Project no. 022704 (SSP)

FOOTPRINT

Functional Tools for Pesticide Risk Assessment and Management

Specific Targeted Research Project

Thematic Priority: Policy-orientated research

Deliverable DL25

Report on the identification of landscape features and contamination pathways at different scales

Due date of deliverable: July 2007
Actual submission date: October 2008

Start date of project: 1 January 2006 **Duration: 36 months**

Organisation name of lead contractor for this deliverable: University Giessen

Revision: N/A

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
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)	

Table of Contents

Foreword

The present report was prepared within the context of the work package WP3 ('Identification of landscape features and contamination pathways') of the FOOTPRINT project (http://www.eu-footprint.org).

The preferred reference to the present document is as follows:
Reichenberger S., Hollis J.M., Jarvis N.J., Lewis K.A., Tzilivakis J., Mardhel V., François O., Cerdan O., Dubus I.G., Réal B., Højberg A.L., Nolan B.T. (2008). Report on the identification of landscape features and contamination pathways at different scales. Report DL25 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 37 p.

Executive summary

Each of the three FOOTPRINT tools provides facilities to integrate landscape features and contamination pathways to provide innovative risk assessment tools. At all three scales covered by FOOTPRINT (local, regional and national/European), we make use of the HOST-CORPEN system, which is the hydrological component of the FOOTPRINT soil classification system developed within FOOTPRINT. The Flow Pathway Categories (FPC) are used in all three tools to identify the main pathways of pesticide transfer to water resources and to recommend suitable mitigation measures specific to each soil.

In the two GIS-based tools FOOT-CRS and FOOT-NES, the FOOTPRINT SUGAR index is used to put modelling results at the bottom of soil profiles in the broader context. Due to different levels of data availability, landscape elements are identified and accounted for differently between the 3 tools: In FOOT-FS, where the farmer should have very good knowledge on the landscape elements present on the farm, the user enters the landscape features directly when setting up the fields and water bodies. In FOOT-CRS the user can use a landscape feature shapefile. This shapefile can be obtained either by digitization against aerial photos (e.g. in the FOOT-CRS landscape feature digitizer tool) or by converting classified satellite images into a shapefile outside FOOT-CRS. At the national and EU scale, there is usually no information on landscape elements available. In FOOT-NES, information on – hypothetical - mitigating landscape elements is specified in the Mitigation Manager, which is included in the Pesticide Scenario Manager Module.

For each Flow Pathway Category (FPC) and season (dry/wet), relative importance classes for the contamination pathways surface runoff, erosion and drainage have been derived and tabulated. Similarly, tables of the relative importance class for leaching have been put together for all occurring FPC/FST combinations. From these tables, relative importance classes for the different pathways are determined for single fields (FOOT-FS) and scenario polygons (FOOT-CRS and FOOT-NES). In FOOT-CRS and FOOT-NES, the initial relative importance class for leaching is updated using the SUGAR index. In FOOT-CRS, the initial relative importance classes for surface runoff and erosion are updated with a reduction index determined by a surface runoff routing procedure. The dominant contamination pathways for two seasonal conditions are obtained by taking the maximum relative importance class value of the four pathways (runoff, erosion, drainage, leaching). In FOOT-CRS, a grid map of relative importance for drift is produced using cost-weighted distances to the surface water network.

1 INTRODUCTION

The main objective of Work Package 3 of FOOTPRINT was the identification of landscape features and contamination pathways for the three different scale levels: farm scale, catchment/regional scale and national/EU scale.

Since there are different purposes of application for the three tools, and also different levels of data availability at the different scales, the approaches used have to be adapted to the requirements of each tool. However, the HOST-CORPEN approach to determine Flow Pathway Categories (FPC) is a key component of all tools, and the FOOTPRINT SUGAR index is used in the same way in both GIS-based tools (FOOT-CRS and FOOT-NES).

In the present report, the methods used to identify landscape features and dominant contamination pathways in the three FOOTPRINT tools are described.

2 SCIENTIFIC BASIS

2.1 The HOST-CORPEN approach

The HOST-CORPEN approach is the hydrological component of the FOOTPRINT soil classification system developed within Work Package #2. HOST-CORPEN relies on a combination of the Hydrology Of Soil Types (Boorman et al., 1995; Schneider et al., 2007) and the CORPEN system (Groupe “diagnostic” du CORPEN, 1996). While HOST provides a quantitative link between soil types and stream response to rainfall, CORPEN provides seasonal differentiation of pollutant transfer pathways. The main features of HOST and CORPEN and their FOOTPRINT derivates are described in the following sections.

2.1.1 HOST

The Hydrology Of Soil Types (HOST) classification system groups soils according to their soil water regime, storage capacity during the climatic field capacity period and hydrogeological characteristics of their substrates. The final framework consists of 11 basic conceptual models of soil hydrological pathways, subdivided into 29 classes according to flow and storage characteristics. The system was originally developed in the UK and calibrated against measured data on catchment stream response to rainfall, the two principal indices being the Base Flow Index (BFI) and Standard Percentage Runoff (SPR). It has now been extended to the whole of Europe as reported by Schneider et al. (2007).

Each HOST class has a base flow index (HOST-BFI) attached to it. The HOST-BFI corresponds to the long-term average proportion of flow that occurs as 'base flow', which is assumed to be generated from groundwater storage as opposed to runoff. Values range from 1.0 to 0.17. HOST-BFI has been derived from measured long term stream flow data from for 575 catchments in the UK. Differences in BFI between HOST classes were derived using multiple regression analysis of the area fraction of each HOST class present in catchments with measured data. In FOOTPRINT, the HOST class is used in four different ways.

(1) It has been harmonised with the CORPEN diagnostic concepts for identification of pollutant transfer pathways in the field to create the HOST-CORPEN class and associated Flow Pathway Categories (FPC).
(2) It has been used to identify the FOOTPRINT hydrologic group (FHG) and the PRZM soil hydrologic group (cf. Annex 1).
(3) The HOST-BFI is used to derive the average BFI for each FOOTPRINT Soil Type (FST-BFI).
(4) The SPR index for each HOST class is combined with the IDPR value to derive the FOOTPRINT SUGAR index.

2.1.2 CORPEN

The CORPEN diagnostic system (Groupe “diagnostic” du CORPEN, 1996) was developed by ‘Comité d’Orientation pour la réduction de la pollution des eaux par les nitrates, les phosphates et les produits phytosanitaires provenant des activitiés agricoles’ (CORPEN), for application in France. The system is a whole-farm approach to reducing pesticide transfer to water resources, and is based on a systematic approach to identifying the main pesticide transfer pathways both within the soil and within the landscape. The CORPEN diagnostic system is designed to be implemented at the farm scale by local experts in consultation with the farmer. There are four basic steps of a CORPEN analysis:

(1) Consultation with the farmer to draw up a farm plan and to identify the basic types of soil and geology present;
(2) Hydrological categorization at the plot scale in the field during the autumn or winter when there is no soil moisture deficit.
(3) Categorisation of likely transfers of pesticides to surface or groundwater at the landscape level;
(4) Identification of the proposed solutions to reduce the impact of pesticide transfers, in consultation with the farmer.

The end product of the soil and hydrological categorisation is a set of diagrams illustrating the principal hydrological (and thus dissolved pesticide transfer) pathways from the field. Two diagrams are presented, one for conditions during the winter and one for conditions during the spring.

The soil component of the pathway identification uses similar features and associated conceptual models to those used in the HOST classification. For use in FOOTPRINT, the first two components of the CORPEN procedure have been harmonised with HOST to create the system of HOST-CORPEN classes and Flow Pathway Categories (FPC). These improve on both systems in that they incorporate the quantitative calibration of HOST class with runoff and base flow, but also include the separation of pollutant transfer routes into seasonal components as in CORPEN.

2.1.3 The HOST-CORPEN class

The HOST-CORPEN class is a combination of the HOST and CORPEN systems providing a set of conceptual models of hydrological and associated pollutant transfer pathways from the land to water resources, based on local soil and land characteristics. There are 7 classes based on hydrogeological characteristics and identified by substrate geology. The classes are coded A to G but some classes also have suffixes to indicate specific types of substrate: Ac, massive pre-Quaternary clay; Ah, Hard impermeable rock; Dc, chalk or soft limestone; Dl, deep permeable loam or clay; El, limestone; Es, sandstone. Each class is associated with a set of six Flow Pathway Categories (FPCs).

The HOST-CORPEN classes have been derived by combining the very similar HOST and CORPEN systems following working meetings between FOOTPRINT partners. They are used in FOOTPRINT to identify specific Flow Pathway Categories (FPC).

2.1.4 The Flow Pathway Category (FPC)

A FOOTPRINT Flow Pathway Category (FPC) comprises two, seasonally differentiated conceptual models of pollutant transfer pathways and their associated mitigation measures.

The FPCs have mainly been derived from the CORPEN conceptual hydrological diagrams with aspects of the HOST diagrams included. There are FPCs for each of 7 soil parent material types and, within each type, different FPCs depending on the presence or absence of artificial drainage systems, topsoil textural characteristics and soil water regimes. The associated, FPC- and season-specific mitigation measures that are recommended to the user were derived during FOOTPRINT activity 3.1.

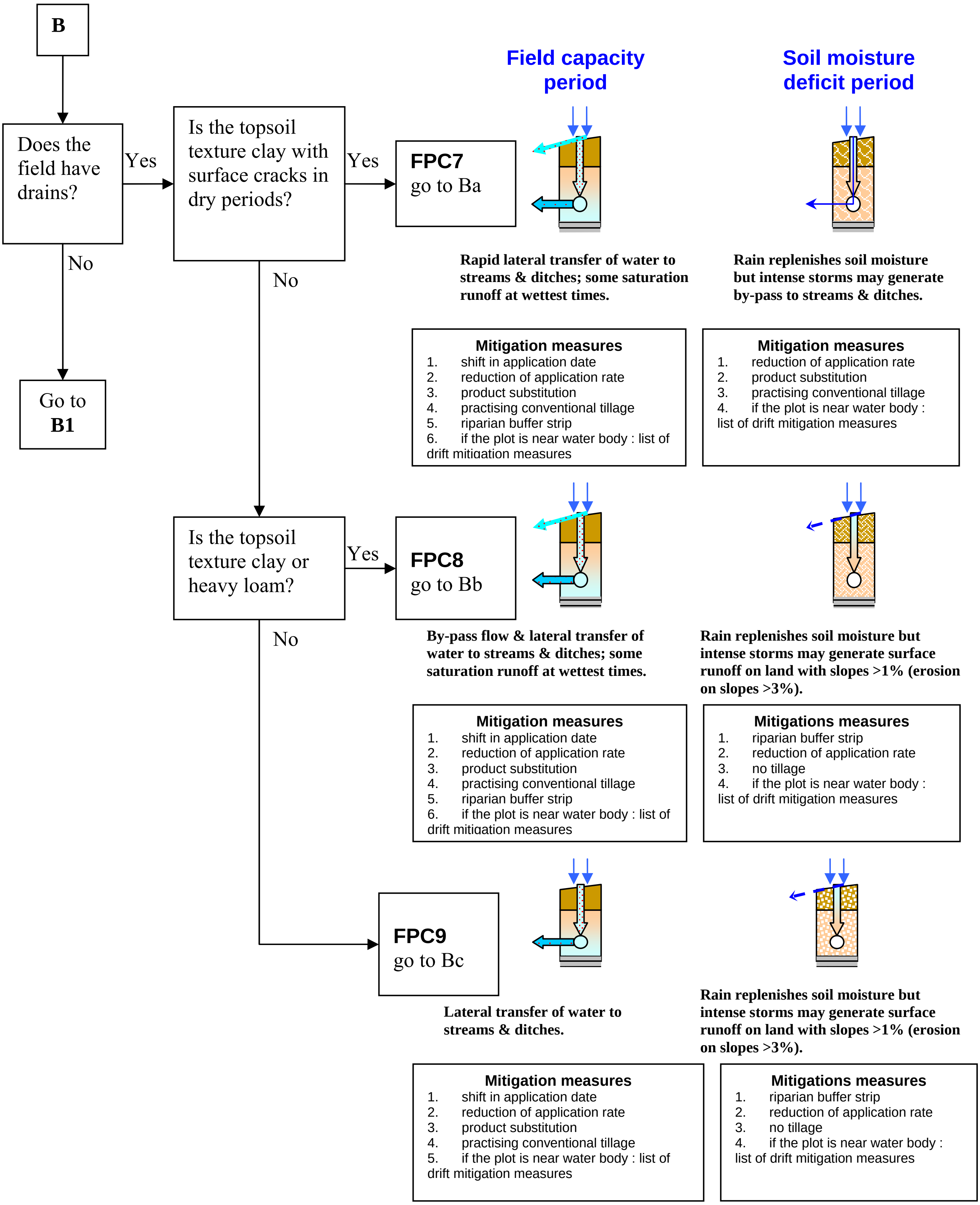

Figure 1 Exert from the FST-FPC-mitigation flow chart.

FPCs are used in all three FOOTPRINT tools to identify the main pathways of pesticide transfer to water resources and to recommend suitable mitigation measures specific to each FPC. There are several ways of identifying FPCs. Firstly by using the 'FOOTPRINT Soil Selector' tool, which was developed as part of FOOT-FS but is also usable as a standalone software application. This enables users to identify an FST and its associated FPC based on their local data, if available. Secondly, by using the FST-FPC-mitigation flow charts available in MS Word format (cf. Fig. 1 as an example). Thirdly, by using the FOOTPRINT 'default' data sets based on the Soil Geographical Database of Europe (SGDBE). Each STU in the SGDBE has a specific “typical” FPC associated with it.

2.2 The FOOTPRINT SUGAR index

The FOOTPRINT SUGAR index is based on the combination of the IDPR (Index of development and persistence of hydrological networks) index and the SPR (Standard Percentage Runoff) characteristic which is attached to each of the FOOTPRINT soil types.

2.2.1 The IDPR index

The general principle of the IDPR methodology is a comparison between the existing hydrological network for a given area and a theoretical one, which is being conceptualised on the basis of a number of factors. The theoretical hydrological network is established through the modelling of the presence of talwegs (this is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel) in the landscape from data originating from a digital terrain model (i.e. altitudes).

The IDPR index reflects the natural tendency of a given area to let water infiltrate and percolate to groundwater (tendency for infiltration) or to transfer water to an adjacent surface water body (tendency for surface or subsurface runoff). Areas with an index close to zero are areas largely contributing to groundwater recharge while those with an index close to 2000 are zones subject to runoff. The IDPR method has been widely used in France since 2004 and has been successfully tested in a number of regional-scale evaluation studies (ca. 8000 to 45000 km^2) in which the methodology was found to perform adequately against more data-hungry procedures (Mardhel and Gravier, 2005; Nowak and Mardhel, 2005). The methodology was also deployed in the Republic of Slovenia to assess the intrinsic vulnerability of groundwater in the country (Mardhel et al., 2004). The main advantage of

IDPR is its low data requirements, which means that the approach can relatively easily be applied to extensive zones where a detailed characterisation to support the use of more complex methodologies is lacking. The IDPR approach is therefore very well suited to support an assessment of the vulnerability of water resources to contamination at the large scale. It should be noted that IDPR methodology is also ideally suited to applications at the catchment scale and we are currently evaluating the IDPR approach at this scale using high resolution drainage network datasets (1:100,000 or finer). A paper on these evaluation/validation activities is being prepared (Dubus et al., in preparation).

The IDPR index is computed for each grid cell as the ratio of the distance to the closest calculated talweg and the distance to the closest actual watercourse, brought to a range of 0-2000 (Mardhel et al., 2006). Since the IDPR index is only little meaningful for single grid cells, the IDPR grid is subsequently aggregated to polygons reflecting e.g. hydrogeological units, administrative units or river catchments.

2.2.2 FOOTPRINT SUGAR

A first IDPR map was produced by BRGM in early 2007 and the map was subsequently discussed at a dedicated workshop in June 2007. Examination of the map revealed that although IDPR results were matching expectations in most European countries, IDPR did not perform well in others characterised by large flat plains. This deficiency could be explained by the use of altitude differences as the main driver of the methodology. To overcome these weaknesses, the IDPR index was further developed by combining it with the SPR index (Standard Percentage Runoff) from the HOST system (Boorman et al., 1995), which is available for each Soil Typological Unit (STU) in the SGDBE. The SPR index is the percentage of rainfall that causes the short-term increase in streamflow observed at the catchment outlet. It is obtained by analysis of flood event hydrographs and can be estimated for each combination of FOOTPRINT hydrological soil grouping and climate.

The FOOTPRINT SUGAR index was calculated from IDPR and SPR as described below in eq. 1. The normalisation of IDPR and SPR to a range of 0-100 before calculating SUGAR is necessary to ensure equal weighting of the two indices.

SUGAR = (IDPR’ + SPR’)/ 2 (eq. 1)

with IDPR’ = IDPR / 20

SPR’ = (SPR - 5) x 100/55

Where: IDPR’ varies between 0 and 100 (IDPR varies between 0 and 2000)

SPR’ varies between 0 and 100 (SPR varies between 5 and 60)

Consequently, like the normalised IDPR and SPR indices, SUGAR takes values between 0 and 100. Low SUGAR values denote areas where recharge to groundwater (infiltration) is dominant and high values denote areas where direct runoff to rivers is dominant. An EU-wide map of SUGAR was produced using the following datasets: the SRTM 90 m × 90 m altitude dataset and the 1 : 1,000,000 DCW drainage dataset. The resulting map is shown in Figure 2.

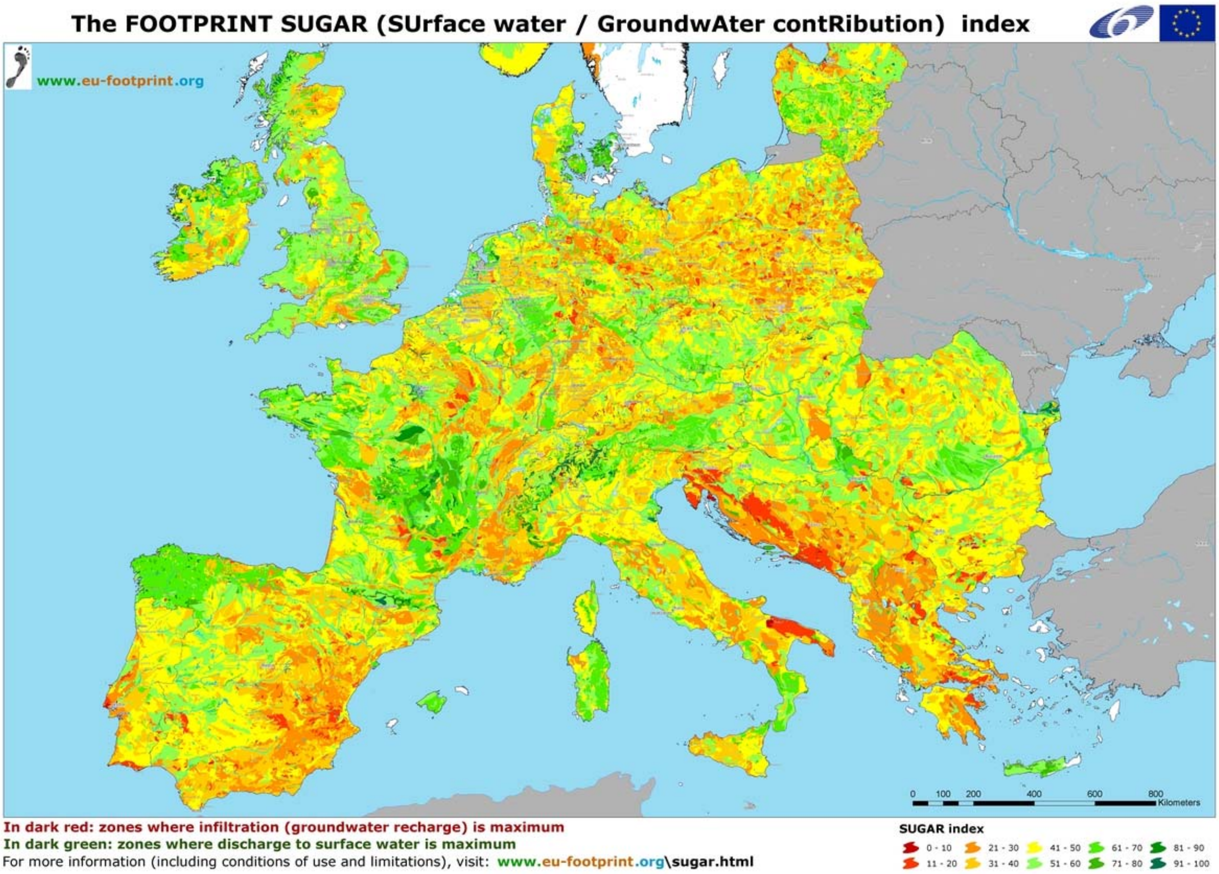

Fig. 2: Map of Europe showing the distribution of the FOOTPRINT SUGAR index

Areas in **dark green** contribute to surface water most whereas zones in **dark red** are infiltration areas which contribute most to groundwater recharge. SUGAR =SUrface water / GroundwAter contRibution index.
The white area (no data) in Southern Sweden and parts of Denmark is caused by a problem in one of the input maps: the soil map, the surface water network map or the DEM.

The limitations of FOOTPRINT SUGAR are as follows:

(1) SUGAR is inherently a qualitative index and cannot be used as a numerical index unless it is demonstrated otherwise in the future.

(2) SUGAR does not consider climatic aspects explicitly such as rainfall or evapotranspiration. However, climate is reflected both in the observed river network

and in the talweg network in the DEM (assuming fluvial erosion is the dominant relief-forming process).

(3) SUGAR is subject to a potential bias due to the fact that the underlying surface network datasets usually do not incorporate intermittent water courses. This is likely to be an issue in the Mediterranean countries where intermittent water courses are often created in response to high-intensity rainfall events.

A reference paper on SUGAR including a detailed technical description and the results of evaluation studies is being prepared (Dubus et al., in preparation). In addition, the European-level SUGAR map created in FOOTPRINT has been released to the general public through the FOOTPRINT web site (*http://www.eu-footprint.org/sugar.html*).

The development of the FOOTPRINT SUGAR index represents a major breakthrough in the identification of zones in the EU which most contribute to either recharge to groundwater or discharge to surface water. The index is not specific to pesticides and has a wide applicability within the context of EU legal initiatives to protect water resources such as the Water Framework Directive. The information can be used to support the definition or optimisation of monitoring programmes, to assess groundwater vulnerability when used in combination with other information and to contribute to the definition of priority zones for protection in Member States.

3 IDENTIFICATION OF LANDSCAPE FEATURES IN THE THREE TOOLS

Landscape features like hedges, riparian vegetation and grassed buffers strips and constructed wetlands are important for mitigation of drift and/or runoff/erosion inputs of pesticides into surface waters. The availability of data on presence, position, dimensions and properties of mitigation landscape elements strongly differs between the different scales at which the FOOT tools operate. Hence, landscape elements are identified and accounted for differently between the 3 tools.

3.1 FOOT-FS (Farm scale)

At the farm scale, the assessment is done for a specific, real farm. Hence, the user should have very good knowledge on the landscape elements present on the land belonging to the farm.

Consequently, the user enters existing landscape elements directly in FOOT-FS when setting up fields and water bodies.

3.2 FOOT-CRS (Catchment and Regional Scale)

Mitigating landscape elements have to be localized in the landscape, because their position is crucial for potential mitigation of pesticide inputs into surface water bodies. At the catchment scale, information on the position and dimensions of landscape elements can be obtained through aerial photos and high-resolution satellite imagery, cf. FOOTPRINT DL17 (François et al, 2007). The FOOT-CRS user will therefore be able to input a landscape feature shapefile into FOOT-CRS, which can be obtained either by digitization against aerial photos (e.g. in the FOOT-CRS landscape feature digitizer tool) or by converting classified satellite images into a shapefile (this has to be done outside FOOT-CRS).

The FOOTPRINT landscape feature types (stored as table in the FOOTPRINT classification database) are:

- hedge/forest (deciduous)
- hedge/forest (evergreen)
- grass
- shrubs
- inland (=freshwater) wetlands
- maritime wetlands

The FOOTPRINT landscape feature shapefile is later intersected with the Land Cover / Land Use map to produce a combined landscape feature / land cover map in grid format; the landscape feature layer is given priority. The reason for this procedure is that the spatial resolution of the landscape feature shapefile is usually finer than that of the land cover / land use layer, which is too coarse to display landscape features like hedges (for instance, the minimum mapping size of objects in CORINE Land Cover is 25 ha).

At the regional scale (e.g. for larger river basins), it will possibly be too much effort to obtain aerial photos or high-resolution satellite imagery that cover the whole assessment area.

However, with increasing scale of the assessment, also the available resolution of other spatial input data for FOOT-CRS decreases (e.g. DEM or surface water network). That means, for a a large river basin (e.g. the Rhine) where the available resolution of the other spatial input data sets is relatively coarse, the benefit of a landscape feature shapefile would be limited, and it’s justified to use only the land cover / land use map in the drift calculation and the routing of surface runoff.

3.3 FOOT-NES (National and EU scale)

At the national and EU scale, there is usually no information on landscape elements available: One simply cannot obtain and process aerial photos or high-resolution satellite imagery for such large areas. Since FOOT-NES is exclusively for prospective, scenario-based risk assessment, e.g. for policy-making or regulatory issues, and uses hypothetical surface water bodies, it is also not necessary to obtain remote sensing data on landscape features. Hence, information on – hypothetical - mitigating landscape elements is specified by the FOOT-NES user in the Mitigation Manager, which is included in the Pesticide Scenario Manager Module.

4 IDENTIFICATION OF CONTAMINATION PATHWAYS IN THE THREE TOOLS

4.1 FOOT-FS (Farm scale)

Activity 3.1 (Diagnostics at the farm scale and mitigation strategies) aimed at identifying pathways of water and pesticide transfers through the agricultural landscape at the farm scale, on the basis of local conditions and cropping/management practices. This identification is based on the HOST/CORPEN system (cf. Section 2.1). The farm-scale diagnostic for diffuse sources is conducted in four steps (cf. FOOTPRINT DL16; Reichenberger et al., 2007c):

1. Expert decision rules are used to determine “priority fields” on a farm which are more prone to contribute to pesticide contamination of groundwater or surface water than the other fields. This first step is a mere screening and is only optional. It serves the purpose of reducing the number of fields for which a risk assessment has to be performed. The screening is done in the “FOOT-FS field prioritiser”. This is a standalone software tool which can be called from the FOOT-FS shell. The rules used to determine “priority fields” are still being modified and therefore not listed here, but will be documented in the FOOT-FS User Manual.
2. The soil type of each “priority field” is classified into a Flow Pathway Category (FPC) using the FST-FPC-mitigation flow chart (cf. Fig. 1). This leads to a “relative importance class” for each field with respect to each combination of soil-related pathway (drainage, surface runoff, erosion, leaching) and season (field capacity season and moisture deficit season).
3. For each combination of FPC and season, specific recommendations for mitigation (= risk reduction) measures are made in the flow charts (cf. Fig 1).

4.2 FOOT-CRS (Catchment and Regional Scale)

4.2.1 Overview

A specific methodology to identify the dominant pathways of water and pesticide transfers through the agricultural landscape at the catchment and/or regional scale (ca. 1–10000 km^2) is used in FOOT-CRS.

The global approach to the identification of dominant contamination pathways consists in combining already available datasets (surface water network, soil maps, land cover, elevation, presence of landscape elements reducing drift or runoff and erosion inputs into surface water) to analyse the landscape with respect to pesticide contamination pathways.

The FOOT-CRS tool is designed to provide two types of output: qualitative (maps of relative importance, dominant pathways map) and quantitative (pesticide losses from fields, inputs into surface waters, PECsw, PECgw). While the quantitative component of FOOT-CRS is described in FOOTPRINT DL23 (Reichenberger et al., 2008), the qualitative component is described below.

The qualitative output of FOOT-CRS is produced by the Dominant Pathways module. The maps of relative importance of contamination pathways and of the dominant contamination pathway only depend on landscape properties: hydrology, topography, soils, land cover, land use, not on pesticide properties or application schemes.

The following chart describes the main steps to map the dominant contamination pathways.

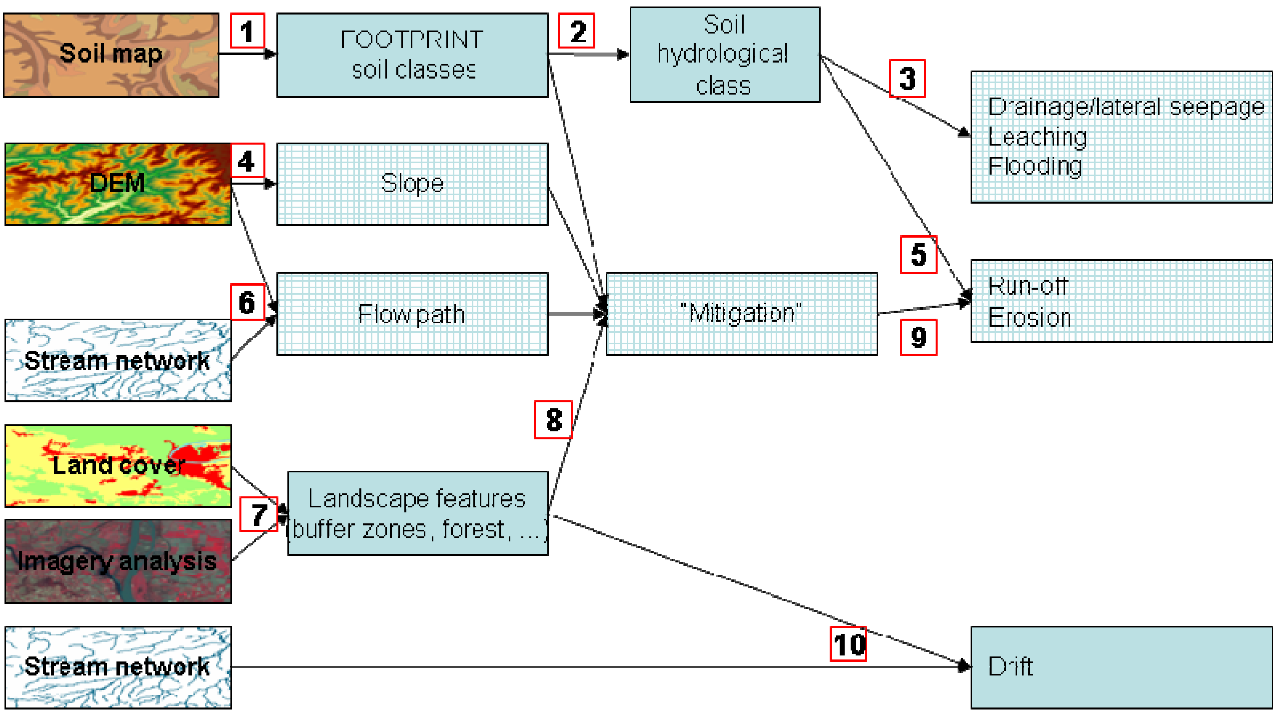

Figure 3 The FOOT-CRS approach for mapping the dominant contamination pathways

1. The first step is to assign a FOOTPRINT soil type FST (as defined in WP2 (cf. DL8)) for each soil map unit. This is already done for default data; for user input data, it can be done through an external soil selector software (FOOTPRINT soil selector) or the flowcharts in Word format (cf. Fig. 1).
2. To each soil typological unit in the user-input soil map a FOOTPRINT flow pathway category (FPC) can be assigned (cf. Fig. 1) simultaneously to the FST assignment. For the default FOOTPRINT soil map, this has already been done.
3. A look up table has been built (Tab. 1) to assign to each FPC a relative value “relative importance class” for each of the pathways runoff, erosion and drainage (and for two seasonal conditions), depending on the frequency of occurrence and magnitude of pesticide loss events. A similar lookup table has been set up for the pathway leaching, with relative importance classes assigned to each FST/FPC combination (not shown due to size).
4. Derive the slope from the Digital Elevation Model. Compute the average slope per soil mapping unit (SMU) polygon.
5. Use the FOOTPRINT agroenv. Scenario map (cf. Centofanti et al., 2008; Centofanti et al., 2007), the slope and the look-up table of relative importance classes (Table 1) to provide an initial class to runoff, erosion, drainage and leaching, for both seasonal conditions. If a soil mapping unit (SMU) contains more than one soil typological units (STU), an area-weighted mean class is calculated for each pathway and then rounded to integer.
6. From the DEM grid and the river network, compute the theoretical flowpaths (direction), for each cell.
7. Intersect landscape feature layer (shape) and land cover layer (shape) to a combined landscape feature / land cover layer in grid format. The landscape feature layer is given priority thereby.
8. Intersect the flowpaths layer, the landscape feature / land cover map and the soil map to a grid.
9. Perform routing procedure (cf. section 4.2.2) to identify the reduction of the transfer for eroded sediment and surface runoff to surface water bodies, taking into account the reinfiltration of surface runoff and redeposition of eroded material.
10. Calculate an area-weighted average “reduction index” for surface runoff and eroded sediment each. Update the relative importance class maps for surface runoff and erosion with the “reduction index”.
11. Use the river network and the landscape feature / land cover layer layer to derive the “relative importance class” for drift, which is a measure for the potential drift contamination risk.

FPC	season		relative importance classes				
	text	code	surface runoff		drainage	erosion	erosion
			slope 0-1 %	slope > 1 %	-	slope 0-3 %	slope > 3 %
FPC1	Field capacity period	FC	2	2	5	0	0
FPC1	Soil moisture deficit period	MD	0	1	1	0	0
FPC2	Field capacity period	FC	1	2	4	0	1
FPC2	Soil moisture deficit period	MD	0	1	0	0	1
FPC3	Field capacity period	FC	0	1	3	0	2
FPC3	Soil moisture deficit period	MD	0	1	0	0	1
FPC4	Field capacity period	FC	3	3	4	0	0
FPC4	Soil moisture deficit period	MD	1	1	1	0	0
FPC5	Field capacity period	FC	1	2	2	0	2
FPC5	Soil moisture deficit period	MD	0	1	0	0	1
FPC6	Field capacity period	FC	2	3	2	0	3
FPC6	Soil moisture deficit period	MD	1	1	0	0	1
FPC7	Field capacity period	FC	2	2	4	0	0
FPC7	Soil moisture deficit period	MD	0	1	1	0	0
FPC8	Field capacity period	FC	1	2	3	0	1
FPC8	Soil moisture deficit period	MD	0	1	0	0	1
FPC9	Field capacity period	FC	0	1	2	0	2
FPC9	Soil moisture deficit period	MD	0	1	0	0	1
FPC10	Field capacity period	FC	3	3	3	0	0
FPC10	Soil moisture deficit period	MD	1	1	1	0	0
FPC11	Field capacity period	FC	1	2	2	0	2
FPC11	Soil moisture deficit period	MD	0	1	0	0	1
FPC12	Field capacity period	FC	1	3	1	0	3
FPC12	Soil moisture deficit period	MD	0	1	0	0	1
FPC13	Field capacity period	FC	2	2	4	0	0
FPC13	Soil moisture deficit period	MD	0	1	1	0	0
FPC14	Field capacity period	FC	1	2	3	0	1
FPC14	Soil moisture deficit period	MD	0	1	0	0	1
FPC15	Field capacity period	FC	0	1	3	0	2
FPC15	Soil moisture deficit period	MD	0	1	0	0	1
FPC16	Field capacity period	FC	2	2	3	0	0
FPC16	Soil moisture deficit period	MD	0	1	1	0	0
FPC17	Field capacity period	FC	1	2	2	0	2
FPC17	Soil moisture deficit period	MD	0	1	0	0	1
FPC18	Field capacity period	FC	1	2	1	0	2
FPC18	Soil moisture deficit period	MD	0	1	0	0	1
FPC19	Field capacity period	FC	2	2	3	0	0
FPC19	Soil moisture deficit period	MD	0	1	1	0	0
FPC20	Field capacity period	FC	1	2	2	0	1
FPC20	Soil moisture deficit period	MD	0	1	0	0	1
FPC21	Field capacity period	FC	0	1	2	0	2
FPC21	Soil moisture deficit period	MD	0	1	0	0	1

FPC22	Field capacity period	FC	2	2	3	0	0
FPC22	Soil moisture deficit period	MD	0	1	1	0	0
FPC23	Field capacity period	FC	1	2	1	0	2
FPC23	Soil moisture deficit period	MD	0	1	0	0	1
FPC24	Field capacity period	FC	1	2	0	0	2
FPC24	Soil moisture deficit period	MD	0	1	0	0	1
FPC25	Field capacity period	FC	2	2	3	0	0
FPC25	Soil moisture deficit period	MD	0	1	1	0	0
FPC26	Field capacity period	FC	1	2	2	0	1
FPC26	Soil moisture deficit period	MD	0	1	0	0	1
FPC27	Field capacity period	FC	0	1	2	0	2
FPC27	Soil moisture deficit period	MD	0	1	0	0	1
FPC28	Field capacity period	FC	2	2	3	0	0
FPC28	Soil moisture deficit period	MD	0	1	1	0	0
FPC29	Field capacity period	FC	1	2	1	0	2
FPC29	Soil moisture deficit period	MD	0	1	0	0	1
FPC30	Field capacity period	FC	1	2	0	0	2
FPC30	Soil moisture deficit period	MD	0	1	0	0	1
FPC31	Field capacity period	FC	2	2	4	0	0
FPC31	Soil moisture deficit period	MD	0	1	1	0	0
FPC32	Field capacity period	FC	1	2	4	0	1
FPC32	Soil moisture deficit period	MD	0	1	0	0	1
FPC33	Field capacity period	FC	0	1	2	0	2
FPC33	Soil moisture deficit period	MD	0	1	0	0	1
FPC34	Field capacity period	FC	2	2	4	0	0
FPC34	Soil moisture deficit period	MD	0	1	1	0	0
FPC35	Field capacity period	FC	1	2	2	0	2
FPC35	Soil moisture deficit period	MD	0	1	0	0	1
FPC36	Field capacity period	FC	1	2	1	0	2
FPC36	Soil moisture deficit period	MD	0	1	0	0	1
FPC37	Field capacity period	FC	0	1	4	0	0
FPC37	Soil moisture deficit period	MD	0	0	1	0	0
FPC38	Field capacity period	FC	0	1	3	0	1
FPC38	Soil moisture deficit period	MD	0	0	1	0	1
FPC39	Field capacity period	FC	0	1	2	0	2
FPC39	Soil moisture deficit period	MD	0	0	1	0	1
FPC40	Field capacity period	FC	0	1	3	0	0
FPC40	Soil moisture deficit period	MD	0	0	1	0	0
FPC41	Field capacity period	FC	0	1	2	0	2
FPC41	Soil moisture deficit period	MD	0	0	1	0	1
FPC42	Field capacity period	FC	0	1	1	0	1
FPC42	Soil moisture deficit period	MD	0	0	0	0	0

Table 1 Lookup table for assignment of relative importance of the different contamination pathways. *The importance is displayed in classes ranging from zero (pathway not relevant) to five (pathway very important).*

4.2.2 Routing procedure in FOOT-CRS for surface runoff and eroded sediment

There are two different uses of the FOOT-CRS routing procedure:

a) qualitative: for updating the relative runoff and erosion classes in the map of contamination pathways
b) quantitative: for routing PRZM losses to the surface water network (see Reichenberger et al., 2008)

The routing has to be performed only 5 times (for 5 different rainfall amounts) and the resulting grids can be used for both the dominant pathways module and the modelling module. The principle is to reduce the runoff and/or erosion relative importance class given to one cell if the surface runoff contribution of this cell to the river network is limited by one or several mitigating landscape features. This is done by taking into account infiltration and deposition processes. Here, a routing approach is used that considers the accumulation of a theoretical initial runoff/erosion flow in the watershed, depending on the slope direction. In order to be able to take mitigating landscape features into account, the recommended analysis cell size is 10 m × 10 m.

In the routing it has to be considered that surface runoff also occurs from non-treated or even non-agricultural areas. There are three different situations:

- agricultural polygons with treated crop
- agricultural polygons without treated crop
- non-agricultural polygons (the agroenv. scenario shapefile doesn't include non-agricultural polygons; therefore, in FOOT-CRS an extra land cover map including non-agricultural parcels is needed)

It is assumed in FOOT-CRS that erosion from forest, grassland and urban areas is not significant. Erosion from non-treated areas can therefore be neglected.

For the reduction of runoff volumes, eroded sediment loads and associated pesticide losses, we use tables with reinfiltration (of surface runoff) and redeposition (of eroded particles) as function of soil, land cover, and runoff volume (Tables 2 and 3). These tables have been derived by Olivier Cerdan (BRGM) based on SCS Curve Numbers. For some land cover classes, redeposition also depends on the slope. The following rules and simplifications are used:

1. No reinfiltration takes place on arable land. This can be justified as follows:
    a. Infiltration will be much smaller on arable land than on forest/hedge;
    b. Arable land is treated as a runoff source area (infiltration capacity is exceeded or soil is saturated) and thus cannot serve as a runoff sink at the same time. Of

course, it can happen that a heavy rainstorm occurs only upslope and the soil downslope can act as a sink. But we consider that this case is less frequent than the occurrence of heavy rainfall on the entire slope or saturation at the footslope.

2. We make a distinction between three types of buffers: forest, grass, shrubs
3. Deposition is treated as independent of infiltration. However, a rule is defined ensuring that deposition percentage ≥ infiltration percentage. This way the occurrence of sediment transport without overland flow is avoided.

Land cover	Runoff index (mm/d)	PRZM soil hydrologic groups A	B	B-C	C	D
Forest	0-3	100	99	98	97	94
	3-12	100	92	86	79	70
	12-45	100	87	78	69	58
Grass	0-3	100	99	98	96	93
	3-12	100	90	84	78	69
	12-45	100	84	76	67	56
Shrubs (macchia)	0-3	100	99	98	96	93
	3-12	100	90	84	78	69
	12-45	100	84	76	67	56
Wetlands	0-3	100	100	100	100	100
	3-12	100	100	100	100	100
	12-45	100	100	100	100	100
Other		0	0	0	0	0

Table 2 Lookup table for reinfiltration (percentage of surface flow that is intercepted)

For arable land, it is assumed that no reinfiltration takes place. For wetlands (e.g. swamps, bogs, constructed wetlands), although complete infiltration occurs, it is assumed that 40 % of dissolved pesticide entering the wetland is transported further to the surface water body in the discharge of the wetland. Since the reinfiltration values have been derived based on tabulated SCS curve numbers, the reinfiltration values are likely to be too high for forest (the CN implicitly include canopy interception, which does not apply in the case of surface runoff inflowing from upslope).

Land cover	Runoff index	Slope class	PRZM soil hydrologic groups				
	(mm/d)	%	A	B	B-C	C	D
Forest	0-3	n.a.	100	100	100	100	100
	3-12	n.a.	100	100	100	95	84
	12-45	n.a.	100	100	94	83	70
Grass + vineyards/orchards/hops with good grass cover between rows	0-3	n.a.	100	100	100	100	100
	3-12	n.a.	100	100	100	93	83
	12-45	n.a.	100	100	91	81	67
shrubs (macchia)	0-3	n.a.	100	99	98	96	93
	3-12	n.a.	100	90	84	78	69
	12-45	n.a.	100	84	76	67	56
Wetlands	0-3	n.a.	100	100	100	100	100
	3-12	n.a.	100	100	100	100	100
	12-45	n.a.	100	100	100	100	100
Arable land (in cropping season, with crop cover)	0-3	0-1	95	94	93	92	89
		1-2	85	84	83	82	80
		2-5	68	68	67	66	64
	3-12	0-1	95	88	82	75	67
		1-2	85	79	73	67	60
		2-5	43	39	37	34	30
	12-45	0-1	95	83	75	66	55
		1-2	85	74	67	59	49
		2-5	17	15	13	12	10
Orchards (bare soil or poor grass cover between rows	0-3	0-1	65	65	64	63	61
		1-2	55	55	54	53	52
		2-5	52	52	51	50	49
	3-12	0-1	65	60	56	51	46
		1-2	50	46	43	40	35
		2-5	32	30	28	25	22
	12-45	0-1	60	52	47	42	35
		1-2	45	39	35	31	26
		2-5	12	10	9	8	7
Vineyards and hops (bare soil or poor grass cover between rows); Arable land (outside cropping season), fallow	0-3	0-1	45	45	44	43	42
		1-2	25	25	25	24	24
		2-5	0	0	0	0	0
	3-12	0-1	35	32	30	28	25
		1-2	0	0	0	0	0
		2-5	0	0	0	0	0
	12-45	0-1	25	22	20	17	15
		1-2	0	0	0	0	0
		2-5	0	0	0	0	0
Other			0	0	0	0	0

***Table 3 Lookup table for redeposition* (percentage of sediment load that is deposited)**

For slopes > 5 % and runoff volumes > 45 mm, deposition can be assumed as zero. For wetlands (e.g. swamps, bogs, constructed wetlands), although complete deposition occurs, it is assumed that 10 % of particle-bound pesticide entering the wetland is transported further to the surface water body in the discharge of the wetland. Since the redeposition values are also dependent on the reinfiltration values (Table 2) and these have been derived based on tabulated SCS curve numbers, the redeposition values are likely to be too high for forest (the CN implicitly include canopy interception, which does not apply in the case of surface runoff inflowing from upslope).

The routing of surface runoff is done on a grid basis. The most convenient solution is to use a user-defined cell size for the analysis. The reinfiltration and redeposition values in Tables 1 and 2 have been derived for a grid size 10 m × 10 m. Their lower limit of applicability is a grid size of 6 m × 6 m. For grid sizes much larger than 10 m * 10 m, there are two effects:

1. the reinfiltration and redeposition values are conservative, because the same reduction applies to a larger distance
2. mitigating landscape elements like hedges, buffer strips or grassed waterways are inevitably lost.

Hence, large grid sizes will yield a worst case analysis rather than realistic inputs of surface runoff and eroded sediment into surface water. In order to be able to take into account mitigating landscape elements, the recommended analysis cell size is 10 m × 10 m. The user will get a warning that the cell size must be compatible with the size of the landscape features and that the computation time will strongly increase when the cell size is small. It is obvious that most mitigation features like edge-of-field buffers, grassed waterways or hedges can only be accounted for with a grid size of 10 m or less. Otherwise they are lost in the transformation of the landscape feature layer and the land cover map to a land cover / landscape feature grid.

To keep the calculation time at an acceptable level, the routing is not performed 240 times, but only 5 times to create the basis for interpolation. Afterwards, the 240 runoff input maps and 240 erosion input maps are obtained by interpolation. The procedure is as follows:

1. Combine landscape feature (LF) map with original Land Cover (LC) map (including non-ag. polygons) to new LC/LF layer (grid) with the rule that LF are more important than LC, discerning three types of buffers: forest, grass, shrubs
2. Use 5 generic rainfall volumes to create the basis for interpolation:
   - 1st value: daily rainfall threshold for the generation of runoff for soil hydrologic group D, fallow condition, antecedent moisture condition II (CN = 94)
   - 2nd value: 90th percentile daily rainfall volume of the 20-year time series of the respective FOOTPRINT climate zone (FCZ). The percentile only refers to the days where rainfalls occurs, not to the whole 20 years.
   - 3rd value: 95th percentile daily rainfall volume of the 20-year time series of the FCZ
   - 4th value: 99th percentile daily rainfall volume he 20-year time series of the FCZ
   - 5th value: max. daily rainfall of the 20-year time series of the FCZ.
3. calculate (area-weighted) initial runoff volume using Curve Numbers specific for soil hydrologic group and CLC class.
   - CN are also needed for non-agricultural CLC classes (forest, urban, etc.).

- Possibly also consider dry and moist antecedent soil moisture conditions or crop vs. no crop.
- need to distinguish in CN for the relevant CLC classes between vines with grass and vines without or with only poor grass cover (same for orchards, olives, hops)

4. The routing is then performed in FOOT-CRS according to Fig. 4 (runoff) and Fig. 5 (erosion), using the reinfiltration and deposition values of Tables 1 and 2. The results are
   - 5 grids with “fraction of runoff volume reaching surface water” → average over polygon using zonal statistics → 5 values for each polygon
   - 5 grids with “fraction of eroded sediment reaching surface water” → average over polygon using zonal statistics → 5 values for each polygon

   The flow accumulation is performed in two iterations:
   (1) First calculate a theoretical flow accumulation of the generic runoff volume and calculate reinfiltration
   (2) From the theoretical flow accumulation and the reinfiltration of step (1), calculate an adjusted flow and recalculate the infiltration.

   For each cell, the total reduction of surface runoff and eroded sediment input into surface water is assessed using a routing function.
5. Calculate an area-weighted average “reduction index” (that is the percentage of runoff volume or eroded sediment that reaches the surface water (cf. Fig. 6) for each agroenv. scenario polygon. The reduction index is first computed on a grid basis and then aggregated to polygons.
6. Update the relative importance classes of the scenario polygons for surface runoff and erosion with the aggregated “reduction index”. Practically, the corrected class is the upper rounded product of the original class value multiplied by the reduction index. The result is updated fields in the attribute table of the FOOTPRINT dominant pathways map and the relative importance maps for runoff and erosion.

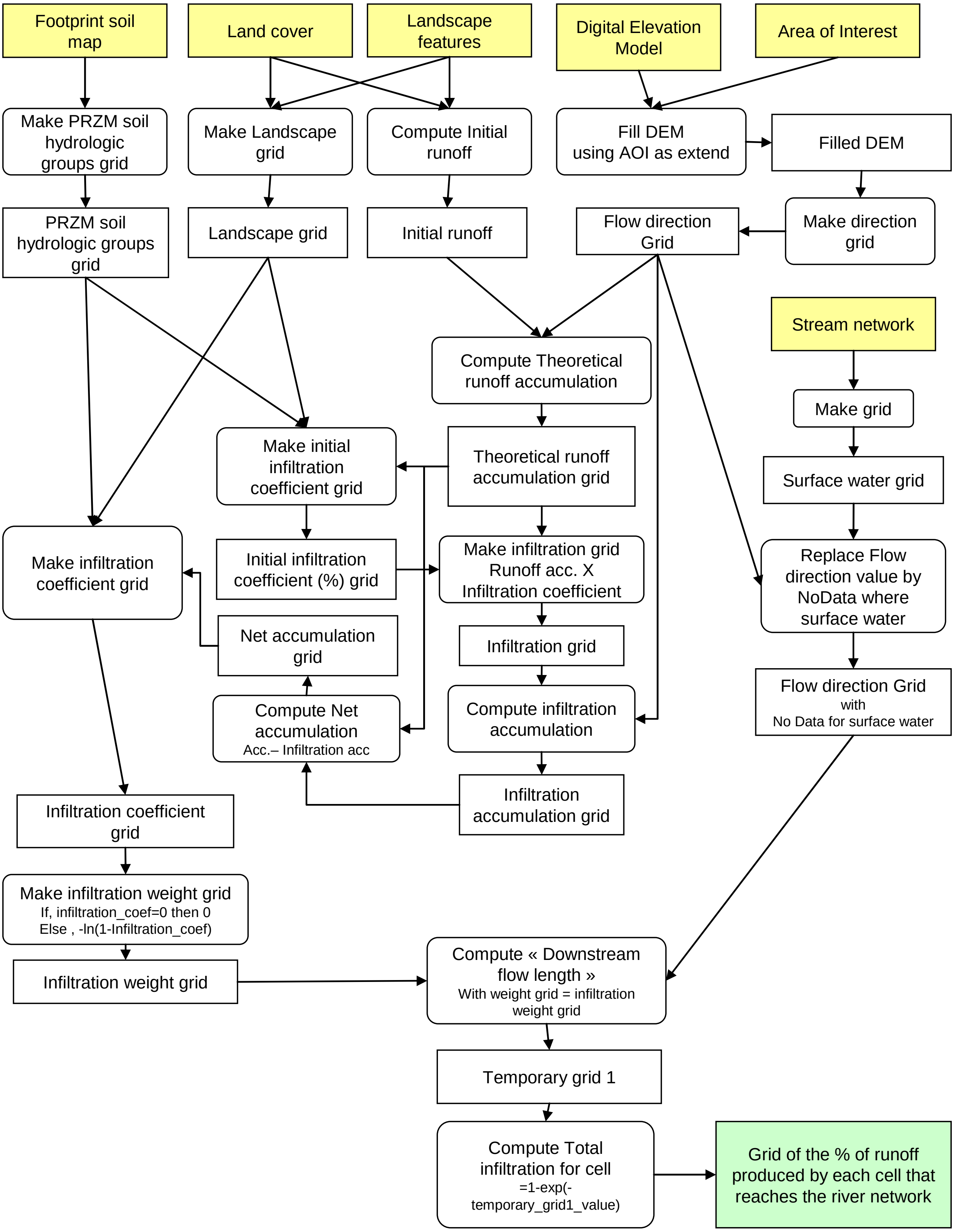

Figure 4 Flow chart to be used in FOOT-CRS for mapping the percentage of surface runoff that reaches the surface water

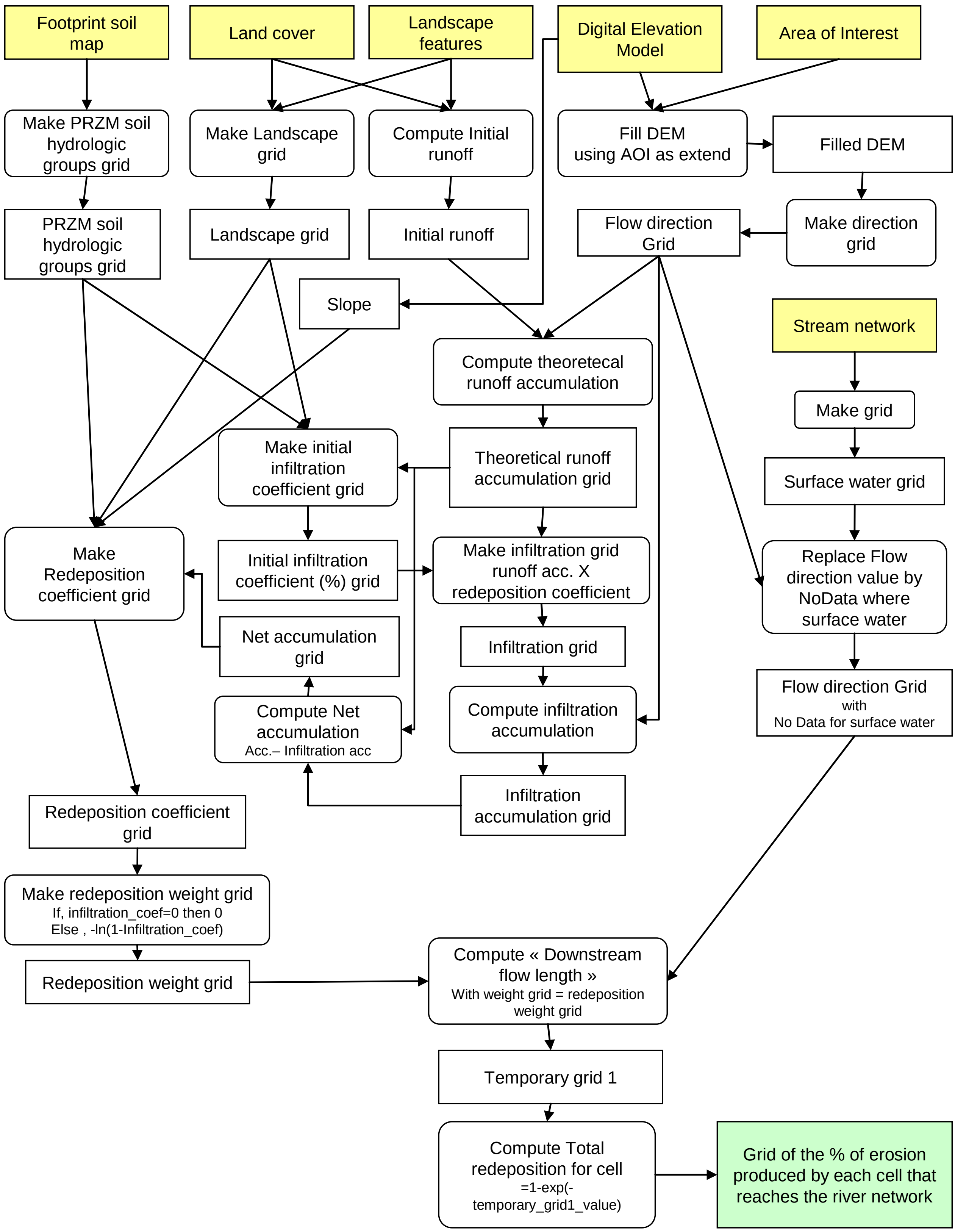

Figure 5 Flow chart to be used in FOOT-CRS for mapping the percentage of eroded sediment that reaches the surface water

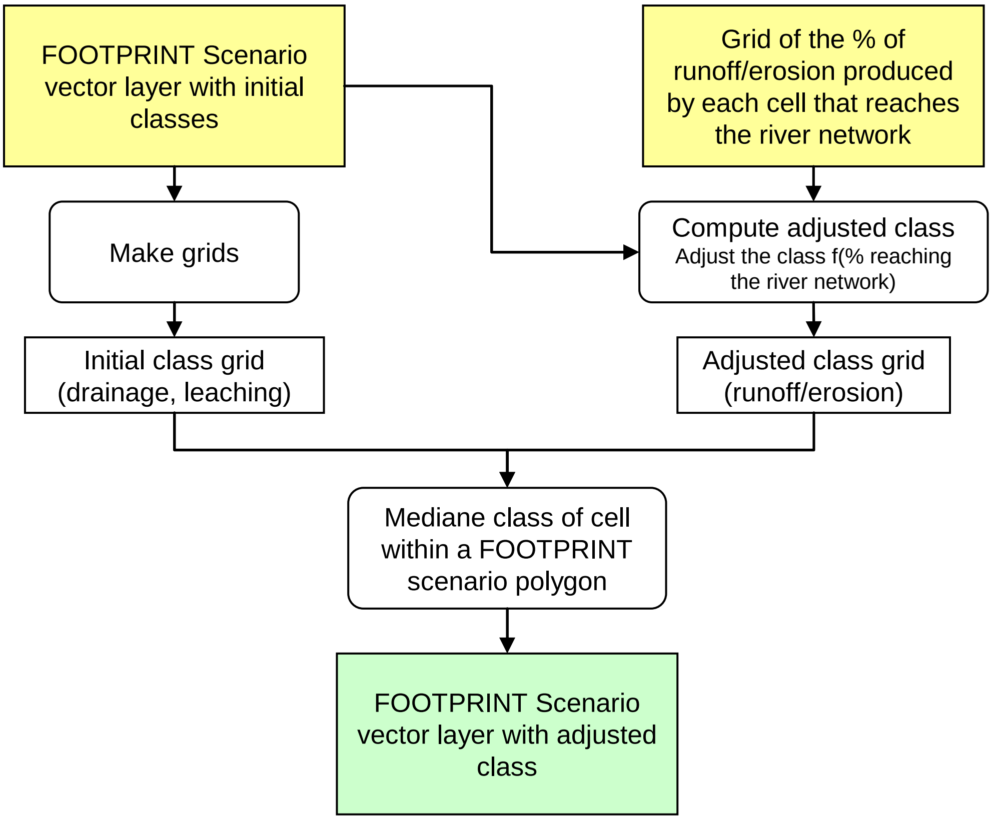

Figure 6 Flow chart to be used in FOOT-CRS for adjusted classes of surface runoff and erosion

4.2.3 Drift

The assessment of the contamination by drift is independent of the soil map. Here, we use the river network and the landscape feature layer to derive the risk of contamination. The two banks of the stream are not considered independently.

The computation of the drift class is performed for a 5 m × 5 m grid, in order to take into account the mitigating landscape features, and only for the cells which distance to the river is smaller than 150 meters. We consider that for larger distances, the contamination by drift is negligible. In order to take into account hedges and riparian vegetation, the proposed methodology uses cost weighted distances in eight directions:

First we compute 2 grids, one for each annual condition (basically: winter and summer), from the Landscape feature layer and the land cover and give a "high cost" to the cell containing a mitigation feature. The cost for mitigating features would be: 1/ (1- mitigation efficiency).

The mitigation efficiency (= reduction efficiency) is dependent on the season – see Table 4. The mitigation efficiency is based on the results of the literature review on mitigation measures and their efficiencies (Reichenberger et al., 2006; Reichenberger et al., 2007a).

	Seasonal condition	
	Winter (deciduous trees without foliage)	Summer (deciduous trees with full foliage)
hedges/forest - deciduous	25 %	75 %
hedges/forest - evergreen	75 %	75 %
Other	0 %	0 %

Table 4 Drift mitigation efficiency of landscape feature for a cell with 5 m * 5 m width (from DL7)

First, a 150 meter buffer around the river network is created. Then for each cell in the buffer and if Land cover = “arable land” or “Orchard” or “Vineyard” we compute the cost weighted distance to the river network, in the eight main directions, and for two annual conditions.

A “drift class” is finally assigned to each pixel using the minimum cost weighted distance of the eight directions (Fig. 7), and two grid maps (one for each season) of drift importance classes are produced (Fig. 8).

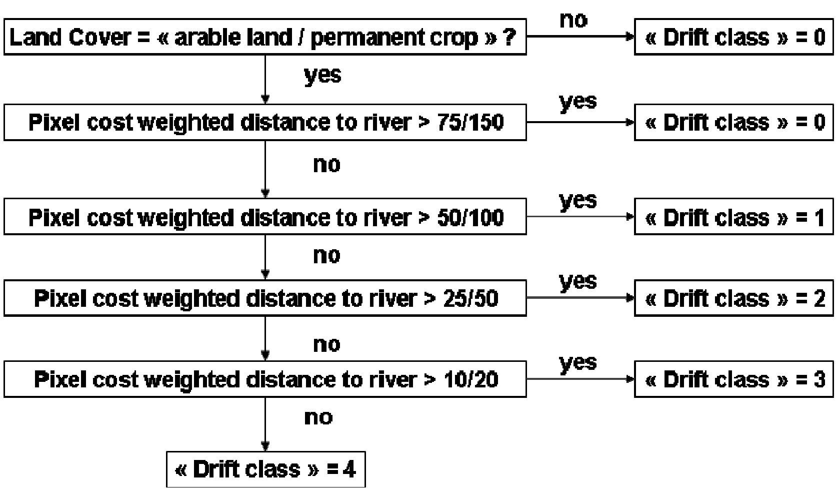

Figure 7 Chart for assignment of a drift class to each pixel using the minimum cost weighted distance

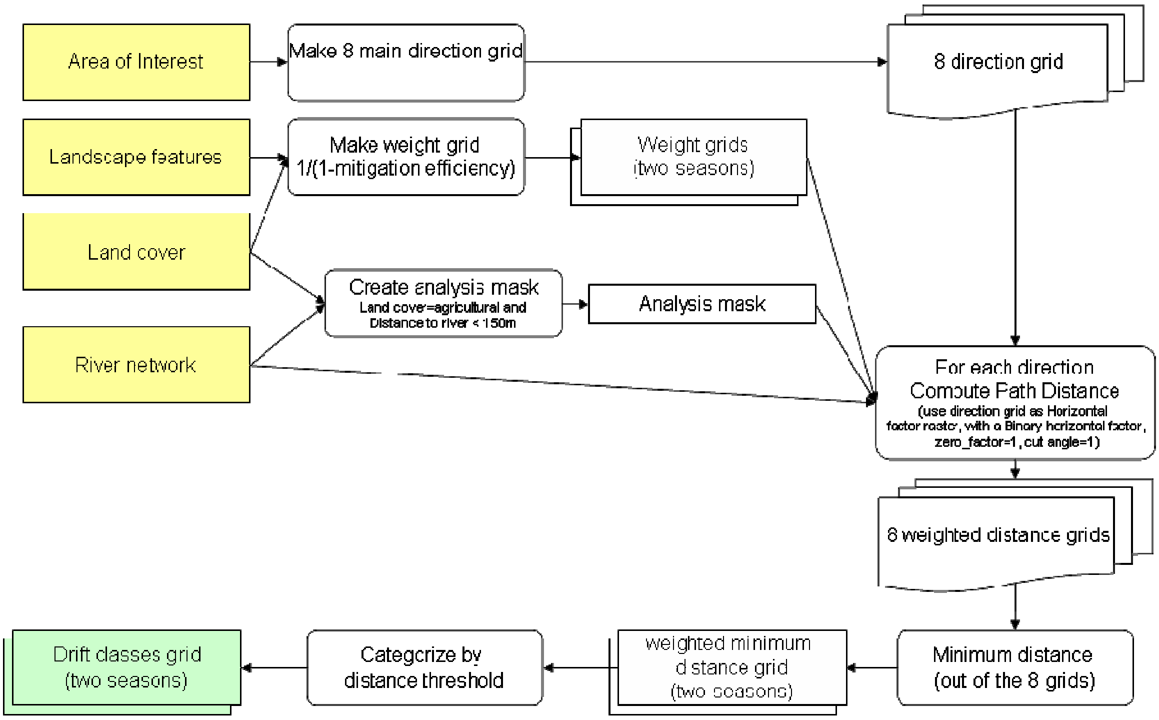

Figure 8 Flow Chart to be used in FOOT-CRS for mapping contamination risk by drift. *To take into account the scale of the landscape feature, the analysis cell size is set to 5 m × 5 m.*

4.2.4 Integration of the SUGAR map

The SUGAR index is calculated outside FOOT-CRS from the IDPR index and the Standard Percentage Runoff (SPR). More information on IDPR, SPR and SUGAR is given in FOOTPRINT DL18 (Reichenberger et al., 2007b) and in section 2.2 of this document. The normalisation of IDPR and SPR to a range of 0-100 before calculating SUGAR is necessary to ensure equal weighting of the two indices.

Integration of SUGAR in the map of dominant contamination pathways is done by updating the leaching importance class given by the FOOTPRINT soil map based on the value of the SUGAR index. This is done by intersecting both vector layers and modify the relative importance class values using the SUGAR index:

For a SUGAR index of 0 - 33, the relative importance class for leaching is not reduced.

For a SUGAR index of >33 - 66, the relative importance class for leaching is reduced by 1. However, it cannot be reduced to a lower value than 1.

For a SUGAR index of >66 – 100, the relative importance class for leaching is reduced by 2. However, it cannot be reduced to a lower value than 1.

4.2.5 Finalising the map of dominant contamination pathways

Intermediate output from actions described in sections 4.2.1-4.2.4:

- maps of relative importance for each soil-related transfer pathway (runoff, erosion, drainage, leaching) for 2 seasonal conditions → 1 vector layer (shapefile) with 8 attributes (only intermediate output)

Action:

- produce map of dominant contamination pathways for 2 seasonal conditions by taking the maximum (modified) class value of the four pathways (runoff, erosion, drainage, leaching) → add 2 attributes to the vector layer above)

Final output (to be displayed in form of colour-coded maps):

- SUGAR map (vector layer; already provided by the Data Manager Module)
- maps of relative importance of soil-related contamination pathways for 2 seasonal conditions (vector layer with 8 attributes). This comprises the pathways
  - drainage (area-weighted classes based on FPC)
  - surface runoff (area-weighted classes based on FPC)
  - erosion (area-weighted classes based on FPC)
  - leaching (area-weighted classes based on FST, FPC and SUGAR)
- map of dominant contamination pathways for 2 seasonal conditions (additional 2 attributes of the vector layer above)
- 2 grids for drift classes, one per seasonal conditions.

4.2.6 Cartographic representation of the dominant contamination pathway map

The “Dominant pathways” module will produce a map that provides the relative importance for contamination for each pathway. From these relative importances, also the “dominant” contamination pathways, i.e. the one with the highest relative importance, in each polygon can be derived. FOOT-CRS allows the user to display the relative importance class maps (Fig. 9 and 11) and the dominant contamination pathway map (Fig. 10) with pre-defined legends:

- For each soil dependent pathways (surface runoff, erosion, leaching, drainage): shape (FOOTPRINT scenario) 6 classes colour legend from 0 (very low) to 5 (extremely high)
- Map of the dominant pathway (s): for each seasonal condition, taking the max of 4 relative value maps. Legend: one colour per pathway, with relative intensity depending on the class from 0 (very low) to 5 (extremely high)

- If a polygon has no single dominant pathway, i.e. the highest relative importance class occurring in the polygon is shared by two or more pathways, the polygon is displayed in a shade of grey (the shade corresponds to the class value). The user can then find out with the ArcGIS "info" tool which are the most important pathways in this polygon.

- For drift : 5 classes colour legend from 0 (very low) to 4 (very high)

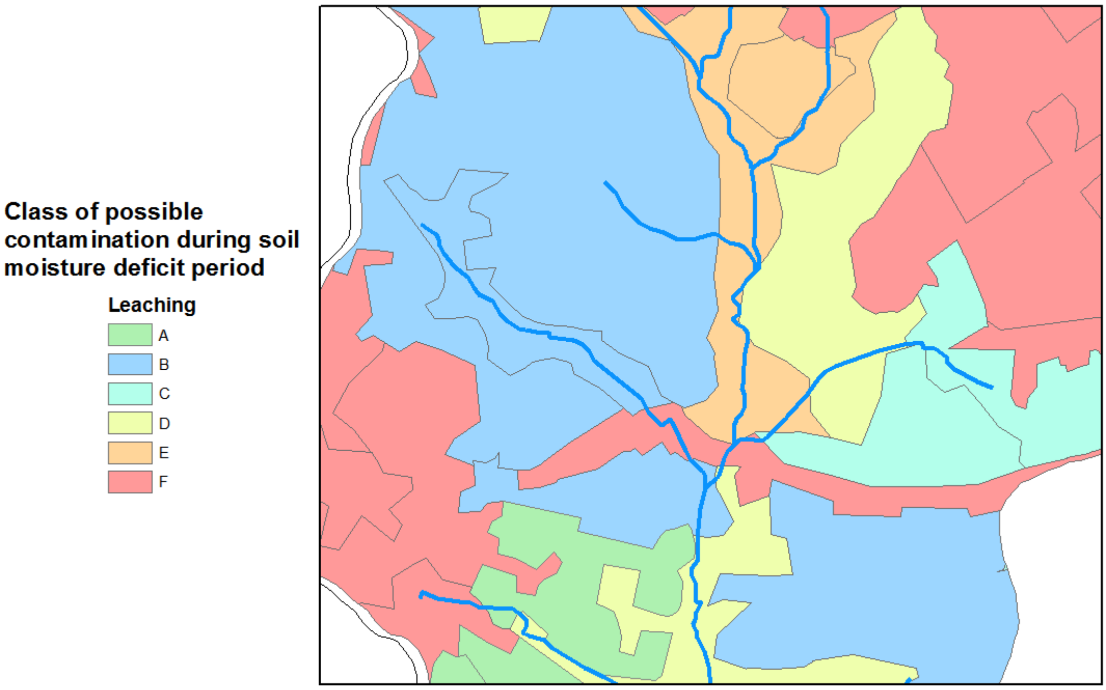

Figure 9 Map of relative leaching importance class during the soil moisture deficit period

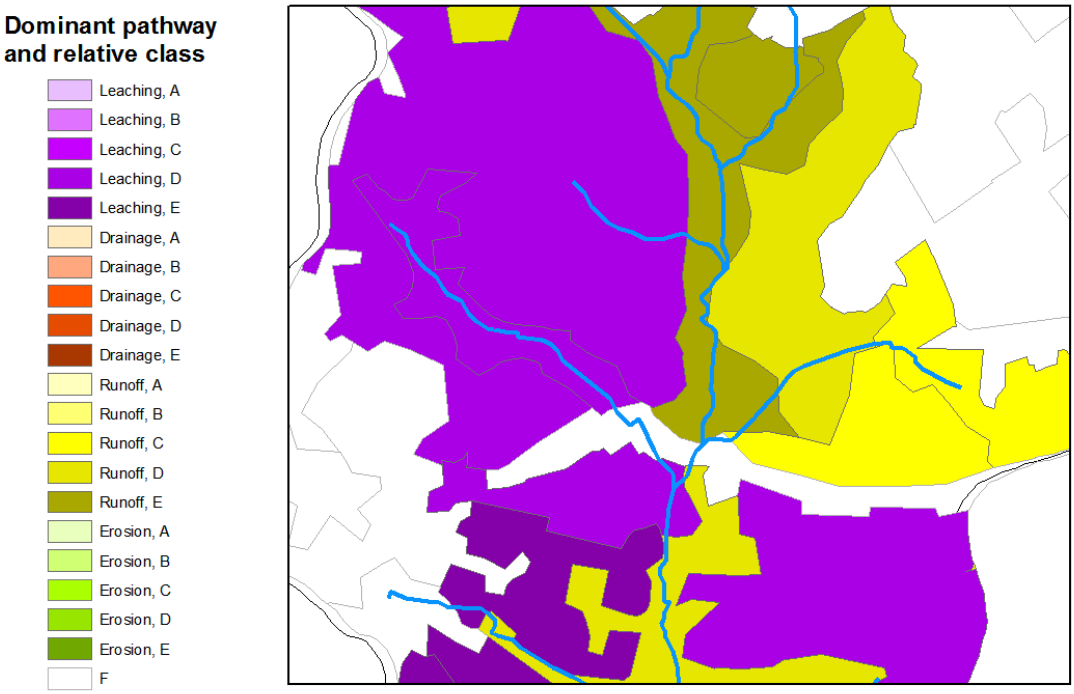

Figure 10 Map of dominant soil-related pathways

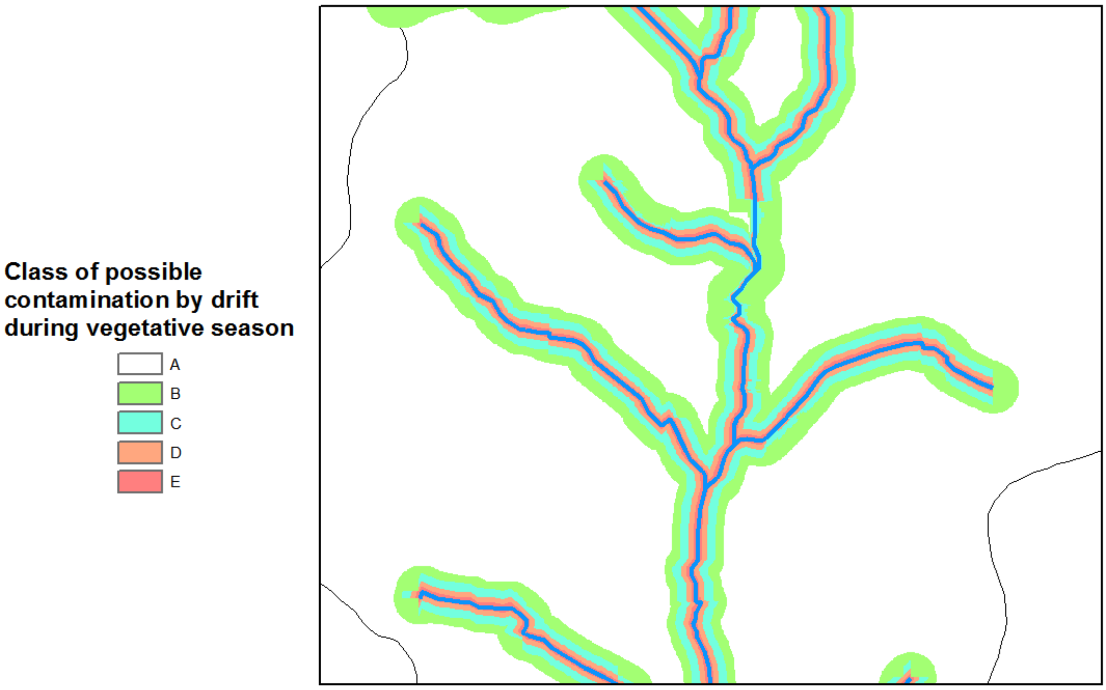

Figure 11 Map of relative importance class for drift during vegetative season

4.3 FOOT-NES (National and EU scale)

Since no landscape feature maps are available at this scale, the map of dominant contamination pathways focuses exclusively on the soil-related pathways and does not consider drift.

With respect to runoff and erosion it should be noted that since there is no landscape information available at these large scales, no routing of water and pesticides fluxes in the landscape is performed in FOOT-NES. The importance classes for runoff and erosion therefore reflect only soil properties, not the position of fields in the landscape nor presence/position of mitigating landscape elements.

Each STU in the agroenvironmental scenario database has an FPC and an FST attached to it. Thus, each STU can immediately be assigned a final relative importance classes for surface runoff, erosion and drainage, and a preliminary one for leaching. Subsequently, an area-weighted average over the different STU's in a polygon is calculated for each class.

The preliminary leaching importance class is thereafter updated with the SUGAR index to yield the final leaching importance class. This is done by intersecting both vector layers and modifying the relative importance class values using the SUGAR index, using the same rules as in FOOT-CRS:

- For a SUGAR index of 0 - 33, the relative importance class for leaching is not reduced.
- For a SUGAR index of >33 - 66, the relative importance class for leaching is reduced by 1. However, it cannot be reduced to a lower value than 1.
- For a SUGAR index of >66 – 100, the relative importance class for leaching is reduced by 2. However, it cannot be reduced to a lower value than 1.

The final output of the procedure is a set of colour-coded maps:

- FOOTPRINT SUGAR map (vector layer; already provided by the Data Manager Module)
- maps of relative importance of contamination pathways for 2 seasonal conditions (vector layer with 8 attributes). This comprises the pathways
  - drainage (area-weighted classes based on FPC)
  - surface runoff (area-weighted classes based on FPC)
  - erosion (area-weighted classes based on FPC)
  - leaching (area-weighted classes based on FST, FPC and SUGAR)
- map of dominant contamination pathways for 2 seasonal conditions (additional 2 attributes of the vector layer above)

5 CONCLUSIONS

The present document reported on current approaches used in the three FOOTPRINT tools to identify landscape features and contamination pathways at different scales. It may occur that during the later stages of the programming or during the evaluation phase changes to some methodologies become necessary. This document therefore only reflects the current state of knowledge and development. Substantial parts of the document will be incorporated in the technical reports of the three tools being developed. The technical reports will of course include all changes that may become necessary in the future development.

6 REFERENCES

Boorman D.B., Hollis J.M. & Lilly A. (1995). Hydrology of Soil Types: A hydrologically-based classification of the soils of the United Kingdom. Institute of Hydrology Report No. 126, Wallingford, UK. 137 pp.

Centofanti T., Hollis J.M., Blenkinsop S., Fowler H.J., Truckell I., Dubus I.G., Reichenberger S. (2008). Development of agro-environmental scenarios to support pesticide risk assessment in Europe. Science of the Total Environment, in press.

Centofanti T., Hollis J.M., Blenkinsop S., Fowler H.J., Truckell I., Dubus I.G., Reichenberger S. (2007). Identification of agro-environmental scenarios characterizing the variability of agricultural landscape within Europe. Report DL14 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 23 p.

François O., Reichenberger S., Cerdan O., Dubus I., Réal B., Hollis J.M., Højberg A.L., Nolan B.T., Mardhel V. (2007). Working methodology for application at the catchment/regional scale. Report DL#17 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 38 p.

Groupe “diagnostic” du CORPEN (1996). Qualité des eaux et produits phytosanitaires: Propositions pour une demarche de diagnostic. Republique Francaise, Ministere de L-Environnement et Ministere de l’Agriculture, de la Peche et de l’Alimentation. 113 pp.

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.

Mardhel V. & Gravier A., 2005 - Carte de vulnérabilité simplifiée du bassin Seine-Normandie. Rapport BRGM/RP- 54148-FR

Mardhel V. , Frantar P., Uhan J. & Mišo A. (2004). Index of development and persistence of the river networks as a component of regional groundwater vulnerability assessment in Slovenia. Poster presentation at the International conference on groundwater vulnerability assessment and mapping. Ustroń, Poland, 15-18 June 2004.

Mardhel V., Gravier A., Koch-Mathian J.-Y., Nowak C., Terreyre J.-L., Raguet M. & Garnier C. (2006). Simplified vulnerability mapping of groundwater in the Seine-Normandy Basin. Application to the BASOL sites. Proceedings Colloque international Gestion des grands aquifères, 30 May – 1 June 2006, Dijon, France. Chapter 37, 14 pp.

Nowak C. et Mardhel V, 2005 - Croisement des données des sites pollués, ou susceptibles de l’être, de l’outil BASOL et des données sur les nappes du bassin Seine-Normandie, rapport intermédiaire BRGM/RP-53253-FR.

Reichenberger S., Bach M., Hollis J.M, Jarvis N.J., Dubus I.G., Lewis K.A., Tzilivakis J., François O. & Cerdan O. (2008). Algorithms for calculation of predicted environmental concentrations based on pesticide inputs, size and discharge of water bodies etc. Report DL23 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 102 p.

Reichenberger S., Bach M., Skitschak A. & Frede H.-G. (2006). State-of-the-art review on mitigation strategies and their effectiveness. Report DL7 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 76p.

Reichenberger S., Bach M., Skitschak A. & Frede H.-G. (2007a). Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness; a review. Science of the Total Environment 384, 1-35.

Reichenberger S., Mardhel V., Allier D., Højberg A.L., Nolan B.T., Dubus I.G., Hollis J.M. & Jarvis N.J. (2007b). Working methodology for application at the national/EU scale. Report DL18 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 14 p.

Reichenberger S., Réal B., Hollis J.M., Jarvis N.J., Lewis K.A. & Tzilivakis J. (2007c). Working methodology for application at the farm scale. Report DL16 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 31p.

Schneider M.K., Brunner F., Hollis J.M. & Stamm C. (2007). Towards a hydrological classification of European soils: Preliminary test of its predictive power for the base flow index using river discharge data. Hydrol. Earth Syst. Sci., 11, 1–13.

Seine-Normandie, rapport intermédiaire BRGM/RP-53253-FR.

7 ANNEX 1: FOOTPRINT SOIL HYDROLOGIC GROUPINGS

FOOTPRINT hydrological code	HOST class	Description	MACRO bottom boundary condition	PRZM Soil Hydrologic Group
L	1, 2, 3, 5, 13	Permeable, free draining soils on permeable sandy, gravelly, chalk or limestone substrates with deep groundwater (below 2m depth).	Unit hydraulic gradient	A
M	4	Permeable, free draining soils on hard but fissured substrates (including karst) with deep groundwater (below 2m depth).	Unit hydraulic gradient	B
N	6	Permeable, free draining soils on permeable soft loamy or clayey substrates with deep groundwater (below 2m depth).	Unit hydraulic gradient	B-C
O	7	Permeable soils on sandy or gravelly substrates with intermediate groundwater (between 1 & 2 m depth)	Zero flow	A
P	8	Permeable soils on soft loamy or clayey substrates with intermediate groundwater (between 1 & 2 m depth)	Zero flow	B-C
Q	9, 10, 11	All soils with shallow groundwater (within 1m depth) and artificial drainage	Zero flow	A
R	17	Permeable, free draining soils with large storage, over hard impermeable substrates below 1 m depth	Zero flow	B
S	19	Permeable, free draining soils with moderate storage, over hard impermeable substrates at between 0.5 & 1 m depth	Zero flow	B-C
T	22	Shallow, permeable, free draining soils with small storage, over hard impermeable substrates within 0.5 m depth	Zero flow	C
U	20	Soils with slight seasonal waterlogging ('perched' water) over soft impermeable clay substrates	Zero flow	B-C
V	23, 25	Soils with prolonged seasonal waterlogging ('perched' water) over soft impermeable clay substrates	Zero flow	C
W	16	Free draining soils over slowly permeable substrates	Percolation rate regulated by water table height	B
X	18	Slowly permeable sois with slight seasonal waterlogging ('perched' water) over slowly permeable substrates	Percolation rate regulated by water table height	B
Y	14, 21, 24	Slowly permeable soil with prolonged seasonal waterlogging ('perched' water) over slowly permeable substrates	Percolation rate regulated by water table height	B-C
Z	12, 15, 26, 27, 28, 29	All undrained peat or soils with peaty tops	Not modelled	D