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FOOTPRINT

Functional Tools for Pesticide Risk Assessment and Management

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Thematic Priority: Policy-orientated research

Deliverable DL8

Characteristics of European soil hydro-chemical scenarios

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Foreword

The present report was prepared within the context of the work package WP2 ('High resolution scenario-based spatial zonation') of the FOOTPRINT project (http://www.eu-footprint.org).

The preferred reference to the present document is as follows:
Hollis J.M., Réal B., Jarvis N.J., Stenemo F. & Reichenbeger S. (2006). Characteristics of European soil hydrochemical scenarios. Report DL8 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 47p.

Executive summary

The principal objectives of the work reported in the present document were to: i) differentiate the European soil population according to those characteristics that determine pesticide fate, especially those that are used to parameterise the pesticide fate models MACRO and PRZM; ii) derive a comprehensive set of unique soil property datasets for this purpose. Four main sources of data have been used: the Soil Geographic Database of Europe v. 1.0, the SPADE-2 database, the Hydrology of Soil Types classification system, and the CORPEN system for identification of pollutant transfer pathways in the field.

Both the MACRO and PRZM models require a wide range of parameters listed under the broad heading of 'soil'. However, most of these are not widely available from measured data and, following extensive use of the models over a number of years, specific sets of algorithms or 'pedo-transfer functions' have been developed and tested in order to derive parameters from basic, widely available soil property data. In summary, a limited set of basic soil property data is required to parameterise the MACRO and PRZM models as follows:

For each soil type:

Soil hydrological type; lower boundary condition; number of soil layers.

For each soil layer:

Sequence number; horizon designation; upper depth (cm); lower depth (cm); clay %; silt %; total sand %; sand content 0.05 – 0.1 mm %; sand content 0.1 – 0.2 mm %; sand content 0.2 – 0.5 mm %; sand content 0.5 - 2 mm %; stones (>2 mm) %; pH; organic carbon content %; bulk density (g cm^{-3}).

The following methodology was used to create a unique set of FOOTPRINT soil classes which represent the entire spectrum of variation in the listed soil parameters within European agriculture:

1. The conceptual models of flow pathways from the HOST and CORPEN systems were amalgamated and a flow chart was created to guide the FOOTPRINT tool user to a specific conceptual hydrological transport model.
2. The HOST system was used to identify the MACRO bottom boundary condition.

3. The combined HOST / CORPEN framework was used to identify the category of 'flow processes' (A – E) required for the groundwater vulnerability method (FOOTPRINT deliverable DL10).
4. A set of 'sorption-degradation kinetics' classes were defined using pedological knowledge derived from the FAO SOIL category name in the SGDBE .
5. HOST, HOST / CORPEN, MACRO bottom boundary, groundwater vulnerability soil flow process categories and sorption-degradation kinetics classes were assigned to each STU (Soil Typological Unit) in the SGDBE 'stu.dbf' file using the soil attributes available in this file.
6. For each STU, the MACRO bottom boundary class, topsoil texture class, subsoil texture class and sorption-degradation kinetics class were combined to create a unique FOOTPRINT soil parameterisation class code. This was restricted to STUs with a dominant or secondary land use in an agricultural category. All other STUs were coded as 'non-agricultural'.
7. All STUs in the SPADE 1 and SPADE-2 databases which had an agricultural land use were allocated an appropriate FOOTPRINT soil parameterisation class code.
8. Using the combined SPADE-1 & 2 datasets, data from all STUs with the same FOOTPRINT soil parameterisation class code were combined to create a single FOOTPRINT soil and land use-specific soil profile property dataset. Any FOOTPRINT soil parameterisation classes without any corresponding data in the SPADE data sets were either allocated to a suitable existing dataset or had a profile property dataset derived using expert judgement based on similar soil profiles.

The methodology resulted in a total of 595 soil profiles required to characterise the complete spectrum of agricultural soils in Europe. It is emphasised that many of these soil types are of limited extent and very few will encompass more than 2 or 3 FOOTPRINT climatic zones (FOOTPRINT deliverable DL9). In addition, most will not carry a full range of agricultural crops and a significant number occur only under managed grassland. The work reported in the present document will directly support the subsequent modelling phase of the project.

1 INTRODUCTION

The overall objective of Work Package 2 is to develop and apply a methodology for defining a large number of generic scenarios that characterise the complete spectrum of European agricultural environments. Each scenario represents a unique combination of those agronomic practices, soil and subsoil hydrological characteristics and climates that determine the fate of agriculturally-applied pesticides within Europe. Within this context, activity WP2.1 focuses on the differentiation of the European soil population according to those characteristics that determine pesticide fate, especially those that are used to parameterise the MACRO and PRZM pesticide fate models.

Soil is a critical environmental component for determining the fate of pesticides applied in agricultural contexts. Soil hydrological characteristics influence the amounts of compound present in soil solutes, the speed at which those solutes are transmitted through or over the soil and the extent to which they interact with the soil matrix. In addition the amounts and types of organic matter and clay minerals in the soil, together with the pH of the soil solution, influence the kinetics of compound sorption and, to a lesser extent, degradation. The pesticide fate models, MACRO and PRZM, attempt to simulate these processes and thus require information on various soil characteristics as input parameters.

Activity WP2.1 of FOOTPRINT has therefore focussed on identifying how the soil properties required to parameterise the FOOTPRINT models MACRO & PRZM vary within Europe and using the only harmonised pan-European data set of soil spatial variability, the Soil Geographical Database of Europe at 1:1,000,000 scale, to develop a set of unique FOOTPRINT soil classes that differentiate soils within Europe according to their critical hydrological and chemical kinetic characteristics.

2 DATA SOURCES

The following data sources were used.

2.1 The Soil Geographic Database of Europe v. 1.0

The European Soil Database (SDBE version 1.0) has been developed over the last two decades through the efforts of the European Soil Bureau Network and its predecessors, co-ordinated since 1990 through the Secretariat of the European Soil Bureau, Institute of Environment and Sustainability, European Commission Joint Research Centre, Ispra, Italy.

It has four main components:

- The 1:1,000,000 Soil Geographic Database of Europe (SGDBE v. 3.2.8.0
- The European Soil Profile Analytical database, SPADE-1 (v 2.1.0.0).
- The European Pedo-Transfer Rules database 2.0.
- The HYPRES pedo-transfer functions v 1.0.

Only those used for this project are described below.

2.1.1 Soil Geographic Database of Europe SGDBE

This database can be used both within ArcView™ (v 3.2, 8.3) and with ArcGIS™ (v 8.2, 8.3). The database is a digital version of the 1:1,000,000 Soil Map of Europe (CEC 1985), which was compiled in the 1970s but considerably updated in the 1990s through the efforts of the European Soil Bureau Network, under institutional funding of the Joint Research Centre. The database has geometric and semantic components, soil information being presented in the form of Soil Map Units (SMUs) with each polygon (geometric or spatial) unit on the map being assigned to a single SMU. Each SMU comprises a number of soil types or Soil Typological Units (STU) which are associated together within the SMU landscape, but cannot be separated spatially at the 1:1,000,000 map scale.

The digital data cover all the Member States (25) of the Enlarged EU, former EFTA nations (Norway & Switzerland), Candidate Countries (Bulgaria, Croatia & Romania), and Neighbouring Countries of the Western Balkans.

Included within the database are four data tables in DBase (.dbf) format:

- SOIL.PAT – Specifies the perimeter length, area, etc. of each polygon.
- SMU – Specifies the area and number of polygons for each SMU.
- STU.ORG – Specifies the code and percentage cover of each STU in each SMU.
- STU – Defines a range of attributes for each STU.

2.1.2 Soil Profile Analytical Database for Europe: SPADE-1

The objective of developing a Soil Profile Analytical Database for Europe (SPADE), Level 1 (version 2.1.0.0) to form an integral component of the European Soil database is to characterise each soil type (STU) defined in the database according to a range of properties that are important for agricultural and environmental interpretation and modelling. The original intention for the SPADE database was to collect representative soil profile data for all the main soil types distinguished on the published Soil Map of Europe. However, because of the large range of data required and the limited financial resources available, it was proposed to develop the database in different stages (levels). The number of soil types to be computerized would vary according to the time available and the funding forthcoming. It was decided to start by compiling data for a few important and extensive soil types (Level 1) and then later follow up with more comprehensive characterisation. SPADE-1 represents the Level 1 database and was compiled using two different formats or ‘Proformas1 (Breuning-Madsen & Jones, 1995):

- Proforma I (estimated data): for capture of profile data recognised as truly representative of specific soil types, but not geo-referenced to any particular location. National experts were requested to provide the data preferably from measurements or, where no measured data existed, estimated data according to the specified format and where data had been determined by analytical methods that could not be harmonised. Some problems of data confidentiality were avoided because the data could be linked to spatial units (map units) only though soil type and not to any particular place.
- Proforma II (measured data): was designed to capture measured data from georeferenced sample points, for which the soil had been examined and analysed. The analytical methods applied are recorded, but not necessarily harmonized between samples. It was accepted that some of these data might not be truly representative of soil types shown on the map and some data might be missing for some parameters.

These two different types of data are held separately and only the former (the estimated data) is intended for use to support modelling, because it was derived specifically to represent the STU components of soil map units (SMU) included in the Soil Geographic Database for Europe.

2.1.3 HYPRES database

The HYPRES database comprises a set of pedo-transfer functions (PTF) for deriving soil hydraulic characteristics from basic soil property data. The functions are derived from measured soil hydraulic properties collected during the HYPRES network project (Wösten *et al* 1998) funded under the European Commission’s FP5 Capability and Mobility (DGXII) programme. Data from 4030 soil horizons were collated, comprising 1136 soil horizons with measured water retention and hydraulic conductivity and 2894 horizons with measured water retention only. The data were analysed statistically to derive two sets of pedo-transfer functions:

- A set of 11 ‘class functions’ related to each of the 5 broad mineral texture classes (e.g. TEXT1, TEXT2) and the organic texture class used in the STU attribute tables in the

SGDBE v. 3.2.8.0. PTFs are derived for both topsoils and subsoils in each mineral texture class but no such distinction is made for the organic texture. For each of the 11 classes, values are given for the Mualem-van Genuchten hydraulic model parameters as well as derived moisture contents and conductivities at 14 pressure heads.

- A set of 'polynomial continuous functions' which derive the Mualem-van Genuchten hydraulic model parameters from basic data on clay%, silt% (0.002 – 0.05 mm), bulk density and organic matter (see van Genuchten & Leij, 1992).

The objective of deriving the two sets of functions is to enable hydraulic characteristics to be derived for STU in the SGDBE either using the broad texture class attributes in the STU data table or using the soil property data available in the SPADE-1 database.

2.2 The SPADE-2 database

The SPADE-2 database was developed to address limitations that were identified when trying to use the SPADE-1 Estimated Profile database for modelling purposes. Although the SPADE-1 database has a total of 447 estimated profile data sets, this is a very small number to represent the 3164 STUs that were represented as covering the 15 Member States that comprised the EU at that time. Further, of the supplied profile datasets, only 132 could be explicitly linked to an STU and each estimated profile only represented a single (normally the dominant) land use and for some countries no specific land use was identified. As a result of these limitations, the European Crop Protection Association (ECPA), supported by the European Soil Bureau of the European Commission Joint Research Centre sponsored the collation of a second profile database (SPADE-2) for use with the SGDBE. The overall objective was to provide sufficient soil property data to support higher tier modelling of pesticide fate at the European level. Its main was to expand the 'estimated' soil profile database to include 'primary soil properties' for all Soil Typological Units in the SGDBE v 3.2.8 and for both the designated dominant and secondary land uses (USE1 and USE2 in the stu.dbf file) for all the EU Member States as of November 2002. Primary Soil Properties are:
Percentage clay, percentage silt, percentage fine sand, percentage medium sand, percentage coarse sand, percentage organic carbon, pH, bulk density.

The database was completed in 2005 and its derivation, harmonisation and validation are described in detail by Hollis *et al* (2006). The harmonised and validated data is supplied as a database file (SPADE_2.dbf) that can be easily used in conjunction with the SGDBE. The data file comprises 1897 soil profiles directly linked to 1077 STU (35% of all STU for the 15 countries) and fully characterising 313 SMUs of the SGDBE. Of the 1897 SPADE-2 profiles included, 1288 have an agricultural land use and the remainder represent a variety of non-agricultural land uses. The number of profiles within the SPADE_2.dbf file is summarised in Table 2.2-1.

Land Use	Total STU (dominant land use)	Total SPADE-2 profiles (dominant & secondary land use)	With an explicit link to an STU
No specified land use	23	8	8
“Agriculture”	0	0	0
Arable	1206	632	632
Grassland	547	483	483
Extensive pasture	114	94	94
Horticulture	15	62	62
Vineyards	15	33	33
Orchards	5	17	17
Industrial Crops	5	5	5
Rice	4	6	6
Cotton	3	0	0
Olives	17	38	38
Vegetables	0	0	0
Poplars		12	12
Non agricultural	1206	601	601
Totals	**3164**	**1897**	**1897**

Table 2.2-1. SPADE-2 Profiles and links to STU on a land use basis.

2.3 The Hydrology of Soil Types (HOST) system

The UK Hydrology of Soil Types (HOST) system was developed as a collaborative project by The Institute of Hydrology (now Centre for Ecology & Hydrology), The Soil Survey & Land Research Centre (now Cranfield University National Soil Resources Institute), the Macaulay Lund Use Research Institute and the Department of Agriculture Northern Ireland. It derived a classification of UK soils that can be applied via soil maps to aid hydrological studies and analyses. The system is based on conceptual models of the hydrological process and pathways within soils and, where appropriate, their substrates

Two groups of properties were used to create a conceptual framework:

- Soil water regime, as indicated by depth to a ‘gleyed’ horizon, depth to a slowly permeable layer & the presence or absence of a ‘raw peaty’ topsoil and soil ‘drainable porosity’, as an indicator of soil storage capacity during the climatic field capacity period and saturated hydraulic conductivity;
- Substrate lithology as it differentiates hydrogeological characteristics such as relative permeability, porosity and susceptibility to by-pass flow.

These properties were used to group soils into a limited number of classes and the hydrological differences between classes were studied using regression analysis against long-term flow data for >800 catchments throughout the UK. The full methodology is described in detail by Boorman *et al*, 1995. The final framework consists of 11 basic conceptual models of soil hydrological pathways, subdivided into 29 classes according to flow and storage characteristics as shown in Figure 2.3-1. Each HOST class is associated with a numerical value for a steam flow index, the two principal ones being the Base Flow Index (BFI) and Standard Percentage Runoff (SPR).

	Slowly permeable layer >100 cm; Gleyed layer > 100 cm	**Gleyed layer at 40 -100 cm, OR gleyed layer at > 100 cm and slowly permeable layer < 100 cm**		**Gleyed layer at < 40 cm**	**Raw peaty topsoil present**
Aquifer substrate. Groundwater At > 2 m Depth	**1**. Weakly consolidated microporous, by-pass flow uncommon (chalk)	**13**. (no hydrogeological subdivision)		**14**. (no hydrogeological subdivision)	**15**. (no hydrogeological subdivision)
	2. Weakly consolidated microporous, by-pass flow uncommon (limestone)				
	3. Weakly consolidated macroporous, by-pass flow very uncommon.				
	4. Strongly consolidated non- or weakly porous, by-pass flow normal				
	5. Unconsolidated macroporous, by-pass flow very uncommon				
	6. Unconsolidated microporous, by-pass flow common.				
Aquifer substrate. Groundwater at ≤ 2 m depth	**7**. Unconsolidated macroporous, by-pass flow very uncommon.			**9**. Mean drainable pore space <12.5 % volume (< 1 m/day)	**12**. Undrained peat
	8. Unconsolidated microporous, by-pass flow common.			**10**. Mean drainable pore space ≥12.5 % volume (≥1 m/day)	
				11. Drained peat	
Non-aquifer. No significant groundwater present		Mean drainable pore space > 7.5 %	Mean drainable pore space ≤ 7.5 %		
	16. Weakly consolidated, slowly permeable	**18**. Weakly consolidated, slowly permeable.	**21**. Weakly consolidated, slowly permeable.	**24**. Weakly consolidated, slowly permeable	**26**. Weakly consolidated, slowly permeable
	17. Strongly consolidated, impermeable	**19** Strongly consolidated, impermeable	**22** Strongly consolidated, impermeable		**27** Strongly consolidated, impermeable
		20. Weakly consolidated, impermeable	**23**. Weakly consolidated, impermeable	**25**. Weakly consolidated, impermeable	
					28. Eroed peat
					29. Blanket peat

Figure 2.3-1. The HOST framework.

Using the percentage distribution of HOST classes within catchments to predict measured stream flow characteristics explains 79% of the variation in the measured BFI, 62% of the variation in SPR and around 60% of the variation in low flow hydrological parameters.

HOST separates soils according to their major flow pathways and routes for solute and associated colloid transport. Such pathways are directly linked to the extent of stream response to rainfall and the relative magnitude of such responses can be quantified through the HOST SPR & BFI indices. This system is now actively used in the UK and forms the basis of the recently revised Flood Estimation Handbook (FEH) methodology (Institute of Hydrology, 1999).

The question for the FOOTPRINT project is whether the HOST system can be usefully extended to the remainder of Europe? Initial assessment suggested that, whereas the conceptual framework is likely to remain valid, UK-derived values for stream flow coefficients are likely to be different although the relative differences between classes should be retained. A potential major problem was identified with permeable, free draining HOST classes (1 to 6 and 16 & 17) and runoff. In such soils, runoff is the dominant ‘rapid transfer route’ and is principally determined by slope and rainfall. In such soils HOST classes are mainly differentiated by substrate hydrogeological type and, within the UK, each class tends to occur in areas with different slope ranges and / or rainfall. In a much larger area such as Europe, which contains regions with distinctively different rainfall patterns and where similar types of substrate can have very different slope ranges in different regions, use of a class based solely on soil and substrate characteristics is unlikely to be as valid. UK HOST classes 1 – 6 and 16 & 17 are thus likely to need refining using additional slope & climate factors. These assessments have recently been supported by the results of Brunner (2006), who made use of the SGDBE to derive HOST classes groupings for all STUs in the database and used the UK HOST BFI coefficients to predict measured BFI values for a range of European catchments.

2.4 The CORPEN system

CORPEN is a diagnostic system designed to be implemented at the farm scale by local experts in consultation with the farmer. There are four basic steps:

1. *Consultation with the farmer to draw up a farm plan and to identify the basic types of soil and geology present.* Soils are described using textural and management terms and the geological background mainly using lithological terms.
2. *Hydrological categorization at the plot scale in the field.* This is carried out in the autumn or winter when there is no soil moisture deficit. This categorization confirms the soil type, its main inherent characteristics that may affect its hydrology and the presence of any discontinuities in permeability. An example of a field soil categorization is given in Table 2.4-1.

Soil type	Silty capping soil	
Soil water holding capacity	180 mm	
Deep soil	Y ✓	N
Stones	Y	N ✓
Drainage	Y	N ✓
Discontinuities in permeability	Y	N ✓
Water saturation in soil surface	Y	N ✓

Table 2.4-1. Example of soil categorisation in the CORPEN system.

The end product of this hydrological categorisation is a set of diagrams illustrating the principal hydrological (and thus pesticide solute transfer) pathways from the field. Two diagrams are presented, one for conditions during the winter (code H for ‘Hiver’) and one for conditions during the spring (coded P for ‘Printemps’). Figure 2.4-1 shows the diagrams for the example soil categorised in Table 2.4-1.

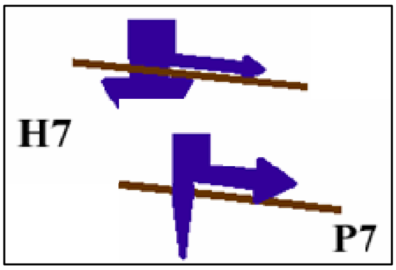

Figure 2.4-1. Illustration of hydrological pathways derived for the silty capping soil described in Table 2.4-1.

In order to formalise the identification of hydrological pathways, a flow chart related to each geological setting and soil type has been developed and an example of this is shown in Figure 2.4-2.

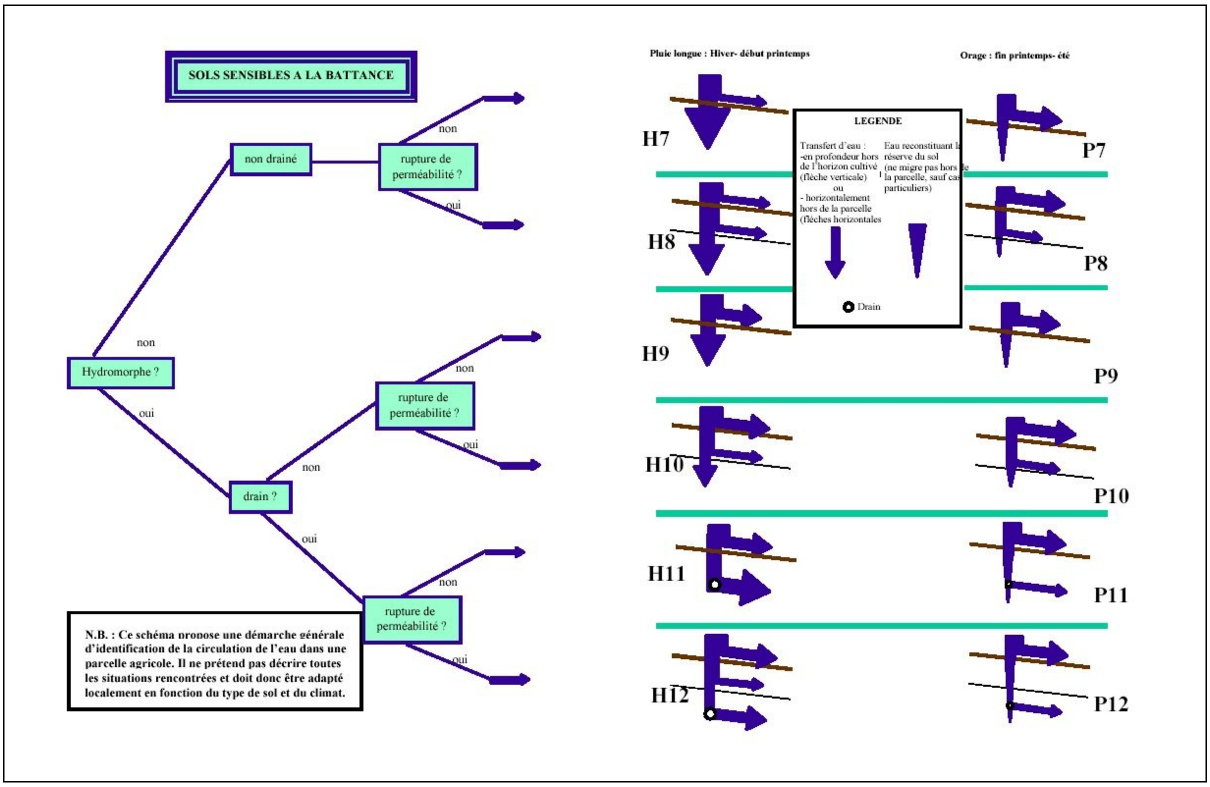

Figure 2.4-2. Flow chart for identifying hydrological pathways in soils susceptible to capping

3. *Categorisation of likely transfers of pesticides to surface or groundwater at the landscape level.* This involves integrating the field level descriptions of hydrological transfer pathways with landscape level information on the proximity to water bodies the presence of significant slopes, the existence of features likely to channel local runoff and the

presence of any buffer zones. An example of a completed CORPEN landscape assessment is shown in Figure 2.4-3.

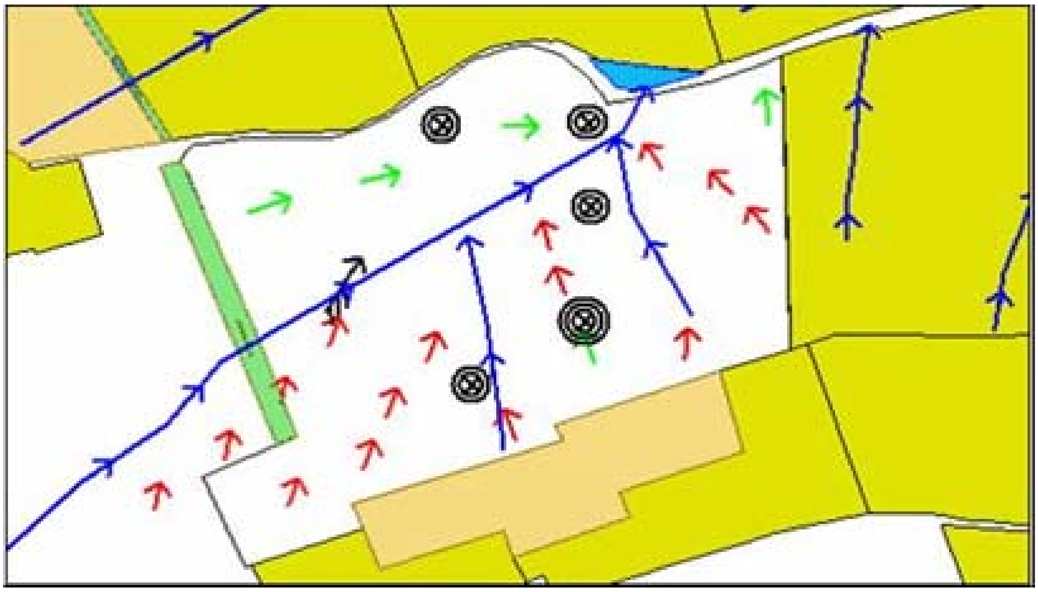

Figure 2.4-3. Example of a CORPEN landscape level assessment of pesticide transfer.

4. *Identification of the proposed solutions to reduce the impact of pesticide transfers, in consultation with the farmer.* The CORPEN system thus represents a whole-farm approach to reducing pesticide transfer, but one that is based on a systematic approach to identifying the main pesticide transfer pathways both within the soil and within the landscape. The soil component of the identification uses similar features and associated conceptual models to those used in the HOST classification.

3 SOIL PROPERTY DATA REQUIRED TO PARAMETERISE THE FOOTPRINT MODELS

3.1 The MACRO model

MACRO is a dual porosity model that uses a complex mechanistic description of water and pesticide solute movement through the micropore and macropre systems. It requires many soil-specific parameters, most of which are derived internally from algorithms applied to basic soil data such as content of different the particle-size fractions present and the organic carbon content and pH of the different soil layers. Nevertheless, MACRO has a set of key soil parameters on which it requires information. These are the bottom boundary condition and, for each soil layer present, soil its structural attributes and hydraulic characteristics.

3.1.1 The bottom boundary condition

MACRO requires information on whether to set the bottom boundary condition to one of the following:

- A unit hydraulic gradient (free draining conditions).
- Zero flow (because of an impermeable layer or saturated conditions).
- Percolation controlled by the water table height (for slowly permeable conditions)

In addition, for the latter bottom boundary condition, it is necessary to know how to scale the BGRAD parameter (Hydraulic gradient at the bottom boundary of the soil profile) to asses its relative magnitude. These characteristics will be derived using the HOST and CORPEN systems which provide specific information on such conditions.

3.1.2 Soil structural attributes

MACRO requires information on the dimensions of soil aggregates to set parameters determining the level of interaction between micropore and macropore domains. A rule-based system for deriving macropore flow parameters from structural characteristics has been developed and this is illustrated in Figures 3.1.2-1 and 3.1.2-2.

The required soil structure characteristics are not available in the SGDBE or in the SPADE-2 database and therefore need to be estimated from the available data. Using a comprehensive database of soil physical properties and structural characteristics supplied by Cranfield University from its Land Information System, *LandIS*, a method for deriving the required structural characteristics is being developed using regression tree analysis that is based on soil texture (sand, silt and clay content), organic carbon content, horizon depth and horizon designation. All these properties are available in the SPADE-1 and SPADE-2 databases.

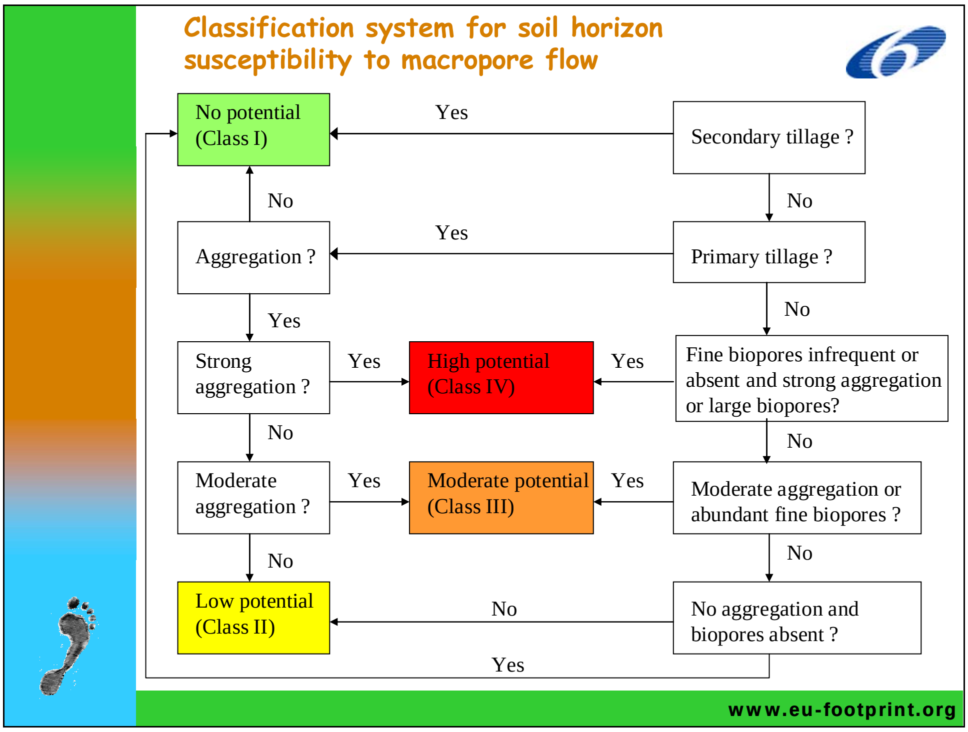

Figure 3.1.2-1. Derivation of classes of susceptibility to macropore flow from soil structural characteristics.

Class	Effective diffusion pathlength (mm)	Kinematic exponent
I	1	5
II	10	4
III	50	3
IV	150	2

Figure 3.1.2-2. Derivation of macropore flow parameters from susceptibility classes.

3.1.3 Soil hydraulic characteristics

MACRO requires data necessary to parameterise the Richardson equation for water flow, based on the van Genuchten – Mualem approach, as well as the saturated hydraulic conductivity of the soil matrix. The latter will be derived using a modification of the function used by Jarvis *et al* (2002) to account for the effects of bulk density (compaction). This modification will use data from Jarvis *et al* (2002) together with basic data on bulk density, particle-size distribution (texture) and organic carbon content.

All the remaining van Genuchten – Mualem parameters will be estimated from bulk density, texture and organic matter content using the HYPRES pedotransfer functions from the SGDBE version 1.0 (see section 2.1.3).

3.2 The PRZM model

The manual for PRZM 3.12 list a range of parameters under the heading 'soil' and these are given in Table 3.2-1 below, together with a brief description of them and a summary of how they are derived.

Parameter	Meaning	Derivation
ANETD:	Minimum depth from which evaporation is extracted.	Depends on the climate and will be set independently of soil type except for shallow soils (see CORED below).
USLEK:	Soil erodibility factor.	Will be estimated using Table 5.3 and a USDA textural triangle (e.g. Fig. 5.10) in the PRZM 3.12 Manual.
USLELS:	Combined slope length / steepness factor.	Will be estimated from Table 5.5 in PRZM 3.12 Manual.
USLEP:	Erosion control practice factor.	Will be estimated from Table 5.6 in PRZM 3.12 Manual.
AFIELD:	Field size (ha).	Will use a generic value, e.g. 1 ha.
SLP:	Slope (%).	To be estimated largely independently of soil, probably related to crop / land cover type.
HL:	Hydraulic length (m).	To be estimated using recommendations from the FEMVTF report (R.L. Jones and M.H. Russell (eds.), 2001). Independent of soil
AMXDR:	Maximum rooting depth of crop.	Depends on crop and CORED (see below).
USLEC:	crop management factor.	Values from Table D.1 in FOCUSsw report.
MNGN:	Manning's roughness coefficient.	To be estimated independently of soil, probably related to crop?
CN:	Curve numbers for antecedent moisture condition II.	Can derived from Table 5.10 in PRZM 3.12 Manual using the Soil Hydrologic Groups A to D. But revised methodology being developed
CORED:	Depth of soil profile (cm).	Default value is 200 cm unless limited by rock.
ALBEDO:	Soil surface albedo for each calendar month.	Default value of 0.18 will be used from FOCUSsw report.
EMMISS:	Infrared emissivity of soil surface.	Default value of 0.96 will be used from FOCUSsw report.
ZWIND:	Height of wind speed measurement above soil surface.	To be taken from weather datasets. Independent of soil
BBT:	Average monthly values of bottom boundary soil temperatures.	To be calculated from weather datasets. Independent of soil
NHORIZ:	total number of horizons	From FOOTPRINT soil datasets
For each soil horizon		
THKNS:	Thickness of horizon	From FOOTPRINT soil datasets
BD:	dry bulk density (g/cm3)	From FOOTPRINT soil datasets
THETO:	Dnitial soil water content.	Will be set to a default value = THEFC.
DPN:	Thickness of compartments (cm).	Will use the FOCUS default of 0.1 cm for 0-10 cm depth; set to 5 cm for > 10 cm depth. The length of numerical dispersion is said to equal half the compartment thickness.
THEFC:	Field capacity water content (pF 2.5).	Will be computed externally from SAND, CLAY, OC, BD.
THEWC:	Wilting point water content (pF 4.2)	Will be computed externally from SAND, CLAY, OC, BD.
OC:	Organic carbon content (%).	From FOOTPRINT soil datasets
SPT :	Initial soil temperature of horizon (°C).	Will be calculated from climate data and horizon thickness and sequence number.
SAND:	Sand content (%)	From FOOTPRINT soil datasets
CLAY:	Clay content (%).	From FOOTPRINT soil datasets

Table 3.2-1. 'Soil' parameters required by PRZM and their derivation.

3.3 Summary

Both the MACRO and PRZM models require a wide range of parameters listed under the broad heading of 'soil'. However, most of these are not widely available from measured data and, following extensive use of the models over a number of years, specific sets of algorithms or 'pedo-transfer functions' have been developed and tested in order to derive parameters from basic, widely available soil property data. In addition, most of the runoff and erosion parameters in PRZM are site-specific rather than soil-specific and will be derived from topographic and land cover data rather than soil data. PRZM runoff curve numbers are usually derived from the soil hydrologic group but there are some conceptual problems with this approach and alternative methods are being developed to derive this parameter from other data, including soil hydrological characteristics.

In summary therefore, a limited set of basic soil property data is required to parameterise the MACRO and PRZM models as follows:

For each soil type:

Soil hydrological type; Lower boundary condition; number of soil layers;

For each soil layer:

Sequence number; horizon designation; upper depth (cm); lower depth (cm); percentage clay; percentage silt; percentage total sand; percentage sand content 0.05 - 0.1 mm; percentage sand content 0.1 - 0.2 mm; percentage sand content 0.2 - 0.5 mm; percentage sand content 0.5 - 2 mm; percentage stones (>2 mm); pH; percentage organic carbon content; bulk density (g /cm^3).

4 OVERVIEW OF THE METHODOLOGY FOR IDENTIFYING FOOTPRINT SOIL CLASSES

The requirement for the FOOTPRINT soil classes is that they should represent the entire spectrum of variation in those soil parameters that are required by the FOOTPRINT models, within European agriculture. As most of the soil parameters required by the models will be derived from various purpose-derived algorithms and 'pedotransfer' functions (see section 3.3), only a basic set of soil properties defining the soil profile hydrologic characteristics and the particle-size distribution, organic carbon content, pH and bulk density of each significantly different soil layer present to a depth of 100 cm or rock (whichever is shallower) are required. This requirement was achieved using the following methodology:

1. The conceptual models of flow pathways from the HOST and CORPEN systems were amalgamated and a flow chart created to guide the FOOTPRINT tool user to a specific conceptual hydrological transport model. This was achieved during a series of meetings between Benoît Réal of Arvalis and John Hollis of Cranfield University.
2. The HOST system was used to identify the MACRO bottom boundary condition (conditions, 1 - 5) as illustrated in Figure 3.1-1.
3. The combined HOST / CORPEN framework was used to identify the category of ‘flow processes’ (A – E) required for the groundwater vulnerability method (see deliverable 10).
4. A set of ‘sorption-degradation kinetics’ classes were defined using pedological knowledge derived from the FAO SOIL category name in the SGDBE ‘stu attribute’ database.
5. HOST, HOST / CORPEN, MACRO bottom boundary, groundwater vulnerability soil flow process categories and sorption-degradation kinetics classes were assigned to each STU in the SGDBE ‘stu.dbf’ file using the soil attributes available in this file.
6. For each STU, the Macro bottom boundary class, topsoil texture class, subsoil texture class and sorption-degradation kinetics class were combined to create a unique FOOTPRINT soil class code. This was only done for STUs that had a dominant or secondary land use in an agricultural category (see Table 4.0-1). All STUs to which this did not apply were coded as ‘NA’, non-agricultural.
7. All STUs in the SPADE 1 database that had an agricultural land use and an explicit link to an STU were identified, amalgamated with the profile data in the SPADE-2 database and all the STUs in this combined data were allocated an appropriate FOOTPRINT soil code.
8. Using the combined SPADE-1 & 2 datasets, data from all STUs with the same FOOTPRINT soil code were combined to create a single FOOTPRINT soil and land use-specific soil profile property dataset. Any FOOTPRINT soil classes without any corresponding data in the SPADE data sets were either allocated to a suitable existing dataset or had a profile property dataset derived using expert judgement based on similar soil profiles.

5 HARMONISING HOST AND CORPEN

The CORPEN and HOST methodologies incorporate very similar approaches for conceptualising the transfer routes and pathways for water and associated pollutants through soils. The conceptual models in both systems are formalised as arrows showing the direction of water movement through soil and subsoil. CORPEN (and Aquavallé) have an additional component which identifies the likelihood of transfer of water from within, or over the soil to both surface and groundwater, whereas in HOST this transfer component is inferred (and to some extent, quantified) through the associated stream flow indices of SPR and BFI.

There are two immediate advantages to be gained by harmonisation of the methodologies. Firstly, the HOST SPR & BFI indices do not differentiate between the different pathways to surface water, either via subsurface through-flow / field drains or by surface runoff, so an additional element derived from the CORPEN methodology would enable this separation to be formalised. Secondly, the CORPEN methodology only identifies a single level of transfer to surface water via surface runoff or subsurface through-flow / field drainage, whereas HOST enables the relative amounts of such transfers to be quantified, particularly across different soil hydromorphic types. Combining the two methodologies would thus bring distinct advances to both systems.

5.1 Need within FOOTPRINT

Within FOOTPRINT, a harmonised CORPEN – HOST methodology fulfils two distinct requirements. Firstly, it provides the critical hydrological component for differentiating FOOTPRINT soil classes across Europe. Secondly, it provides a conceptual framework that enables users of the FOOT_CRS & FOOT_FS tools to visualise the local pesticide transfer pathways to surface and ground-waters. However, in order to do this, the local distribution of HOST/CORPEN types needs to be identified.

In order to fulfil these two requirements, the HOST & CORPEN systems have been combined to create a series of diagrammatic models of water and associated solute transfer at the field level. Each model is related to a specific combination of substrate, soil, slope and seasonal characteristics and users are guided to a specific set of models through a question & answer flow chart. The questions are all based on characteristics that can be identified using the STU.dbf attribute database in the SGDBE. This format thus enables a specific HOST-CORPEN hydrological class to be identified either from the users local knowledge, or as a 'default' from the SGDBE, if the user has no local/national information to use.

5.2 The flow chart

The HOST-CORPEN flow chart has been developed by building on existing question and answer type rules in CORPEN as well as other rule-based systems to identify slowly permeable horizons, gleyed (seasonally wet) horizons, soil water regimes and texture classes for HOST purposes. The full flow chart is shown in Annex 1 and uses the following set of properties:

- Geology (grouped by permeability and transmissivity characteristics).
- Topsoil texture groups, primarily the presence of ‘cracking’ clay or other types of clay and ‘heavy’ textures.
- Water regime. This is identified through questions relating to the presence or absence of field drainage and the number of days that soils ‘lie wet’ following rainfall. Most field practitioners and farmers can identify with these characteristics. In addition however, for the more experienced soils practitioners, additional questions relate to the presence or absence of ‘gley morphology’ within specified depths. ‘Gley morphology’ is defined in Annex 2 and identifies a soil layer that is, or has at some time in the recent past, been waterlogged for at least about 30 days in most years. Such characteristics give a more precise identification of soil water regime but require some experience to identify.
- Presence of plough pans (compacted layers), surface runoff and ‘capped’ (sealed) topsoil surfaces at some points in the agronomic cycle.

5.3 Seasonal differences in pollutant transfer routes

CORPEN includes an identification of the period when the soil has no potential moisture deficit. It is an important component that identifies which suite of flow pathway models is used. The concept is identical to the agroclimatic parameter of ‘field capacity period’ used in the UK (Jones & Thommasson, 1985) and incorporated into the SEISMIC information system (Hallett *et al*, 1995). On most soils, relatively rapid transfer of water and associated solutes, either via field drains, through-flow or surface runoff, occurs more frequently when there is no moisture deficit. This is because the soil has less storage space for excess water. In the combined HOST-CORPEN framework therefore a distinction is made between the ‘climatic field capacity period’, when there is no soil moisture deficit and the ‘soil moisture deficit period’. In Europe, the former usually occurs sometime during the autumn, winter and spring. For each HOST-CORPEN hydrological class, separate diagrams are given for these two seasonal states.

6 ASSIGNING FOOTPRINT SOIL CLASSES TO STUs IN THE SGDBE

6.1 HOST and HOST / CORPEN classes

A number of attributes in the SGDBE 'stu.dbf' file were used to allocate STUs to a HOST and CORPEN class: the soil parent material (MAT1 & MAT2), the soil water regime (WR) and associated water management attributes (WM1 & WM2); the soil texture groups (TEXT1, TEXT2, TD1 & TD2) and the FAO pedological soil type name (SOIL).

Initially, all STUs were assigned to a substrate hydrogeological group using the MAT 1 attribute, as shown in Table 6.1-1. Where necessary this assignation was amended using expert judgements based on the MAT2 attribute in combination with the texture attributes and / or the SOIL attribute. In addition, in many cases allocation to a hydrogeological group was checked using the soil profile data available in the SPADE-1 and SPADE-2 databases.

Hydrogeological group	MAT1 codes	HOST classes	CORPEN group
Microporous Chalk	216 to 220	1, 8, 10, 13 or 14	Dc
Microporous Limestone	200, 210, 212, 213, 214, 901	2, 8, 10, 13 or 14	El
Macroporous Sandstone	419, 450, 451, 452, 454, 459	3, 7, 10, 13, 14 or 15	Es
Hard, fissured Lst & Sst	211, 215, 240, 250, 455 to 457	4, 8, 10, 13, 14 or 15	F
Loose sands & gravels	111, 112, 130, 140, 400 to 442	5, 7 or 10	C
Loose loams & clays	500 to 521, 523, 539	6, 8 or 9	Dl
Alluvium	100, 110, 113, 120, 150	7, 8, 9 or 10	G
Slowly permeable materials	131, 230 to 234, 300, 310, 311, 314 to 324, 340, 350, 453, 600 to 640	16, 18, 21. 24 or 26	B
Hard impermeable materials	530, 700 to 825, 902	17, 19, 22 or 27	Ah
Soft impermeable clays	312, 313	20, 23 or 25	Ac
Organic materials	910	11 or 12	Organic

Table 6.1-1. Allocation of HOST & CORPEN hydrogeological groups according to MAT1
Notes: Thin loess (code 522 allocated to a group according to MAT2).
Residuum from calc rocks (code 209) allocated according to texture and SOIL.
Residual clay from calcareous rocks (codes 330 to 333) allocated according to SOIL

Each of the hydrogeological groups has a single CORPEN group and a limited range of HOST classes as shown in Table 6.1-1. Allocation of a HOST class within each hydrogeological group was than determined mainly from the soil water regime attributes WR, WM1 and WM2 as indicated in Table 6.1-2. In addition, as with the allocation of hydrogeological groups, expert judgement was used to amend the water regime allocation where judged necessary, based on the SOIL attribute as a guide to the presence of 'gley morphology'.

Water regime	HOST classes
WR = 1 and WM1 = 2	1, 2, 3 , 4, 5, 6, 16 or 17
WR = 2 or WR = 1 AND WM1 = 1 AND WM2 = 1, 3, 4 or 5	13, 7, 8, 11, 18 to 23
WR = 3 or 4	9, 10, 14, 24, 25

Table 6.1-2. Allocation of HOST classes according to water regime attributes

All STUs allocated to HOST classes 18 to 23 were differentiated according to their texture attributes. Where TEXT1 or TEXT2 had a value of ‘1’ STUs were allocated to classes 18, 19 or 20, depending on hydrogeological group. All other STUs in these classes were allocated to 21, 22 or 23, depending on hydrogeological group. Finally, all STUs were allocated to a ‘topsoil texture class’ and a ‘subsoil texture class’ using the TEXT1 and TD1 attribute codes in the stu.dbf file. The range of particle sizes include within each of these texture codes is shown in Figure 6.1-1.

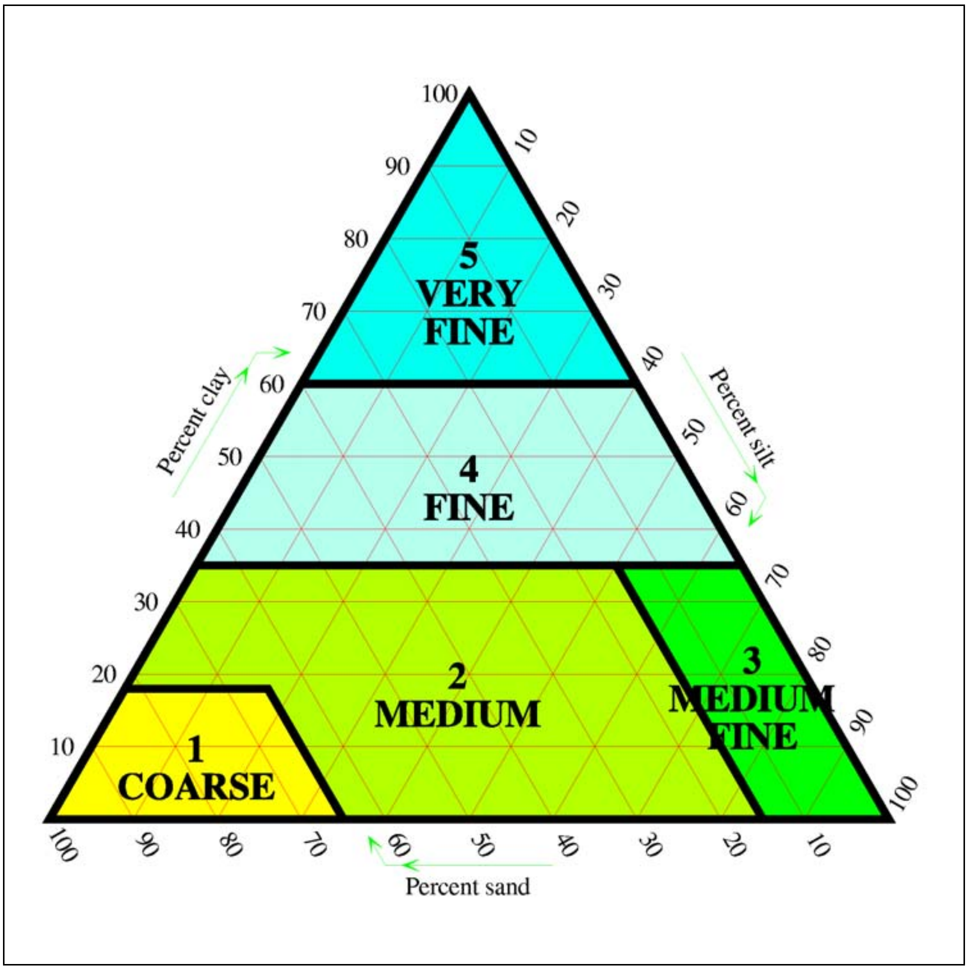

Figure 6.1-1 Particle-size fractions included in the texture groups used in the FOOTPRINT HOST-CORPEN classes

Having allocated all STU’ in the database a CORPEN group, a HOST class and a topsoil & subsoil texture group, the HOST-CORPEN hydrological class was created by combining the two. In this way, the initial code indicates which set of HOST-CORPEN conceptual models (sets A to G in Appendix 1) to work from, whilst the HOST class and texture codes indicate which specific combination of seasonal models to use.

6.2 MACRO bottom boundary class & groundwater vulnerability soil flow processes class

In order to parameterise the MACRO bottom boundary condition and to help scale the BGRAD parameter, information is required on the permeability of the soil substrate material and the soil water regime. All these characteristics are available via the HOST class and this has thus been used to indicate which MACRO bottom boundary condition should be used with each STU in the SGDBE, as indicated in Table 6.2-1.

MACRO bottom boundary condition	**Bottom boundary condition code**	**Type of discharge**	**HOST**	**Description**
Unit hydraulic gradient	1	Recharge to groundwater	1-6, 13	Permeable substrate, groundwater > 2m depth
Zero flow	2	Discharge to	7-12	Groundwater at ≤ 2 m depth
	3	surface water		Impermeable substrate
Percolation controlled by water table height BGRAD large	4	Both recharge and discharge	16,18,21	Slowly permeable substrate Gley features > 40 cm
Percolation controlled by water table height BGRAD small	5	Recharge to groundwater	14,15,24,26	Slowly permeable substrate Gley features ≤ 40 cm

Table 6.2-1. MACRO bottom boundary condition, BGRAD scale and HOST class

In addition, information on the type soil flow processes is required to carry out the groundwater vulnerability assessment described in FOOTPRINT deliverable 10. Again, the HOST-CORPEN hydrological class has been used to allocate all STUs to a soil flow processes grouping as indicated in Table 6.2-2.

6.3 Sorption / degradation kinetics classes

The FAO soil class name used in the SOIL attribute in the ‘stu.dbf’ file indicates the pedological soil type represented by the STU. This soil type provides information about the soil processes that are operating within the soil profile and have given rise to its distinctive sequence of soil horizons, specifically called the ‘diagnostic’ characteristics of the soil profile

(CEC, 1985). Many of these soil processes and the characteristics that develop as a result of them are important for sorption / degradation kinetics. They have thus been used to derive a grouping of STUs according to the presence of specific characteristics not already included in the HOST-CORPEN hydrological groupings. Each group has been allocated a code and these codes, the SOIL name from which it is derived and a description of their characteristics as they affect sorption / degradation kinetics are given in Table 6.3-1.

Code	SOIL	Sorption groups
a	J*, **f : Fluvisols and fluvic subgroups	Recent alluvial profile with irregular organic carbon distribution with depth.
b	*t : Thionic subgroups	Very low pH in subsoil because of sulphuric or sulphidic layers
d	*d, *ds :dystric & spodo-dystric subgroups	Acid soils with low pH
f	*x : gelic subgroups	With frozen subsoil layers
g	g : plaggen soils	Man made soils with organic rich layers to depth
h	*h : humic subgroups	With an acid organic rich topsoil
i	L*, D*, *l : Luvisols, Podzoluvisols and luvic subgroups	With a clay increase in the subsoil
ii	W*, *p : Planosols, planic subgroups	With a large clay increase in the subsoil
k	C*, H*, K*, *k, *c :Chernozems, Phaeozems, Kastanozems, calcic or calcaric subgroups	With free $CaCo_3$ in most of the profile
m	C*, H*, *m :Chernozems, Phaeozems & mollic subgroups	With relatively deep organic-rich topsoil
n		Normal organic profile
o	T*, **a : Andosols, andic subgroups	Profiles in volcanic material with large pH-dependent charge & organic-rich
p	P* : Podzols	With a podzol organic matter profile
r	E*, I*, U*, Pl : Rendzinas, Lithosols, Rankers and leptic podzols	With rock or rock rubble at shallow depth
s	A*, : Acrisols	Soils with weakly sorbing clay minerals
t	O* *hh :Histosols & histic subgroups	With a peaty topsoil
u	R* : Regosols	Undeveloped soil with low organic carbon
y	*y : Gypsic subgroups	With significant amounts of gypsum
z	S*, Z* : Solonetz, solonchaks	With high sodium content

Table 6.3-1. Sorption-degradation kinetic classes, SOIL attributes and their characteristics

6.4 The final FOOTPRINT soil classes

By combining the HOST-CORPEN codes with the sorption-degradation kinetic class codes, a final FOOTPRINT soil class code has been derived for all STUs in the SGDBE. This code has the format shown in Figure 6.4-1. However, this full code is only needed to identify a

HOST-CORPEN pair of conceptual models or a soil flow processes category for assessing groundwater vulnerability.

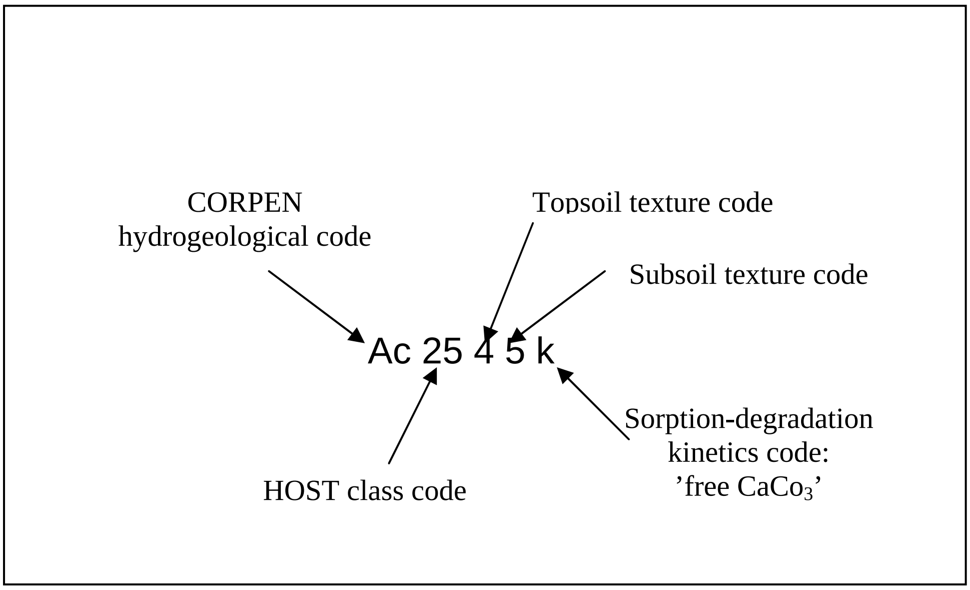

Figure 6.4-1. Format of the full FOOTPRINT soil class code.

The full code is not necessary for undertaking model parameterisation which will only require the MACRO bottom boundary condition code, the texture codes and the sorption-degradation kinetic class codes. In order to support parameterisation therefore a slightly truncated set of 'parameterisation codes' was created for each STU. This parameterisation code comprises the MACRO bottom boundary condition code, the topsoil and subsoil texture codes and the sorption-degradation kinetic class code. Its equivalent for the example given in Figure 6.4-1 is:

3 4 5 k

Once all the STUs that have an agricultural use (as indicated by their USE1 or USE2 attributes) have been assigned a FOOTPRINT soil parameterisation code, there are a total of 595 soil profiles required to characterise the complete spectrum of agricultural soils in Europe. It is emphasised that many of these soil types are of limited extent and very few will encompass more than 2 or 3 climatic zones (FOOTPRINT deliverable 9). In addition most will not carry a full range of agricultural crops and a significant number occur only under managed grassland.

7 DERIVATION OF SOIL PROFILE DATA FOR FOOTPRINT SOIL PARAMETERISATION CLASSES

Using the STU code attached to each profile dataset in the SPADE-1 estimated soil profiles and the SPADE-2 datasets, each was assigned an appropriate FOOTPRINT soil parameterisation code. All profiles with the same parameterisation code were merged to create a single profile dataset comprising the mean values and standard deviation values of each soil parameter. Any FOOTPRINT soil classes without any corresponding data in the SPADE data sets were either allocated to a suitable existing dataset or had a profile property dataset derived using expert judgement based on similar soil profiles.

This activity is continuing but an example of the soil profile data for a single FOOTPRINT soil parameterisation class is given in Table 7.0-1.

344k arable								
HORIZON	A		Bw		Bg		BC	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
DEPTH_UP (cm)	0	0.0	24	2	54	9	75	11
DEPTH_LO (cm)	24	2.2	54	9	75	14	100	33
CLAY %	44	3.4	56	7	56	7	58	0
SILT %	36	11.5	28	7	32	10	35	1
SAND_TOT %	21	8.3	16	10	12	10	7	1
SAND_01 (mm) %	7	7.0	5	7	4	6	2	1
SAND_02 (mm) %	6	1.8	4	1	3	1	3	1
SAND_05 (mm) %	4	0.9	3	1	3	1	3	1
SAND_20 (mm) %	4	2.2	3	2	3	3	1	0
STONES %	1	1.3	1	1	0	0	0	0
PH_KCL	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
PH_H2O	7.5	0.25	7.7	0.25	7.9	0.34	8.1	0.23
OC %	2.59	1.09	1.41	0.86	0.69	0.22	0.44	0.09
DB (g cm^{-3})	1.19	0.08	1.27	0.04	1.30	0.10	1.39	0.02

Figure 7.0-1. Example soil property data for a single FOOTPRINT soil parameterisation class.

8 CONCLUSIONS AND PERSPECTIVES

This activity has amalgamated the knowledge bases incorporated within both the HOST and CORPEN systems to create a unique set of conceptual soil models illustrating the various critical pollutant transport pathways to water sources at the field level. These conceptual models are useful both for illustrating pollutant pathways to field practitioners and for parameterising the hydrological component of pesticide leaching, drainage and runoff models.

Simple question and answer flow charts enable users to identify specific pairs of seasonal pollutant transfer models and these will feed directly in work packages 3 and 5.

The combined HOST-CORPEN concepts have been allocated to each of the 5306 STUs in the SGDBE and, together with textural information and an assessment of significant soil profile characteristics likely to affect sorption-degradation kinetics, have been used to create a set of 595 FOOTPRINT soil parameterisation classes that will be directly used in work package 4. Using the databases available in the SGDBE v 1.0, the spatial distribution of each of the FOOTPRINT soil classes and parameterisation classes can be elaborated through use of GIS. Such spatial differentiation should be considered as a default dataset only. The rule-based flow charts, textural descriptions and descriptive characteristics associated with the sorption-degradation kinetics groupings also form a framework for guiding users to the selection of an appropriate FOOTPRINT soil class and parameterisation class using their local knowledge. Such rule-based frameworks will be incorporated into the FOOTPRINT tools.

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ANNEX 1 - FLOW CHART FOR IDENTIFYING POLLUTANT PATHWAYS WITHIN THE SOIL

Are the soils in your area formed on either massive, pre-quaternary clays or hard & non-porous rocks? Yes → Go to **A**

No ↓

Are the soils in your area formed on some combination of boulder clays, marls or mudstones? Yes → Go to **B**

No ↓

Are the soils in your area formed on loose sands, gravels or river terraces? Yes → Go to **C**

No ↓

Are the soils in your area formed on sandy or granular limestone, or chalk or 'clay with flints' or deep loam over chalk? Yes → Go to **D**

No ↓

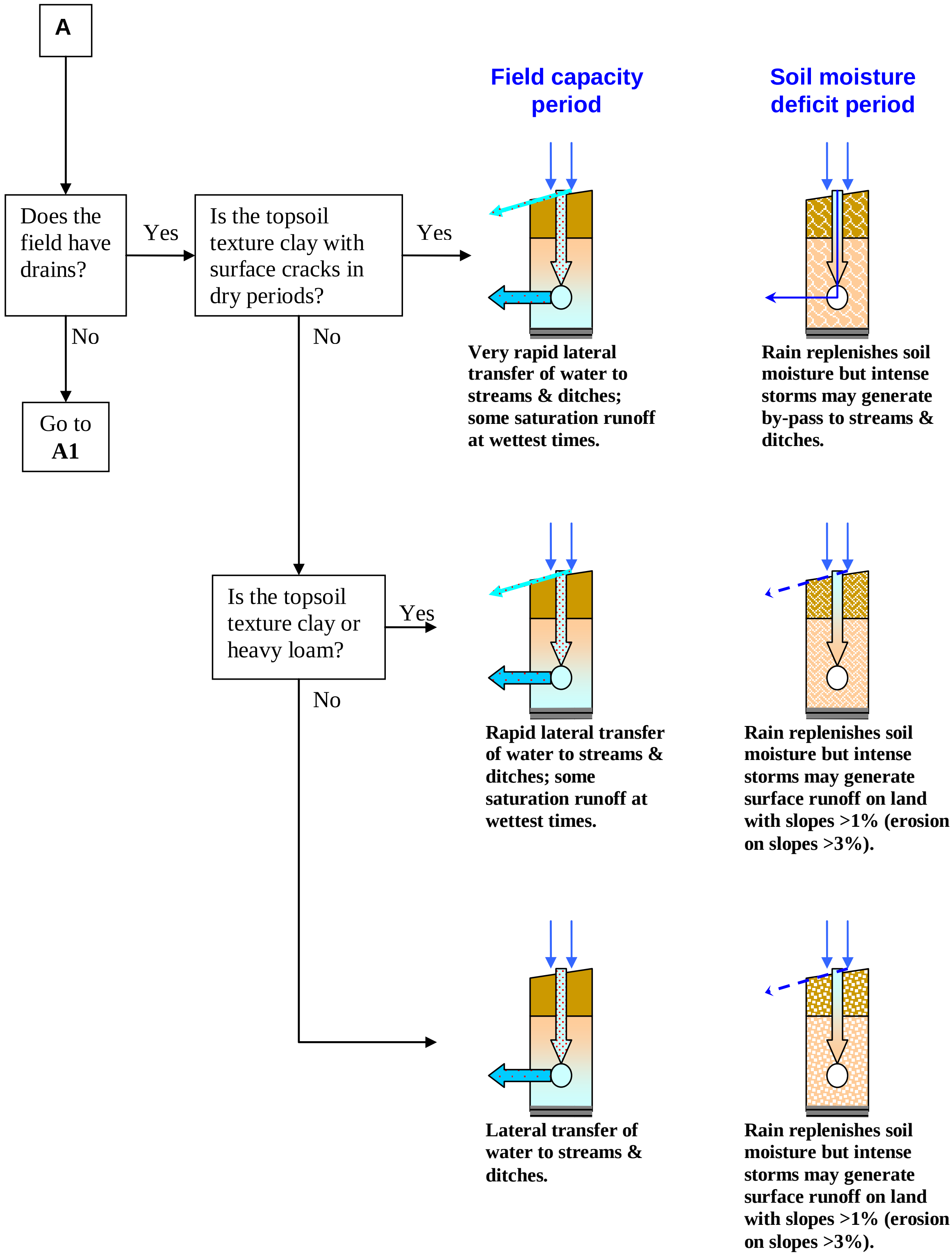
Are the soils in your area formed on non-karstic limestone or sandstone? Yes → Go to **E**

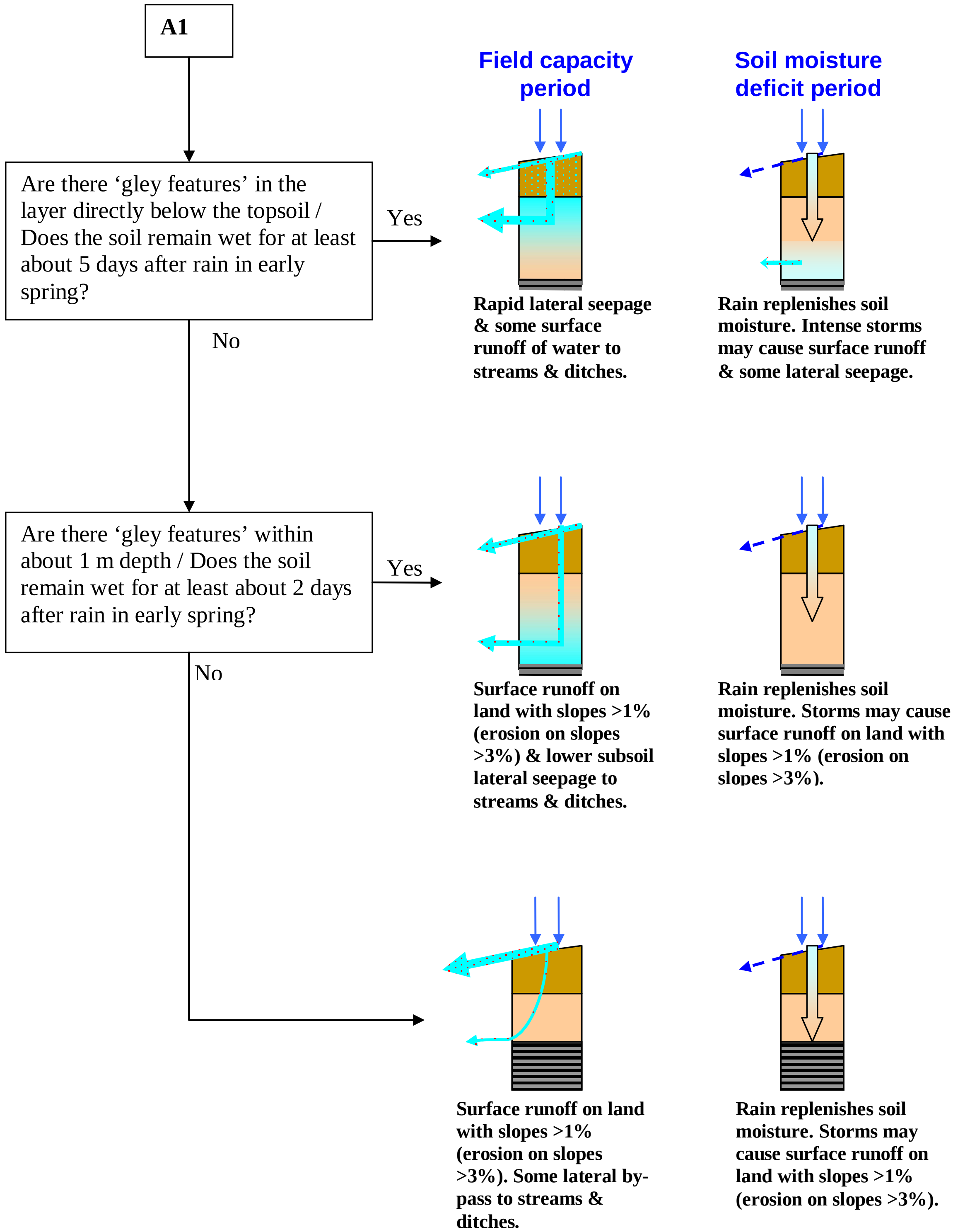
No ↓

Are the soils in your area formed on karstic limestone? Yes → Go to **F**

No ↓

Are the soils in your area formed on alluvium? Yes → Go to **G**

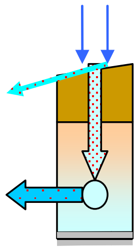
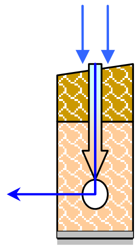
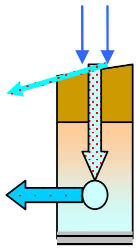
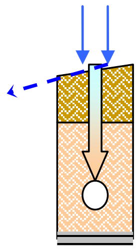
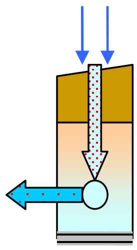
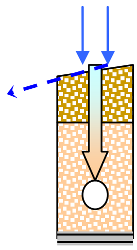

A
Does the field have drains?
Yes
No
Go to A1
Is the topsoil texture clay with surface cracks in dry periods?
Yes
No
Is the topsoil texture clay or heavy loam?
Yes
No
Field capacity period
Soil moisture deficit period
Very rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate by-pass to streams & ditches.
Rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%).
Lateral transfer of water to streams & ditches.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%).


A1
Field capacity period
Soil moisture deficit period
Are there 'gley features' in the layer directly below the topsoil / Does the soil remain wet for at least about 5 days after rain in early spring?
Yes
No
Rapid lateral seepage & some surface runoff of water to streams & ditches.
Rain replenishes soil moisture. Intense storms may cause surface runoff & some lateral seepage.
Are there 'gley features' within about 1 m depth / Does the soil remain wet for at least about 2 days after rain in early spring?
Yes
No
Surface runoff on land with slopes >1% (erosion on slopes >3%) & lower subsoil lateral seepage to streams & ditches.
Rain replenishes soil moisture. Storms may cause surface runoff on land with slopes >1% (erosion on slopes >3%).
Surface runoff on land with slopes >1% (erosion on slopes >3%). Some lateral by-pass to streams & ditches.
Rain replenishes soil moisture. Storms may cause surface runoff on land with slopes >1% (erosion on slopes >3%).

B

Does the field have drains?

- No → Go to **B1**
- Yes → Is the topsoil texture clay with surface cracks in dry periods?
  - Yes → (row 1)
  - No → Is the topsoil texture clay or heavy loam?
    - Yes → (row 2)
    - No → (row 3)

	Field capacity period	Soil moisture deficit period
Yes (clay with surface cracks)	 **Rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.**	 **Rain replenishes soil moisture but intense storms may generate by-pass to streams & ditches.**
Yes (clay or heavy loam)	 **By-pass flow & lateral transfer of water to streams & ditches; some saturation runoff at wettest times.**	 **Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%).**
No	 **Lateral transfer of water to streams & ditches.**	 **Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%).**

B1

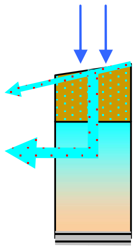
Are there 'gley features' in the layer directly below the topsoil / Does the soil remain wet for at least about 5 days after rain in early spring?

Yes

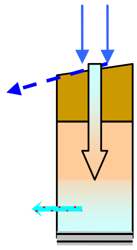
No

Field capacity period

Soil moisture deficit period



Lateral seepage & some saturation runoff of water to streams & ditches.

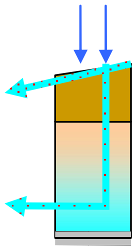


Rain replenishes soil moisture. Intense storms may cause surface runoff & some lateral seepage.

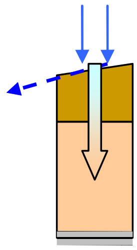
Are there 'gley features' within about 1 m depth / Does the soil remain wet for at least about 2 days after rain in early spring?

Yes

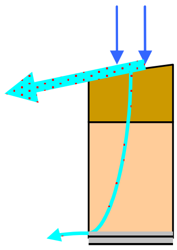
No



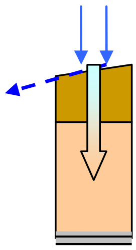
Surface runoff & lower subsoil lateral seepage to streams & ditches.



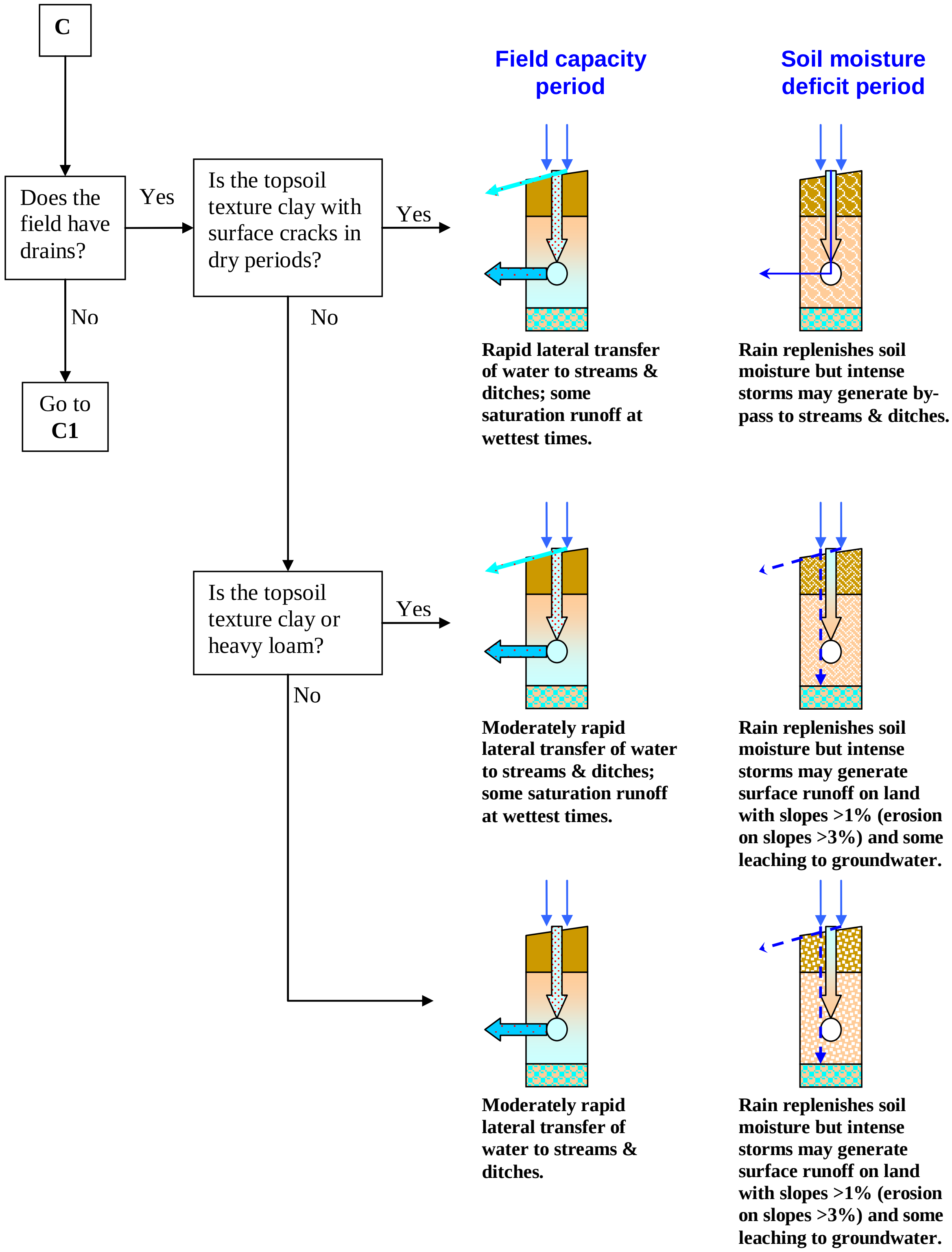
Rain replenishes soil moisture. Storms may cause surface runoff on land with slopes >1% (erosion on slopes >3%).



Surface runoff on land with slopes >1% (erosion on slopes >3%). Some lateral by-pass to streams & ditches.



Rain replenishes soil moisture. Storms may cause surface runoff on land with slopes >1% (erosion on slopes >3%).

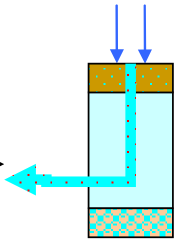

C
Does the field have drains?
Yes
No
Go to C1
Is the topsoil texture clay with surface cracks in dry periods?
Yes
No
Is the topsoil texture clay or heavy loam?
Yes
No
Field capacity period
Soil moisture deficit period
Rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate by-pass to streams & ditches.
Moderately rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.
Moderately rapid lateral transfer of water to streams & ditches.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.

C1

Are there 'gley features' in the layer directly below the topsoil / Does the soil remain wet for at least about 5 days after rain in early spring?

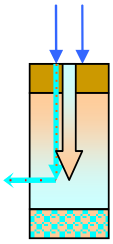
Yes →

Field capacity period



Moderately rapid lateral seepage of water to streams & ditches.

Soil moisture deficit period

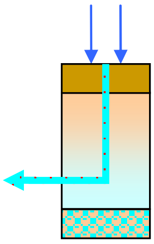


Rain replenishes soil moisture. Intense storms may cause some leaching & lateral seepage.

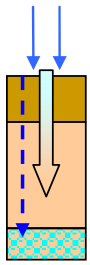
No ↓

Are there 'gley features' within about 1 m depth / Does the soil remain wet for at least about 2 days after rain in early spring?

Yes →

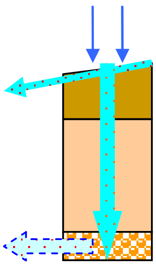


Leaching and lateral seepage of water to streams & ditches.

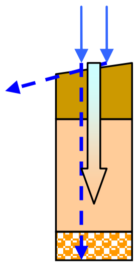


Rain replenishes soil moisture but intense storms may cause some leaching to groundwater.

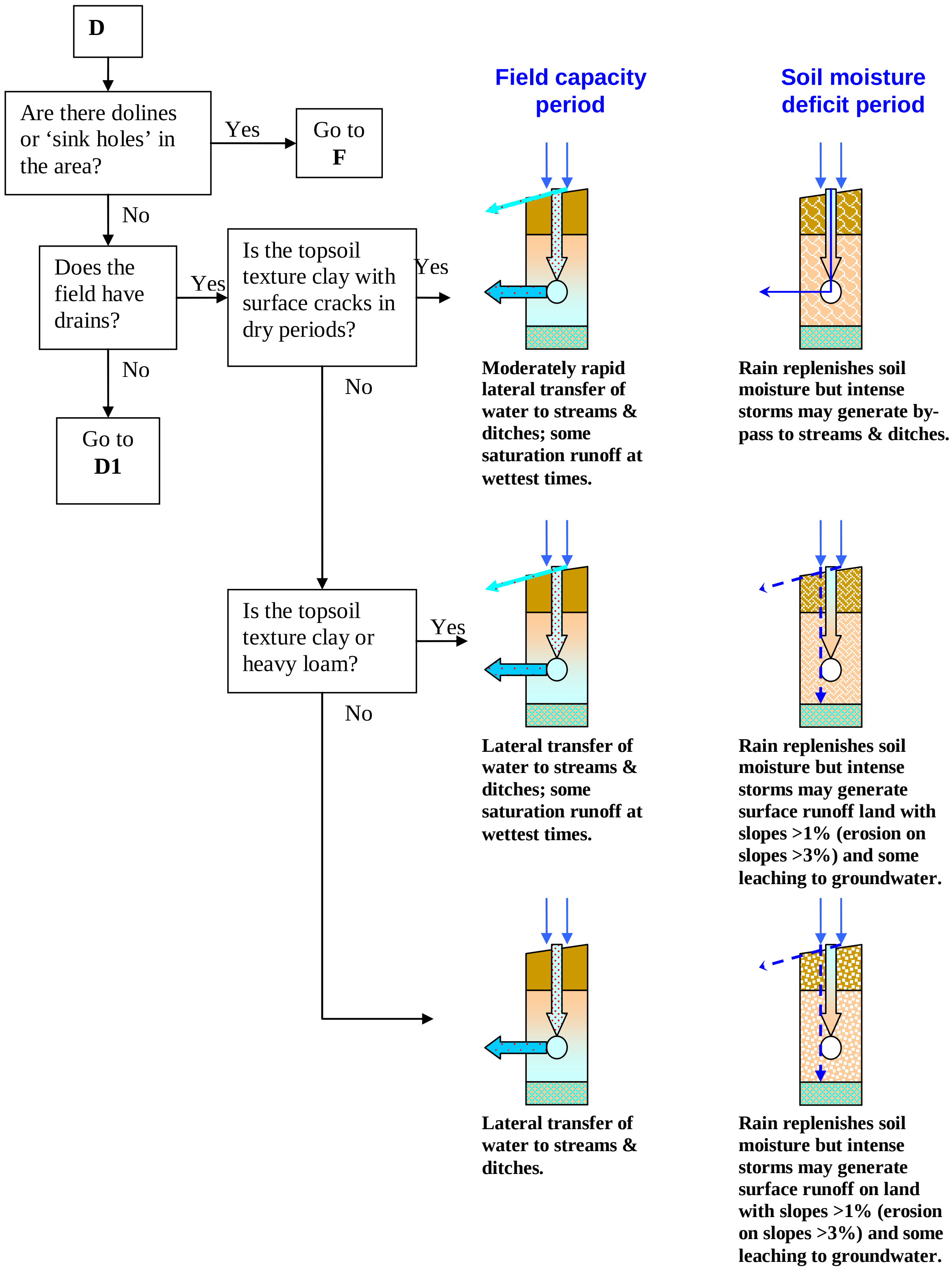
No ↓



Leaching to groundwater with some surface runoff on on land with slopes >1% (erosion on slopes >3%). Prolonged rain may cause by-pass to groundwater & some leakage to stream & ditches. Stream response to rainfall is 'dampened'.



Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.


D
Are there dolines or 'sink holes' in the area?
Yes
Go to F
No
Does the field have drains?
Yes
No
Go to D1
Is the topsoil texture clay with surface cracks in dry periods?
Yes
No
Is the topsoil texture clay or heavy loam?
Yes
No
Field capacity period
Soil moisture deficit period
Moderately rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate by-pass to streams & ditches.
Lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate surface runoff land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.
Lateral transfer of water to streams & ditches.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.

D1

Are there 'gley features' in the layer directly below the topsoil / Does the soil remain wet for at least about 5 days after rain in early spring?

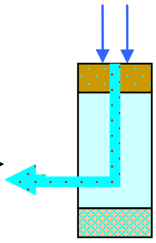
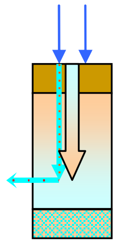
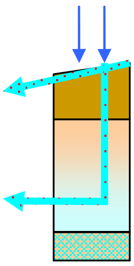
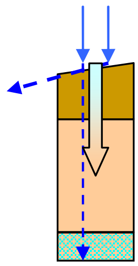
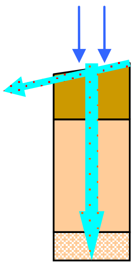
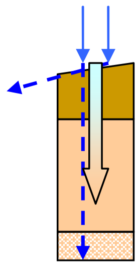
Yes

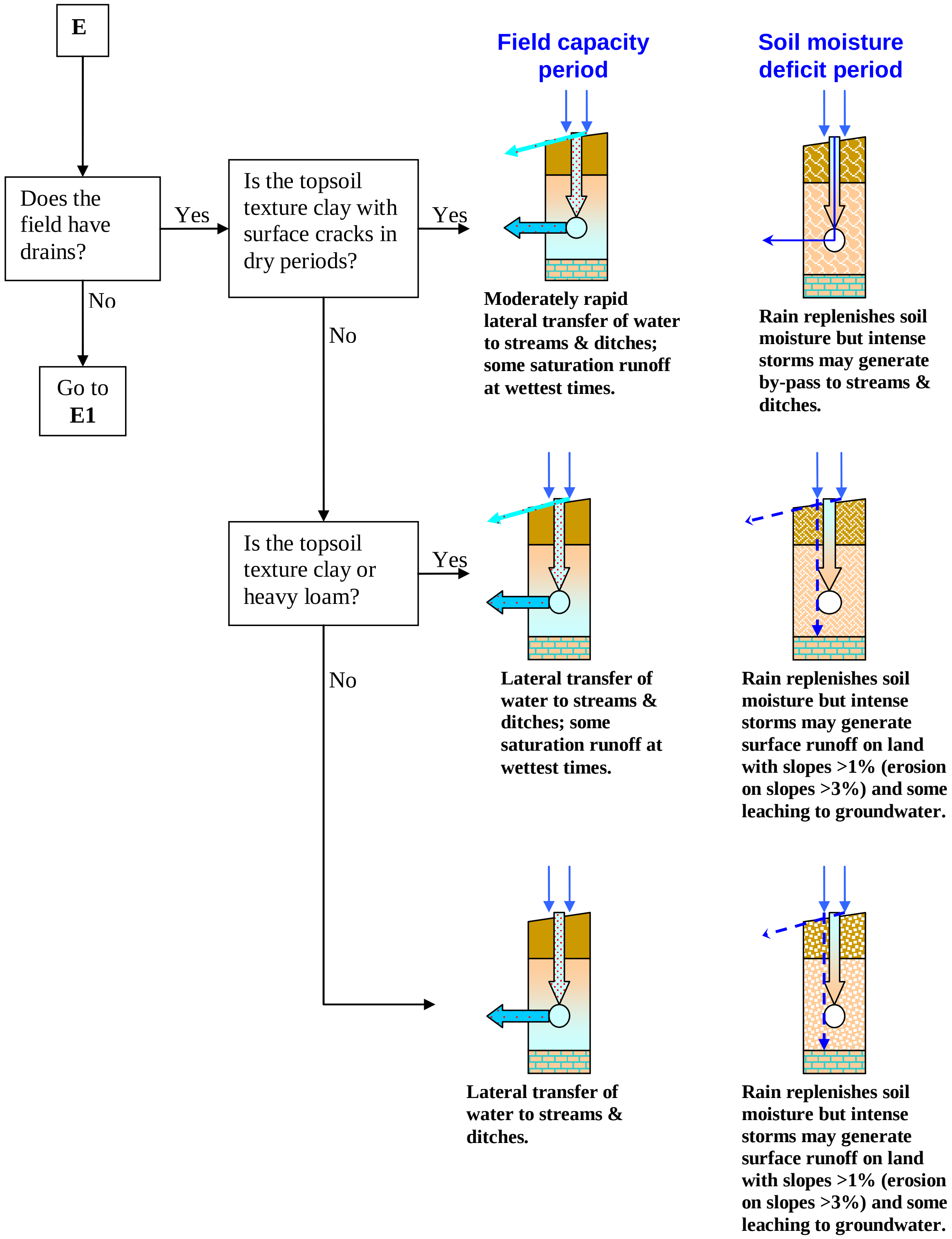
No

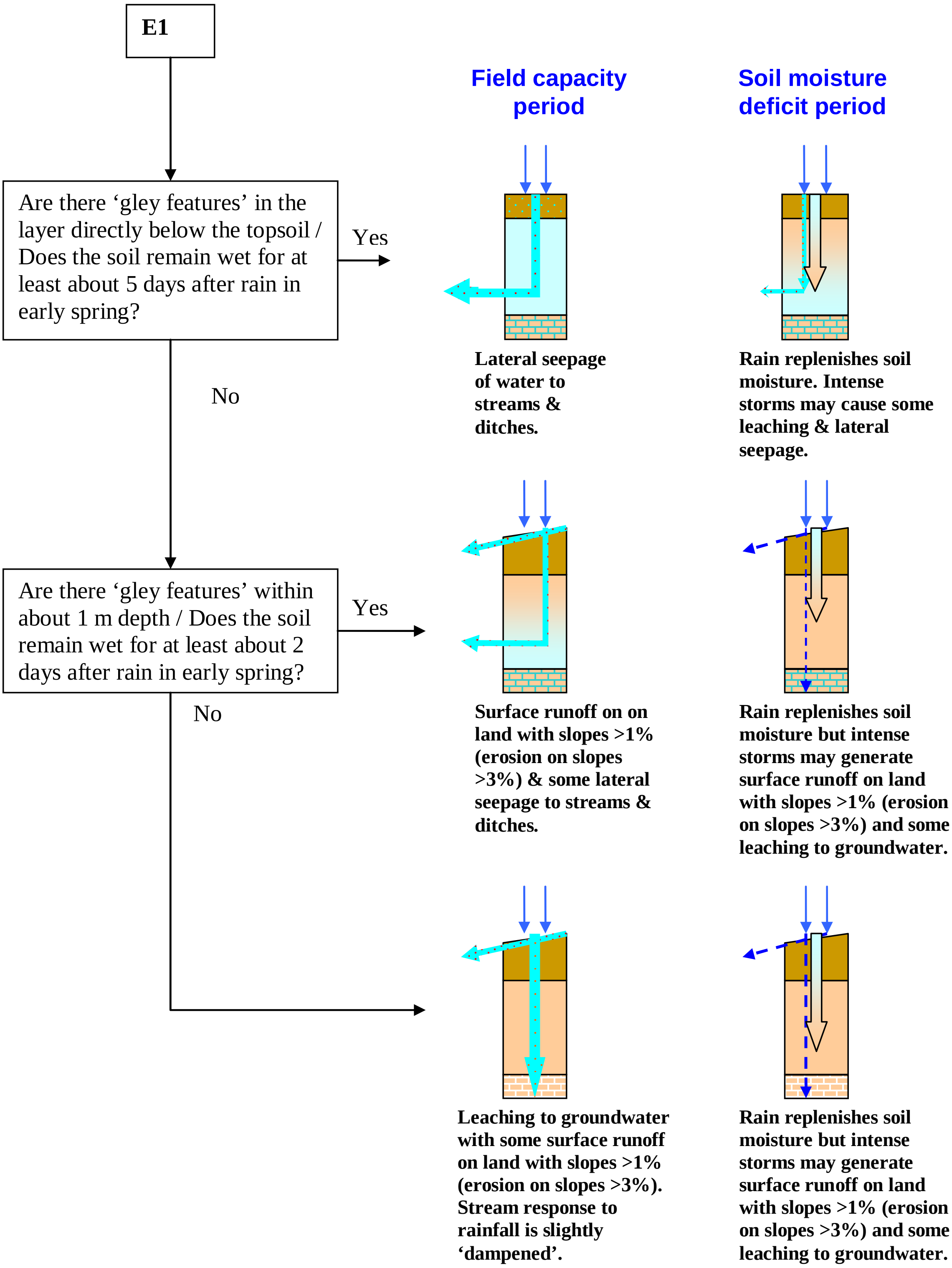
Are there 'gley features' within about 1 m depth / Does the soil remain wet for at least about 2 days after rain in early spring?

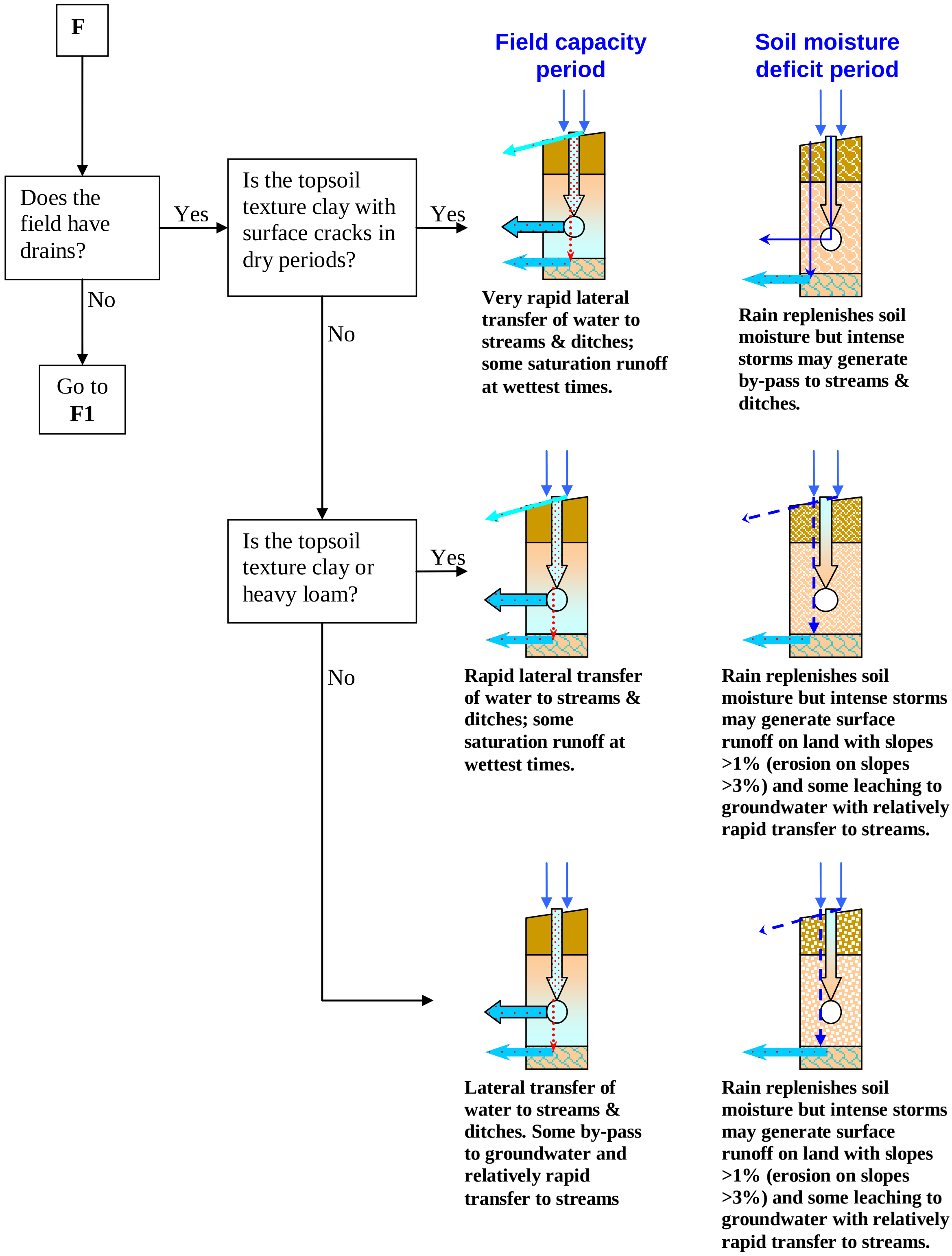
Yes

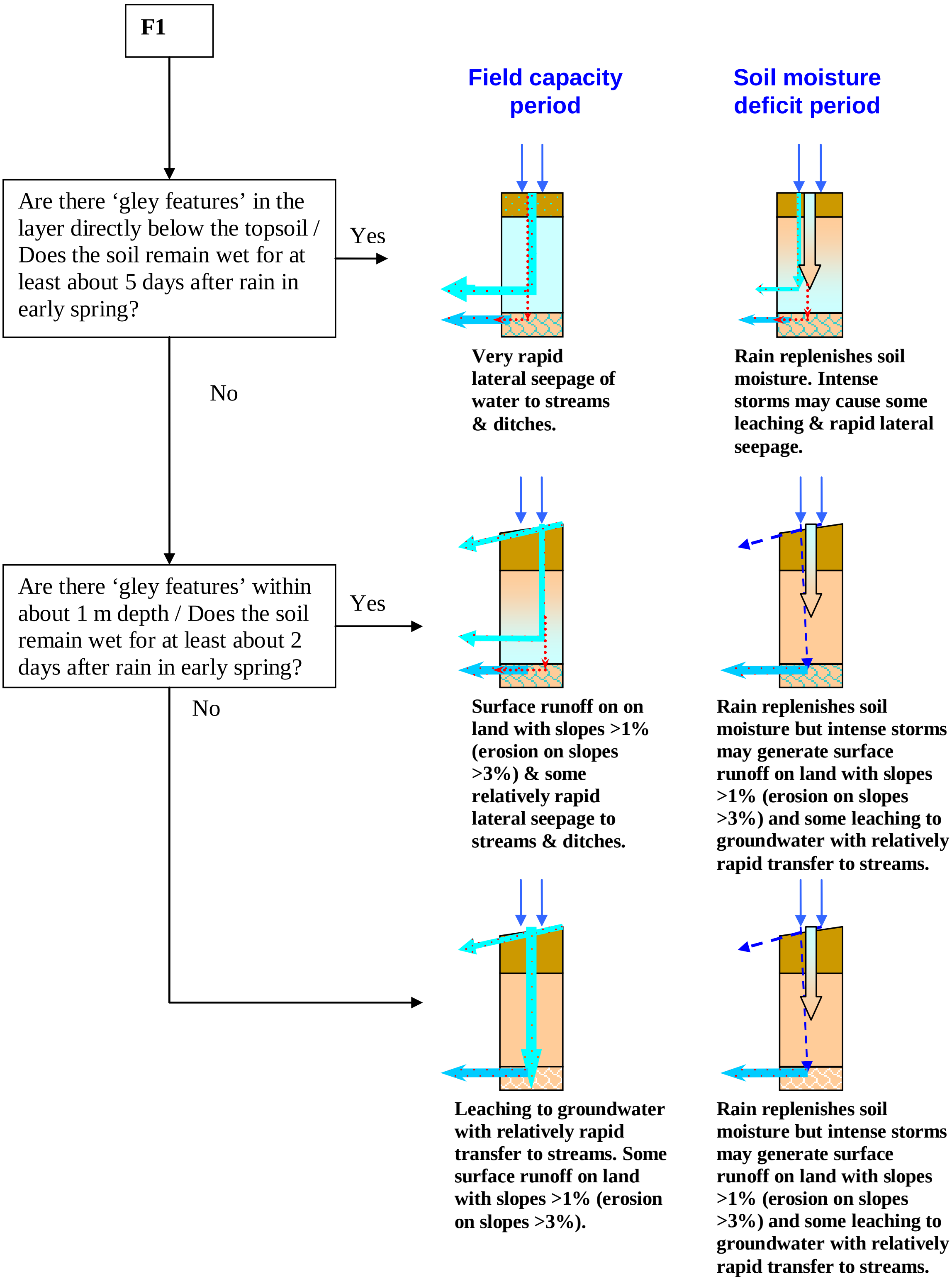
No

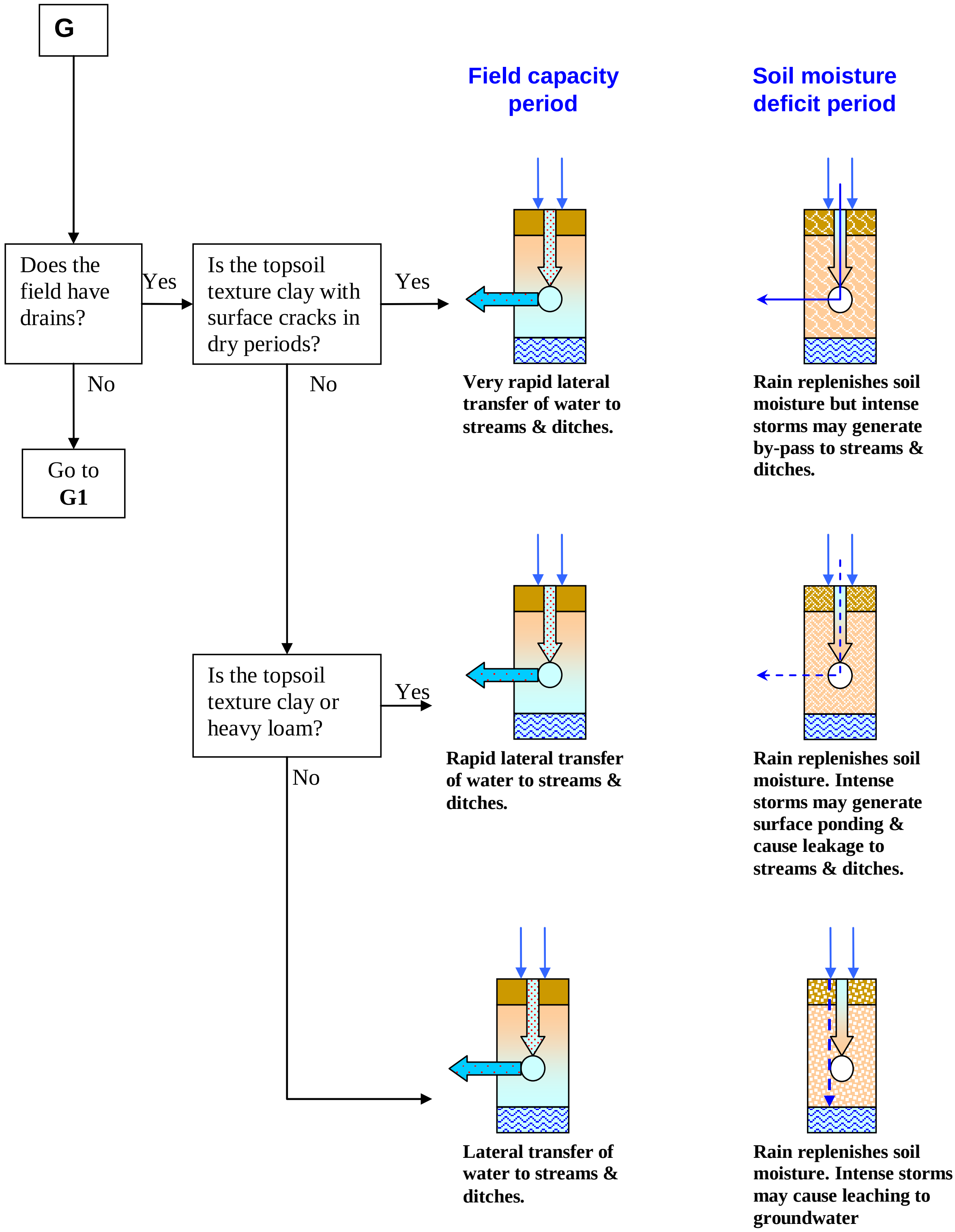
Field capacity period	**Soil moisture deficit period**
 **Lateral seepage of water to streams & ditches.**	 **Rain replenishes soil moisture. Intense storms may cause some leaching & lateral seepage.**
 **Surface runoff on slopes & some lateral seepage to streams & ditches.**	 **Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.**
 **Leaching to groundwater with some surface runoff on slopes. Stream response to rainfall is very 'dampened'.**	 **Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.**


E
Does the field have drains?
Yes
No
Go to E1
Is the topsoil texture clay with surface cracks in dry periods?
Yes
No
Is the topsoil texture clay or heavy loam?
Yes
No
Field capacity period
Soil moisture deficit period
Moderately rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate by-pass to streams & ditches.
Lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.
Lateral transfer of water to streams & ditches.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.


E1
Are there 'gley features' in the layer directly below the topsoil / Does the soil remain wet for at least about 5 days after rain in early spring?
Yes
No
Are there 'gley features' within about 1 m depth / Does the soil remain wet for at least about 2 days after rain in early spring?
Yes
No
Field capacity period
Soil moisture deficit period
Lateral seepage of water to streams & ditches.
Rain replenishes soil moisture. Intense storms may cause some leaching & lateral seepage.
Surface runoff on on land with slopes >1% (erosion on slopes >3%) & some lateral seepage to streams & ditches.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.
Leaching to groundwater with some surface runoff on land with slopes >1% (erosion on slopes >3%). Stream response to rainfall is slightly 'dampened'.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater.


F
Does the field have drains?
Yes
No
Go to F1
Is the topsoil texture clay with surface cracks in dry periods?
Yes
No
Is the topsoil texture clay or heavy loam?
Yes
No
Field capacity period
Soil moisture deficit period
Very rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate by-pass to streams & ditches.
Rapid lateral transfer of water to streams & ditches; some saturation runoff at wettest times.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater with relatively rapid transfer to streams.
Lateral transfer of water to streams & ditches. Some by-pass to groundwater and relatively rapid transfer to streams
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater with relatively rapid transfer to streams.


F1
Field capacity period
Soil moisture deficit period
Are there 'gley features' in the layer directly below the topsoil / Does the soil remain wet for at least about 5 days after rain in early spring?
Yes
No
Very rapid lateral seepage of water to streams & ditches.
Rain replenishes soil moisture. Intense storms may cause some leaching & rapid lateral seepage.
Are there 'gley features' within about 1 m depth / Does the soil remain wet for at least about 2 days after rain in early spring?
Yes
No
Surface runoff on on land with slopes >1% (erosion on slopes >3%) & some relatively rapid lateral seepage to streams & ditches.
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater with relatively rapid transfer to streams.
Leaching to groundwater with relatively rapid transfer to streams. Some surface runoff on land with slopes >1% (erosion on slopes >3%).
Rain replenishes soil moisture but intense storms may generate surface runoff on land with slopes >1% (erosion on slopes >3%) and some leaching to groundwater with relatively rapid transfer to streams.


G
Field capacity period
Soil moisture deficit period
Does the field have drains?
Yes
Is the topsoil texture clay with surface cracks in dry periods?
Yes
Very rapid lateral transfer of water to streams & ditches.
Rain replenishes soil moisture but intense storms may generate by-pass to streams & ditches.
No
No
Go to G1
Is the topsoil texture clay or heavy loam?
Yes
Rapid lateral transfer of water to streams & ditches.
Rain replenishes soil moisture. Intense storms may generate surface ponding & cause leakage to streams & ditches.
No
Lateral transfer of water to streams & ditches.
Rain replenishes soil moisture. Intense storms may cause leaching to groundwater

G1

Are there 'gley features' in the layer directly below the topsoil / Does the soil remain wet for at least about 5 days after rain in early spring?

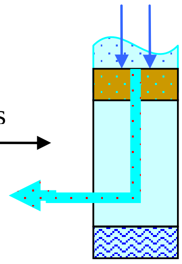
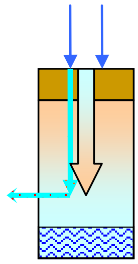
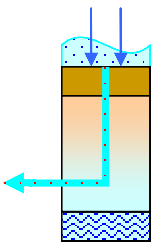
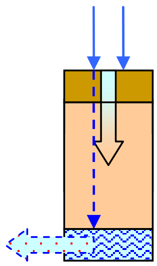
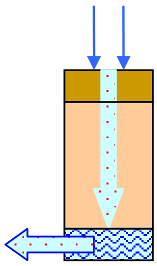
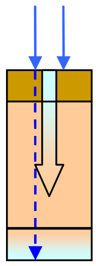
Yes →

No ↓

Are there 'gley features' within about 1 m depth / Does the soil remain wet for at least about 2 days after rain in early spring?

Yes →

No ↓

Field capacity period	Soil moisture deficit period
 **Lateral seepage of water to streams & ditches. Risk of flooding.**	 **Rain replenishes soil moisture. Intense storms may cause some leaching, lateral seepage or local flooding.**
 **Leaching and lateral seepage of water to streams & ditches. Risk of flooding.**	 **Rain replenishes soil moisture. Intense storms may cause some leaching & lateral seepage.**
 **Leaching to groundwater. Some leakage to streams & ditches. Risk of occasional flooding in responsive catchments.**	 **Rain replenishes soil moisture but intense storms may cause some leaching to groundwater.**

ANNEX 2 - IDENTIFICATION OF 'GLEY FEATURES' WITHIN THE SOIL

A soil layer has 'gley features' if it has the following:

Either greyish or pale colours dominant in the matrix or on structure (ped) faces and at least 2% ochreous (rusty) mottles;

Or if it underlies an organo-mineral or peaty topsoil and there are less than 2% ochreous mottles, grey colours are dominant in the matrix;

Or If reddish colours are dominant in the matrix, it has at least 2% greyish, brownish or ochreous mottles and dominantly pale-coloured Structure (ped) faces.

The above colours are defined as follows:

Greyish is a Munsell soil colour of any hue with chroma 2 or less and value more than 3.

Pale is a Munsell soil colour of any hue with *either* chroma 3 and value more than 4 or chroma 4 and value more than 5.

Brownish is a Munsell soil colour of hues 7.5YR to 10YR with *either* chroma 3 and value 4 or chroma 4 and value 4 or 5.

Ochreous is a Munsell soil colour of hue 10YR or redder with chroma more than 4 or value less than 5.

Reddish is a Munsell soil colour of hue 5YR or redder.

Munsell soil colour codes are standardised and given in books published by the Munsell Colour Company Inc., Baltimore, Maryland 21218, USA