Guidelines and Protocols for Investigations to Assess Site Specific Groundwater Vulnerability

British Geological Survey

R&D Technical Report P308

Guidelines and Protocols for Investigations to Assess Site Specific Groundwater Vulnerability

nd, B A Klinck, N S Robins,
M E Stuart and E J Whitehead

Research Contractor:
British Geological Survey

Environment Agency

R&D Technical Report P308

Publishing Organisation
Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol BS32 4UD

Tel: 01454 624400 Fax: 01454 624409

ISBN 1 85705 146 7

This report summarises the findings of work carried out towards the implementation of the Groundwater Regulations 1998. The information within this document is for use by Environment Agency staff and others involved in the management of activities that could pose a threat to groundwater quality from List I or List II substances.

This document was produced under R&D Project P2-142 by:

’s Project Manager
The Environment Agency’s Project Manager for R&D Project P2-142 was:
– National Groundwater & Contaminated Land Centre

CONTENTS

INTRODUCTION TO GUIDELINES AND PROTOCOL

The Groundwater Regulations 1998, which became fully active on 1 April 1999, respond to the requirements of the EC Directive on the Protection of Groundwater against Certain Dangerous Substances (80/68/EEC). The Regulations require that activities are controlled to prevent the entry of List I substances into groundwater, and to minimise the entry of List II substances in order to prevent pollution of the receiving groundwater. In the case of deliberate or discharge onto or into land of materials containing List I or List II substances, an authorisation is required. List I and II substances are shown in Table 1.1.

Summary of the substances controlled under the Groundwater

- Organohalogen compounds and substances which may form such compounds in the aqua environment
- Organophosphorus compounds
- Organotin compounds
- Substances which possess carcinogenic, mutagenic or teratogenic properties in or via t aquatic environment
- Mercury and its compounds
- Cadmium and its compounds
- Mineral oils and hydrocarbons
- Cyanides

List II

- The following metals and metalloids and their compounds:

Antimony	Chromium	Nickel	Tin
Arsenic	Cobalt	Selenium	Titanium
Barium	Copper	Silver	Uranium
Beryllium	Lead	Tellurium	Vanadium
Boron	Molybdenum	Thallium	Zinc

- Biocides and their derivatives not appearing in List I
- Substances which have a deleterious effect on the taste or odour of groundwater, a compounds liable to cause the formation of such substances in water and to render it unfit for human consumption
- Toxic or persistent organic compounds of silicon, and substances which cause the formati of such compounds in water, excluding those which are biologically harmless or which are erted in water into harmless substances
- Inorganic compounds of phosphorus and elemental phosphorus
- Fluorides
- Ammonia and nitrites

Groundwater is an important and finite resource, and like all other controlled waters must be protected from pollution. To this end the 'Policy and Practice for the Protection of ' was published by the former National Rivers Authority, and has updated and reissued by the Environment Agency (Environment Agency, 1998). The Groundwater Regulations 1998 augment a formal system for the control of discharges of List I and List II substances to groundwater. No List I substances are allowe groundwater, whereas low concentrations of List II substances may be tolerated provided that pollution of the groundwater does not occur. The Regulations supplement existing powers under the Environmental Protection Act 1990 and the W

Authorisation for the disposal or discharge of List I and II substances can only be granted 'prior investigation' which demonstrates that List I substances will not enter groundwater, and List II substances will not cause pollution of groundwater.

Concept of Groundwater Vulnerability

Groundwater vulnerability (to contamination) is the likelihood of contaminants reaching the water table after introduction at some point at the ground surface. In the current terminology of risk assessment, a receptor is only at risk if there exists both a hazard (e.g. a pollutant) and a pathway by which that hazard might be transmitted to the receptor (groundwater). Groundwater vulnerability is a measure of the significance of a pathway context of the Groundwater Regulations, discharge of one or more List I or List II substances constitutes a hazard, whilst the underlying groundwater constitutes the receptor. The investigation addresses the pathway in order to evalu watertable, and what form and concentration they will be in. It therefore concentrates on an understanding of the processes that may take place in the soil and the unsaturated zone of the

ability is a function of the intrinsic properties of the overlying soil and the unsaturated zone of the aquifer, with the risk of groundwater pollution dependent on the interaction of groundwater vulnerability (hydrogeology) and the contaminant properties (contaminant physico-chemistry). The Environment Agency (EA 1998) take this forward to define groundwater vulnerability as a function of:

-
- the presence and nature of any overlying superficial or glacial deposits;
- the nature of the geological strata forming the aquifer;
- the thickness of the unsaturated zone or thickness of confining beds.

However, predicting the movement and fate of a pollutant arriving at the ground surface is difficult and complex. A pesticide sprayed in dilute aqueous form onto agricultural land may be broken down into harmless compounds by biological activity in the soil quite quickly. Disposal of the same pesticide in concentrated form to landfill may result in relatively rapid

penetration into an aquifer without any significant degradation.

The thickness of the unsaturated zone and the potential it offers for pollutant attenuation by physical, chemical or biological processes makes it the key to resolving site-specific ssues. In the absence of fractures and other potential by-pass features, unsaturated flow is normally slow and intergranular in a chemically aerobic and usually neutral or alkaline environment. There is considerable potential for:

- and elimination of pathogenic bacteria and viruses;
- attenuation of heavy metals, and other inorganic chemicals, through precipitation, sorption or cation exchange;
- sorption of many, and biodegradation of some, natural and synthetic organic compounds.

However, the ability of the unsaturated zone to attenuate pollutants is difficult to predict and it

-
- the physico-chemical nature of the substances released, and;
- the biochemical environment, physical properties and thickness of the unsaturated zone.

In effect, persistent and mobile substances are only delayed on their transit to the water table whereas attenuation of less persistent compounds is enhanced the greater the unsaturated zone thickness. These same effects are most active in the soil zone greatest. However, where the waste is discharged below the soil zone (to soakaway or

A phased approach to evaluating groundwater vulnerability has been adopted for t unsaturated zone. An assessment is made at the end of each phase; the application for authorisation under the Groundwater Regulations 1998 will be given or refused a consent where a clear result is obtained at the end of the first phase. This to be made on the discharges with least risk but supported by a limited amount of data, whilst increasingly complex decisions are supported with an increased amount of site investigation

be dealt with at Phase 1 of the assessment protocol, while more complex applications for the disposal of List I/II substances are essentially supported by more intensive investigations detailed in Phases 2a and 2b. In this way it is intended to ensure that the data collection exercise is in proportion to the potential risk that the proposal represents.

The conclusion for any application may result in one of three options:

- acceptance of the proposal to discharge where there is no perceived risk;
- outright refusal of the proposal to discharge where the there is a clear unacceptable risk;
- referral of the proposal to discharge for consideration at Phase 2 in all other cases.

Phase 1a assessment requires only the information on the application form, and the scale Groundwater Vulnerability Maps. It is anticipated that the majority of applications would be dealt with at Phase 1 level. In some cases a rapid supplementary assessment based on desk access to basic information on topography, land use, lan can be made. The approach has been designed in anticipation of GIS type data storage and handling facility being available for use throughout the Environment Agency in due course. In th manual gathering of relevant information. The source-pathway-receptor methodology is used and applications will be given consent where either there is no receptor (groundwater) or surface water or no pathway to surface water can be y and a receptor can be defined for surface water the application is refused. Where an aquifer is present the application passes to Phase

In Phase 1b the groundwater vulnerability is assessed using relevant information from soil and , and borehole records. Where there is no Major or Minor Aquifer present the application can be accepted. Where an aquifer is present but there is insufficient clay cover the application may be refused or additional investigations undertaken to quantify b attenuating properties of the soil and unsaturated zone. Other cases would be referred to Phase 2. Applications in more sensitive locations or involving a significant loading of List I substances are also considered to require assessment at Phase

Phase 2 is subdivided into consideration of attenuation in the soil (Phase 2a) and the unsaturated zone beneath the soil layer (Phase 2b). The properties of the contaminant, the method of disposal and the properties of the subsurface are all taken int contaminant transport model is used to calculate the concentration of contaminants leaving the base of the soil (Phase 2a) or the unsaturated zone (Phase 2b). These are termed the modelled s are then compared to criteria specified by the EA. It is necessary to provide a safety margin which allows for the uncertainties in the assessment

These phases are based on the application of models such as the CONSIM model to determine ature and loading of material likely to arrive at the water table. Such models assume that discharge is maintained at a level at which the unsaturated zone remains unsaturated. Data inadequacy is covered by a range of literature values, so that model res comprise ranges rather than single values. It is assumed that an application at this level would involve an expert to prepare the technical simulation or that it would be carried out by experts protocol describes the mechanics of the Phase 2 evaluation and the ranges of values for specific materials which may result in acceptance,

Where the modelled concentration at the base of the unsaturated zone does not meet the criteria following modelling of both the soil and unsaturated zones, then the application will not be accepted unless the applicant can demonstrate to the satisfaction Agency using site-specific data for soils, the aquifer and the contaminant that disposal would

not produce unacceptable concentrations at the water table. This would require collecting primary data using standard methodologies such as those prescribed by the BSI and applying these to the model. It is probable that this would involve invasive site investigation.

Where the modelled concentration is still unacceptable consideration of the effect of dilution y be taken into account for List II substances but is not relevant in respect of List I substances.

Phased approach for assessing site-specific vulnerability

2. GUIDELINES AND PROTOCOL

2.1 Phase 1

Phase 1 is intended principally to evaluate the land disposal of agricultural fluids. Phase 1a evaluates the hazard to surface water and considers disposal to areas classed as being on a Non-Aquifer by the Groundwater Vulnerability maps. Disposal over Major or Minor Aquifers , where aquifer type and protection by clay cover are evaluated. Disposal of agricultural fluids, be they spent sheep dip, farm slurry or unwanted pesticide, is also subject to recommendations within the exiting Codes of Practice for disposal of al materials with particular regard to dilution. Disposal to soakaway and of all other materials is referred to Phase 2 for consideration of additional information.

Phase 1a assessment using application form and vulnerability map

be made using two information sources only: the application form, and the groundwater vulnerability map. It enables a three-way decision to be made as follows

application approved either because there is no receptor (surface or ndwater) or no pathway to the receptor (surface water only);
application refused because there is a clear risk to surface water

Figure 2-1Figure 2-2

or application referral for further scrutiny in Phase 1b (aquifer present).

The Phase 1a assessment process works via a tick list/flowchart for which acceptance criteria are identified in Table 2.1. The tick list is shown in Figure 2.1. This information will be largely supplied by the applicant, although groundwater vulnerability and proximity to sily supplied by the Environment Agency.

If the groundwater vulnerability map indicates that an aquifer is present then this must be assessed in Phase 1b, even where a Major Aquifer with no clay cover is indicated, since there he groundwater vulnerability map alone could be misleading. If an area of Non-Aquifer is indicated then the site must be at least 200 m from the mapped boundary. This is both to ensure that sites on the feather edges of Non-Aquifers overlying a inor Aquifer have at least 5 m of impermeable cover and to allow for boundary uncertainty arising from scaling errors in information used to compile the vulnerability maps. If this is not the case referral to Phase 1b is appropriate.

tion not available from the application form the assessment process can be supplemented by additional information available to the EA. This is presently available from a variety of diverse sources but a logical development would be to bring these sources within a GIS so that they can be interrogated collectively. Suggested additional data relevant

2) Topographic maps
3) Field drain register
5) Run-off data

Some of these data may also be carried forward to any Phase 2 assessment.

8

Table 2.1 Phase 1a criteria for disposal to land

Aquifer vulnerability	All area designated Non-Aquifer more than 200 m from the area	Areas of Major and Minor Aquifer Areas of Non-Aquifer less than m from an aquifer boundary (to	
Substance to be disposed	Some List II substances conditional on dilution and prevailing conditions Grassland and stubble conditional on there being no animal access for a period of one month	All List I substances (to Phase 2) Other List II (to Phase 2)	Set-aside, conservation and
Surface water courses and			<10 m distant; areas liable to
Groundwater sources (springs, wells and	>50 m distant; but >500 m d source used for drinking water supply		<50 m distant; but <500 m distant if source used for drinking water supply

Topography	<1 in 5	>1 in 5; or undulating areas where ponding of disposal fluid
Ground conditions	Well vegetated and na	Bare or compacted soil; sparsely vegetated; surface baked hard, frozen or waterlogged.

R&D Technical Report P308	**Acceptable**	**Referral**	**Not acceptable**
9 **Information type**			
Soil type*	Loamy, peaty		Gravel, sand, loamy sand
Soil drainage	Free or moderate		Poor
Soil thickness	>0.6 m		<0.6 m
Field drains	Absent; drainage pipes covered by >0.6 m of loamy or peaty soil		Areas of ridge and furrow; areas with shallow stone drains or shallow drains with permeable backfill; also land recently mole drained or subsoile
	>0.2 ha per 4 000 l of discharge at prescribed dilution ie < 20 m		
Previous disposal	Land not used in the previous 4 weeks for disposal		

where insufficient data are supplied to identify criteria the application is automatically re

*soil pH should lie in the range 5.0 to 7.5, but not all applicants will be able to provide this information

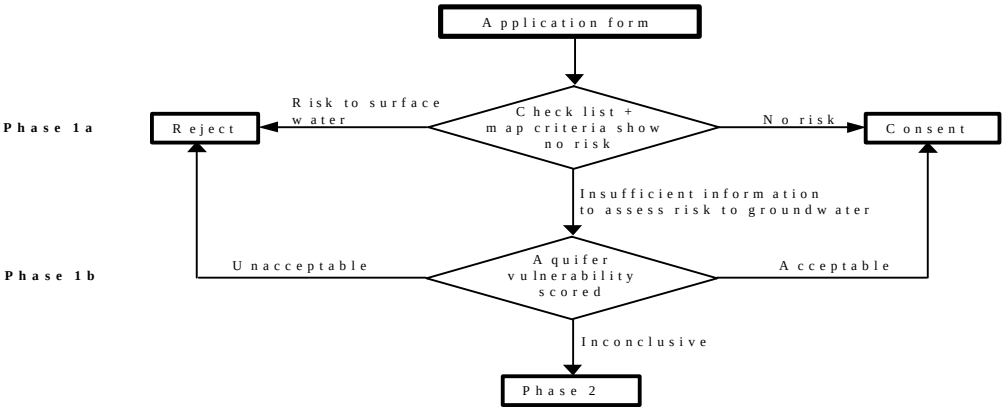

Figure 2.1 Flowchart for Phase 1 assessment

Phase 1b assessment of groundwater vulnerability

Applicants are referred to Phase 1b where there is insufficient information to assess the risk to groundwater. This could be due to a lack of information on the nature and thickness of the drift cover over the aquifer or uncertainty in cases where the site is on a Non-Aquifer but is close to the boundary of an aquifer (due to the coarse scale of the information used to construct the vulnerability map in some areas). For these latter cases information from the geological map and BGS well records can be used to ascertain whether an aq
Where there is no aquifer the application can be accepted without further vulnerability

The following methodology is suggested for assessing vulnerability information. The information is collated into an additive scoring system which is shown in Table 2.2. This assesses the information on the following basis: a) Major or Minor Aquifer type; b) fissured or flow system; c) thickness and nature of drift cover.

The groundwater vulnerability map defines whether
as Major, Minor or Non-Aquifer in the area being assessed in the geological classification notes, but it is important to understand how sequential systems are classified. Reference to

the geological map will provide information on what strata are present.

AQUIFER VULNERABILITY MAP

		➟
Minor Aquifer	go to Phase 1b	➟
Non-Aquifer (< 200 m from boundary)		➟
Non-Aquifer (> 200 m from boundary)	☺	x

SUBSTANCE TO BE DISPOSED

List I	go to Phase 2	➟
List II	☺	x

LAND USE

Fallow land, set-aside	rejection	☹
Conservation and amenity land	rejection	☹
Grassland and stubble	☺	x

SURFACE WATERS

<10 m distant or liable to flooding		☹
>10 m distant	☺	x

GROUNDWATER SOURCES

<50 m distant, but		
<500 m distant if used for drinking water		☹
>50 m distant, or		
>500 m if source used for drinking water	☺	x

TOPOGRAPHY AND SLOPE

Slope > 1: 5, or undulating land		☹
Slope < 1: 5	☺	x

Figure 2.2 Phase 1a prior investigation tick list

GROUND SURFACE CONDITIONS		
Bare and compacted soil, hard baked, frozen or waterlogged		☹
Well vegetated and naturally drained soil	☺	x
SOIL DRAINAGE		
Gravel, sand, loamy sand	rejection	☹
Free or moderately free	☺	x
SOIL THICKNESS		
<0.6 m	rejection	☹
> 0.6 m	☺	x
PRESENCE OF FIELD DRAINS		
ridge and furrow, shallow stone drains, permeable backfill drains and land recently mole drained or subsoiled		☹
no field drains or pipes covered by 0.6 m loamy or peaty soil	☺	x
LAND AREA AVAILABLE FOR DISPOSAL		
in accordance with codes of practice	☺	x
PREVIOUS DISPOSAL		
not less than 4 months previously	☺	x

Table 2.2 Scoring system for Phase 1b groundwater vulnerability

1) One category from each row is selected. For a score of 6 up to 9, the site is acceptable for disposal of farm derived substances at prescribed intervals and dilution; for a score 3 or less the site is not acceptable; for a score of 4 or 5 the

2) Where scores are obtained from Table 2.3 these give a combined score for aquifer type and

- It is also valuable to know whether the aquifer transmits water through its pore anular aquifer) or whether it principally transmits water through cracks and joints (fractured aquifer). Reference to the hydrogeological map (where available) will provide this information, otherwise the generic listing in Table 6.3 will assist.

the groundwater vulnerability maps show by means of a stipple where it is believed that >5 m thickness of clayey till is present, reference to more detailed information will often be useful in areas that are peripheral to the stippled zone o
is some doubt as to the integrity of the till, e.g. has the till been locally removed by engineering work, could the till be largely sandy in this particular area? Inspection of the BGS 1: 50 000

and integrity of the drift. The borehole database may also provide a local description

- The scoring system is designed to enable a three-

to identify all areas of Major and Minor Aquifer outcrop where clay cover is considered insufficient to attenuate contaminants and to reject the application

of less vulnerable aquifers where clay cover exceeds10 m in thickness and to accept these without further assessment;

to refer all other cases to Phase 2 for more detailed assessment, including those where there is insufficient information to enable a d

Table 2.3 Nature of principal aquifers in England and Wales and appropriate

MAJOR AQUIFERS (highly permeable)
river gravels (Middle Thames valley)
Upper Greensand (except east of Hog's Back)
Lower Greensand (undifferentiated and Folkestone and Hythe Beds)
Corallian/Brantingham Formation (Yorkshire) and Osmington Oolite
Cornbrash Formation (if in hydraulic cont
Forest Marble and Great Oolite limestones (south of Oxford)
Inferior Oolite/Lincolnshire Limestone
Upper Lias (Cotteswold, Midford, Yeovil sands)
Permian Sandstones (including Dawlish Sandstone, Collyhurst Sandstone, Bridgnorth Sandstone, St Bees Sandstone, Penrith Sandstone)
Upper Magnesian Limestone/Brotherton and Seaham
Middle Magnesian Limestone/Ford Formation
Lower Magnesian Limestone/Cadeby and Raisby Formations
Carboniferous Limestone (except in Northern England)
MINOR AQUIFERS (variably permeable)
Crag (Norwich, Red and Coralline Crags)
d Oldhaven beds/Harwich Formation
Woolwich Formation and Reading Formation/Lambeth Group
Upper Greensand (east of Hog's back)

Sandgate Beds	intergranular	3

Aquifer	Type	Score
MINOR AQUIFERS continued		
Weald Clay (sandstones and limestones)		
Tunbridge Wells Sands		
Wealden Beds (sands)		
Wadhurst Clay Formation (sands)		
Ashdown Beds (except clay)		
Corallian Group (except Yorkshire and Osmington Oolite)		
West Walton Formation (limestone)		
Kellaways Sand/Osgodby Formation		
Cornbrash Formation		
Blisworth Limestone		
Glentham Formation (limestones)		
Fuller's Earth Rock		
Upper Lias (Yeovil/Bridport Sands)		
Marlstone Rock Formation		
Lower Lias (limestones)		
White Lias/Langport Member		
Sandstones in Mercia Mudstone Group		
ermian breccias and conglomerates (south-west England)		
Basal Permian Sands		
Coal Measures (including Barren Measures)		
Carboniferous Limestone (limestones in northern England, Yoredales, Limestone Shales)		
Devonian sandstones		
Silurian limestones		

Whilst it is anticipated that a decision on many lower risk applicat
applications will need to be referred to Phase 2 for a more detailed assessment where:

- the disposal site has been identified in Phase 1b as situated over a Major or Minor Aquifer with potentially inadequate drift cover

- uate data were available to make an assessment at Phase 1;

In addition the proposal will automatically be referred to Phase 2 where:

- the disposal substance is List I;

- a method other than land spreading is planned (for example soakaway drainage).

The Phase 2 assessment requires quantification of the transport processes operating between the discharge point and receiving water table. It is assumed that an application directly at this level would be sufficiently significant to involve a contracted expert
simulation or that it would be carried out by experts in the employment of the applicant. The onus is on the applicant to demonstrate, through the use of appropriate quantitative methods,

Phase 2 is subdivided into consideration of attenuation in the soil (Phase 2a) and the unsaturated zone beneath the soil layer (Phase 2b), where the properties of the contaminant, isposal and the properties of the subsurface are all taken into account. A flow

A suitable contaminant transport model, such as ConSim, is used to calculate the concentration of contaminants leaving the base of the soil (‘modelled concentrations’ in this report. This calculated impact is then compared to criteria specified by the EA. It assumes that discharge is maintained at a level at which the unsaturate

The ConSim model data requirements for an assessment of leaching through the unsaturated zone from an area of contaminated soil are shown in Table 2.4.

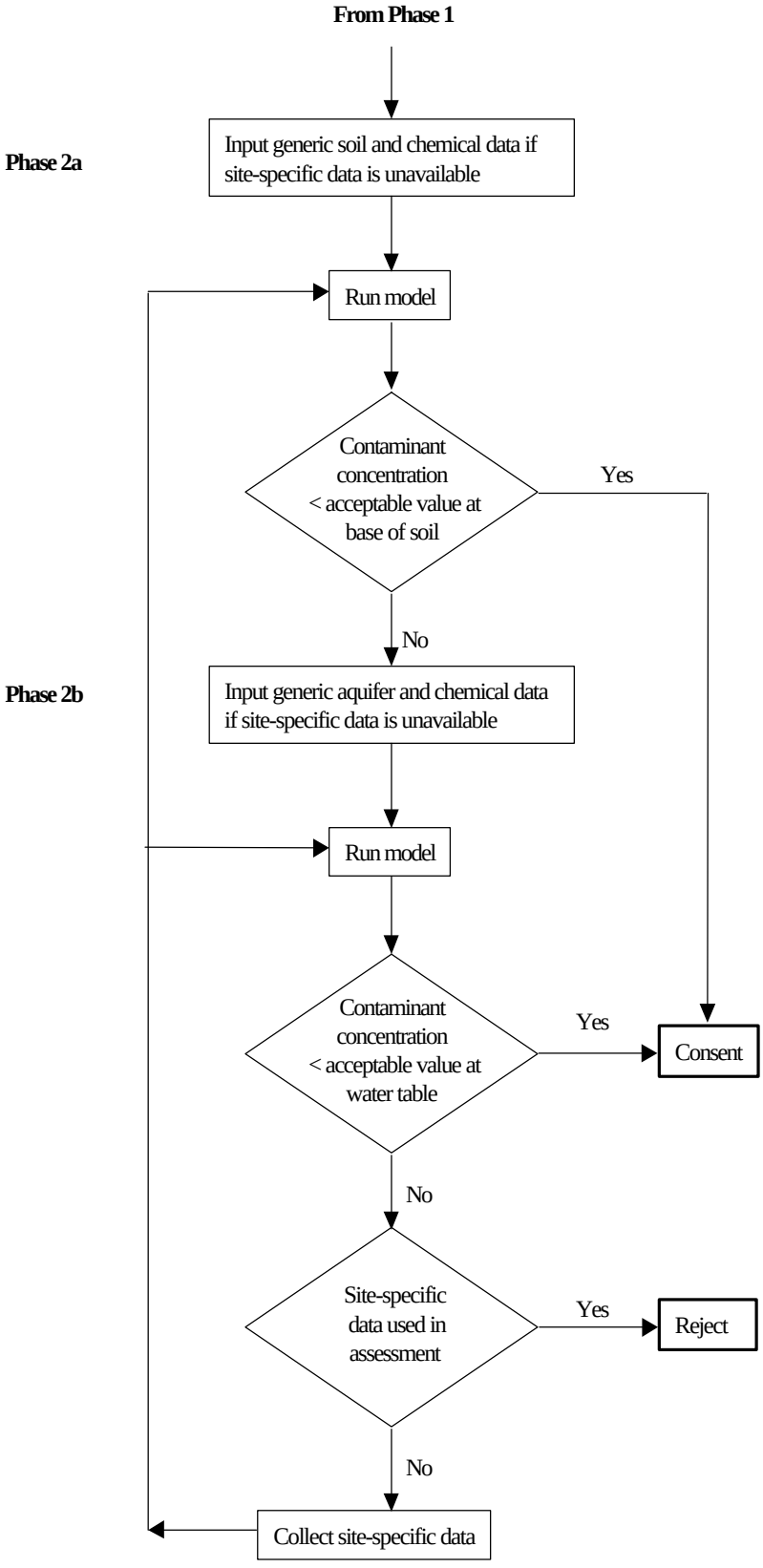

Figure 2.3 Flow chart for Phase 2 assessment

Table 2.4 ConSim model data requirements for leaching from soil

	Hydrophobic sorption coefficient K
	Contaminant concentration, Area of application, Infiltration rate to unsaturated zone, Soil thickness
	Effective porosity, Fissure porosity, Hydraulic conductivity, Dry bulk density

Since data inadequacy is covered by a range of model default val
model results will inevitably comprise ranges rather than hard and fast values.
to take into account this element of uncertainty in any assessment and one way to build in a 'acceptable concentration' at a value less than the permitted concentration. That is if the modelled concentration is lower than the acceptable concentration for either phase the application can be passed. It is appropriate for different criteria to apply st 1 and List II compounds. For List I compounds the EC Directive requirement is zero and we suggest the detection limit should be used as the permitted concentration. We also suggest that for List 1 compounds the acceptable concentration should be two or magnitude less than the permitted concentration. For List II one order of magnitude less may

Where the soil is of a fissured clay type, attenuation in the soil zone cannot be assumed.

criteria following modelling both the soil and unsaturated zones, then the application will not

It is assumed that an application at this level would involve an expert to prepare the technical

The applicant must satisfy the Environment Agency that the following issues have been

exceed the infiltration capacity of the soil and the application rate will

erical models consistent with the conceptual models developed in the Phase 1 evaluation

That appropriate data have been used. If default values are being used in place of site specific data an analysis of the impact of this on the model o

The onus is then on the applicant to demonstrate, to the satisfaction of the Environment

Agency using site-specific data for soils, the aquifer and the contaminant that disposal would not produce unacceptable concentrations at the

Modelling with site-specific data

This would require collecting primary data using standard methodologies such as those described in Chapter 4 and applying these to the model. It is probable that this would involve either to collect data for the assessment or as part of a monitoring programme stipulated as part of the consent to discharge.

All applications where site investigation is required should address the following issues:

vestigation in terms of what data will be collected and how these data will fit into the overall assessment

Define the methods that are going to be used. Methodologies should be described or reference made to standards which will be followed.

the site investigation programme which should be detailed are:

sample collection (including methods and frequency)