening system for applications for land spreading of listed substances (other than sheep dip).*

*Section 6.5 Monitoring of authorisations and requisite surveillance of groundwater.*

This technical report should be used in conjunction with the Environment Agency's Process Manual and is intended to provide technical support for the existing screening tools and to set out the procedure for more detailed assessment of applications.

## 1.7 Key Aspects of Prior Investigation and Requisite Surveillance

The overall procedure for the assessment of applications made under the Groundwater Regulations, 1998, is set out in Figure 3.1.

## 1.8 Document Layout

This report has four Sections following this Introduction. Background information on processes that can influence the fate of contaminants applied to land or discharged via soakaways is provided in Section 2. Guidance on the "***prior investigation***" assessment of applications is provided in Sections 3. Section 4 sets out a strategy for "***requisite surveillance***

***and monitoring***" and a final review with recommendations for further work is given in Section 5.

An accompanying project record (Environment Agency, 2002a) provides supporting information on regulatory requirements, prior investigation tools used elsewhere, the development of the Level 2 screening procedure described in Section 3 and a review of the designs and performance of soakaways.

# 2. IMPORTANT PROCESSES

## 2.1 Introduction

This section provides brief details of the processes and parameters controlling risks to groundwater from land spreading operations and discharges to soakaways. It is not part of the framework for prior investigation and requisite surveillance, but is provided as a reference section to allow the user to understand the background behind the procedures. The descriptions of processes are brief, but reference is made to other sources of information for more details.

For each application for an authorisation, there is a need to consider several elements in terms of protection of the environment (human health issues are not considered here). These elements are described in Table 2.1.

**Table 2.1 – Main Considerations for each Application**

| Element | Legislative Drivers | Concern |
|---|---|---|
| Surface Water | Water Resources Act (1991) | Will runoff wash contaminants into watercourses? |
| Groundwater | Groundwater Regulations (1998)<br>Water Resources Act (1991) | Will contaminants be transported to and/or pollute groundwater? |
| Soil/land Quality | Part IIA Environmental Protection Act (1990) | Will the land area become contaminated long-term? |
| Conservation | Wildlife & Countryside Act (1981)<br>Habitats Regulations (1999) | Will ecosystems be damaged? |

Note: Air quality is a minor concern for the types of contaminants being considered.

This report's main focus is on protecting groundwater from List I and II substances discharged to the land surface or to soakaways. The main processes considered are those that control contaminant migration in the soil zone and to a lesser extent in the unsaturated zone. Beneath the water table, only the process of dilution is considered and this is only for List II substances. Dilution also applies to List I and II substances where the water has been determined as "permanently unsuitable for other uses" (see Section 4.2.2 of the Agency's Process Manual), and where the discharge of List I substances is due to reinjection into the same aquifer subject to 'prior investigation', as detailed in Regulation 4(5)b of the Groundwater Regulations.

Pollution of surface waters through runoff from land spreading areas is not assessed in detail and takes the same approach as the Agency's initial screening procedure (see Section 3.4). Soil or land quality is examined in terms of build-up of persistent contaminants to produce contaminated land. Air pollution and conservation interests are not considered here.

Figure 2.1 illustrates the general conceptual model of the environment being considered.

The processes, their controls and effects, are summarised in Table 2.2 and discussed briefly in the following sections in terms of how these processes can be quantified and relevant data sources. The importance of these different processes is shown schematically in Figure 2.2.

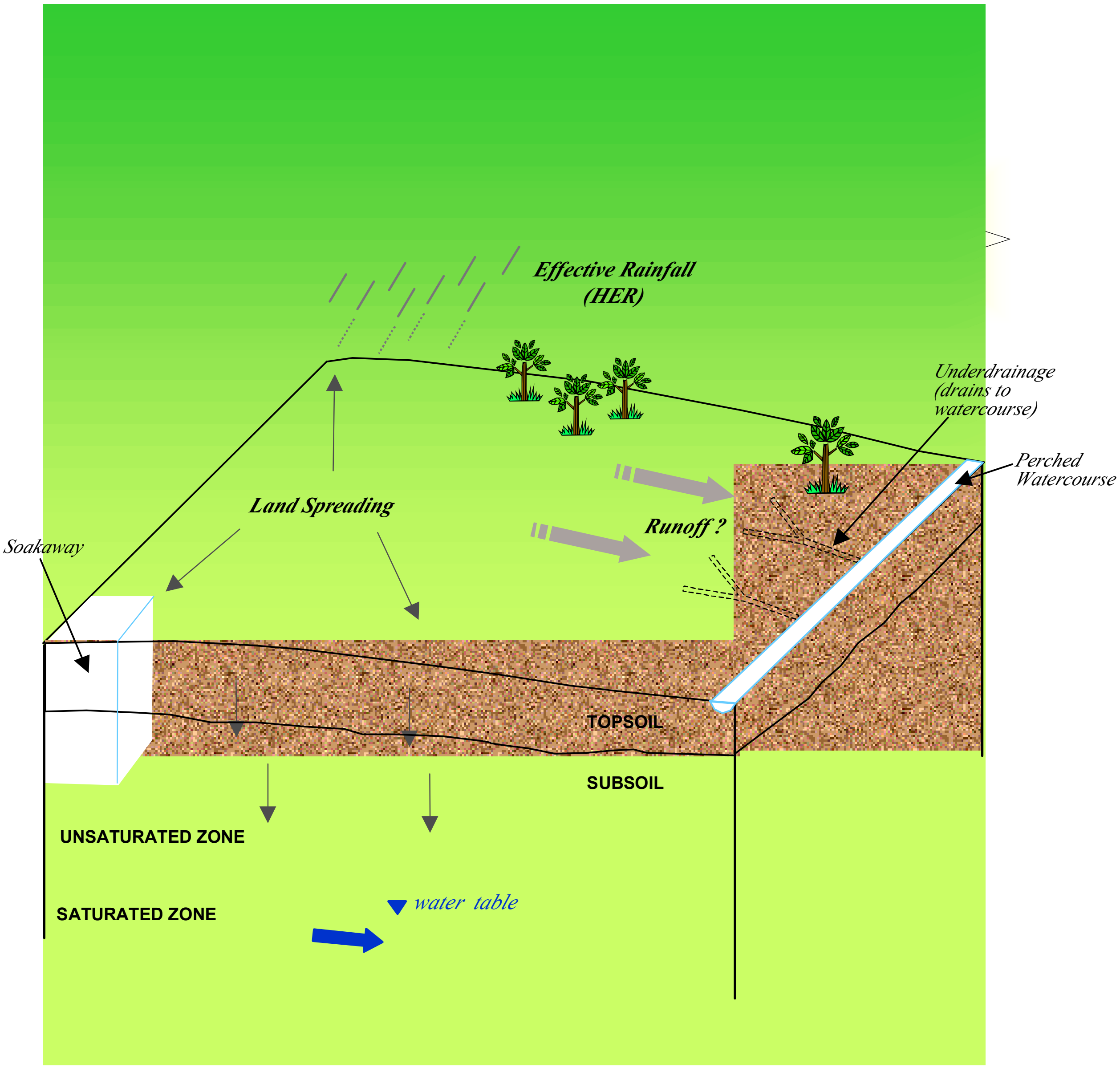
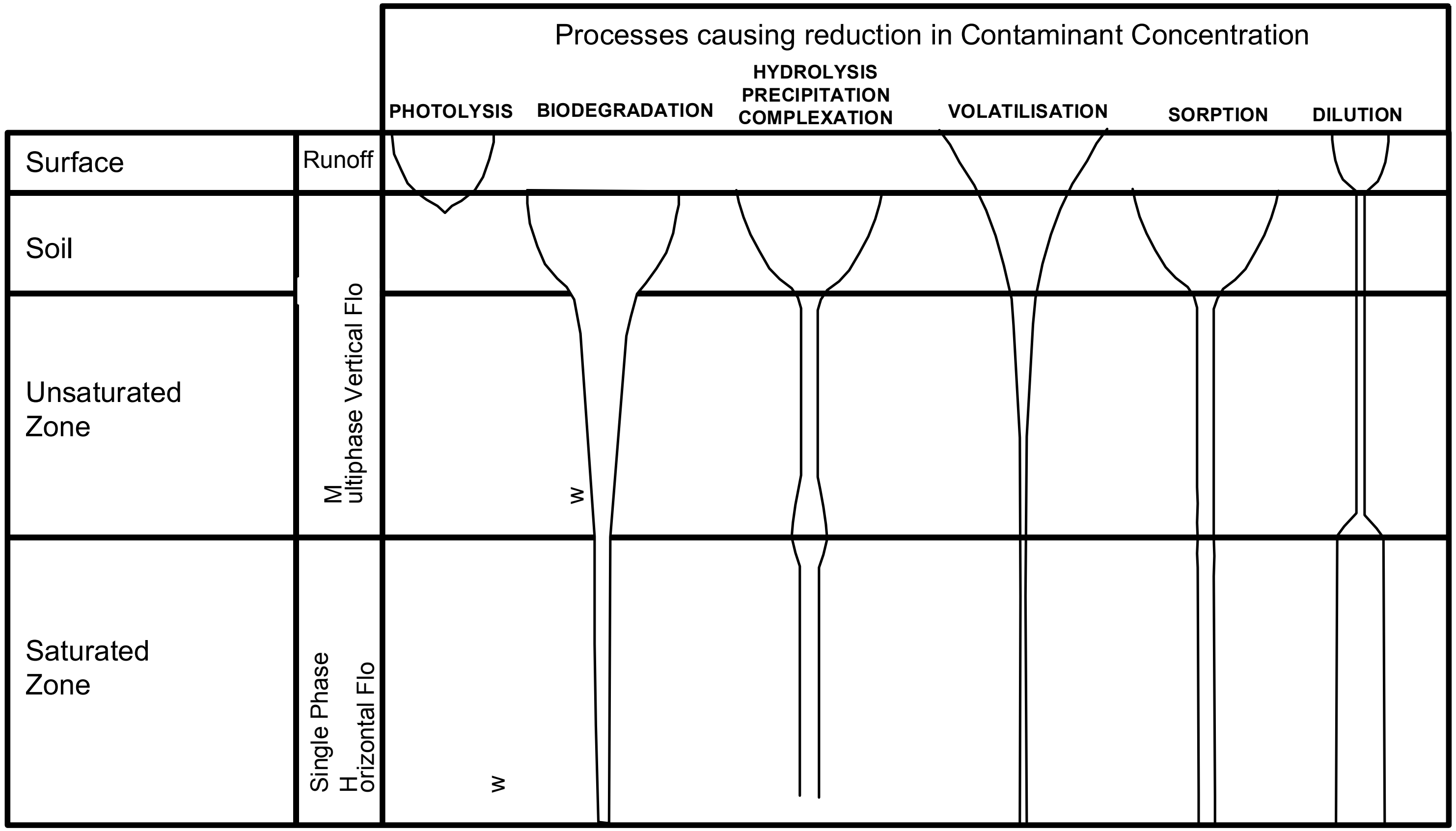


Figure 2.1 General Conceptual Model



The thickness of the corresponding line indicates typically the relative importance of the process at the surface in the soil, and above, at and below the groundwater table

Figure 2.2 Summary of Processes Promoting Contaminant Attenuation (adapted from Foster 1988)

**Table 2.2 – Main Processes and their Controls and Effects**

| **Process** | **Control** | **Effects** |
|---|---|---|
| Hydraulic Loading | Method of Application<br>Rate of Application | Potential to overwhelm the infiltration capacity of soil and lead to runoff, or saturated or bypass vertical flow within the soil. |
| Chemical Loading | Concentration and number of disposals | Source concentration with the potential to leach into runoff or to groundwater or to accumulate in the soil.<br>Possible exceedence of sorption capacity, toxic effects on soil biology and effect on degradation rate. |
| | Contaminant Properties | List I or II, potential to volatilise, adsorb on soils, float, sink or leach in water, toxicity to soil microbial population, biodegradability. |
| Runoff | Climate<br>Slope<br>Vegetation & Soil Type | Potential for contamination of adjacent land areas, pollution of surface waters or indirect contamination of recharge to groundwater. |
| Infiltration Rate | Hydraulic Loading<br>Climate and vegetation<br>Soil permeability, pore size and type<br>Moisture Content | Variation in rate of downward movement of unretarded leached contaminant. |
| Sorption | Organic matter content<br>Clay content and type<br>CEC, pH | Retardation of contaminants compared to infiltration rate.<br>Possible inaccessibility for biodegradation. |
| Degradation<br>(Abiotic and Biotic) | Concentration<br>pH, temperature, air, water, clay and organic matter content, salinity, nutrients, oxygen.<br>Acclimatisation of microbes. | Degradation rate is site specific (dependant on biochemical environment).<br>Degradation leads to mass loss which is key for ensuring sustainability of operation and reducing concentrations.<br>Breakdown products can be more mobile and toxic than the parent compound, though generally not.<br>Biodegradation may be inhibited at high contaminant concentrations. There may be a time lag before microbial degradation becomes effective. |
| Volatilisation | Henry's Law Constant<br>Soil air/water content<br>Temperature | Contaminants are lost to air and so are unavailable to leach to surface water or groundwater. |
| Mechanical Dispersion | Soil thickness and type of porosity | Faster (turbulent) flow in larger pores than smaller leads to spreading out of contaminants in the direction of water movement. This reduces average concentrations. |
| Diffusion | Concentration and type of porosity | Diffusion of contaminants between less mobile water in micropores and more mobile water in macropores. |

Throughout this section, the objective has been to identify a practical approach in terms of quantifying the effect of different processes on contaminant migration through the soil zone. More sophisticated modelling approaches (e.g. using the computer codes PRZM and MACRO, see Project Record) which are data hungry and require time and expertise to use, are considered to be inappropriate for use in screening a large number of applications directly. However, such models can be used in conjunction with laboratory and field experiments which may inform screening systems that rely on a smaller number of, or lumped, parameters.

## 2.2 Hydraulic Loading

### 2.2.1 Background

Hydraulic loading is the measure of liquid application over an area, and for land spreading typically has units of $m^3$/ha/day. Depending on the nature of the soil and time of year, high hydraulic loading rates can lead to:

- Rapid infiltration through the soil via large gravity-drained macropores (e.g. worm holes and cracks). This is likely to lead to limited sorption and limited time for degradation (more discussion in Sections 2.7 and 2.9) and thus a higher risk of groundwater contamination.
- Exceedance of the field capacity of the soil leading to surface ponding, lateral saturated flow in the soil and in drains, and runoff on sloping ground. Lateral movement in drains and runoff can both lead to contamination of adjacent land areas and potential pollution of surface waters.

Lower hydraulic loading rates allow the downward movement of the water and its contents to be delayed by:

- Soil moisture deficit (if any) and evapotranspiration;
- Diffusion of contaminants into smaller saturated pore spaces;
- Sorption of contaminants onto the soil (clays, organic matter etc).

This delay provides time for degradation to reduce the concentrations of contaminants applied.

### 2.2.2 Determining suitable rates of land spreading

Determination of the maximum acceptable hydraulic loading rate for land spreading requires consideration of a number of parameters including climatic data, crop uptake, saturated soil permeabilities, presence of macro-pores, land use etc.

Infiltration tests can be carried out, but these will give the bulk infiltration capacity of the soil regardless of whether the water moves via bypass routes. They are therefore inappropriate unless bypass flow can be excluded.

The simplest approach to determining suitable disposal rates is to use the Code of Good Agricultural Practice for Water (COGAP-W, MAFF, 1998) for land spreading; an empirical approach designed primarily to limit runoff, but also with some consideration of groundwater. COGAP-W indicates a maximum of 5 $m^3$/ha for disposal of undiluted waste dip and implies a maximum of 20 $m^3$/ha/day for diluted waste dip. A maximum of 50 $m^3$/ha (it is assumed per day) is given for a variety of organic wastes. The Environment Agency's initial screening procedure for land spreading of sheep dip and other chemicals considers what maximum rate is reasonable and sets an upper limit of 30 $m^3$/ha/day. Disposals with rates higher than 30 $m^3$/ha/day require more detailed evaluation. 30 $m^3$/ha/day equates to an infiltration rate of 3 mm/day or assuming spreading occurs over one hour, 3 mm/hour for that hour.

3 mm is less than or equal to the average monthly soil moisture deficit (SMD) for grassed land for the whole year in East Anglia (MORECS Sq152) and for mid-March to mid September for North Wales (MORECs Sq112). This means that for most areas, for most of the year, it is likely that the water applied in a single application should be taken up by the soil and limited downward movement will occur. A very high summer SMD is not justification of higher hydraulic loading rates, as the SMD may be bypassed in cracked or macro-porous soils. High SMD's suggest that a number of low loading rate applications may be acceptable, in terms of hydraulic loading, over a period of several days.

3 mm/day or 3 mm in 1 hour is also low when compared to saturated hydraulic conductivities of silty clays and clay loams which are typically in the range 2-10 mm/hour (Hern and Melancon, 1986). This means that runoff is unlikely, except on very clayey soils on sloping ground.

Repeat disposals, particularly during the winter months, may result in some downward movement, or if carried out within a short time of the previous disposal or shortly before heavy rainfall could lead to some bypass flow. The Agency's initial screening procedure has a minimum interval of 3 days between each disposal of waste sheep dip. COGAP-W notes the need to avoid spreading when heavy rainfall is expected. COGAP-W also notes that, for slurry, at least 3 weeks should be allowed between disposals to avoid surface sealing and to allow the soil to recover.

In hydraulic terms, a number of disposal rates of 3 mm/day are insignificant when compared to annual soil infiltration rates of several hundred mm/yr. Consequently the main reason for the downward movement of contaminants will be as a result of the flushing or leaching as rainfall infiltrates down through the soil column.

From the above discussions, and in the absence of any site-specific data, 30 $m^3$/ha/day is considered to be an appropriate maximum rate of disposal. There is some uncertainty as to the period needed between disposals; the conservative view would be to follow COGAP-W for land with high risk of runoff and allow at least 3 weeks, to reduce the surface sealing and allow the soil to recover. This aspect requires further research.

For soakaways constructed below the soil zone, the saturated hydraulic conductivity (assuming a hydraulic gradient of 1) and the presence or absence of macropores (e.g. fissures) are the main controls. Soakaways, by their nature, have very high hydraulic loading rates compared to land spreading operations.

### 2.2.3 Method of disposal

From the discussion above, it is clear that hydraulic loading rate is an important consideration. The method of disposal has a direct control on the loading rate. Soakaways are designed to concentrate large amounts of liquid into a small area, but land spreading methods vary greatly.

Methods that spread the effluent evenly over an area are preferred as these ensure that each part of the disposal area has the same low loading rate. Such methods include use of spraying equipment (particularly for pesticides) or slurry spreading equipment (e.g. for sheep dip and treated sewage).

Some methods, whilst disposing of the same volume over the same total area can lead to much higher loading rates locally. Methods such as tipping the liquid out of a container onto the land or “pulling the plug” on a sheep dip bath are inappropriate and, more importantly, are contrary to good practice.

## 2.3 Runoff

### 2.3.1 Background

Detailed assessment of the potential for runoff is not within the scope of this work. The effect of hydraulic loading rates on the potential for runoff has been discussed in Section 2.2. The risk of runoff during the land spreading operation is low at rates of <3 mm/ha/day except for slopes of 1 in 5 (11°) or steeper.

The main concern is washing off of contaminants (dissolved or particulate) retained on the land surface by subsequent rainfall-runoff into adjacent streams and swallow holes or onto adjacent land.

The potential for runoff depends on:

- Rainfall intensity and amount;
- Slope of the land;
- Vegetation (more runoff and higher particulate load from bare soil than grassed land);
- Soil type and wetness.

Further discussion of these matters is provided in standard texts such as Smedema & Rycroft (1988).

### 2.3.2 Determining likelihood of runoff

The likelihood of contamination of surface waters by runoff from land spreading areas, either during the application or by subsequent rainfall, is controlled by standard conditions on the authorisation. These are that no disposal shall take place on land:

- Within 10 m of the nearest watercourse or 30 m from a river designated as a SSSI or SAC;
- Within 25 m of an identified swallow hole (*optional condition*);
- With a slope greater than 11° (~1 in 5) (based on COGAP-W);
- Which is frozen hard or snow covered, liable to flooding, is severely compacted or waterlogged.

COGAP-W also indicates that spreading should not take place when heavy rain is expected, so this means that the weather forecast should be checked prior to spreading. For herbicide wash-off in runoff, the critical period is between 0 and 15 days after the application date (Wauchope, 1978 referenced in Vighi and Funari, 1995).

### 2.3.3 Data

Slopes can be determined from topographic maps. Slope classes as used by the National Soil Resources Institute (NSRI) formally known as the Soil Survey and Land Research Centre (SSLRC) in their soil profile descriptions are shown in Table 2.3.

Data on the propensity for different soil types to be waterlogged and their standard percentage runoff factors are part of the Hydrology of Soil Types (HOST) Class system described by Institute of Hydrology (IoH )(1995). Figure 2.3 plots the standard percentage runoff factor and baseflow factor for the different HOST Classes.

**Table 2.3 – Slope Classes (in Soil Survey, 1984)**

| Slope Class | Slope | Slope Class | Slope |
|---|---|---|---|
| Level | 0-1° | Moderately steeply sloping | 12-15° |
| Gently Sloping | 2-3° | Steeply sloping | 16-25° |
| Moderately Sloping | 4-7° | Very steeply sloping | 26-35° |
| Strongly Sloping | 8-11° | Precipitous | >35° |

Note: There should be no disposal onto land classified as more than strongly sloping (COGAP-W). Runoff coefficients increase with slope, but it is noted that there is no obvious stepped change in these coefficients at 11°.

## 2.4 Chemical Loading

### 2.4.1 Background

The chemical loading rate is the total amount of chemical spread on the land or discharged to the soakaway each year. It is defined by the concentration of the substance(s) or chemical(s) multiplied by the hydraulic loading rate per area per disposal and by the number of disposals (per year).

The chemical loading rate is the amount of List I and List II substances added to the soil or substrata and thus a hazard to groundwater. The chemical loading rate affects the risks from the disposal activity through:

- The amount of chemical that could be adsorbed by the soil. For some combinations of contaminants and soils there may be a limited sorption capacity (e.g. ammonium and soil cation exchange capacity) and sorption may be reversible (see Section 2.7 for more discussion on sorption).
- The build-up of non-degradeable or very persistent chemicals in the soil over time, potentially leading to contaminated land.
- Degradation rates. Some substances may degrade only slowly at high soil concentrations or low temperatures. There may also be benefits from re-application to the same area following the acclimatisation of soil microbes.

### 2.4.2 Type of chemicals

The type of substance(s), chemical(s) or active ingredient(s) subject to disposal affects its fate in terms of loss from the soil through volatilisation, degradation (photolysis, hydrolysis and biodegradation) or desorption and leaching to groundwater. These substances can be divided into four main groups, based on their persistence and leachability, as shown in Table 2.4.

Some types of substances (insecticides, herbicides, etc) fall into each of the four groups and there is a transition between each group. Within each group there are List I and II substances.

**Table 2.4 – Groups of Substances Considered**

| Group | Persistence | Leachability | Typical Substances | Issues |
|---|---|---|---|---|
| A | Low | Low | Straight chain aliphatic hydrocarbons, volatile compounds[a] | Air quality for some. |
| B | Low | High | Aromatic hydrocarbons (BTEX), some PAHs, phenols, Mecoprop[c], 2,4D[c], Atrazine[c] | Likely to be found in groundwater. |
| C | High | Low | Branched aliphatics e.g. lube oil, PCBs, some PAHs, many metals[b], $NH_4$[b] | Soil contamination. |
| D | High | High | Anions (e.g. Cl, $SO_4$) Chlorinated Solvents[b], Simazine[c] | Soil contamination and long term release to groundwater |

Note:

a: Excluding chlorinated solvents.

b: Depends on environmental conditions.

c: Many sheep dip chemicals and pesticides fall into the category of moderately mobile and moderately persistent.

It is important to note that some substances that are degradable in aerobic environments are persistent and highly mobile in the groundwater environment (which is often low in oxygen). Moreover assessments of the risk of migration of substances based on their normal <u>use</u> may not be appropriate to the conditions of <u>disposal</u> of wastes containing those substances.

### 2.4.3 Data

Wherever possible, the applicant should provide the active ingredients or product name of the waste products to be disposed of, together with the volume for disposal. The Agency has a database of product names and the chemicals these contain. If this information is not available, a targeted chemical analysis may be required. It should be noted that an authorisation is not usually specific to a particular compound and may only specify, for example, 'sheep dip' or types of sheep dip e.g. synthetic pyrethroids. The exact chemical nature of proprietary sheep dip may change over the period of an authorisation and this is one reason why a review period is needed. Given the variation in properties of different chemicals, this means that the quantitative assessment of a general activity should conservatively use the properties of the most persistent, toxic and mobile chemical in the group of chemicals being used.

For waste pesticides and waste sheep dip disposal, the concentration of the application should be compared to the working strength recommended by the manufacturer. It is likely that much of the environmental data for a particular compound will relate to this strength. Applications of compounds in excess of the working strength are prohibited as it is against the product instructions.

Some applicants may incorporate a dilution step prior to land spreading. In the case of sheep dip this may be due to use of spreading equipment which only functions satisfactorily with a certain starting volume.

Information on the chemical properties and fate mechanisms of different substances is available in a number of standard texts. These include:

- Handbook of Environmental Data on Organic Chemicals (Verschueren, 1996).
- Handbook of Environmental Degradation Rates (Howard *et al*, 1991).
- OSU Extension Pesticide Properties Database (Vogue *et al.* 1994).
- Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals (Four Volumes) Volume 1 Monoaromatic Hydrocarbons, Chlorobenzenes and PCBs (Mackay *et al*, 1992).
- USEPA Soil Screening Guidance (1996).
- Environment Agency and SEPA internal database for substance classification purposes.
- Groundwater Chemicals Desk Reference (Montgomery J H and Welkom, L M, 2nd Edition 1996 or Montgomery J H, 3rd Edition June 2000).

## 2.5 Infiltration/Recharge Rate

### 2.5.1 Background

Once the liquid has been applied to land or discharged to a soakaway, the rate of movement of unretarded (no absorption) contaminants is controlled in part by the infiltration rate through the soil.

Infiltration is assumed to be the water which percolates through the soil and unsaturated zone to the water table to eventually become baseflow rather than becoming runoff or rapid shallow interflow. The Hydrology of Soil Types (HOST) Class system (IoH, 1995) provides a baseflow index (BFI) for each HOST Class and this allows the infiltration rate to be calculated from the hydrologically effective rainfall (HER) as:

$$\text{Infiltration Rate} = \text{HER} \times \text{HOST Baseflow Index}$$

Where the infiltration rate and HER are in the same units e.g. mm/day or mm/yr.

Baseflow indices (BFI) are plotted against standard percentage runoff (SPR) for each of the 29 HOST soil classes in Figure 2.3. Coarse soils effectively allow all the HER through, whereas for more clay-rich soils only 20% of the HER may infiltrate (IoH, 1995).

### 2.5.2 Data

Monthly and annual hydrologically effective rainfall (HER) data are available from the Meteorological Office in their MORECS (40 km x 40 km grid square, 25 year statistics) data, and should be obtained based on information on land use provided by the applicant. The land use options in MORECS are: bare soil, vegetated and permanently grassed.

All soil map units as referenced on soil maps are classified under the HOST system (IoH, 1995). Further discussion of soil data sources is given in Section 3.5.5.

## 2.6 Unretarded Travel

### 2.6.1 Background

The travel time through the soil and unsaturated zone depends on the infiltration rate, but also depends on factors such as thickness, soil moisture deficit, moisture content, saturated vertical hydraulic conductivity's.

A relatively simplistic approach to estimate travel times through the soil and unsaturated zone is to assume 'plug' or 'piston' flow, where water added at the surface of the layer displaces water held in the soil and leads to a release of water at the base of the layer. Other Agency methodologies (LandSim and ConSim) use a version of this approach. It is represented by an equation of the form:

$$T_u = \frac{365\frac{1}{4}\, z\theta_w}{I}$$

where:

$T_u$ = the unretarded travel time through the soil (days)

365¼ = the number of days in a year

$z$ = the thickness of the soil (mm)

$\theta_w$ = the moisture content when there is no soil moisture deficit (fraction)

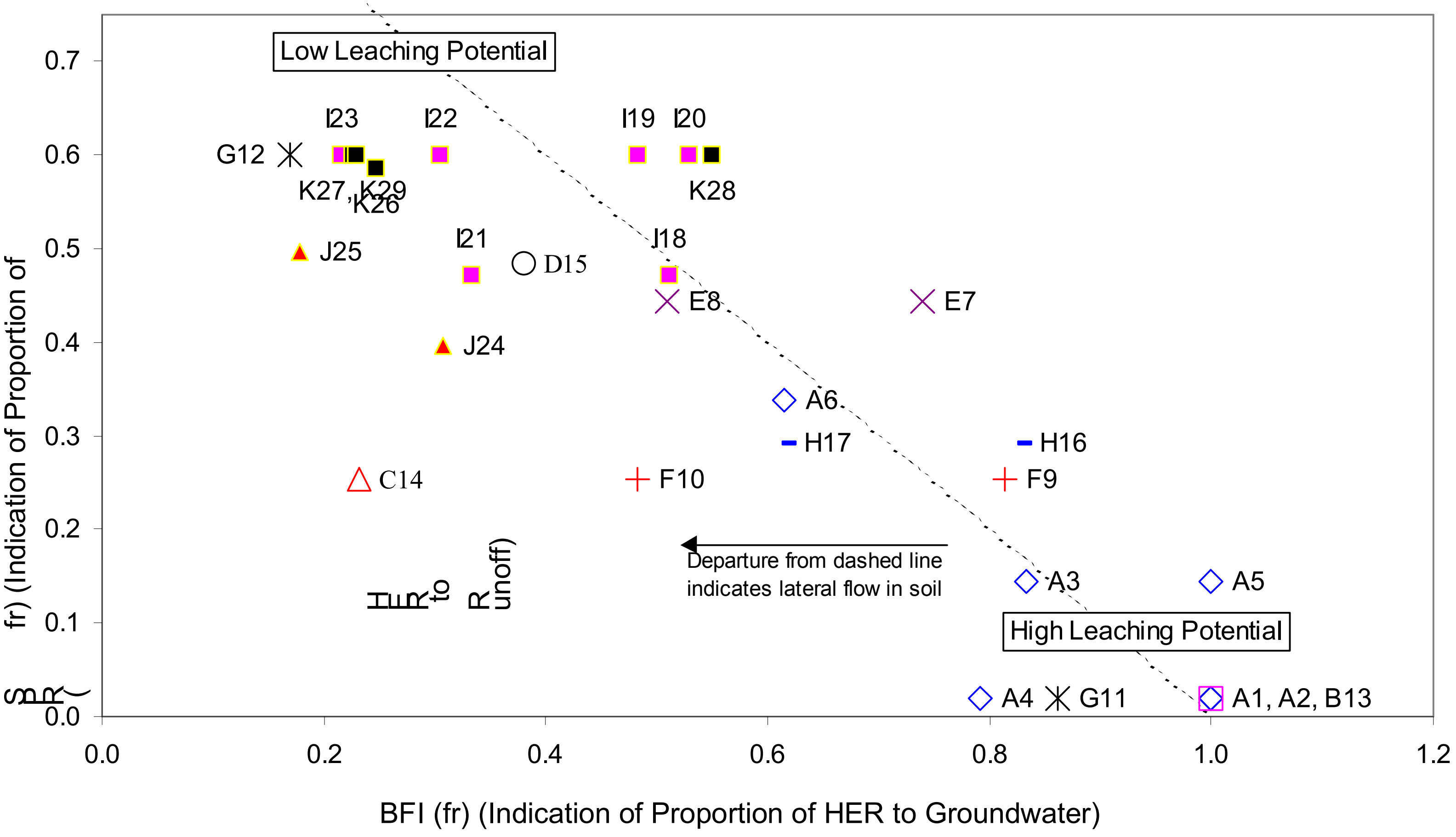
$I$ = the average infiltration rate through the soil (mm/yr)

To obtain a total unretarded travel time to the water table, this calculation will need to be undertaken for the topsoil, subsoil and unsaturated zones due to their different thicknesses and effective moisture contents.

This approach assumes conservatively that there is no soil moisture deficit and no lateral flow in the soil, but ignores bypass flow through macropores such as wormholes.

Soil moisture deficit can be important as, when present, water added to the soil will be taken up by capillary forces and will not lead to downwards movement. This can therefore lead to a delay in the unretarded travel time through the soil. Soil moisture deficits depend on climate and land use and so may vary in time as well as space.

Bypass flow is discussed by Larson and Jarvis (1999). It is believed that water movement in soils can be represented by piston flow in the micro-pores as long as the infiltration rate does not exceed the vertical hydraulic conductivity of the micro-pore system. Once exceeded, excess water (and any contaminants within it) moves rapidly under gravity through the macro-pores. LandSim's dual porosity option uses this approach to model flow in unsaturated Chalk, for example.



**Notes:**
**Symbols** - The Host classification has 11 response models (A to K) which describe the dominant pathways of water movement (as runoff, intraflow or downward movement). These 11 response models are identified on the figure as different symbols.
**Symbol Labels -** The 11 Host response models are further sub-divided into a total of 29 Host classes on factors such as substrate hydrogeology. Refer to Section 5.5.5, Project Record and IoH, 1995.

**Figure 2.3 Comparison of BFI to SPR for Different HOST Classes (after IoH, 1995)**

As long as the hydraulic loading rate during the application does not lead to bypass flow, and any contaminated water is held within the micro-pore system then it is assumed that infiltration moving during subsequent intense rainfall events has the potential to bypass much, if not all of the contaminants. This is, in part, due to slow diffusion rates (hours, days and for some soils months) between parts of the soil micropores to the larger pores (Jones *et al.* 2000) compared to the rapid travel times during storms. Bypass flow of relatively uncontaminated infiltration will also mean that the rate of flow in the micro-pores is overestimated. The main factor will be the time between an application and a rainfall event which could induce bypass flow. For rainfall events which occur within days of the application there is a high potential for movement of contaminants as bypass flow. With time, a greater proportion of the contaminant will be present within the micro-pore system or sorbed on to the soil matrix and is less likely to form part of bypass flow, as rates of desorption are typically slower than sorption rates.

### 2.6.2 Approach

For most topsoils less than 0.3 m thick, unretarded travel times will be less than a month or two unless there is a soil moisture deficit. This is illustrated by the calculation (see Section 2.6.1 for equation):

$$T_u = \frac{365\tfrac{1}{4}\, z\, \theta_w}{I}$$

$$T_u = \frac{365\tfrac{1}{4} \times 300 \times 0.1}{600} \approx 18\ days$$

This means that unretarded contaminants have the potential to move rapidly through the soil and thin (<1 or 2 m) unsaturated zones. This leaves little time for degradation (if any) and so groundwater is likely to be impacted.

This potential for rapid travel also means that it is inappropriate to use average annual infiltration rates as travel will be much faster during wetter months. Where there is no seasonal condition on the authorisation, the infiltration rates used should be at least at the maximum monthly rate. This may be as high as 200 mm/month in some areas.

If a seasonal condition is an option for the disposal, then MORECS 25 year minimum monthly soil moisture deficit data could be used to identify the period of no downward movement of soil water and then used as the minimum unretarded travel time. This minimum unretarded travel time is June-September for East Anglia (MORECS Sq152), but is non-existent for North Wales (MORECS Sq112).

The overall approach therefore involves calculation of unretarded plug flow travel time ($T_u$) as defined in Section 2.6.1 and then (for seasonal disposals only) to add the time following the disposal when a soil moisture deficit exists (based on MORECS 25 year minimum SMD data).

### 2.6.3 Data

Determination of infiltration rates has been discussed in Section 2.5. Monthly data should be used for unretarded or poorly retarded contaminants.

Soil thicknesses (topsoil and subsoil) should be measured on site. An indication of soil profiles can be gained from the soil profiles reported in Soil Survey Bulletins (e.g. Soil Survey, 1984). It should also be possible to provide an estimate of site-specific soil and subsoil thickness by interpreting the various databases held by the NSRI (National Soil Resources Institute).

Note : The Agency currently has a Framework Agreement with and leases key data sets from the NSRI to provide soil data and interpretative services.

Methods for estimating and measuring moisture contents are given in Appendix A1. It is important to note that it is the moisture content and not the total porosity which should be used for unsaturated soils and substrata.

## 2.7 Sorption

### 2.7.1 Background

Many contaminants have a preference to adhere to soil particles rather than remain dissolved or suspended in water. This leads to the contaminants moving through the soil at a retarded velocity compared to the water.

There are a number of processes included under this description:

- Filtration of particulates and microrganisms;
- Precipitation of dissolved substances, particularly metals as metal carbonates;
- Cation exchange (electrostatic adsorption) of ammonium and some metals onto clays and some metal oxides;
- Adsorption of hydrophobic organics onto organic carbon (and to a much lesser extent clays);
- ‘Filtration’ of non aqueous phase liquids (NAPL’s) disposed to the soil as an emulsion;
- Adsorption of cationic hydrophilic organics (e.g. triazine herbicides) onto clays.

In assessing the likelihood of a substance moving through the soil and unsaturated zone, contaminant migration models all assume that sorption can be represented by an instantaneous reversible linear equilibrium between the soil and water and by a soil/water distribution ratio, $K_d$. This assumption makes the mathematical simulation of the sorption process simple, but is not always conservative as it leads to an infinite capacity to adsorb. More detailed discussion of sorption processes is given in R&D Technical Report P340 (Environment Agency, 2000b) and in Project Record P2/142/01 (Environment Agency, 1999d).

There have been a number of studies (e.g. Jones *et al*, 2000) in recent years that indicate that whilst sorption generally occurs rapidly, desorption is often kinetically controlled. Some desorption occurs quickly (in hours), but there are proportions of the contaminant that desorb slowly (rate constant of $10^{-3}$/hr) or very slowly (rate constant of $10^{-5}$ to $10^{-4}$/hr) due to diffusion and tight binding in micropores. So, overall, sorption is faster than desorption. The proportion of slow, plus very slow to rapid, desorption increases with increasing $K_d$. This slow desorption means that the assumption of instantaneous linear equilibrium sorption/desorption is conservative from the viewpoint of migration to groundwater and also that some contaminants will remain in the soil indefinitely if they are not degraded.

It is noted that none of the contaminant migration models consider issues such as emulsions or co-solvency affects which could influence the transport characteristics of the main active ingredient. For example, many sheep dip formulations are emulsions and also contain other additives which, whilst not being active ingredients in themselves, may influence the physicochemical characteristics of the main active ingredient(s). If a single substance was present as an emulsion, then an approach would be to assume that its initial concentration in water transported through the soil zone would be equal to its solubility limit. However, given the potential for co-solvency affects with additives, this approach is unlikely to be conservative for many disposals, such as sheep dip. Until further research clarifies the significance of emulsions and co-solvency affects on contaminant transport then the approach described below is recommended.

### 2.7.2 Approach and data requirements

The approach used to represent sorption is to assume instantaneous linear equilibrium sorption and desorption. Discussion of the effect of sorption on travel times is given in Section 2.7.3.

For hydrophobic organic contaminants, $K_d$ (l/kg) can be represented well for most soils as:

$$K_d = K_{oc} \cdot f_{oc}$$

where $K_{oc}$ is the organic carbon/water partition coefficient (l/kg) and $f_{oc}$ is the fraction of organic carbon in the soil. The relationship underestimates sorption at very low organic carbon contents (typically <0.1%) as sorption on clays becomes important. The minimum organic carbon content below which sorption on clays becomes important is contaminant specific. Generally, this is lower for higher values of $K_{oc}$.

For hydrophilic organic contaminants, $K_{oc}$ is pH dependent and $K_d$ can increase with the amount and type of clays. However, the $K_d = K_{oc}.f_{oc}$ approach is often used to conservatively represent hydrophilic sorption.

For hydrophilic organic contaminants and non-organics, $K_d$ cannot be accurately estimated from $K_{oc}$. Literature values can be inappropriate and, where possible, soil specific tests are best carried out. This is because factors such as soil clay content and pH are important. Methods of determining $K_d$'s are discussed in R&D Technical Report P340 (Environment Agency, 2000b).

An important point when selecting values of $K_d$ from the literature is to ensure that the values have been determined from comparable conditions (especially for hydrophilic organics and metals) and through consideration of similar concentration levels of similar formulations in the soils. This helps to reduce the importance of non-linear sorption, emulsions and co-solvency affects.

There are many sources of information on $K_{oc}$ and $K_d$'s. These include those referenced in Section 2.4.3.

Organic contents are dependent on the climate, soil type and land use. An indication of likely organic content can be obtained from comparison of soil types on maps with soils data published in the Regional Soil Memoirs (e.g. Soil Survey, 1984). The NSRI is the custodian of the National Soil Inventory (NSI). The NSI data set was obtained from 5500 rural 5 km grid square samples and contains data on site properties (i.e. soil series, slope and land use), soil profiles (i.e. boundaries, colour, structure) and topsoil analytical properties (i.e. texture, pH, % organic carbon and various chemical elements). Next to that, national soil map datasets describing soil series were published in 1983 based on a 'free' survey with an average of 2-3 soil observations per sq km. The NSRI digitised database which brings this all together for 296 soil associations is called LandIS and contains many additional calculations for values such as bulk density, pore space, water retention as well as information from many unpublished research projects. The NSI is accessible to Agency staff via the Agency's Framework Agreement with NSRI. This agreement covers the following services:

- Advice on and provision of digital soil information and data.
- Generation and interpretations of soil and related information across England and Wales.
- Soil reports and advice.
- Assistance and training.

The contact for further information at the time of preparation of this report is the Soil Policy Manager, Land Quality, Environment Agency, Rio House, Bristol.

### 2.7.3 Sorption and Retarded Contaminant Transport

Sorption leads to contaminants being retarded compared to the water. This retardation factor ($R_f$) is given by the equation:

$$R_f = \left[1 + \left(\frac{K_d.\rho}{\theta_w}\right)\right]$$

where:

$K_d$ = the soil/water distribution ratio or partition coefficient (l/kg)
$\theta_w$ = the water filled soil or unsaturated zone effective porosity (fraction)
$\rho$ = the dry bulk density (g/cm$^3$).

The retarded travel time ($T_r$) is then given by:

$$T_r = T_u \, . \, R_f$$

The unretarded travel time ($T_u$) is defined in Section 2.6.1

This retarded travel time is the time until the arrival of the **peak** concentration, vertical dispersion being ignored. This is the time available for degradation (see below) to occur such that the peak concentration ($C_{max}$) can be predicted by the equation:

$$C_{\max} = C_0.0.5^{\left(\frac{T_r}{T_{½}}\right)}$$

where:

$C_o$ = the concentration in the source on application (mg/l)
$T_r$ = the retarded travel time (days)
$T_{½}$ = the soil degradation half-life (days) ($T_{½} = ln2/\lambda = \sim 0.693/\lambda$)
$\lambda$ = the decay or rate constant (day$^{-1}$).

## 2.8 Volatilisation

In the prior investigation methodology, volatilisation is assumed to be accounted for in the soil degradation rate and so is not considered separately. Should volatilisation, photolysis, chemical degradation and biodegradation be considered separately by an applicant, then this section provides some background on volatilisation and its assessment.

### 2.8.1 Background

Volatilisation is the process of partitioning contaminants from the soil-water system into the vapour phase. Henry's Law constant describes this vapour/water partitioning for dissolved contaminants.

Many contaminants are not volatile, but for those that are, excluding the process of volatilisation from an assessment will conservatively over-predict the amount remaining in the soil or leached to groundwater.

To examine the likely influence of volatility on a contaminant's distribution, partitioning between the soil, water and vapour phase must be considered. This is discussed in the P20 Methodology (Environment Agency, 1999a) and described by the equation:

$$C_t = C_w\left[K_d + \frac{\left(\theta_w + \theta_a H\right)}{\rho}\right]$$

where:

$C_t$ = the total soil concentration (mg/kg)
$C_w$ = the concentration in the water (mg/l)
$K_d$ = the soil/water distribution ratio (l/kg)
$\theta_w$ = the water filled soil porosity (fr)
$\theta_a$ = the air filled soil porosity (fr)
$H$ = Henry's Law constant (unitless)*
$\rho$ = the dry bulk density (g/cm$^3$).

*Note: Henry's Law constant can also be expressed in units of Pa.m$^3$/mol or atm.m$^3$/mol. Conversion factors are given below:

1atm = 101300 Pa

Unitless Henry's Law constant = $H$(atm.m$^3$/mol)/[8.314 × T(°K)]

Solving this equation for soils in which the total voids are less than 90% water saturated, indicates that for Henry's Law constant values of up to 1, volatilisation will be unimportant (<20%) as long as $K_d$ is greater than about 1. For values of $H$ above 1, volatilisation will be unimportant (<20%) as long as $K_d$ (l/kg) is not less than $H$ (unitless).

### 2.8.2 Data

Henry's Law constants are provided in a number of environmental data 'handbooks', see Section 2.4.3.

## 2.9 Degradation

### 2.9.1 Background

Degradation is defined here as any mass-reducing process that leads to a reduction in concentration of a contaminant in the soil or water other than the processes of leaching and volatilisation. Degradation processes include:

- Photolysis (degradation of a contaminant by sunlight);
- Chemical degradation (e.g. hydrolysis);
- Biodegradation (microbial degradation).

Details of these processes have been summarised recently in R&D Project Record P2/142/01 (Environment Agency, 1999d).

**Photolysis** is an important abiotic degradation mechanism for some contaminants such as pesticides and chlorinated solvents. It is only likely to occur on the soil surface or in surface waters through exposure to sunlight. Once the contaminant has infiltrated to the soil, this mechanism is unimportant as a mechanism for reducing risks to groundwater.

**Chemical degradation** is an abiotic degradation mechanism that occurs through the reaction of a contaminant with reactants in the environment, particularly oxygen (oxidation) and water (hydrolysis). Hydrolysis results in the replacement of one functional group (e.g. chloride) with a hydroxyl group and can lead to toxicity changes. Not all contaminants are susceptible to hydrolysis, but for pesticides, hydrolysis is a primary route for degradation.

**Biodegradation** is the breakdown of substances by microbially (biotic) catalysed reactions. The breakdown products can be as harmful as the original contaminant, although these 'metabolites' may also biodegrade.

Organic compounds may be biodegraded by many different mechanisms and microorganisms (bacteria, fungi and actinomycetes). The three major mechanisms are:

- Catabolism or direct oxidation where the molecule is utilised as a nutrient or energy source.
- Co-metabolism where utilisation is coincidental to normal metabolic functions.
- By enzymatic action where microorganisms have secreted enzymes to the soil, such as phosphatases and amidases, which may persist long after the parent cells are dead.

Many compounds undergo a series of biochemical transformations that eventually result in the complete removal of the compound. Most of these processes involve an increased preference for water over soil. Microbial degradation rates increase with a number of factors including increasing temperature, oxygen content (aerobic/anaerobic), availability of nutrients and degradeable organic matter and size of microbial culture. This tends to make degradation rates higher in coarse soils than in clay-rich, high moisture content soils and peaty soils. As microbial populations and degradeable organic contents are much higher in topsoils than in underlying mineral soils and unsaturated zones, degradation rates decrease rapidly with depth.

For most compounds, aerobic degradation is several times more rapid than anaerobic degradation (Howard *et al*, 1991). Anaerobic degradation is important for some compounds such as chlorinated solvents, PCBs and DDT due to the process of reductive dechlorination. Between aerobic and anaerobic processes, the presence of dissolved nitrate, iron and manganese oxy-hydroxides in the soils and dissolved sulphate can support degradation at intermediate rates.

Each of the degradation processes is dependent to some extent on temperature. Compounds are more volatile at warmer temperatures and both chemical and biochemical reaction rates increase with temperature. This means that there will be some seasonal variations in degradation rates in soils. This seasonality will be highest in the near surface layers, but will be lower in the subsoil where temperatures will more closely reflect the annual average air temperature.

### 2.9.2 Acclimatisation and effect of repeat applications

Application of a new contaminant to a soil means that there is often a lag time before the soil microbes are acclimatised and degradation rates are optimised. Lag times have been reported (in Hern and Melancon, 1986) to range from a few hours to a few months depending on the contaminant and its concentration. The lag period may be similar to the degradation half-life.

Repeat applications of the same pesticides and herbicides to the same soil under the same crop leads to an adjustment of the microbial population of the soil. This can greatly affect the persistence and therefore agronomic efficacy of some molecules (Vighi and Funari, 1995). Crop rotation reduces this effect, preserves the efficacy of the molecules for the crop, but potentially leads to an increased risk to groundwater.

### 2.9.3 Approach

The approach adopted in this methodology is consistent with most other approaches to assessing contaminant transport (e.g. P20, Environment Agency, 1999a). This approach is to represent degradation as a first order decay reaction as follows:

$$C_t = C_0.0.5^{\left(\frac{t}{T_{½}}\right)}$$

where:

$C_t$ = the concentration in the source at time, $t$ (mg/l)
$C_o$ = the concentration in the source on application (mg/l)
$t$ = time since the application occurred (days)
$T_{½}$ = the soil degradation half-life (days) ($T_{½} = ln2/\lambda = \sim 0.693/\lambda$)
$\lambda$ = the decay or rate constant (day$^{-1}$).

Use of the total soil degradation half-life or rate constant allows for all the processes of degradation (abiotic or biotic).

Acclimatisation of microbes has been ignored as this is a site-specific factor. It should not be significant for existing sites where disposals are regular, but may be significant for the first few disposals on a new site or at sites where disposals are very infrequent.

Further discussion of the effect of degradation on contaminant transport is provided in Section 2.10.

### 2.9.4 Data

Data sources on typical degradation rates for different compounds have been noted in Section 2.4.3. Data are normally presented as half-lives ($T_{½}$) or rate constants ($\lambda$) where:

$$T_{½} = \frac{0.693}{\lambda}$$

Literature sources of information include degradation rates for soils, groundwater and surface water and under aerobic and anaerobic conditions. For the soils, rates pertaining to aerobic conditions in soils should be used unless the soils are waterlogged, when anaerobic rates should be used. For subsoils and unsaturated zones, rates relating to aerobic conditions for groundwater are likely to be more appropriate than those for soil due to the different prevailing microbial conditions.

It is important to note that many literature values will be based on laboratory measurements and field studies in the United States and that these may therefore be relevant to temperatures closer to 20°C than typical annual average soil temperatures in the UK of about 10°C. Based on reaction rates typically doubling with a 10°C increase in temperature, degradation half-lives should be doubled unless the temperatures quoted in the literature are appropriate.

Degradation rates can also be influenced by pH and by the concentration of the contaminant. Some contaminants are toxic to microbes and so tend only to be degraded when present at low concentrations. Degradation rate data for pesticides will be related to the working strength for a specified use. Consequently, applications of compounds in excess of the relevant working strength should be avoided as there may be variation in toxicity to soil micro-organisms with concentration and will be in contravention of the product use instructions.

Many data sources based on field and lab studies provide degradation in soil half-lives. It should be noted that these data can incorporate all the processes of volatilisation, sorption, hydrolysis and microbial degradation. When these soil half-lives are used, it is important not to double count other processes such as volatilisation.

## 2.10 Changes in Processes with Depth

Three distinct zones can be recognised at most sites. These are:

**Topsoil** - usually the highest organic content, roots and often a soil moisture deficit.

**Subsoil** - less organic content than the topsoil, but more than the unsaturated zone.

**Unsaturated Zone** - low organic content, possibly rocky substrata.

Topsoils typically contain more organic carbon, have a higher microbial population and often have soil moisture deficits or higher overall moisture contents than subsoils or unsaturated strata. This means that both water and contaminant movement is slower in this layer and that degradation is faster. For many contaminants, therefore, the soil zone is the key zone for attenuation.

Organic carbon contents in topsoils (1 to >20%) are typically higher than in subsoils (typically less than 0.5%) and considerably higher than in unsaturated strata such as the Sherwood Sandstone (0.02 to 0.05%) and Chalk (0.01 to 0.05%) respectively (Pacey, 1989; Foster *et al*, 1991; Steventon-Barnes, 2000). The nature of the organic matter also tends to change with depth from amorphous organics to more mineralised. Both these factors mean that sorption of hydrophobic organics generally decreases significantly with depth.

Microbial activity decreases with depth generally due to decreased food source (organic carbon), but also due to less oxygen and nutrients.

Seasonal temperature fluctuations also decrease with depth down to about 3 m below ground level.

## 2.11 Hydrodynamic Dispersion

Hydrodynamic dispersion comprises the processes of mechanical dispersion and molecular diffusion.

Mechanical dispersion occurs as a result of water flowing through a porous medium at different velocities. This is because flowpaths differ depending on the porosity and hydraulic conductivity of the route taken. Where the water is sourced from a disposal to land and from rainfall, mechanical dispersion leads to mixing of the two types of waters and thus a reduction in the concentration along the flowpath.

Mechanical dispersion increases with increasing velocity and so tends to be less significant in the unsaturated zone than the saturated zone (Environment Agency, 1999d). However, it can be important in soils with a high macroporosity as a result of more rapid transport in the macropores than in the micropores of the soil.

Molecular diffusion is the movement of contaminants from high concentration areas to low concentration areas. This leads to contaminants moving from larger to smaller pores that are otherwise not accessed by moving water. Diffusion is generally very slow compared to flow rates but can be important in low permeability soils or dual porosity strata and soils with significant macroporosity. This process does not remove mass from the system, but slows down the contaminant movement and thus allows more time for degradation processes.

The two parameters that describe diffusion and mechanical dispersion are combined to provide the hydrodynamic dispersion coefficient, D:

$$D = \tau D_w + \alpha . v = D^* + D_d$$

where:

$D$ = hydrodynamic dispersion ($m^2/s$)
$D^*$ = mechanical dispersion ($m^2/s$ )
$D_d$ = molecular diffusion coefficient through medium ($m^2/s$)
$\alpha.$ = dispersivity (m)
$v$ = groundwater velocity (m/s)
$\tau$ = tortuosity of medium
$D_w$ = molecular diffusion coefficient in water ($m^2/s$)

## 2.12 Dilution

### 2.12.1 Background

The compliance point for List I substances is the water table and this means that dilution should be considered only for List II substances. However, dilution can also be considered for:

- List I substances if the groundwater beneath the site has been designated as 'permanently unsuitable'.
- Evaluating whether, in principle, List I substances would be measurable in any groundwater monitoring.

Dilution is the reduction in concentration of a contaminant leaching from the base of the unsaturated zone by mixing with groundwater beneath the water table. Mixing in the aquifer may not be with all the groundwater flowing beneath the site due to stratification. However, sampling of groundwater from a monitoring well or abstraction well will lead to mixing of the water in the screened section of the borehole.

### 2.12.2 Estimating groundwater flow beneath a site

Flow beneath the site can be estimated using a Darcy Flow approach or groundwater catchment method.

The ***Darcy flow approach*** uses the equation:

$$Q_{gw} = Kiwd_a$$

where

$Q_{gw}$ = the estimated flow beneath the site ($m^3$/day)
$K$ = the hydraulic conductivity of the strata (m/day)
$i$ = the hydraulic gradient (m/m)
$w$ = the width of the site perpendicular to the flow direction (m)
$d_a$ = the saturated depth of aquifer beneath the site (m)

For some sites there will be good control on the site width and saturated aquifer thickness, but hydraulic conductivities will rarely be known to better than an order of magnitude even with extensive field data.

The ***groundwater catchment approach*** uses the equation:

$$Q_{gw} = A_{gw}.I$$

where

$A_{gw}$ = the groundwater catchment area estimated from groundwater contour maps or for unconfined aquifers approximated to the surface water catchment ($m^2$)
$I$ = the estimated recharge rate over the groundwater catchment area (m/d).

Ideally the two methods should be compared for consistency and checked for plausibility.

### 2.12.3 Mixing zones

Although in theory the point of assessment for compliance with the Groundwater Directive for List II substances is at (or within) the water table, in practice a mixing zone is needed to facilitate dilution by the groundwater flow in the aquifer. In the case of a **lateral** mixing zone, this can be set at the width of the land spreading area or soakaway at 180 degrees to the direction of groundwater flow.

As far as mixing in **the direction of groundwater flow** is concerned, a range of between 10 and 50 m could be set, albeit arbitrarily. These down-gradient distances are based on the buffer zones for surface water (10 m) and groundwater (50 m) features that are applied to all authorisations.

With respect to **vertical** mixing zones, these will generally be less than the aquifer thickness and can be estimated based on a hydrogeological evaluation of the site using the equation (from USEPA, 1994):

$$b_{mz} = \left(0.0112L^2\right)^{0.5} + \left(d_a\left(1 - \exp\left[\frac{-L.I}{K.i.d_a}\right]\right)\right)$$

where:

$b_{mz}$ = the vertical mixing depth (m) at distance $L$. Note $b_{mz}$ cannot exceed the saturated aquifer thickness $d_a$.
$L$ = the distance (m) in the direction of groundwater flow that mixing is considered (arbitrarily 10 to 50 m);
$d_a$ = the saturated thickness of (isotropic) aquifer (m);
$I$ = the infiltration rate through the site (m/day);
$K$ = the hydraulic conductivity of the strata (m/day);
$i$ = the hydraulic gradient (m/m).

In the above equation, the denominator term $K.i.d_a$ is the groundwater flow beneath each 1 m width (w) of site (see Section 2.12.2). This flow can also be estimated from the multiplication of the infiltration/recharge rate ($I$ in m/d) over the site's groundwater catchment area by the up-gradient distance ($L_{gw}$) from the edge of the site to the groundwater catchment boundary.

For **land spreading activities** with low disposal rates (<30 $m^3$/ha/day = 3 mm/day) and a limited number (<~5) of disposals per year, the total infiltration/recharge rate to the site will be more or less the same as in the groundwater catchment. This assumption is reasonable as long as the soil types and drift cover are broadly the same at the site as in the catchment area.

Therefore, for land spreading disposals, replacing the term $K.i.d_a$ with $I.L_{gw}$, the equation simplifies to:

$$b_{mz} = \left(0.0112L^2\right)^{0.5} + \left(d_a\left(1 - \exp\left[\frac{-L}{L_{gw}}\right]\right)\right)$$

where:

$L_{gw}$ = the up-gradient distance from the site to the groundwater catchment boundary (or for catchments with relatively permeable drift cover, the surface water catchment boundary).

### 2.12.4 Dilution factors

The ***dilution factor*** is calculated as:

$$DF = \frac{IA}{\left(Q_{gw}.\left[\frac{b_{mz}}{d_a}\right] + I.A\right)}$$

where

$DF$ = the dilution factor (unitless);
$I$ = the infiltration rate through the site (m/day);
$A$ = the site area ($m^2$);
$Q_{gw}$ = the groundwater flow rate beneath the site ($m^3$/day);
$b_{mz}$ = mixing zone thickness (m);
$d_a$ = the thickness of saturated aquifer beneath the site.

Guidance on how to determine mixing zone thicknesses is provided in Section 2.12.3.

Where a site lies in the potential groundwater catchment area of an abstraction borehole, then a check on the possible impact on the borehole should be made. In this instance the dilution factor should be calculated as:

$$DF = \frac{IA}{\left(Q_{abs}. + I\right)}$$

where

$Q_{abs}$ = the minimum abstraction rate at the borehole ($m^3$/day).

## 2.13 Soakaways

Background information on the design of soakaways and their potential impact on water quality is provided in Section 4 of the Project Record (Environment Agency, 2002a). Some of these details have been provided here.

Soakaways cover a range of possible disposals to ground including:

- Discharges to boreholes/shafts/well (in some cases the borehole may allow discharge below the water table, i.e. direct to groundwater);
- Discharges to specially constructed structures (manhole chambers);
- Discharges to permeable ground/swales;
- Discharges to ditches or trenches;
- Discharges to natural drainage features such as solution features or fissures. This practice is not recommended, particularly for List 1 compounds, as rapid rates of flow are usually associated with such features. The exception will be (for List 2 compounds) if it can be demonstrated that the contaminant loading is sufficiently small that pollution will not occur.

Soakaways can generally be considered as point discharges.

In most cases, the discharge to a soakaway will bypass the soil zone, such that the only processes that will affect contaminant concentrations are attenuation in the unsaturated zone (List I and II substances) and dilution in the saturated zone (List II substances).

## 2.14 Summary

The key parameters that are used to describe contaminant behaviour in the soil zone, the unsaturated zone and saturated zone and which can be taken into consideration in technical assessments under the Groundwater Regulations include:

- contaminant concentration (contaminant phase);
- contaminant/source term properties (Henry's law constant, solubility, $K_{oc}$ or $K_{ow}$, $K_d$ (pH dependency), soil degradation half-life) hydraulic loading (area, rate of infiltration/spreading, frequency, runoff);
- properties of soil zone (thickness, porosity/moisture content, clay content, $f_{oc}$, capacity for bypass flow in macropores);
- properties of unsaturated zone (thickness, porosity/moisture content, clay content, $f_{oc}$, capacity for bypass flow in fissures);
- properties of saturated zone (thickness, porosity, hydraulic gradient, hydraulic conductivity, mixing depth);
- bio-chemical environment (dissolved oxygen, redox, pH).

# 3. PRIOR INVESTIGATION

## 3.1 Introduction

This section provides the recommended methodology for 'Prior Investigation' of applications for ***land spreading*** or ***soakaway*** discharge of List I and List II substances. Background information is also provided on legislative requirements and Agency duties.

The general procedure for prior investigation of applications is shown on Figure 3.1. This flow chart maps the path from initial screening through subsequent levels of investigation to authorisation or rejection. Reference is made to:

- **Level 1**: the Agency's initial screening procedures for assessing applications related to land spreading (see Section 3.4).
- **Level 2**: a conservative quantitative screening tool for assessing land spreading and initial assessment of soakaways (see Section 3.5).
- **Level 3**: Quantitative risk assessment based on approaches such as the P20 Methodology (Environment Agency, 1999a) (see Section 3.6).
- **Level 4**: Assessment of Dilution (see Section 3.7).
- Permanently unsuitable for other uses (see Agency Process Manual Section 4.2.2).

The four levels of assessment are described in more detail in Table 3.1.

The levels are normally progressive and incremental, although Level 4 (dilution) would normally be carried out before Level 3 (attenuation in the unsaturated zone) for List II substances.

As soakaways typically bypass the soil zone, their prior investigation will normally start at Level 3 (attenuation in the unsaturated zone). If List I substances are not present, Level 4 alone may be adequate, although dilution of soakaway discharges will often be small.

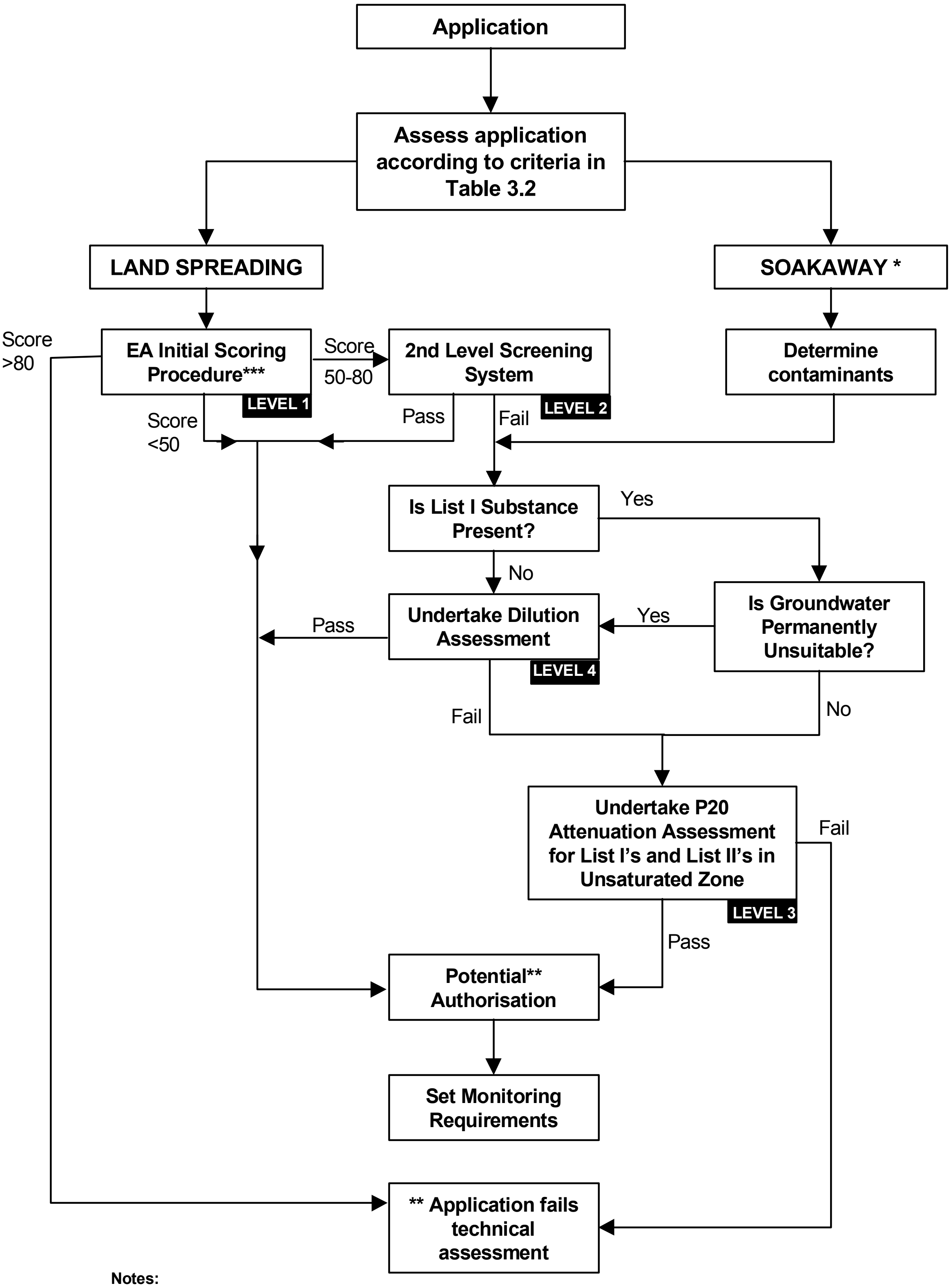
## 3.2 Background

### 3.2.1 Legislative requirement

Regulation 7 of the Groundwater Regulations (1998) describes the requirements of ***prior investigation*** as consideration of:

- the hydrogeological conditions of the area concerned;
- the possible purifying powers of the soil and subsoil;
- the risk of pollution and alteration of the quality of the groundwater from the discharge.

The Regulations also state that prior investigation also shall establish whether the discharge of substances into groundwater is a satisfactory solution from the point of view of the environment.



**Notes:**

* Same procedure should be used if discharge is being dealt with as Discharge Consent.

**Other factors may influence actual approval or rejection of an application.

***Level 1 score thresholds are approximate.

**Figure 3.1 General Framework for Prior Investigations**

**Table 3.1 – Summary of Technical Assessment Levels (From Section 6.2 of the Groundwater Regulations Process Manual)**

| Level | Characterisation Of | Substances of Concern | Processes Under Investigation | Point of Assessment | Data Collection Method | Assessment Procedure |
|---|---|---|---|---|---|---|
| 1 | Source material and inherent site sensitivity | List I and II | Overview of all processes | Not applicable | Desk study (primarily application form) | Initial screening assessment. |
| 2 | Source term and soil type/ characteristics | List I and II | Loading and attenuation in soil | Base of soil zone | Further desk study.<br>Site inspection.<br>Trial pits and shallow on-site boreholes.<br>Substance analysis | $2^{nd}$ Level Screening Assessment (fate and behaviour assessment for soil).<br>Site verification of application details.<br>Assessment of samples.<br>Calculations and/or Soil models. |
| 3 | Unsaturated zone below soil | List I and II | Attenuation in unsaturated zone | Base of unsaturated zone | Trial pits and boreholes (site) | Fate and behaviour assessment (unsaturated zone).<br>Assessment of samples.<br>Calculations.<br>Analytical equations.<br>Models e.g. ConSim. |
| 4 | Impact on groundwater | List II only, except where the List I prohibition is relaxed. | Dilution at the water table | Water table beneath site | Boreholes (site and off-site) | Calculations.<br>Analytical equations.<br>Numerical flow models. |

### 3.2.2 Guidance on requirements

DETR (2001) guidance states that the Environment Agency:

- Should assess the information submitted in applications with reference to groundwater protection zones, groundwater vulnerability maps, and any other available relevant information about groundwater quality and sensitivity in the vicinity of the proposed disposal site.
- Should provide reasonable assistance to the applicant in determining the scope of further (including intrusive) investigations needed for more complex applications.

Section 6.2 of the Agency's Process Manual provides additional guidance on the "*Framework for Technical Assessments and Prior Investigations for Regulation 18 Authorisations*". Prior investigation is related specifically to protecting groundwater, whereas technical assessment covers the whole environment including surface water and conservation issues. Reference to parts of this guidance is made in Sections 3.2.3 and 3.3, but otherwise this guidance is not repeated here.

### 3.2.3 Agency's context for prior investigation

The Agency's context for prior investigation is provided in detail in the Agency's Process Manual and is summarised below.

*Prior investigation is a process whereby a conceptual model of the environmental and hydrogeological setting of the site is developed and the implications of the discharge/disposal are assessed within this model. The process should be directed at the provision of sufficient information to enable both the applicant and the regulator to make an assessment of the pollution potential of the activity. This information will also determine the range of essential or technical precautions that are necessary to control the activity, which will be expressed as the conditions that are placed on any authorisation in order to prevent pollution, or may indicate that the application should be refused.*

*To ensure an appropriate level of regulation, there is a clear need to develop a hierarchy of investigation requirements that is:*

- *consistent with the scale of the activity and the ensuing risks;*
- *focused on the ability of the applicant and the Agency to obtain the necessary information at reasonable cost;*
- *compatible with the administrative systems that support the implementation of the GWR (e.g. application forms).*

This guidance describes a system of prior investigation to meet all of these requirements.

## 3.3 Categories of Activity

Disposal methods fall into two broad categories:

- Land spreading;
- Soakaways.

For some land spreading sites, the hydraulic loading will be high and the site will behave as a large soakaway or swale (see glossary). The criteria for categorising sites are given in Table 3.2.

**Table 3.2 – Recommended Category Definitions**

| **Activity** | **Hydraulic Loading Rate** | | **Other Criteria** |
|---|---|---|---|
| | **Per Day ($m^3$/ha/d)[a]** | **Per Year ($m^3$/ha/yr)[b]** | |
| Land Spreading | < 30 | < 520 | Discharge must be to land surface |
| Soakaway | ≥ 30 | ≥ 520 | Also if discharge is below soil zone |

Notes:

*a Criteria based on ensuring no bypass flow through soil or runoff.*

*b Arbitrary criteria based on hydraulic loading rate (equivalent to 52 mm/yr) not exceeding about 25% of hydrologically effective rainfall and on average not exceeding about one application of 30 $m^3$/ha/day every three weeks.*

Once categorised, land spreading activities should be assessed starting at Level 1. Soakaways that do not bypass the soil zone can be initially screened using a Level 2 assessment, but for the majority of soakaways a Level 3 or 4 assessment will be needed (See Section 3.8).

## 3.4 Level 1 - Initial Screening Procedures

### 3.4.1 Methodology

Two technical screening procedures have been developed and are in use by the Environment Agency for assessing applications for ***land spreading***. Both procedures are based on a scoring system. One of these procedures is specifically for sheep dip and the second is for listed substances other than sheep dip, e.g. waste pesticide or non-agricultural chemicals. Neither method is suitable for ***soakaways***.

The two procedures are documented in Section 6.3 and 6.4 of the Agency's Process Manual and this detail is not repeated here. Both procedures are very similar in the factors they use. These factors are shown in Table 3.3.

The two procedures recognise the importance of the soil in preventing chemicals reaching the water table. The systems examine the soil's vulnerability based on:

- ***Depths of soils***: Shallow (0-20 cm), Moderate (20-30 cm) and Deep (>30 cm).
- ***Organic Content***: Organic (<20%) or Peaty (>20%).
- ***Texture***: e.g. stony, sandy, silty, clay, loamy, chalky, fine/medium/coarse grained.
- ***Drainage***: Free, moderate (no ponding) or poor (rainfall ponds or waterlogged).

Topography is dealt with by the system by not allowing disposal onto slopes greater than 11°**.**

## Table 3.3 – Agency Screening Bands & Scores Matrix for Land Spreading (Level 1)

| | **Very High or Unacceptable Risk** | **High Risk** | **Medium Risk** | **Low Risk** |
|---|---|---|---|---|
| **Hydraulic Loading** | Considers application rate and number of applications to give a score of up to 80. | | | |
| **Chemical Loading** | Considers type (List I or II) and strength of source to give a score of up to 80. | | | |
| **Soil Type**<br>(based on a number of parameters) | Shallow (<200 mm)<br>**25** | High leaching<br>**15** | Intermediate leaching<br>**5** | Low leaching<br>**0** |
| **Unsaturated Zone** | <0.5 m<br>**80** | 0.5 – 4.9 m<br>**15** | 5 – 15 m<br>**10** | >15 m or non-aquifer cover [1]<br>**0** |
| **Aquifer** | Karst<br>**25** | Major (high permeability)<br>**15** | Minor (variable permeability)<br>**5** | Non-aquifer (low permeability) or non-aquifer cover [1,2]<br>**0** |
| **Land Use** | ---- | Bare soil<br>**15** | Vegetated soil<br>**5** | Permanent pasture<br>**0** |
| **Substance Toxicity**[3] | ---- | High<br>**15** | Moderate<br>**10** | Low<br>**0-5** |
| **Proximity** | | | | |
| **to surface water** | <10 m<br>**80** | 10 – 29 m<br>**15** | 30 – 49 m<br>**5** | 50 m<br>**0** |
| **to groundwater abstractions** | <50 m<br>**80** | 50-250 m or Zone I<br>**15** | 250 – 500 m or Zone II<br>**5** | 500 m<br>**0** |

**Scoring bands:** **80 +** proposed disposal is unacceptable and application is a candidate for refusal.
**50–79** grey zone (application requires further consideration/prior investigation).
**<50** proposed disposal is acceptable and application can proceed.

Notes:

*Shaded boxes are where scores automatically place the disposal in the unacceptable category.*

[1] *At least 5 metres of undisturbed relatively impermeable cover known to exist over the entire spreading area. If site-specific investigation needed to confirm presence, the next level of assessment may be appropriate.*

[2] *Where there is a considerable thickness of relatively impermeable non-aquifer (for example, 10 m of the Weald or Kimmeridge Clay), a score of -15 can be added to the total score for the application.*

[3] *Each procedure gives broad qualitative guidance on the assessment of substance toxicity.*

These scoring systems have been trialled/calibrated qualitatively by the Environment Agency to determine the various threshold scores. This Level 1 procedure does not quantify the fate and transport of the List I or II substances to be applied. Neither does it take account of substance persistence in the soil. Instead, it qualitatively examines the general sensitivity of the site and the proposed activity.

As noted on Table 3.3, the total scores from the Level 1 procedures are used as follows:

- <50 application acceptable;
- 50-79 (***grey zone***) application requires further assessment (go to Level 2, after first examining whether modifications to the disposal, which are acceptable to the applicant, could reduce the score);
- >80 application is a candidate for rejection.

The main factors that move applications into the grey zone are: if the application is located on a major aquifer, on high leaching soil and with a thin unsaturated zone. The scoring system gives an equal weighting to different categories.

It is emphasised that the scoring system is simply a tool in the decision-making system and that there will be uncertainty attached to some of the components of the total score. The sensitivity of the result to uncertain individual scores should be examined and the scoring bands applied in an approximate manner.

Use of these two systems on the 12,000 applications up to March 2000 has led to very few outright rejections, but more than 70% fall into the grey zone requiring further consideration.

### 3.4.2 Information requirements

The information requirements for, and sources of information used in, this first level assessment are shown in Table 3.4.

Much information is provided on the application form, but this is supplemented by use of topographical, soil, geological and hydrogeological maps, details of private and licensed abstractions, and sometimes by use of borehole records and conservation management plans.

### 3.4.3 Evaluation of level 1 screening

Following initial use of the Level 1 screening procedure, the options are:

- Accept application if score <50.
- If score >50, negotiate with applicant to modify proposed activity and re-evaluate.
- Refuse application if score >80.

If score is between 50 and 80 carry out Level 2 assessment or consider options 1, 2 & 3 in Table 3.10.

### Table 3.4 – Information Requirements and Sources for Level 1 Initial Screening Procedures

| Parameter | Component | Detail Required | Sources of Information |
|---|---|---|---|
| **The Activity** | Type of Substance (e.g. chemical) | Sheep dip<br>Waste pesticide<br>Other listed substances (brand name or active ingredients)<br>(Initially assessed on highest toxicity substance present) | Application Form, Chemical packaging information or chemical analysis. Further detail, if necessary, to be ascertained through liaison with applicant and/or site inspection. |
| | Treatment and Dilution | Details (if any) of how the substance is treated (e.g. in a treatment plant) and/or diluted (No. of times and with what slurry, wash water). | Application Form |
| | Rate of Disposal | <5 $m^3$/day or <30 $m^3$/yr (Yes or No) | Application Form |
| | When and How? | Frequency (number of days per year)<br>Maximum daily disposal volume (before and after dilution)<br>How it is disposed (e.g. sprayer, soil injection, vacuum tanker) and details of field rotation. | Application Form |
| **Land Area** | Location | Address, grid reference, map (1:25k or 1:10k) and site plan of spreading. | Application Form + OS Maps |
| | Area | Dimensions of spreading area | Application Form, Site Inspection |
| | Vegetation | Description of vegetation/land use (bare, vegetated or permanent pasture) e.g. rough grazing. | Application Form, Site Inspection |

**Table 3.4 (continued) – Information Requirements and Sources for Level 1 Initial Screening Procedures**

| Parameter | Component | Detail Required | Sources of Information |
|---|---|---|---|
| **Soils** | Depth of Topsoil | Shallow(0-20 cm), Moderate (20-30 cm) or Deep (>30 cm) | Application Form + Site Inspection |
| | Texture | Stony, sandy, silty, clay, loamy, chalky, or fine, medium or coarse-grained. | Application Form, Soil Maps, Groundwater Vulnerability Maps |
| | Organic Content | Organic (<20%), Peaty (>20%) or Unknown (assume minimal) | Application Form + Soil Maps & Memoirs |
| | Drainage | Free draining (rainfall drains immediately), moderate (rainfall drains more slowly, but does not pond) of poor drainage (rainfall ponds on surface, often waterlogged).<br>Note on presence and location of any underdrains | Application Form, Soil Maps and Memoirs, Groundwater Vulnerability Maps |
| **Unsaturated Zone** | Depth to Water Table | Depth to rest water level in any borehole, well, spring or catchpit.<br>Existing site investigation information on or adjoining the land area. | Application Form, Agency, BGS or published records of Boreholes, Hydrogeological Maps |
| | Subsoils and strata | Description e.g. gravels, sandstone, chalk, clay, limestone or hard rock | As above (but not Application Form) |
| **Groundwater Sensitivity** | Groundwater Use | Location (marked on a plan), owner, type (well, spring, borehole), use (marked on a plan) within 500 m of site or potential use (aquifer/non-aquifer status) | Application Form, Agency details of licensed abstractions and Environmental Health details of private water supplies. Aquifer status from groundwater vulnerability maps |
| **Surface Water** | Proximity and Nature | Surface water within 500 m, type (e.g. ditch) | Application Form, OS Maps |
| **Conservation** | Location and Type | Nature conservation or land management agreements in or adjoining the site, within 500 m of disposal area. | Application form, Agency and English Nature Conservation Management Plans |

If adequate information cannot be provided to give reassurance that the proposed disposal will not cause pollution or it is too costly for the applicant to provide data for subsequent levels, the assessment of the application stops here and is a candidate for rejection.

It is advisable that, whilst the decision to move to Level 2 may be based on the scores from Level 1, these should be used as a supporting tool only. The assessor should review the individual circumstances and record the reasons for proceeding or not proceeding to Level 2.

## 3.5 Level 2 - Quantitative Screening

### 3.5.1 Introduction

To help evaluate those applications for ***land spreading*** on soil which score in the grey area of the Level 1 screening procedure, a conservative quantitative screening tool has been developed. This Level 2 assessment (see Table 3.1) examines whether contaminants will break through the base of the soil zone. It can also be used to assess the likelihood of subsequent breakthrough at the base of the subsoil or thick unsaturated zones.

The tool is inappropriate for assessment of ***soakaways*** as the assumptions within the method are invalid at high hydraulic loading rates. If used for assessing subsoil soakaways or for land spreading activities which exceed the hydraulic loading rates in Table 3.2, the Level 2 method is likely to underestimate the effect of the activity (no bypass flow, no kinetic effects). This means that if the activity fails at Level 2 it is unlikely to pass at subsequent levels and this can be used to help evaluate the success of further investigation.

### 3.5.2 Methodology

The method uses a retarded-plug-flow-with-degradation calculation (available in *Microsoft Excel v97 R2, see Appendix A*) to simulate contaminant movement through the soil zone. The development of this tool is described in the Project Record (Environment Agency, 2002a).

The calculation has a number of components as shown in Table 3.5. In summary:

- The method calculates the travel time for water through the soil zone assuming 'plug' or 'piston' flow, where water added at the surface of the layer displaces water held in the soil and leads to a release of water at the base of the layer. This assumes that the soils are fully wetted, i.e. that there is no soil moisture deficit. The piston flow approach pushes the applied contaminants through the soil thickness as a discrete layer and ignores, from a concentration point of view, subsequent dilution (through hydrodynamic dispersion) from contaminant free infiltration.

- From the unretarded plug flow travel time of the water, a retarded travel time for the contaminant is calculated using a retardation factor. This retarded travel time is the time until the maximum concentration of contaminant leaves the base of the soil zone.

**Table 3.5 – Components of Level 2 Screening Calculation**

| Component | Parameters | | Description |
|---|---|---|---|
| | Symbol | Units | |
| **Risks to Groundwater** | | | |
| Infiltration Rate | $I$ | mm/yr | Infiltration rate |
| $I = (0.1 \times AR \times N) + (HER \times BFI)$ | $AR$ | $m^3$/ha/day | Application Rate |
| | $N$ | No/yr | Number of applications per year |
| | $HER$ | mm/yr | Effective Rainfall |
| | $BFI$ | (fr) | Fraction of HER to recharge |
| Unretarded Travel Time in Soil | $T_u$ | days | Unretarded travel time |
| | $z$ | m | Thickness of soil |
| $T_u = z \times \theta_w / I$ | $\theta_w$ | (fr) | Mobile moisture content |
| Soil/Water Distribution Ratio | $K_d$ | l/kg | Soil/water distribution ratio |
| | $K_{oc}$ | l/kg | Organic carbon/water distribution ratio |
| $K_d = K_{oc} \times f_{oc}$ | $f_{oc}$ | (fr) | Fraction of soil organic carbon |
| Retardation Factor | $R_f$ | (fr) | Retardation Factor |
| $R_f = [1 + (K_d \times \rho / \theta_w)]$ | $\rho$ | $g/cm^3$ | Soil bulk density |
| Retarded Travel Time | $T_r$ | days | Retarded travel time |
| $T_r = T_u \times R_f$ | | | |
| Total Retarded Travel Time with 'Lag' Time | $T_T$ | days | Total retarded travel time |
| $T_T = T_r + T_{lag}$ | $T_{lag}$ | days | Minimum no. of days with SMD following application* |
| Attenuation Factor | $T_{1/2}$ | days | Soil degradation half-life |
| $AF = 0.5^{\left(\frac{T_T}{T_{1/2}}\right)}$ | | | |
| Peak Concentration | $C_{max}$ | mg/l | Peak concentration |
| $C_{max} = C_0 \times AF$ | $C_0$ | mg/l | Starting concentration applied |
| **Soil/Land Quality** | | | |
| Mass Loaded to Soil | $M_o$ | $mg/m^2/yr$ | Total mass loaded to soil per year |
| $M_0 = 0.1 \times C_0 \times AR \times N$ | | | |
| Mass Not Degraded in Soil | $M_t$ | $mg/m^2/yr$ | Mass remaining in soil after one year (365¼days) |
| $M_t = M_0 \times 0.5^{\left(\frac{365\frac{1}{4}}{T_{1/2}}\right)}$ | | | |
| Residual Soil Concentration | $C_t$ | mg/kg/yr | Average soil concentration after one year |
| $C_t = M_t/(1000 \times z \times \rho)$ | | | |

Note:

**The "lag" time is for use with land spreading activities that occur only in summer months. No vertical flow is assumed when a soil moisture deficit (SMD) exists.*

- Where land spreading occurs **only in summer** (not common), there may be some soil moisture deficit and under these conditions, plug flow (whether retarded or not) will not occur until the SMD is exceeded. To make some allowance for this SMD a "lag" time is estimated based on the time following the application until the SMD becomes zero. As soil moisture deficits vary from year to year, the time until SMD=0 should be estimated using minimum monthly SMD data from MORECS 25 year statistics under the same land use (grass, vegetated or bare soil). Each month's SMD should exceed the application rate. Adding this lag time to the retarded plug flow travel time, gives a total retarded travel time. In wetter parts of the country, this lag time will be zero, whereas in others it could add three months to the travel time of contaminants spread in late spring. It is noted that such a lag time will only be significant for **poorly retarded contaminants** and this procedure will only find use in a small number of applications.
- In this total retarded travel time, degradeable contaminants have time to degrade, and this serves to reduce both the maximum concentration in the water leaving the base of the soil zone and also the concentration remaining in the soil.

### 3.5.3 Assumptions

The assumptions made by the Level 2 screening tool are given in Table 3.6. There are a number of **key aspects of this procedure** in this table. Further discussion of these assumptions is made in the Project Record (Environment Agency, 2002a).

As part of the method the assumptions should be checked and evidence for compliance with these recorded as part of the assessment. This would include, for example, a note that the potential for bypass flow is not visibly obvious (i.e. there are no large cracks under typical disposal conditions).

### 3.5.4 Data requirements

The data requirements in excess of those provided for the Level 1 initial screening procedure are set out in Table 3.7.

### 3.5.5 Default values for soils

The NSRI is the custodian of a National Soil Inventory (NSI) which includes details of the following soil properties for all soil series/land use combinations:

- Bulk density
- Organic matter content
- Water (moisture) retention at 5, 10, 40, 200 and 1500 kPa tension
- Total porosity
- Clay/silt/sand proportions
- pH.

These data and statistics have not been obtained as part of this work, but from examination of part of this dataset published in Soil Survey (1984), conservative estimates of properties have been made for different soil types as classified on the groundwater vulnerability maps. These estimates are provided in Table 3.8.

**Table 3.6 – Assumptions Made in Level 2 Screening Calculation**

| Parameter | Assumption |
|---|---|
| Effective Rainfall (HER) | For year round operations, the effective rainfall following application is the maximum monthly rate, unless retarded travel time is more than two months. When retarded travel time using maximum monthly rates is closer to one year then the annual effective rainfall should be used. For retarded travel times of between two and twelve months, maximum monthly rates should be used unless conditions are imposed concerning the timing of the disposal to allow justification of annual average rates. |
| Runoff | No runoff during land spreading due to conditions on authorisation based on slope and waterlogged nature of soils. (See infiltration below). |
| Infiltration | 100% of HER on high vulnerability, 60% on intermediate vulnerability and 20% on low vulnerability soils based on HOST soil types. Residual becomes runoff, so separate check on wash-off potential needed. |
| Soil Moisture Deficit | There is no soil moisture deficit (SMD) for year round disposals. Where disposals are only in summer, allowance is made for the time following disposal when minimum SMD is greater than application rate. |
| Bypass flow | Bypass flow is not modelled. No bypass flow is assumed to occur during the application as a result of the low application rates. There are few firm rules controlling the likelihood of bypass flow in soils[1]. Qualitatively, there will be little or no bypass flow in unstructured sandy soils, but for finer textured and more structured soils (clay content ~>25%) the risk of bypass flow is higher. In these finer textured soils, bypass flow will be more common where soils become cracked in summer or in dry parts of the country. Bypass flow is also affected by features such as worm-holes, with worm activity likely to increase in more organic-rich soils. Once disposed material has been absorped, bypass flow during subsequent heavy rainfall is assumed[2] to carry relatively uncontaminated water (due to desorption kinetics). |
| Stones | Stones do not provide moisture or absorption sites, so it is advisable to reduce the thickness of the soil by the percentage of stones (e.g. if soil 0.2 m and stones 10%, input thickness is 0.18 m). |
| Soil water movement | Plug flow displacement of mobile water. |
| Dispersion | Dispersion is not modelled. With vertical dispersion, contaminants may break through earlier at the base of the soil at lower concentrations than the maximum predicted. Horizontal dispersion reduces maximum concentrations. |
| Sorption | Linear instantaneous equilibrium sorption and desorption. |
| Degradation | First order kinetics (degradation can be represented by half-life). Assume no acclimatisation time or concentration control on degradation. |
| Half-life | Safety factor of ×2 on input soil half-life to take account of lower UK temperatures compared to laboratory data or US field data. |
| Volatilisation | Assume taken into account in soil degradation half-life or none. |

Notes:

1: This assumption is discussed in Section 2.7.1, but needs further research.

2: The HOST Classification of soils (IoH, 1995) provides details of the likelihood of bypass flow, but this relates to the substrata and not the topsoil.

## Table 3.7 – Additional Information Requirements and Sources for Level 2 (Soil) Screening Calculation

| Parameter | Component | Detail Required | Sources of Information |
|---|---|---|---|
| **The Activity** | Type & concentration of substance (after treatment and dilution) | Contaminant/product name (e.g. diazinon, mecoprop, ammonium, cadmium) and concentration.<br>Concentration of List I and II's after treatment and dilution | Application Form, Sheep Dip Procedure for Working Strengths/Dilution, applicant, manufacturer, pesticide handbook etc.<br>Targeted laboratory chemical analysis, dilution calculation. |
| | Other details | As for Level 1 | Application Form |
| | Chemical Properties | *Organics*: Organic partition coefficient ($K_{oc}$) and soil degradation half life (T½). *Others*: Partition coefficient ($K_d$) | Environmental Handbooks (also see text) |
| **Land Area** | All details | As for Level 1 | Application Form + OS Maps |
| **Soils** | Depth of Topsoil | Estimate or measurement of soil thickness or depth to drains whichever is least. | Application Form, applicant + Site inspection* |
| | Bypass Flow | Qualitative assessment of likelihood of bypass flow | Texture of soil (sandy soils low, clayey soils high), Wetness (wet - lower, dry - higher). Site inspection*. |
| | Other Properties | Estimate of percentage stones and packing density, laboratory measurement of bulk density ($\rho$), moisture content ($\theta_w$) and organic content ($f_{oc}$). | Application Form, applicant, Soil Maps, Soil Memoirs and National Soil Inventory, Site Inspection*. Laboratory Analysis. See Table 3.8 for default values. |
| **Infiltration Rate** | Effective Rainfall | Maximum effective rainfall (HER) per month and per year, otherwise assume 200 mm/month and 1000 mm/yr. | MORECs 25 year (40 *x* 40 km) or IoH Statistics for surface water catchment area. |
| | Recharge rate | Free draining/high leachability (100% recharge)<br>Moderate drainage/intermediate vulnerability (60% recharge)<br>Poor drainage/low vulnerability (20% recharge). | Application Form details of drainage, HOST Soil Class from Soil Maps and Memoirs, Groundwater Vulnerability Maps. Also see Table 3.8 for default values. |
| | Lag Time | Minimum Soil Moisture Deficit (SMD) per month for months following application, otherwise assume none. | Application Form details of time of application and MORECS 25 year (40 *x* 40 km) statistics for area. |

Note: *See Environment Agency (2001f) for information which could be obtained from a site inspection.

Published HOST Class data (IoH, 1995) on baseflow indices have also been used to estimate the likely amount of hydrologically effective rainfall infiltrating to groundwater.

Further discussion of these datasets is given in the Project Record.

**Table 3.8 – Default Values[a,b] for Soil Types (in Wales)**

| **Leaching Potential[c]** | | **Depth** | **Fraction of Organic C** | **Bulk Density** | **Moisture Content** | **Infiltration as % of HER** |
|---|---|---|---|---|---|---|
| **Class[d]** | **Sub-class[d]** | **(m bgl)** | **$F_{oc}$ (fr)** | **$\rho$ (g/cm$^3$)** | **$\theta_w$ (fr)** | **BFI[e]** |
| High | H1 | 0.0-0.25 | 0.034 | 1.1 | 0.10 | 100% |
| | | 0.25-0.4 | 0.011 | 1.3 | 0.10 | 100% |
| | H2 | 0.0-0.30 | 0.017 | 1.4 | 0.10 | 100% |
| | | 0.30-1.0 | 0.004 | 1.4 | 0.10 | 100% |
| | H3 | 0.0-0.25 | 0.026 | 1.1 | 0.10 | 100% |
| | | 0.25-0.7 | 0.006 | 1.2 | 0.10 | 100% |
| Intermediate | I1 | 0.0-0.25 | 0.021 | 1.3 | 0.15 | 60% |
| | | 0.25-1.0 | 0.005 | 1.4 | 0.15 | 60% |
| | I2 | | 0.057 | 1.0 | 0.15 | 60% |
| Low | L | | 0.070 | 0.8 | 0.20 | 20% |

*Notes:*

***a: The soils data are from Wales and are likely to represent thin upland organic soils. Soils from other areas, such as Central England, will generally show higher bulk densities, lower organic carbon contents and lower percentages of available water capacity.***

*b: These default values are broadly comparable with, if less refined than, those basic soil properties used in POPPIE (Annex 2).*

*c: Leaching potential as noted on groundwater vulnerability maps.*

*d: Class and Sub-Class as defined on groundwater vulnerability maps.*

*e: Base Flow Index (BFI) from HOST data (IoH, 1995) is assumed to reflect amount of water infiltrating vertically through soil. It should also be seen as a flag for the potential of wash-off in runoff.*

*f: Non-aquifers are not subdivided into classes on vulnerability maps, and in these cases the general leachability classes deduced using Annex 6.3.1(Version 2) of the Environment Agency (1999) Groundwater Regulation Process Manual (reproduced in Appendix B) should be used together with the lowest fraction of organic carbon for that class, unless the applicant notes that it is organic-rich, when the highest fraction of organic carbon for that class should be used.*

In undertaking a Level 2 assessment, detailed site-specific data should ideally be used, but as an initial screening exercise Soil Survey data can be used, provided conservative values are selected. Table 3.8 provides conservative estimates of soil parameters based on data from Wales, but these values may not be appropriate for other areas in England (see Note *f*, Table 3.8). Additional information on soil types can be obtained from the database of soil information held by the Agency, the Soil Survey, or values obtained from the POPPIE (2000) database.

Guidance on when default values, database information and site specific information should be used is given in the box below:

| **Criteria** | **Default Values** | **Further Data** |
|---|---|---|
| Application form information agrees with vulnerability maps. | As per soil type for leachability class selected. | If default values fail examine POPPIE or soils database held by the Agency or use site specific data. |
| For areas recorded as Non-Aquifers or on soil survey maps for area are available. | Use H2. | |
| Site inspection shows soils different from that used in assessment. | Adjust to appropriate values. | |
| Assumptions for Level 2 are invalid with respect to hydraulic loading and bypass flow. | | Need site specific data to demonstrate no bypass flow at higher hydraulic loading rate. |

### 3.5.6 Interpretation of results

The Level 2 tool output allows two aspects of environmental protection to be considered. These are ***Groundwater Protection*** and ***Soil or Land Quality***.

**Groundwater protection** can be assessed using:

- The attenuation factor or maximum breakthrough concentration for degradable organics.
- The retarded travel time for non- or slowly-degradable contaminants. The method predicts these contaminants will break through at the base of the soil with the starting concentration, which would not be acceptable for a List I substance. Further evaluation of such activities may be necessary to examine the effects of dispersion and attenuation in the unsaturated zone (Level 3) or, for List II substances, dilution at the water table (Level 4).

**Soil or land quality** can be assessed using:

- The amount and concentration of contaminant remaining in the soil after one year. This recognises that non- or slowly retarded contaminants could accumulate in the soil and lead to the land being designated as contaminated. For contaminants that degrade within four years (the maximum period for review of authorisations), area rotation could be considered.

The criteria for evaluating the results of the Level 2 method are set out in Table 3.9.

Sensitivity analyses should be undertaken as part of the Level 2 assessment to identify key parameters. If the acceptance or rejection of the application is marginal the data used to define key parameters should be examined to determine whether these have been adequately defined.

**Table 3.9 – Assessment Criteria for Level 2 Screening Method**

| **Component** | | **Pass Criteria** | **Comment** |
|---|---|---|---|
| ***Groundwater Protection*** | | | |
| Maximum Concentration in Water at Base of Soil Zone | $C_{max}$ | List I substances <0.01 µg/l<br>List II substances - relevant water quality standard[a] | If fail consider seasonal constraints on land spreading. |
| | | **OR** | |
| Retarded Travel Time | $T_R$ | >1000 yrs | Taken as no risk of breakthrough. |
| | | **AND** | |
| ***Soil/Land Conservation*** | | | |
| Residual Amount in Soil after 1 Year | $M_t$ | <10% of applied amount | If fail, consider land rotation for 4 years or pre-treatment and/or dilution of application. |
| | | **AND** | |
| Residual Soil Concentration after 1 year | $C_t$ | $^{1}/_{10}$th of Contaminated Land Soil Criteria[b] | |

Notes:

[a] *As there are no formal groundwater quality standards in the UK at present, site-specific standards should be determined. These standards should be based on the use of the water, natural background quality, consideration of what may constitute pollution in this instance and reference to established standards for other uses such as drinking water standards (Water Supply (Water Quality) Regulations, 1989 - as amended), surface water Environmental Quality Standards etc. As many of these standards include a factor of safety and the point of assessment is at the base of the soil zone, not the water table, it should not be necessary to include any further factor of safety.*

[b] *Reference should be made to current land quality guidelines such as ICRCL and Dutch Guidelines or CLEA model data as these become available. Sludge to Land Regulations could also be considered. The intention is to avoid creation of contaminated land and ensure that the activity is acceptable in terms of the wider environment.*

### 3.5.7 Worked Example

A worked example of this Level 2 screening tool is shown in the box below.

**Level 2 Soil Screening Procedure (refer to Table 3.5 for definitions of terms)**

a. **Determine Input Parameters** for (e.g. two disposals of 30 $m^3$/ha/day of 400 mg/l Chlorphenvinphos (as active ingredient) in one year to an intermediate (I2) vulnerability soil of 0.3 m thick).

| Parameter | Input Value | Source |
|---|---|---|
| Chlorphenvinphos Disposal | | |
| Starting concentration ($C_0$) | 400 mg/l | See above |
| Partition Coefficient ($K_{oc}$) | 374 l/kg | Vogue (1994) |
| Degradation Rate ($T_{½}$) | 7 days × 2 (safety factor) | Vogue (1994) |
| Application Rate ($AR$) | 30 $m^3$/ha/d | See above. |
| Number of Applications (N) | 2 per year | See above. |
| Soil | | |
| Soil thickness ($z$) | 0.3 m | See above. |
| Soil moisture content ($\theta_w$) | 15% = 0.15 | Table 3.8 - I2 Soil |
| Soil bulk density ($\rho$) | 1.0 $g/cm^3$ | Table 3.8 - I2 Soil |
| Soil organic content ($f_{oc}$) | 0.057 | Table 3.8 - I2 Soil |
| Soil base flow index (BFI) | 60% = 0.6 | Table 3.8 - I2 Soil |
| Climate | | |
| Effective rainfall (HER) | | |
| -Maximum monthly | 200 mm/month | Default assumed |
| -Average annual | 1000 mm/yr | Default assumed |

b. **Calculate infiltration rates**

Infiltration Rate(I) is $(0.1 \times AR \times N) + (HER \times BFI)$, so:

-maximum monthly $(0.1\times30\times2)+(200\times0.6)$ = 126 mm/month
= 1.512 m/yr

-average annual $(0.1\times30\times2)+(1000\times0.6)$ = 0.606 m/yr.

c. **Calculate retardation factor** for the soil zone.

$R_f = 1+(K_{oc}.f_{oc}.\rho/\theta_w) = 1+(374\times0.057\times1.0/0.15) = 143$ (no units).

d. **Calculate unretarded travel time** for the soil zone using monthly infiltration rate.

$T_u = z.\theta_w/I = 0.3 \times 0.15/1.512 = 0.0298$ yrs = 10.9 days.

e. **Calculate retarded travel time** for the soil using monthly infiltration rate.

$T_r = T_u \times R_f = 0.0298\times143 = 4.26$ yrs

As retarded travel time is > 1 year, recalculate Steps 'd' and 'e' using annual infiltration rate of 0.606 m/yr to give revised $T_u$ of 27.1 days and revised $T_r$ of 10.63 yrs or 3883 days.

f. **Determine period of SMD** ($T_{lag}$) dependent on timing of application. If application occurs all year, use $T_{lag} = 0$. (assumed 0 here).

*g.* **Determine total retarded travel time**

$T_T = T_r + T_{lag}$ ($T_T$ = *3883 days + 0 days*) = 3883 days or 10.63 yrs.

h. **Calculate attenuation factor:**

$$AF = 0.5^{\left(\frac{T_T}{T_{½}}\right)} = 0.5^{\left(\frac{3883}{14}\right)} = 3 \times 10^{-84}.$$

i. **Calculate contaminant concentration** at base of the soil zone as follows:

$C_{max} = C_0 . AF = 400 \times 3\times10^{-84} = 1\times10^{-81}$ mg/l = below detection.

j. **Calculate mass of contaminant added to soil**:

$M_0 = 0.1 \times C_0 \times AR \times N = 0.1 \times 400 \times 30 \times 2 = 2400$ mg/yr/m$^2$

k. **Calculate mass not degraded in soil after one year**:

$$M_t = M_0 \times 0.5^{\left(\frac{365\frac{1}{4}}{T_{½}}\right)} = 2400 \times 0.5^{\left(\frac{365\frac{1}{4}}{14}\right)} = 3.4 \times 10^{-5}\,\text{mg/yr/m}^2$$

l. **Calculate concentration left in soil each year**:

$C_t = M_t/(1000 \times z \times \rho) = 3.4\times10^{-5}/(1000 \times 0.3 \times 1.0) = 1\times10^{-7}$ mg/kg/yr.

**Illustration of Sensitivity of Calculation to Soil Type**

To illustrate the sensitivity of these calculations to soil type, the I2 soil properties have been replaced with those of an H2 soil and the calculations repeated. This gives the following results for comparison:

| **Parameter** | **I2 Soil** | **H2 Soil** |
|---|---|---|
| Total Retarded Travel Time (yrs) | 10.63 | 2.68 |
| Contaminant concentration at base of soil (mg/l) | $1\times10^{-81}$ | $3\times10^{-19}$ |
| Concentration left in soil each year (mg/kg/yr) | $1\times10^{-7}$ | $1\times10^{-7}$ |

**Assessment of results**

For ***degradable contaminants***. Accept application if calculated concentration is less than target concentration (see Table 3.9). Check that mass of contaminants present within the soil zone would not fail on soil quality grounds (see Table 3.9).

For ***persistent/non degradable contaminants (such as metals)***. If retarded travel time is greater than 1000 years, then accept application. Check that mass of contaminants present within the soil zone would not fail on soil quality grounds (see Table 3.9). It may be necessary to limit the number of years or applications for persistent or non degradable contaminants. This may require calculating the number of years until the soil quality criteria were exceeded, by dividing the criteria by the predicted concentration after one year.

For applications that fail the Level 2 Screening procedure, undertake Level 3 or Level 4 assessment depending on substance type, although this decision will need to be based on cost of assessment and whether more detailed assessment was likely to show that this activity was acceptable.

### 3.5.8 Scoping options for applications failing at Level 2

For those applications scoring between 50 and 80 in the initial screening procedure (Level 1) and which fail this Level 2 assessment, guidance on possible options is provided in Table 3.10, prior to undertaking a Level 3 or 4 assessment. Additional notes associated with the table are given below. It is noted that options 1 to 3 in Table 3.10 are also open for applications failing at Level 1.

**Table 3.10 – Options for Applications Failing at Level 2**

| | Description | Additional Data Requirements | Sources of Information |
|---|---|---|---|
| 1 | Using an alternative area for spreading or increase area to reduce hydraulic loading. | As per Level 1 & 2 for new area | As per Level 1 & 2 for new area |
| 2 | Consideration of reduced loading, pre-treatment or dilution before disposal. | Proposed and approved method and effect of treatment and dilution on chemical loading. | Applicant, product manufacturer. |
| 3 | Use of a different pesticide or sheep dip chemical. | Chemical properties of new substance. | As for Level 2. |
| 4 | Use site specific information for soil properties, such as $f_{oc}$, $K_d$, if application fails using default values. The Level 2 tool could be used to assess the sensitivity to these parameters before data collection. The key soil parameter for organic (hydrophobic) contaminants is the fraction of organic carbon. | Site specific data for e.g. $f_{oc}$, $K_{oc}$, *pH*, $K_d$ or *CEC*. Also bulk density and moisture content. | Field/lab measurement of *pH*, otherwise soil sampling and laboratory measurements or strong case put on the basis of literature data. |
| 5 | Demonstration of more rapid soil degradation half-lives (see Notes for method of calculating half-life). | Laboratory tests (new sites) or (see note in text) application history and soil concentration for existing sites. | Site's soil & applied contaminants<br>Applicant's records and laboratory analysis of site's soils. |
| 6 | Consider the potential attenuating capacity of the unsaturated zone using the Level 2 tool (see Notes). | Depth to water table.<br>Nature and likelihood of bypass flow. $f_{oc}$ (typically <0.1%), Moisture content, bulk density, CEC, $K_d$ based on pH. | As for Level 1 (see Table 3.4), also POPPIE.<br>HOST Class subdivision based on substrate. Borehole logs/geological maps for nature of strata, then literature such as LandSim, ConSim , and Aquifer Properties Manuals. |
| 7 | Carry out Level 4 (dilution) assessment for List II's or Level 3 assessment for List I's and List II's if Level 4 is inadequate. | See Section 3.6 | See Section 3.6 |

Notes: (see Section 3.5.8 on next page)

***Notes for Table 3.10***

***Note 1 (for Option 5):***

*The soil half-life could be determined by measuring the soil concentration now (see Environment Agency 2000g for soil sampling protocol) and determining the chemical loading to the soil. It is calculated by:*

$$T_{\frac{1}{2}} = \sqrt{\frac{0.693.t}{\ln\left(\frac{M_0}{M_t}\right)}}$$

*where:*

$T_{\frac{1}{2}}$ *is the calculated soil degradation half-life (days).*

*t is the time elapsed since the last application (days).*

$M_0$ *is the concentration applied to the soil (mg/m$^2$/yr) (see Table 3.5 for derivation).*

$M_t$ *is the concentration remaining in the soil (mg/m$^2$/yr) (see Table 3.5 for derivation).*

*ln is the natural logarithm.*

*Care must be made when using this method that the concentration in the soil is not low due to excessive leaching to groundwater.*

***Note 2 (for Option 6)***

*In the unsaturated zone, levels of organic carbon are likely to be significantly lower (10 to 100 times) and degradation rates are likely to be similarly lower than in the topsoil and so attenuation is likely to be low for hydrophobic contaminants with slow degradation rates. This means that it is unlikely to be worthwhile undertaking unsaturated zone calculations for these contaminants if this zone extends for less than 2 m below the base of the soil zone.*

*However, unsaturated zones may provide a significant attenuation capacity for some inorganic contaminants (e.g. ammoniacal nitrogen and metals) due to different conditions (compared to the overlying soil) of e.g. pH or CEC and, for rapidly degrading organics (e.g. phenols), due to relatively long travel times for the water where infiltration is low and moisture contents are significant. For example, for 2 m of unsaturated fine sands with a moisture content of 10%, plug-flow of 200 mm/yr infiltration would take 1 year.*

*For the unsaturated zone it is important to assess the likelihood of bypass flow. This can be done using the HOST Class system (IoH, 1995), but is also addressed in the POPPIE system.*

*For degradable contaminants, the safety factor for the degradation half-life in the unsaturated zone should be increased from ×2 for soils to ×4 to accommodate for the lower microbial population. This doubling of the soil degradation half-life is consistent with the approach taken by Howard (1991, page xviii) to differentiate between rates in soils and in groundwater. Both the ×2 and ×4 factors may require subsequent revision based on research and monitoring results.*

*To calculate a combined (soil plus unsaturated zone) attenuation factor then the soil zone attenuation factor should be multiplied by that estimated for the unsaturated zone. Should this total attenuation factor allow the activity to meet the acceptance criteria in Table 3.9, then it will be necessary to validate the unsaturated zone properties used including the risk of bypass flow.*

## 3.6 Level 3 - P20 Style Quantitative Risk Assessment

### 3.6.1 Introduction

The Level 3 assessment is intended to provide a detailed assessment of contaminant movement through the soil, the subsoil and unsaturated zone. Level 3 will require development and support of a conceptual model of contaminant behaviour and collection of site specific data. It is also likely to involve the use or development of a more sophisticated, probably probabilistic model than previously used.

It is not the intention of this report to reproduce the quantitative risk assessment methods that already exist for assessing the likely impact to groundwater from soil contamination (e.g. the P20 Methodology, Environment Agency, 1999a). Instead this section references these methods and then provides specific guidance on how they could be used to assess the risks posed by the proposed activity.

Due to the site investigation and/or consultancy costs of undertaking a Level 3 assessment, it is likely that only a few of the larger applications will progress to this stage. Alternatively, the Agency may decide to develop Level 3 generic tools to specifically address common disposal activities.

### 3.6.2 Why a Level 3 assessment may result in approval of application

It is important to recognise that a Level 3 assessment may confirm that the application is unacceptable and the applicant should bear this in mind when considering costs. A proposed discharge or disposal that is acceptable at Level 3 may also require significant monitoring (e.g. of the soil or unsaturated zone) as part of the authorisation. Given these warnings, it is also important to identify the reasons why an application failing Level 2 may be successful at Level 3.

The Level 2 assessment is a conservative screening tool valid for assessment of land spreading activities as defined in Table 3.1. In particular, it does not consider:

- Mixing (through hydrodynamic dispersion) of the disposed volume of contaminant with rainfall infiltrating down through the soil column. This will reduce contaminant concentrations;
- Desorption kinetics - this could lead to a slower release of contaminants from the soil to the water and thus less impact at the water table;
- Volatilisation, hydrolysis and microbial degradation separately - this could lead to greater losses from the soil than predicted by the Level 2 soil-degradation half-life;
- A probabilistic distribution of parameter values. The Level 2 assessment uses conservative input values;
- Attenuation in the unsaturated zone below the soil zone.

In addition, the Level 2 tool is inappropriate for assessing sites with high hydraulic loading rates such as soakaways. The Level 3 assessment would need to generate evidence of low risk of bypass flow (and runoff) in both the soil and the unsaturated zone. This would require consideration of microporosity and macroporosity limited flow rates and retardation through examination of soil and strata type, and perhaps through use of models such as MACRO and the AMBER based scoping tool (see Environment Agency 2002a).

As for the options for applications failing at Level 2 (see Table 3.10 and its accompanying Note 2), consideration of the attenuation in the unsaturated zone at Level 3 is only likely to be worthwhile where this zone is thicker than about 2 m. There may be exceptions for some contaminants e.g. for metals where the chemical conditions (e.g. pH) are markedly different to the soil zone or, for highly degradable contaminants, in areas where infiltration rates are low (drier parts of the country or beneath low permeability soils).

### 3.6.3 Existing Level 3 compatible methods

Existing methods and tools that could be used or adapted by a competent specialist are:

- 'P20' - 'Methodology for Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources' (Environment Agency R&D Publication 20, 1999);
- LandSim (Environment Agency, 1996);
- ConSim (Environment Agency, 1999b);
- Soil leaching models such as PESTAN and MACRO (Environment Agency, 2000a).

In each case it is important that the assessor has the requisite skills and experience to use these tools.

For each of these existing tools, it is also important to note that attenuation should be considered only in the soil and unsaturated zones. Attenuation down-gradient of the disposal area cannot be relied upon, because of the requirements of the Groundwater Directive.

Soil leaching models have been reviewed in the Project Record (Environment Agency, 2002a) which accompanies this technical report. The review notes the extensive research, which has been carried out to help predict the likelihood of contaminants reaching groundwater. However, much of this work has been focussed on examining the risks to groundwater from the diffuse application of pesticides onto crops and little, if anything has been done to assess risks from their disposal.

The methods range from simple qualitative scoring systems, screening tools which examine the properties of the contaminant (pesticide) in more detail and complex and data hungry models.

It is clear from all of these models, that representing the many complex physical, chemical and biochemical processes occurring in soils under field conditions is difficult and simplification requires either a very conservative approach or their calibration by field data. Many of the existing models assume no bypass flow at the low application rates of crop spraying, but this assumption is likely to be invalid for some soils at the higher hydraulic loading rates associated with disposal. Of all the existing models, only MACRO models bypass flow, but this requires a large amount of information, including daily climatic data and can take several hours to run. It is therefore unlikely to be a suitable tool for processing a large number of applications.

### 3.6.4 Other reference material including POPPIE

Reference should also be made to recent Environment Agency guidance on 'Contaminant Transport Modelling' (Environment Agency, 2001b). This guidance sets out best practice with respect to:

- Describing the site's conceptual model;
- Selection of the appropriate approach or computer model;
- Selection of model input parameters;
- Model construction, refinement and validation against field data;
- Sensitivity and uncertainty analysis;
- Interpretation of results.

The Environment Agency's (2000a) system for 'Prediction of Pesticide Pollution in the Environment (**POPPIE**)' has been developed to predict the potential pesticide pollution in the aquatic environment resulting solely from diffuse pesticide usage.

A recent project has developed a methodology for groundwater that can be incorporated as a module within the POPPIE system. This module will utilise the existing POPPIE databases (climate, soil properties, land use, pesticide usage and depth to groundwater estimates) and other available Agency datasets (groundwater vulnerability, groundwater source protection zones).

To give an indication of potential pesticide concentrations entering the water table, the module developed uses a 'meta model' version of the dual-porosity soil leaching model MACRO (Jarvis, 1994). This is coupled to a simple Attenuation Factor model to simulate pesticide dissipation in the unsaturated zone of the soil substrate material (unsaturated aquifer zone).

Although some of the underlying data sets may be useful for GWR purposes, it is stressed that, due to the nature of the data and the model, POPPIE cannot be used to assess the impact of point source or small scale disposals, or the fate and transport of pesticides in groundwater.

### 3.6.5 Site specific assessments

Level 3 assessments are likely to be site-specific, focussing on the key aspects of attenuation at the site.

For many sites and contaminants, the ***soil*** will provide the most attenuation (particularly for hydrophobic organic chemicals) and so the focus will be on more accurately simulating:

- Water transport in soil micropores and macropores at high rates of hydraulic loading and rainfall. This could require more detailed climatic data;
- Contaminant partitioning between air, water and the soil in macropores and micropores;
- Degradation processes in the soil.

For other sites, where the soil is thin, has low organic carbon or the contaminants are hydrophilic organics or inorganics, the focus may be on:

- Water transport in micropores, macropores and fissures within the subsoil and unsaturated zone;
- Partitioning and chemical reaction in the unsaturated zone.

The advantage of representing processes in greater detail will be to have greater confidence in their importance and then be able to use less conservative assumptions and input parameters.

### 3.6.6 Additional data requirements for Level 3 assessments

The data requirements for Level 3 assessments will be site specific, but Table 3.11 provides sources of information for those parameters that may be considered. It is assumed at this stage that the applicant or the Agency has already met the information requirements of Levels 1 and 2.

### 3.6.7 Interpretation of Level 3 results

The criteria for assessment of Level 3 results are the same as those at Level 2 (see Table 3.9) with the compliance point at the water table, beneath the disposal site (in the case of List II substances a mixing zone and dilution factor can be used - see Section 2.12.3 and Section 2.12.4).

### 3.6.8 Options for applications failing Level 3

These will be as for Level 2 Options 1-3 (different land area, treatment and dilution or use of a different chemical) and Level 4 assessment for List II substances or for List I substances where exemptions apply.

### 3.6.9 Overall Procedure for Level 3

Each Level 3 assessment will be site specific, but the general procedure should be as follows:

1. Define conceptual model in terms of:
    - Physical description of topsoil (and if necessary), subsoil and unsaturated zone including likelihood of bypass flow;
    - Processes that affect contaminant transport e.g. volatilisation, sorption, degradation;
2. Select/develop approach or computer code;
3. Identify model input parameters and data sources;
4. Agree pass/failure criteria with Agency;
5. Undertake the investigation;
6. Undertake sensitivity analysis;
7. Assess need and cost of obtaining additional site investigation or monitoring data for key input parameters;
8. Determine if concentrations at; base of soil zone, or (if necessary) at base of subsoil, or at base of unsaturated zone are acceptable;
9. Determine if monitoring requirements are to be attached to the authorisation and the nature of these.

**Table 3.11 – Possible Additional Information Requirements and Sources for Level 3 Assessment**

| Parameter | Component | Detail Possibly Required | Sources of Additional Information |
|---|---|---|---|
| **The Activity** | Type and concentration of substance (after treatment and dilution) | As for Level 2 | As for Level 2, but with targeted laboratory chemical analysis of sample collected by Agency staff or independent consultant to confirm the concentrations of different substances to be applied. |
| | Other details | Demonstration of effect of method of application on hydraulic loading rate. | Site specific study or Agency R&D. |
| | Chemical properties | Site specific information on soil or rock/water partition coefficients ($K_{oc}$ and $K_d$) and soil degradation half life(s). | Soil profiles in National Soil Inventory. Laboratory batch tests, column tests or Lysimeter trials. Also degradation rate tests such as soil incubation studies.<br>BOD tests for microbial activity and determination based on existing soil concentrations and application history (see Note 1 for Table 3.10). |
| **Land Area** | All details | As for Level 1. | As for Level 1. |
| **Soils** | Depth of topsoil | The lesser of soil thickness or depth to drains. | Multiple measurements (augering or use of spade) of depths. |
| | Macroporosity | Determination of importance of macroporosity and microporosity on contaminant movement. | Estimates of the volume of pores >60 µm in diameter from laboratory measurement of particle size distribution and estimated packing density. Also estimated from retained and available water content (Soil Survey, 1984). |
| | Other properties | Site specific measurement of bulk density ($\rho$), moisture content ($\theta_w$), organic content ($f_{oc}$) & CEC. Also saturated hydraulic conductivity. | Site inspection by a soil scientist. Also sampling and laboratory determination. Laboratory measurement of CEC (BS test using $BaCl_2$ see Environment Agency, 2000b). See also methods under infiltration rate. |

### Table 3.11 (continued) – Possible Additional Information Requirements and Sources for Level 3 Assessment

| Parameter | Component | Detail Possibly Required | Sources of Additional Information |
|---|---|---|---|
| **Infiltration Rate** | Effective rainfall | Maximum effective rainfall per month and per year or on a daily basis. For soakaways, maximum daily rainfall for a 5 year return period. | MORECS 25 year (40 *x* 40 km) statistics or site specific calculation of effective rainfall using Met Office rainfall and climatological data or site specific weather station data. |
| | Infiltration/recharge rate | Maximum saturated vertical hydraulic conductivity or moisture content | Visual inspection by soil scientist for likely Soil Series and HOST Class. Saturated hydraulic conductivity estimate for coarse textured soils using particle size distribution (BS 1377) and assumption of porosity. Recharge rates based on calibrated groundwater flow models. Field infiltration tests (double ring infiltrometer), lysimeters, pore water profiling or determination of water flux from neutron probes. |
| **Unsaturated Zone (rock)** | Thickness | Depth to maximum water table elevation. | Existing representative borehole logs near (and sufficiently close to be representative) within 500 m of site or site investigation by trial pitting (<~6 m in unconsolidated strata) or drilling. |
| | Degradation Rate | Justification for degradation rate in unsaturated zone. | Literature data for similar conditions elsewhere.<br>(For an existing site) calibration of rate using site monitoring data. |
| | Other Properties | Site specific measurement of bulk density ($\rho$), moisture content ($\theta_w$), organic content ($f_{oc}$) and CEC. Also saturated hydraulic conductivity. | Existing representative borehole logs near (and sufficiently close to be representative of the) site then use of Aquifer Properties Manual(s), LandSim or ConSim.<br>Site Investigation by trial pitting (<~6 m in unconsolidated strata) or drilling, collection of undisturbed (U100) samples and soils description to BS5930.<br>Sampling and laboratory determination including laboratory Measurement of CEC (BS test using $BaCl_2$). See also methods under infiltration rate. |

Note: Shading denotes components for which information is required for the assessment of soakaways below the water table.

## 3.7 Level 4 - Dilution Calculations

### 3.7.1 Background

The compliance point for List I substances is the water table and this means that dilution should only be considered for List II substances. However, dilution can also be considered for:

- List I substances if the groundwater beneath the site has been designated as "permanently unsuitable for other uses" (Regulation 4(5)). However, the likely basis of this designation makes it unlikely that there will be substantial dilution.
- Evaluating whether List I substances would be measurable in any groundwater monitoring.

As noted in Section 2.12, dilution is the reduction in concentration of a contaminant leaching from the base of the unsaturated zone by mixing with groundwater beneath the water table. Mixing in the aquifer may not be with all the groundwater flowing beneath the site due to stratification. However, sampling of groundwater from a monitoring well or abstraction well will lead to mixing of the water in the screened section of the borehole. Guidance on how to determine mixing zones is provided in Section 2.12.3.

### 3.7.2 Estimating groundwater flow beneath the site

Flow beneath the site can be estimated using a Darcy Flow approach or groundwater catchment method as noted in Section 2.12.2.

### 3.7.3 Calculating dilution factors

The ***dilution factor*** is calculated as noted in Section 2.12.4.

## 3.8 Specific Guidance for Prior Investigation of Soakaways

### 3.8.1 Introduction

This section provides specific guidance on the assessment of soakaways. Background information on the design of soakaways and their potential impact on water quality is provided in Section 6 of the Project Record (Environment Agency, 2002a). The range of activities that are covered by soakaways are described in Section 2.13.

In assessing the acceptability of a soakaway discharge the following need to be taken into account:

- Assessment will need to be site specific;
- Soakaways are likely to be characterised by a high hydraulic loading as the discharge is concentrated over a relatively small area (for example, the area of a borehole), this may result in rapid travel times (for example, via activation of fissure flow) reducing the potential for attenuation;
- The construction of the soakaway usually results in the bypass of the soil zone and possibly the unsaturated zone, again reducing the potential for attenuation;

- The discharge from a soakaway may result in mounding of the groundwater table, which will reduce the unsaturated zone thickness and consequently the potential for attenuation.

The potential for dilution by groundwater flow may be limited as the discharge is concentrated over a relatively small area.

### 3.8.2 Regulation

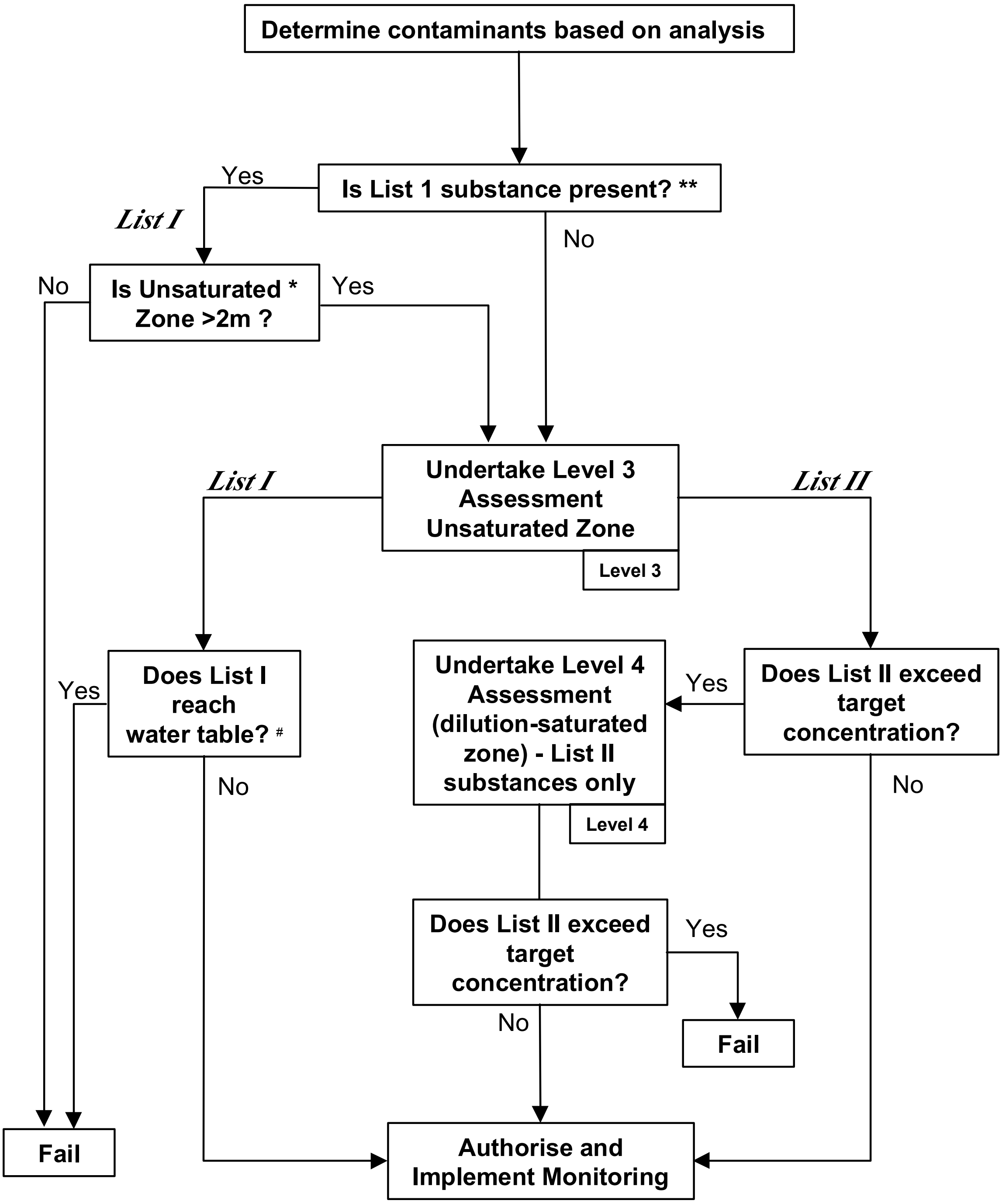
Dependent on the construction, the soakaway may result in a direct discharge to the water table (e.g. boreholes, shafts). Under the Groundwater Directive this is unacceptable for List I substances unless:

- The receiving groundwater body can be classified as 'permanently unsuitable for other uses';
- The discharge is a re-injection of mine waters or groundwater from civil engineering works back into the same aquifer (acceptance of such a discharge is still subject to prior investigation).

For List II substances, the acceptance of a direct discharge to the water table should be subject to demonstrating that this will not result in pollution.

### 3.8.3 General procedure for soakaway assessment

The overall procedure for the assessment of the acceptability of a soakaway discharge is summarised in Figure 3.2.



**Note**

* After consideration of the effects of mounding

** It should be noted that discharges of very low concentrations or quantities of listed substances may be exempt from the provisions of the Groundwater Regulations under Regulation 2

\# See Groundwater Protection assessment criteria in Table 3.9

**Figure 3.2 Soakaway Assessment - List I/II (assessment required)**

The recommended procedure for the assessment of a soakaway discharge is:

i) Determine location of soakaway in relation to groundwater abstractions, surface watercourses.

ii) Determine construction of soakaway (including dimensions and depth) and whether the base of the soakaway is below the soil zone or water table.

iii) Determine area draining to soakaway (if appropriate) including details of any activities that could lead to contamination.

iv) Determine quality of discharge. The analysis of the discharge should be linked to activities or processes that could give rise to contamination with consideration of variations in quality with discharge rate. Consideration should also be given to any pre-treatment of the discharge.

v) Determine hydraulic loading to the soakaway, based on measured flow or estimated as the effective rainfall over the area draining to the soakaway. This latter calculation should be undertaken using both the annual rainfall and the rainfall from a one day storm event (5 year return period).

vi) Determine depth to water table. This will generally require site specific data to be obtained from measurement of the depth to groundwater in the soakaway or in boreholes within close proximity to the soakaway, unless desk study information (such as borehole logs, regional groundwater level contour maps) provides adequate data to demonstrate that the unsaturated zone thickness is greater than 10 m. If the base of the soakaway is less than 10 m above the water table, supporting information will be required to demonstrate that mounding of the water table (due to the soakaway discharge) is taken into account in the assessment of attenuation or affect the rate of infiltration from the soakaway. This could comprise field experiments to determine the influence of the proposed discharge on groundwater levels (using clean water) or mathematical (numerical or analytical) modelling to determine the likely rise in groundwater levels. A hydrogeologist should be consulted to check the validity of this exercise.

vii) Determine proximity to karstic features (e.g. solution holes) and whether there is a high risk of rapid contaminant migration to the water table via preferential pathways. In general, the discharge of List I or List II substances via soakaways located in the proximity of karstic features should not be authorised.

viii) Determine capacity of the strata to accept the discharge from the soakaway. This will normally be by infiltration tests or permeability tests (for solid strata) such as falling head tests (see Section 6 of Project Record, Environment Agency, 2002a). It is assumed that the design of the soakaway will be such so as to ensure that this infiltration capacity is not exceeded.

ix) Determine the target concentration for contaminant(s) in groundwater as set out in Table 3.9. The objective of the assessment should be to demonstrate that this target concentration is not exceeded.

x) Develop conceptual model to describe system behaviour, and in particular key processes which may affect the migration of contaminants through the unsaturated zone.

xi) Levels 1 and 2 Initial Screening of Soakaways.

xii) An initial assessment should be made to determine whether the proposed activity can be classified as a soakaway discharge, namely it is either:

- A discharge to land (land spreading) which exceeds a rate of 30 $m^3$/ha/d or 520 $m^3$/ha/year; or
- A discharge to an underground structure (e.g. chamber, pit, trench, borehole) that results in the discharge bypassing the soil zone. In some cases the soakaway may allow direct discharge to the water table.

The application should only be assessed if the applicant has provided the information identified in Table 3.12.

In addition, applications that are likely to represent a high risk to controlled waters or which are likely to breach the Groundwater Regulations (i.e. direct discharge of List I substance to the water table) should be screened out. Criteria that should be used include:

i) The soakaway lies within:

- 50 m of a groundwater abstraction;
- 10 m of a surface watercourse;
- Inner groundwater source protection zone (with the exception of sewage effluent e.g. from septic tanks, for which a separate assessment will need to be undertaken).

ii) The soakaway is likely to result in a discernible discharge of a List I substance to the water table (such as where the base of the soakaway is within 1 m of or below the water table).

### 3.8.4 Level 3 assessment (List I and List II substances)

### 3.8.5 General

A quantitative assessment of the migration of contaminants through the unsaturated zone should be undertaken to determine whether the discharge is acceptable; the predicted concentration of the contaminant (at the base of the unsaturated zone) should not exceed an agreed Target Concentration (see Table 3.9).

### 3.8.6 Methodology

The assessment should take account of attenuation of contaminant concentrations within the unsaturated zone and allow the concentration of contaminants at the base of the unsaturated zone to be calculated (possible approaches include P20 Tier 3 assessment methodology or ConSim, Level 2). An example of an analytical approach that could be applied is given by Equation 1 where:

$$C_d = C_o \exp\left( \frac{d}{2.a_v} \left( 1 - \left( 1 + \left( \frac{4a_v.\ddot{e}}{v} \right) \right)^{0.5} \right) \right) \qquad (1)$$

where
$C_o$ = contaminant concentration in discharge to soakaway (mg/l)
$C_d$ = contaminant concentration at base of unsaturated zone (mg/l)
$d$ = thickness of unsaturated zone (m)
$a_v$ = dispersivity (m), for the purposes of this assessment set $a_v = 0.1\, d$ (m)
$\lambda$ = decay rate = $\frac{0.693}{T_{½}}$
$T_{½}$ = half life for contaminant (days)
$v$ = retarded contaminant velocity (m/d) which can be calculated from Equation 2 as follows:

$$v = \frac{DS}{n.A.R_f} \text{ and } R_f = 1 + \frac{K_d.\rho}{\theta_\omega} \qquad (2)$$

where:
$DS$ = discharge rate to soakaway (m$^3$/d)
$A$ = area of soakaway (m$^2$)
$\theta_w$ = mobile moisture content
$K_d$ = partition coefficient (1/kg)
$n$ = effective porosity
$\rho$ = soil bulk density (g/cm$^3$)
$R_f$ = retardation factor.

The discharge rate should be based on:

- Measured flow (if available); or
- Average flow (annual rainfall over drainage area). A check calculation should also be undertaken using the peak flow (1 day storm event over drainage area) to calculate the travel time through the unsaturated zone using equation (3) as follow: The travel time (assuming no retardation) can be estimated using the following Equation:

$$\text{Travel time } (T) = \frac{d.\theta_w}{Ac.I} \qquad (3)$$

where

$T$ = travel time (d)

$Ac$ = area of catchment draining to the soakaway (m$^2$)

$d$ = thickness of unsaturated zone (m)

$\theta_w$ = mobile moisture content

$I$ = Rainfall (mm/d) during 1 day storm event with return period of 5 years

If this unretarded travel time is less than 50 days, then the peak flow should be substituted into Equation (2) to calculate the contaminant velocity through the unsaturated zone, provided this peak flow does not exceed the infiltration capacity of the soakaway.

It should be stressed that the above approach is appropriate only to relatively simple conditions, e.g. intergranular flow, and that degradation can be represented as a first order reaction. Other approaches may be more appropriate, particularly where fissure flow is significant.

A sensitivity analyses should also be undertaken to identify which parameters have the greatest influence on the model results. These should then be checked to determine whether these have been defined with sufficient accuracy. For example, the analysis will show that the calculations are sensitive to the thickness of the unsaturated zone and to hydraulic conductivity. Field measurements may show that the depth of the unsaturated zone can be defined relatively accurately, whereas measurements of hydraulic conductivity may show more than an order of magnitude variation. This may demonstrate the need to obtain further measurement, to undertake the analysis using conservative values, or to undertake a probabilistic analysis.

A probabilistic analysis should be the preferred approach of taking account of parameter uncertainty.

### 3.8.7 Acceptance criteria

The application should be accepted if the Level 3 assessment confirms that the predicted concentration of any List I or II substances is less than the target concentration.

If the Level 3 assessment fails, then potential options include:

- negotiation with the applicant to change the activity (such as reduce the volume of discharge, pre-treatment of the discharge water);
- collection of additional site specific information, where conservative assumptions may have been used in the assessment (a sensitivity analyses should be used to determine whether such data collection is worthwhile);
- undertake Level 4 assessment to take account of dilution (List II substances only).

## 3.9 Level 4 Assessment (for List II substances only)

### 3.9.1 General

A Level 4 Assessment comprises a quantitative assessment of the dilution by groundwater, and whether the predicted concentration of the contaminant (below the water table) is acceptable.

### 3.9.2 Methodology

Determine effect of dilution by groundwater flow (according to the P20 Tier 2 procedure or using ConSim, level 2) where:

$$C = \frac{C_o DS + C_b Q}{DS + Q} \tag{4}$$

and $Q = Kiwb_{mz}$

where:

$C$ = contaminant concentration in discharge (mg/l)

$C_o$ = contaminant concentration at base of the unsaturated zone (mg/l)

(if attenuation in the unsaturated zone is not considered then the contaminant concentration of the discharge should be used)

$C_b$ = background concentration in groundwater (mg/l)

$DS$ = discharge to soakaway ($m^3/d$)

$Q$ = groundwater flow ($m^3/d$)

$K$ = hydraulic conductivity (m/d)

$i$ = hydraulic gradient

$b_{mz}$ = vertical mixing depth (m)

$w$ = width of zone of mixing (m)

The mixing depth will generally be less than the aquifer thickness (see also Section 2.12.3). The mixing depth can either be estimated based on a hydrogeological evaluation of the site (taking account of aquifer thickness, seasonal water level variation) or estimated using an empirical approach as illustrated by equations 5 and 6:

$$\text{Mixing depth } (b_{mz}) = (0.0112.L^2)^{0.5} + d_a.(1-\exp[(-L.I/K.i.d_a)] \qquad (5)$$

$$\text{or mixing depth} = \frac{x^2}{100} \qquad (6)$$

where:

$L$ = dimension of soakaway parallel to groundwater flow direction (m) Section 2.12.3 arbitrarily recommends a value of between 10 and 50 m

$d_a$ = the saturated thickness of (isotropic) aquifer (m)

$I$ = infiltration rate (m/day)

$K$ = the hydraulic conductivity of the strata (m/day)

and

$x$ = distance to receptor (m) Section 2.12.3 recommends a value of between 10 and 50 m.

The width of flow could be taken as the dimension of soakaway. However, this takes no account of spreading of the contaminant due to mounding below the soakaway and dispersion. For most cases it is considered to be reasonable to take a minimum mixing width of 10 m.

Equation 5 is referred to in the P20 remedial target methodology (Environment Agency 1999a) and Equation 6 in ConSim (Environment Agency 1999b). The first equation is considered to be more appropriate to soakaways as Equation 6 is likely to result in the calculation of unrealistically small mixing depths.

This assessment will require site specific data as summarised in Table 3.12.

### 3.9.3 Acceptance criteria

For the discharge to be acceptable, the calculated concentration should be less than the Target Concentration (Section 3.8.1 and Table 3.9).

**Table 3.12 - Summary of Data Requirements for Soakaway Assessment**

| Parameter | Site Specific Data | Comment |
|---|---|---|
| ***Levels 1 and 2*** | | |
| Soakaway location | ✓ | Location map plus 8 figure grid reference |
| Details of soakaway construction | ✓ | Plan area (area, diameter)<br>Depth<br>Details of construction<br>Details of lining and infill<br>Drawing of construction/soakaway |
| Details of activity giving rise to discharge | ✓ | |
| Chemical analysis of discharge | ✓ | |
| Details of area draining to soakaway | ✓ | Including details of any activities within this area |
| Catchment area draining to soakaway | ✓ | |
| Distance to nearest surface watercourse | ✓ | |
| Rate of discharge of soakaway (DS) | ✓ | |
| Soil infiltration rate ($I$) | ✓ | |
| Annual rainfall and daily rainfall (5 year return period) | ✓ | |
| Location of any licensed or unlicensed groundwater abstractions | ✓ | |
| Depth to water table | ✓ | Borehole measurement |
| Location of site in relation to groundwater protection zone | ✓ | |
| Details of any pre-treatment of discharge | ✓ | |
| ***Level 3 - Unsaturated Zone*** | | |
| Unsaturated zone thickness (d) | ✓ | From base of soakaway to water table (taking account of any mounding) |
| Moisture content ($\theta_w$) | ✓ | |
| Partition coefficient ($K_d$) or organic carbon partition coefficient ($Koc$) | | Literature values likely to be acceptable when applied to similar site conditions. |
| Fraction of organic carbon ($foc$) | ✓ | For hydrophobic organics |
| Hydraulic conductivity of unsaturated zone ($K$) | ✓ | Based on infiltration tests |
| ***Level 4 - Dilution*** | | |
| Hydraulic gradient ($i$) | ✓ | Field measurement, minimum of three boreholes |
| Hydraulic conductivity ($K$) | ✓ | Field measurement, although initial assessment could be based on aquifer properties manual |
| Mixing depth ($b_{mz}$) | ✓ | Saturated thickness, if greater than 5 m calculate mixing depth from Equation 5 or 6 |
| Width of flow ($w$) | ✓ | Width of soakaway, or use minimum width of 10 m |

| **Parameter** | **Site Specific Data** | **Comment** |
|---|---|---|
| Background quality | ✓ | |

*The capacity of the soakaway to accept the discharge needs to be assessed. Where the strata are fractured, the assessment should consider whether flow is likely to be intergranular flow or fissure flow, and the implications for attenuation (e.g. in the unsaturated zone, bypass flow).*

# 4. MONITORING AND REQUISITE SURVEILLANCE

## 4.1 Introduction

This section recommends an approach for "Monitoring and Requisite Surveillance" of activities involving the land spreading or soakaway discharge of List I and List II substances. The approach includes requirements on both the applicant and the Environment Agency to ensure compliance with the Groundwater Regulations (1998).

***Monitoring*** is used in this section to describe the general monitoring requirements that are necessary to ensure that an authorisation complies with the Groundwater Regulations, including monitoring of the discharge, and any additional monitoring to determine if the discharge impacts on groundwater, and particularly its quality.

***Requisite surveillance*** is used in this section to refer specifically to the monitoring of groundwater (as indicated in the Groundwater Regulations) and is regarded as only part of the monitoring activity that is necessary to ensure that an authorisation complies with the requirements of the Groundwater Regulations. For example, if monitoring of soil and/or the unsaturated zone is to be carried out, this should be under the general requirements for monitoring of the authorisation rather than the heading of "requisite surveillance".

It is noted that this approach should only be used where the activity has been successfully assessed through the prior investigation methodology discussed in Section 3. An activity should not be authorised without ensuring that appropriate arrangements are in place for monitoring in general and, where necessary, for requisite surveillance of groundwater.

To provide a background to this recommended approach, this section first describes the relevant legislative requirements and guidance and discusses existing monitoring in England and Wales. It then considers the technical options available for monitoring and for requisite surveillance.

From this background, an overall monitoring strategy is developed and then the recommended approaches are described for:

- monitoring by the applicant as part of the conditions of authorisation;
- enforcement (defensive) monitoring by the Environment Agency;
- assessment of monitoring results;
- research and development.

Additional information on the design of groundwater monitoring is provided in Appendix B.

## 4.2 Legislation and Guidance

### 4.2.1 Legislative requirements

The requirements for monitoring and requisite surveillance are set out in the Groundwater Regulations, 1998 as follows:

> *Regulation 8 'An Authorisation which is subject to any of the provisions of regulations 4, 5 or 6 may only be granted if the Agency has checked that the groundwater (and, in particular its quality) will undergo the requisite surveillance'.*
>
> *Regulation 9 requires that all authorisations for discharges must specify the arrangements for monitoring of effluents discharged to groundwater and, if necessary, measures for monitoring groundwater, and in particular quality.*
>
> *Regulation 10 requires that an authorisation for the disposal or tipping of matter containing listed substances, must specify the maximum quantity for disposal, the rate of disposal and the concentration of disposal substances.*
>
> *This regulation also indicates that an authorisation shall specify, if necessary, the measures for monitoring groundwater, and in particular its quality.*
>
> *Regulation 11(3) states that the Agency shall monitor the compliance with the conditions of an authorisation and the effects of discharges on groundwater.*

The object of the requisite surveillance is not specifically defined, but is clearly to confirm that control measures are working and pollution of groundwater is not occurring.

### 4.2.2 DETR guidance

Further guidance on the interpretation of these requirements, in relation to requisite surveillance, is given by the DETR (2001) guidance which notes that:

- The Agency will need to monitor List I and II substances in background quality and the potential impact of an authorised discharge where required.
- This may be achieved through the national monitoring network and through monitoring conditions imposed as part of the authorisation.
- The degree and location of monitoring, the monitoring facility, sampling frequencies etc, will be "what is appropriate for the Agency to meet its obligations under the Groundwater Regulations". It will also depend on local circumstances and the Agency's own assessment of risks to groundwater.
- It is unlikely that individual monitoring boreholes will be required for the majority of disposal sites (though no basis for this statement is given).
- In requiring the installation of monitoring facilities, the Agency should ensure the costs to the operator are in proportion to the perceived risks to groundwater from the proposed disposal.
- Where possible the Agency should consider the use of monitoring facilities which serve a group of discharges or disposals although it is likely that hydrogeological conditions will allow this in only a minority of cases.
- The Agency is likely to undertake the sampling of boreholes where the applicant does not have the necessary expertise.
- The cost of monitoring that is part of a prior investigation before determination should be borne by the applicant.

### 4.2.3 Implementation in other EU Countries

From a review of literature, websites, and contact with Regulatory Bodies in Europe (Project Record, Environment Agency, 2002a), no specific information could be obtained on European implementation of Monitoring and Requisite Surveillance, except that surveys are undertaken in a number of countries for specific organics and pesticides.

## 4.3 Adequacy of Existing Groundwater Monitoring

### 4.3.1 Main objectives for monitoring groundwater

The monitoring of groundwater quality in aquifers and /or groundwater bodies is an essential component of statutory environmental monitoring. Effective monitoring enables the Agency and others to:

- assess the status of, and trends in, groundwater quality;
- identify emerging problems;
- develop and implement management programmes;
- fulfil statutory requirements; and
- evaluate effectiveness and compliance of a wide range of processes and controls developed for the protection of groundwater and the wider environment.

### 4.3.2 Environment Agency overall monitoring strategy

The Environment Agency is currently developing a strategy for groundwater quality monitoring in England and Wales. Its principal intention is to enable the range of objectives, listed above, to be achieved. Through its implementation, the strategy will enable priority based collection, interpretation and presentation of groundwater quality data to improve the availability of high quality, reliable information for decision making.

Groundwater monitoring can be split into two broad categories:

1. ***Baseline/strategic monitoring*** to determine background quality and any long-term changes in quality. Monitoring undertaken by the Agency is mainly targeted at providing this information.
2. ***Defensive/enforcement monitoring*** for an activity (such as disposal to soakaways, disposal to landfills etc.) which represents a potential risk to groundwater. For the majority of the disposal activities, this is the responsibility of the operator. This monitoring is to provide confirmation that the activity does not give rise to an unacceptable impact on groundwater. Requisite Surveillance falls within this category.

The Agency has approximately 2100 monitoring points from which it collects or receives groundwater quality data, the numbers ranging from 42 in South West Region to 398 in North East Region. An assessment of monitoring needs has indicated that the total number of monitoring points should be increased to approximately 3400 in order to meet monitoring objectives (Environment Agency, 2001e).

### 4.3.3 Adequacy of existing monitoring for Groundwater Regulations

The majority of the monitoring points within the existing Agency network are for the purposes of baseline/strategic monitoring and are located away from authorised activities.

The analytical suite is also mainly targeted at inorganic compounds, although specific surveys for organics and pesticides have been undertaken in some Regions.

Additional monitoring data arise through water quality analysis of public water supplies undertaken by Water Companies (though only a proportion of this is for raw water quality). These analyses include certain pesticides and organics.

It is clear from these points that, much of the existing monitoring network is unlikely to be relevant to the needs of requisite surveillance (i.e. it fulfils different objectives), both in terms of background monitoring and in determining the impact of authorisations on groundwater.

## 4.4 Options for Monitoring for the Purposes of the Groundwater Regulations

### 4.4.1 General

As part of developing a sensible and scientifically defensible approach for monitoring and requisite surveillance, it is important to first consider the options available.

There are four aspects related to an activity that could be monitored. These are:

- the activity itself (see Section 4.4.2);
- the soil zone (see Section 4.4.3);
- the unsaturated zone (see Section 4.4.4);
- the saturated zone (see Section 4.4.5) - requisite surveillance.

There are separate objectives and techniques for each of these aspects and these are discussed in the sections below. The choice of which of these elements are needed in any particular case is a site-specific decision; this is discussed in Section 4.5.

### 4.4.2 The activity

The **objectives** of monitoring of the activity itself should be to ensure that:

- there is a good control on the activities that use List I and List II substances;
- the method of disposal follows the authorisation conditions and any statutory codes of practice;
- the details about the activity provided on the application form, and used in the prior investigation assessment, are valid and to ensure that subsequently periodic review continues to be based on valid information.

The **techniques** that could be used are:

- record keeping;
- instrumented monitoring of discharge rates;
- site inspection.

### 4.4.3 Soil zone

The **objectives** of soil zone monitoring should be to determine:

- contaminant concentrations in soil pore water (as an indicator of the quality of water moving down to the unsaturated zone and possibly to the water table);
- contaminant concentrations in soils (baseline and post disposal) to establish whether there is a build up of contaminants (which may be an issue in relation to soil toxicity) and the potential for these contaminants to be subsequently leached and act as a source of contamination;
- the depth profile for contaminant concentrations to establish the rate of downward migration of contaminants and the effectiveness of attenuation processes.

The **techniques** that could be used include:

- soil chemical analysis;
- soil leaching tests, based on the NRA methodology, NRA (1994);
- pore water extraction and analysis;
- lysimeters and pressure vacuum lysimeters to obtain pore water analysis;
- sampling of water in drains at the base of the soil zone.

The main problem in using and interpreting the results from these methods is that they require significant technical expertise and time, and are, therefore, inappropriate for the majority of authorisations. Soil zone monitoring may be appropriate for high risk sites or for applications that result in high chemical loadings (see Section 4.4), although it would be expected that these would be screened out by a Level 1 and 2 assessment (see Section 3).

The main use is considered to be for test or research sites to improve the science, to validate the screening/assessment procedure detailed in Section 3 and possibly to determine appropriate sampling and monitoring techniques.

### 4.4.4 Unsaturated zone monitoring

The **objective** of monitoring in the unsaturated zone should be to determine the:

- absence of contaminants where prior investigation has suggested no break-through at the base of the soil zone;
- contaminant flux migrating down through the unsaturated zone;
- rate of contaminant migration;
- vertical variations in pore water quality;
- significance of attenuation processes.

The **techniques** that can be used include:

- pore water extraction from samples obtained from the unsaturated zone;
- lysimeters and pressure vacuum lysimeters to obtain pore samples for analysis;

- neutron probes to determine soil moisture.

The **main disadvantages** of unsaturated zone monitoring are:

- cost of installation of instruments within the unsaturated zone;
- difficulties in obtaining sufficient sample volume to allow analysis of trace organics;
- cost of analyses of water samples (particular where there is uncertainty on the listed substances present);
- considerable technical expertise is required to undertake instrumentation and interpretation of the results;
- potential for bypass of the sampling point, e.g. contaminant movement may be mainly via fissure flow;
- timescale: contaminant migration through the unsaturated zone can be slow (of the order of centimetres to metres per year), such that monitoring is likely to be a long-term exercise;
- the installation may provide a pathway for contaminant migration;
- unsaturated zone monitoring is still largely a research activity rather than a standard monitoring procedure.

The main application of unsaturated zone monitoring is considered to be for test or research sites to improve the science and to validate the screening/assessment procedure. In general, it is considered to be inappropriate for the majority of authorisations, although could be considered for high risk sites or for applications that result in high chemical loadings (see Section 4.5). For high risk sites which have been in operation for many years, sampling of the unsaturated zone could be used to prove or disprove predicted attenuation.

### 4.4.5 Groundwater (saturated zone) monitoring

The **objective** of monitoring of groundwater (requisite surveillance) should be to determine:

- background quality;
- the thickness of the unsaturated zone;
- the activity has not resulted in the discharge of List I compounds or pollution by List II compounds (i.e. validation of any prior investigation predictions).

The **techniques** that can be used include:

- sampling of boreholes, springs or rivers fed by groundwater discharge;
- water level monitoring in boreholes;
- non-intrusive methods, such as geophysical methods, in terms of identifying a deterioration in groundwater quality in the vicinity of the activity, but which would need to be validated by groundwater sampling. These methods are only likely to appropriate in a few particular cases (Environment Agency, 2001e). An example could be a geophysical leak detection system as part of a containment liner system or as part of a site survey to detect leaks.

The **main disadvantages** of monitoring groundwater are:

- cost of borehole construction where no existing facilities are available. Many of the activities that require authorisation are small, and the cost of requisite surveillance may be too onerous;
- cost of analyses of water samples (particular where there is uncertainty on the listed substances present);
- groundwater dilution can be large, such that the detection of listed substances may be impractical;
- the delay for contaminants to migrate through the soil zone and the unsaturated zone can be significant at some sites (tens of years), such that any problem may be identified in groundwater only after a substantial source of pollution has built up above the water table;
- groundwater flow systems can be complex, such that there will be uncertainty as to whether the borehole is situated at the correct location or depth. This particularly applies to fractured and karst aquifers and consequently a number of boreholes may be required;
- sampling, particularly for List I compounds, requires technical expertise and specialist equipment;
- poor borehole installation may cause pathways to be created for contaminant migration (bypassing the unsaturated zone or short circuiting the natural protection of underlying confined aquifers).

For this reason monitoring of groundwater (requisite surveillance) may not be appropriate for many Groundwater Regulations authorisations which are for relatively small or infrequent disposals and which have been predicted to have negligible impact on water quality either at the base of the soil zone or at the water table. However, there is still a requirement to formally assess the need for requisite surveillance for each application and the method of doing this is recommended below.

## 4.5 Recommended Monitoring Strategy

Based on the above assessment of monitoring options, the recommended monitoring strategy for the purposes of the Groundwater Regulations is given below. This strategy or framework is summarised in Table 4.1 and the process is illustrated on Figure 4.1.

**Table 4.1 - Framework for Monitoring/Requisite Surveillance and relationship with Prior Investigation.**

| **Type of Monitoring :**<br>***Phase of Regulation :*** | **Background**<br>***Prior Investigation*** | **Operational**<br>***Authorisation (Conditions)*** | **Long Term Assessment**<br>***Compliance (Enforcement)*** | ***Underpinning Research*** |
|---|---|---|---|---|
| **SOURCE** | Source characterisation (activity-based and site-specific). | Locations and quantities to be disposed of, including formulations, mixtures etc. | Site audit – visits and inspections (samples of source material, inspection of records, observation of activity). | Total and average loadings by area, through time. |
| **PATHWAY** | Soil and aquifer conditions. | Potential throughflow to water table (where necessary, soil samples, unsaturated zone monitoring). | Actual throughflow to water table (where necessary, soil samples, unsaturated zone monitoring). | Detailed monitoring of soil and unsaturated zone at test sites; laboratory tests and models. Results to be fed back into Level 1 and 2 assessment criteria. |
| **RECEPTOR** | Background water quality. | Requisite surveillance : on and off-site impact (where necessary, groundwater samples etc). | Requisite surveillance : on and off-site impact ( where necessary, groundwater samples etc). | Detailed groundwater monitoring at test sites; laboratory tests and models. Results to be fed back into Level 1 and 2 assessment criteria. |
| ***Responsibilities*** | *Applicant has prime responsibility for the costs of investigation, but supplemented by Agency-held information.* | *Applicant is responsible for the costs of compliance with an authorisation.* | *Agency has prime responsibility for overseeing.* | *Variety of participants, including Agency, applicants, research establishments etc.* |

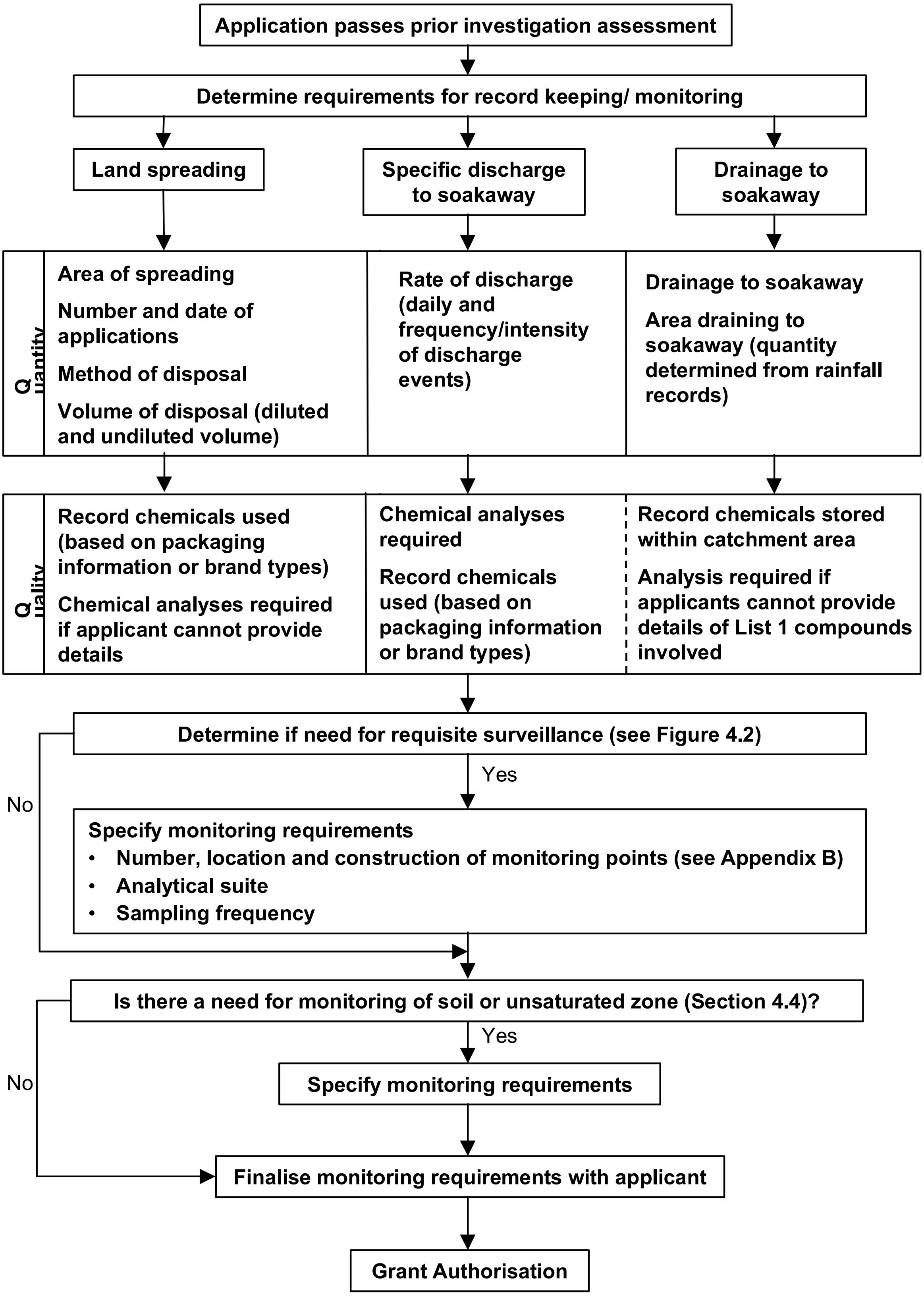


**Figure 4.1 Determination of Monitoring Requirements**

### 4.5.1 As part of conditions of authorisation

- ***Record keeping by the applicant.*** This is a requirement of all authorisations. (See Section 4.6.1);
- ***Monitoring of the discharge*** by the applicant. This will be dependent on the activity and associated risk. (See Section 4.6.1);
- Monitoring (***requisite surveillance***) of groundwater (e.g. boreholes) or groundwater discharges (e.g. springs, river baseflow) by the applicant. This will also be dependent on the activity and associated risk. (See Section 4.6.3).

### 4.5.2 As part of enforcement by the Environment Agency

- ***Site visits*** by the Environment Agency to verify details of the application and compliance with the technical measures required by the authorisation including record keeping. (See Section 4.7.1).
- ***Defensive monitoring*** of groundwater (e.g. boreholes) or groundwater discharges (e.g. springs, river baseflow) by the Environment Agency. The objective of this monitoring should be to provide confirmation that the overall assessment process is appropriate (i.e. protects groundwater from the discharge of effluents containing listed substances, rather than directed to monitoring specific authorisations which should be a requirement for the applicant) (see Section 4.7.2). This assessment monitoring will also require information on background quality.
- ***Strategic (baseline) monitoring*** of groundwater by the Environment Agency to determine background quality (see Section 4.8). This information will be required as part of any assessment of whether authorised activities are resulting in a significant change in groundwater quality.

### 4.5.3 As part of supporting research and development

Research should be undertaken at selected sites with known histories (including active use) of land spreading or soakaway disposal to provide confirmation of the assessment procedure and, if appropriate, to improve the methodology used (See Section 4.10). This research should include:

- Monitoring of contaminant concentrations in the soil and unsaturated zone with the objective of using this information to refine the Level 1 to Level 3 methodologies. The results of this exercise should also be used to identify activities where monitoring of the soil and /or unsaturated zone should be required and the most appropriate methods to be used;
- Monitoring of the underlying groundwater quality, with the objective of examining the possible significance of bypass of the soil and unsaturated zone;
- Establishing the key uncertainties in understanding a site and, if appropriate, changing safety factors within the prior investigation methodology or improving record keeping or monitoring practices.

The following sections provide guidance on how each of these three areas of the strategy should be implemented and on how the results should be assessed. Reference should be made to Table 4.2.

**Table 4.2 - Potential Monitoring/Requisite Surveillance Requirements.**

| **Type of Monitoring :**<br>***Phase of Regulation :*** | **Background**<br>***Prior Investigation*** | **Operational**<br>***Authorisation (Conditions)*** | **Long Term Assessment**<br>***Compliance (Enforcement)*** |
|---|---|---|---|
| **LOW RISK**<br>**(Level 1 screening score <50)** | Source characterisation (representative analysis of material for disposal) + desk study data only. | Record of locations (including area) and quantities to be disposed of. For discharges, the quantity and concentration of listed substances in the effluent. | Occasional site audit – at least one visit per four year period review period (confirm nature of source material, inspection of records, observation of facilities and, where possible, activity). |
| **MEDIUM RISK**<br>**(Level 1 screening score 50 to 65)** | Confirmation of soil and aquifer characteristics, as appropriate. Background water quality where appropriate (normally from existing facilities).<br>+ above | Occasional soil monitoring, where appropriate. Requisite surveillance where existing monitoring point. If chemical loading exceeds score of 20, or area of single application exceeds 4 ha, then requisite surveillance.<br>+ above | Soil and/or water samples, as appropriate, at least once per review period<br>+ above |
| **HIGH RISK**<br>**(Level 1 screening score >65)**<br>**Soakaways** | Background water quality (existing facilities, Agency network and site-specific facilities).<br>++ above | Regular (annual +) saturated zone monitoring in aquifer or via springs, unless travel to unsaturated zone exceeds 10 years, in which case the monitoring frequency needs to be determined on a site-specific basis. Background monitoring as appropriate.<br>++ above | Groundwater/spring samples on/off-site as appropriate at least once per review period, but potentially more frequent inspection necessary.<br>++ above |

Note: The score defining the risks may need to be adjusted following experience of use.

## 4.6 Recommended Monitoring as part of the Conditions of the Authorisation

### 4.6.1 Monitoring and record keeping (Applicant)

The objective of this exercise is to quantify the rate of discharge and the quality of the discharge, to demonstrate that the conditions of the authorisation are being met and that the information used in the assessment of the activity is appropriate. As soakaways represent a potentially higher risk to groundwater than land spreading, some of the monitoring is specific to soakaways only.

It is recommended that monitoring should include (refer to Figure 4.1):

- **Either** recording chemicals used and their concentration (this would normally be based on providing specific details of chemicals from packaging information, or possibly from chemical analysis undertaken by/on behalf of the applicant). It is also recommended that records should include the disposal of mixtures and formulations as these may affect the transport of 'active' compounds (for example 'non-active' compounds could change the solubility of the 'active' compounds). This may also include stock reconciliation for contents of storage tanks when accurate long-term records are kept;
- **Or** chemical analysis of the discharge (land spreading or soakaway), if the composition of the waste cannot be readily determined (e.g. from packaging information);
- Measurement of the volume or rate of discharge (this should be appropriate to the activity, for example, for land spreading a record should be kept of the undiluted and diluted volume of waste disposed of, together with the method of disposal; for a soakaway it could involve metered flow);
- Recording the area of spreading on a map, together with the number and date of each application.

The applicant should maintain appropriate records and make these available for inspection by the Environment Agency to determine compliance with the conditions of the authorisation.

### 4.6.2 Soil and unsaturated zone monitoring (Applicant)

Monitoring of the soil or unsaturated zone should be considered where a Level 2/3 assessment has been undertaken **and** some uncertainty still exists that the discharge may breach the Groundwater Directive. In this case, an authorisation should only be granted if the applicant can comply with conditions relating to monitoring of the soil and/or unsaturated zone. Cases where this approach is likely to be warranted are:

- Disposals where requisite surveillance would be required (see Section 4.6.3), but the calculated delay for migration to the water table is greater than 10 years;
- Application involves high contaminant loading (Level 1 chemical loading score of greater than 20 and area for single application exceeds 4 ha);
- The assessment identifies that a build up of contaminants within the soil zone could occur through repeated applications.

For constructed soakaways, which by design bypass the soil zone and (or overwhelm) the unsaturated zone, this monitoring is unlikely to be appropriate and requisite surveillance is likely to be required.

### 4.6.3 Requisite surveillance of groundwater (Applicant)

In general, requisite surveillance is unlikely to be necessary for the majority of land spreading applications as the assessment procedure has been designed to screen out activities that would give rise to a risk of the discharge of List I substances at the water table or of pollution by groundwater from List II substances.

For soakaways, requisite surveillance of groundwater should be carried out, except where the applicant is able to demonstrate to the satisfaction of the Environment Agency that the activity represents a low risk to groundwater.

For each application, however, the Environment Agency should assess whether requisite surveillance is required in addition to monitoring of the discharge (specified as part of the authorisation) and to site inspection by the Environment Agency (refer to Figure 4.2). The decision on whether or not requisite surveillance is required should be fully documented.

Particular factors that should be considered are:

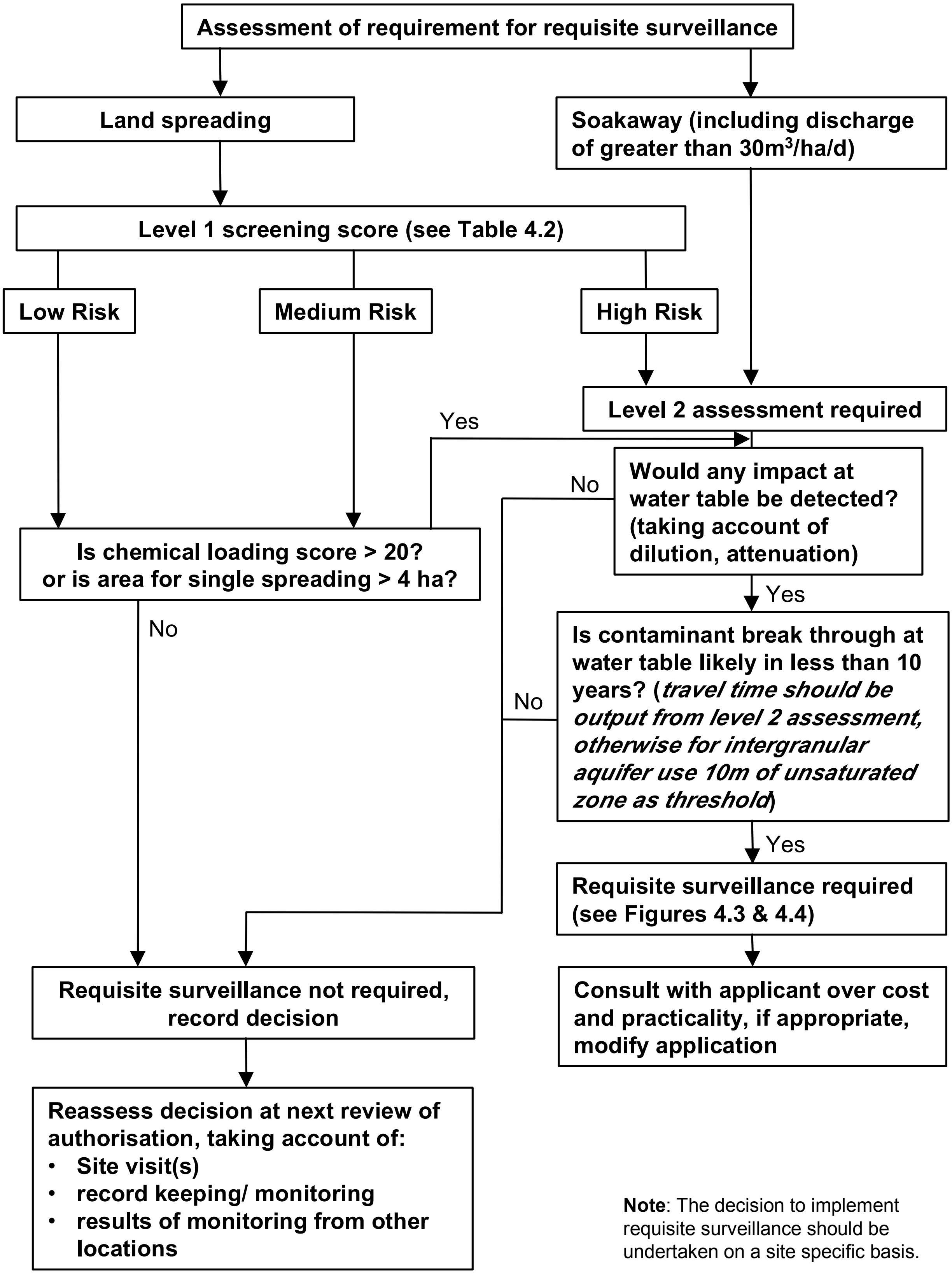
- The results of the Level 1 assessment procedure. In general, for applications where the screening score is within the low risk category noted in Table 3.3, no impact would be expected. For a high risk category site, requisite surveillance should be considered, **unless** further assessment (Level 2 to 4), confirms that no impact on groundwater would be expected. For intermediate scores, the decision should be based on the scale of the proposed activity and the likelihood that an impact could be measured;
- The delay for contaminants to migrate through the soil and unsaturated zone, particularly where the travel time through the unsaturated zone exceeds 10 years*. In some cases, it may be more appropriate to consider monitoring of the soil or unsaturated zone;
- The likelihood that any impact could be detected (i.e. where the proposed rate of discharge is sufficiently small in relation to groundwater dilution* such that any List I/II substance would not be detectable);
- The practicality and cost of implementing a groundwater monitoring scheme (Appendix B provides guidance on the design of a groundwater monitoring scheme including determination of analytical suite and sample frequency);
- The nature of the activity and whether there is a risk of hydraulic overloading of the soil or unsaturated zone, resulting in rapid transport to the saturated zone, i.e. soakaways and invalidation of the assumptions behind the prior investigation assessment carried out.

Requisite surveillance by the applicant is considered to be a reasonable potential requirement (Figure 4.2) where:

- Screening indicates high risk. This threshold, noted in Table 4.2 should be reviewed based on applying the Level 2 and Level 3 methodology to a range of applications to determine the risk associated with different Level 1 screening scores, and in due course on the basis of the results from actual monitoring;

- Activities with high loading (hydraulic loading of greater than 30 $m^3$/ha/d, i.e. soakaway, and chemical loading score of greater than 20, Level 1. This threshold will need to be reviewed based on applying the Level 2 and Level 3 methodology to a range of applications to determine the risk associated with different Level 1 screening scores);
- Discharge is to soakaway, except where the applicant is able to demonstrate that the activity represents a low risk to groundwater;
- Area used for a single spreading exceeds 4 ha (this is intended to identify larger applications where the hydraulic/chemical loading is sufficient to require spreading over a larger area).

*Note: *The travel time through the unsaturated zone and dilution by groundwater flow will be an output from the Level 2 to 4 assessments.*



**Note**: The decision to implement requisite surveillance should be undertaken on a site specific basis.

**Figure 4.2 Determination of Need for Requisite Surveillance by Applicant**

## 4.7 Enforcement Monitoring by the Environment Agency

### 4.7.1 Site visits (Environment Agency)

The **objectives of the site visit** should be to:

- Check that the information provided in the application is correct (e.g. verification of spreading area, soil type for land spreading activities and confirmation of the area draining to the soakaway);
- Confirm that the activity meets the requirements of the authorisation, including record keeping and that all necessary technical precautions to protect groundwater and surface water are in place;
- Identify whether site practices comply with relevant codes of practice (e.g. storage of chemicals);
- Confirm that the activity or site operations do not represent a risk to groundwater and surface water (e.g. the disposal area is not located near to a spring, borehole or watercourse);
- Identify potential monitoring points. An assessment will subsequently need to be made as to whether these should be monitored by the applicant or included within the Environment Agency monitoring network;
- Identify possible alternative options for the activity (e.g. alternative areas of spreading), if subsequent reviews of the activity conclude that it represents an unacceptable risk to groundwater or surface water;
- Identify if additional investigation (prior investigation) is warranted (e.g. soil testing if site inspection finds that the soil conditions differ from those used in assessment).

The **frequency of site visits** for all authorisations should be at least once during the 4 year period (prior to review of the authorisation), and higher risk sites at least twice during the 4 year period (see Table 4.1). Authorisations for which a higher frequency of site visit is recommended include:

i) Initial (Level 1) screening assessment indicates high risk (see Table 4.2). This threshold should be reviewed based on applying the Level 2 and Level 3 methodology to a range of applications to determine the risk associated with different Level 1 screening scores;

ii) Discharge to soakaway;

iii) Activities which involve land spreading rates of greater than 30 $m^3$/ha/d.

Site visit questionnaires have already been designed by the Environment Agency (an example is included in the Project Record).

The **basic components of the site visit** should include:

- Review of records including:
    - types of chemicals (including packaging information);

  - diluted and undiluted volumes;
  - rates of land spreading and number of applications;
  - method of land spreading;
  - measured rates and quality of discharge to soakaway.

- Assessment of site practices including:
  - storage and handling of chemicals;
  - area of application (land spreading);
  - record of chemical/activities in area draining to the soakaway;
  - identification of activities and processes that may result in contamination;
  - confirmation of details of soakaway and any prior treatment facilities (e.g. interceptors).

- Assessment of risk of groundwater and surface water contamination including:
  - proximity to surface water, springs, boreholes;
  - presence of soil drains providing pathway to watercourses.

- Identification of possible monitoring points (boreholes/wells/springs/drains) and source of applicant's water supply;

- Assessment of land spreading application area including:
  - vegetation cover and slope;
  - soil drainage;
  - soil thickness;
  - soil characteristics;
  - any indications of depth to water table.

### 4.7.2 Supplementary defensive monitoring (Environment Agency)

For the majority of applications requisite surveillance by the applicant is unlikely to be necessary as the assessment procedure has been designed to screen out activities that could represent a risk to groundwater. However, it is considered that some monitoring should be undertaken by the Environment Agency to confirm that the overall assessment procedure is appropriate and that these widespread activities are not impacting groundwater quality.

In Section 4.3, it has been noted that the majority of groundwater monitoring points currently sampled by the Environment Agency are understood to be located away from authorised activities and the analytical suite is mainly targeted at inorganic determinands (major ions, metals). Consequently additional monitoring points will need to be identified.

It is considered that any additional monitoring by the Agency should initially be based on existing abstractions or springs or groundwater fed streams (due to the relatively high cost of new borehole construction), although additional boreholes may be required if suitable monitoring points cannot be identified.

Particular cases where supplementary defensive groundwater monitoring would be warranted are if:

- There is a high density of authorisations (for example, greater than 4 per square kilometre) and where individually the applicant would not be required to undertake requisite surveillance (this may be, for example, in an area dominated by sheep farming); or
- There is an existing monitoring point which could be used to monitor several activities;
- There are limited existing monitoring data in the groundwater catchment/aquifer.

The proposed **procedure for identifying possible monitoring points** is outlined below (based on approach being adopted by the Environment Agency, Wales):

i) Generate GIS map showing location of:

  - authorisations (should also include discharge consents);
  - existing monitoring points (boreholes, springs etc);
  - licensed groundwater abstractions, private abstractions and water features (wells, springs etc). Much of this information is likely to be identified from applications, review of applications and site inspection.

ii) Identify or rank suitable monitoring locations on the following criteria:

  - monitoring point should be in the same aquifer unit as the authorised activity;
  - monitoring point should be located down-gradient of authorised disposal locations;
  - distance to monitoring point. For fissured aquifers, the monitoring point should be within 500 m and for intergranular aquifers within 100 m of the authorisation.

In many cases a compromise may be required in selecting the monitoring point. In this case, important to take account of:

- there may be more than one source of contamination;
- the travel time for contaminants to migrate through the aquifer;
- the possibility that the contaminant may bypass the monitoring point.

The selection of monitoring points should be discussed and agreed with a hydrogeologist.

The procedure to be adopted (with the aim of identifying the source of contamination) when contaminants are identified is summarised in Figure 4.4).

## 4.8 Strategic/Baseline Groundwater Monitoring

To provide confirmation that authorised activities do not impact on groundwater quality, it is necessary to be able to define background quality by monitoring in groundwater catchments where authorisations have been granted. This monitoring will need to be undertaken up-hydraulic gradient of a disposal area or outside of the likely flowpath from a disposal area. Whilst some applicants will be required to undertake background monitoring, additional monitoring is likely be needed by the Environment Agency to supplement this information (as noted in Section 4.7.2, requisite surveillance is unlikely to be required for the majority of applications).

It is considered that any additional baseline monitoring by the Agency should initially be based on existing abstractions or springs or groundwater fed streams (due to the relatively high cost of new borehole construction), although additional boreholes may be required if suitable monitoring points cannot be identified (see also Section 4.7.2).

Particular cases where supplementary groundwater monitoring would be warranted are where:

- There are no or limited existing background quality data on a catchment for which authorisations have been granted (greater priority should be given to groundwater bodies with strategic importance in terms of existing licensed abstractions or baseflow to streams);
- There is a high density of authorisations (for example, greater than 4 per square kilometre) and where individually the applicant would not be required to undertake background monitoring.

The proposed **procedure for identifying possible monitoring points** is outlined below (similar to the approach outlined in Section 4.7.2):

i) Generate GIS map showing location of:

  - authorisations (should also include discharge consents);
  - existing monitoring points (boreholes, springs etc);
  - licensed groundwater abstractions, private abstractions and water features (wells, springs etc).

ii) Identify or rank suitable monitoring locations on the following criteria:

  - importance of groundwater resource (e.g. licensed abstraction, baseflow to streams);
  - monitoring point should be located either up-gradient of an authorised disposal location or outside of the flowpath from the disposal area.

The selection of monitoring points should be discussed and agreed with a hydrogeologist.

In assessing background quality the following factors should be taken into account:

- natural variations in groundwater quality both laterally and vertically in the aquifer;
- natural seasonal variation in groundwater quality;
- uncertainty in the measurement of the parameters due to sampling practice and analytical technique;
- the potential for groundwater contamination arising from other activities within a catchment.

Further guidance on the assessment of background quality is given in Environment Agency 2001f.

## 4.9 Assessment of Monitoring Results

### 4.9.1 Site records and site visit

Based on the review of the site records and site visit, the following actions may arise:

- The authorisation is appropriate and the conditions have been met by the applicant, such that the authorisation could be extended at the next review.
- The assessment of the activity needs to be revised (for example, soil conditions differ to those given in the application), leading to higher or lower score under the screening system. For significantly higher scores, then:
    - The authorisation may need to be assessed using Level 2 or Level 3 methods and subsequently may either need an increased amount of monitoring, modification to the conditions on the authorisation, or even need to be revoked - it may be giving rise to pollution;
    - The activity may need to be modified (e.g. reduced rate of spreading, or moved to a lower risk area);
    - Further investigation (including soil sampling) may be necessary (see below).
- Enforcement action due to non-compliance with the conditions of the authorisation. Unless the applicant agrees to modify site practices, the authorisation may be revoked.
- Additional monitoring of the discharge needs to be implemented by the applicant as:
    - There is uncertainty regarding the nature of the discharge (applicant has been unable to provide adequate records on the discharge);
    - Site inspection has identified number of contaminant sources that may contribute to the discharge (this is likely to relate to drainage areas feeding a soakaway).
- Monitoring of groundwater (well/borehole) or groundwater discharge needs to be implemented by the applicant (see Section 4.4.1), particularly if the applicant’s water supply is located near to the point or area of discharge.
- Identified monitoring point is included in Environment Agency network, subject to agreement with the groundwater quality monitoring officer.
- A prohibition or conditional notice needs to be served due to identification of site practices which breach Codes of Practice (e.g. inappropriate storage of chemicals) or could give rise to contamination of groundwater or surface water.

The basis for additional investigation being required following a site inspection should be:

- Site visit indicates that the soil is of different character (higher leaching potential) from that determined by the applicant or from examination of soil survey or groundwater vulnerability maps/datasets, and where the authorisation may need to be modified or revoked unless an assessment based on site specific data shows that the activity is acceptable.

- Site inspection confirms that the soil is shallow or is high leaching potential, such that a site specific assessment is required to confirm that the activity does not present a risk to groundwater.
- Inspection of site discharge/disposal arrangements indicate that the soil zone is being bypassed and there is reliance on the unsaturated zone, data for which are not available.

### 4.9.2 Requisite surveillance of groundwater

The results of any requisite surveillance should be reviewed initially after the first sampling exercise and thereafter at least every four years for land spreading activities and at least every two years for soakaways (refer to Figures 4.3 and 4.4). The results should be used to:

- Confirm that the authorisation is acceptable, e.g. the rate and quality of discharge complies with the authorisation and that there is no evidence of groundwater pollution; or
- Determine whether the authorisation should be revoked or varied (including variation to monitoring conditions). This should be on the basis of evidence for pollution of groundwater (e.g. the observed contaminant concentrations exceed the target concentration) taking into account any baseline quality trends. This will be subject to:
    - undertaking repeat analyses to confirm the results;
    - confirming the analysis is consistent with the activity;
    - confirming that the exceedence is not a result of other activities (this may require sampling of an upgradient monitoring point) or checking contaminant concentrations in other monitoring points in the catchment. Further investigation (including monitoring) should be considered where the cause of contamination cannot be determined.
- Refine the programme of requisite surveillance.

In the case of a revision to the authorisation (such as a change in rate or area of spreading), continuation of the activity should be subject to a higher level of monitoring, at least initially.

## 4.10 Recommended Research and Development

It is recommended that the Environment Agency should undertake research and development as part of validating the assumptions and predictions relating to the prior investigation methodology. Recommended projects include:

- Soil sampling to provide additional information on the characteristics of soil within a particular region (particularly where existing information from the NSRI is limited). This is in addition to any information that the applicant may have provided. For a large number of sites the applicant may not be required to provide these data (low Level 1 screening score). This information can then be used to check the assessment of applications where soil default values have been used in Level 2/3 assessments.

  For this process, soil samples should be obtained for around 1 in 30 applications, according to the procedure set out in Environment Agency 2001f. The results of this exercise should be fed back into the overall assessment process.

- Carry out detailed soil sampling at sites where there is good control on the history of land spreading. This should include soil sampling across an area (including background samples) and through the soil profile. Where possible soil water samples and soil samples should be analysed for the range of substances applied together with possible breakdown products. It would be prudent to phase such an investigation by developing some of the techniques on simple sites (e.g. small sites with disposal of a single sheep dip chemical) before going on to examine more complex sites such as disposals of a large variety of pesticides.

- Cost effective methods of soil and soil water sampling should be investigated to allow their potential use on the large number of land spreading activities not requiring requisite surveillance.

- For some sites (approximately 1 in 60 applications), soil chemical analyses should also be undertaken to assess the build-up of contaminant concentrations within the soil and with time, and to determine whether this is consistent with the results of the Level 2/3 assessment.

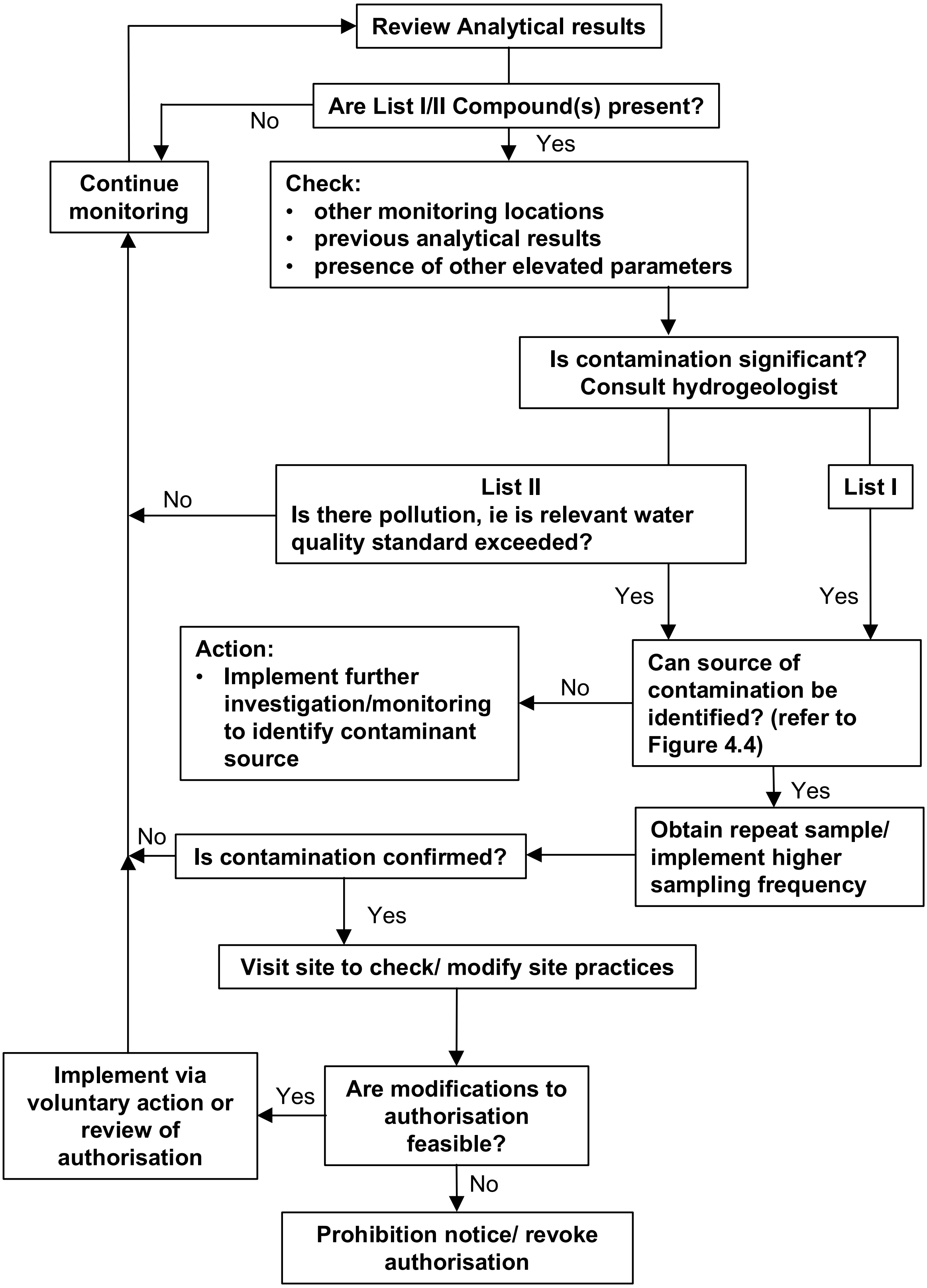


**Figure 4.3** **Review of Groundwater Monitoring Results**

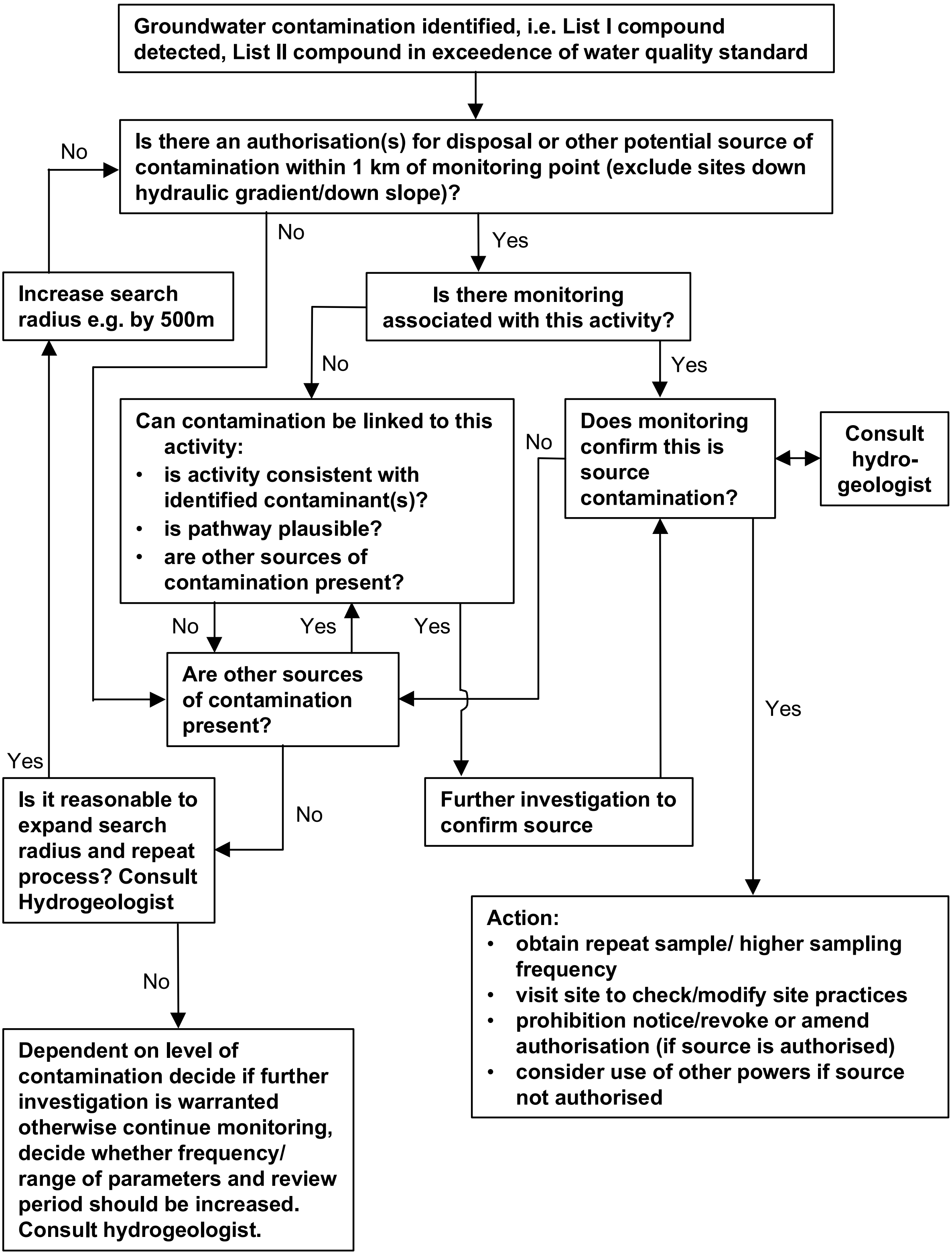


**Figure 4.4 Identification of Contaminant Source**

# 5. FINAL REVIEW

## 5.1 Summary

The risks to groundwater from the disposal of List I and II substances to land, by land spreading or soakaway, are controlled by a large number of processes and variables. To date, assessment of these factors has been undertaken by the Environment Agency using a qualitative screening procedure based on a scoring system. However, validation of this procedure and further assessment of sites falling between pass and fail is required.

At the outset of this project, the focus was not on the complexities of the processes controlling contaminant movement, but on developing an overall framework for prior investigation, and monitoring and requisite surveillance. However, to allow the further assessment of sites, it was not possible to provide a quantitative assessment tool without understanding the relative importance each process has on contaminant transport.

From a broad understanding of the processes controlling contaminant movement (given in Section 2), a quantitative screening tool has been developed for the assessment of land spreading. This tool is based on a number of conservative assumptions and default input parameter values have been estimated.

Calibration of this screening tool has shown that the assessment is very sensitive to the rate of degradation, particularly for soils with a high leaching potential. The procedure relies on the use of literature values for degradation rates in soils which may not be appropriate to some UK soil conditions. For this reason a safety factor of ×2, has been included in the assessment, but this highlights the need to verify the procedure through research sites (Section 6.2).

A broad framework for prior investigation has been produced (in Section 3) and is shown in Figure 3.1. The framework has four levels of assessment:

- **Level 1**: the Agency's initial screening procedures for assessing applications related to land spreading (see Section 3.4);
- **Level 2**: a conservative quantitative screening tool for assessing land spreading and initial assessment of soakaways (see Section 3.5);
- **Level 3**: quantitative risk assessment based on approaches such as the P20 Methodology (Environment Agency, 1999a) (see Section 3.6);
- **Level 4**: assessment of dilution (see Section 3.7).

For each level, discussion is given on the assumptions made, information requirements and sources, assessment criteria and guidance for addressing "failed" applications. The four levels are for use for land spreading activities and the assessment of soakaways starts with initial appraisal at Level 2. A more detailed assessment procedure for soakaways is given in Section 3.8.

A strategy for both general monitoring and requisite surveillance of groundwater has been developed (Section 4). This includes determining the monitoring and requisite surveillance required by the applicant, and also by the Environment Agency to ensure the protection of groundwater.

## 5.2 Recommendations

Prior Investigation

- To date, the Level 2 quantitative screening tool has been tested against 14 existing applications, and the results of this suggest that the tool is neither too pessimistic (all sites fail) nor too optimistic (all sites pass). Testing against further applications is needed. The testing to date has also indicated that there may be some initial difficulties in data collection and so the Environment Agency may need to review its accessibility to information and staff training in Area offices.
- The Level 2 quantitative screening tool should also be tested using field data and compared with other models to determine whether the tool's assumptions are over or under conservative.
- The default soil values suggested are based on a subset of the soils data available for the UK. In particular, as the subset is for soils in Wales, the default values are likely to over-represent thin, upland, organic soils. Data for the West Midlands, for example, will generally show higher bulk-densities, lower organic carbon contents and lower moisture contents and this will lead to different default values. Further work is needed to establish either a single set of UK default values or regional sets of default values by examination of data in the National Soils Inventory, held by the NSRI.
- Soil samples should also be obtained for selected application sites for analysis for fraction of organic content, moisture content, and bulk densities. This information should be fed into a more detailed assessment using the Level 2 and Level 3 to determine the validity of using non-site specific data at Levels 2 and 3.

Requisite Surveillance/Monitoring:

- The existing Environment Agency groundwater monitoring network should be extended to include monitoring points within catchments where authorisations have been granted. This monitoring should be strategic in terms of defining background quality in groundwater catchments where authorisations have been granted and defensive in terms of providing confirmation that authorised disposals are not resulting in a significant change in groundwater quality. This monitoring should also aim provide to confirmation that the Level 1 to 3 assessment process provides adequate protection to groundwater;
- Possible groundwater monitoring locations (boreholes/wells/springs) should be identified as part of site visits made by Environment Agency Officers. The suitability of these monitoring points for incorporation into the Agency's groundwater monitoring network should be assessed.
- Test/research sites should be identified (this may include existing research sites) for monitoring of the soil and unsaturated zone to provide validation data for the assessment process.

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# Appendix A
# Example of Level 2 Screening Tool Spreadsheet

2 Pages

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Note:

The Level 2 Screening Tool Spreadsheet referred to in this document is available electronically by downloading from the Environment Agency's website:

www.environment-agency.gov.uk

## Appendix A - Basic Outline of Level 2 Screening Tool Spreadsheet

| Parameter | Units | Topsoil |
|---|---|---|
| **Hydraulic Loading** | | |
| Application Rate | $m^3$/ha/d | 30 |
| No of Applications per year | - | 2 |
| Max Monthly HER | mm/month | 200 |
| Maximum Annual HER | mm/yr | 1000 |
| Proportion to Groundwater | - | 0.6 |
| Total (max per month) | mm/month | 126 |
| Total (max per year) | mm/yr | 606 |
| | | |
| **Chemical Loading** | | |
| Substance | | e.g. Sheep Dip |
| Concentration | mg/l | 400 |
| | | |
| **Substance Mobility** | | |
| Koc | l/kg | 374 |
| t½(soil) | days | 7.0 |
| t½(safety factor for T°C difference) | days | 2 |
| | | |
| **Soil Type** | | |
| *Leachability* | | Intermediate |
| *Thickness* | m | 0.3 |
| *Moisture Content* | % | 15 |
| *Bulk Density* | g/$cm^3$ | 1 |
| *foc* | % | 5 |
| *Hydrophilic organic or inorganic Kd* | l/kg | |
| | | |
| **Calculations** | | |
| *Unretarded Travel Time (at monthly rate)* | days | 10.9 |
| *Unretarded Travel Time (at annual rate)* | days | 27.1 |
| *Retardation Factor for Hydrophobic Organics* | - | 126 |
| *Retardation Factor for Other* | | not used |
| *Retardation Factor Used* | | 126 |
| *Retarded Travel Time (at monthly rate)* | days | 1369 |
| *Retarded Travel Time (at monthly rate)* | yrs | 3.75 |
| *Retarded Travel Time (at annual rate)* | yrs | 9.3 |
| | | |
| **Assessment Criteria** | | |
| | | |
| Groundwater Protection | | |
| *Retarded Travel Time Used* | yrs | 9.3 |
| Attenuation Factor (for degradeable) | - | 5.2E-74 |
| Peak Concentration | µg/l | 2.1E-68 |
| | | |
| Soil/Land Quality | | |
| Annual Budget | | |
| Mass Loaded to Soil | mg/yr/$m^2$ | 2400 |
| Mass Not Degraded in Soil | mg/yr/$m^2$ | 0 |
| Mass Not Degraded in Soil | (fr) | 0.00 |
| Concentration left in soil | mg/kg/yr | 0.0 |

# Appendix B
# Design of Groundwater Monitoring Schemes

8 Pages

## Appendix B: Design of Groundwater Monitoring

### Introduction

This appendix provides a discussion of the factors that need to be taken into account when designing a groundwater monitoring scheme (see also Figure B.1). It is important to note that a groundwater monitoring scheme will need to be site specific, and it is not possible to give precise guidelines on its design.

### Number and Locations of Monitoring Points

For most monitoring schemes, a minimum of three monitoring boreholes would be required in order to define the groundwater flow direction. This should include an up-gradient borehole and two down-gradient boreholes (or springs). The number of boreholes (or springs) will depend on the site geology, hydrogeology and the area of disposal. For larger application areas (greater than 1 ha), then an initial design density of one borehole per 100 m width of site is recommended, although in fissured aquifers a higher density (say every 50 m of site width) may be required. Further guidance on the design of monitoring networks is given in Environment Agency, 2001a.

For some activities it may be justifiable to accept a single monitoring point where:

- the direction of groundwater flow can be determined with reasonable confidence;
- the disposal is a point discharge (i.e. soakaway);
- the background quality is known or sampling indicates that potential contaminants from the disposal are at natural baseline levels;
- the monitoring point is located at the boundary of the point or area of disposal.

Thus it is acceptable if it can be shown that the area of spreading is likely to be sufficiently large that a single down gradient monitoring point would allow any contamination to be identified.

In general the down gradient monitoring point(s) should be located close to (between 10 and 100 m from) the area of spreading or within 20 m of the soakaway.

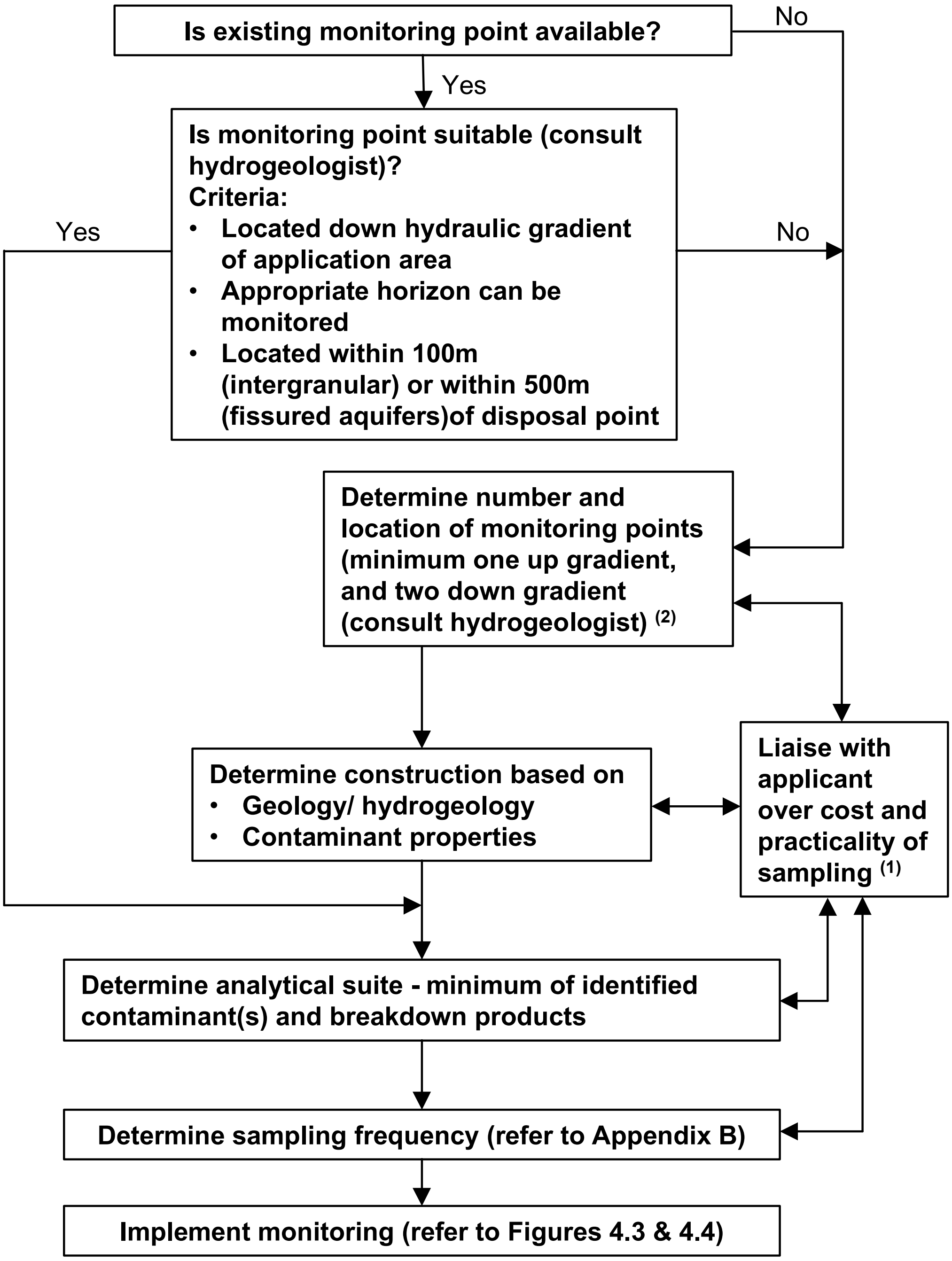
### Use of Existing Monitoring Points

In some cases the applicant may be able to use an existing sampling point (particularly if this is a spring or groundwater abstraction). However, if this point is a sensitive receptor (e.g. a potable abstraction) at risk from the disposal, a further advance warning monitoring point is likely to be needed, up-gradient of the receptor. The criteria for acceptance of an existing monitoring point should be:

- The monitoring point should be located within 100 m of the disposal area for intergranular aquifers and within 500 m for fissured aquifers. This is considered not to be ideal, but recognises the high cost of constructing a monitoring point to most applicants.
- Down hydraulic gradient of the application area, and that there is reasonable confidence that the appropriate horizon is sampled.
- If it is an “at risk” potable abstraction, an advance warning monitoring point is also installed.

In assessing whether an existing monitoring point is suitable or in specifying a groundwater monitoring network, a hydrogeologist should be consulted.

## Figure B.1 Design of Monitoring Network



Notes:
Flow chart assumes that existing monitoring points should be used where feasible.
(1) Applicant may decide to withdraw or modify application
(2) A single monitoring point could be accepted where:
- The direction of flow is known
- Background quality is known
- The monitoring point is less than 20m from area of point of disposal

**Use of Springs**
Springs could potentially be used as monitoring points, although they should be subject to:

- Determining, with reasonable confidence, that groundwater flow below the disposal area discharges at the spring, based on an assessment of the topography and geology of the area. For fissured aquifers there may be considerable uncertainty in the catchment draining to the spring, and tracer tests will normally be required.
- Understanding the surface water and groundwater catchment to the spring (some springs can comprise artificial collection systems, such that it may be difficult to determine the source of spring water).
- Deciding whether any groundwater contamination could be detected due to dilution by groundwater and surface water draining to the spring.
- Assessing the vulnerability of the spring to other sources of contamination, and whether it would be possible to identify the activity as the source of any contamination.

**Design and Construction of New Boreholes**
The borehole design will ensure that the appropriate horizon is being monitored and take account of the site geology and hydrogeology, and any seasonal variation in groundwater level. The borehole should also be designed to ensure that is does not provide a conduit for contamination migration.

As a minimum requirement the borehole should have sealed headworks, be cased out through a significant portion of the unsaturated zone and be of such a depth to allow all water level variations to be monitored, but not so deep that significant dilution occurs in the screened interval. A hydrogeologist should be consulted for the exact requirements needed at each site.

The construction and geological details of all new boreholes should be supplied by the applicant to the Environment Agency and copied to the British Geological Survey at Keyworth.

**Method of Sampling**
It is important to ensure representative groundwater samples are obtained. Guidance on sampling practice is given in International Standards Organisation, 1993 and 2001 and Environment Agency 2001a.

**Cost**
The monitoring scheme should be discussed with the applicant in terms of its cost and practicality, as the applicant may prefer to modify their application or provide alternative proposals

**Analytical Suite and Sampling Frequency**
The analytical suite will need to be determined based on the activity and take account of:

- existing chemical analysis of discharge;
- chemicals identified from packaging information;
- chemicals stored on site;

- common breakdown products of the chemicals in question (particularly where these are of themselves a concern with respect to pollution;
- cost of analysis;
- detection limit of analysis.

Further guidance on the design of monitoring schemes is given in Environment Agency 2001a.

Consideration should also be given to measurement of parameters on site which indicate geochemical conditions, which could influence the mobility and transport of contaminants such as pH and dissolved oxygen.

The method of laboratory analysis and limit of detection should also be specified. The limit of detection should relate to any appropriate water quality standards, i.e. should be less than the standard.

The main difficulty in defining an analytical suite will probably arise from poor information from the applicant and/or changes in the type of substance over the period of the authorisation (most applicants will not have the technical expertise to be able to provide the appropriate information on the composition of the waste). The following approaches should be adopted:

- request that the applicant provide details of:
    - chemical information from packaging;
    - range of substances that may be used;
    - chemical and or formulation/product name and supplier;
    - details of any dilution prior to disposal.
- consult laboratory, check chemical data bases, consult specialist within the Agency.

If it is not possible to identify particular compounds, then an initial screening suite should be undertaken and use this to define a more targeted suite. Analysis should also be undertaken by an accredited laboratory using accredited techniques.

A balance will need to be made between the cost of analysis and ensuring that the waste is characterised and appropriate sampling of groundwater can be undertaken. Table B1 provides an indication of the cost of typical analytical suites.

**Table B1 – Analytical Costs - (for indicative purposes only)**

| Analytical Suite | Method of Analysis | Limit of Detection ì g/l | Approximate Cost Per Sample £ |
|---|---|---|---|
| Synthetic pyrethroids | GC-ECD | 0.05-0.1 | ~35 |
| Organophosphorus compounds | GC-FPD/GC-MS | 0.1 | ~35 |
| Pesticides | GC-ECD/<br>GC-MS-MS | 0.01-0.1 | ~35 |
| Acid herbicides | GC-MS | 0.1-200 | ~35 |
| Volatile organics | GC-MS | 1-25 | 27-33 |
| Semi-volatile organics | GC-MS | 1 | 55-85 |
| Metals | ICP-OES | 4-20 | 1-2 |

NB These costs are indicative only and may vary according to the analytical technique and level of detection specified.

For specific activities such as disposal of sheep dip, then the chemical analysis should be either for organophosphorus compounds or for synthetic pyrethroids (including breakdown products). For the disposal of waste pesticides, the analysis could be based on the chemical packaging information of pesticides used or laboratory pesticide analysis (a hierarchy of pesticide analysis may need to be developed). It should be noted that the type of pesticide may change, such that a broader analysis may be more appropriate.

From the above discussion, specific guidelines cannot be provided in terms of an analytical suite (see Note 1). However the following approach should be adopted as a minimum:

- identify specific contaminants or contaminant groups (e.g. organophosphorus pesticides);
- identify potential breakdown products (consult Environmental Chemistry);
- identify appropriate analytical technique and level of detection (liaise with laboratory).

In addition consideration should be given to monitoring of ‘non-active’ compounds within the waste as these may be provide early warning indicators when monitoring or may be cheaper and easier to measure in the laboratory.

In addition the following are recommended (particularly where monitoring is undertaken by the Environment Agency as part of defensive or strategic monitoring):

- field measurement of pH, dissolved oxygen, redox, and electrical conductivity (to define geochemical environment);
- calcium, magnesium, sodium, potassium, chloride, sulphate, bicarbonate (to define major ion chemistry of groundwater);

- iron, manganese, nitrate and sulphate (as indicators of anaerobic degradation);
- total organic carbon, chemical oxygen demand, ammoniacal-nitrogen (as indicators of possible organic contamination).

*Note 1: Information should be collated on contaminants (and breakdown products) associated with different activities as this may allow a prioritised table of analytical suites to be drawn up.*

*Note 2: For some disposals, for example, waste sheep dip, the product formulation may present particular difficulties with respect to analysis, due to the inclusion of solvents (most sheep dip formulations are emulsions) and other additives. These substances may not themselves be active ingredients but may influence the physicochemical characteristics of the active components and complicate the sampling, analytical and assessment procedures. Wherever possible, samples or details of the original product and details of any dilution or treatment of the waste prior to disposal should be provided to the analytical laboratory.*

**Sampling Frequency**

Most activities involve periodic discharges (surface water runoff to soakaways after rainfall events), or applications to land related to land spreading, such that it is unlikely that the sampling exercise can coincide with the discharge or application. The potential implication is that the impact on groundwater from the discharge may not be identified, particularly in rapid flow systems. The alternative is to use passive samples (charcoal bags, moss bags) in the borehole column or spring discharge, although this will only be applicable for some substances (additional work will also be necessary to develop and test a protocol for such monitoring), Atkinson (1980), BGS (1998). These have the advantage that single pollution events could be detected, although would not provide a direct measure of contaminant concentrations and only approximate timing (since the passive samples were last installed) for the contamination. In addition, the passive sampler could be subject to interference and for observation boreholes, would be dependent on flow through the borehole.

The frequency of monitoring should be related to the groundwater flow regime and an estimate of the rate of groundwater flow in the context of how far would any contamination spread between sampling events. The rate of groundwater flow can be estimated using the following equation:

Rate of groundwater flow ($v$) = $Ki/n$

*Where*

$K$ = hydraulic conductivity (m/d)

$i$ = hydraulic gradient

$n$ = effective porosity

For the majority of sites this information may not be available, and will need to be estimated based on experience. For some aquifers the aquifer properties manual and hydrogeological maps may provide some useful background information. In Table B2, travel times have been calculated for a range of aquifer properties to provide an indication of rates of groundwater flow.

**Table B2 – Estimate of Rates of Groundwater Flow (for indicative purposes only)**

| Hydraulic Conductivity (m/d) | Hydraulic Gradient (m/m) | Effective Porosity (-) | Approx Range of Groundwater Flow Velocity (m/year) | Example |
|---|---|---|---|---|
| 1 to 10 | 0.005 | 0.2 to 0.3 | 6 to 90 | Sand (intergranular flow) |
| 10 to 100 | 0.005 | 0.2 to 0.3 | 60 to 900 | Sand and gravel (intergranular flow) |
| 0.5 to 2 | 0.005 | 0.1 to 0.15 | 6 to 70 | Sandstone (intergranular flow) |
| 1 to 100 | 0.005 | 0.01 to 0.02 | 90 to 18000 | Limestone (fissure flow) |

The frequency of monitoring should then be determined based on how far a contaminant may migrate and should be discussed with a hydrogeologist. As a guide where the rate of contaminant migration is less than 10 m/year then a low monitoring frequency (every 1 to 2 years) would be acceptable, whereas if migration rates are greater than 100 m/year, then a higher frequency (greater than twice a year) should be adopted. The rate of groundwater flow should also be taken into account in determining the location of groundwater monitoring points; for low rates of groundwater flow it is important that the monitoring borehole should be located close to the point of disposal.

The above calculations make no allowance for retardation of contaminants due to interaction with the aquifer matrix. The significance of retardation will mainly depend on the contaminant properties. The rate of contaminant migration can be estimated using the following equation:

Rate of contaminant migration (u) = $v/(1 + K_d\rho/n)$

*Where*

$v$ = *groundwater flow velocity (m/d)*

$K_d$ = partition coefficient (ml/g or l/kg)

$\rho$ = bulk density

n = effective porosity (fraction)

The proposed minimum frequency of monitoring is as follows:

| Aquifer type | Minimum frequency of monitoring | |
|---|---|---|
| | First year of disposal | Subsequent years |
| Intergranular | Twice yearly | Every 2 years |
| Fissured | Quarterly | Twice yearly |

Note (1) If contamination is identified then a repeat sample(s) should be obtained.

Note(2) For soakaways the minimum frequency of monitoring should be doubled (i.e. quarterly for the first year of disposal to intergranular aquifers).

The higher frequency of monitoring during the first year of disposal is intended to better define background conditions and provide additional confirmation that there is no impact on groundwater from the disposal.

If evidence of significant contamination is identified from groundwater sampling, the frequency of monitoring may need to be increased (see Section 4.6).

As far as practical, water samples should be obtained within one month of discharge or spreading (typically late Spring and early Autumn for Sheep Dip).

Further guidance on the design of monitoring schemes and procedures for water sampling are given in ASTM (1990), Environment Agency (2001a), Nielsen (1991), ISO(2001).

# Appendix C
# List I and List II Substances

2 Pages

## Appendix C: Definition of List I and II Substances as given in the Annex of the Groundwater Directive 80/68/EEC.

### List I of Families and Groups of Substances

List I contains the individual substances which belong to the families and groups of substances enumerated below, with the exception of those which are considered inappropriate to List I on the basis of low risk of toxicity, persistence and bioaccumulation.

Such substances which with regard to toxicity, persistence and bioaccumulation are appropriate to List II are to be classed in List II.

1. Organohalogen compounds and substances which may form such compounds in the aquatic environment.
2. Organophosphorus compounds.
3. Organotin compounds.
4. Substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment(1).
5. Mercury and its compounds.
6. Cadmium and its compounds.
7. Mineral oils and hydrocarbons.
8. Cyanides.

### List II of Families and Groups of Substances

List II contains the individual substances and the categories of substances belonging to the families and groups of substances listed below which could have a harmful effect on groundwater.

1. The following metalloids and metals and their compounds:
    1. Zinc
    2. Copper
    3. Nickel
    4. Chrome
    5. Lead
    6. Selenium
    7. Arsenic
    8. Antimony
    9. Molybdenum
    10. Titanium
    11. Tin
    12. Barium
    13. Beryllium
    14. Boron
    15. Uranium
    16. Vanadium
    17. Cobalt
    18. Thallium
    19. Tellurium
    20. Silver
2. Biocides and their derivatives not appearing in List I.
3. Substances which have a deleterious effect on the taste and/or odour of groundwater, and compounds liable to cause the formation of such substances in such water and to render it unfit for human consumption.
4. Toxic or persistent organic compounds of silicon, and substances which may cause the formation of such compounds in water, excluding those which are biologically harmless or are rapidly converted in water into harmless substances.
5. Inorganic compounds of phosphorus and elemental phosphorus.
6. Fluorides.
7. Ammonia and nitrites.

Note: (1) Where certain substances in List II are carcinogenic, mutagenic or teratogenic they are included in category 4 of List 1.