FRENCH REFINEMENT OF GROUNDWATER SCENARIOS

(VERSION 3.3.3.3)

Report of the UIPP Environmental Methodology Working Group

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Foreword

The placing of plant protection products on the market is regulated by Regulation 1107/2009 (European Parliament, 2009). The aim of these regulations is to ensure a high level of protection for both human and animal health and the environment and at the same time to safeguard the competitiveness of Community agriculture. They set the list of approval criteria and requirements which need to be addressed in order to authorize a crop protection product on the market, and the harmonized principles which have to be followed to assess and authorize these products.

At European level, and as far as the protection of groundwater is concerned, an active substance shall only be approved for Annex I listing where it has been established for one or more representative uses (after application of the plant protection product consistent with realistic conditions on use) that the predicted concentration in groundwater (PECgw) of the active substance or of relevant metabolites, degradation or reaction products are below the value of 0.1 µg/L as defined in the Directive 2006/118/EEC (European Parliament, 2006).

The calculation of these PECgw relies on the existence of modelling tools and associated European scenarios, which have been developed and validated under the requirements fixed under Directive 91/414/EC[1]. These tools and scenarios were set up by the FOCUS (FOrum for the Co-ordination of pesticide fate models and their USe) workgroup in order to describe realistic worst-case conditions As realistic worst-case, an overall vulnerability corresponding to the 90th percentile is defined. This is approximated by combining a 80th percentile value for soil and a 80th percentile value for weather (FOCUS, 2000). The FOCUS workgroup also contributes in creating and updating guidelines for the use and evolution of these tools.

Individual Member States have to ensure for the whole area where the Plant Protection Product will be used that the active substance "can be used safely for most of the relevant environmental conditions."(FOCUS, 2009). However, if this conclusion cannot be reached, unfavourable conditions should be identified and risk management may be considered. So, a key point is to know if authorization may be granted only for certain conditions (certain areas, e.g. climatic zones, or certain factors, e.g. soil pH or clay content) or in other words if risk management may be proposed for ground water.

In the absence of adequate national scenarios representative of the environmental conditions of their country, most member states use the FOCUS European scenarios to assess the safety of Plant Protection Products towards Groundwater. For instance, in France, the Agence Nationale de SEcurité Sanitaire (ANSES) considers that the safe use of the Plant Protection Product is demonstrated if the 80th percentile of

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[1] When models are used for estimation of predicted environmental concentrations they must:

- make a best-possible estimation of all relevant processes involved taking into account realistic parameters and assumptions,
- where possible be reliably validated with measurements carried out under circumstances relevant for the use of the model,
- be relevant to the conditions in the area of use.

annual average PECgw[2] at 1-meter depth for all nine EU FOCUS groundwater scenarios (Châteaudun, Hamburg, Kremsmünster, Jokioinen, Okehampton, Piacenza, Porto, Sevilla and Thiva) are under 0.1 µg/L (Farama et al., 2007). In case the PECgw are above 0.1 µg/L for the active substance and relevant metabolites, and/or > 10 µg/L for non-relevant metabolites (European Commission, 2003; ANSES, 2010), a refined risk assessment is needed and restriction measures may be enforced such as the limitation of the maximum number of applications per year, timing application or dose reduction. However, the variety, scope and applicability of these measures remain limited. Indeed, the FOCUS scenarios were developed as benchmark scenarios at European scale. Thus the vulnerability they represent for a specific nation cannot be accurately defined. For a refined risk assessment, the underlying agro-pedo-climatic information has to be re-evaluated at national scale to define appropriate scenarios. In contrast to the European FOCUS scenarios, national scenarios also allow to define risk mitigation measures based on soil properties or specific cropping practices.

Therefore, the need for a representative set of French scenarios for the assessment of groundwater contamination by Plant Protection Product was identified by the previous Authority in charge of the assessment of PPPs dossiers in France (Commission d'étude de la toxicité des produits antiparasitaires à usage agricole et des produits assimilés, des matières fertilisantes et des supports de culture, ComTox, Structure Scientifique Mixte, INRA-DGAL) and a specific joint workgroup between members of the Authority, technical institutes and UIPP (Union des Industries de Protection des Plantes) was established with the objective to generate adequate French groundwater scenarios based on selection of relevant soil/climatic/agronomic properties (Groupe méthodologie, sous-groupe Environnement, Atelier Eaux souterraines).

The joint ComTox workgroup stopped in July 2006 due to the reorganization of the regulatory system for pesticides in France, even though the new regulatory authority in charge of the evaluation of PPPs evaluation in France, AFSSA-DiVE (Agence Française de Sécurité Sanitaire des Aliments – Direction du Végétal), which was created in September 2006, showed continuous interest in the project (Balot, 2007; Balot et al., 2008). The project was continued and completed by a dedicated UIPP workgroup, who finalized the scenarios and produced a workable tool, including a database and a user-friendly model interface, as presented in this report.

This report is intended for potential users of FROGS for its regulatory purpose, hence primarily notifiers (companies seeking pesticide registration in France and consultants providing support in dossier preparation) and dossier reviewers (regulators), but also for any party interested in higher-tier national groundwater risk assessment.

FROGS 1.1.1.1 was published in 2010 and FROGS 2.2.2.2 was published in 2011. Both of these earlier versions were mainly based on regulatory modelling concepts outlined in FOCUS (2000). The update of the FROGS tool to the new version 3.3.3.3 was initiated to (i) take into account new guidance for groundwater modelling (FOCUS, 2009), (ii) make the tool compatible with the most recent model version of the underlying groundwater exposure model, PEARL 4.4.4 and its incorporated hydrologic model, SWAP 3234, (iii) improve the method for allocating crop surfaces and (iv) update the crop statistics with the agricultural survey data from 2010 (Agreste, 2010). FROGS 3.3.3.3 is described in this report.

[2] Deemed representative of an overall 90th percentile vulnerability since combined with 80th percentile vulnerability on soil.

References:

Agreste (2010) Recensement Agricole 2010 – Disar – Données en ligne, Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt

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FOCUS. (1995). Leaching Models and EU registration. European Commission Document 4952/VI/95.

FOCUS. (2000). FOCUS groundwater scenarios in the EU pesticide registration process. Report of the FOCUS Groundwater Scenarios Workgroup, EC Document Reference Sanco/321/2000 rev 2. 202pp.

FOCUS (2009) "Assessing Potential for Movement of Active Substances and their Metabolites to Ground Water in the EU" Report of the FOCUS Ground Water Work Group, EC Document Reference Sanco/13144/2010 version 1, 604 pp.

Main changes between FROGS 2.2.2.2 and FROGS 3.3.3.3.

Adaptation to FOCUS (2009)

- Implementation of changes as recommended by FOCUS (2009)
- The calculation of the temporal 80th percentile and spatial 80th percentile were updated to reflect FOCUS (2009) methodology. This is presented in section 9.2.
- FAO method to calculate reference evapotranspiration was included.
- Crop factors needed for the calculation of actual evapotranspiration were updated.

Adaption to PEARL 4.4.4

- FROGS 3.3.3.3 generates input files for Pearl 4.4.4.
- New bfo files have been generated due to the new version of the soil hydrologic model SWAP (v. 3234) employed in Pearl 4.4.4
- Splitting of rainfall due to problems with the earlier version of the hydrologic model SWAP integrated in PEARL 3.3.3 and therefore also in FROGS 2.2.2.2 was withdrawn.
- Eleven 4-year crop rotations that had been reduced to 3-year rotations in earlier versions of FROGS due to simulation time restriction in the former SWAP version were reintegrated as the new SWAP 3234 is capable to run 86 years of simulation time.

Improvement of crop surfaces allocation and use of agricultural survey data from 2010

- The methodology to estimate scenarios surfaces (i.e., soil-AU-crop combination) has been revised and FROGS database was updated accordingly.
- The crop statistics have been updated with the 2010 agricultural survey data. As a consequence, two new crop rotations where included.
- The methodology, the new surfaces and resulting new cumulative distribution are presented in Section 7.8.2, Section 10, Appendix 15, Appendix 16, Appendix 18, Appendix 19 and Appendix 20.

Finally, the Microsoft Excel® template ("FROGS_Template_Mitigation.xls") included with the FROGS package has been updated to include top soil pH as a potential mitigation.

Version number of FROGS package

It consists of four numbers corresponding to the shell, the database, the weather files and the hydrology *.bfo files

Version number	Corresponding version number of			
	Shell	Database	Weather	Hydrology
FROGS v3.3.3.3	3	3	3	3

The version numbers of the FROGS manual, FROGS database description and FROGS report should reflect the version number.

Table of Content

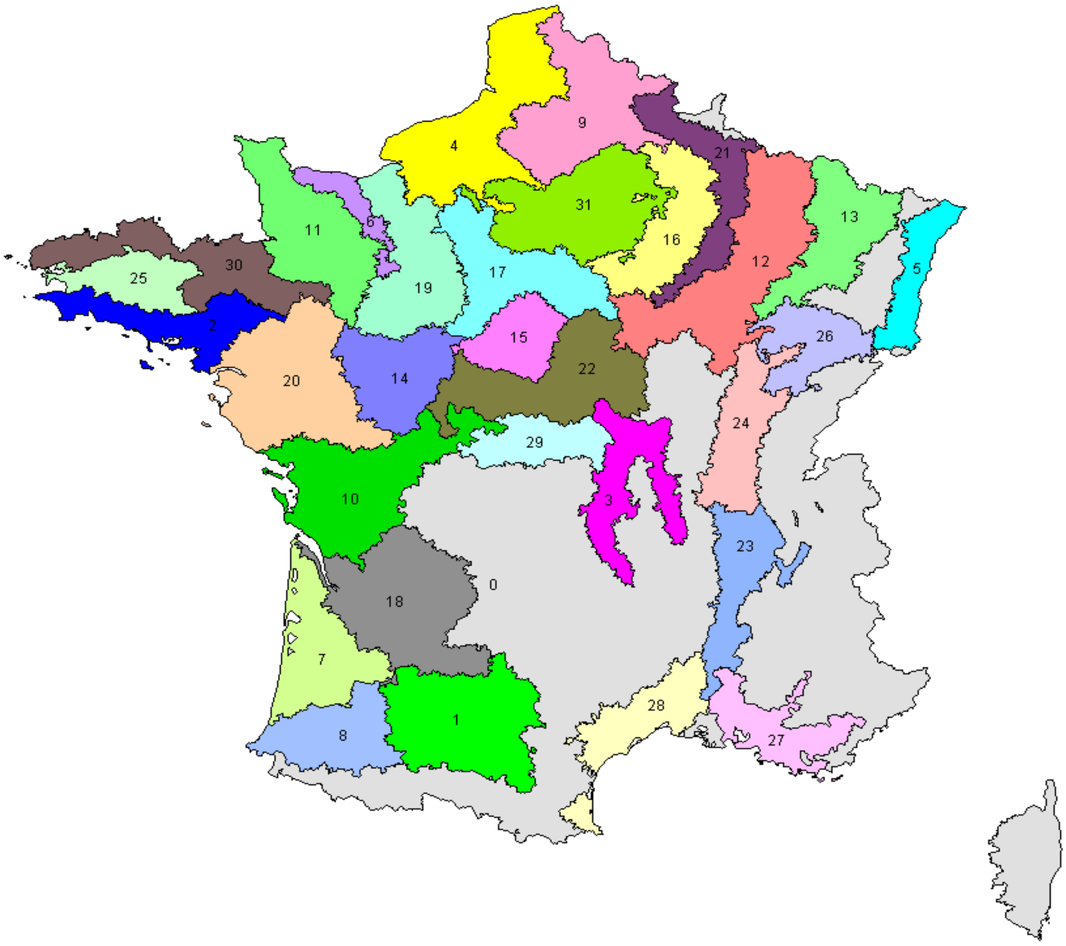
Summary

This report presents the rationale for the design and output of the FROGS modelling tools.

National scenarios have been constructed for pesticide-related groundwater risk assessment for sugar beet, winter wheat, oilseed rape, maize fodder, maize grain, winter barley, potato and sunflower. These scenarios consist of the combination of limited number of Agronomic Units (AUs) associated to soil, meteorological, crop rotations and phenological information. They have been generated to reflect typical realistic conditions and practices under which arable crops are grown in France.

The first step of the construction of the scenarios was the definition of Agronomic Units (AU) (see Chapter 2). AUs are homogeneous geographic entities which show common agricultural (intensity of cultivation, crop rotations) and physical conditions (climate, hydrogeology,) for the growing of arable crops. They were obtained by combining information on spatial crop distribution in farmland (agricultural census), agricultural environment types and climatic zones. A total of 31 agronomic regions were defined, which cover the whole of France. These are represented in the following map:

Agronomic Units for use in French Refinement of Groundwater Scenarios



No.	Agronomic Unit	No.	Agronomic Unit
0	Not accounted for [(1)]	16	Champagne crayeuse
1	Collines molassiques - Lauragais	17	Beauce - Drouais - Gâtinais
2	Bretagne sud	18	Bordelais - Périgord - Coteaux du Lot
3	Limagnes - Plaine du Forez	19	Perche - Pays d'Auge - Pays d'Ouche
4	Bordure maritime Nord - Picardie - Normandie	20	Bocages de l'ouest
5	Alsace - Sundgau	21	Ardenne - Argonne - Champagne humide
6	Plaine normande - Bessin	22	Champagne berrichonne - Boischaut
7	Aquitaine - Landes	23	Bas Dauphiné - Vallée du Rhône
8	Bassin de l'Adour	24	Fossé bressan
9	Picardie - Nord - Pas-de-Calais	25	Bretagne centrale
10	Charentes	26	Plateaux de Haute-Saône
11	Bocage normand	27	Provence
12	Barrois - Plateaux bourguignons	28	Plaine du Languedoc-Roussillon
13	Plateau lorrain	29	Boischaut du sud
14	Gâtines - Vallées de Loire	30	Bretagne nord
15	Sologne - Orléanais	31	Ile-de-France

[(1)] Corresponds to territory for which the proportion of arable land is negligible compared to non-agricultural areas (mainly forests and mountains)

Selection of representative soil, climate and cropping conditions within each agronomic unit was then performed as follows:

- Land cultivation (agricultural census 2000)
  Crops covering a significant surface were identified in each agronomic unit based on the 2000 agricultural census. Thus depending on the surface of the crop within the AU, a crop might or might not be considered relevant for this AU (see Chapter 2).

- Crop rotations (Agreste data, local expertise)
  Typical rotations were determined for each unit based on local expert knowledge and validated based on available Agreste data (see Chapter 3).

- Crop phenology
  One of the features of FROGS is to allow representative scheduling of application timing according to the specific crop development stage. This means that the user specifies BBCH code, application rate, and target crop, while the FROGS shell derives the actual application dates for each year in the relevant AUs for the target crop. The actual application dates are calculated in function of the weather data of each AU using crop phenological sub-models implemented in the shell. The phenological sub-models were validated with actual biological data from France (see Chapter 4).

- Climatic data (MARS database, Meteo France)
  For each agronomic unit (AU) one MARS tile had to be defined to represent the meteorological conditions within the corresponding AU. The selection was based on the most representative tile regarding agricultural conditions and range of weather conditions within the AU (see Chapter 5).

- Crop irrigation (Agreste, local expertise)
  Data obtained from the Agreste database and local expert knowledge (Chambres d'Agriculture) were aggregated for each (AU) (see Chapter 6).

- Agricultural soil properties and parameters (Geographic Database of French Soils [BDGSF], DONESOL 2, BDAT)
  The distribution of 19 typical agricultural soils selected by INRA (Infosol Unit) was used to determine representative combinations of crops and soils in each agronomic unit. These combinations, which reflect typical farmland situations, are at the basis of national scenarios. Their representativeness can be expressed in terms of surface area (see Chapters 7-8).

A total of 1074 scenarios were defined as relevant unique combinations of AU, soil type and crop. The number of defined scenarios varies depending on the selected crop (from 21 for potatoes to 219 for winter wheat, see Appendix 1), since not all AUs are relevant for a given crop, and not all soil types are relevant for a given AU.

The parameters defining the scenarios are stored in the FROGS database. The FROGS interface (GUI) is then used to generate the relevant model input files for PEARL from the FROGS database, the model batch file to run the scenarios and some basic output files to compile and plot the results. Currently, PEARL is the only model which is used by the FROGS GUI, but in principle, any of the FOCUS so-called chromatographic models (PEARL, PELMO, PRZM) could be used with the parameters in the FROGS database (with some adaptation of the soil parameters, which are expressed differently in PEARL compared to PRZM and PELMO, but are based on the same basic information). Further work would be necessary to implement the scenarios in a preferential flow model such as MACRO or to make use of the preferential flow capabilities of PEARL 4.4.4, since the relevant model parameters for soil macroporous flow have not been determined.

The input data required by the FROGS GUI (active substance parameters, metabolism scheme and application scheme) is the same as required for any standard FOCUS groundwater calculations, except for the application relative to BBCH, which is a specific feature of FROGS. In addition, all specific features of the PEARL model, such as pH-dependent sorption or non-equilibrium sorption, can be used in FROGS.

The proposed output format from FROGS is a cumulative agricultural area distribution of predicted environmental concentrations in groundwater from low to high concentrations. Ideally, if all scenarios show minimal potential for leaching, all concentrations will be below 0.1µg/L. However if scenarios representing vulnerable conditions are found, for which the regulatory limit in groundwater is exceeded, these can be easily identified. Based on localization and/or specific soil or hydro-geological conditions, mitigations may be proposed or more refined modeling may be conducted.

The FROGS scenarios are developed for the main field crops. However, with additional work, a more complete range of crops may be added, including perennial and other fruit and vegetable crops so that, with further work specific to perennial crops, all of the major crops grown in France could be included.

Test runs were performed using parent and metabolite dummy substances, and comparing the FROGS output to the corresponding FOCUS groundwater results. The results demonstrate that the FROGS modelling tool can be used to assess groundwater risk in France.

A full discussion of these findings along with suggestions for how the cumulative predicted environmental concentrations can be used in risk assessment are presented (see Chapters 9 and 10). Some use restrictions may also be proposed if specific combinations of crop/soil/climate are identified that show increased potential for leaching to groundwater of the substance of interest. Alternatively, additional higher-tier modeling refinements or other higher tier assessment (e.g. field leaching studies, groundwater monitoring) may be performed to further evaluate the leaching potential on the identified critical conditions.

GLOSSARY OF ABREVIATIONS

AFSSA	Agence Française de Sécurité Sanitaire des Aliments
AGRESTE	Division of French Ministry of Agriculture dealing with Statistics
ANSES	Agence Nationale de SEcurité Sanitaire
a.s.	active substance
AU	Agronomic Unit
AUID	FROGS Agronomic Unit Identification Number
AWC	Available Water Content
BBCH	growth stage scale developed by German authorities and chemical industry (Biologische Bundesanstalt, Bundessortenamt and CHemical industry)
BDAT	Base de Données d'Analyse de Terre
BDGSF	Base de Données Géographique des Sols de France
BRGM	Bureau de Recherches Géologiques et Minières
CGSM	Crop Growth Monitoring System
CID	FROGS Crop Identification Number
CLC	Corine Land Cover
ComTox	Commission d'étude de la toxicité des produits antiparasitaires à usage agricole et des produits assimilés, des matières fertilisantes et des supports de culture
CORPEN	Comité d'Orientation pour des Pratiques agricoles respectueuses de l'Environnement
DGAL	Direction générale de l'alimentation
DONESOL	Base de données nationale des informations spatiales pédologiques
DiVE	Direction du Végétal
ECPA	European Crop Protection Association
EEA	Europe Environmental Agency
ESBN	European Soil Bureau
ESGDB	European Soil Geographical DataBase
ETC	European Topic Centre

EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FOCUS	FOrum for Co-ordination of pesticide fate models and their Use
FROGS	French Refinement Of Groundwater Scenarios
GAP	Good Agricultural Practice
GIS	Geographical Information System
GISSOL	Système d'information des sols de France
GUI	Graphical User Interface
GW	Groundwater
HER	Hydro-Eco Régions
HYPRES	HYdraulic PRoperties of European Soils
IFEN	Institut Francais de l'ENvironnement
INRA	Institut national de recherche agronomique
INSEE	Institut National des Statistiques et des Etudes Economiques
JRC	Joint Research Centre
MACRO	MACRO is a one-dimensional, process oriented, dual-permeability model for water flow and reactive solute transport in soil
MARS	Monitoring of Agriculture with remote Sensing
MF	Fodder Maize
MG	Grain Maize
MS	EU Member State
OC	Organic Carbon
OCTOP	Organic Carbon content in the TOPsoil layer
OECD	Orgnaisation for Economic Co-operation and Development
PECgw	Predicted Environnemental Concentrations for the groundwater
PEARL	Pesticide Emission Assessment at Regional and Local Scales
Pelmo	PEsticide Leaching Model

PO	Potato
PRA	Petites Régions Agricoles
PRZM	Pesticide Root Zone Model
PTF	Pedo-Transfer Function
RA	Recensement Agricole
RECLUS	Réseau d'Etude des Changements dans les Localisations et les Unités Spatiales
SANCO	Directorate-General for Health and Consumer Protection
SAU	Surface agricole utile
SB	Sugar Beet
SCEES	Service Central des Enquêtes et des Etudes Statistiques
SETAC	Society of Environmental Toxicology and Chemistry
SF	Sunflower
SID	FROGS Soil Type IDentification Number
SMU	Soil Mapping Units
SOLHYDRO	Analytical database of hydraulic properties
SPADBE	Soil Profile Analytical DataBase for Europe
STU	Soil Typological Units
SWAP	Soil, Water, Atmosphere and Plant model
UCS	Unité Cartographique de Sol
UIPP	Union des industries pour la protection des plantes
USDA	United States Department of Agriculture
USR	Unité de Sols Regroupés
UTS	Unité Typologique de Sol
WB	Winter Barley
WOFOST	WOrld FOod STudies
WOSR	Winter Oilseed Rape
WW	Winter Wheat

1 Introduction

Objectives of French Refinement Of Groundwater Scenarios (FROGS)

EU and national registration processes under Regulation 1107/2009, require the assessment of the potential of an active ingredient and its metabolites to move to groundwater. However, the assessment objectives are different for EU registration of the active ingredient (Annex I) and product registrations in the Member States. With regard to groundwater contamination at EU level, no official decision scheme for Annex I inclusion of active substances currently exists. The current practice is to propose Annex I inclusion as far as safe use is demonstrated for a relevant crop and a significant area in Europe (FOCUS, 2009) or, as stated in FOCUS (2002):" If a substance is less than 0.1ug/l for at least one but not for all relevant scenarios, then in principle the substance can be included on Annex 1 with respect to leaching to groundwater".

For national assessments, all supported crops and the entire potential use area must be considered. If the active substance cannot be used safely throughout the country, then the registration may be limited to the subset of conditions under which the compound can be used safely.

For the development of FROGS, the UIPP workgroup has built on the approach originally designed by the ad hoc ComTox workgroup for conducting the French national assessment. As opposed to a small number of worst-case scenarios, this assumes parameterization of multiple scenarios representing a variety of normal, realistic conditions regarding crop locations, phenology, agronomic practices including cropping rotations, soil types and actual soil profiles of different depths, and climate, based on available information from national and European databases and local expert knowledge.

Scenarios which reflect representative combinations of crop, soil and climate conditions were determined by attributing pertinent soil types to Agronomic Units defined as geographic areas in which annual crops are considered as homogeneous with regard to land use, cropping characteristics and most frequent rotations. The overall scheme retained is represented in Figure 1.

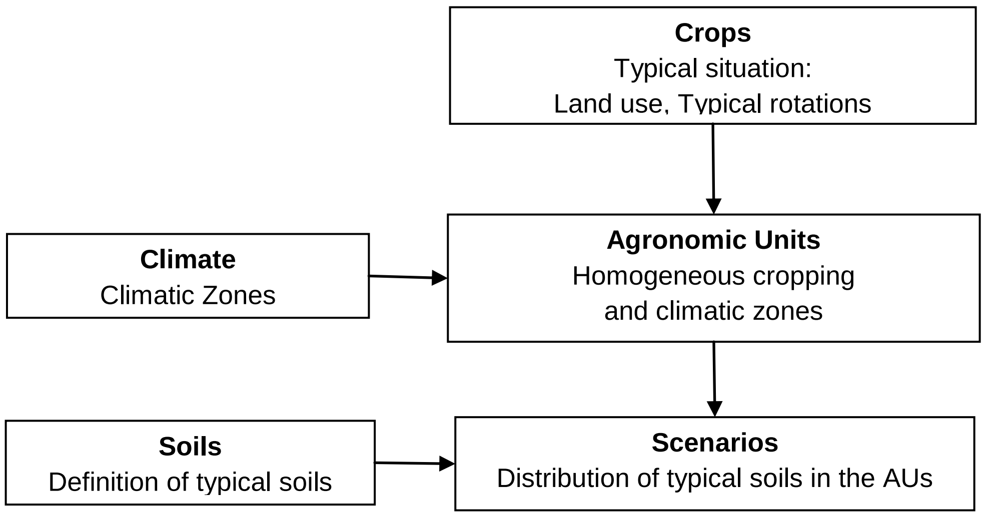


Figure 1 Construction of ground water national scenarios

FROGS fits within the guidance provided by the proposed final FOCUS report (FOCUS, 2009). FROGS would allow groundwater assessment as a Tier 2b (or Tier 3a if combined with a refinement of input parameters), as described in the FOCUS (2009) document and represented in the graphical scheme below.

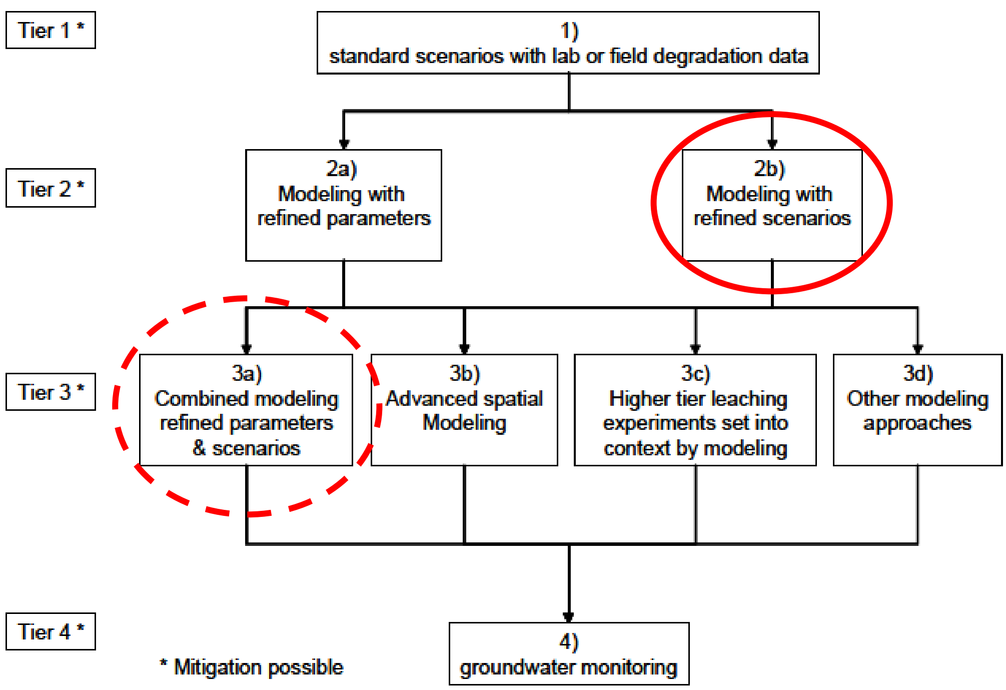


Figure 2 Proposed European generic tiered assessment scheme for ground water (source: FOCUS, 2009).

For the harmonisation of assessment schemes between EU and Member States (MS), FOCUS has suggested that differences between assessments at EU and MS level should be based on differences in the environmental conditions/management practice rather than on pesticide parameters. Various Member States have already implemented national scenarios on this basis for their national groundwater contamination risk assessment, as detailed in Appendix 1-2 of FOCUS (2009). FROGS is fully aligned with this approach.

The groundwater risk assessment made at the national level with FROGS would fit within the currently defined interactions between national and EU assessment schemes such as detailed in Chapter 5 page 64 of FOCUS (2009) (Figure 3).

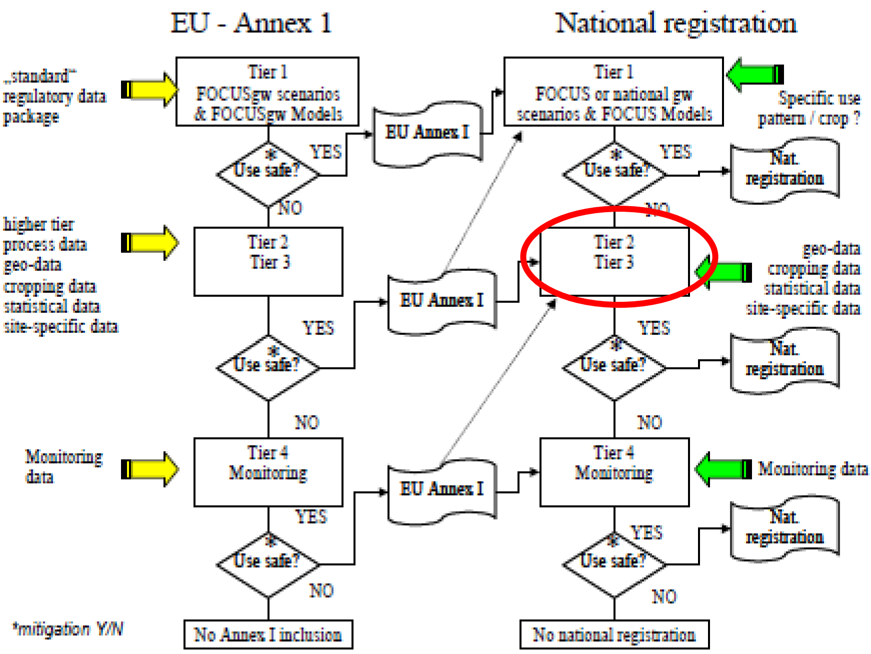


Figure 3 Illustration of likely interactions between EU and national assessment schemes (source: FOCUS, 2009).

FROGS is not based on a Geographic Information System (GIS) (Tier 3b of FOCUS assessment scheme). Indeed the definition of some layers of information (soil) is not precise enough at the moment to allow proper localization and thus the integration within a GIS. FROGS is intended to be used in the French national assessment scheme as an intermediate step between the standard EU FOCUS scenarios (realistic worst-case approach) and the highly defined advanced spatial modeling, as illustrated in Figure 4.

FROGS is designed to allow the risk assessor to evaluate the overall risk at national level based on cumulative area distribution of the predicted concentrations. The tool automatically provides as model output a plot of the cumulative agricultural land area distribution versus predicted environmental groundwater concentration, which gives a visual representation of the safe uses of a product. Based on a defined protection goal for groundwater, this feature of FROGS can subsequently be used by the regulator to make a decision regarding groundwater risk assessment.

To align FROGS with existing FOCUS recommendations for defining a percentile protection goal, an overall 90^{th} percentile value is targeted. This takes into account the spatial variability for soil and climatic conditions, and the temporal variablility on a multi-year basis in the agricultural use area of a product. An overall 90^{th} percentile protection goal is therefore assumed, which results from an 80^{th} percentile temporal and 80^{th} percentile spatial distribution output from the FROGS model.

FROGS may also be used to identify scenarios and specific conditions that present potential risk to groundwater in order to propose appropriate risk management measures. Scenarios representing vulnerable conditions (soil/climate combinations) for a given pesticide application can be identified so that mitigations may be proposed based on specific soil/climatic properties. Alternatively, these vulnerable conditions may be further investigated through refined groundwater modeling (corresponding to FOCUS Tier 3), or groundwater monitoring (corresponding to FOCUS Tier 4). As an example, vulnerable soils may be identified and located more precisely within a given agronomic unit using local soil maps at the 1/250 000 scale (such as IGCS - Inventaire, Gestion et Conservation des Sols -, when available).

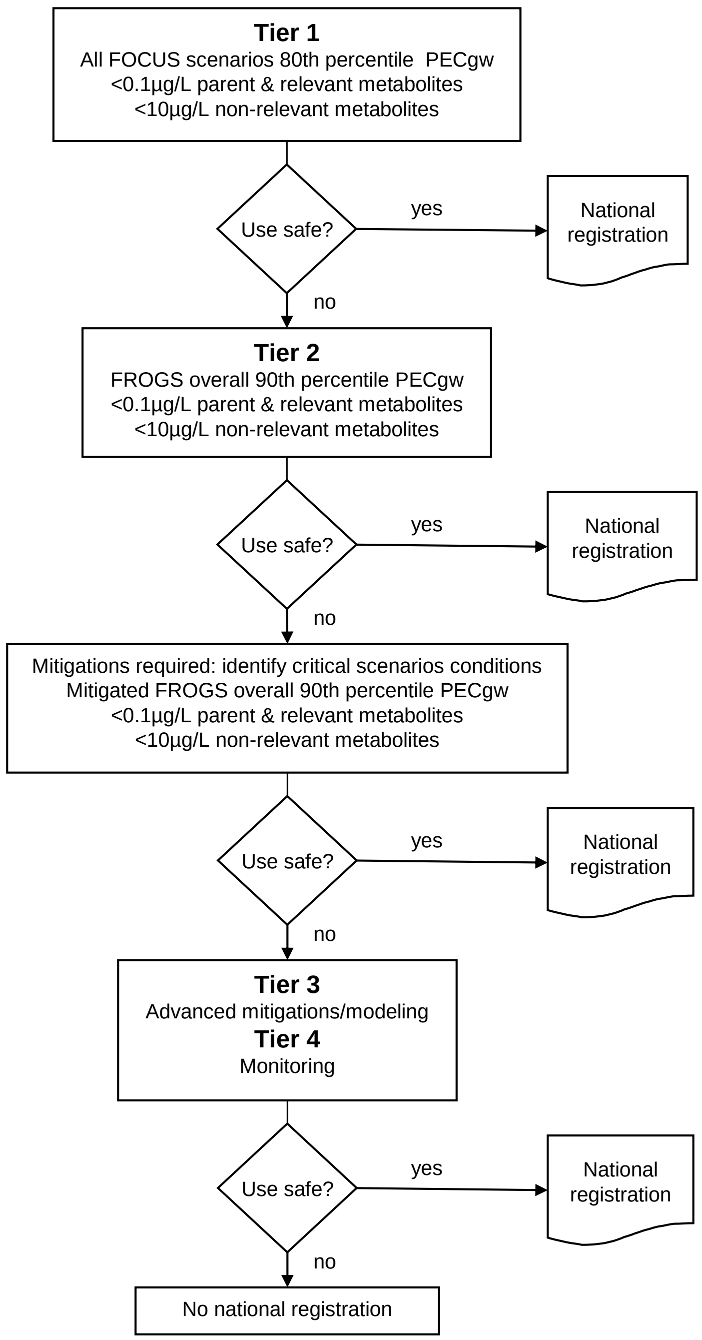


Figure 4 Proposed use of FROGS in the French groundwater assessment scheme.

1.1 References

FOCUS (2000). FOCUS groundwater scenarios in the EU pesticide registration process. Report of the FOCUS Groundwater Scenarios Workgroup, EC Document Reference Sanco/321/2000 rev 2. 202pp.

FOCUS (2002). Generic guidance for FOCUS groundwater scenarios, Version 1.1, April 2002.

FOCUS (2009). Assessing Potential for Movement of Active Substances and their Metabolites to Ground Water in the EU" Report of the FOCUS Ground Water Work Group, EC Document Reference Sanco/13144/2010 version 1, 604 pp.

2 Delimitation of agronomic units

At first level of national evaluation, one assumes that land occupation by various crops (arable crops), cropping characteristics and rotations can be correctly described by a set of typical situations. To define them, the variability of parameters describing soils, crops and climate should be reduced to a limited number of representative cases which can be then converted into scenarios. From this typological description should result a number of cases, necessary and sufficient, compatible with the simplicity specifications of information for modeling and the assessment objectives. The outcome of this process safeguarding a sufficient level of realism is a set of geographic zones corresponding to cropping basins named “Agronomic Units”

2.1 Agronomic Unit Concept

Agronomic Units (AUs) are geographic areas in which annual crops are considered as homogeneous with regard to land use (homogenous distribution throughout the AU), cropping characteristics (dates at which key stages are reached) and most frequent rotations. Each unit can be characterized by a set of descriptors to be parameterized for modeling of the fate and behavior of plant protection products in soil. Two different agronomic units should exhibit significant differences with regard to crop land use and/or cropping characteristics.

Evidently the concept of agronomic unit is very similar to a geographic cropping basin, such as the Beauce or the Alsace plains, for example. To avoid any possible confusion with this latter concept, which does not necessarily fulfill the requirements for groundwater risk assessment, AUs correspond to areas defined in the restricted framework of ground water risk assessment.

AUs were defined for eight important annual crops: sugar beet, winter wheat, oilseed rape, fodder maize, grain maize, winter barley, potato and sunflower. These units are not specific to these crops so that they can also serve for other annual crops providing the same method is used to define the corresponding factors (crop characteristics, rotations, etc.).

Selection of soil types in farmland is made in a separate process, independent from the determination of AUs (see Chapter 7). Soils were then allotted to AUs according to their relevance. Due to the selection method and the considerable reduction of variation, typical soil cannot be spatially located in the AUs.

2.2 Construction of Agronomic Units

The AUs were constructed using a set of pertinent descriptors allowing for the delimitation of zones satisfying the above-mentioned homogeneity criteria using an adapted method.

2.2.1 Pertinent descriptors

Three descriptor sets are relevant for the definition of AUs:

- the land use by crops, based on statistical data and most frequent rotations;
- the environment, described using geomorphologic and topographic information, including geologic substratum and soil coverage;
- the climate.

These three data sets need to be taken into account simultaneously, considering the relationships between the environment and the land use. While the soil component can be analyzed separately to determine the principal soil types, the environment and the climate factors cannot be considered independently of crops, particularly because of specific requirements of certain crops.

To reach the two-fold objective of realism and simplicity for national scenarios, each AU should exhibit a sufficient homogeneity of climatic and cropping factors, so that it can be characterized using a unique set of parameters. In each AU, the proportion of surface covered by a crop, the corresponding crop parameters (key dates for crop development stages), the typical rotations are determined.

AUs correspond to defined geographic areas and their spatial delimitation is justified by two main reasons:

- the selection process sets limits of a defined geographic area which corresponds to a cropping basin;
- modeling a set of typical situations provides a distribution of predicted concentrations in groundwater in the cultivated areas which can be weighed by surface of crops potentially treated. This corresponds to an estimate of the safety level of the product use with regard to the treated area.
-

2.2.2 Construction Method

Two different approaches may be considered to construct the AUs. Both approaches were already considered in the framework of CORPEN regional audit to determine areas where residues of plant protection products are likely to contaminate water (CORPEN, 2003).

1. Analysis of exhaustive geographic information on crops, climate and soils at high resolution; for instance, crop statistics at canton scale, weather data from synoptic Météo-France weather stations (about 100) using records of 30-year reference period, etc. Creation of homogeneous cropping and climatic zones is achieved by aggregation of elementary data using standard multivariate descriptive statistical methods.

2 Use of existing zonings corresponding to typological descriptions of the territory. Elementary data are already aggregated in the defined zones by a method implicitly including some expertise. Overlay of different information layers after eventual aggregation of adjacent zones allows for the determination of homogenous zones with regard to selected homogeneity criteria (land use, crop characteristics, weather pattern).

This second method was used in the project, considering the availability of means (data and manpower). Consequently, a set of existing zonings descriptive of the environment and the climate was used along with statistics of land occupation by crops to construct the Agronomic Units. Two homogeneity criteria were retained to aggregate or keep separate adjacent zones in the existing zonings: crop parameters, including land use and key cropping dates, and climatic factors, likely to be correlated with crop characteristics. Statistical data of the national agricultural census conducted in 2000, “Recensement agricole 2000” (RA 2000) for eight major crops was also used to build up the Agronomic Units.

2.2.3 Agricultural Statistics

RA 2010 is an exhaustive information base providing cultivated surfaces for a number of crops at different administrative scales: community, canton, department and region. Data by canton provide sufficiently accurate information for the description of land use. Cultivated surface by canton is approximately 7678 ha in average, peaking at 39 359 ha in intensively cultivated areas.

Changes in the cultivated surfaces of certain crops have been observed since the last census, the main cause being an economic reason since the surfaces of opportunistic crops vary relatively quickly according to their profitability. However they do not modify the distribution of crop surfaces in the Agronomic Units. Land use data in FROGS 3.3.3.3. is based on the agricultural census of 2010 (Agreste, 2010).

Conversely, a number of crops are known to be more or less closely dependent on environmental characteristics, even though means of modern agriculture have largely reduced this dependency. The old land zoning in “Small Agricultural Regions": Petites Régions Agricoles (PRA) reflects well the relationship between environment and agricultural production. To insure a sufficient stability of the AUs despite short-term changes of land use by certain crops, it is useful to include in their basic determinants a number of stable factors which are also strong determinants of agricultural activities.

Land occupation by certain crops in well identified cropping basins or AUs is clearly displayed on crop density maps which represent the proportion of surface covered by the crop of interest in the cultivated surface of a canton. Density thresholds aiming at selecting the cantons in which a crop can be considered as significantly present have been set by INRA in the soil selection process (Morvan and Lebas, 2006, see Chapter 7). Hence, only a certain proportion of the crop surface is taken into account once a density threshold is set, overlooking the cultivated surface in the cantons where the crop is not significantly present.

This selection excludes areas which are not cultivated (forests, urban areas) or where arable crops are of little importance (hilly and mountainous zones). The contours of territories are well delineated for crops under the dependence of environmental factors (sugar beet, sunflower). They look imprecise or are even difficult to establish for ubiquitous crops which are less dependent on environmental factors (cereals, maize). Most often, a gradient of crop density is observed from the center to the boundaries of the AU. Inclusion of peripheral cantons in a cropping basin where the crop density is close to the selection threshold is problematic since expanding excessively a cropping basin would contradict the criteria of crop and climate homogeneity.

2.2.4 Environmental Zoning

Existing environmental zonings used in the construction of Agronomic Units are described in this section.

2.2.4.1 Small Agricultural Regions

The concept of Small Agricultural Region (« Petite région agricole »: PRA) is based on two sets of characteristics of different nature:

- permanent environmental characteristics (geology, geomorphology, topography, pedology, climate, etc.);
- characteristics variable in a decade time frame, linked to the socio-economic framework (farming systems, land use, farm size, etc.).

This land partition, initially designed to collect and process structural and economic data (first publication in 1956) is used with different purposes: data interpretation of demographic and agricultural census, enforcement of certain regulations, etc. (INSEE-SCEES, 1983). Although PRA contours have been modified in certain occasions, the statistical character of the zoning justifies the fact that no fundamental revision has taken place since then (last publication in 1983).

Agricultural Regions (« Région agricole »: RA) are defined by grouping several communities, leading to 433 RA in total, 255 being located within one single département (RA intra-département) and 178 in more than one département (RA inter-départements). After splitting the latter with department limits, a total of 713 PRA are obtained. The PRA is defined in function of a same dominant agricultural orientation. It characterizes well the basic agronomic units as a function of both their production and their environmental characteristics.

The alternative concept of "Small Natural Region" corresponds to the need for zoning territorial entities on the basis of permanent environmental features. In general, it is possible to split Small Agricultural Regions into several Small Natural Regions with a pedologic significance. An order of magnitude of the average surface for these units is a few thousand hectares. Although attractive, the concept of Small Natural Region was not used since the corresponding zoning is not available for the entire territory.

2.2.4.2 Cropping Basins

A number of pedologic and agroclimatic reference documents include a territory zoning at the scale of an administrative region or a département. The typological description of the environment and land use they propose reflects relatively well typical situations suitable for scenario construction. For example, the pedologic repository for West (« Référentiel des sols de l'Ouest »: http://www.cript-bretagne.fr) defines 20 cropping basins and 41 soil types in the four administrative regions of West (Basse-Normandie, Bretagne, Pays de la Loire, Poitou-Charentes) These basins are built by grouping 69 Small Agricultural Regions and include from 1 to 7 PRAs by basin.

Following the example of the procedure used for the West pedologic Repository, PRA aggregation into larger units can be realized in other areas using geomorphologic and climatic similarity criteria. Nevertheless a reduced number of cropping basins is difficult to achieve. Except for large alluvial plains of main streams, PRA aggregation erases the units corresponding to smaller river plains, for the benefit of larger inter-stream structural units. Furthermore, some PRA, which are well defined geographic entities but have a too small size to constitute an agronomic unit, are in a transition position between agricultural regions with contrasted features. In this case, the decision to aggregate the PRA to one or another adjacent region is arbitrary in absence of precise rules. Similarity criteria at a larger scale are then necessary to achieve a consistent grouping.

Various regional agronomic repositories (Ailliot B. and Verbeque B., 1995 ; Delaunois A., Longueval C., 1995 ; Froger D. *et al.*, 1994 ; Jacquin J., Florentin L., 1988) and pedologic repositories (Ballif J.L. *et al.*, 1995 ; Chrétien J., 2000 ; Roque J., 2003 ; Sterckeman *et al.*, 2002), and other national or regional geographic documents (Battiau-Queney Y., 1993 ; Mottet G., 1993), among many others not listed in the bibliography (including information taken from web sites of various organizations such as DIREN, Chambres d'agriculture, etc. and from the GIS layers they provide), describe the environment on a geomorphologic basis. This information was used for grouping PRAs into AUs.

2.2.4.3 Climatic Regions

Several agro-climatic zonings can be used for the delimitation of the AUs.

29 agro-climatic regions have been defined by Choisnel, 18 corresponding to cultivated areas, (Appendix 2).

Monograph n°4 of Météo-France (Céron J.P. *et al.*, 1991) defines not connected climatic zones for temperature (18 zones), precipitation (18 zones) and solar irradiance (11 zones), along with a reference weather station for each zone. Combination of synthetic maps for these three parameters, which exclude mountainous areas, does not produce a usable climatic zoning. In a same zone of intersection for the three climatic parameters, reference stations often differ. However, the synthetic map for precipitation is in relative good agreement with the large cropping basins.

Maps representing classes of annual and seasonal precipitation (quintile), aggregated by PRA were produced by INRA and Météo-France to estimate the risk of erosion (Le Bissonais Y. *et al.*, 1998, 2002). Mean monthly precipitation calculated using 30-year records are one of the parameters used to estimate the erosion intensity. Local weather information provided by 95 primary stations of Météo-France (about one per département) was spatialized at a scale of 5 km square grid using the AURELY method which takes into account the topography. Mean monthly precipitation data are distributed in five classes for each climatic season and the year. The corresponding maps of precipitation aggregated by PRA are shown in Appendix 3. They are used for grouping PRAs with similar seasonal precipitation patterns.

Finally, complementary weather information can be found in the document on Hydro-ecoregions (HER) outlined in the next chapter (Wasson J.G. et al., 2002), in particular the analysis of spatial distribution of mean annual precipitation.

2.2.4.4 Hydro-ecorégions

Hydro-ecorégions (HER) define a typology of ecosystems for surface water to help establishing reference levels of aquatic invertebrate populations for the Water Framework Directive (Wasson J.G. et al., 2002). A first level (HER-1) identifies the large environment structures corresponding to important changes of at least one fundamental, geographic or climatic parameter. Hence, 22 level-1 Hydro-ecorégions are defined using criteria combining geology, topography and climate which are considered as primary determinants in the functions of continental aquatic ecosystems. A second level (HER-2) identifies zones within which the different parameters can be considered as homogeneous with regard to the global heterogeneity of national territory. It addresses the internal variability of HER of level 1. The list of HER of both levels and the corresponding map is in Appendix 4.

Even though Hydro-ecoregions are aiming at establishing a typology of continental fresh waters, the criteria used in the HER construction method belong to general domains (geology, topography, climate) which are combined in an approach mostly based on geomorphologic considerations. An important element in this analysis of the environment is the lithology of geologic materials which, with its permeability characteristics (interstitial, fissure, fracture), largely influences the partition of water between surface and ground resources. Actually, lithology data of geologic materials, complemented by geomorphologic information (geomorphologic maps at the 1/1 000 000 scale, GIP RECLUS Montpellier, 1988-1993) constitutes the physical basis of HER determination.

Consequently, Hydro-Ecoregions can also be considered as determinants of terrestrial environment which allows for a reduction of the global variation in a limited set of typical situations. HER contours very often match the limits of mapping units of the 1/1000 000 scale geologic map (BRGM). Furthermore, the physical basis of HER determination helps linking the HER units with anthropic pressures such as agricultural activities.

The use of HER in the construction of AUs is described in the following section.

2.3 Zoning Method of Agronomic Units

2.3.1 Overlay of Information Layers

Considered individually, existing zonings reflect only a part of the criteria needed for the determination of AUs. In addition to the two basic zoning criteria retained (land use by crops and climate), integrated physical environment information was added thanks to the two HER levels. Combination of these three homogeneity criteria of zones allows for a pertinent aggregation of elementary units (cantons, PRAs) into homogeneous AUs. These are defined by expert judgment using the combinations of climatic regions and Hydro-ecoregions as a consistency basis.

In an implicit way, a hierarchy is established between the criteria. PRAs which reflect the more or less strict dependency of cultivated crops with the environment characteristics are used as basic elements of the zoning. Difficulties encountered in PRA grouping into larger units result from aggregation uncertainties in the question of to which of two or three adjacent AUs this PRA should be included. This hurdle is overcome thanks to the HER level 2 zoning. It actually provides a sound reason for assembling units which have been differentiated on the basis of particular characteristics. Grouping PRAs which differ on a number of characteristics in a same AU is guided by physical and essentially geomorphologic considerations. This process also takes into account weather information at PRA scale using the annual and seasonal precipitation classes. Climatic homogeneity within the AUs is an important requirement to select a unique representative set of crop parameters.

As a second criterion of PRA grouping, land use by crops is not taken into account in the same way according to the crop considered. For ubiquitous crops which are well represented in most of the AUs, the density variation between two adjacent AUs does not usually show a clear transition. In this case, the limits between AUs are set following environmental (physical and/or climatic) limits. The distinction between the two AUs is maintained since it can be fully justified for crops which exhibit a significant density difference between the two Units. Conversely, land use by crops which are not ubiquitous is often consistent with environmental characteristics. In this case, the limit between AUs corresponds to a clear transition in crop density.

No rigorous protocol was therefore used in the PRA pooling. Depending on the situations, the limit between adjacent AUs was defined using the weather (precipitation) or the geomorphology (HER 2) parameter. In many cases, the limit was determined using expert judgment rather than following a strict operating procedure. The decisions made about AU boundaries might be arbitrary in a number of cases, but are not expected to have any significant impact on the scenarios, since the overall aim of the AUs is to reflect typical situations that exist more likely around the centroid of the AU polygons rather than close to their limits.

2.3.2 Practical Method of PRA Aggregation

The various information layers call for different geographic delimitation bases: administrative limits for crop statistical information (cantons) and PRAs (municipalities), physical limits for Hydro-ecoregions and climate. Hence, the contours of the elementary units cannot strictly overlap. For practical use, AUs are built by PRA aggregation. Consequently the contours follow community limits. Seeing that they principally reflect homogeneous typical agronomic situations, AUs do not require to be delimited with very accurate contours, so that limits of PRA groups can serve the purpose. Resulting contours provide a sufficient spatial resolution to follow the limits of physical units represented at scales of 1/1 000 000 (geology) or 1/500 000 (geomorphology).

Crop land use in an AU is estimated using information from the cantons which are located within its geographic limits. Ideally, estimation of land use with agricultural statistics at community scale is preferable since AU contours will fully correspond to municipality limits. Such accurate information is not readily available and is probably not needed considering the uncertainties of limits between two adjacent AUs. As a consequence of the different zonings for AUs (PRAs with municipality limits) and crop statistics (cantons), some cantons are intersected by the limits between two, sometimes three, adjacent AUs. Hence the following rule is applied to allot the canton to one or the other AU. A canton polygon intersected by two adjacent AUs is allotted to the AU which covers the largest surface of the polygon, or eventually best matches the limit between the two AUs. This rule assumes a regular distribution of the cultivated surfaces in the canton. In absence of more accurate information on land use in the canton, this assumption is necessary, although it is likely to be wrong in certain cases, particularly when the limit between the two AUs corresponds to physical boundaries.

A decreasing gradient of crop density is frequently observed in the AUs from the center to the boundaries. If the crop considered is not present in an adjacent AU, the limit with the former can be arbitrary. Conversely, such difference is not necessarily observed with another crop which is more ubiquitous. This is the reason why climatic and geomorphologic criteria (HER) are of primary importance in the delimitation and have been preferred to strict land occupation by crops. Consequently, the spatial distribution of a crop can be uneven in a large AU.

2.4 Zoning Results

2.4.1 Delimitation of Agronomic Units

The method outlined in the previous section leads to 31 AUs which include between 2 and 32 Small Agricultural Regions (PRA). They are named explicitly in reference with cropping basins (Table 1). Agronomic Unit code "0" corresponds to the excluded territory (forests, urban areas, mountainous zones, areas with small surface of arable crops). AU surfaces range between 335 and 2118 kha, with a mean value of 1238 kha. SAU (Surface Agricole Utilisée from Agreste, 2010) correspond to cultivated surfaces in the AUs and are expressed as kha and percentage of the total AU surface.

The contours of the AUs are represented in Figure 5. Each AU is a set as Small Agricultural Regions (PRA) as shown on Figure 6, the list of which is given in Appendix 4. Digital geographic information for AUs is provided in the FROGS v2.2.2.2 package under ESRI ArcGis format.

Table 1 Defined Agronomic Units

AU N°	Agronomic Unit	Surface (kha)	SAU (kha)	SAU (%)	AU N°	Agronomic Unit	Surface (kha)	SAU (kha)	SAU (%)
0	Territoire non pris en compte	16303	5627	34.5	16	Champagne crayeuse	1113	723	65.0
1	Collines molassiques - Lauragais	1902	1195	62.8	17	Beauce - Drouais - Gâtinais	1333	943	70.7
2	Bretagne sud	896	438	48.9	18	Bordelais - Périgord - Coteaux du Lot	2068	856	41.4
3	Limagnes - Plaine du Forez	1024	596	58.2	19	Perche - Pays d'Auge - Pays d'Ouche	1385	840	60.6
4	Bordure maritime Nord - Picardie - Normandie	1825	1194	65.4	20	Bocages de l'ouest	2002	1315	65.7
5	Alsace - Sundgau	588	276	46.9	21	Ardenne - Argonne - Champagne humide	913	547	59.9
6	Plaine normande - Bessin	335	244	72.8	22	Champagne berrichonne - Boischaut	1640	1038	63.3
7	Aquitaine - Landes	1263	154	12.2	23	Bas Dauphiné - Vallée du Rhône	1025	417	40.7
8	Bassin de l'Adour	1058	557	52.6	24	Fossé bressan	1036	538	51.9
9	Picardie - Nord - Pas-de-Calais	1587	1121	70.6	25	Bretagne centrale	685	416	60.7
10	Charentes	1917	1296	67.6	26	Plateaux de Haute-Saône	784	345	44.0
11	Bocage normand	1467	1060	72.3	27	Provence	892	179	20.1
12	Barrois - Plateaux bourguignons	2118	1050	49.6	28	Plaine du Languedoc-Roussillon	1000	324	32.4
13	Plateau lorrain	1139	640	56.2	29	Boischaut du sud	712	511	71.8
14	Gâtines - Vallées de Loire	1099	620	56.4	30	Bretagne nord	1246	813	65.2
15	Sologne - Orléanais	698	145	20.8	31	Ile-de-France	1637	916	56.0

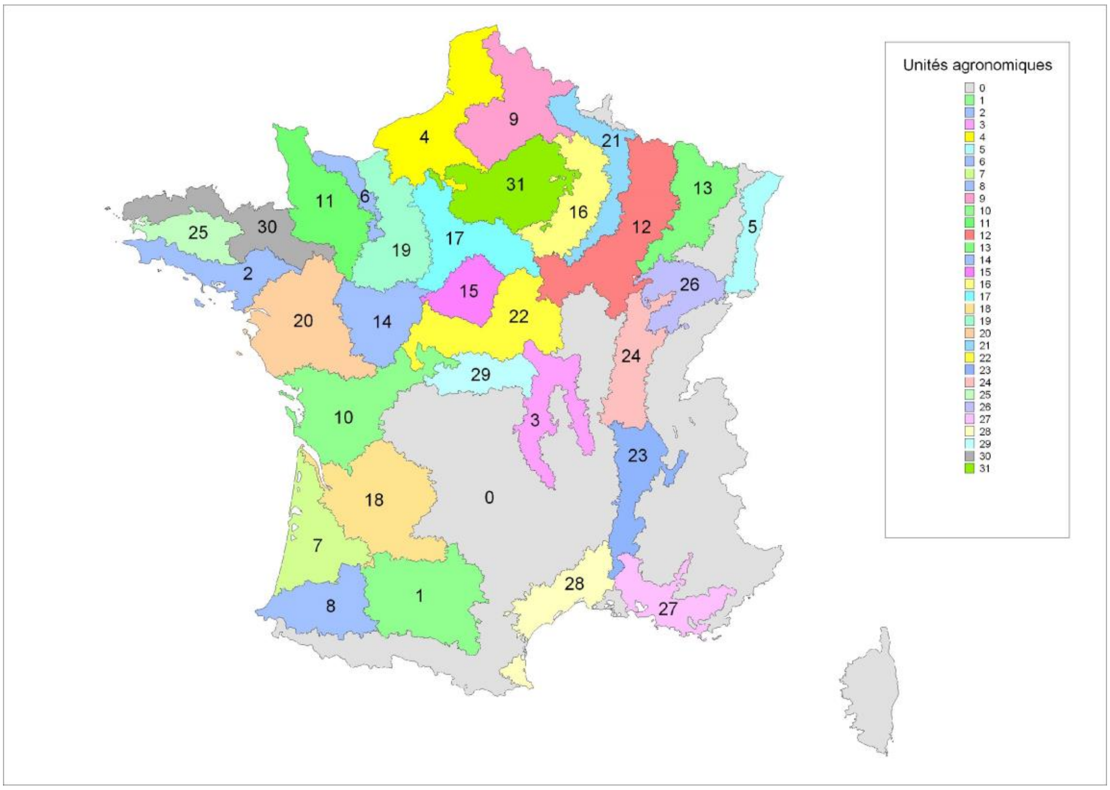


Figure 5 Map of Agronomic Units

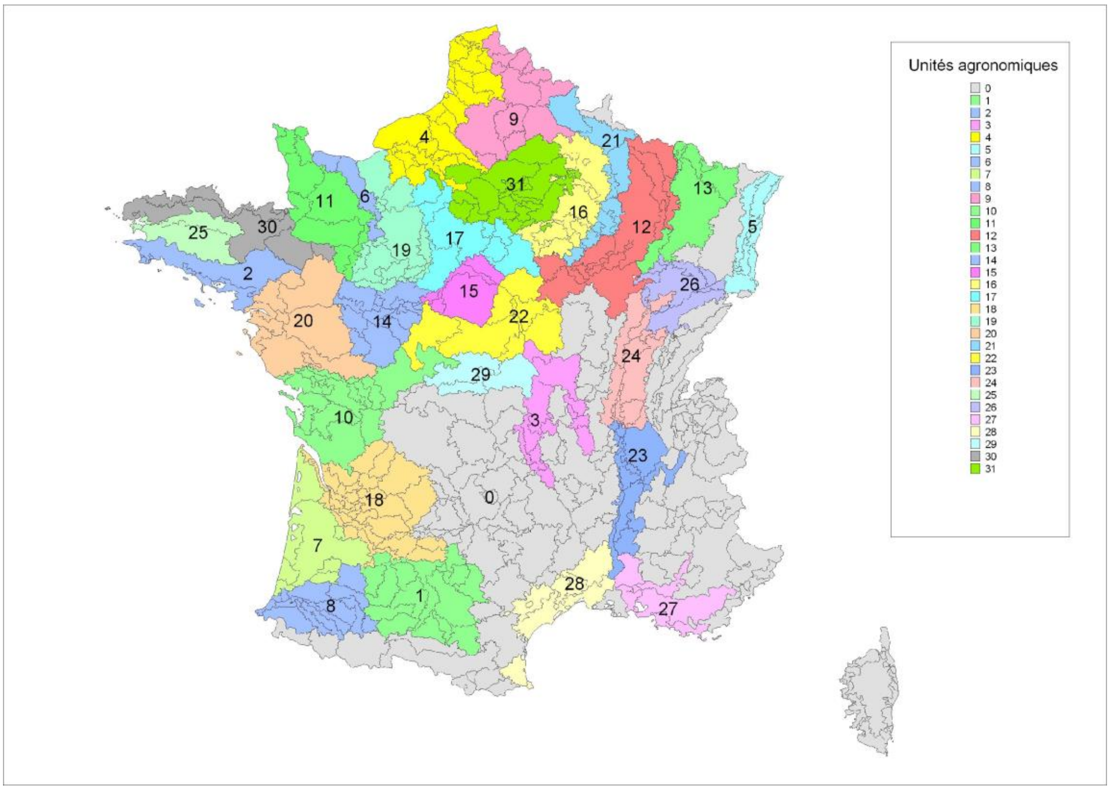


Figure 6 PRA Agregation in the Agronomic Units

2.4.2 Crop Land Use

Surfaces of eight arable crops are estimated in the different AUs using statistical data of RA 2010 (Agreste, 2010) at canton scale. Cantons are alloted to AUs according to the rule defined above. The final allocation of Cantons in the AUs is given in tables of Appendix 6.

Thematic maps representing crop density by canton for the eight crops of interest illustrate the relationship between land use and AUs, particularly for crops that depend more closely from environmental characteristics, such as sugar beet (see Figure 7 to Figure 14). Class limits for crop density are adjusted for each crop according to the data range of variation.

Crop surfaces in the AUs are estimated without using the selection threshold aiming at the determination of cropping regions in relationship with the selection of soil types (Chapter 7). Consequently, the total surface occupied by one crop is taken into account, even when the density is lower than the selection threshold. Cultivated surfaces located ouside the 31 AUs were excluded and allocated to AU 0 in Table 1. Distribution of crop surfaces in the AUs is given in Appendix 7. For each of the eight crops considered, the proportion of surfaces taken into account in the AUs is higher than 90% of the total crop cultivated surface (Table 2).

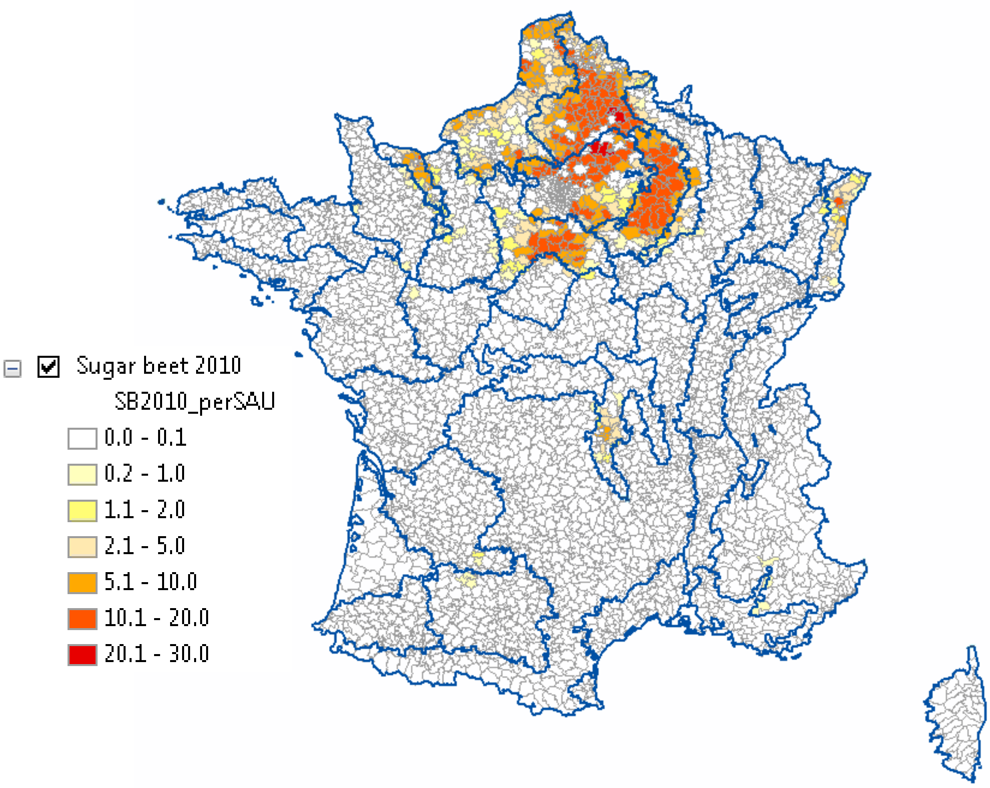


Figure 7 **Sugar Beet - Crop Density (% SAU)**

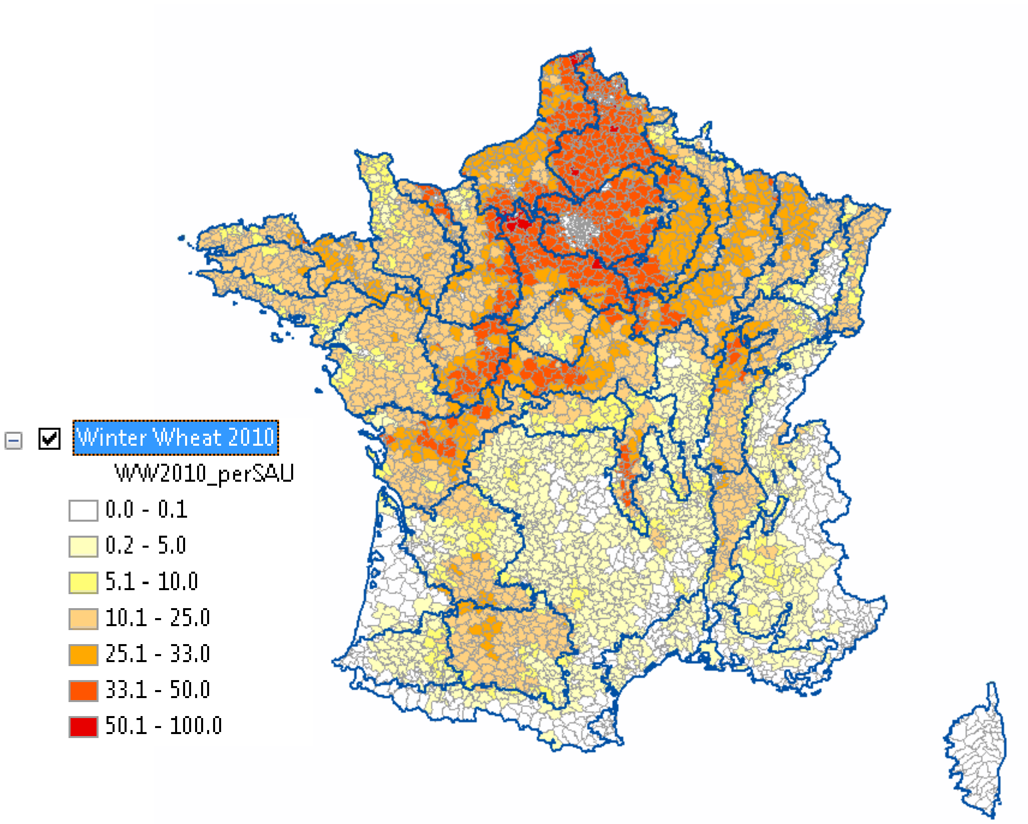


Figure 8 **Winter Wheat - Crop Density (% SAU)**

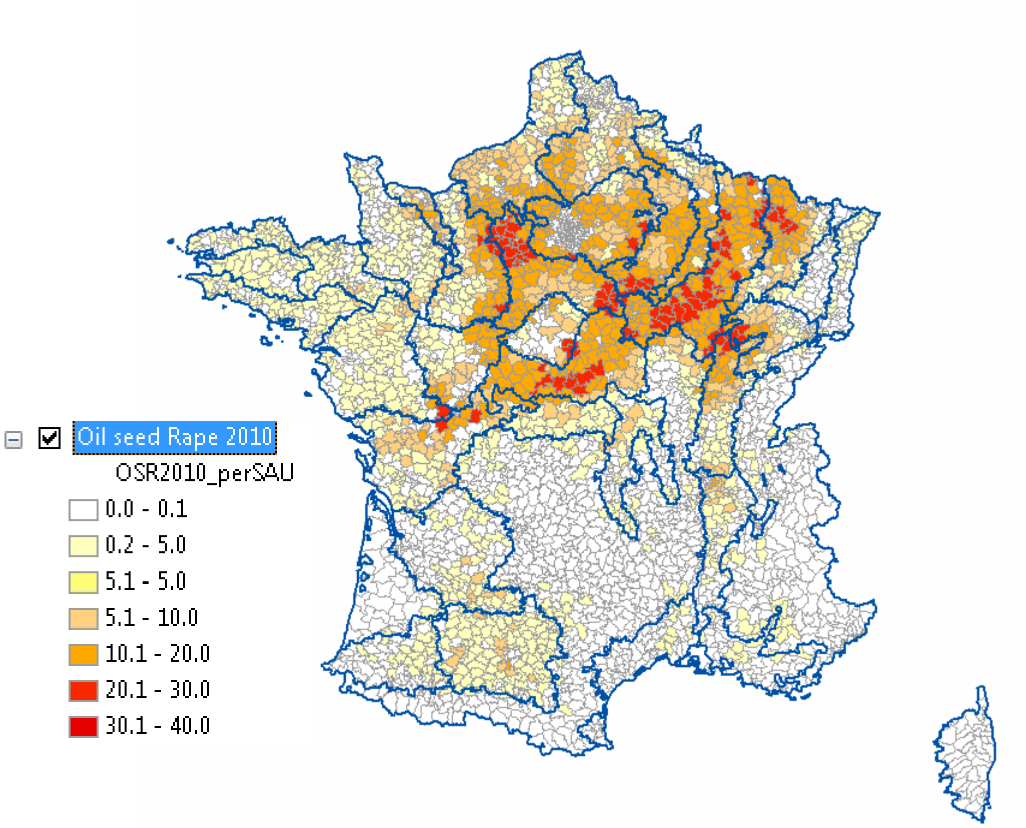


Figure 9 **Oilseed Rape - Crop Density (% SAU)**

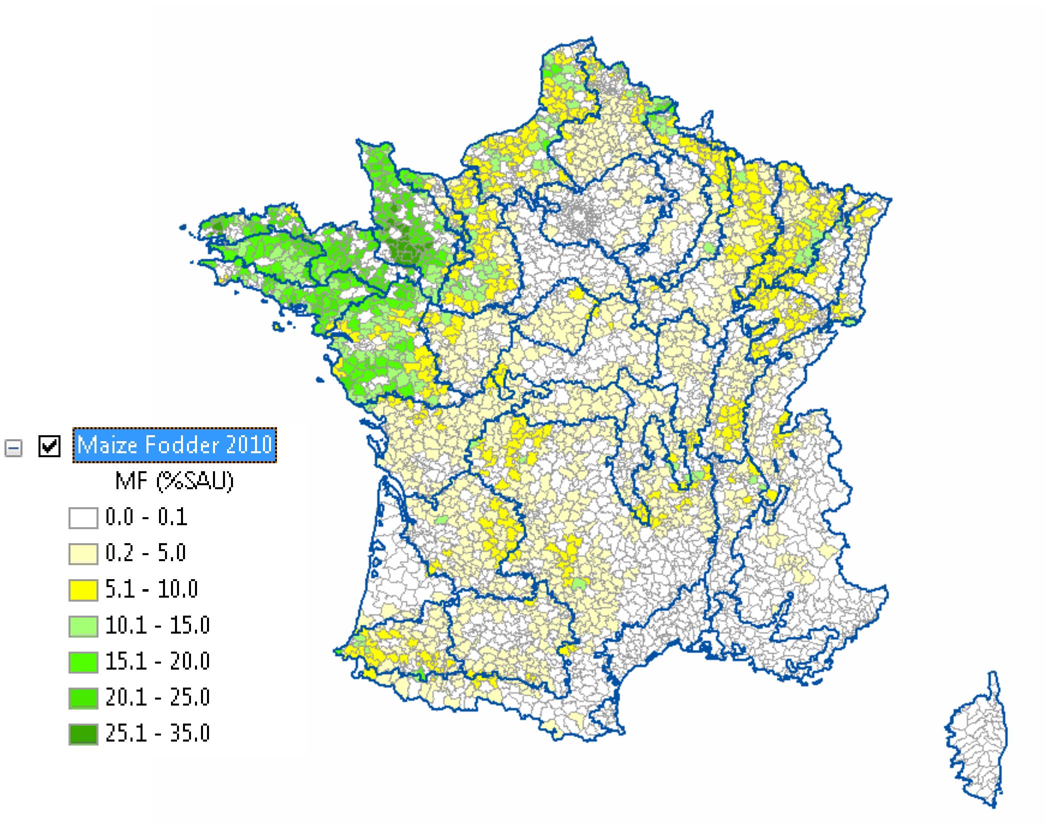


Figure 10 **Maize Fodder - Crop Density (% SAU)**

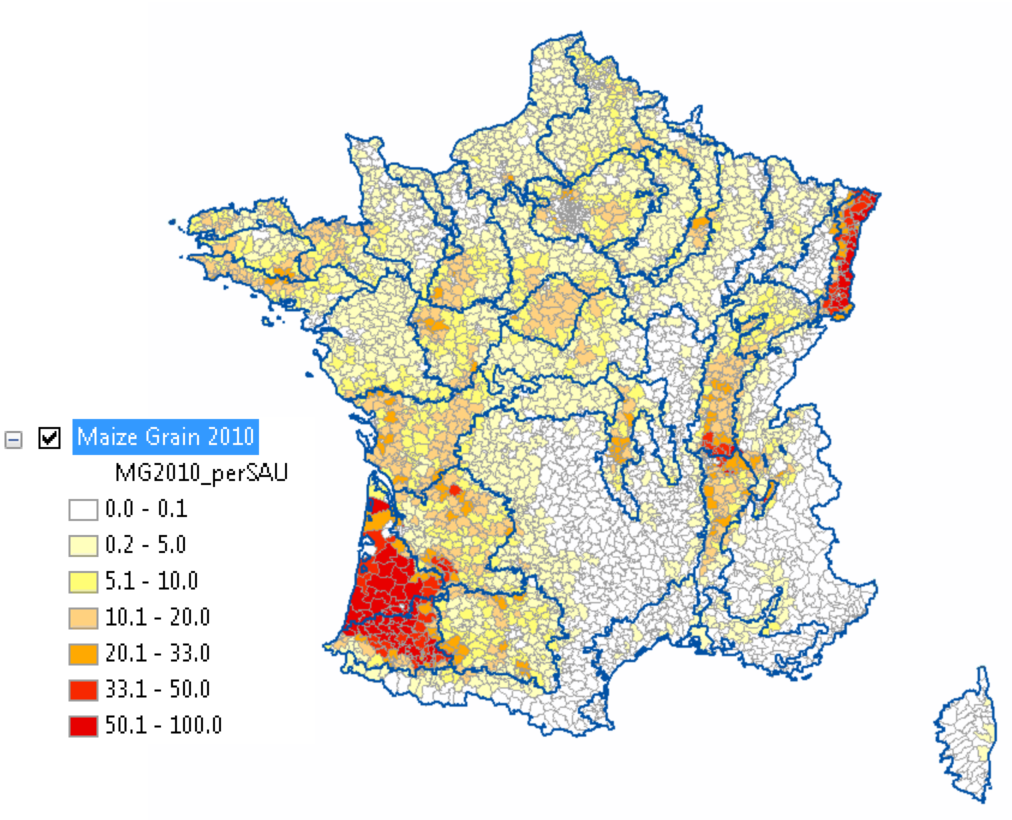


Figure 11 **Maize Grain - Crop Density (% SAU)**

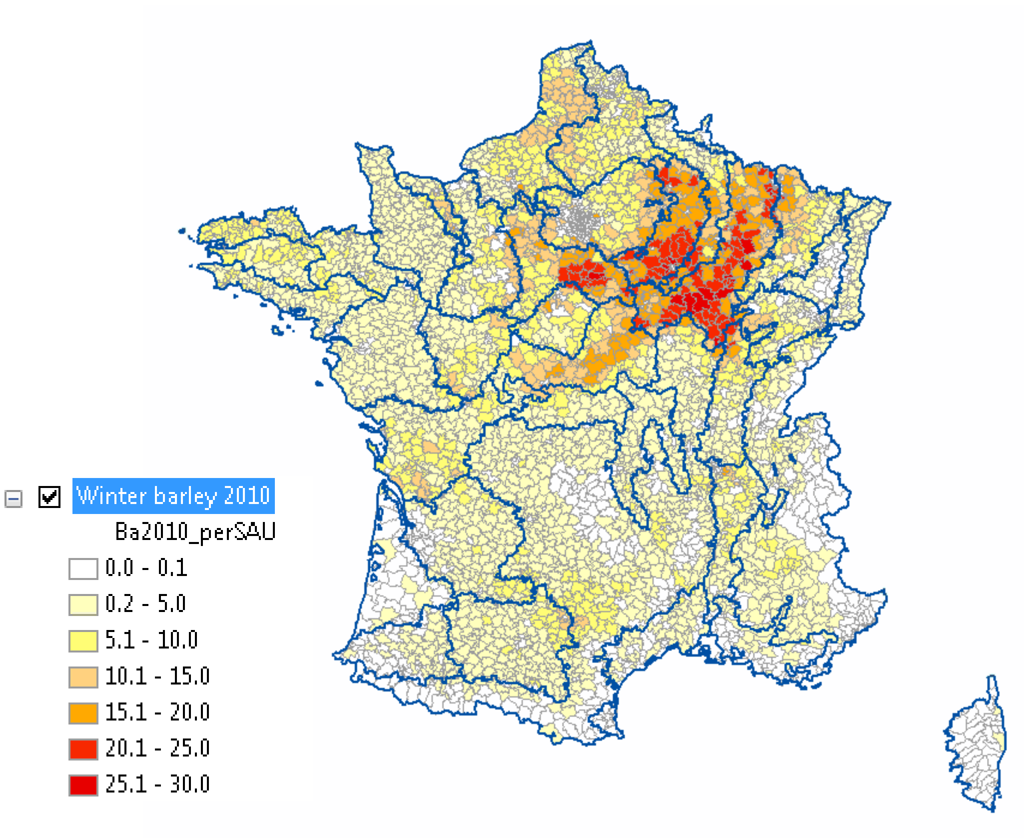


Figure 12 Winter barley - Crop Density (% SAU)

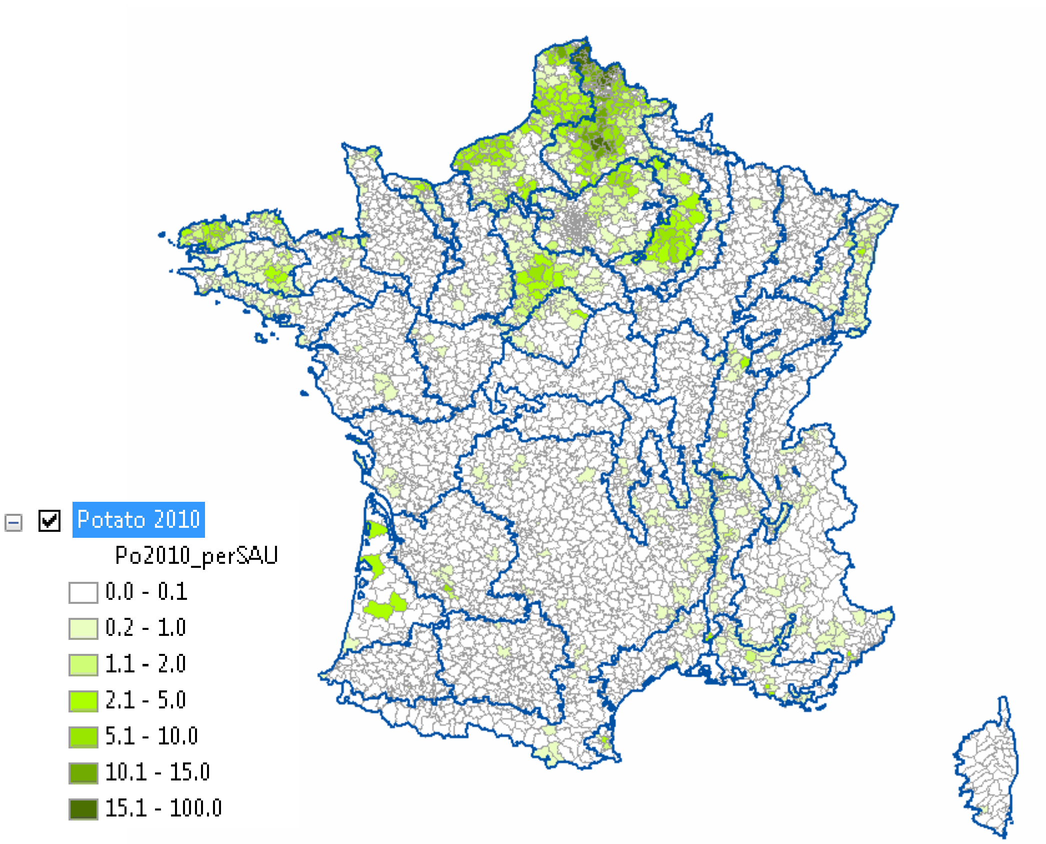


Figure 13 Potato - Crop Density (% SAU)

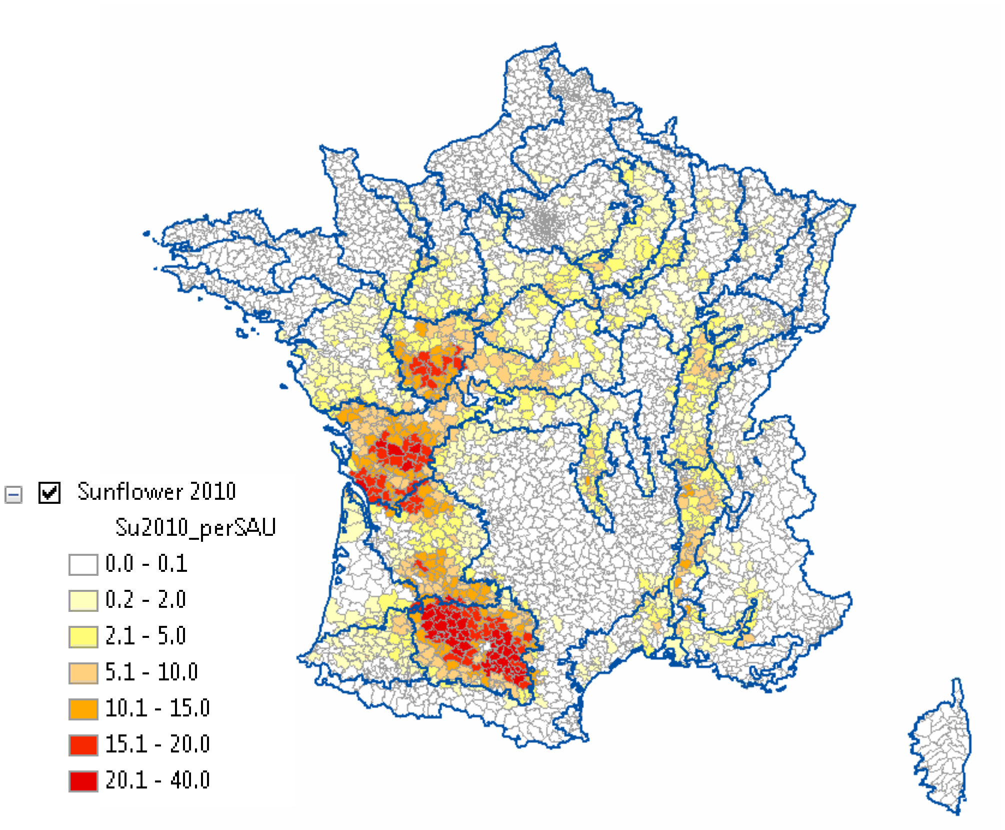


Figure 14 Suflower - Crop Density (% SAU)

Table 2 Cultivated Surface considered in the Agronomic Units

Crop	Total Surface (ha)[a]	Surface considered in the AUs (ha)[b]	Proportion of Surface considered (%)
Sugar Beet	383 588	350 422	91.4
Winter Wheat	4 896 895	4 882 009	99.7
Oilseed Rape	1 463 869	1 370 560	93.6
Maize Fodder	1 387 081	1 339 126	96.5
Maize Grain	1 616 087	1 596 269	98.8
Barley	1 574 621	1 537 787	97.7
Potato	154 621	147 968	95.7
Sunflower	691 870	646 411	93.4
Total of 8 crops in FROGS	12 168 632	11 870 552	97.6
Total cultivated surface in France (SAU)	27 087 794	26 931 918	99.4

a: Total surfaces as reported by Agreste (2010) for France
b: surfaces considered in the AU 0-31 when summing data at canton level
c: Potato surfaces are calculated as the sum of “pomme de terre primeurs et nouvelles”, “pomme de terre demi-saison et conserve”, “plants de pomme de terre“ and “féculerie“ from Agreste 2010 data

Importance of surfaces in the Agronomic Units is qualitatively represented according to four surface boundaries: 5 000 ha, 10 000 ha, 50 000 ha and 100 000 ha) in Table 3, where surfaces are expressed as kha. This representation by color codes is used throughout this document in descriptive tables of crop surfaces.

The number of AUs retained as a function of a surface threshold is indicated at the bottom of Table 3. This number varies largely according to the crop and the class surface. For instance, the potato surface in the AUs is always less than 100 000 ha and is higher than 50 000 ha in only one AU. Conversely, winter wheat is present in a large number of AUs, most of them belonging to the surface class corresponding to surfaces higher than 100 000 ha. Surfaces taken into account as a function of thresholds and corresponding proportions in the total cultivated surface are indicated in Table 4. Surfaces ranging between 5 000 and 10 000 ha do not significantly increase the proportion of surfaces taken into account in the AUs.

The distribution of crops in the Agronomic Units as a function of density classes (proportion of surface for a crop in the cultivated surface of the AU) is shown in Appendix 8. Class limits, specific for each crop, are indicated at the bottom of the table. Implicitly, this approach recalls the representativity thresholds defined in the INRA study.

Table 3 Distribution of crops in the AUs by Surface Classes (kha)

AU	Agronomic Unit	Sugar Beet	WinterWheat	Oilseed Rape	Maize Foder	MaizerGrain	Barley	Potato	Sunflower
1	Collines molassiques - Lauragais	0	193	33	12	91	40	0	199
2	Bretagne sud	0	65	9	74	31	15	1	0
3	Limagnes - Plaine du Forez	4	79	9	14	37	14	0	8
4	Bordure Nord - Picardie - Normandie	44	392	75	101	16	94	29	0
5	Alsace - Sundgau	5	41	2	9	126	4	1	0
6	Plaine normande - Bessin	7	66	14	21	5	15	1	2
7	Aquitaine - Landes	0	2	0	0	71	0	1	2
8	Bassin de l'Adour	0	15	3	22	230	2	0	8
9	Picardie - Nord - Pas-de-Calais	108	461	65	44	46	71	65	0
10	Charentes	0	292	62	36	151	68	0	147
11	Bocage normand	1	150	16	213	18	22	1	2
12	Barrois - Plateaux bourguignons	0	283	185	34	12	204	0	6
13	Plateau lorrain	0	133	65	42	5	55	0	0
14	Gâtines - Vallées de Loire	0	185	37	18	45	32	0	61
15	Sologne - Orléanais	0	30	10	2	17	11	0	3
16	Champagne crayeuse	70	229	87	2	20	140	14	10
17	Beauce - Drouais - Gâtinais	36	330	146	3	43	129	11	13
18	Bordelais - Périgord - Coteaux du Lot	0	105	10	21	103	22	1	65
19	Perche - Pays d'Auge - Pays d'Ouche	1	212	71	61	45	42	0	9
20	Bocages de l'ouest	0	210	30	170	42	29	1	15
21	Ardenne - Argonne - Champagne H.	8	118	48	33	25	56	1	3
22	Champagne berrichonne - Boischaut	0	276	152	13	41	107	0	27
23	Bas Dauphiné - Vallée du Rhône	0	54	7	11	58	18	1	16
24	Fossé bressan	0	108	34	17	78	31	1	16
25	Bretagne centrale	0	68	5	70	35	22	3	0
26	Plateaux de Haute-Saône	0	54	26	16	17	20	0	3
27	Provence	0	1	1	0	1	1	0	3
28	Plaine du Languedoc-Roussillon	0	2	0	0	0	2	0	2
29	Boischaut du sud	0	50	19	12	7	20	0	7
30	Bretagne nord	0	165	16	152	64	39	6	0
31	Ile-de-France	67	349	106	4	52	94	9	3
	No. of AUs with Surface ≥ 100 000 ha	1	18	4	4	4	4	0	2
	No. of AUs with Surface ≥ 50 000 ha	2	7	6	3	6	6	1	2
	No. of AUs with Surface ≥ 10 000 ha	2	3	12	16	16	16	3	6

Table 4 **Cultivated Surface considered according to Surface Thresholds**

Crop	S ≥ 100 000 ha		S ≥ 50 000 ha		S ≥ 10 000 ha		S ≥ 5 000 ha	
Sugar Beet	108057	30.8%	244206	69.7%	324174	94.7%	343571	98.0%
Winter Wheat	4356557	89.2%	4741457	97.1%	4877547	99.9%	4877547	99.9%
Oilseed Rape	589604	43.0%	1015169	74.1%	1315784	96.0%	1365368	99.6%
Maize Fodder	745079	55.6%	950248	71.0%	1317523	98.4%	1326504	99.1%
Maze Grain	609722	38.2%	1088049	68.2%	1577542	98.8%	1590030	99.6%
Barley	700119	45.5%	1137597	74.0%	1528729	99.4%	1528729	99.4%
Potato	-	-	64981	43.9%	118685	80.2%	133117	90.0%
Sunflower	346170	53.6%	472018	73.0%	575524	89.0%	622206	96.3%

Density classes (low, medium and high) are set empirically for each crop considering the density distribution shown in histograms of Figure 15. The class limits selected for each crop are indicated below the caption of the X-axis of the chart. Based on these crop-specific class limits, crop distribution by density classes in the AUs is indicated in Table 5.

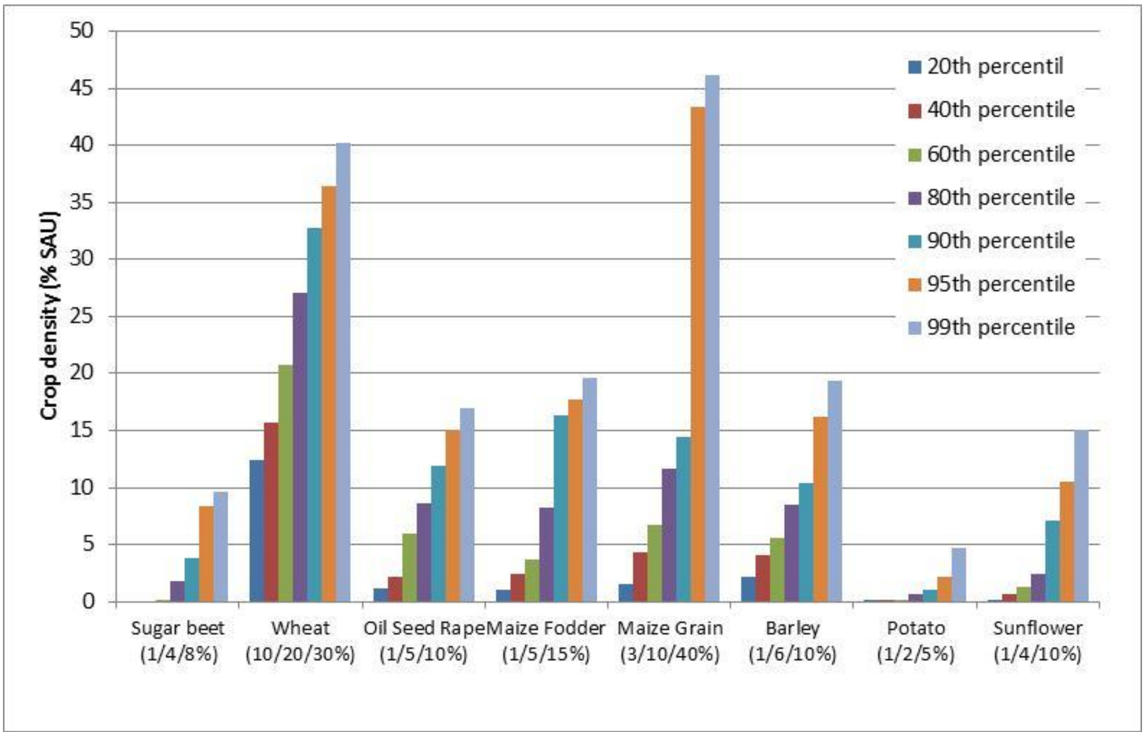


Figure 15 **Crop Density Distribution**

Table 5 Distribution of Crops in the AUs by Density Classes

AU	Agronomic Unit	Sugar Beet	Winter Wheat	Oilseed Rape	Maize Fodder	Maize Grain	Barley	Potato	Sunflower
1	Collines molassiques - Lauragais	0.0	16.2	2.8	1.0	7.6	3.3	0.0	16.7
2	Bretagne sud	0.0	14.7	2.0	16.9	7.1	3.4	0.1	0.0
3	Limagnes - Plaine du Forez	0.6	13.2	1.5	2.4	6.2	2.3	0.0	1.3
4	Bordure Nord - Picardie - Normandie	3.7	32.8	6.3	8.4	1.3	7.8	2.4	0.0
5	Alsace - Sundgau	1.8	15.0	0.5	3.3	45.9	1.3	0.4	0.1
6	Plaine normande - Bessin	2.8	27.1	5.7	8.6	2.1	6.0	0.4	0.7
7	Aquitaine - Landes	0.0	1.4	0.0	0.3	46.3	0.1	0.5	1.3
8	Bassin de l'Adour	0.0	2.7	0.5	4.0	41.2	0.4	0.0	1.4
9	Picardie - Nord - Pas-de-Calais	9.6	41.1	5.8	3.9	4.1	6.3	5.8	0.0
10	Charentes	0.0	22.6	4.8	2.8	11.6	5.3	0.0	11.3
11	Bocage normand	0.1	14.2	1.5	20.1	1.7	2.1	0.1	0.2
12	Barrois - Plateaux bourguignons	0.0	26.9	17.7	3.3	1.1	19.4	0.0	0.5
13	Plateau lorrain	0.0	20.7	10.1	6.6	0.8	8.6	0.0	0.1
14	Gâtines - Vallées de Loire	0.0	29.9	6.0	2.9	7.2	5.2	0.0	9.9
15	Sologne - Orléanais	0.3	20.7	6.6	1.6	11.4	7.2	0.3	2.0
16	Champagne crayeuse	9.6	31.7	12.0	0.3	2.8	19.4	2.0	1.3
17	Beauce - Drouais - Gâtinais	3.8	35.0	15.5	0.3	4.5	13.7	1.1	1.4
18	Bordelais - Périgord - Coteaux du Lot	0.0	12.2	1.1	2.5	12.0	2.6	0.1	7.5
19	Perche - Pays d'Auge - Pays d'Ouche	0.2	25.2	8.5	7.3	5.4	5.0	0.0	1.0
20	Bocages de l'ouest	0.0	16.0	2.3	12.9	3.2	2.2	0.1	1.1
21	Ardenne - Argonne - Champagne H.	1.4	21.5	8.7	6.1	4.6	10.2	0.1	0.6
22	Champagne berrichonne - Boischaut	0.0	26.6	14.6	1.2	4.0	10.4	0.0	2.6
23	Bas Dauphiné - Vallée du Rhône	0.0	13.0	1.7	2.5	13.9	4.2	0.2	3.9
24	Fossé bressan	0.0	20.1	6.4	3.2	14.5	5.8	0.2	2.9
25	Bretagne centrale	0.0	16.2	1.3	16.8	8.5	5.3	0.7	0.0
26	Plateaux de Haute-Saône	0.0	15.6	7.4	4.6	5.0	5.8	0.0	0.8
27	Provence	0.0	0.4	0.3	0.0	0.5	0.4	0.2	1.6
28	Plaine du Languedoc-Roussillon	0.0	0.5	0.1	0.0	0.1	0.7	0.1	0.7
29	Boischaut du sud	0.0	9.7	3.8	2.4	1.5	3.9	0.0	1.4
30	Bretagne nord	0.0	20.3	2.0	18.7	7.8	4.8	0.7	0.0
31	Ile-de-France	7.3	38.1	11.6	0.5	5.7	10.2	1.0	0.3
	No. of AUs of high density class	2	5	6	4	3	6	1	2
	No. of AUs of medium density class	5	11	9	6	5	4	1	2
	No. of AUs of low density class	1	10	11	14	14	17	2	13

The distributions shown in Table 3 and Table 5 are similar, with a few additional AU x Crop combinations in the analysis of densities corresponding to surfaces below 10 000 ha. Consequently, surface classes were used to characterize the importance of crops in the AUs (Table 3).

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3 Crop Rotations

In order to be as representative as possible of standard agricultural practices, typical crop rotations are implemented in FROGS. Surveys were conducted with field experts from Arvalis – Institut du Végétal and from UIPP members to identify the most common crop rotation or rotations associated to the different relevant crop – AU combinations. These crop rotations were further checked using a probabilistic approach based on Agreste data (Agreste, 2001), and in some circumstances the probabilistic approach was used to select the most representative rotation between two possible typical crop rotations.

The selected crop rotations were implemented in FROGS with some adaptations in order to fit the PEARL crop calendar concept.

3.1 Crop rotation surveys

Surveys were conducted to determine the most typical crop rotations (in order of importance) associated with each relevant crop – AU combination (see Chapter 2). Each of the crops considered in FROGS, i.e. winter wheat, winter barley, oilseed rape, fodder maize, grain maize, potatoes, sugar beet and sunflower, were considered separately in the surveys, as a so-called primary crop, to get the most typical crop rotation for the crop under consideration in a given AU as opposed to the most typical crop rotation in the AU. This means that the same crop may appear in different rotations in the same AU, and that a primary crop may appear as rotation crop when looking at another primary crop. For example, Sugar beet-Winter Wheat-Winter Wheat may be the most typical crop rotation when considering sugar beet as primary crop, while Winter Wheat-Maize fodder would be the most typical crop rotation in the same AU when considering winter wheat as primary crop. This means that in the AU in question (Limagnes – Plaine du Forez), sugar beet (not a major crop in that AU but still representing a significant surface area) is most often associated with winter wheat, while winter wheat (a major crop in that AU) is most often not associated with sugar beet but rather with fodder maize.

The results of the surveys gave between 3 to 5 possible crop rotations for each Agronomic Unit[3]. Rotation periods extending from 2 to 6 six years were obtained. Information on typical planting, emergence and harvest dates for the crops included in the rotations were also collected in the surveys.

3.2 Probabilistic approach

For sugar beet, wheat, oilseed rape, grain maize, fodder maize and barley, the Ministry of Agriculture conducted a survey that included information on previous crop in the same field (Agreste, 2001). These data are available at administrative Region level and are summarized in Table 6.

[3] The first survey was conducted before the AUs were fully delimited and mapped. The initial data collection was made based on geographical zones (e.g. Flandre maritime, Drouais-Thymerais, Nord-Pas-de-Calais (sauf littoral)) corresponding to well-known cropping regions for the local experts and which are very close to the current AU definition. Subsequent data collection was made based on the actual AUs. To ease the reading of this document, these cropping regions are considered equivalent to AU and as a consequence only the AU names are used.

__Table 6 Acreage of previous crop for each primary crop available in Agreste (2001)__

Primary crop	**Oilseed rape**		**Barley**			**Wheat**					**Maize**			**Sugar beet**		
Previous Crop (year n-1)	Wheat	Barley	Wheat	Barley	Maize	Wheat	Maize	Oilseed rape	Sunflower	Others	Wheat	Maize	Other cereals	Wheat	Barley	others
Administrative region	(% acreage)															
Alsace	-	-	-	-	-	9%	73%	9%	1%	8%	17%	73%	2%	-	-	-
Aquitaine	-	-	-	-	-	13%	23%	4%	34%	26%	5%	84%	2%	-	-	-
Auvergne	-	-	-	-	-	34%	27%	13%	9%	18%	38%	43%	8%	-	-	-
Basse Normandie	-	-	-	-	-	13%	50%	14%	0%	24%	40%	41%	7%	-	-	-
Bourgogne	35%	63%	85%	8%	1%	19%	8%	54%	9%	10%	23%	44%	15%	-	-	-
Bretagne	-	-	52%	5%	33%	11%	65%	6%	0%	17%	30%	36%	12%	-	-	-
Centre	62%	35%	79%	8%	4%	26%	13%	34%	10%	17%	46%	31%	11%	-	-	-
Champagne Ardenne	35%	63%	72%	7%	3%	13%	7%	35%	2%	43%				58%	35%	6%
France Comté	46%	46%	67%	12%	9%	8%	32%	45%	6%	8%	27%	39%	21%	-	-	-
Haute Normandie	56%	43%	74%	7%	6%	23%	20%	23%	0%	33%	48%	22%	22%	-	-	-
Ile de France	59%	40%	81%	10%	5%	24%	13%	23%	1%	37%	72%	12%	11%	74%	26%	1%
Lorraine	38%	60%	72%	14%	6%	21%	14%	58%	1%	5%	41%	34%	20%	-	-	-
Midi Pyrénées	-	-	18%	23%	11%	18%	13%	7%	44%	18%	9%	67%	7%	-	-	-
Nord pas de calais			85%	6%	0%	13%	20%	3%	0%	63%	63%	14%	17%	71%	23%	6%
Pays de la loire	-	-	-	-	-	14%	48%	17%	11%	11%	27%	42%	6%	-	-	-
Picardie	48%	51%	84%	4%	3%	20%	12%	10%	0%	57%	53%	15%	21%	85%	13%	2%
Poitou charentes	72%	22%	48%	8%	13%	12%	11%	28%	40%	8%	22%	57%	7%	-	-	-
Rhones Alpes	-	-	-	-	-	21%	31%	17%	18%	12%	17%	62%	11%	-	-	-

(-): indicate that no information were available in Agreste

From these data, the probabilities of having specific 3-year crop rotations were calculated. For instance the probability of having the rotation oilseed rape – winter wheat – winter barley in the “Ile de France” region was calculated by multiplying the probability of having oilseed rape before winter wheat (i.e., 23 %) by the probability of having winter wheat before winter barley (i.e., 81%) by the probability of having winter barley before oilseed rape (i.e., 40%). The resulting probability is therefore 7.45%. These probabilities were calculated for 12 potential 3-year crop rotations and are reported in Appendix 9*.* When no information were available in Agreste on the possibility of having one crop followed by another (e.g., wheat before oilseed rape in Alsace), the probability was assumed to be zero. As the probabilities were calculated by “Région administrative”, they were attributed to the relevant 31 AUs based on the overlap between the AU and the “Région” as illustrated in Appendix 10*.*

It is emphasized that these probabilities were only used to confirm or to choose between possible crop rotations identified from the survey, they cannot be used alone as only some major crops were included in the Ministry’s survey (Agreste, 2001). One should also note that more recent data have become available (Agreste, 2006). Whilst these include updated data on previous crops in the same field and new information for Sunflower, Potato and Peas, it is considered that these will not drastically change the choice of crop rotation that were based mainly on a survey conducted with field experts.

3.3 Selected crop rotations for the 31 AU

The crop rotations implemented in each AU for each primary crop are summarised in Table 7*.* In few scenarios in which maize is included as rotational crop, no distinction is made between fodder and grain maize. Hence another crop was introduced, called “maize”, with identical crop parameterization as grain and fodder maize.

Former versions of FROGS (1.1.1.1. and 2.2.2.2) were based on PEARL 3.3.3 which makes use of SWAP 209e. SWAP 209e has a limitation of maximum 70 simulation years which was the reason why in total eleven 4-year crop rotations had to be reduced to 3-year crop rotations. 4-year rotations require a run time of 86 years (6 years warm up period + twenty 4-year rotations). As SWAP 3234 employed in PEARL 4.4.4 is capable to run this simulation period, the eleven 4-year crop rotations originally identified being most representative for some combinations of agronomic unit and crop were reintegrated in FROGS 3.3.3.3 (*Table 7*).

Table 7 Crop rotations implemented in FROGS for each AU and each primary crop

AU code	AU Name	Primary crop	Crop rotation	Rotation length (years)
1	Collines molassiques - Lauragais	Winter Wheat	Winter Wheat-Sunflower	2
		Oilseed rape	Oilseed rape-Winter Wheat-Sunflower	3
		Maize fodder	Maize fodder	1
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Winter Wheat-Sunflower	3
		Sunflower	Sunflower-Winter Wheat	2
2	Bretagne sud	Winter Wheat	Winter Wheat-Maize fodder-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Maize fodder	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Maize fodder-Winter Wheat	3
		Sunflower	Sunflower-Winter Wheat	2
3	Limagnes - Plaine du Forez	Sugar beet	Sugar beet-Winter Wheat-Winter Wheat	3
		Winter Wheat	Winter Wheat-Maize fodder	2
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Barley-Winter Wheat	3
		Barley	Barley-Winter Wheat-Sugar beet	3
		Sunflower	Sunflower-Winter Wheat	2
4	Bordure Nord - Picardie - Normandie	Sugar beet	Sugar beet-Winter Wheat-Winter Wheat	3
		Winter Wheat	Winter Wheat-Barley-Maize fodder	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Winter Wheat-Sugar beet	3
		Potato	Potato-Winter Wheat-Barley	3
5	Alsace - Sundgau	Sugar beet	Sugar beet-Maize grain-Maize grain	3
		Winter Wheat	Winter Wheat-Maize grain	2
		Maize fodder	Maize fodder	1
		Maize grain	Maize grain	1
		Barley	Barley-Winter Wheat-Oilseed rape	3
6	Plaine normande - Bessin	Sugar beet	Sugar beet-Winter Wheat-Maize fodder	3
		Winter Wheat	Winter Wheat-Maize fodder	2
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Maize fodder-Winter Wheat	3
		Barley	Barley-Oilseed rape-Winter Wheat	3
		Sunflower	Sunflower-Winter Wheat	2
7	Aquitaine - Landes	Winter Wheat	Winter Wheat-Maize grain	2
		Maize fodder	Maize fodder	1
		Maize grain	Maize grain	1
		Sunflower	Sunflower-Winter Wheat-Oilseed rape	3
8	Bassin de l'Adour	Winter Wheat	Winter Wheat-Maize grain	2
		Oilseed rape	Oilseed rape-Winter Wheat-Maize	3
		Maize fodder	Maize fodder	1
		Maize grain	Maize grain	1
		Barley	Barley-Winter Wheat-Oilseed rape	3
		Sunflower	Sunflower-Winter Wheat	2
9	Picardie - Nord - Pas-de-Calais	Sugar beet	Sugar beet-Winter Wheat-Barley	3
		Winter Wheat	Winter Wheat-Barley-Sugar beet	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Winter Wheat-Winter Wheat	3
		Potato	Potato-Winter Wheat-Barley	3
10	Charentes	Winter Wheat	Winter Wheat-Barley-Oilseed rape	3
		Oilseed rape	Oilseed rape-Winter Wheat-Sunflower-Barley	4
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Oilseed rape-Winter Wheat-Sunflower	4

AU code	AU Name	Primary crop	Crop rotation	Rotation length (years)
		Sunflower	Sunflower-Winter Wheat-Oilseed rape-Barley	4
11	Bocage normand	Winter Wheat	Winter Wheat-Maize fodder-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Maize fodder-Winter Wheat	3
		Sunflower	Sunflower-Winter Wheat	2
12	Barrois - Plateaux bourguignons	Sugar beet	Sugar beet-Winter Wheat-Barley	3
		Winter Wheat	Winter Wheat-Oilseed rape-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat-Barley	3
		Barley	Barley-Winter Wheat-Oilseed rape	3
		Sunflower	Sunflower-Winter Wheat-Barley	3
13	Plateau lorrain	Winter Wheat	Winter Wheat-Oilseed rape-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Winter Wheat-Oilseed rape	3
		Sunflower	Sunflower-Winter Wheat-Barley	3
14	Gâtines - Vallées de Loire	Winter Wheat	Winter Wheat-Barley-Oilseed rape	3
		Oilseed rape	Oilseed rape-Winter Wheat-Sunflower-Winter Wheat	4
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Winter Wheat-Oilseed rape	3
		Barley	Barley-Oilseed rape-Winter Wheat-Sunflower	4
		Sunflower	Sunflower-Winter Wheat-Oilseed rape-Winter Wheat	4
15	Sologne - Orléanais	Winter Wheat	Winter Wheat-Barley-Oilseed rape	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Winter Wheat-Winter Wheat	3
		Barley	Barley-Oilseed rape-Winter Wheat	3
16	Champagne crayeuse	Sugar beet	Sugar beet-Winter Wheat-Barley	3
		Winter Wheat	Winter Wheat-Oilseed rape-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Barley-Winter Wheat	3
		Barley	Barley-Winter Wheat-Oilseed rape	3
		Potato	Potato-Winter Wheat-Oilseed rape	3
		Sunflower	Sunflower-Winter Wheat	2
17	Beauce - Drouais - Gâtinais	Sugar beet	Sugar beet-Winter Wheat-Barley	3
		Winter Wheat	Winter Wheat-Barley-Oilseed rape	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat-Winter Wheat	3
		Barley	Barley-Oilseed rape-Winter Wheat	3
		Potato	Potato-Winter Wheat-Barley	3
		Sunflower	Sunflower-Winter Wheat-Sunflower-Winter Wheat	4
18	Bordelais - Périgord - Coteaux du Lot	Winter Wheat	Winter Wheat-Sunflower	2
		Oilseed rape	Oilseed rape-Winter Wheat-Sunflower	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain	1
		Barley	Barley-Winter Wheat-Sunflower	3
		Sunflower	Sunflower-Oilseed rape-Winter Wheat	3
19	Perche - Pays d'Auge - Pays d'Ouche	Sugar beet	Sugar beet-Winter Wheat-Barley	3
		Winter Wheat	Winter Wheat-Maize fodder	2
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Winter Wheat-Oilseed rape	3

AU code	AU Name	Primary crop	Crop rotation	Rotation length (years)
		Sunflower	Sunflower-Winter Wheat	2
20	Bocages de l'ouest	Winter Wheat	Winter Wheat-Maize fodder	2
		Oilseed rape	Oilseed rape-Winter Wheat-Maize-Barley	4
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Winter Wheat-Maize fodder	3
		Sunflower	Sunflower-Winter Wheat-Oilseed rape-Winter Wheat	4
21	Ardenne - Argonne - Champagne H.	Sugar beet	Sugar beet-Winter Wheat-Barley	3
		Winter Wheat	Winter Wheat-Oilseed rape-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Winter Wheat-Barley	3
		Barley	Barley-Winter Wheat-Oilseed rape	3
		Sunflower	Sunflower-Winter Wheat	2
22	Champagne berrichonne - Boischaut	Winter Wheat	Winter Wheat-Barley-Oilseed rape	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Oilseed rape-Winter Wheat	4
		Maize grain	Maize grain-Winter Wheat-Barley	3
		Barley	Barley-Oilseed rape-Winter Wheat	3
		Sunflower	Sunflower-Winter Wheat-Oilseed rape-Winter Wheat	4
23	Bas Dauphiné - Vallée du Rhône	Winter Wheat	Winter Wheat-Maize grain	2
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Oilseed rape	3
		Maize grain	Maize grain	1
		Barley	Barley-Winter Wheat-Winter Wheat	3
		Sunflower	Sunflower-Winter Wheat-Barley	3
24	Fossé bressan	Sugar beet	Sugar beet-Winter Wheat-Barley	3
		Winter Wheat	Winter Wheat-Oilseed rape-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat	2
		Maize grain	Maize grain-Barley-Winter Wheat	3
		Barley	Barley-Winter Wheat-Oilseed rape	3
		Sunflower	Sunflower-Winter Wheat	2
25	Bretagne centrale	Winter Wheat	Winter Wheat-Maize fodder-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Maize fodder-Winter Wheat	3
		Potato	Potato-Winter Wheat-Barley	3
26	Plateaux de Haute-Saône	Winter Wheat	Winter Wheat-Oilseed rape-Barley	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat-Oilseed rape	3
		Barley	Barley-Winter Wheat-Oilseed rape	3
27	Provence	Sunflower	Sunflower-Winter Wheat	2
28	Plaine du Languedoc-Roussillon	Barley	Barley-Winter Wheat-Winter Wheat	3
29	Boischaut du sud Bretagne nord	Winter Wheat	Winter Wheat-Barley-Oilseed rape	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Winter Wheat	3
		Maize grain	Maize grain-Winter Wheat-Barley	3
		Barley	Barley-Maize-Winter Wheat	3
		Sunflower	Sunflower-Winter Wheat-Barley	3
		Winter Wheat	Winter Wheat-Maize fodder-Barley	3
30	Bretagne nord Ile-de-France	Oilseed rape	Oilseed rape-Winter Wheat-Maize fodder	3
		Maize fodder	Maize fodder-Winter Wheat-Barley	3
		Maize grain	Maize grain-Winter Wheat	2
		Barley	Barley-Maize fodder-Winter Wheat	3
		Potato	Potato-Winter Wheat-Barley	3
		Sugar beet	Sugar beet-Winter Wheat-Barley	3

AU code	AU Name	Primary crop	Crop rotation	Rotation length (years)
31	Ile-de-France	Winter Wheat	Winter Wheat-Barley-Oilseed rape	3
		Oilseed rape	Oilseed rape-Winter Wheat-Barley	3
		Maize fodder	Maize fodder-Winter Wheat-Winter Wheat	3
		Maize grain	Maize grain-Winter Wheat-Winter Wheat	3
		Barley	Barley-Oilseed rape-Winter Wheat	3
		Potato	Potato-Winter Wheat-Barley	3
		Sunflower	Sunflower-Winter Wheat	2

3.4 Implementation of the crop rotations in FROGS

The crop calendar in PEARL consists of three columns (emergence date, harvest date, and crop name). For every year one line has to be entered for the corresponding rotational crop (see example in Table 8 for winter barley rotation in AU 1). Since PEARL prohibits that one crop is entered in more than one line it is necessary to define each crop multiple times in the PEARL Crop Section.

Table 8 Crop Calendar for the first years of barley rotation in AU 1 (Collines molassiques – Lauragais) as implemented in PEARL

```
table Crops
25-Nov-1981  03-Jul-1982  BARLEY0
25-Nov-1982  03-Jul-1983  WWHEAT0
01-May-1984  31-Aug-1984  SUNFL0
25-Nov-1984  03-Jul-1985  BARLEY1
25-Nov-1985  03-Jul-1986  WWHEAT1
01-May-1987  31-Aug-1987  SUNFL1
25-Nov-1987  03-Jul-1988  BARLEY2
25-Nov-1988  03-Jul-1989  WWHEAT2
01-May-1990  31-Aug-1990  SUNFL2
25-Nov-1990  03-Jul-1991  BARLEY3
25-Nov-1991  03-Jul-1992  WWHEAT3
01-May-1993  31-Aug-1993  SUNFL3
25-Nov-1993  03-Jul-1994  BARLEY4
25-Nov-1994  03-Jul-1995  WWHEAT4
01-May-1996  31-Aug-1996  SUNFL4
25-Nov-1996  03-Jul-1997  BARLEY5
25-Nov-1997  03-Jul-1998  WWHEAT5
01-May-1999  31-Aug-1999  SUNFL5
25-Nov-1999  03-Jul-2000  BARLEY6
25-Nov-2000  03-Jul-2001  WWHEAT6
01-May-2002  31-Aug-2002  SUNFL6
25-Nov-2002  03-Jul-2003  BARLEY7
25-Nov-2003  03-Jul-2004  WWHEAT7
01-May-2005  31-Aug-2005  SUNFL7
25-Nov-2005  03-Jul-2006  BARLEY8
end_table
```

The emergence and harvest dates were chosen based on feedback from local Arvalis and UIPP field experts and checked by comparing with Agreste data (2001), whenever available. Remaining data gaps were filled with data from FOCUS (Châteaudun for Northern France and Piacenza for Southern France). Assignment of the different AUs to Northern or Southern France is shown in Table 9. Dates for sunflowers were taken from Piacenza also for Northern France, since sunflowers are not defined in Châteaudun.

Table 9 Assignment of the AUs to Northern or Southern France

AUID	Name	North_South
1	Collines molassiques - Lauragais	S
2	Bretagne sud	N
3	Limagnes - Plaine du Forez	S
4	Bordure Nord - Picardie - Normandie	N
5	Alsace - Sundgau	N
6	Plaine normande - Bessin	N
7	Aquitaine - Landes	S
8	Bassin de l'Adour	S
9	Picardie - Nord - Pas-de-Calais	N
10	Charentes	S
11	Bocage normand	N
12	Barrois - Plateaux bourguignons	N
13	Plateau lorrain	N
14	Gâtines - Vallées de Loire	N
15	Sologne - Orléanais	N
16	Champagne crayeuse	N
17	Beauce - Drouais - Gâtinais	N
18	Bordelais - Périgord - Coteaux du Lot	S
19	Perche - Pays d'Auge - Pays d'Ouche	N
20	Bocages de l'ouest	N
21	Ardenne - Argonne - Champagne H.	N
22	Champagne berrichonne - Boischaut	N
23	Bas Dauphiné - Vallée du Rhône	S
24	Fossé bressan	N
25	Bretagne centrale	N
26	Plateaux de Haute-Saône	N
27	Provence	S
28	Plaine du Languedoc-Roussillon	S
29	Boischaut du sud	S
30	Bretagne nord	N
31	Ile-de-France	N

Technical limitations in the PEARL crop calendar as explained below meant that some of the emergence dates (18 values) and harvest dates (25 values) had to be changed (see Appendix 11). SWAP has to define the beginning of the agricultural year at the beginning of a month. The agricultural year is defined in a way that the transition between two agricultural years is crop free. This means that at least one transition between two months (e.g. 31st October to 1st November) must not be included in any of the rotational crops. This problem typically occurs in rotations where a winter- and a spring crop are grown with overlapping emergence and harvest dates. For example, the following crop calendar (Table 10) would fail because all transitions between the months are covered by at least one of the two crops (November – July by winter wheat and May – November by maize). Changing the harvest date of maize from 02-Nov-1983 to 31-Oct-1983 makes the crop calendar valid, because now the transition between October and November is free in both crops and can be defined as the beginning of the agricultural year. Failing crop calendars were individually checked to determine which date could be changed leading to the smallest possible deviation to the original parameterization.

Table 10 Example of an invalid crop calendar (no agricultural year can be defined, left) and corrected crop calendar (right)

table Crops	table Crops
15-Nov-1981 08-Jul-1982 WWHEAT	15-Nov-1981 08-Jul-1982 WWHEAT
08-May-1983 02-Nov-1983 MAIZEG	08-May-1983 31-Oct-1983 MAIZEG
end table	end table

All emergence and harvest dates are listed in Appendix 11, together with comments on the source of the data and whether the dates were changed due to the limitations of the PEARL crop calendar.

With the introduction of 4-year rotations it was necessary to change the algorithm that sets up the crop calendar in the FROGS shell. Otherwise it would be possible that the simulation stops within and not at the end of the final rotation. The new algorithm does not start with the first year of the simulation, e.g. the first year of the warm up period, but with the first year of the evaluation period. In a first step the calendar is built in reverse from the first year of evaluation to the first year of the warm-up period. Therefore, the first year of the simulation can start within a rotation and not necessarily with the start of a rotation. The second step builds the calendar for the evaluation period: from first year of evaluation to the last year. A few scenarios are now running for 87 years, since the last crop of the rotation is not harvested in the 80th year of cropping, but in the following year; therefore, the weather data was extended (see 5.4).

3.5 References

Agreste (2001). Enquête sur les pratiques culturales, La statistique agricole SCEES – Collection chiffres et données n°159.

Agreste (2006). Enquête pratiques culturales 2006, Données en ligne (http://agreste.agriculture.gouv.fr/).

4 Application timing based on BBCH growth stages

In the FOCUS scenarios and models, applications can only be made at specific dates or relative to emergence or harvest. The same application dates are used over the whole simulation period of 26 years. The FROGS interface allows scheduling of the pesticide applications relative to the crop development (in accordance with the BBCH growth stages as specified in the GAP), taking into account spatial and temporal variations in crop development in function of the meteorological conditions of each scenario and year of application. This means that the user specifies the BBCH code, application rate, and target crop, and the FROGS interface then derives the actual application dates from the corresponding crop phenological sub-model implemented in the shell.

4.1 Phenological sub-model origin

Phenology is largely based on the temperature sum gathered by the respective crop. In the shell the same algorithm as in the crop sub-model (SWAP) of FOCUS Pearl 3.3.3 is implemented. It should be noted that SWAP contains the same phenology related routines as the model WOFOST (http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Models-Software-Tools/World-Food-Studies-WOFOST), which is used by JRC (http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST) for the European Crop Growth Monitoring System (CGSM). Crop-specific parameters, including phenological parameters (see below for definitions), were gathered by Boons-Prins et al. (1993) and were also used in FROGS.

For winter oilseed rape (WOSR), phenological development cannot be simulated successfully with consideration of temperature sums only. Habekotté (1997) presents a more detailed model comprising temperature sums, influence of photoperiod, as well as vernalization.

4.2 Phenological sub-model theory

Phenological development is expressed in development stage Ds (-) [0 at emergence, 1 at flowering, 2 at maturity]. Ds is a function of temperature sum.

$$D_s^{j+1} = D_s^j + \frac{T_{\text{eff}}}{T_{\text{sum},i}}$$

(j = day number, T_{eff} = effective daily termperature, $T_{sum,i}$ = temperature sum required to complete certain growth stage)

Effective daily temperature T_{eff} is defined by a minimum temperature (T_{lb}) for development and a maximum temperature (T_{ub}) where development saturates:

For

$T_{avg} <= T_{lb}$ → $T_{eff} = 0$,
$T_{lb} < T_{avg} < T_{ub}$ → $T_{eff} = T_{avg} - T_{lb}$,

$T_{avg} >= T_{ub} \rightarrow T_{eff} = T_{ub} - T_{lb}$.

Two temperature sums are required for the model, e.g. one for Ds between 0 and 1, as well as one for Ds between 1 to 2. Default values for the major crops in the EU are provided by Boons-Prins et al. (1993).

Table 11 Crop specific parameters for phenological sub-model.

Crop	$T_{sum,1}$	$T_{sum,2}$	T_{lb}	T_{ub}
	[degree days]		[°C]	
Sugar beet	365	1622	3	35
Winter wheat	1255	909	2	30
Winter oilseed rape	240	600	4	35
Maize fodder	693	786	7	30
Maize grain	693	786	7	30
Winter barley	1255**	500**	2**	30**
Potato	500*	1000*	2	29
Sunflower	1050*	1100*	2	40
Maize	693	786	7	30

* Parameter values obtained from Boons-Prins et al. (1993) yielded poor fits to observed growth stages, therefore, values where derived from fitting the model to observations.

** Boons-Prins et al. (1993) do not list values for winter barley, therefore, values from winter wheat are used. However, since development during the linear growth phase is faster in barley than in wheat (Ellen, 1993), $T_{sum,2}$ is decreased to 500 degree days.

Initial testing of the routines indicated that for winter oilseed rape phenological development could not be simulated successfully. Therefore, a more detailed model was implemented in the FROGS interface. Besides temperature sums, Habekotté (1997) considered the effects of day length and vernalization requirement on the development of winter oilseed rape. These two additional factors only take effect for the period extending from emergence to flowering, e.g. for $0 < D_s < 1$:

$$D_s^{j+1} = D_s^{j} + \frac{T_{eff}}{T_{sum,1}} \cdot F_v \cdot F_p \cdot a_T$$

The degree of vernalization is represented by a state variable (F_v), with values between 0 (not vernalized) and 1 (fully vernalized) and is calculated by integrating the vernalization rate ($d F_v / d t$) from emergence until the onset of flowering or until full vernalization. The effect of temperature on the vernalization rate is described in a vernalization response curve (*Figure 16*a).

The effect of day length/photoperiod (F_p) is expressed as multiplication factor that varies between 0 and 1 and increases linearly between a basal photoperiod (P_b) and a saturating photoperiod (P_{sat}) (*Figure 16*b). Actual day length is calculated from day of year and latitude of the AU's centroid.

Additionally, Habekotté (1997) introduces a scaling factor (a_T) to the development rate. The values for a_T is derived by fitting experimental data to the model. However, in the original publication a slightly different scale for D_s is used and this value cannot be used in the FROGS shell. Following an iterative approach it was shown that a value of 0.15 fits the winter oilseed rape growth stage data best.

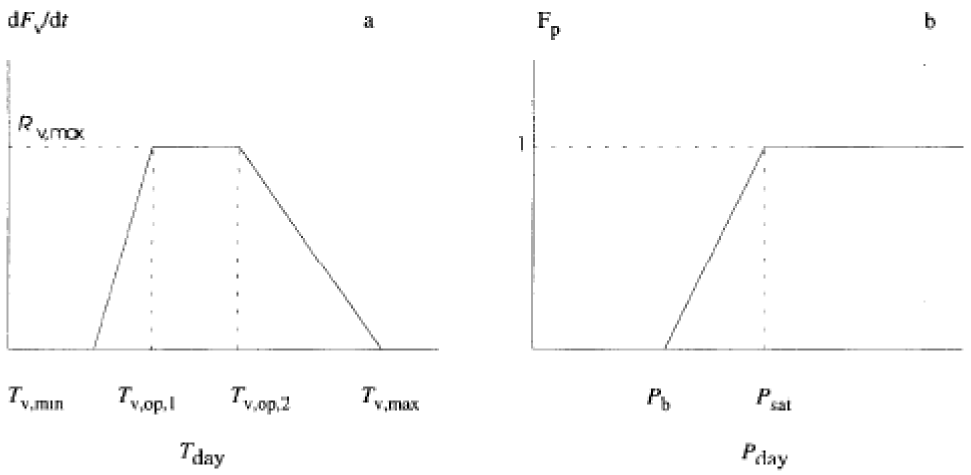


Figure 16 ***Effect of vernalization (left) and photoperiod (right) on winter oilseed rape (from Habekotté, 1997)***

Table 12 Parameters for detailed winter oilseed rape model (based on Habekotté, 1997).

Parameter	Unit	Value
Vernalization		
$R_{v,max}$	d^{-1} °C^{-1}	0.014553
$T_{v,max}$	°C	17.2022
$T_{v,min}$	°C	-3.7182
$T_{v,op1}$	°C	0.726
$T_{v,op2}$	°C	5.377
Photoperiod		
Pb	h	8
Psat	h	14
Scaling factor		
a_T	d^{-1} °C^{-1}	0.15

4.3 Relating development stage D_s to BBCH code

JRC [http://agsys.cra-cin.it/tools/cropml/help/] provides the following definitions that can be related to BBCH (Table 13). A piecewise-linear relationship was constructed from the D_s-BBCH correspondences (Figure 17).

Table 13 ***Correspondence between development stage and BBCH code.***

	D_s	BBCH
Emergence:	0	9
Beginning of tillering:	0.25	21
Mid tillering:	0.35	25
Panicle initiation:	0.6	30
Full Heading:	0.9	59
Full Flowering:	1	65
Full Grain filling:	1.5	75
Physiological maturity:	2	90

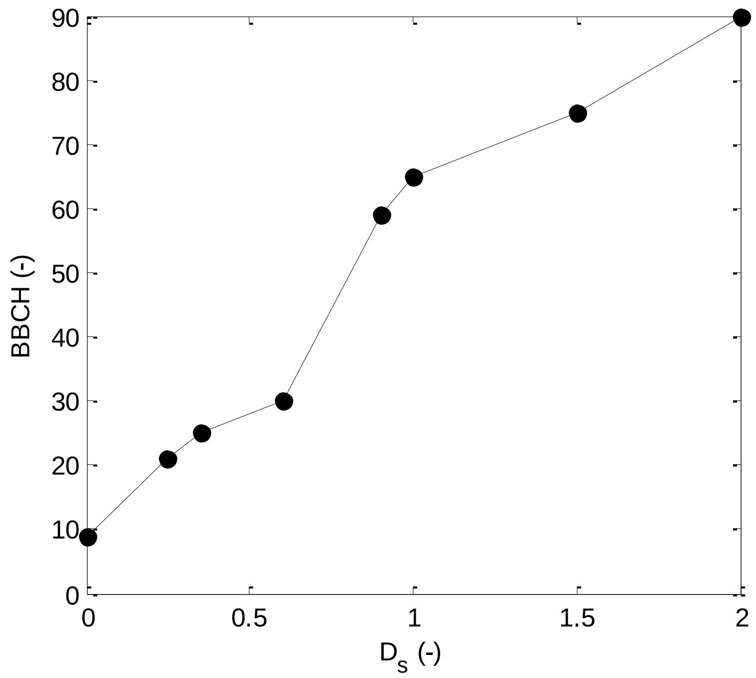


Figure 17 Piecewise-linear relationship between development stage (D_s) and BBCH code.

For the bi-annual crop sugar beet, a different relationship is required since harvest occurs at BBCH 50. Boons-Prins (1993) assign D_s = 1 to the stage where the crop canopy starts covering the ground fully. This growth stage corresponds to BBCH 40. Hence, the piecewise-linear relationship for sugar beet was constructed as shown in Table 14 and Figure 18.

Table 14 Correspondence between development stage and BBCH code for sugar beet

	D_s	BBCH
Emergence:	0	9
Full ground cover (LAI = 2.5):	1	40
Harvest:	2	49

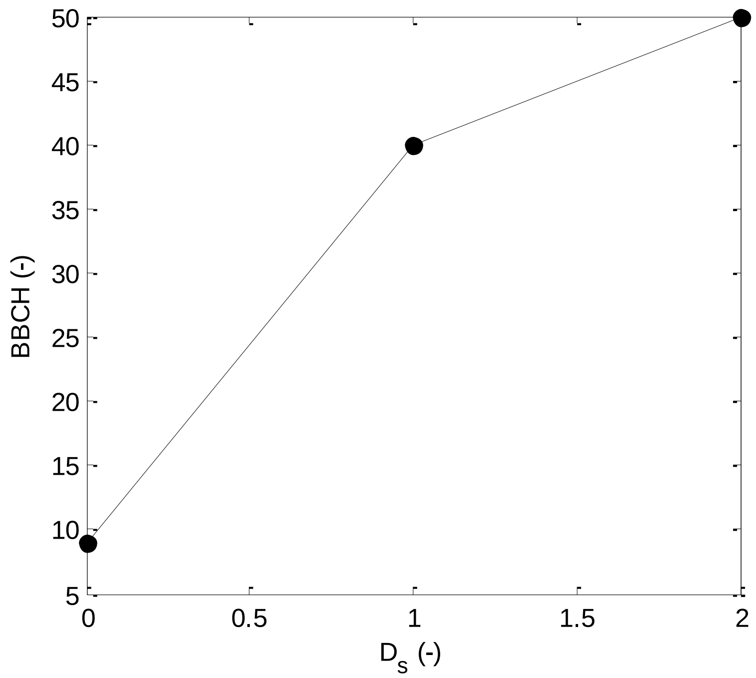


Figure 18 Piecewise-linear relationship between development stage (Ds) and BBCH code for sugar beets

4.4 Validation

The phenological models were tested against data gathered by industry from its biological efficacy trials. The same emergence and harvest dates were used as defined for each crop-AU combination in the FROGS database. Temperature data were obtained from the selected weather file assigned to each AU.

Examples of the phenological models predictions of the crop development are shown in *Figure 19* to *Figure 25*, for the four most relevant AUs for each crop, as determined in Chapter 2, Table 3. For most of the crop-AU combinations, the phenological model for the respective crop yielded very good descriptions of the development, even though emergence dates were kept constant for each year. Only winter barley showed some discrepancy, which may be attributable to a larger range of sowing/emergence dates. Winter barley is a crop that is often grown for rotational reasons giving management priority to crops with higher economic priority. Therefore, sowing can vary more due to machinery or pre-crop harvest constraints.

While the type of cultivar may in particular cases have a strong impact on phenological development, the growth models were validated against crop stages observations from numerous field trials comprising many different cultivars (all available data were considered regardless of cultivars). It could therefore be shown that the models depict the overall or average phenological development among the different cultivars well for the different AUs. This is considered sufficient as the groundwater modeling itself will also be performed for a given crop regardless of the cultivars.

Figure 19   Sugar beet development in the four most representative AUs

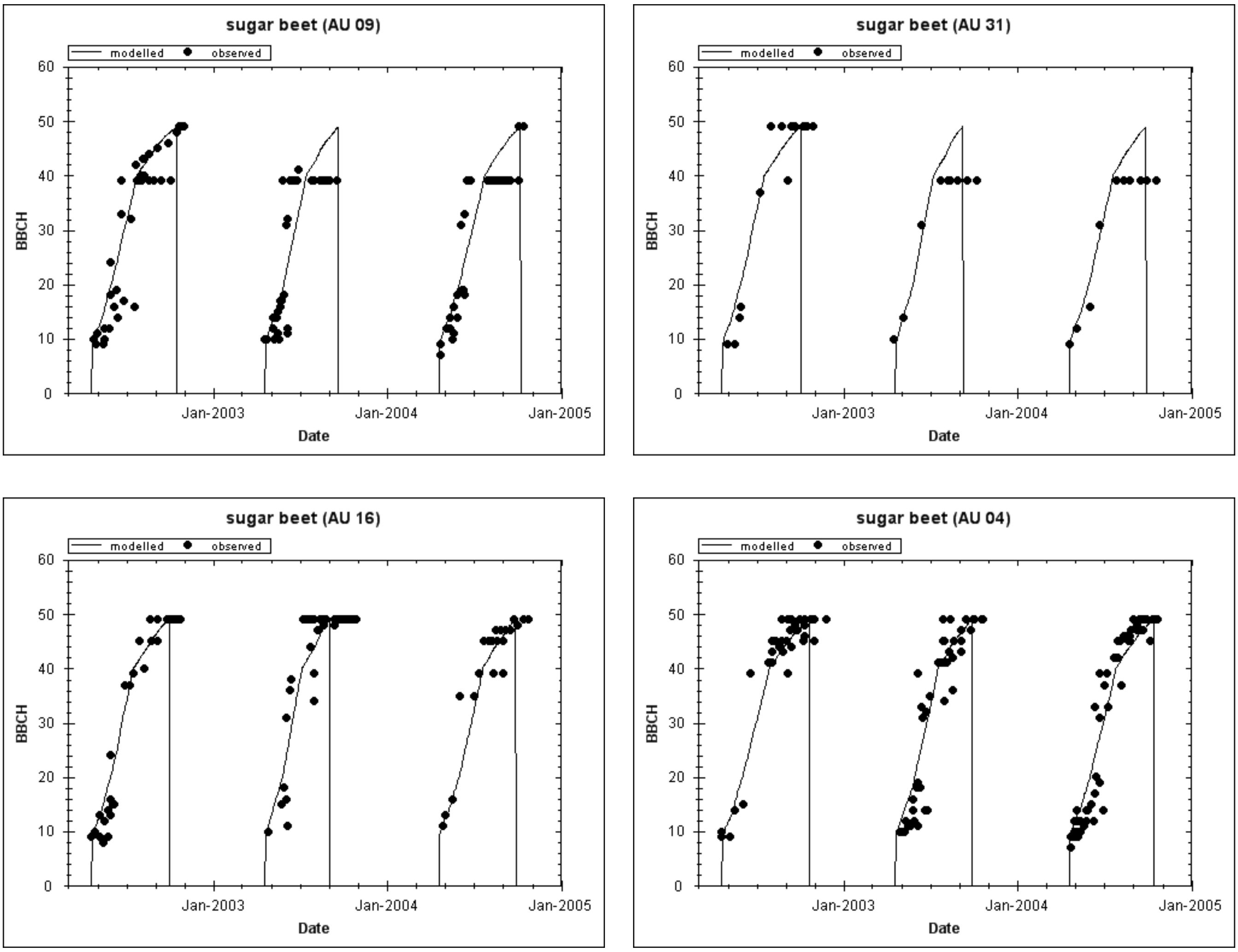
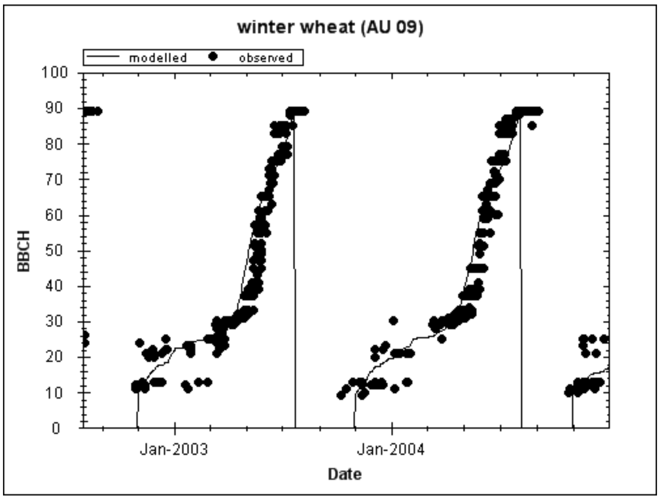
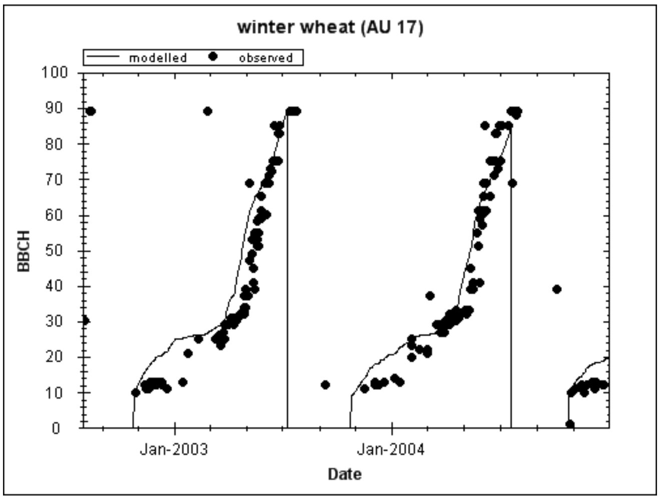
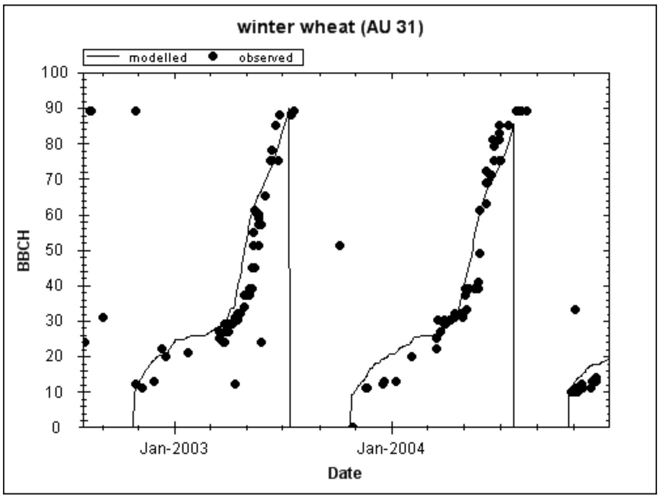


Figure 20 Winter wheat development in the four most representative AUs







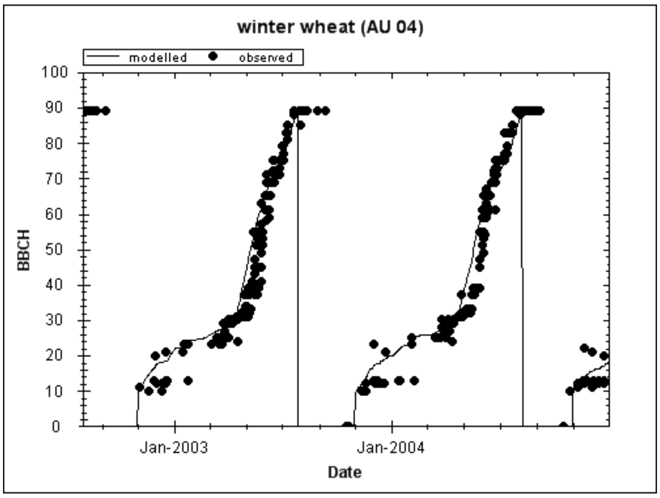


Figure 21 Winter oilseed rape development in the four most representative AUs

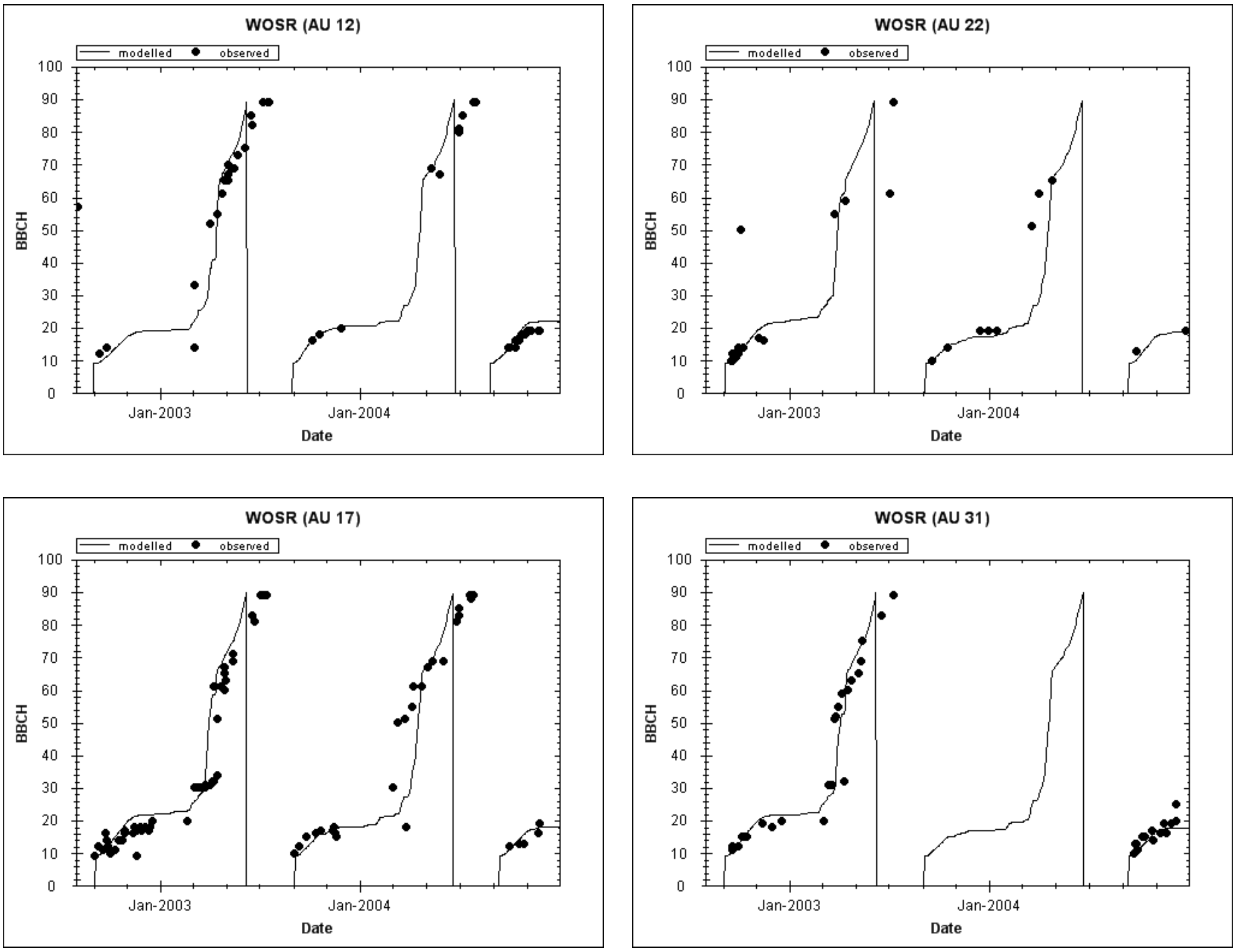


Figure 22 ***Maize (fodder and grain) development in the four most representative AUs (8, 10 grain maize; 11, 20 fodder maize). Phenology observations and phenology model do not distinguish fodder and grain maize.***

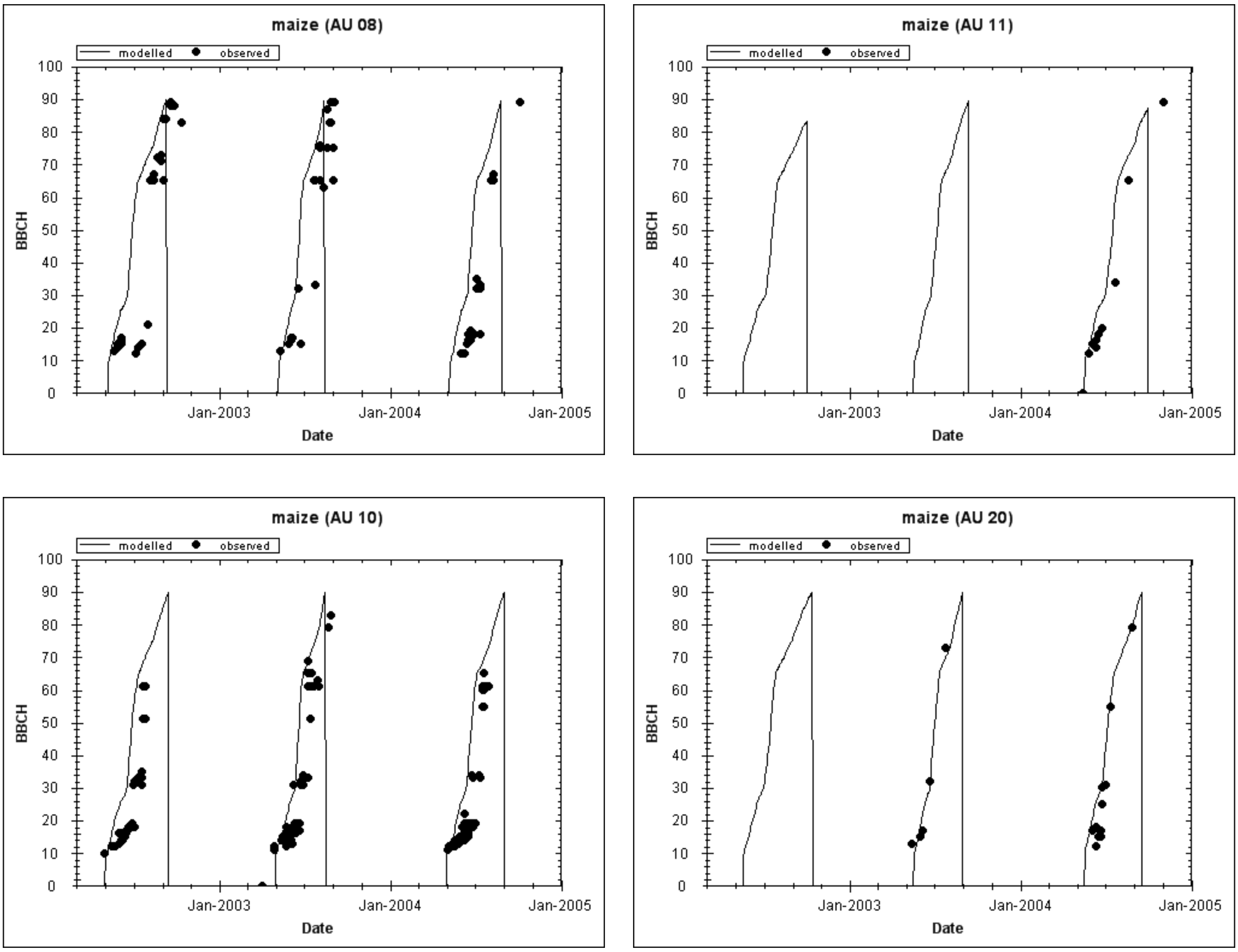


Figure 23 Winter barley development in the four most representative AUs

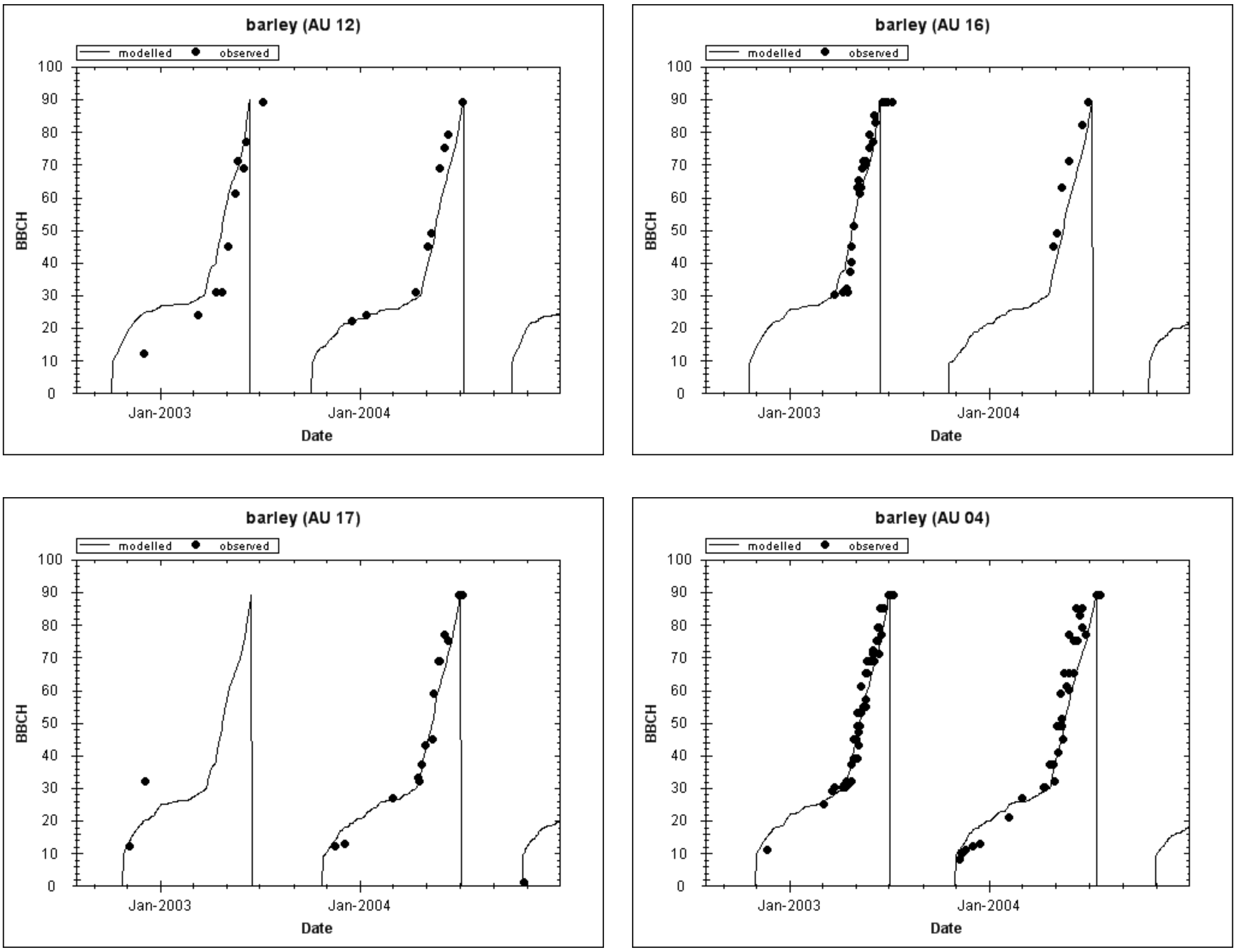


Figure 24 Potato development in the four most representative AUs

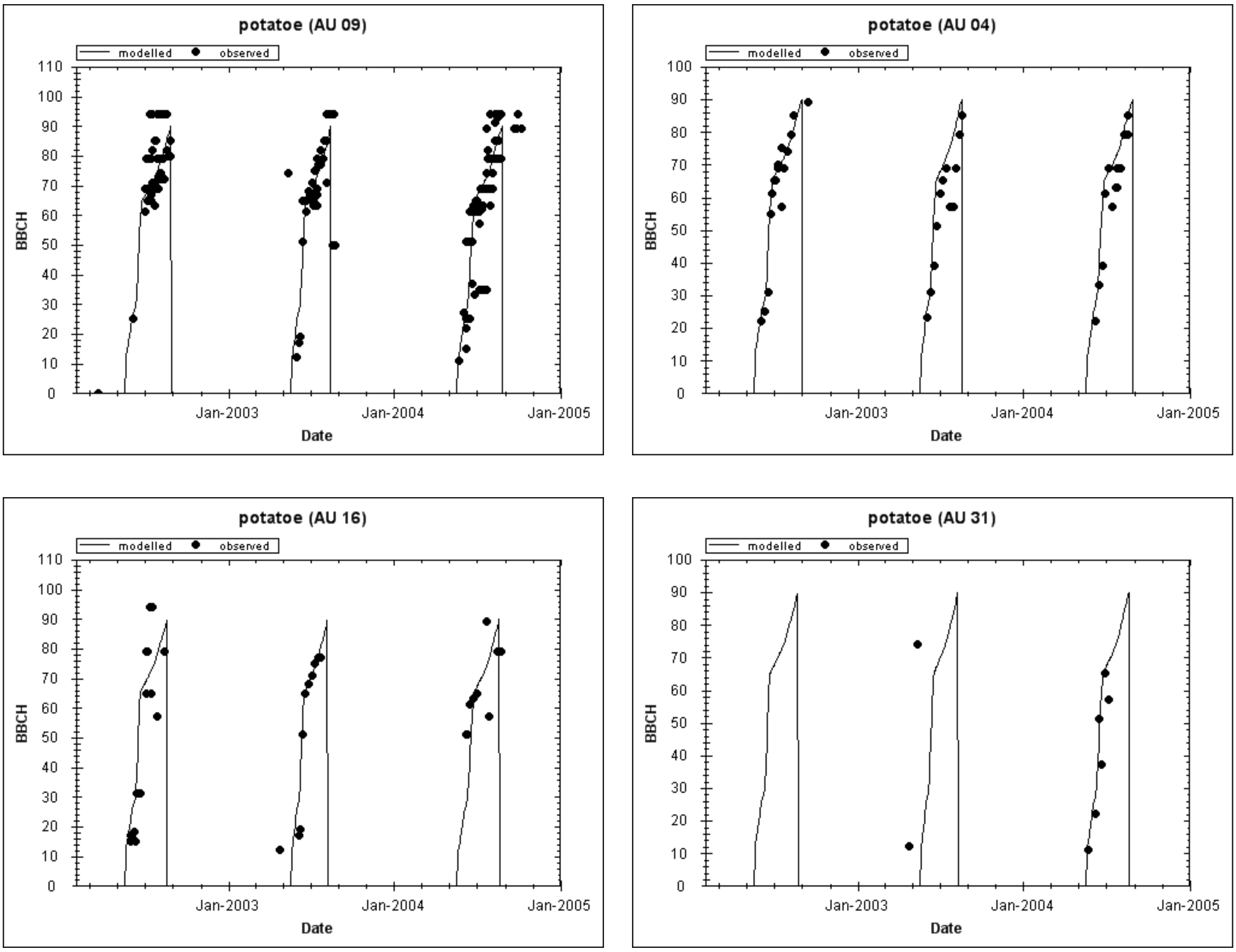
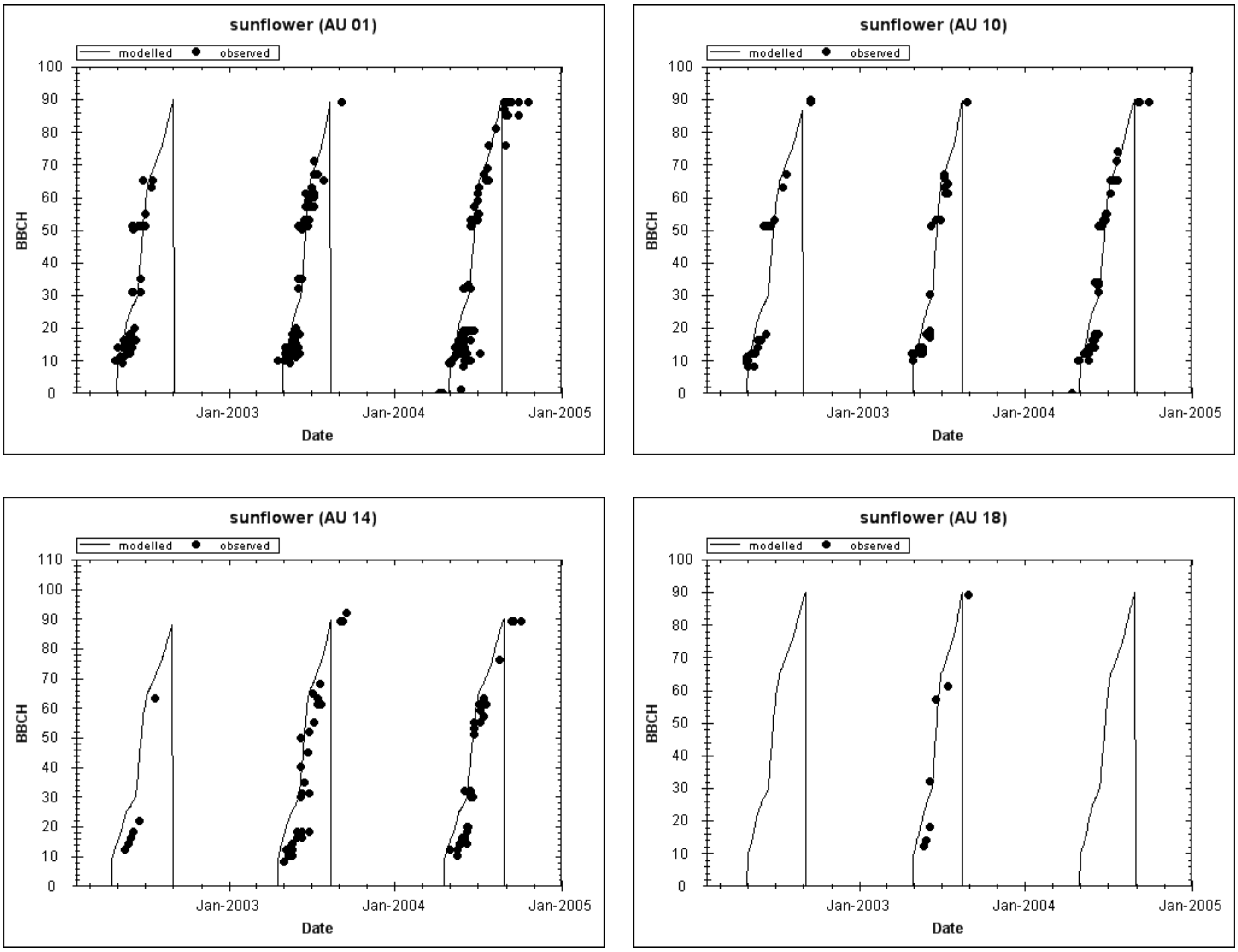


Figure 25 Sunflower development in the four most representative AUs (AU 18 is actually the 5th representative AU, however, for the 4th representative AU 22 no measurement data are available for the time period considered)



4.5 References

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5 Weather data

5.1 Introduction

The MARS database [MARS, 2004] was used as meteorological input for FROGS, since it uses data from local weather stations (partially interpolated) and is commonly accepted in the European scientific and regulatory community.

For each agronomic unit (AU) one MARS tile was selected as representative of the meteorological conditions within the AU. The selection process is summarized in the following section. For further details refer to Appendix 12. The basic principle of the selection process was that the selected tile should be the most representative one in terms of climate and regarding agricultural occupation (i.e. relevance to the AU under consideration).

5.2 Short description of the MARS database

The MARS database consists of tiles or grid-cells (50 * 50 km) that cover Europe. Each tile consists of a data set of long-term daily weather records. The weather data describe the “average” conditions in one grid and not the conditions at the grid cell centre. Most parameter values were collected on local weather station level and interpolated for the whole grid-cell. Since global radiation and potential evaporation are not widely measured they are calculated from available measured meteorological parameters.

In order to determine representative meteorological conditions for one grid-cell the most suitable stations were identified. Suitability of stations was determined using four criteria: distance between station and grid centre, difference in altitude, difference in distance to coast, climatic barrier separation (e.g. mountains). After identifying up to four suitable stations for one grid-cell, a simple averaging procedure was applied for most parameters (corrected for altitude in case of temperature and vapour pressure). Only rainfall was not interpolated but rather taken from the most suitable station. Missing data values were filled with long-term average data of that day for that station.

For more details on the MARS-data set and the interpolation procedure please refer to van der Goot and Orlandi (2003).

5.3 Summary of the tile selection process in FROGS

The driving objective in selecting the meteo data for each of the AUs was to be as representative as possible of the main agricultural conditions in that AU. It was therefore not the aim to implement any conservativity or worst-case assumptions in the weather scenarios.

In order to find the most representative MARS-tile regarding agricultural conditions for each AU, the agricultural occupation of the cantons was extracted from the Agreste database. A map of the cantons was intersected with the AUs and the MARS tiles in GIS. For each MARS tile the agricultural occupation within one AU was calculated. The tile with the largest agricultural area in each AU was selected as the default tile. In the following, the tile with largest acrigultural occupation in one AU is noted $T_{1,AU}$. The tile with the second largest occupation is noted $T_{2,AU}$.

In additional steps it was checked if this default tile could be accepted as the weather scenario for an AU or if there were objective reasons (geographically separated agricultural areas, high variability of climatic conditions, relative location to mountains or the coast) to choose another tile. The procedure is summarized in Figure 26.

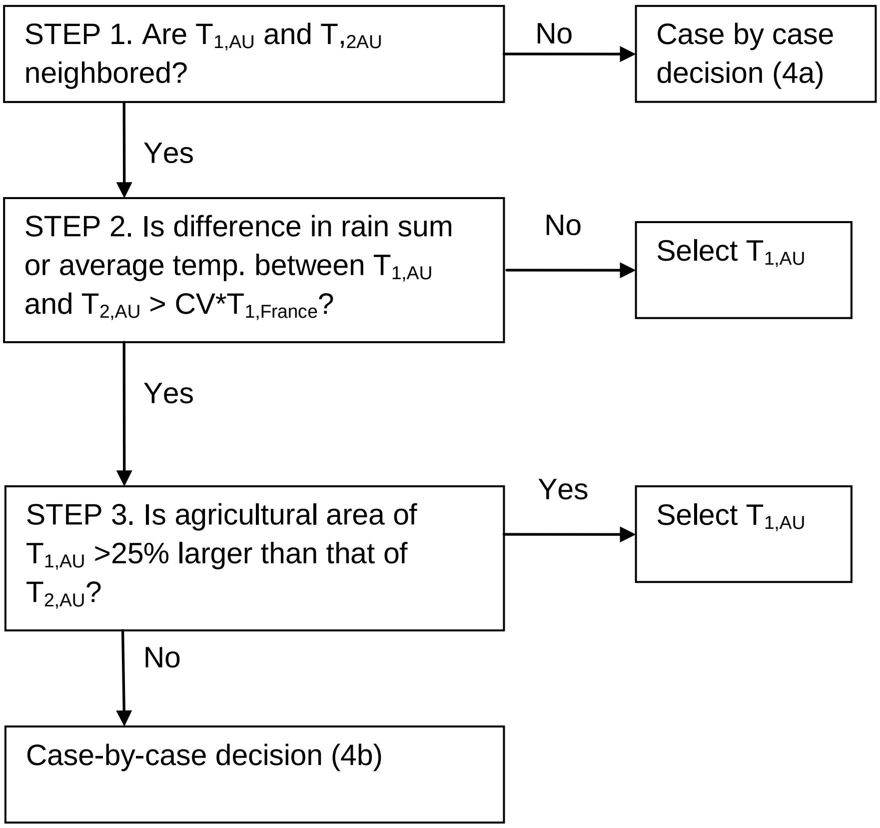

Figure 26 Decision tree for confirmation of the selection of weather tile for each AU

- In STEP 1 it was determined whether there are AUs in which two geographically separated agricultural areas exist. This was assumed to be true when the two tiles with largest agricultural occupation are not adjacent. In these cases it was decided by expert knowledge which of the two areas is most representative for the agricultural conditions in the AU (STEP 4a). If no preference could be identified the default tile was kept.

- In the cases where only one main agricultural area was identified, the range of climatic conditions within the AU was evaluated in STEP 2. If the variability within the unit is too large it was checked on a case-by-case basis whether another MARS-tile might be more suitable than $T_{1,AU}$ to represent the weather conditions for the AU.

  The usage of 26 years of weather data already contains a certain (temporal) variability in rainfall and temperature. It is assumed that spatial variability has to be considered additionally only in cases where it is larger than the temporal variability. Therefore, the average temporal variability identifies the acceptable spatial variability threshold.

To evaluate the temporal variability the standard deviation of annual rain fall sums and annual average temperatures were calculated for the most representative tile ($T_{1,AU}$) and divided by the mean over the 30-year period to derive the coefficient of variation (CV) for each AU. The mean CV was calculated for all AUs for rain and temperature (CV_{rain} = 0.19, CV_{temp} = 0.06) as an expression of the temporal variability of these 31 tiles. This was identified to be about 160 mm/a (4800 mm over the whole period of 30 years) of rainfall sum and 0.7°C average temperature if multiplied by the mean values ($T_{1,France}$ = 25296 mm and 11.6 °C) of all MARS tiles in France. The usage of the CV (instead of the standard deviation) from the $T_{1,AU}$ tiles ensures that the threshold is proportionate to the mean value of all MARS tiles ($T_{1,France}$).

In STEP 2 it is therefore checked whether the difference in rainfall sum and average temperature between the two main tiles $T_{1,AU}$ and $T_{2,AU}$ is larger than allowable based on the temporal variability included in the default tiles. In case that the spatial differences are smaller than 4800 mm or 0.7 °C, it is assumed that the spatial variability is already covered by the temporal variability of the default tiles $T_{1,AU}$. In these cases the default tile is selected.

- In case the spatial variability within the main agricultural area is too high it was checked in STEP 3 whether the agricultural occupation of the default tile is much larger than that of the next most representative tile within the AU. As a threshold a pragmatic value of 25% was chosen since only few AUs (3 in case of rain and 5 in case of temperature) were affected by this threshold. In case the $T_{1,AU}$ tile has an agricultural occupation which is at least 25% larger than the occupation of the $T_{2,AU}$ tile, the $T_{1,AU}$ default tile was chosen for the weather scenario. This ensures that a default tile which is representative of a very large agricultural area is not rejected in favor of a tile with a relatively small occupation. In case of similar agricultural occupation of the most representative tiles within one agricultural region, it was investigated if the tiles are influenced by their position in the landscape (distance to mountain ranges or the coast). It was then decided on a case-by-case basis which tile represented the corresponding AU best (STEP 4b).

Applying the above-described selection scheme, in the end the default tile with the largest agricultural area was confirmed for all AUs. The MARS ID and the geographic position of the selected MARS-tiles are given in Table 15, Table 17 and Figure 27. For a more detailed description of the selection process and its results refer to the Appendix 12.

Table 15 ***Selected MARS-tiles for each AU***

CODE_AU	Mars Code	CODE_AU	Mars Code
1	43044	16	53050
2	52041	17	53047
3	48049	18	46044
4	57048	19	52045
5	51055	20	50042
6	55044	21	53051
7	44042	22	50048
8	43043	23	46052
9	56048	24	50052
10	48043	25	53040
11	53043	26	51053
12	51051	27	42052
13	54054	28	42050
14	50044	29	49047
15	51047	30	53041
		31	54049

In order to confirm that the selected tiles were indeed representative of the average conditions in the AU, the rainfall and temperature data of the MARS tile selected for each AU ($T_{1,AU}$) was compared to the median rainfall and temperature data of all tiles within the respective AU. The sum of rainfall (and the average temperature) over 30 years was calculated for each selected tile. Then for each AU the median of the rainfall sums (and average temperatures; Med_{AU}) was calculated from the tiles located within the AU. The normalized difference of the rainfall (or temperature) is then calculated by $(VT_{1,AU}-Med_{AU})/Med_{AU}$, with $VT_{1,AU}$ being the rainfall sum (or average temperature) of the selected default tile for one AU. The results of these calculations are shown in Table 16. The observed small differences (in general <10%) indicate that the conditions in the selected tiles can indeed be considered as representative in all AUs. The only exception is AU 30, where the rainfall of the selected tile is about 20% below the median rainfall. A closer inspection of AU30 revealed that tiles with small agricultural occupation (<20% of the agricultural area) have large median rainfall (30310 mm) while the rest of the AU (>80% of the agricultural area) is characterized by mainly low rainfall (22861 mm). Calculating the difference to the main agricultural area shows that the selected tile is only 6% below the median rainfall. In about half of the AUs the conditions are slightly more favorable than the median of the AU, while in the other half they are more conservative or no difference can be observed. Overall, it can be concluded that average conditions are met.

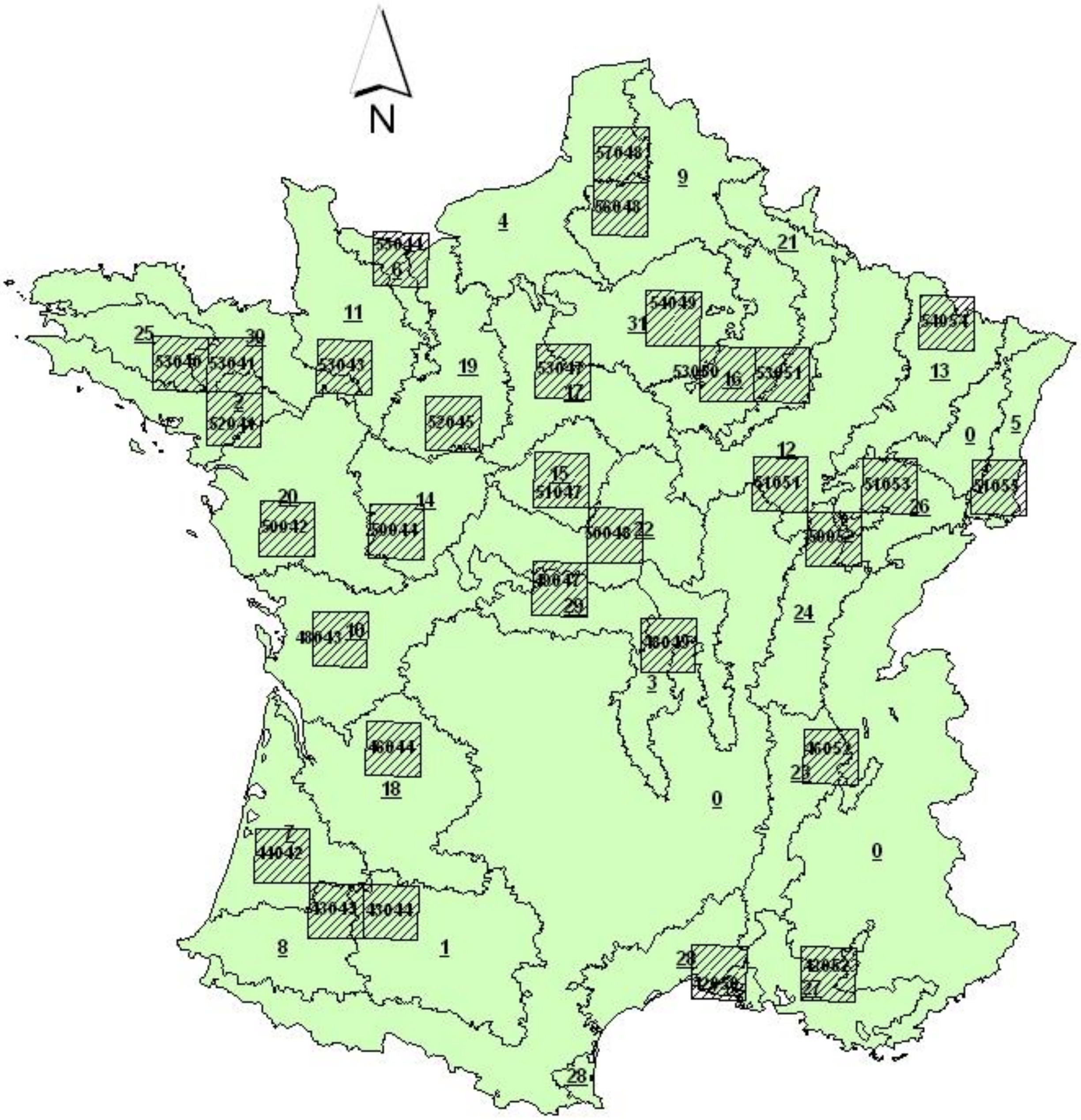

Figure 27 Location of the selected MARS tiles within the Agronomic Units

Table 16 ***Normalized differences in rainfall sum and average temperature between $T_{1,AU}$ and the median of each AU***

AU	Normalized Difference in Rainfall sum (-)	Normalized Difference in average Temperature (-)
1	-0.06	0.01
2	-0.14	0.01
3	-0.06	0.04
4	0.05	-0.02
5	-0.04	0.01
6	0.00	0.02
7	0.01	0.00
8	-0.11	-0.01
9	-0.04	-0.01
10	0.12	0.02
11	0.00	0.00
12	0.00	-0.01
13	-0.11	0.01
14	0.00	0.02
15	-0.05	0.01
16	0.07	0.00
17	-0.11	-0.01
18	-0.03	-0.04
19	-0.05	0.04
20	0.12	0.00
21	0.07	0.09
22	0.02	0.00
23	0.05	-0.06
24	-0.11	0.01
25	-0.11	0.00
26	0.08	0.03
27	-0.03	-0.05
28	0.00	0.04
29	0.00	0.00
30	-0.18	0.00
31	-0.03	0.00

5.4 Parameterisation

The MARS meteo data was downloaded in 2008. The parameters listed in Table 17 are available for the time frame from 1975 – 2006 in daily resolution. For the scenario calculation the years 1981 – 2006 are used. Simulation years 1987 – 2006 were copied to extend the total simulation time this was done according the rule also described in FOCUS (2000, section 2.2.2) by shifting the first year to the end of the simulation period for the second set of 20 weather years and going on with this strategy also for the second, fourth and fifth[4] set of the 20 repeated weather years (i.e. simulation period 2007-2026 starts with weather year 1988, simulation period 2027-2046 starts with weather year 1989, simulation period 2047-2066 starts with weather year 1990 and simulation period 2067-2086 starts with weather year 1991). This strategy allows that each application is conducted in each weather year throughout the whole simulation period.

Table 17 Available daily MARS data

Value	Description
MAXIMUM_TEMPERATURE	maximum temperature (°C)
MINIMUM_TEMPERATURE	minimum temperature (°C)
VAPOUR_PRESSURE	mean daily vapour pressure (hPa)
WINDSPEED	mean daily windspeed at 10m (m/s)
RAINFALL	mean daily rainfall (mm)
E0	Penman potential evaporation from a free water surface (mm/d)
ES0	Penman potential evaporation from a moist bare soil surface (mm/d)
ET0	Penman potential transpiration from a crop canopy (mm/d)
CALCULATED_RADIATION	daily global radiation (kJ/m^2/d)

For PEARL input all parameters listed in Table 18 are necessary to be defined in the .met file, MARS data could be directly used in most cases.

[4] NB: in few cases of the newly employed 4-year crop rotations 87 years were simulated in total due to the fact that FROGS always runs until the end of the year in which the last crop from the last rotation is harvested. In these cases the last crop is either a winter cereal which is harvested in the year 2067 or sunflower.

Table 18 Required daily PEARL input data and the corresponding MARS data

PEARL Input	MARS Parameter
Daily global radiation (kJ/m^2/d), between 0 and 5 E6	CALCULATED_RADIATION
Minimum daily temperature (°C), between -50 and 35	MINIMUM_TEMPERATURE
Maximum daily temperature (°C), between -30 and 60	MAXIMUM_TEMPERATURE
Average vapor pressure (kPa), between 0 and 10	VAPOUR_PRESSURE / 10
Average windspeed (m/s), between 0 and 50	WINDSPEED
Daily precipitation (mm/d), between 0 and 1000	RAINFALL
Reference evapotranspiration (mm/d), between 0 and 100	calculated based on FAO approach (see text)

FOCUS (2009) introduced several changes to harmonise the water balance predicted by different regulatory leaching models. Beside others (see section 11.5 in FOCUS, 2009) the reference evapotranspiration was updated for Southern European FOCUS groundwater scenarios by employing the FAO method (Allen et al., 1998) considered to be the most appropriate method for these scenarios and to generate consistency between the evapotranspiration values and the FAO crop coefficients whichare used to calculate the actual evapotranspiration. According to Annex I of Regulation (EC) No 1107/2009 France belongs to the Southern European zone so that the FAO approach of calculating reference evapotranspiration was adopted for all FROGS scenarios based on the latitude of the specific MARS tile and a default height above sea level of 100 m. For details of the calculation of FAO potential reference evapotranspiration please refer to FOCUS (2009, Appendix 18, p. 533 – 537) and more extensive information given by Allen et al. (1998).

In earlier versions of FROGS, the former version of the hydrologic model, SWAP 209e, failed in some situations characterised by heavy rainfall in combination with soils of low hydraulic conductivity. As a workaround for such situations the rainfall data was splitted over several days while the total amount of rainfall was kept. Although this workaround worked for most of the problematic scenarios there were still nine scenarios in FROGS 2.2.2.2 that failed and which were not further accounted for in the risk assessment. The new SWAP 3234 used by PEARL 4.4.4 facilitates the calculation of all scenarios with the original weather data without any model falures. Therefore, the original rainfall data were employed in FROGS 3.3.3.3 without any changes.

5.5 References

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6 Crop irrigation

Crop irrigation is implemented in FROGS for the main irrigated crops, i.e. maize, sugar beets and potatoes. Average irrigation schedules corresponding to standard practices in the different AUs of interest, expressed as x irrigation events of volume of water y from a start date z and interval i between two events, were entered as PEARL irrigation files.

The methodology to implement irrigation in FROGS follows a stepwise approach as illustrated in Figure 28.

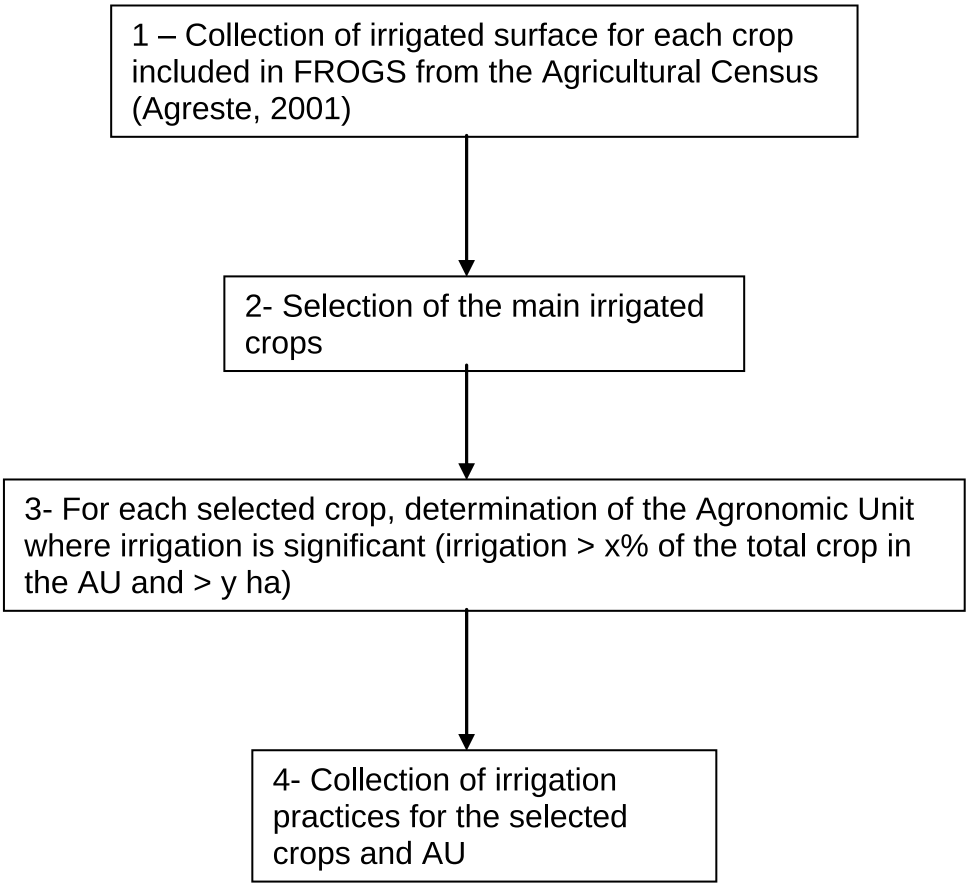

Figure 28 Methodology used to implement irrigation in FROGS

Crop irrigation was completely revised by FOCUS (2009) and is now calculated based on crop demand. The extensive approach of integrating irrigation data in FROGS outlined above and presented in detail in the following is considered to be both, realistic and representative for French agricultural conditions. Thus, the irrigation data already implemented in the former version of FROGS were kept and the FOCUS (2009) approach was not adopted.

6.1 Irrigated crops and surfaces in France

Data on irrigated crops were obtained from the French agricultural census: Recensement Agricole 2000 (Agreste, 2001). Total irrigated acreage of crops that are currently included in FROGS (hereafter called "FROGS crops") are summarized in Table 19.

Table 19 Irrigation acreage from Agreste (2001)

	Acreage (ha)	Acreage (% of FROGS crops irrigated)	Cumulative acreage (% of FROGS crops irrigated)
Total FROGS crop irrigated	1151375	-	
Irrigated Grain maize	780952	67.8	67.8
Irrigated Fodder maize	105085	9.1	77.0
Sum of oilseed crops irrigated (a)	66774	5.8	82.8
Sum of other irrigated cereals (b)	63831	5.5	88.3
Irrigated potato	56424	4.9	93.2
Irrigated sugarbeet	34257	3.0	96.2
Irrigated Hard wheat	17378	1.5	97.7
Irrigated wheat	15182	1.3	99.0
Irrigated Sunflower	11492	1.0	100.0

(a) including oilseed rape
(b) including barley

These data were aggregated for each agronomic unit (AU). Table 20 summarizes the acreage of irrigation for the 31 AUs. Seventeen AUs represent over 90% of the irrigated surface, and these also correspond to the most intensive AUs for irrigation.

Table 20 Irrigated acreage for the 31 Agronomic Units

Name AU	Code AU	SAU (ha) *(a)*	FROGS crops Irrigated (ha)	Cumulative Irrigation (% Total FROGS crops irrigated)	FROGS crops irrigated (% AU_SAU)
Collines molassiques - Lauragais	1	1243320	154609	13.4	12.4
Charentes	10	1322839	151400	26.6	11.4
Beauce - Drouais - Gatinais	17	958676	108899	36.0	11.4
Bordelais - Perigord - Coteaux du Lot	18	921868	100474	44.8	10.9
Bassin de l'Adour	8	589991	94154	52.9	16.0
Aquitaine - Landes	7	157250	70271	59.0	44.7
Bocages de l'ouest	20	1353504	55366	63.9	4.1
Alsace - Sundgau	5	276558	50726	68.3	18.3
Bas Dauphine - Vallee du Rhône	23	450219	50672	72.7	11.3
Gatines - Vallees de Loire	14	636638	39878	76.1	6.3
Champagne berrichonne - Boischaut	22	1059459	36827	79.3	3.5
Limagnes - Plaine du Forez	3	612973	27407	81.7	4.5
Perche - Pays d'Auge - Pays d'Ouche	19	871648	24106	83.8	2.8
Picardie - Nord - Pas-de-Calais	9	1141433	22674	85.8	2.0
Sologne - Orleanais	15	157615	19395	87.4	12.3
Fosse bressan	24	559439	15261	88.8	2.7
Champagne crayeuse	16	732977	13101	89.9	1.8
Plaine du Languedoc-Roussillon	28	375316	11160	90.9	3.0
Ile-de-France	31	931602	10502	91.8	1.1
Provence	27	192698	7423	92.4	3.9
Boischaut du sud	29	521777	4937	92.9	0.9
Bordure maritime Nord - Picardie - Normandie	4	1224365	4877	93.3	0.4
Bocage normand	11	1112296	3356	93.6	0.3
Bretagne sud	2	459222	1771	93.7	0.4
Ardenne - Argonne - Champagne humide	21	556896	1392	93.9	0.2
Bretagne nord	30	841643	1169	94.0	0.1
Plaine normande - Bessin	6	251501	1151	94.1	0.5
Barrois - Plateaux bourguignons	12	1046559	926	94.1	0.1
Bretagne centrale	25	430730	700	94.2	0.2
Plateaux de Haute-Saone	26	350511	347	94.2	0.1
Plateau lorrain	13	640234	80	94.2	0.0
Territoire non pris en compte	0	5872415	66364	100.0	1.1
Total		27854172	1151375	-	-

(a): SAU = Surface Agricole Utile = Arable land

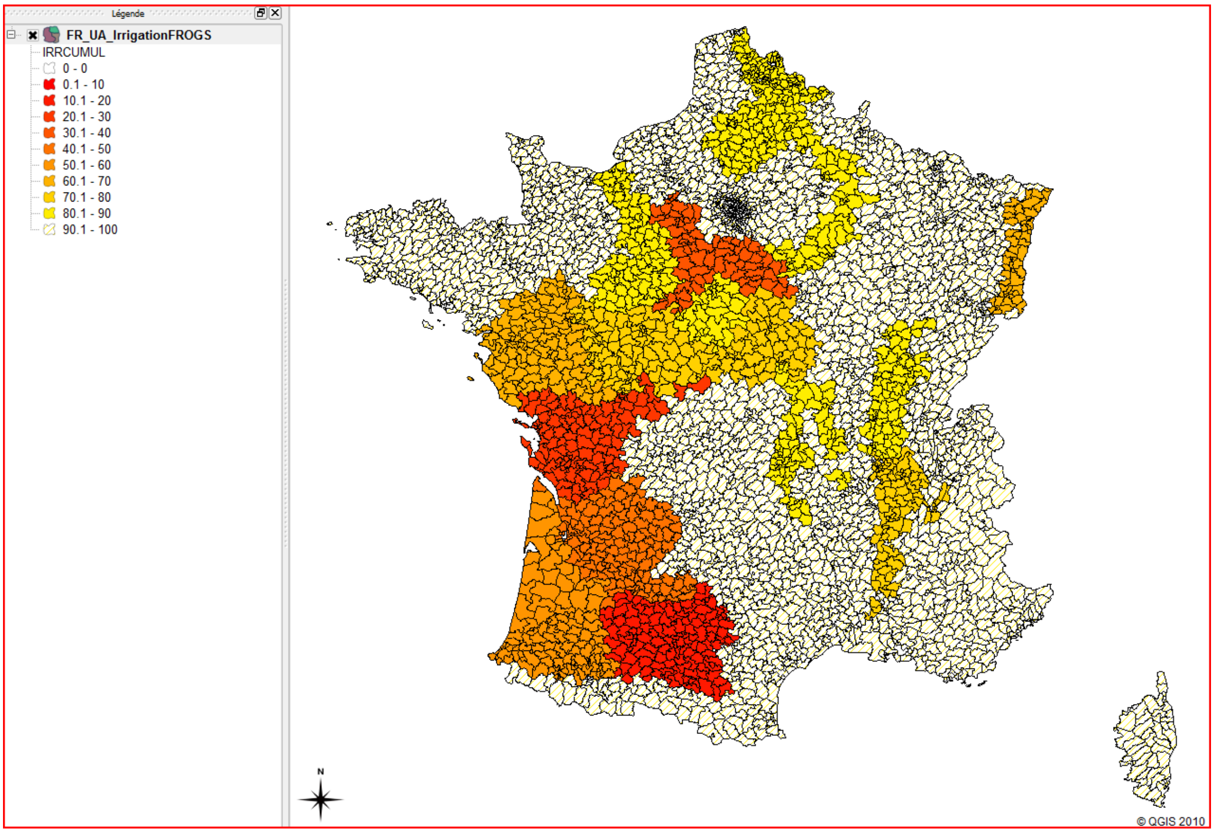

Figure 29 ***Agronomic Unit representing 90% of the irrigated crops included in FROGS (cumulative irrigation area - % Total FROGS crops irrigated)***

6.2 Selection of the main irrigated crops in FROGS

Detailed irrigation surface by crops for each AU clearly indicate that maize is the main irrigated crop for most of the AUs (Figure 30 and Table 21). However there are some AUs in which irrigated potato and sugar beet can be very important (e.g., 91.1 % of the irrigated FROGS crops in Picardie are potato).

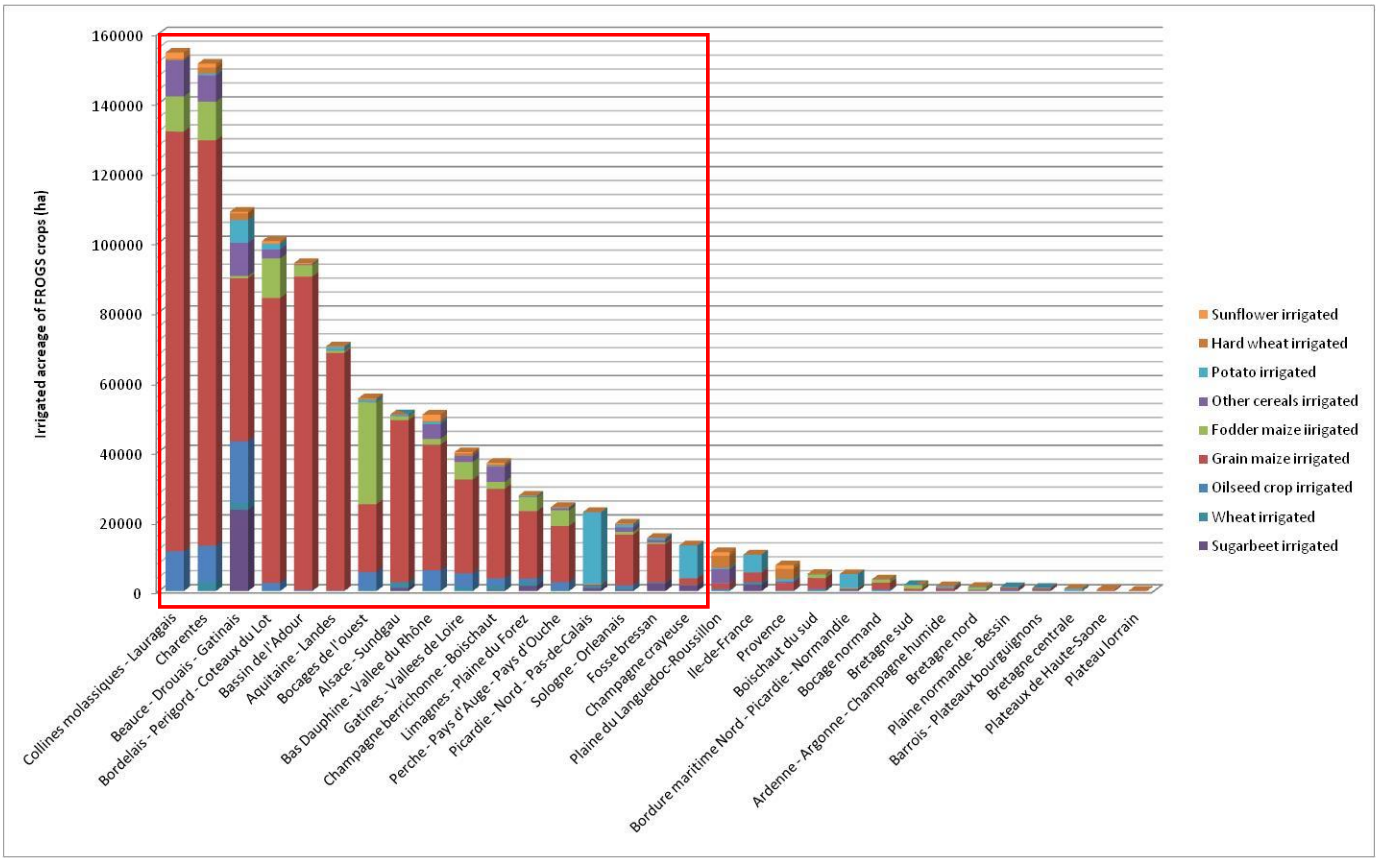

Figure 30 ***Detailed irrigated acreage by crops for the 31 Agronomic Unit (AU that are circled in red represent 90.9% of the total FROGS crops irrigated)***

Grain maize, fodder maize, sugar beet and potato collectively represent 84.8% of the irrigated crops included in FROGS (from 71 to 100% of the irrigation of each AU, except in Provence and in Plaine du Languedoc-Roussillon) (Table 21). Even though the total acreage of irrigated oilseed crops and irrigated wheat plus others cereals is significant, at AU scale it generally represents small acreage and/or low density (*Table 59* and *Table 60* in Appendix 13).

It was therefore decided to implement irrigation only on grain maize, fodder maize, sugar beet and potato.

Table 21 ***Relative acreage of the main 4 individual irrigated crops within each Agronomic Unit***

Name AU	Code AU	Grain Maize Irrigated (%)*	Fodder Maize Irrigated (%)*	Potato Irrigated (%)*	Beetroot Irrigated (%)*	Sum of the main 4 individual irrigated crops (%)*
Collines molassiques - Lauragais	1	77.9	6.5	0.1	0.0	84.6
Charentes	10	76.9	7.3	0.3	0.0	84.5
Beauce - Drouais - Gatinais	17	42.9	0.6	6.0	21.4	71.0
Bordelais - Perigord - Coteaux du Lot	18	81.4	11.3	1.6	0.0	94.3
Bassin de l'Adour	8	95.6	3.5	0.0	0.0	99.2
Aquitaine - Landes	7	97.1	1.0	1.3	0.1	99.4
Bocages de l'ouest	20	35.3	52.8	1.1	0.0	89.2
Alsace - Sundgau	5	91.7	2.4	0.6	1.8	96.5
Bas Dauphine - Vallee du Rhône	23	71.2	3.2	1.3	0.0	75.7
Gatines - Vallees de Loire	14	67.6	12.6	0.2	0.0	80.4
Champagne berrichonne - Boischaut	22	69.8	5.4	0.7	0.7	76.6
Limagnes - Plaine du Forez	3	70.5	14.7	0.9	5.5	91.5
Perche - Pays d'Auge - Pays d'Ouche	19	66.8	18.7	0.7	0.2	86.5
Picardie - Nord - Pas-de-Calais	9	1.5	0.5	91.1	3.7	96.9
Sologne - Orleanais	15	74.7	4.4	4.2	1.7	85.0
Fosse bressan	24	72.3	2.7	3.6	14.7	93.4
Champagne crayeuse	16	14.6	0.5	71.2	11.9	98.3
Plaine du Languedoc-Roussillon	28	14.2	0.4	4.0	0.0	18.6
Ile-de-France	31	25.4	0.8	48.0	17.7	91.9
Provence	27	27.2	0.1	9.3	0.0	36.6
Boischaut du sud	29	64.0	20.2	0.3	1.1	85.6
Bordure maritime Nord - Picardie - Normandie	4	5.5	4.5	81.4	6.6	98.1
Bocage normand	11	57.7	25.3	2.3	0.0	85.3
Bretagne sud	2	33.6	56.2	6.5	0.0	96.4
Ardenne - Argonne - Champagne humide	21	46.0	1.5	39.6	9.4	96.6
Bretagne nord	30	21.0	50.6	18.7	0.9	91.1
Plaine normande - Bessin	6	43.1	7.6	10.8	19.7	81.2
Barrois - Plateaux bourguignons	12	52.4	14.3	4.1	14.0	84.8
Bretagne centrale	25	8.0	5.0	87.0	0.0	100.0
Plateaux de Haute-Saone	26	83.3	13.8	0.6	0.9	98.6
Plateau lorrain	13	97.5	0.0	2.5	0.0	100.0
Territoire non pris en compte	0	37.3	22.0	1.6	0.6	61.5

*: expressed as percent of the total FROGS crops irrigated in each AU

6.3 Determination of relevant AUs for implementing irrigation

Irrigation implementation by farmers varies amongst AUs due to pedo-climatic differences and local water policies. The aim of the implementation of irrigation in FROGS is to represent these differences and also to avoid including irrigation in AUs where it is not standard practice. Therefore for each selected crop, irrigation data were analyzed to select AUs for which more than 20% of the crop is irrigated and the irrigated crop covers more than 1000 ha. The 20% and 1000 ha criteria were chosen by expert judgement in view of the irrigation statistic data available and were voluntarily kept flexible. The overall concept was to include irrigation for a crop when it is a significant practice for the crop in the AU (the trigger of 20%), represents a significant area within the AU (the trigger of 1000 ha) and to include most of the irrigated area for that crop. The crops for which irrigation is relatively very important (more than 90%) but represents a very small area (< 1000 ha) like beetroot in Aquitaine and Brittany or potato in Aquitaine or Provence were not considered as these crops are not even considered in the crop rotations for the respective AU due to the low surface they represent.

6.3.1 Grain Maize

Grain maize is the most irrigated crop in FROGS. The total irrigated grain maize acreage represent 780952 ha, i.e. 46.4 % of the maize covered by FROGS[5]. Irrigated grain maize acreage in the AU varies 56 ha in Bretagne centrale to 120 494 ha in Collines molassiques-Lauragais. The ratio of irrigated grain maize to the total acreage of maize for each of the 31 AUs varies from 0.2 % in Bretagne centrale to 93.9 % in Plaine du Languedoc-Roussillon (Table 22). Considering all AUs with more than 20% of the grain maize being irrigated and with an absolute irrigated grain maize surface above 1000 ha, 94.1 % of the total irrigated grain maize is accounted for.

6.3.2 Fodder maize

Fodder maize is the second most irrigated crop in FROGS. The total irrigated grain maize acreage represent 105085 ha, i.e. 8.3 % of the maize covered by FROGS[6]. Irrigated fodder maize acreage in the AU varies 4 ha in Provence to 29 236 ha in Bocages de l'Ouest. The ratio of irrigated fodder maize to the total acreage of maize for each of the 31 AU varies from 0.1 % in Bretagne centrale to 86.5 % in Plaine du Languedoc-Roussillon (Table 23). For fodder maize, it was decided to implement irrigation in the AU where irrigation is implemented on grain maize, which corresponds to AU with more than 7.1% of the fodder maize being irrigated and with absolute surface above 669 ha. With this approach, 82.6 % of the total irrigated grain maize is accounted for.

[5] The total grain maize acreage covered by the 31 AU of FROGS is 1 680 066 ha (see section 2.4.2, Table 2)

[6] The total fodder maize acreage covered by the 31 AU of FROGS is 1 259 194 ha (see section 2.4.2, Table 2)

Table 22 Grain Maize – Selection of AUs in which irrigation is implemented, selected AUs are highlighted in bold

Name AU	Code AU	Irrigated Grain Maize (% Grain Maize of the AU)	Irrigated Grain Maize (ha)	Irrigation implemented in FROGS	Cumulative Surface
Plaine du Languedoc-Roussillon	**28**	**93.9**	**1582**	**Yes**	**0.2**
Aquitaine - Landes	**7**	**90.7**	**68235**	**Yes**	**8.9**
Collines molassiques - Lauragais	**1**	**85.4**	**120494**	**Yes**	**24.4**
Beauce - Drouais - Gatinais	**17**	**83.6**	**46751**	**Yes**	**30.4**
Sologne - Orleanais	**15**	**77.1**	**14497**	**Yes**	**32.2**
Provence	**27**	**74.7**	**2022**	**Yes**	**32.5**
Charentes	**10**	**66.7**	**116376**	**Yes**	**47.4**
Champagne berrichonne - Boischaut	**22**	**61.5**	**25717**	**Yes**	**50.7**
Bordelais - Perigord - Coteaux du Lot	**18**	**61.1**	**81783**	**Yes**	**61.1**
Bas Dauphine - Vallee du Rhône	**23**	**56.0**	**36076**	**Yes**	**65.8**
Limagnes - Plaine du Forez	**3**	**53.3**	**19315**	**Yes**	**68.2**
Boischaut du sud	**29**	**49.1**	**3159**	**Yes**	**68.6**
Gatines - Vallees de Loire	**14**	**46.2**	**26945**	**Yes**	**72.1**
Bocages de l'ouest	**20**	**39.9**	**19537**	**Yes**	**74.6**
Alsace - Sundgau	**5**	**37.0**	**46496**	**Yes**	**80.5**
Bassin de l'Adour	**8**	**36.6**	**90025**	**Yes**	**92.1**
Perche - Pays d'Auge - Pays d'Ouche	**19**	**31.8**	**16101**	**Yes**	**94.1**
Fosse bressan	24	13.2	11040	No	95.5
Bocage normand	11	11.1	1938	No	95.8
Plaine normande - Bessin	6	9.9	496	No	95.9
Champagne crayeuse	16	9.3	1912	No	96.1
Ile-de-France	31	5.1	2665	No	96.4
Barrois - Plateaux bourguignons	12	3.9	485	No	96.5
Ardenne - Argonne - Champagne humide	21	2.8	641	No	96.6
Bordure maritime Nord - Picardie - Normandie	4	2.7	270	No	96.6
Bretagne sud	2	1.9	595	No	96.7
Plateaux de Haute-Saone	26	1.6	289	No	96.7
Plateau lorrain	13	1.3	78	No	96.7
Picardie - Nord - Pas-de-Calais	9	1.2	348	No	96.8
Bretagne nord	30	0.4	245	No	96.8
Bretagne centrale	25	0.2	56	No	96.8
Territoire non pris en compte	0	33.6	24783		100.0

Table 23 Fodder Maize - Selection of AUs in which irrigation is implemented (the implementation of irrigation for grain maize is applied to fodder maize) – Selected AUs are highlighted in bold

Name AU	Code AU	Irrigated Fodder maize (% Fodder Maize of the AU)	Irrigated Fodder maize (ha)	Irrigation implemented in FROGS	Cumulative Surface
Aquitaine - Landes	**7**	**60.8**	**669.0**	**yes**	**0.6**
Collines molassiques - Lauragais	**1**	**52.6**	**10118.0**	**yes**	**10.3**
Bordelais - Perigord - Coteaux du Lot	**18**	**38.1**	**11372.0**	**yes**	**21.1**
Sologne - Orleanais	**15**	**33.3**	**844.0**	**yes**	**21.9**
Charentes	**10**	**26.1**	**11092.0**	**yes**	**32.4**
Limagnes - Plaine du Forez	**3**	**25.1**	**4028.0**	**yes**	**36.3**
Gatines - Vallees de Loire	**14**	**23.9**	**5029.0**	**yes**	**41.1**
Bocages de l'ouest	**20**	**16.8**	**29236.0**	**yes**	**68.9**
Beauce - Drouais - Gatinais	**17**	**15.9**	**693.0**	**yes**	**69.5**
Bas Dauphine - Vallee du Rhône	**23**	**14.5**	**1643.0**	**yes**	**71.1**
Champagne berrichonne - Boischaut	**22**	**13.5**	**1991.0**	**yes**	**73.0**
Alsace - Sundgau	**5**	**11.5**	**1226.0**	**yes**	**74.2**
Bassin de l'Adour	**8**	**11.2**	**3319.0**	**yes**	**77.3**
Boischaut du sud	**29**	**8.8**	**995.0**	**yes**	**78.3**
Perche - Pays d'Auge - Pays d'Ouche	**19**	**7.1**	**4519.0**	**yes**	**82.6**
Plaine du Languedoc-Roussillon	28	86.5	45.0	No	82.6
Provence	27	26.7	4.0	No	82.6
Fosse bressan	24	2.4	419.0	No	83.0
Champagne crayeuse	16	1.8	70.0	No	83.1
Bretagne sud	2	1.4	996.0	No	84.0
Ile-de-France	31	1.3	87.0	No	84.1
Plaine normande - Bessin	6	0.4	88.0	No	84.2
Bocage normand	11	0.4	850.0	No	85.0
Bretagne nord	30	0.4	591.0	No	85.6
Barrois - Plateaux bourguignons	12	0.4	132.0	No	85.7
Plateaux de Haute-Saone	26	0.3	48.0	No	85.7
Picardie - Nord - Pas-de-Calais	9	0.3	122.0	No	85.9
Bordure maritime Nord - Picardie - Normandie	4	0.2	220.0	No	86.1
Ardenne - Argonne - Champagne humide	21	0.1	21.0	No	86.1
Bretagne centrale	25	0.1	35.0	No	86.1
Plateau lorrain	13	0.0	0.0	No	86.1
Territoire non pris en compte	0	11.6	14583.0		100.0

6.3.3 Beetroot / Sugar beet

The total irrigated beetroot / sugar beet acreage represent 34257 ha, i.e. 8.4 % of the beetroot covered by FROGS[7]. Irrigated beetroot acreage in the AU varies from 3 ha in Plateaux de Haute-Sâone to 23 327 ha in Beauce-Drouais-Gâtinais. The ratio of irrigated beetroot to the total acreage of beetroot for each of the 31 AU varies from 0.6 % in Bordure maritime nord – Picardie - Normandie to 100 % in Aquitaine-Landes (Table 24). Considering all AUs with more than 20% of the beetroot being irrigated and with an absolute irrigated beetroot above 1000 ha, 79 % of the total irrigated beetroot is accounted for.

6.3.4 Potato

The total irrigated potato acreage represent 56 424 ha, i.e. 36.5% of the potato covered by FROGS[8]. Irrigated potato acreage in the AU varies from 2 ha in Plateau Lorrain to 20 665 ha in Picardie-Nord-Pas-de-Calais. The ratio of irrigated potato to the total acreage of potato for each of the 31 AU varies from 1.5 % in Plateau Lorrain to 99.3 % in Aquitaine-Landes (Table 25). Considering all AUs with more than 20% of the potato being irrigated and with an absolute irrigated potato above 1000 ha, 73.7 % of the total irrigated potato is accounted for. It was decided to also include the Bordure maritime Nord – Picardie – Normandie unit, resulting in an overall coverage of 80.8 % of the total irrigated potato.

[7] The total sugar beet acreage covered by the 31 AU of FROGS is 408 123 ha (see section 2.4.2, Table 2)

[8] The total potato acreage covered by the 31 AU of FROGS is 154 593 ha (see section 2.4.2, Table 2)

Table 24 Beetroot/Sugar beet – Selection of AU in which irrigation is implemented (irrigation intensity >20%, absolute surface > 1000 ha) – selected AUs are highlighted in bold

Name AU	Code AU	Irrigated Beetroot (% Beetroot of the AU)	Irrigated Beetroot (ha)	Irrigation implemented in FROGS	Cumulative Surface
Beauce - Drouais - Gatinais	**17**	**65.9**	**23327**	**Yes**	**68.1**
Fosse bressan	**24**	**52.8**	**2236**	**Yes**	**74.6**
Limagnes - Plaine du Forez	**3**	**44.7**	**1503**	**Yes**	**79.0**
Aquitaine - Landes	7	100.0	38	No	79.1
Bretagne nord	30	90.9	10	No	79.1
Collines molassiques - Lauragais	1	84.6	22	No	79.2
Sologne - Orleanais	15	77.1	336	No	80.2
Bordelais - Perigord - Coteaux du Lot	18	76.9	30	No	80.3
Champagne berrichonne - Boischaut	22	69.7	260	No	81.0
Boischaut du sud	29	23.0	56	No	81.2
Alsace - Sundgau	5	17.2	916	No	83.9
Barrois - Plateaux bourguignons	12	7.4	130	No	84.3
Plateaux de Haute-Saone	26	7.0	3	No	84.3
Plaine normande - Bessin	6	3.9	227	No	84.9
Perche - Pays d'Auge - Pays d'Ouche	19	3.4	52	No	85.1
Ile-de-France	31	2.3	1858	No	90.5
Champagne crayeuse	16	2.2	1562	No	95.1
Ardenne - Argonne - Champagne humide	21	1.1	131	No	95.4
Picardie - Nord - Pas-de-Calais	9	0.7	845	No	97.9
Bordure maritime Nord - Picardie - Normandie	4	0.6	324	No	98.9
Charentes	10	0.0	0	No	98.9
Bassin de l'Adour	8	0.0	0	No	98.9
Bocages de l'ouest	20	0.0	0	No	98.9
Bas Dauphine - Vallee du Rhône	23	0.0	0	No	98.9
Gatines - Vallees de Loire	14	0.0	0	No	98.9
Plaine du Languedoc-Roussillon	28	0.0	0	No	98.9
Provence	27	0.0	0	No	98.9
Bocage normand	11	0.0	0	No	98.9
Bretagne sud	2	0.0	0	No	98.9
Bretagne centrale	25	0.0	0	No	98.9
Plateau lorrain	13	0.0	0	No	98.9
Territoire non pris en compte	0	40.8	391	No	100.0

Table 25 Potato - Selection of AU in which irrigation is implemented (irrigation intensity >20%, absolute surface > 1000 ha) – selected AU are highlighted in bold

Name AU	Code AU	Irrigated Potato (% Potato of the UA)	Irrigated Potato (ha)	Irrigation implemented in FROGS	Cumulative Surface
Beauce - Drouais - Gatinais	**17**	**95.2**	**6562**	**Yes**	**11.6**
Champagne crayeuse	**16**	**51.1**	**9334**	**Yes**	**28.2**
Ile-de-France	**31**	**41.4**	**5037**	**Yes**	**37.1**
Picardie - Nord - Pas-de-Calais	**9**	**32.0**	**20665**	**Yes**	**73.7**
Bordure maritime Nord - Picardie - Normandie	**4**	**17.3**	**3968**	**Yes**	**80.8**
Aquitaine - Landes	7	99.3	930	No	82.4
Provence	27	92.5	694	No	83.6
Sologne - Orleanais	15	92.2	808	No	85.1
Champagne berrichonne - Boischaut	22	91.3	241	No	85.5
Plaine du Languedoc-Roussillon	28	90.8	445	No	86.3
Bordelais - Perigord - Coteaux du Lot	18	90.4	1612	No	89.1
Bocages de l'ouest	20	75.8	617	No	90.2
Charentes	10	73.5	516	No	91.1
Collines molassiques - Lauragais	1	55.4	107	No	91.3
Bas Dauphine - Vallee du Rhône	23	53.8	652	No	92.5
Fosse bressan	24	52.3	552	No	93.5
Boischaut du sud	29	51.6	16	No	93.5
Gatines - Vallees de Loire	14	51.1	94	No	93.7
Limagnes - Plaine du Forez	3	47.2	239	No	94.1
Perche - Pays d'Auge - Pays d'Ouche	19	39.5	180	No	94.4
Bassin de l'Adour	8	36.5	31	No	94.5
Ardenne - Argonne - Champagne humide	21	36.3	551	No	95.4
Alsace - Sundgau	5	28.0	303	No	96.0
Bretagne centrale	25	20.6	609	No	97.1
Bretagne sud	2	14.9	116	No	97.3
Plaine normande - Bessin	6	14.1	124	No	97.5
Barrois - Plateaux bourguignons	12	11.2	38	No	97.5
Bocage normand	11	4.4	76	No	97.7
Plateaux de Haute-Saone	26	3.3	2	No	97.7
Bretagne nord	30	2.2	219	No	98.1
Plateau lorrain	13	1.5	2	No	98.1
Territoire non pris en compte	0	34.5	1084		100.0

6.4 Irrigation practices for maize, potato and beetroot

For maize and potato, which already represent 81.9% of the irrigated crops included in FROGS, data dealing with the number of irrigation events and the amount of water applied are available in Agreste (2006) (Table 26 and Table 27). As these data are reported by administrative regions, they were attributed to the relevant 31 AUs based on the overlap between the AUs and the region as illustrated in Figure 31. When an AU overlap with more than one region, then the overlap between the crop distribution at canton level in the AU and the region was considered.

Table 26 Number of irrigation event and total amount of water for Maize as available from Agreste (2006)

Maize			
Region	Code region	Mais_IRR_Nbres_Passages	Mais_IRR_Dose_totale (mm)
Centre	24	6	165
Alsace	42	4	114
Pays de la Loire	52	5	131
Poitou-Charentes	54	5	156
Midi-Pyrennees	73	6	171
Rhone-Alpes	82	5	170
Auvergne	83	5	138

Table 27 Number of irrigation event and total amount of water for Potato as available from Agreste (2006)

Potato			
Region	Code region	PdT_IRR_Nbres_Passages	PdT_IRR_Dose_totale (mm)
Picardie	22	5	103
Nord-Pas-de-Calais	31	3	62

In addition, detailed irrigation schedules for beetroot, potato and maize in the Beauce region were also available from Golaz (2006). Since no information on beetroot was available from Agreste, the data from Golaz (2006) were used for the Beauce - Drouais - Gatinais AU, and also deemed valid by extrapolation to Fossé bressan and Limagnes - Plaine du Forez. The irrigation data from Golaz (2006) on potato were also used for the Beauce - Drouais - Gatinais AU, since there were no data in Agreste for that AU. For maize, Agreste data were used for all AUs including Beauce - Drouais – Gatinais.

Finally, the first irrigation date and the interval between two irrigation events were set for each crop based on expert judgment and also using external references (Deumier *et al.*; Chambre Agriculture de la Somme, 1997; Deumier *et al.*, 2006).

The parameters describing irrigation and used as input in FROGS for grain maize, fodder maize, beetroot and potato are summarized in Table 28 to Table 31.

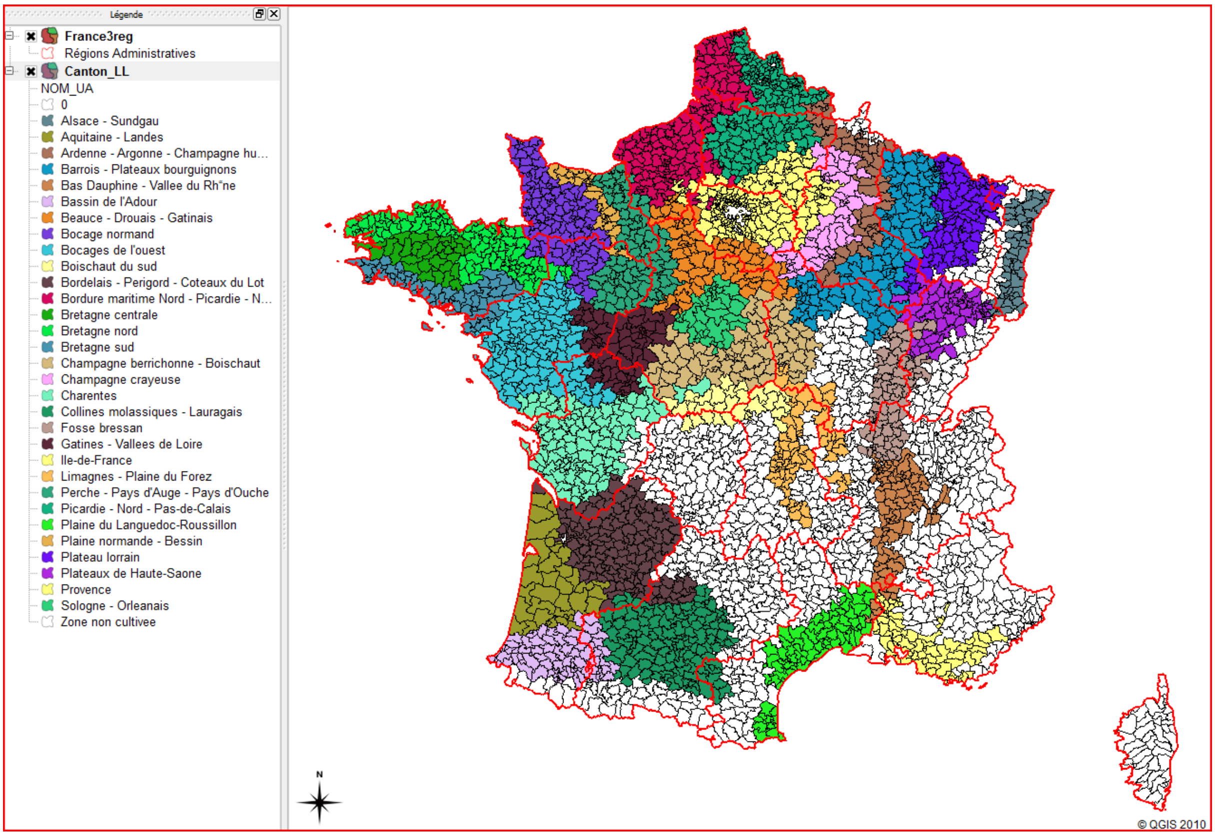

Figure 31 ***Overlap of the 31 Agronomic Units (colored blocks) and the "Régions administratives" (red lines) - Small unit (black lines) represent the "Cantons".***

Table 28 Grain Maize - Main parameters describing irrigation

Nom UA	First irrigation date	Interval between 2 irrigation events (d)	Number of irrigation events	Amount of water/event (mm)
Plaine du Languedoc-Roussillon	15 June	8	7	24
Aquitaine - Landes	15 June	8	7	24
Collines molassiques - Lauragais	15 June	8	7	24
Beauce - Drouais - Gatinais	1 July	9	6	28
Sologne - Orleanais	1 July	9	6	28
Provence	15 June	8	7	24
Charentes	15 June	9	6	28
Champagne berrichonne - Boischaut	1 July	9	6	28
Bordelais - Perigord - Coteaux du Lot	15 June	8	7	24
Bas Dauphine - Vallee du Rhône	15 June	11	5	34
Limagnes - Plaine du Forez	15 June	11	5	34
Boischaut du sud	15 June	9	6	28
Gatines - Vallees de Loire	1 July	9	6	28
Bocages de l'ouest	1 July	11	5	31
Alsace - Sundgau	1 July	14	4	29
Bassin de l'Adour	15 June	8	7	24
Perche - Pays d'Auge - Pays d'Ouche	1 July	9	6	28

Table 29 Fodder Maize - Main parameters describing irrigation

Nom UA	First irrigation date	Interval between 2 irrigation events (d)	Number of irrigation event	Amount of water/event (mm)
Aquitaine - Landes	15 June	8	7	24
Collines molassiques - Lauragais	15 June	8	7	24
Bordelais - Perigord - Coteaux du Lot	15 June	8	7	24
Sologne - Orleanais	1 July	9	6	28
Charentes	15 June	9	6	28
Limagnes - Plaine du Forez	15 June	11	5	34
Gatines - Vallees de Loire	1 July	9	6	28
Bocages de l'ouest	1 July	11	5	31
Beauce - Drouais - Gatinais	1 July	9	6	28
Bas Dauphine - Vallee du Rhône	15 June	11	5	34
Champagne berrichonne - Boischaut	1 July	9	6	28
Alsace - Sundgau	1 July	14	4	29
Bassin de l'Adour	15 June	8	7	24
Boischaut du sud	15 June	9	6	28
Perche - Pays d'Auge - Pays d'Ouche	1 July	9	6	28

Table 30 ***Beetroot/Sugarbeet - Main parameters describing irrigation***

Nom UA	First irrigation date	Interval between 2 irrigation events (d)	Number of irrigation event	Amount of water/event (mm)
Beauce - Drouais - Gatinais	11 June	7	4	35
Fosse bressan	11 June	7	4	35
Limagnes - Plaine du Forez	11 June	7	4	35

Table 31 ***Potato - Main parameters describing irrigation***

Nom UA	First irrigation date	Interval between 2 irrigation events (d)	Number of irrigation event	Amount of water/event (mm)
Beauce - Drouais - Gatinais	21 May	4	7	25
Champagne crayeuse	1 June	8	5	21
Ile-de-France	1 June	8	5	21
Picardie - Nord - Pas-de-Calais	1 June	8	5	21
Bordure maritime Nord - Picardie - Normandie	1 June	8	5	21

6.5 Implementation of irrigation in FROGS

The above-listed irrigation schedules for the relevant crop – AU combinations were included in the FROGS database. Irrigation is implemented on the same fixed dates year by year over the whole simulation period and does not take into account the actual soil moisture content or temporal meteorological variations over that period. The fixed irrigation scheduling also does not account for weather events, which means that postponing of scheduled irrigation due to rainfall is not considered. However, as pointed out by Golaz (2006), ideal irrigation calendars based on soil moisture content and weather forecasts are seldom used in reality in the field, as the irrigation scheduling is in fact a compromise between crop water needs, water retention capacity of the soil and practical constraints related to equipment and timing of irrigations (for given field and crop among all irrigated fields and crops at the farm level). During the main irrigation period it is difficult for farmers to adjust inputs, since increasing irrigation dose would increase irrigation time, and therefore delay following irrigation (next field in farm irrigation rotation program). In reality irrigation scheduling is often not that flexible due to lack of equipment and irrigation rounds are made regardless of particular weather events. The implementation of irrigation in FROGS based on fixed dates is therefore justified.

Irrigation schemes are implemented the same way in FROGS as they are in standard FOCUS simulations, i.e. irrigation water is applied directly to the soil surface. Canopy processes are not simulated. The relevant irrigation schemes were considered in the generation of the pre-run SWAP soil hydrology (*.bfo files).

6.6 References

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7 Selection of representative soil-types

INRA INFOSOL Orléans was mandated by SSM to select a limited number of representative soil-types at national level and representative soil profiles associated with these soil-types for the ComTox groundwater scenarios workgroup. The selection of representative soils was limited to the arable land representative for the cultivation of the selected field crops (cereals, maize, sunflower, oilseed rape, sugar beets and potatoes), which means that these soils are not necessarily representative of other crops, e.g. vegetable crops and perennial crops such as orchards fruits and grapevines. The arable land relevant for production of the selected field crops was determined using the 2000 agricultural census and Corine Land Cover database. Within the relevant surface, INRA then used the BDGSF soil database to select a total of 19 predominant soil-types. Finally, representative soil profiles were selected from the DONESOL2 database for each of the 19 soil-types. INRA reported its work in Morvan and Le Bas, 2006 (in French), and this report is the main basis for this chapter on the selection of representative soils.

7.1 Land use data

7.1.1 Agricultural census

The agricultural census (recensement agricole) is a ten-yearly census organized by the French Ministry for Food, Agriculture and Fisheries. It contains information at the farm scale on population, production, production methods and side-activities (on-site processing, tourism). INRA extracted from the 2000 agricultural census the latest available detailed information on the cultivation of the selected field crops at the canton administrative level (canton = administrative district consisting of several communes (municipalities); there are 4039 cantons in France).

7.1.2 Corine Land Cover

The Corine Land Cover (CLC) database is a European geographical database for land use coordinated by the European Environment Agency (EEA). CLC 2000 (ETC, 2000) is the year 2000 update of the first CLC database which was finalised in the early 1990s as part of the European Commission programme to COoRdinate INformation on the Environment (Corine). In France, IFEN has been responsible for the Corine data production, maintenance and diffusion. IFEN (Institut Français de l'Environnement) joined SOeS (Service de l'Observation et des Statistiques) in July 2008. The database contains land use information at a scale of 1/100000. The CLC 2000 database was used to delimit arable land within the selected cantons and exclude all non-cropped land. The database was updated in 2006, but INRA conducted the analysis using the 2000 database, in line with the timing of the agricultural census.

7.2 Soil data

7.2.1 BDGSF

For detailed information on soils and to identify the dominant soils for the different crops, INRA used the Geographical DataBase of French Soils (BDGSF, Base de Données Géographique des Sols de France), which contains information on soil types at a scale of 1/1000000. BDGSF is managed by GIS Sol, a conglomerate of French administrative institutes and scientific partners. These data are also part of the European Soil Geographical DataBase (ESGDB, Finke et al. 2001) since GIS Sol participates in this program as member of the European Soil Bureau (ESBN).

The soil classification in BDGSF is adapted from standard FAO terminology (FAO, 1974) to include French specificities. The different soil types are identified in BDGSF as Unités Typologiques de Sol (UTS = STU, Soil Typological Units in ESDB), however given the scale of 1/1000000 of the database, the data do not permit to delimit and locate precisely these different UTS (917 in total). Instead, UTS are regrouped in Unités Cartographiques de Sol (UCS = SMU, Soil Mapping Units in ESDB). These UCS are defined by their geometry (set of polygons described by their shape and geographical position) and their composition in term of relative contribution of the different UTS that are included in the UCS. They can therefore be spatially located and consist of well-identified UTS, but the UTS themselves cannot be located within the UCS, only their relative proportion in the UCS is known. One should note that the same UTS can be found in different UCS (Figure 32).

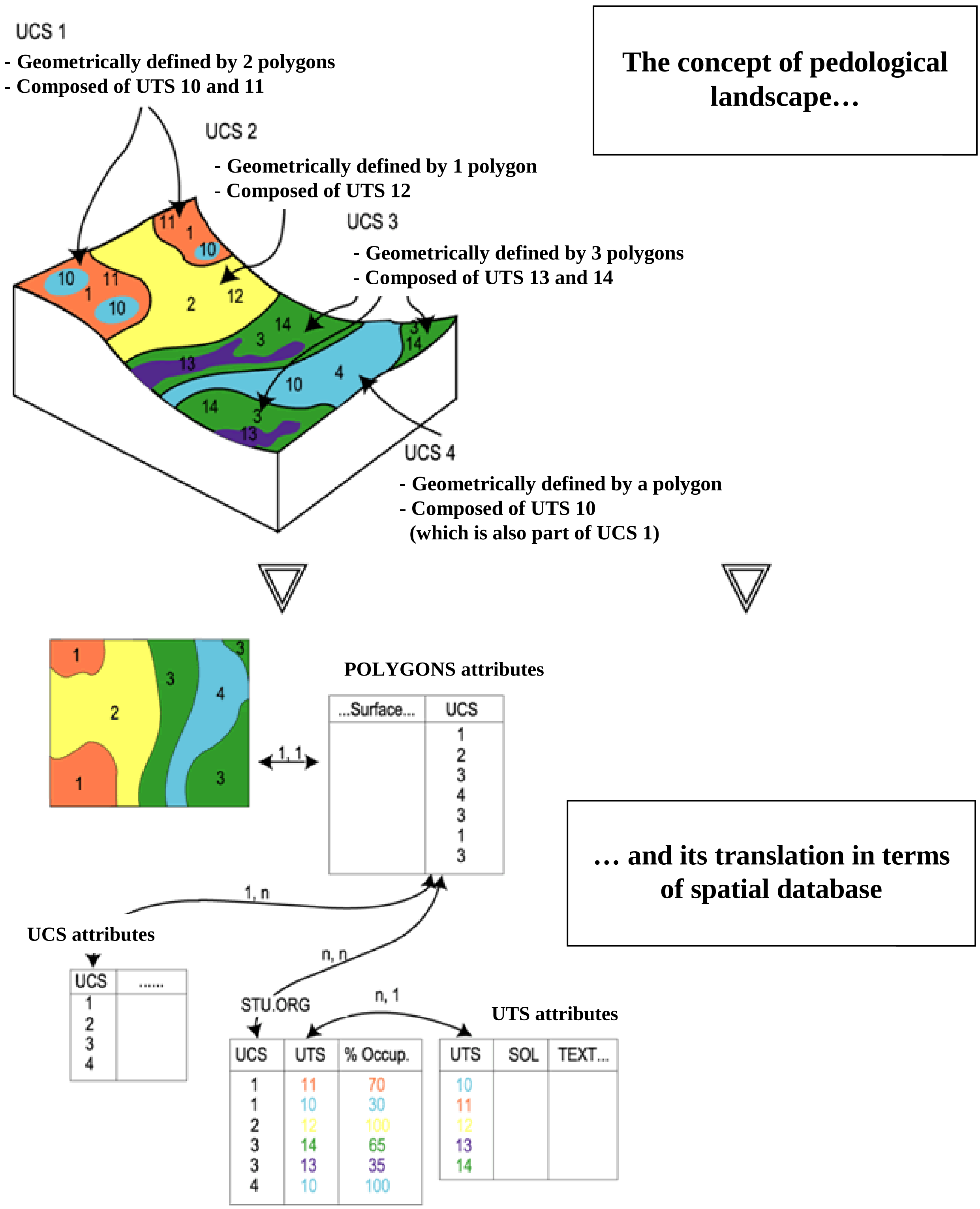

Figure 32 Relationship between geographical (UCS) and typological (UTS) representation of soils in the BDGSF database (adapted from BDGSF and ESGDB on-line documentation)

7.2.2 DONESOL

Representative soil profiles for each of the selected dominant soil types were obtained from the DONESOL2 database. DONESOL2 is the French national database of spatial pedological information. It is also managed by GIS Sol. In 2006, this database contained information for over 7000 (now over 13000) soil profiles in relation to the different UTS and UCS from BDGSF. However the spatial distribution of these profiles over France is not homogeneous. The data contained in DONESOL2 is proprietary to the different Institutes participating in its elaboration and is therefore not publicly available. At least some of the DONESOL data are included in the European database SPADBE (Soil Profile Analytical DataBase for Europa).

7.3 Determination of the relevant regions of cultivation

For each of the selected crops, the cultural region was delimited using information from the agricultural census and CLC. In a first step, the percentage of arable land in each canton that is cultivated with a given crop based on information from the agricultural census. A threshold level (minimum percentage of arable land cultivated with the crop in a canton for the canton to be considered representative for that crop) was selected by expert opinion for each of the selected crops to delimitate the main cultural area for the crop under consideration. Different threshold levels were selected for the different crops depending on how localized the cultural area is. This means that for crops which are highly localized in specific regions, such as sugar beet, potato or sunflower, low threshold levels can be used without spreading out outside of the main cultural region, while for more ubiquitous crops like cereals higher threshold levels need to be used. Selecting lower threshold levels for the crops would mean increasing the percentage of total cultivated surface covered, but going away from the main cultural area for the crop under consideration.

The threshold selection process is illustrated in Figure 33 for potato and wheat. With a threshold level of 2%, the main cultural area for potato is clearly delimited and the achieved coverage of the total surface cultivated with potato at national level is 78%. Lowering the threshold to 1% would raise the overall coverage to 87%, but would mean including a multitude of additional cantons all over France, so no clear cultural area can be distinguished anymore. For wheat, the cultural region is already well delimited with a threshold level of 10%, corresponding to an overall coverage of 93.5%.

Based on the selected threshold levels, the achieved coverage of the total surface cultivated with the crop at national level range from 75 to 98% depending on the crop (Table 32).

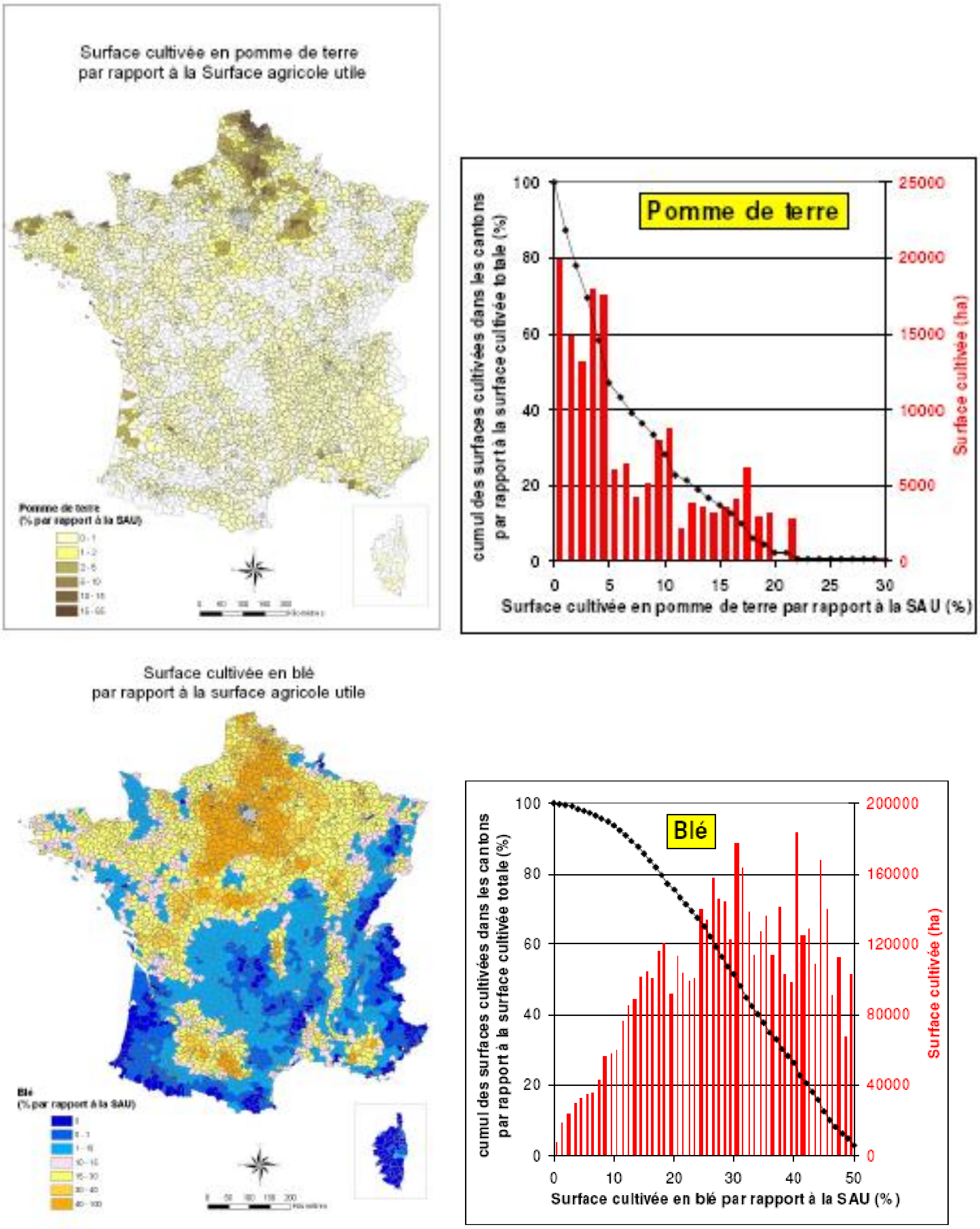

Figure 33 Cultural region: example of potato (top) and wheat (bottom) (source: Morvan and Le Bas, 2006)

Table 32 Selected threshold levels for representativity of the selected crops in the cantons and associated surface covered

Crop	Threshold level (%)	Surface covered (ha)	Surface cultivated in France (ha)	% of surface cultivated covered
Potato	2	123057	157736	78.0
Sugar beet	1	402000	408817	98.3
Sunflower	2	667842	722884	92.4
Oilseed rape	3	1032527	1175976	87.8
Fodder maize	6	1038804	1384936	75.0
Total maize	11	2845345	3138687	75.5
Grain maize	6	1154666	1753751	82.4
Barley	5	1185579	1521865	77.9
Wheat	10	4895629	5234341	93.5

Once the representative cantons were selected for each crop, the information was intersected with CLC to eliminate non arable land (urban, industrial and commercial land, swamps and other humid land, ponds, lakes, rivers and streams, forests and other natural land), as illustrated in Figure 34. With this method, cultural regions representative for each of the selected crops are obtained.

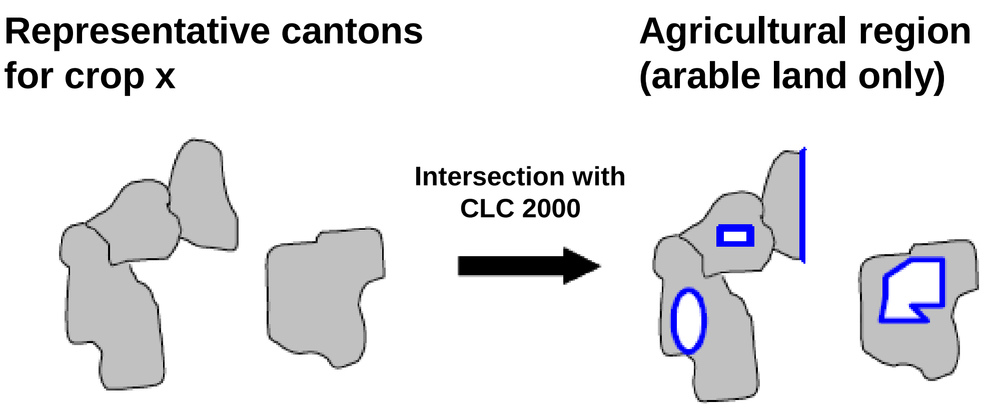

Figure 34 Exclusion of non-arable land from the representative cantons to obtain the agricultural region

7.4 Selection of typical soils within the agricultural regions

For determination of the dominant soil types for each crop, the cultural region for the crop under consideration was intersected with the BDGSF. This is performed in successive steps as follows:

1. The surface associated with the different UCS within the cantons arable land is calculated. This gives the arable surface of each UCS by canton.
2. This surface is then multiplied by the % of arable land cultivated with the crop of interest in the canton to obtain the surface of soil representative for that crop in each canton.
3. This representative surface per canton is then summed up for all the relevant cantons in the crop cultural region to provide the representative surface of the UCS for the whole cultural region.
4. The representative surface for each UTS is then back-calculated from the UCS surface, by multiplying the UCS surface by the relative percentage of each UTS within that UCS.
5. UTS were then regrouped in clusters of UTS of similar properties (USR, Unité de Sols Regroupés). The reason for this regrouping was that UTS are characterized in BDGSF by textural class (Figure 35), number of horizons and soil depth, but also by additional criterias that are not necessarily relevant for the setting up of groundwater scenarios within the scope of FROGS (i.e. leaching at the bottom of the soil profile) such as composition of the bedrock, slope, etc. Grouping UTS in USR was performed based on textural class, number of horizons and soil depth, meaning that all the soils contained in a given USR are of the same textural class and are comparable in terms of number of horizons and depth of the profile. The grouping resulted in 96 different USR (from 917 UTS).
6. The surface represented by each USR in the cultural region is calculated from the UTS surface, by summing up the surface associated to the different UTS relevant for the USR in question.
7. While the different UTS within a USR have the same textural class, number of horizons and depth of profile, these include soils from different origin and of different denomination according to FAO pedogenesis classification. In order to account for the different physico-chemical environment associated to the particular origin of the soils, and to facilitate the link with the soil profile database DONESOL, the soils of the same denomination within the USR were regrouped and these USR subgroups were considered as the different soil types relevant for FROGS.
8. For each crop and associated cultural region, the representative soil types are classified in function of the surface and associated percentage of the cultural region they represent. The most dominant soils are actually common to the majority of the different cultural regions, which is to be expected since due to crop rotations the same cantons are representative for different crops and are therefore accounted in several agricultural regions. It is therefore possible with a limited number of soil types to achieve a good representation of the most relevant soils for all crops considered.

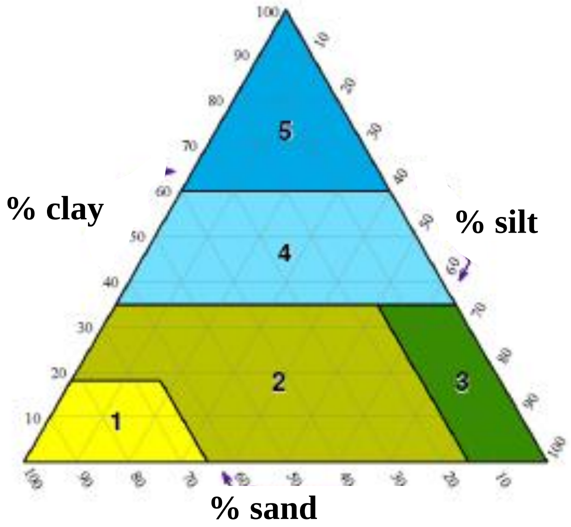

Figure 35 Textural classification in BDGSF

Canton	UCS	Surface arable land (ha)
586	20	300
586	25	120
587	20	30
587	25	40
587	28	100
588	28	100
595	25	100
595	28	50
595	34	120

X

Canton	% of arable land cultivated with crop x
586	2.5
587	10.0
588	2.0
595	5.0

Canton	UCS	Surface cultivated with crop x (ha)
586	20	7.5
586	25	3
587	20	3
587	25	4
587	28	10
588	28	2
595	25	5
595	28	2.5
595	34	6

Sum by UCS

UCS	Surface cultivated with crop x (ha)
20	10.5
25	12
28	12
34	6

UCS to UTS

UCS	UTS	% of UTS in UCS
20	330	38
20	331	62
25	337	50
25	338	25
25	339	25
28	350	100
34	400	33
34	401	67

UTS	Surface cultivated with crop x (ha)
330	4
331	6.5
337	6
338	3
339	3
350	12
400	2
401	4

Figure 36 Extraction of the dominant UTS in the agricultural region for crop x (steps 2-4 of above-described methodology, adapted from Morvan and Le Bas, 2006)

UTS	Surface cultivated with crop x (ha)
330	4
331	6.5
337	6
338	3
339	3
350	12
400	2
401	4

UTS to USR

UTS	USR
330	1
331	2
337	2
338	2
339	3
350	4
400	1
401	3

USR	Surface cultivated with crop x (ha)
1	6
2	15.5
3	7
4	12

USR to soil-types (split by soil pedogenesis denomination)

USR	Soil denomination	Surface cultivated with crop x (ha)
1	Luvisol	4.5
1	Cambisol	1.0
1	Gleysol	0.5
2	Rendzine	8.5
2	Podzoluvisol	5.0
2	Cambisol	2.0
3	Luvisol	5.5
3	Fluvisol	1.5
4	Luvisol	8.0
4	Cambisol	2.0
4	Rendzine	2.0

Figure 37 Extraction of the dominant USR and soil-types in the agricultural region for crop x (steps 5-7 of above-described methodology, adapted from Morvan and Le Bas, 2006)

7.5 Selection of representative soil profiles

Representative soil profiles for the dominant soil-types extracted from the BDGSF were selected from the DONESOL2 database.

While the pedogenesis classification in BDGSF is according to FAO, most soil profiles contained in DONESOL2 are classified according to the RP 1995 (Référentiel Pédologique 1995, Baize, 1995) classification, which is more detailed. Correspondence between these two classifications is provided in Table 33.

Table 33 Correspondence between FAO and RP 1995 soil classifications

FAO, 1974 classification	RP 1995 classification
Luvisol	Luvisol
Cambisol	Brunisol
Podzoluvisol	Degraded Luvisol
Rendzine	Rendisol
	Rendosol
	Calcisol
	Calcosol
Fluvisol	Fluviosol
Gleysol	Reductisol
	Rédoxysol
Solonchak	Salisol
	Sodisol
Arénosol	Arénosol

All the relevant soil profiles corresponding to a given selected soil-type were first extracted from DONESOL2 according to the following criteria:

- Land cover (cultivated soil)
- Soil denomination
- Texture of the soil horizons
- Depth of the soil profile
- Geographical location (preferentially within the cultural regions)

This lead to the identification of a number of representative soil profiles for each of the 19 soil-types. A single representative soil profile was selected among these soils according to the following criteria:

- Profiles with measured OC content (not available for all profiles)
- Preference for soil profiles with textural analysis performed without decarbonation (since dissolving with acid for removal of the carbonates results in destruction of soil particles)
- Soil profile with parameters (OC content, particle size distribution, depth of profile) in the medium range within the available soil profiles for the soil-type (exclusion of soils with extreme characteristics)
- Preference for soil profiles originating from the main cultural regions (in case there were several soil profiles satisfying the medium range criteria,

preference was allocated to soil profiles originating from a well defined cultural region, such as that for sugar beets or sunflower)

7.6 Selected soil-types

According to the followed stepwise approach, 19 dominant soil-types were identified (Table 34). These dominant soil-types cover a variety of pedogenesis classes, textural classes and depth of the soil profile.

These 19 soil-types represent altogether between 57.2% (oilseed rape) and 73.9% (sugar beets) of the cultural regions for the respective crops (Morvan and Le Bas, 2006). Each additional soil-type would only add a minor contribution to the total represented surface of the cultural regions (<1-2%) and it was therefore decided to limit the soil selection to these 19 soil-types. Among these soils, the solonchak soil-type 18, which is a very particular soil with unusually high organic carbon content, turned out not to be relevant for the crops considered in FROGS (see section 7.8.2 and Appendix 16) and was therefore not considered any further.

Table 34 FAO 1974 pedogenesis classification, BDGSF textural class and depth of profile of the selected soil-types

n° soil-type	FAO denomination	Texture class	Depth of profile
1	Luvisol	3	>80 cm
2	Cambisol	4	>80 cm
3	Rendzine	2	>80 cm
4	Luvisol	2	>80 cm
5	Cambisol	3	60 cm
6	Rendzine	2	60 cm
7	Rendzine	4	40 cm
8	Fluvisol	2	>80 cm
9	Fluvisol	1	>80 cm
10	Gleysol	4	>80 cm
11	Cambisol	2	60 cm
12	Podzoluvisol	3	>80 cm
13	Cambisol	3	>80 cm
14	Podzoluvisol	2	>80 cm
15	Cambisol	2	>80 cm
16	Rendzine	3	60 cm
17	Rendzine	3	>80 cm
18	Solonchak	4	>80 cm
19	Arenosol	1	>80 cm

7.7 Selected soil profiles

The original soil parameters for the selected soil profiles for the 18 representative soil-types (excluding soil-type 18 as explained above) are presented in Table 35.

Table 35 Original soil parameters for the selected soil profiles, taken from Morvan and Le Bas (2006). Highlighted in bold are values that were added later to fill data gaps (see Chapter 8).

Profile ID	Horizon ID	Depth (cm)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	OC (g/kg)	pH (water) (-)
1	1	29	0.188	0.611	0.201	10.3	7.1
	2	41	0.125	0.562	0.313	6.7	7.6
	3	75	0.122	0.556	0.322	6.1	7.8
	4	100	0.131	0.541	0.328	3.4	7.9
	5	130	0.164	0.358	0.478	2.8	7.8
2	1	20	0.062	0.615	0.323	14.6	7.4
	2	50	0.041	0.598	0.361	6.0	7.2
	3	80	0.029	0.599	0.372	5.0	7.2
	4	110	0.04	0.522	0.438	3.0	6.9
3	1	25	0.379	0.363	0.258	12.9	7.9
	2	50	0.378	0.349	0.273	6.5	8.1
	3	70	0.417	0.327	0.256	5.5	8.2
	4	100	0.472	0.262	0.266	4.5	8.1
4	1	25	0.464	0.348	0.188	11.7	5.8
	2	50	0.408	0.323	0.269	5.3	6.8
	3	121	0.361	0.302	0.337	3.7	7.4
5	1	10	0.08	0.648	0.272	19.9	6
	2	28	0.072	0.646	0.282	13.2	5.3
	3	40	0.083	0.569	0.348	9.5	5.6
	4	70	0.08	0.485	0.435	5.2	5.8
6	1	20	0.357	0.429	0.214	11.6	8.2
	2	40	0.369	0.419	0.212	8.8	8.4
	3	50	0.261	0.468	0.271	3.3	8.6
7	1	15	0.134	0.452	0.414	20.2	8.1
	2	35	0.106	0.381	0.513	9.2	8.3
8	1	20	0.22	0.61	0.17	15.0	8
	2	60	0.25	0.59	0.16	**5.0**	**8**
	3	120	0.229	0.59	0.181	**2.5**	8
9	1	25	0.649	0.238	0.113	8.6	6.2
	2	60	0.682	0.209	0.109	5.3	6.2
	3	100	0.809	0.1	0.091	1.5	6.6
	4	120	0.895	0.068	0.037	0.9	6.7
10	1	15	0.018	0.336	0.646	31.2	8
	2	30	0.02	0.351	0.629	26.8	7.9
	3	40	0.019	0.398	0.583	9.2	8.1
	4	120	0.013	0.413	0.574	7.6	7.9
11	1	15	0.542	0.302	0.156	19.6	6.8
	2	55	0.561	0.296	0.143	6.4	7.5

12	1	20	0.04	0.76	0.2	8.1	7.2
	2	35	0.04	0.76	0.2	8.1	7.2
	3	60	0.05	0.69	0.26	1.5	7.1
	4	140	0.08	0.67	0.25	*0.1*	**7.1**
13	1	20	0.038	0.682	0.28	11.0	7.8
	2	50	0.027	0.698	0.275	6.6	7.5
	3	110	0.013	0.615	0.372	3.8	7.5
	4	130	0.04	0.687	0.273	**1.9**	7.9
14	1	3	0.197	0.707	0.096	32.5	4.2
	2	10	0.189	0.713	0.098	32.5	4.4
	3	36	0.195	0.7	0.105	8.1	4.7
	4	64	0.155	0.719	0.126	3.0	4.6
	5	80	0.077	0.788	0.135	2.0	4.8
	6	95	0.137	0.624	0.239	2.3	4.9
	7	132	0.203	0.284	0.513	2.7	5.1
	8		0.088	0.356	0.556	2.4	5.1
15	1	25	0.337	0.469	0.194	11.6	6
	2	35	0.323	0.495	0.182	11.5	6
	3	48	0.28	0.55	0.17	**5.7**	6.3
	4	100	0.31	0.51	0.18	**3.1**	6.4
	5	110	0.3	0.5	0.2	**2.1**	6.4
16	1	30	0.091	0.6	0.309	11.1	8.2
	2	60	0.188	0.529	0.283	5.4	8.6
17	1	8	0.072	0.631	0.297	14.6	8
	2	28	0.07	0.628	0.302	14.2	8.1
	3	40	0.227	0.479	0.294	8.0	8.3
	4	75	0.306	0.48	0.214	2.7	8.5
	5	120	0.407	0.326	0.267	2.1	8.7
19	1	28	0.843	0.111	0.046	7.3	5.8
	2	38	0.885	0.081	0.034	1.6	6.3
	3	56	0.894	0.077	0.029	1.0	6.7
	4	90	0.957	0.022	0.021	1.0	6.1
	5	130	0.961	0.014	0.025	**0.5**	6.6

7.8 Soil – Agronomic Units relationship

The selected soil types and corresponding soil profiles are linked to the AUs in order to combine soil, crop and climatic information and finalize the construction of the scenarios.

7.8.1 Distribution of Soils in the Agronomic Units

The surfaces of the 19 representative soil types in the AUs were calculated by INRA Infosol (Appendix 14). Results expressed as kha are given in Table 36. Surface boundaries defined by the thresholds of 5 000, 10 000, 50 000 et 100 000 ha are displayed in this table using a color coding, to help selecting pertinent soils according to the degree of accuracy wished in the assessment. Soils with surfaces lower than 1 000 ha are not displayed in the table.

7.8.2 Soil Distribution as a function of Crops

The surfaces of the relevant soils in the relevant cropping regions were calculated by INRA Infosol and are indicated in Table 37 (Annexe 2, choix n°3 of Morvan and Le Bas, 2006). The corresponding proportions of surface are given in Table 38, using the same color coding for the different surface classes of 5 000, 10 000, 50 000 and 100 000 ha. These tables show the global partition of soils among the different crops, i.e. which soils are relevant for which crops. Therefore, only those combinations of soils and crops listed in the tables were considered as scenarios in FROGS and soil – crop combinations not appearing in the tables were excluded as non-representative of standard growing conditions or marginal.

As there is no detailed geographical distribution of crops available at canton level for the entire country and no detailed geographical distribution of soil type unit (STU) within soil map unit (SMU), a precise overlap of crop and soil at canton level for each AU is not possible. Therefore the surface of each soil for each crop within each AU was estimated using:

- the cultivated acreage of each crop within each AU which is calculated from the 2010 agricultural census and AU delineation (Appendix 7);
- the distribution of soils in the cropping region as provided by INRA Infosol (Table 38);
- and the surface of each soil within each AU as provided by INRA Infosol (Appendix 14).

The methodology is detailed and exemplified in Appendix 15.

Only final soil – crop – AU combinations above 1000 ha were selected as scenarios. They are listed together with the surface they each represent in Tables of Appendix 16. These include for each crop the AUs representing surfaces above 1000 ha (see Appendix 7) and realistic soil – crop combinations as explained above.

Table 36 Soil Surfaces in the Agronomic Units (kha)

AU	Sol n°																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	7	498		116	3	5	239	182	4		43		34	293	57	93			
2	35			98	61					6	205	17	101	67	7				
3		89			7	21		71	25		35			215	30				4
4	571	103	18	8		105		150	28	26	45	21	118	6	2		167		41
5	6	187		37				87	14	23	1		3		5				
6	61	38		2	56	2		3	4	2	12	7	3	2	10				2
7		11	1	7				48	20					20	1				17
8	5	66		253	1		25	102		0	52		17	91	184				1
9	570	13		6		221		60	32	7	96	17	105	7	7		8		55
10		36		77	121	118		22	4	60	328		11	36	64	22	3	113	3
11	235	9		131	179	15		1	3		161	93	248	48	82				
12	6	326			670	18		55	62	18	118	6	7	11	46	58	3		7
13	1	246		3	24	15		57	25	16	13		3		18	18			2
14	201	125		3	23	140		1	100	1	66	53	3		43		9		9
15	37	16		3	1	14		5	60		6	4		1	0				1
16	32	46	468			123		30	72	9	54	23	29	9	54		62		8
17	411	119		1	67	99		47	5	16	59	62	17	15	7		46		25
18		287	19	48	19	41	127	97			131		7	159	53	33			25
19	342	213		7	42	39		29	12		25	283	4	20	4		11		5
20	52	3		269	162	10			18	9	25	26	133	130	496	1			
21	97	70	11		42	34		10	60		26		8	128	18				16
22	162	175		26	230	9			118	4	17	46		51	4		5		32
23	18	2		213	39		2	124			159				61				
24	41	73		52	53			50	6		39	4	5	4	64				2
25	53			58	59						103	27	116	18	122				
26	16	113		5	145	9			22		34	14			13				3
27	7			27		1		84			214		55		0				
28			14	1		121		89	25	1	150				45				
29		57		106	1	7		16	17		190			59	16				4
30	255	2		103	112						137	102	278	31	32				
31	331	182	18	5		175		95	8	19	74	158	16	14	23		39		110
Total	3549	3103	549	1667	2116	1343	393	1514	743	219	2618	965	1324	1434	1565	225	354	114	369

Table 37 Soil Surfaces in the cropping Regions

Soil N°	Sugar Beet	Winter Wheat	Oilseed Rape	Maize Fodder	Maize Grain	Barley	Potato	Sunflower
1	119684	866205	125752	135990	78044	179641	47239	26544
2	24721	521979	111059	32247	217419	124510		138120
3	54268	157327	22702			85226	12916	
4		161081	31057	92331	223496			64631
5		294782	113453	69006	40690	109577		33352
6	83509	451256	46420			115981	19465	45137
7								43676
8	19280	177579	26471		125526	35025	6183	38343
9	11936	99954	25245		19624	31663		14223
10					16660			
11				85126	49126			56743
12		196041	49566	41334	88183	42478	3965	
13	19732	216287		123544	47707	33881	7614	
14				37528	112314			46053
15				91791	104246			36072
16								16301
17			21544					
18								
19	15336	74172						
Total	348466	3216663	573269	708897	1123035	757982	97382	559198

Table 38 Distribution of Soils in the cropping Regions (%)

Soil N°	Sugar Beet	Winter Wheat	Oilseed Rape	Maize Fodder	Maize Grain	Barley	Potato	Sunflower
1	25.4	16.9	12.6	13.3	44.4	13.9	31.4	3.3
2	5.2	10.2	11.2	3.2	12.3	9.6		17.3
3	11.5	3.1	2.3			6.6	8.6	
4		3.2	3.1	9.0	12.7			8.1
5		5.8	11.4	6.8	2.3	8.5		4.2
6	17.7	8.9	4.7			9.0	12.9	5.7
7								5.5
8	4.1	3.5	2.7		7.1	2.7	4.1	4.8
9	2.5	2.0	2.5		1.1	2.4		1.8
10					0.9			
11				8.3	2.8			7.1
12		3.8	5.0	4.0	5.0	3.3	2.6	
13	4.2	4.2		12.1	2.7	2.6	5.1	
14				3.0	6.4			5.7
15				9.0	5.9			4.5
16								2.0
17			2.2					
18								
19	3.3	1.5						
Total	73.9	63.1	57.7	69.4	63.6	58.6	64.7	70.0

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8 Parameterization of the soil profiles

Soil water flow is described in PEARL with the Richards equation, which requires the Mualem-van Genuchten functions. Parameter values for the Mualem-Van Genuchten functions must therefore be provided, however these are not available from the DONESOL2 database and consequently needed to be estimated using pedotransfer functions (PTF). The most commonly used PTF available from the literature were tested against measured water retention curves for a variety of French soils and the HYPRES functions were consequently selected for estimation of the Mualem-Van Genuchten for FROGS. Soil bulk density is one of the required parameters for HYPRES. In the majority of cases it was not available from DONESOL, so this parameter was also estimated using PTF. In addition, a few subsoil layers OC content and pH values were missing from the selected DONESOL soil profiles and had to be estimated. Finally, the topsoil OC content and the pH of the soils were corrected based on the comprehensive data available from BDAT to better reflect spatial variation in surface OC between AUs.

Whenever possible, the same PTF as used in the PEARL model were used to estimate these parameters, for consistency with the model and for consistency with the approach taken in the FOCUS scenarios. These PTF were first checked against available measured data for French soils to confirm applicability to French conditions.

8.1 Adjustment of Topsoil Organic Carbon Content to BDAT

Among all soil properties probably the content of organic carbon (OC) is the most important with respect to the leaching of most pesticides, with the exception of ionic substance, in which case soil pH is key and the use of pH-dependent sorption in PEARL is recommended. The content of OC generally determines the sorption and thereby the relative mobility of non-ionic compounds. The OC of soils may vary significantly due to soil type, vegetation and climate (Jones et al., 2004). Thus the 18 topsoil OC values from the profile set might be too few to represent large areas in the order of 100 000 km^2 as considered here. The soil profiles selected to represent the 19 soil types were taken from the DONESOL database which shows a considerable variation of the geographic distribution of the soil samples. The number of profiles available for a specific soil type is indeed highly variable between the various regions. Most of the profiles selected to represent the 18 soil types were taken from the Centre region where the profiles are particularly abundant (Morvan and Lebas, 2006). This is also the region where the organic carbon content of the top soil layer is the most depleted. Therefore a large French database on topsoil properties denoted as BDAT (Base de données d'analyses de terre) (INRA, 2005) was used to adjust the topsoil OC at regional level. This database provides statistical descriptors (mean, median and several quantils) of physico-chemical parameters of the topsoil (texture, OC, pH and $CaCO_3$) at canton level based on a large number of individual samples.

8.1.1 Correction method

The adjustment of surface OC content of the selected DONESOL soils using BDAT data was based on areal median values OC_{med} at the spatial scale of the AU. This means that in 50 % of the area of a specific AU, $OC < OC_{med}$, and in the other 50 % $OC > OC_{med}$. The adjustment considers the uppermost 0.3 m of the soil which represents the sampling depth underlying the BDAT values. The BDAT values used were denoted as “Carbone organique, oxydation humique” from the time period 2000 -2004. As mentioned above the BDAT data are compiled at canton level of which the median values were used (“med : médiane”). These values can be considered as the most robust ones. The spatial resolution of these data is relatively high (2286 cantons in the 31 AU). As consequence of this adjustment, the topsoil (0 - 0.3 m) OC for a given soil depends on the AU.

First, the %OC values of the DONESOL soils were calculated for the top 30 cm. For this purpose a depth-weighted mean value was calculated in case the first horizon was < 0.3-m thick, according to Equation 1

Equation 1: $\%OC(\text{DONESOL soil}) = \Sigma_{i=1,n}(\%OC_i\ \Delta z_i) / \Sigma_{i=1,n}(\Delta z_i)$,

Where n is the number of horizons to reach a depth of 0.3 m,

Δz_i is thickness of horizon i in the soil layer from 0 to 0.3 m, and

$\Sigma_{i=1,n}(\Delta zi) = 0.3$ m.

The $\%OC_{med}$ (representing the median, i.e. 50 % percentile) of the INRA soils was then calculated as follows. The relevant DONESOL soils for a specific AU are sorted by their %OC (0 - 0.3 m) in ascending order. The relative surface of a specific soil is used to calculate the corresponding areal percentiles, i.e. the areal percentile P_A is equal to the cumulative relative surface. The procedure is illustrated in the following example:

> Soil A has an OC content of 1.0% and a relative surface of 0.2, soil B has an OC content of 1.4 % and a relative surface of 0.5, and soil C has an OC content of 1.6 % and a relative surface of 0.3. Then OC (P_A=20%)=1%, OC (P_A=20+50=70%)=1.4%, and OC (P_A=20+50+30=100%)=1.6%. In other words, for 20 % of the surface the OC is 1.0 % or lower, for 70 % of the surface the OC is 1.4% or lower, and for 100% of the surface the OC is 1.6% or lower.

Although the number of soils per AU is greater than in the example above, in most cases the $\%OC_{med}$ is not met directly. In such cases $\%OC_{med}$ is determined by linear interpolation between the two percentile values surrounding $P_A = 50$ % (see also Table 39 for AU = 3 as example). For the example above these percentiles are P_A = 20% and P_A = 70%, so

$\%OC_{med} = 1.0\% + (50\% - 20\%) \times (1.4\% - 1.0\%) / (70\% - 20\%) = 1.24\%$.

The same procedure as above is applied to the BDAT values. Because there are sufficient data per AU interpolation was not necessary to obtain %OC (P_A = 50 %). The corresponding data for AU = 3 as example are shown in Table 40.

Finally a correction factor is derived as $\%OC_{med}$ (BDAT) / $\%OC_{med}$. (DONESOL).

***Table 39** Percentiles of OC contents calculated based on the selected DONESOL soils, example of Agronomic Unit 3*

AU No.	Soil No.	Area (kha)	Surface fraction	OC (%, 0-0.3 m)	Percentile (%)	OC_{med} (%, 0-0.3 m)
3	19	4	0.008	0.69	0.8	
3	9	25	0.050	0.81	5.8	
3	6	21	0.042	1.06	10.1	
3	15	30	0.060	1.16	16.1	
3	2	89	0.179	1.17	34.0	
3	8	71	0.143	1.20	48.3	1.22
3	11	35	0.070	1.30	55.3	
3	5	7	0.014	1.52	56.7	
3	14	215	0.433	1.62	100.0	

***Table 40** Percentiles of OC content calculated based on BDAT[1], example of AU 3. The 50th percentile OC is given in bold.*

Canton Name	No.	Area[2)] (kha)	OC[3)] (%)	AU	Percentile (%)
DORNES	5810	17	0.93	3	3
CHATELDON	6309	3	0.99	3	3
YZEURE	333	13	1.05	3	6
CHEVAGNES	304	29	1.08	3	10
NEUILLY-LE-REAL	325	19	1.11	3	14
SAINT-HAON-LE-CHATEL	4227	9	1.12	3	15
ROANNE-SUD	4234	5	1.25	3	16
MOULINS-SUD	323	3	1.27	3	17
DOMPIERRE-SUR-BESBRE	307	23	1.28	3	21
PERREUX	4214	10	1.29	3	22
LEZOUX	6322	11	1.29	3	24
BRIOUDE-NORD	4305	6	1.31	3	25
SAINT-GALMIER	4223	8	1.33	3	27
DONJON	308	26	1.34	3	31
MONTBRISON	4209	15	1.34	3	34
SAINT-JUST-SAINT-RAMBERT	4231	10	1.34	3	35
BOURBON-LANCY	7103	20	1.35	3	39
SAINT-SYMPHORIEN-DE-LAY	4232	18	1.37	3	42
IMPHY	5832	11	1.40	3	43
AUBIERE	6355	1	1.44	3	44
SAINT-POURCAIN-SUR-SIOULE	326	17	1.45	3	47
DIGOIN	7117	7	1.47	3	48
CHARLIEU	**4205**	**11**	**1.48**	**3**	**50**
BILLOM	6306	7	1.50	3	51
MARINGUES	6324	5	1.51	3	52
SAINT-PIERRE-LE-MOÛTIER	5822	18	1.55	3	55
ROANNE-NORD	4216	4	1.56	3	55
CLERMONT-FERRAND	6398	1	1.56	3	56
COURPIERE	6315	6	1.63	3	57
NEVERS-SUD	5830	4	1.68	3	57
ENNEZAT	6317	10	1.70	3	59
RIOM	6399	2	1.74	3	61
ESCUROLLES	310	12	1.74	3	61
GERZAT	6359	2	1.74	3	62
PACAUDIERE	4212	14	1.74	3	64
RANDAN	6332	9	1.74	3	66
COMBRONDE	6314	7	1.75	3	67
CHAMPEIX	6308	9	1.79	3	69

BRIOUDE-SUD	4334	5	1.79	3	69
VARENNES-SUR-ALLIER	328	15	1.79	3	72
VEYRE-MONTON	6348	5	1.80	3	73
GUEUGNON	7120	16	1.80	3	76
BLESLE	4304	7	1.80	3	77
RIOM-EST	6333	3	1.80	3	77
SAINT-GERMAIN-LAVAL	4226	13	1.80	3	80
VIC-LE-COMTE	6349	8	1.80	3	81
MARCIGNY	7128	16	1.80	3	84
VERTAIZON	6347	6	1.83	3	85
LAVOÛTE-CHILHAC	4311	8	1.86	3	86
AIGUEPERSE	6301	13	1.88	3	89
ISSY-L'EVEQUE	7122	20	1.90	3	92
PONT-DU-CHATEAU	6330	4	1.95	3	93
ISSOIRE	6319	9	1.98	3	94
CUSSET-NORD	306	2	2.04	3	95
PAULHAGUET	4316	9	2.18	3	96
LANGEAC	4310	12	2.21	3	98
GANNAT	311	11	2.25	3	100

[1)] Période début 2000 à fin 2004, version 3.2.1.0 du 11/02/2009 [2)] surface agricole utile [3)]Carbone organique, oxydation humique: médiane

8.1.2 Results and Discussion

The areal median $\%OC_{med}$ obtained for the selected DONESOL soils and those derived from BDAT are shown in Table 41. The corresponding correction factors range from 0.7 to 2.41.

Table 41 Areal median OC_{med} for DONESOL soils and derived from BDAT

AU No.	DONESOL OC_{med} (%)	BDAT OC_{med} (%)	Correction factor
1	1.17	1.01	0.86
2	1.19	2.26	1.91
3	1.22	1.48	1.21
4	1.01	1.10	1.09
5	1.17	1.19	1.02
6	1.16	1.74	1.50
7	1.18	0.97	0.82
8	1.13	1.33	1.18
9	1.00	1.10	1.10
10	1.24	1.57	1.26
11	1.03	1.85	1.80
12	1.30	1.89	1.45
13	1.17	1.55	1.33
14	1.06	1.09	1.03
15	0.86	0.78	0.91
16	1.18	1.67	1.42
17	1.01	1.10	1.08
18	1.18	0.95	0.80
19	1.16	1.23	1.06
20	1.13	1.45	1.29
21	1.16	1.51	1.30
22	1.16	1.32	1.14
23	1.18	1.15	0.98
24	1.16	1.13	0.98
25	1.08	2.60	2.41
26	1.18	1.46	1.24
27	1.20	1.02	0.85
28	1.19	0.83	0.70
29	1.20	1.37	1.14
30	0.99	1.65	1.66
31	1.06	1.00	0.94

The median correction factor is 1.14, e.g. the adjusted topsoil %OC are on average slightly higher than the DONESOL soils values. The overall distributions of topsoil %OC before and after corrected were calculated for all AUs together, i.e. for the whole of France, and compared with the BDAT distribution in Figure 38. The overall BDAT OC distribution is as expected very well reproduced after application of the correction factors shown in Table 41 to the DONESOL values on an AU basis. It is also clear from the figure that the original DONESOL OC distribution was biased towards lower values for OC of 1 % and more, while the proportion of OC values < 1% was properly represented.

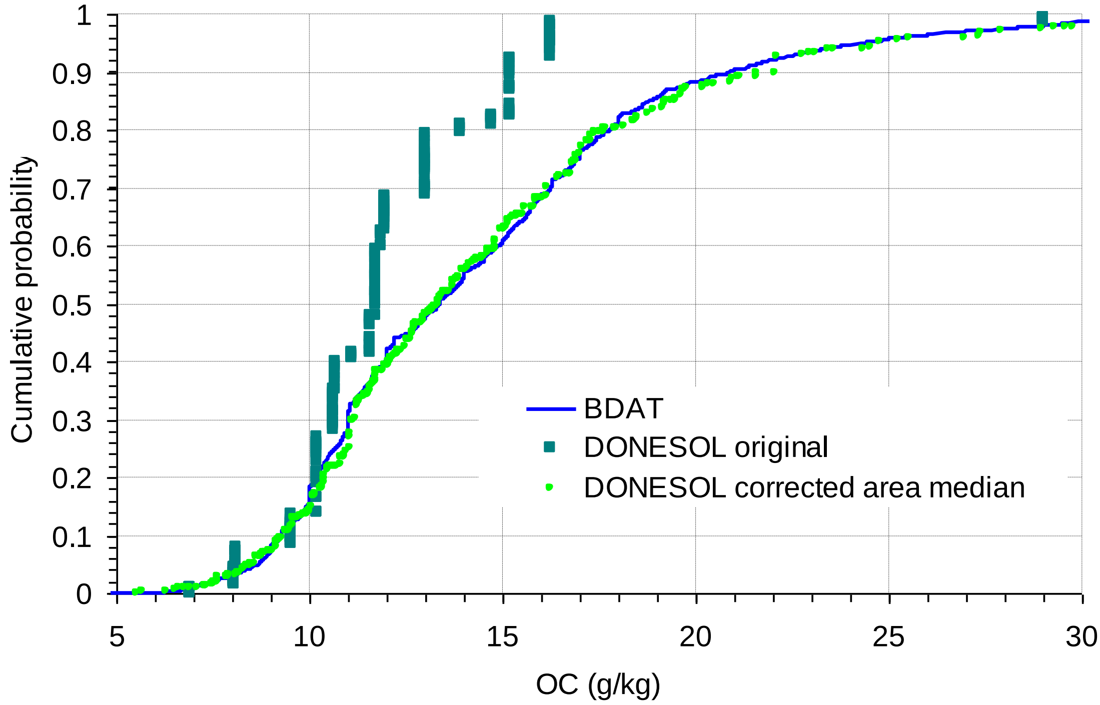

Figure 38 Distribution of topsoil OC for DONESOL soils, derived from BDAT, and INRA soils corrected over all AU.

The BDAT OC data were further compared with European databases suitable to derive OC values for France. The European databases considered were the SPADE 2 (Finke et al., 2001) soil data base and the OCTOP map (Jones et al., 2004). The BDAT OC database was preferred because it comprises much more data than SPADE 2, and because the values were measured and not estimated as is the case for OCTOP. The target area was defined as arable land (nonirrigated and permanently irrigated) in France based on CORINE land cover (ETC, 2000). For comparison the areal median $\%OC_{med}$ were used. For SPADE 2 an OC_{med} value of 1.5 % and for OCTOP an OC_{med} value of 1.6 % were obtained which are similar to OC_{med} = 1.34 % obtained for BDAT (Figure 38). The $\%OC_{med}$ derived from BDAT is thus considered consistent with the other databases. It is slightly lower than the other values and therefore more protective with respect to leaching.

8.2 Estimation of Organic carbon content for subsoil layers

Measured OC content were available in DONESOL for all the selected soil profiles, however for a limited number of soil layers values were missing (soil 8, 20-60 et 60-120 cm; soil 13, 110-130 cm; soil 15, 35-50, 50-100 and 100-110 cm; soil 19, 90-130 cm). Organic carbon content in subsoils may be estimated based on the soil horizon depth according to a PTF derived by Bruand et al., 2006 (personal communication). This function (Equation 2) was derived from available measured data from the region Ile-de-France.

Equation 2: $$c(x) = 0.22 + \frac{1.29 \cdot (e^{-0.028x} - e^{-2.8})}{1 - e^{-2.8}}$$

with x = depth (cm)
c(x) = OC content (%)

The applicability of the PTF to subsoil profiles outside of the region Ile-de-France region still needs to be checked. A comparison of estimated OC content versus measured values for the deeper layers of the 18 selected soil profiles shows that the PTF provides reasonable estimates of the OC content (Figure 39). The ComTox workgroup considered the PTF as acceptable and consequently used it to complete the OC content for the selected soil profiles.

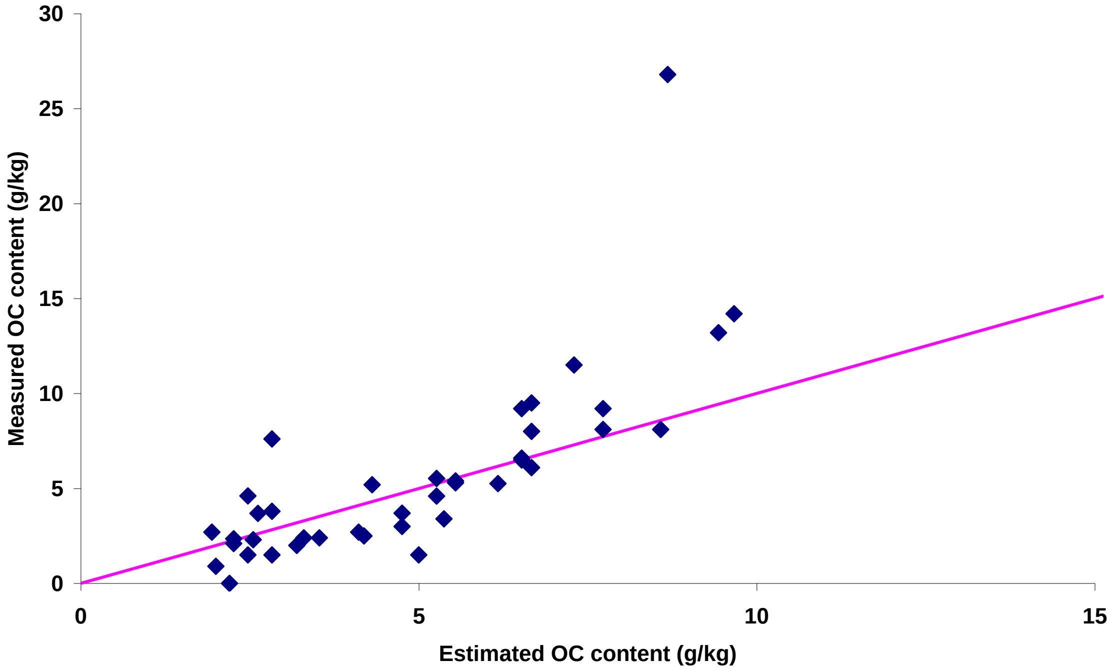

Figure 39 Comparison of OC contents estimated from the soil depth with measured values for the selected soil profiles

8.3 Adjustment of soil pH to BDAT

Degradation rates and sorption properties of some particular pesticides can be substantially influenced by soil pH. For example, the sorption of weak acids is dependent on the pH of the soil and degree of dissociation (Dubus et al., 2001). A corresponding model is implemented in the PEARL program which can be used also in the FROGS system. In case of pH dependent degradation the PEARL model does not provide a comparable module.

For compounds with pH-dependent degradation or sorption, the soil pH may be of equal importance as the soil OC (see section OC correction). The soil pH is depending on a number of environmental factors in addition to soil type such as topography, geology and land use to name only the most important. The soil pH is therefore expected to exhibit substantial spatial variation. For example, Reuter et al. (2008) found a variability, i.e. standard deviation of about 0.6 pH units at field-scale (approximately 3 km) and of about 0.9 pH units at a scale of 50 - 100 km. Thus the 18 soil pH profiles from the DONESOL profile set appeared too few to reliably represent an area roughly as large as the arable land of total France. Note that soil 18 (solonchak) represented less than 0.5 % of the total surface. This soil did not appear representative for any of the selected crops and was therefore not implemented in FROGS as soil scenario.

For the reasons given above it was concluded, as for the topsoil soil OC%, to compare the areal distribution of pH derived from the DONESOL soils selected with corresponding data derived from the comprehensive BDAT (Base de données d'analyses de terre) database (INRA, 2005). In case of major deviations the topsoil pH values were to be adjusted so that they fit the BDAT distribution.

The pH values for the DONESOL soils are given as pH measured in aqueous solution (pH water). Therefore, the pH water values from BDAT were used for consistency and only the pH water is considered in the following. For the PEARL model the type of pH used is irrelevant as long as soil pH type and pH type used for the sorption module are consistent. However, since it is mentioned in the PEARL documentation that pH measured in $CaCl_2$ (pH_{CaCl2}) is preferred, pH_{water} was transformed to pH_{CaCl2} using the transfer functions given in section 8.3.4.

8.3.1 Comparison of Original pH with BDAT

The BDAT values used were denoted as "ph eau" from the time period 2000 -2004. The BDAT data are representative for the uppermost 0.3 m of the soil and are compiled at canton level. The median values at canton level were used ("med : médiane") which can be considered as the most robust values. The spatial resolution of these data is relatively high (2286 cantons in the 31 AU). The area fraction for a specific pH was calculated using the agricultural area (sau: surface agricole utile) per associated canton as given in BDAT normalised to the total agricultural area. The area distribution was finally determined by sorting the cantons by their pH in ascending order and cumulating the area fractions.

Correspondingly, the pH values of the DONESOL soils were calculated for the top 30 cm as was done for OC (section OC correction). For this purpose a depth weighted mean value was calculated in case the first horizon was less than 0.3 m thick, pH(DONESOL soil) = $\Sigma_{i=1,n}(pH_i \Delta z_i) / \Sigma_{i=1,n}(\Delta z_i)$, where n is the number of horizons to reach a depth of 0.3 m, Δz_i is thickness of horizon i in the soil layer from 0 to 0.3 m and $\Sigma_{i=1,n}(\Delta zi)$ = 0.3 m. The area fraction for a specific soil (with specific pH) was calculated using the area fraction in the AU multiplied with the area of the AU, summed up over all AU, and finally normalised to the total area of all AU. The area distribution was finally determined by sorting the soils by their pH in ascending order and cumulating the area fractions (Table 42).

The comparison of the two distributions over all AU shows clearly that there are substantial differences (Figure 40). Especially for low pH (soil 14) a shift of more than one pH unit would be necessary to match the corresponding BDAT value. In contrast to the corresponding OC areal distributions (Figure 38) the pH distributions do not have a similar shape. In case of OC, the original DONESOL soil areal percentiles were consistently higher than the corresponding BDAT percentiles (indicating more soils with lower OC). However, the original DONESOL soil pH areal percentiles are higher for low pH (indicating more acidic soils), lower for neutral soils (e.g. no soils between pH = 6.5 and pH = 7) and similar for alkaline soils compared to the corresponding BDAT probabilities.

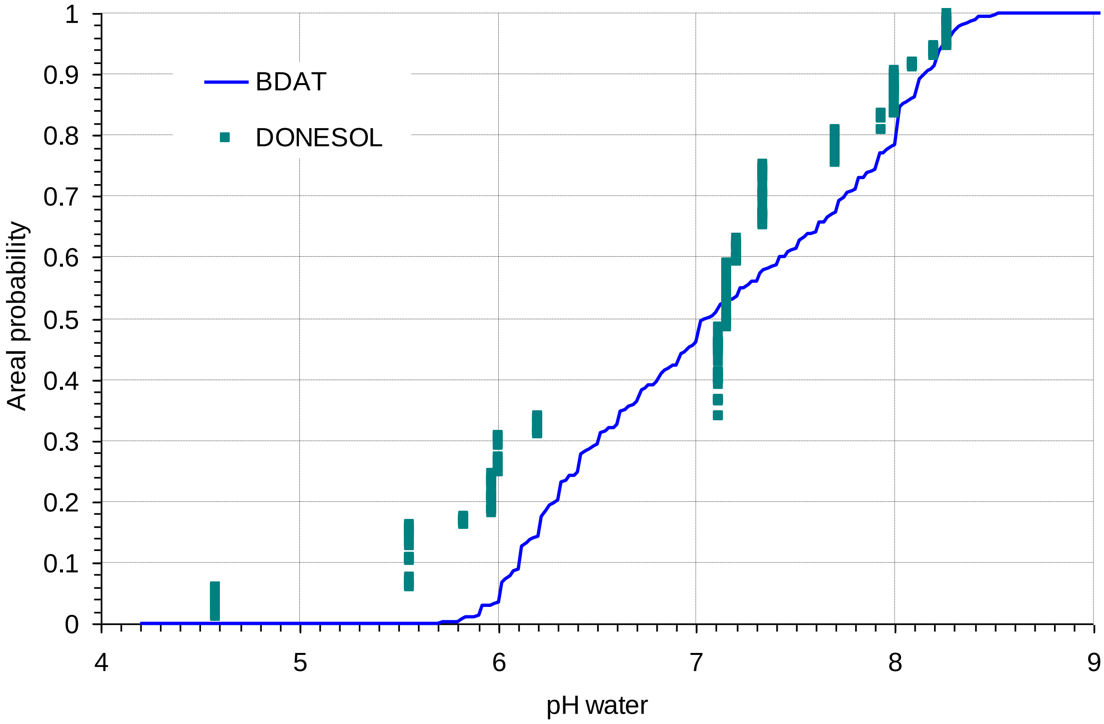

Figure 40 Distribution of topsoil pH for DONESOL soils and derived from BDAT

Due to considerable differences between the two distributions it was deemed appropriate to adjust the topsoil pH values to fit better to the BDAT distribution.

8.3.2 Correction method

In general, a correction method as was applied for OC could have also been applied to pH. This method, however, requires a certain proportionality between the original DONESOL and the reference values (BDAT) which is expressed in the similar shape of the distributions. However this is not the case for the pH (Figure 40). Therefore a different approach was taken which is based on the individual adjustment of topsoil pH per soil as follows.

The areal probabilities or the cumulative relative surface for both distributions are calculated as described in the previous section for total France. Every soil has a given relative surface area f_j and a rank j with regard to pH which is given in Table 42. Then the areal percentile P_A for a specific pH_j is given by $P_A(pH_j) = \Sigma^{j}_{k=1} f_k$.

Table 42 Topsoil pH water for DONESOL soils (weighted mean for 0 - 30 cm) and correction shift derived from BDAT pH water values

Soil Type(No.)	Rank	Relative surface area (%)	Areal percentile P_A (%)	DONESOL pH water	BDAT pH water	pH water correction shift
Podzoluvisol (14)	1	5.9	5.9	4.58	5.94	+1.36
Cambisol (5)	2	10.2	16.1	5.55	6.10	+0.55
Arenosol (19)	3	1.5	17.6	5.83	6.20	+0.37
Luvisol (4)	4	6.8	24.4	5.97	6.30	+0.33
Cambisol (15)	5	6.4	30.9	6.00	6.40	+0.40
Fluvisol (9)	6	3.0	33.9	6.20	6.58	+0.38
Luvisol (1)	7	14.5	48.4	7.12	6.82	-0.30
Cambisol (11)	8	10.7	59.1	7.15	7.20	+0.05
Podzoluvisol (12)	9	3.9	63.1	7.20	7.46	+0.26
Cambisol (2)	10	12.2	75.3	7.33	7.70	+0.37
Cambisol (13)	11	5.4	80.7	7.70	7.98	+0.28
Rendzine (3)	12	2.7	83.4	7.93	8.00	+0.07
Gleysol (10)	13	0.9	84.3	8.00	8.00	+0.00
Fluvisol (8)	14	6.2	90.5	8.00	8.10	+0.10
Rendzine (17)	15	1.4	92.0	8.09	8.18	+0.09
Rendzine (7)	16	1.6	93.6	8.20	8.20	+0.00
Rendzine (16)	17	0.9	94.5	8.20	8.20	+0.00
Rendzine (6)	18	5.5	100.0	8.27	8.30	+0.03

For example, DONESOL soil 14 (podzoluvisol) has a pH of 4.58 which is the lowest pH of the profile set (rank = 1) and has a relative surface area f_1 = 5.9 % and P_A = 5.9 %. Because the BDAT distribution represents much more pH values it is much smoother than the DONESOL pH distribution and a representative pH value has to be selected for 0 % < P_A < 5.9 %. For this purpose the class centre between the lower and upper areal percentile, 0.5 × ($P_A(pH_{j-1}) + P_A(pH_j)$), of the DONESOL pH distribution is selected which leads to a good adjustment of both distributions. So for pH of rank 1 the BDAT pH value is obtained as the one for which P_A = 0.5 × (0 % + 5.9 %) = 2.95 % leading to pH = 5.94. For soil 5 with pH rank 2, f_2 = 10.2 % and P_A = 10.2 % + 5.9 % = 16.1 %. The corresponding BDAT pH for which P_A = 0.5 × (5.9 % + 16.1 %) = 11.0 % yields a value of pH = 6.1. This procedure is applied to all soils and finally the correction is defined by the shift which represents the difference between DONESOL and BDAT pH for the specific P_A (Table 42). A comparison between the original DONESOL, BDAT and adjusted to BDAT pH distribution is shown in Figure 41.

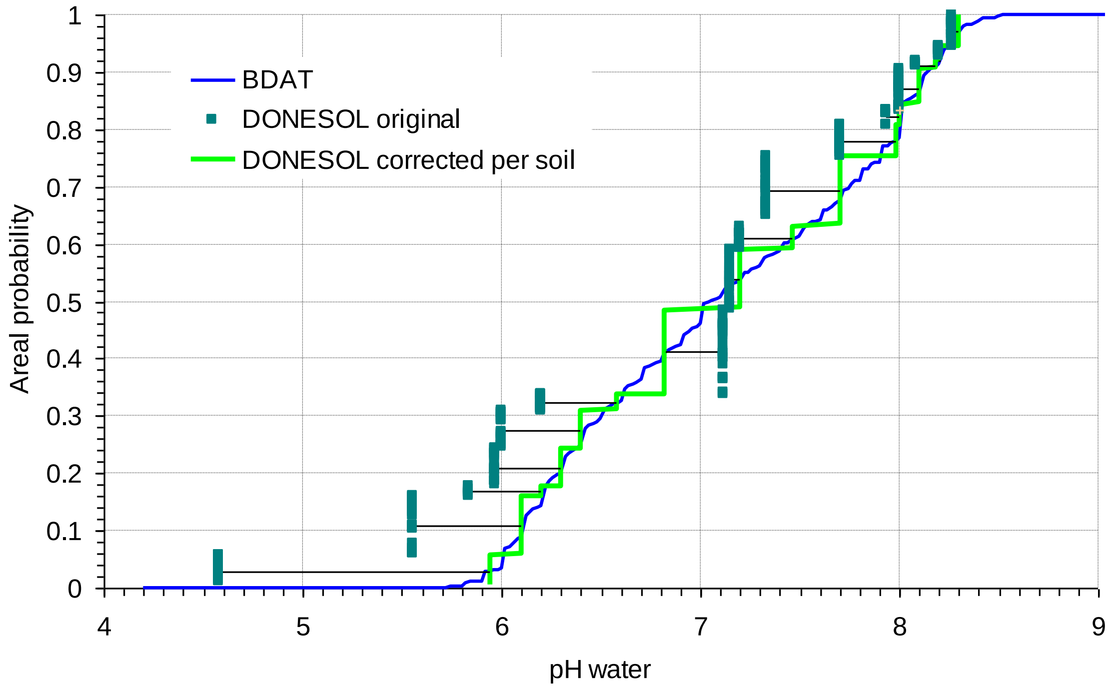

Figure 41 ***Distribution of topsoil pH for DONESOL soils, derived from BDAT and DONESOL soil corrected. The vertical position of horizontal lines indicates the reference areal probability for the correction and its length indicates the magnitude of the correction.***

Inspection of Figure 41 shows that the correction proposed leads to a good approximation of the BDAT distribution.

In general an adjustment at AU level would be also possible which could provide an even better approximation of the BDAT data at regional scale. This would lead to individual corrections at AU level which, due to the smaller spatial scale, would potentially require considering not only median values but also other percentiles. To assess the necessity of such a more complex approach, the representation of individual AU by the proposed correction was considered. If the representation is sufficient a refined approach would not be required. For this purpose the range of corrected pH (the soil with min. and max. pH after the correction) was compared to the inner 90^{th} areal percentile (5^{th} and 95^{th} areal percentile) of the canton median pH for individual AU (Figure 42). The result of this comparison is that the range of pH values within a specific AU as given by BDAT is well represented by the range of topsoil pH obtained after the correction described above. Although a correction at AU level would probably lead to a better representation, the increase in accuracy is not expected sufficiently significant to justify the additional effort to derive a correction at AU level.

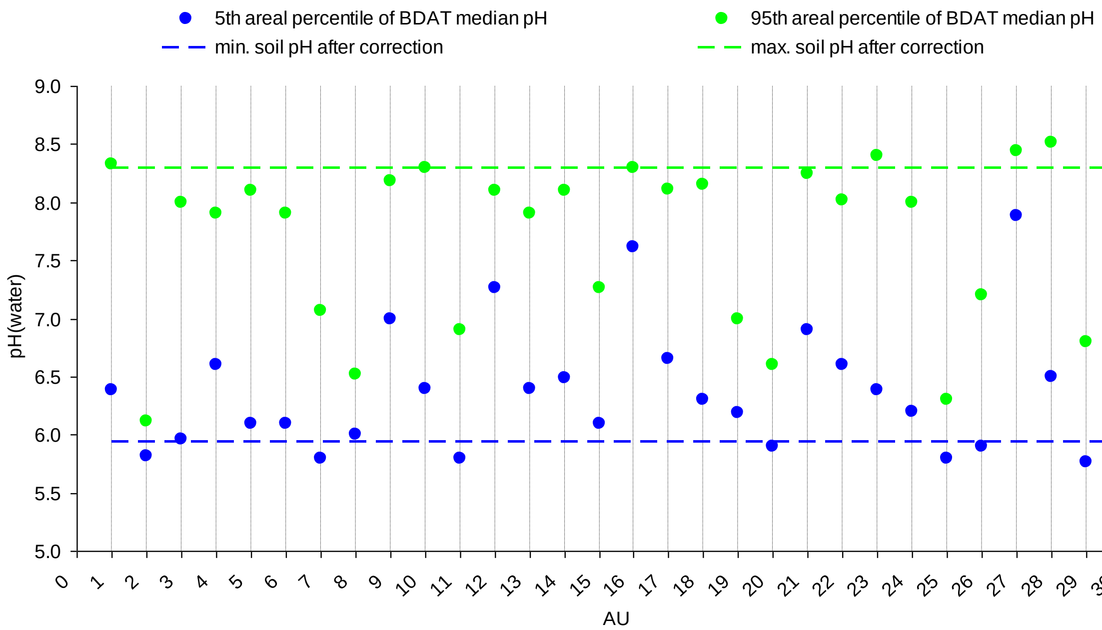

Figure 42 ***Comparison between 5th and 95th areal percentile of the BDAT canton median topsoil pH for individual AU (Agronomic Units) and topsoil pH after proposed correction (min. and max. pH after the correction).***

For soil 14 a major correction by +1.36 pH units is necessary, for soil 5 a medium correction by +0.55 pH units is obtained. For the other soils the correction is moderate to minor, ranging form -0.3 to +0.4 pH units. Because the correction for soil 14 is relatively large, the BDAT 10th percentile pH values were considered. These indicate the variability of pH at canton level. If this variability is large compared to the variability over all cantons, the surface area of soils with pH far below the median could have been underestimated. However, a pH of 4.58 as for soil 14 (weighted mean for 0 - 30 cm) is practically not found in the BDAT data even as 10th percentile (P_A < 0.000001 %, corresponding to 1 canton). A pH of 5.55 as for soil 5 or lower representing a 10th percentile at canton level is found for 18 % of the total surface area, i.e P_A = 18 %. Presuming that the 10th percentile pH of a canton represents approximately 10 % of the surface area, the total relative surface area with pH ≤ 5.55 is only 10 % of 18 % which is 1.8 %.

Therefore it was concluded that the correction described above is appropriate to adjust the original topsoil pH of the DONESOL soils to the reference values derived from the BDAT database. The relatively large correction for soils 14 and 5 based on median values at canton level was confirmed by consideration of the distribution within cantons (10th percentile values).

8.3.3 Correction of pH for subsoil layers

Generally, the pH values for the subsoil of the selected DONESOL soil profiles are relatively similar to the value in the topsoil. There is also a tendency that the pH slightly increases with depth for most of the soils (13 of 18) which is consistent with the expectation due to soil genesis. Normally progressing formation and development of a soil leads to acidification because cations released by weathering are leached from the profile. Because soil formation takes place from top to bottom, cation leaching and acidification is more intense at the top and decreasing with depth. To conserve this natural gradient in soil pH and to not introduce artificial pH skips from topsoil to subsoil it is considered most appropriate to apply the same correction to the subsoil pH as was applied to topsoil pH.

8.3.4 Relation between pH measured in Different Solutions

Soil pH values are typically measured in different solutions (e.g. water, 1 M KCl, 0.01 M $CaCl_2$). Thus the situation may occur that the dependency of sorption for a specific compound is defined, for example, in terms of pH measured in $CaCl_2$ solution (pH_{CaCl2}). However, FROGS soil pH values are given in terms of pH measured in aqueous solution (pH_{water}). In order to transform pH values obtained in different solutions it is recommended to use the pedotransfer function developed and validated by Reuter et al. (2008) given as :

$$pH_{water} = (pH_{CaCl2} + 0.427) / 0.9761 \quad (R^2 = 0.92, n = 1997)$$

$$pH_{CaCl2} = 1.0572 \times pH_{KCl} + 0.123 \quad (R^2 = 0.90, n = 377)$$

The following order is obtained, $pH_{KCl} < pH_{CaCl2} < pH_{water}$.

Since in PEARL 3.3.3 pH_{CaCl2} –values are preferred, the corrected pH_{water}-values are transformed to pH_{CaCl2} –values by the first of the above equations.

The FOCUS ground water group (FOCUS, 2009) has decided to make the pH_{water} values of the FOCUS groundwater scenarios available electronically because most of the values provided for the soil profiles were pH_{water} values (FOCUS, 2000). For FROGS the already integrated pH_{CaCl2}-values were not changed since pH-values measured in 0.01 M $CaCl_2$ are considered to better represent the electrolyte background solution prevailing in standard batch sorption experiments according to the soil sorption test guidance OECD 106 (0.01 M $CaCl_2$ at a soil to solution-ratio of 1:5) and also to be more representative for the background cation concentration in soil water under natural conditions. According to McBride (1994) the measurement of soil pH in a salt solution such as 0.01 M $CaCl_2$, the the so-called suspension effect, leading to misinterpretation of soil pH-measurements, is suppressed.

Examples for the correction of pH_{water} and its conversion to pH_{CaCl2} are given for the first layer of each selected soil profile in Table 43. The pH_{CaCl2} values are the values finally implemented in the FROGS-database.

Table 43 pH-correction and conversion examples for the first layer of each soil

SID	HID	pH_{water} (DONESOL)	Shift	pH_{water} (corrected)	pH_{CaCl2} (corrected)
1	1	7.10	-0.30	6.80	6.21
2	1	7.40	0.37	7.77	7.16
3	1	7.90	0.07	7.97	7.35
4	1	5.80	0.33	6.13	5.56
5	1	6.00	0.55	6.55	5.97
6	1	8.20	0.03	8.23	7.61
7	1	8.10	0.00	8.10	7.48
8	1	8.00	0.10	8.10	7.48
9	1	6.20	0.38	6.58	6.00
10	1	8.00	0.00	8.00	7.38
11	1	6.80	0.05	6.85	6.26
12	1	7.20	0.26	7.46	6.85
13	1	7.80	0.28	8.08	7.46
14	1	4.20	1.36	5.56	5.00
15	1	6.00	0.40	6.40	5.82
16	1	8.20	0.00	8.20	7.58
17	1	8.00	0.09	8.09	7.47
19	1	5.80	0.37	6.17	5.60

8.4 Soil bulk density

Bulk density measurements were not available for the selected DONESOL2 profiles since there are few measurements for this parameter in DONESOL2. It therefore needed to be estimated since bulk density is an input parameter in PEARL and in addition it is required for estimation of the Mualem-van Genuchten parameters.

Bollen et al., 1995 proposed a PTF to estimate dry bulk density from the content of organic matter (Equation 3).

Equation 3: $$\rho_d = 1800 + 1236 \cdot m_{om} - 2910 \cdot \sqrt{m_{om}}$$

with ρ_d: bulk density (kg/m^3)
m_{om} (kg/kg): organic matter content, $m_{om} = 1.724\ m_{oc}$
m_{oc} (kg/kg): organic carbon content

This PTF is already used in the PEARL model. However, it was derived from measured data in Dutch soils only and applicability to French soils needed to be checked. The PTF was therefore tested on a variety of topsoils and subsoils from the SOLHYDRO database, for which bulk density measurements are available (Table 44).

The SOLHYDRO measured data were also compared to the average bulk density values per soil texture classes published by Bruand et al. (2004). On the tested topsoil and subsoil horizons, the continuous PTF of Bollen et al. (1995) provided reasonable estimates of the measured bulk density and performed better compared to the average of soil class approach, with a mean error (estimated value / measured value) of 5.7% for topsoils and 3.3% for subsoils. The workgroup therefore considered the continuous PTF as acceptable and consequently used it to derive dry bulk density for all soil layers in the selected DONESOL2 soil profiles.

The PTF used for estimating soil density is based on the OM content. For 7 of the subsoil layers the OC content was itself estimated with a PTF (see section 8.2). While this is not ideal, it was necessary as neither parameters were available for these 7 subsoil layers. For all topsoil layers and for a majority of the subsoil layers, the measured OC content was available and used. The few estimated OC contents were consistent with the available data for the other layers. No significant impact is therefore expected from the double estimate in the few layers for which OC measurements were not available.

Table 44 Characteristics of the 16 soils from the SOLHYDRO database used for comparison of estimated Vs measured dry bulk density

Texture class*	Horizon	% clay	% silt	% sand	%OC	ρ_d (g/cm^3)
			Topsoil horizons			
AL	A	40.9	57.1	2.0	1.55	1.500
AL	A	38.9	56.7	4.4	1.67	1.321
ALO	A	48.9	31.4	19.7	1.60	1.323
LA	A	24.8	68.9	6.3	1.24	1.373
LM	A	15.4	80.3	4.3	0.74	1.588
SA	A	18.6	12.5	68.9	1.15	1.670
SA	A	13.4	16.7	69.9	0.84	1.436
SL	A	10.0	15.6	74.4	0.81	1.380
			Subsoil horizons			
AL	B	32.3	64.0	3.7	0.37	1.583
ALO	B	53.1	20.4	26.5	0.38	1.613
AS	B	26.5	8.2	65.3	0.31	1.605
LA	B	28.9	68.7	2.4	0.25	1.583
LA	B	20.1	75.9	4.0	0.35	1.554
SA	B	14.3	16.1	69.6	0.41	1.722
SL	B	9.6	16.3	74.1	0.27	1.770
S	E	4.3	10.4	85.3	0.38	1.580

*According to classification of Jamagne et al. (1967), AL=loamy clay, Alo=heavy clay, AS=sandy clay, LA=clay loam, LM=loam, SA=clay sand, SL, loamy sand, S=sand

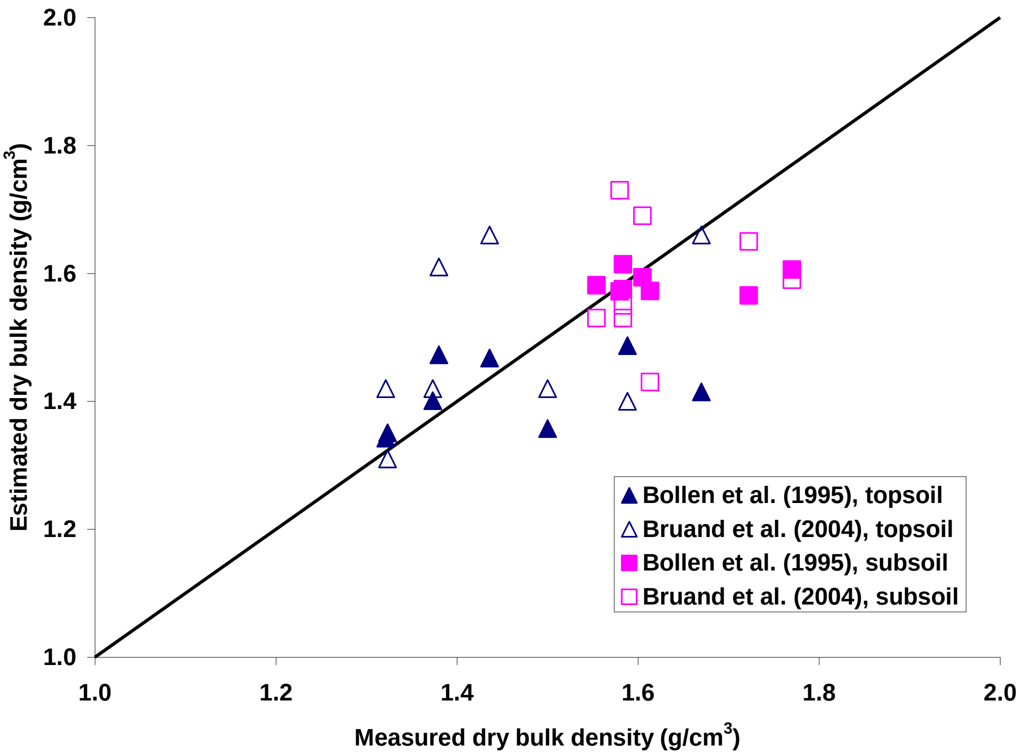

***Figure 43** Comparison of bulk density estimated according to Bollen et al. (1995) and mean bulk density by class according to Bruand et al. (2004) with measured bulk density for 16 different soil horizons*

8.5 Soil hydrological parameters

The hydrological properties of the soils are described in PEARL according to the Mualem - van Genuchten functions (van Genuchten, 1980) (Equation 4 to Equation 6).

Equation 4: $$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha|h|)^n\right]^m}$$

Equation 5: $$K(h) = K_s S_e^{\lambda}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2$$

Equation 6: $$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$ (relative water saturation)

With the following hydrological parameters:

- Residual volumetric water content, θ_r (m^3/m^3)
- Saturated volumetric water content, θ_s (m^3/m^3)
- α (alpha parameter)
- n et m (exponent parameters), with m = 1-1/n in the form of the Mualem - van Genuchten functions used in PEARL
- λ (lambda parameter)
- Saturated hydrolic conductivity, K_s (m/d)

These parameters are best estimated by fitting of measured θ (h) and K (h) curves for the soil of interest, however θ (h) and K (h) measurements are in many cases not available and a number of PTF have been derived to estimate these parameters. Among the most commonly used PTF for parameterization of scenarios for groundwater modeling are the following three models:

1/ **Rosetta version 1.2** (Riverside USDA Salinity Laboratory, United States, Schaap et al. 2001) is a hierarchical model using textural class, textural distribution, bulk density and one or two water retention points as input parameters. There is no differentiation in the model between topsoil and subsoil horizons. The PTF were derived from an array of soils, mostly originating from the US, but also containing some EU soils.

2/ **HYPRES** (Wösten et al, 1999) propose class and continuous PTF using bulk density, textural distribution and organic matter content as input parameters. A correction factor is included for subsoil horizons. The PTF were derived from an array of European soils, mostly originating from Germany, but also containing some French soils.

3/ **Vereecken** et al (1989) proposed continuous PTF using bulk density, textural distribution and organic matter content as input parameters. There is no differentiation in the model between topsoil and subsoil horizons. The PTF were derived from Belgium soils exclusively. One should note that in this model, the parameter m is set to 1 as opposed to 1-1/n in the other PTF and in the PEARL model (different form of the Mualem – van Genuchten functions). Revised PTF based on the Vereecken database were published in 2009 (Weynants et al., 2009) among other things constraining m to 1-1/n.

These PTF were all derived by more or less complex regression analysis on a selection of soils for which θ (h) and K (h) had been measured and the Mualem – van Genuchten parameters estimated from these measured θ (h) and K (h) curves. In all three cases, the regression coefficients for some of the parameters were relatively low, indicating that the PTF cannot be expected to perform well for all soils. In addition, these PTF are most representative of the soils used in the respective regression analyses (mostly US soils for Rosetta, mostly German soils for HYPRES, and exclusively Belgium soils for Vereecken) and applicability to other soil types needs to be checked.

The workgroup tested the Rosetta, HYPRES continuous, original Vereecken and revised Vereecken PTF against 16 French soils from the SOLHYDRO database, for which bulk density, textural distribution, organic matter content and water content at different pressure heads (pF1, 1.5, 2, 2.5, 3, 3.5 and 4.2) had been measured (Table 2). These 16 soils (8 topsoils and 8 subsoils) were selected to represent a variety of soil types, from sand to heavy clay.

The Mualem-van Genuchten parameters were estimated for each soil with the 4 selected PTF models, then the respective θ (h) curves were calculated with the estimated Mualem-van Genuchten parameters, and finally these were plotted against the measured water content at different pressure heads. The calculations were performed twice, first with the measured soil bulk density, and second with the estimated soil bulk density calculated according to Bollen et al., 1995 (see above), to check the impact of the estimation of the bulk density on the estimation of the hydrological parameters.

The respective quality of fit of the θ (h) curves was evaluated for the different PTF models using a statistical chi-square (χ^2) test. The χ^2 test considers the deviations between observed (measured) and calculated values in relation to the uncertainty associated to the measurements. The uncertainty associated to the measured θ (h) from the SOLHYDRO database is not known, but the χ^2 test is used here to compare the different PTF models, by determining the minimum error percentage for which the test is passed for each PTF.

The χ^2 is calculated according to Equation 7.

Equation 7: $$\chi^2 = \sum \frac{(C - O)^2}{(err / 100 \cdot \overline{O})^2}$$

with C = estimated value, O = observed value, $\overline{O}$ = mean of observed values, err = error percentage associated to measurements

If χ^2 > tabulated $\chi^2_{m,\alpha}$, then the model is not appropriate according to the selected significance level.

with m = levels of freedom, α = probability to obtain χ^2 superior or equal by chance

The tabulated $\chi^2_{m,0.05}$ for a selected significance level of 5% are obtained in Excel 2000 using the CHIINV(α,m) function. The minimum error percentage (err) for which the test is passed is determined according to Equation 8.

Equation 8:

$$\text{err} = 100 \cdot \sqrt{\frac{1}{\chi^2_{m,\alpha}} \cdot \sum \frac{(C-O)^2}{\overline{O}^2}}$$

For a given soil, the PTF model that best predicts the measured θ (h) is the one which gives the lowest minimum error percentage.

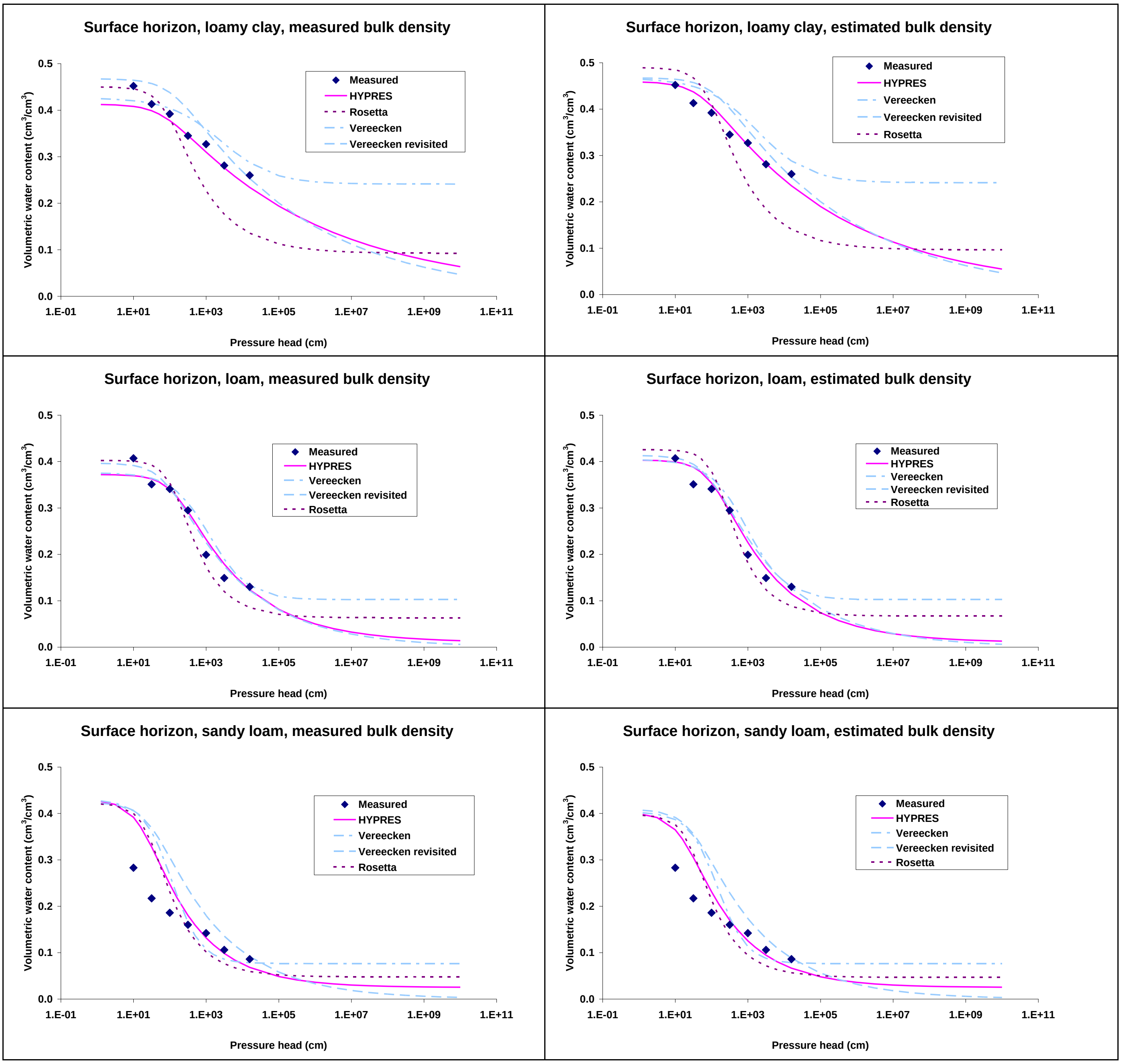

***Figure 44** Comparison between measured θ(h) and θ(h) estimated with Rosetta, HYPRES, Vereecken and revisited Vereecken PTF for 3 soil types from loamy clay, loam and sandy loam topsoils, considering measured bulk density (left figures) and estimated bulk density (right figures)*

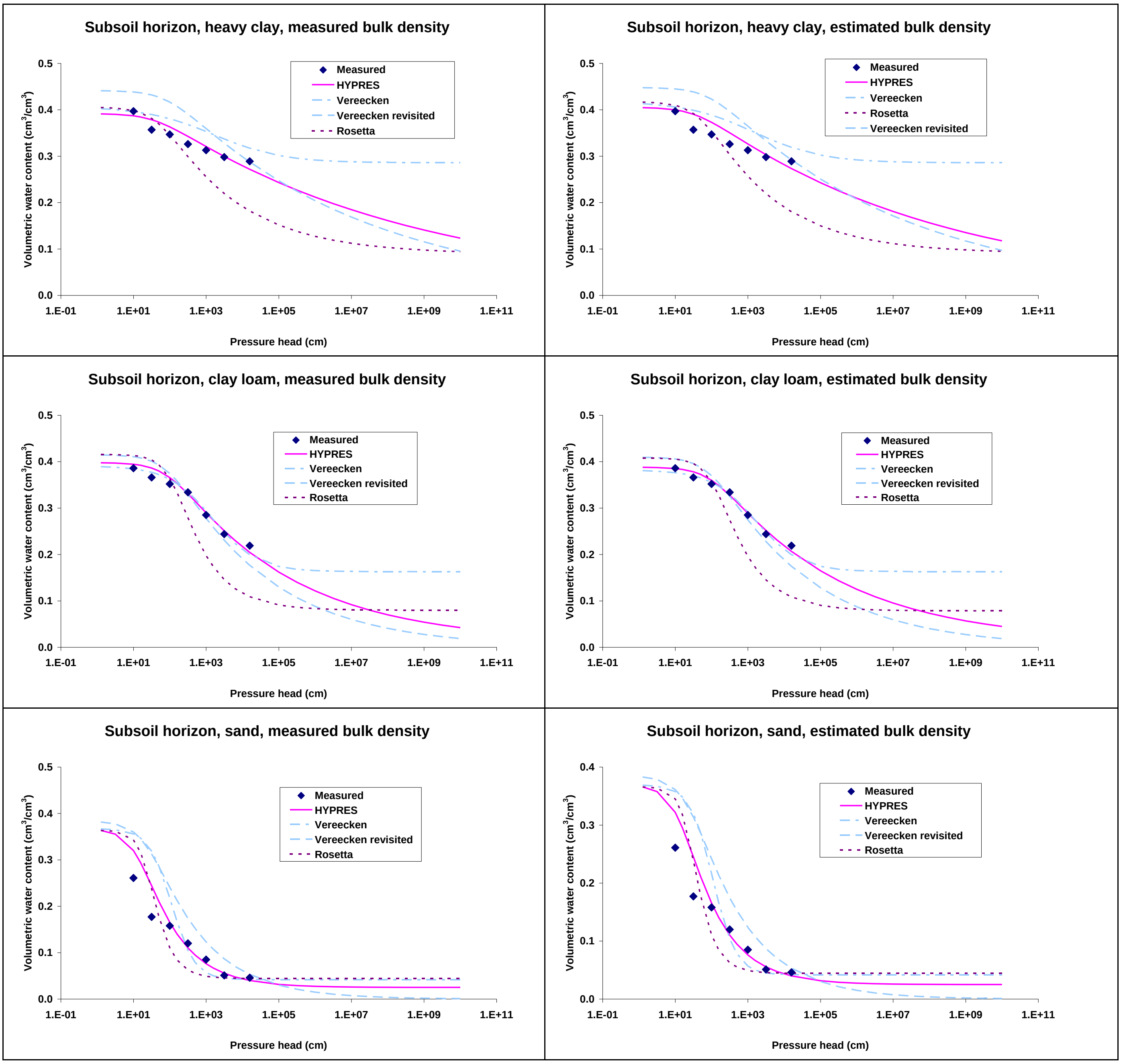

***Figure 45** Comparison between measured θ(h) and θ(h) estimated with Rosetta, HYPRES, Vereecken and revisited Vereecken PTF for 3 soil types from heavy clay, clay loam and sand subsoils, considering measured bulk density (left figures) and estimated bulk density (right figures)*

Not surprisingly, none of the 4 tested PTF is able to estimate perfectly the water retention curves of the 16 different soils. Nevertheless, it is evident from the fits shown in Figure 44 and Figure 45 as well as the minimum Chi^2 errors listed in Table 45 that HYPRES performed better than the other PTF, especially regarding subsoils. In general, the Vereecken and Rosetta PTF did not provide satisfactory description of the retention curves, although the revisited Vereecken performed much better than the original Vereecken PTF. The minimum Chi^2 error values were higher for sandy soil types compared to soils of finer texture, for topsoils as well as for subsoils. The use of bulk density values estimated according to Bollen et al. (1995) as opposed to measured bulk density had little impact on the description of the water retention curves.

Similar investigations regarding the estimation of conductivity were not performed since measured conductivity curves were not available for the selected soils, and would be more difficult to evaluate. Measurements of the saturated conductivity are particularly complex, since this parameter is known to be highly variable in space (even at the field scale) as well as in time (seasonal variations) and depending on the soil workup (disturbed Vs undisturbed).

Based on these conclusions of the comparative PTF test on the θ (h) curves, the workgroup decided to use the HYPRES PTF for estimation of all the Mualem-van Genuchten parameters. In addition, the HYPRES PTF have the following advantages compared to the other tested PTF:

- the HYPRES model provides better soil representativity, since these PTF were derived from a European database containing a number of French soils, even though the majority of soils were from Germany (Rosetta is based on US soils exclusively and Vereecken is based on Belgian soils);

- the HYPRES model is the only one that differentiates between topsoil horizons and subsoil horizons, with the use of a correction factor for subsoils;

- the HYPRES PTF are fully in line with the Mualem-van Genuchten functions as used in PEARL and MACRO, when the original Vereecken PTF were based on a different expression of the parameter m.

One should note that these PTF for the description of the water retention curve, although based on the same equations used in the Richards-based models (PEARL and MACRO), would also be valid for the reservoir-based models (PRZM and PELMO) since these models require as input parameters water contents at different pressure heads, which would also need to be estimated.

All relevant hydraulic parameters estimated with HYPRES for the different soil-types are listed in Appendix 17.

***Table 45** Minimum Chi^2 error (in %) obtained for the comparison of measured $\theta(h)$ versus $\theta(h)$ estimated with Rosetta, HYPRES and Vereecken PTF*

Soil texture*	**HYPRES**		**Vereecken**		**Revisited Vereecken**		**Rosetta**	
	Measured ρ_d	**Estimated ρ_d**	**Measured ρ_d**	**Estimated ρ_d**	**Measured ρ_d**	**Estimated ρ_d**	**Measured ρ_d**	**Estimated ρ_d**
Topsoil horizons								
AL	4.4	3.3	6.2	8.5	4.2	7.2	14.9	14.5
AL	8.3	7.5	13.9	13.3	12.8	12.2	16.3	16.0
ALo	8.0	7.0	14.5	13.8	15.5	14.8	14.6	14.3
LA	9.5	8.5	12.6	11.7	12.0	11.2	17.3	16.7
LM	6.0	5.5	7.9	8.2	5.0	6.7	8.0	9.4
SA	17.3	18.3	10.7	17.7	12.9	17.6	17.4	22.5
SA	19.4	17.8	26.5	25.6	30.9	29.7	24.1	22.7
SL	26.8	20.8	33.2	30.9	39.0	35.1	28.8	24.3
Subsoil horizons								
AL	4.1	4.3	4.3	4.5	6.2	6.4	15.0	15.0
ALo	3.1	4.3	7.1	8.3	11.2	12.3	12.0	12.2
AS	18.8	18.7	10.1	10.2	9.7	9.7	15.8	15.9
LA	2.7	1.9	2.3	2.0	5.7	5.4	15.9	15.9
LA	7.3	6.8	6.0	5.5	6.8	6.1	11.4	11.1
SA	6.5	11.4	12.5	17.8	16.4	21.7	11.0	16.9
SL	11.1	17.7	20.9	27.6	24.9	31.7	13.6	21.2
S	18.9	19.3	38.2	38.4	42.0	42.4	27.3	27.7

*According to classification of Jamagne et al. (1967), ALo = heavy clay, AL = loamy clay, AS = sandy clay, LA = clay loam, LM = loam, SA = clayey sand, SL = loamy sand, S = sand

8.6 Soil lower boundary conditions

The PEARL input file parameter OptLbo determines which type of boundary condition is used by the hydrological model SWAP for the bottom of the soil profile. For all FROGS scenarios the value of OptLbo is set to FreeDrain (= free drainage). This case assumes unit gradient at the lower boundary (flux equals unsaturated conductivity of lowest soil layer).

In addition, in order to avoid boundary effects on the model simulations, the last soil horizon of each of the soil profiles as listed in Table 35 was artificially extended to 200 cm in FROGS, similar to what was done in the standard European FOCUS scenarios. This extension of the deepest soil layer is reflected in Appendix 17. The output concentrations for the evaluation are calculated at the bottom of the soil profile as listed in Table 35. This means that for each soil the lower boundary of the deepest horizon describes the target depth for risk assessment. FOCUS (2009) decided to limit the maximum rooting depth to the FOCUS groundwater target depth of 1 m. For the field crops parameterized in FROGS, maximum root density was already limted to 1 m so that this parameter did not need to be changed.

8.7 Soil numerical layers

For setting up the numerical layers/compartments for the selected soil profiles in PEARL, a similar resolution as in the FOCUS-chateaudun scenario in PEARL 3.3.3 was used. This means 2.5-cm numerical layers/compartments from 0 to 50 cm depth, 5-cm numerical layers from 50 to 100 cm depth and 10-cm layers/compartments for depths >100 cm. In addition, a high resolution of 1-cm numerical layers/compartments was added for about 10 cm around the target depth (bottom of the soil profiles as listed in Table 35).

These basic rules for the resolution were applied to all soils, but relaxed to overcome the following three limitations:

1) The boundaries of the horizons in the selected soil profiles are often overlapping the depths of 50 cm or 100 cm. Hence, in some instances the resolution was changed earlier or later than 50 or 100 cm to better match the horizon boundaries.
2) It is not always possible to reach the wished resolution with an integer as layer number. For example in Soil 3 the last horizon has a depth of 0.95 m. To reach a resolution of 10 cm the number of layers must be 9.5. Instead, the layer number was set to 10, yielding a resolution of 9.5 cm.
3) In SWAP 3234 the ratio of horizon depth and number of numerical layers in the respective horizon is not allowed to result in an irrational number and the sum of of each layer’s depth over a horizon must exactly equal the horizon’s depth taking into account the defined accuracy of 4 decimal places. To account for these new requirements of SWAP 3234, the number of layers in some cases had to be slightly adjusted without having significant impact on the water balance. Finally the number of soil compartments must be chosen so that the distance between two nodal points is smaller than two times the dispersion length.

The selected numerical resolutions of the soil layers are listed in the tables of Appendix 17.

8.8 Biodegradation factor

For setting up the biodegradation factor in PEARL for the adjustment of the degradation rate with soil depth, similar rules as in the FOCUS scenarios were used. Between 0-30 cm, a biodegradation factor of 1 is applied, between 30-60 cm the biodegradation factor is 0.5, and between 60-100 cm the biodegradation factor is 0.3.

The target depth in FOCUS is 1 meter, so no degradation is considered in the FOCUS scenarios below 100 cm. In contrast, the target depth in FROGS is at the bottom of the soil profiles, which ranges from 40 to 140 cm. For those soils extending beyond 100 cm, the biodegradation factor was set to 0.15 below 100 cm, since there are no indications that degradation stops abruptly at 100 cm and organic carbon is observed down to the very bottom of the profiles, which is interpreted as indication of biological activitiy. It was therefore assumed that the degradation is indeed substantially lower (half of the biodegradation factor between 60-100 cm) but not zero.

8.9 Adjustment of ponding depth and max. number of iterations

As already stated in section 5.4, the new SWAP version 3234 was able to run through all scenarios without any model failures and splitting of heavy rainfall events over several days is not necessary any more. Creating the bfo-files with SWAP 3234 the former amendmend to the parameter “Maximum Ponding Depth” (value set to 0.005 m instead of default FOCUS-PEARL value of 0.002 m) was kept wheras the maximum number of iterations was reset to the default value as employed in PEARL 4.4.4 of 30 (maximum number in PEARL 4.4.4 for this parameter is 100). In FROGS 2.2.2.2 this parameter was increased to 1 000 000.

Since the adjustments applied to all scenarios (not only to the originally failing ones) it has to be shown that the changes do not influence the PECgw values significantly. For testing a relatively mobile substance was used (Sub1: DT50 = 50 days, kom = 10 L/kg).

The Figure 46 and Figure 47 below are copied in from the FROGS 2.2.2.2 report (FROGS, 2011; p. 139 & 140) as it was already demonstrated for the previous version of FROGS that the effect of the described changes was marginal:
Figure 46 (all crops) and Figure 47 (winter oilseed rape only) show that no large differences between the areal distributions of the PEC values can be observed for those runs which execute with normal parameterization and with adjustments. Hence, it can be concluded that no significant influence of the adjustments on the PECgw values exist. On average the PECgw values increase with the adjustment by 0.1% for all crops and 0.09% for winter oilseed rape only.

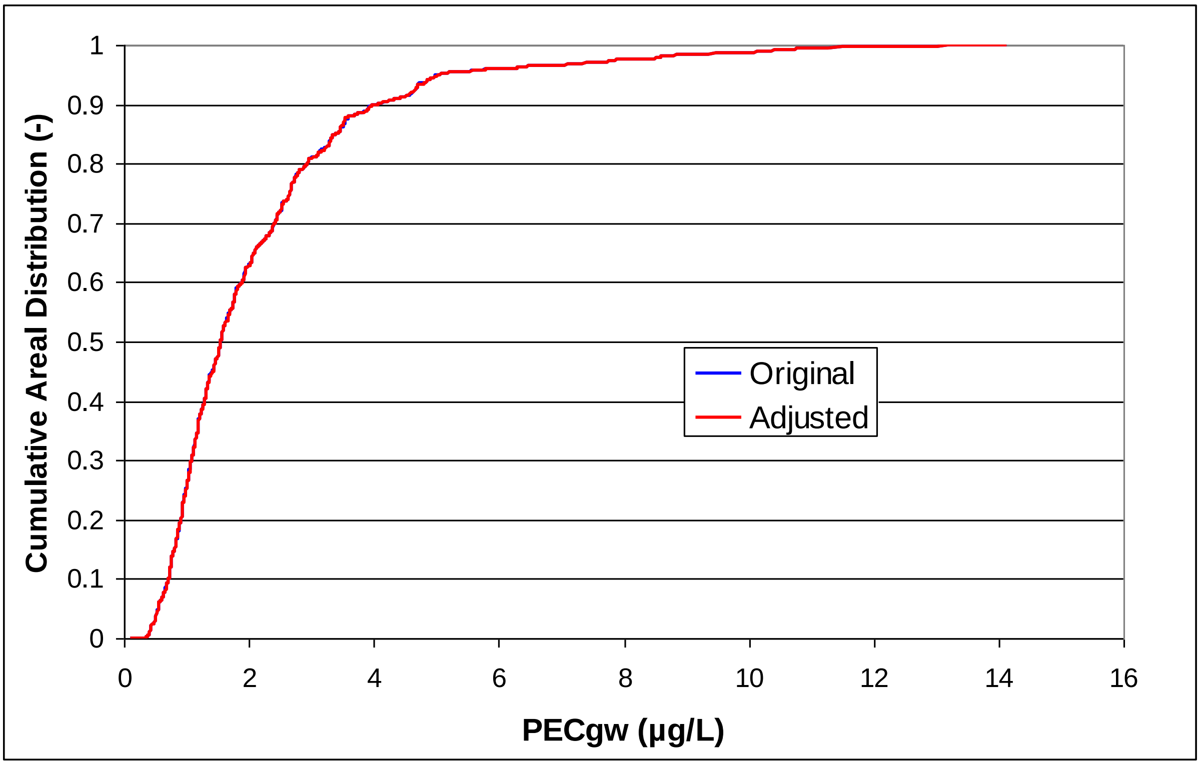

Figure 46 ***Cumulative areal distributions of the PECgw values obtained with FROGS 2.2.2.2 from the "Original" parameterization and the parameterization with adjusted iterations and maximum ponding depth ("Adjusted") for all crops to exemplarily demonstrate the rather low impact of the changes. It is noted that the maximum number of iterations in FROGS 3.3.3.3 was reset to the FOCUS-PEARL default value of 30. To be comparable for both curves only those scenarios are included, which succeeded with both parameterizations.***

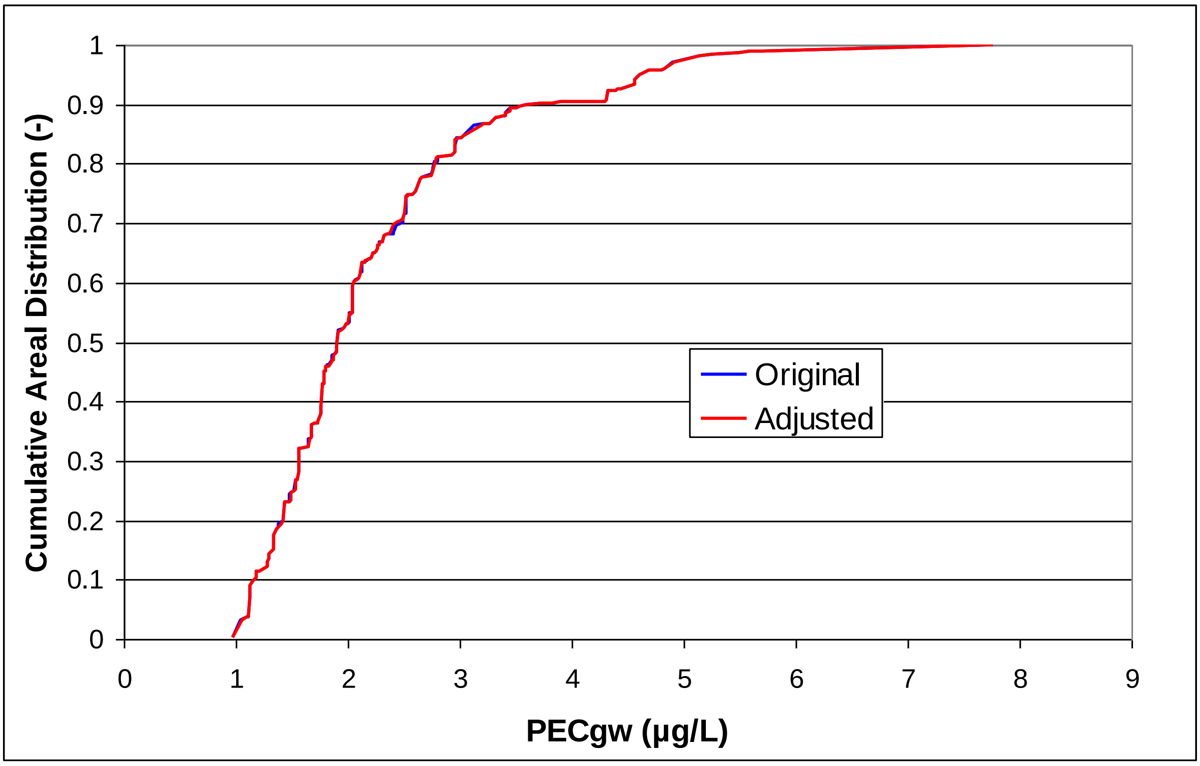

Figure 47 ***Cumulative areal distributions of the PECgw values obtained with FROGS 2.2.2.2 from the "Original" parameterization and the parameterization with adjusted iterations and maximum ponding depth ("Adjusted") for winter oilseed rape to exemplarily demonstrate the rather low impact of the changes. It is noted that the maximum number of iterations in FROGS 3.3.3.3 was reset to the FOCUS-PEARL default value of 30. To be comparable for both curves only those scenarios are included, which succeeded with both parameterizations.***

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9 Selection of relevant output for national assessment

9.1 European Regulatory Framework

The target protection goal at EU level is a maximum annual average concentration in groundwater of 0.1 µg/L for active substances and relevant metabolites considering an overall 90th percentile vulnerability of scenarios (FOCUS, 2000). This should take into account spatial variability (e.g. of soil conditions) and temporal variability (inter-annual variability of the weather conditions) over the simulation period. The overall 90th percentile can be approximated by taking the spatial 80th percentile and the temporal 80th percentile. This protection goal is also recommended for assessment at national level in the new FOCUS groundwater report (FOCUS, 2009).

For applications every other year or every three years (as is the case for most FROGS-rotations), it is recommended in FOCUS (2000) and confirmed in FOCUS (2009) to calculate flux-weighted average values over the rotation period for a total simulation period of 20 rotations (i.e. 40 years for applications every other year and 60 years for applications every three years, plus 6 years of warm-up period) and then select the 80th percentile of these 20 values. As in FROGS 3.3.3.3 4-year crop rotations were implemented, the analogue rule applies also in this case so that 20 rotations resulted in a total simulation time of 86 years (1981 - 2066 [9]). This temporal 80th percentile is approximated by the 17th value of the ranked concentrations (FOCUS, 2000) or the average of the 16th and 17th value (FOCUS, 2009).

9.2 FROGS Calculation Procedure

The evaluation procedure within FROGS is following closely the approach described in the European regulatory framework. Calculation is always performed for 6 warm-up years followed by 20 rotations (resulting in 26 years, 46 years, 66 years or 86 [9] years for 1-, 2-, 3- and 4-year rotations, respectively). The output is the concentration in the leachate at the bottom of the soil profile (as opposed to a target depth of 1-meter in FOCUS).

Since no conservativity assumption was made during the set-up of the FROGS-scenarios regarding climate, soil and crop, the spatial 80th percentile can be derived from the area-weighted cumulative frequency distribution of the concentrations from the relevant scenarios for the considered crop (FOCUS, 2009, pp. 58, 119 and 132). This is then combined with the temporal 80th to achieve an overall 90th percentile.

To calculate the temporal 80th percentile, the average concentrations over each rotation (C_{rot} [µg/L]) are calculated for every run according to Equation 9.

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[9] NB : in few cases of the newly employed 4-year crop rotations 87 years were simulated in total due to the fact that FROGS always simulates until the end of the year in which the last crop from the last rotation is harvested. In these cases the last crop is a winter cereal which is harvested in the year 2067.

Equation 9: $$C_{rot} = 100 \frac{\sum AmaLea}{\sum FlvFoc}$$

where AmaLea [kg/ha] is the annual area substance mass leached from the target layer (bottom of soil profile) and FlvFoc [m^3/m^2] is the volume of water leached from the target layer (bottom of soil profile).

The sums are calculated from the beginning of the year in which the main crop emerges until the end of the 2nd or 3rd year for 2- or 3-year rotations, respectively. The temporal 80th percentile is approximated by the arithmetic mean of the 16th and 17th value of the ranked concentrations according to current European guidance (FOCUS 2009).

To derive the spatial 80th percentile of the temporal 80th percentile concentrations all runs are sorted by ascending order, and their cumulative areas are divided by the total area. This leads to an area-weighted cumulative frequency distribution of the concentrations. As the overall 90th percentile the concentration is selected at which the cumulative area is 80% of the total area. In most cases no concentration at exactly the 80th percentile can be derived, so that a linear interpolation between the closest concentrations below and above the spatial 80th percentile is made.

9.3 References

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10 Test runs using FROGS

Test runs were performed for all FROGS crops in order to (i) check that all the scenarios were running, (ii) provide reference runs and (iii) present and discuss some example results. It is highlighted that all scenarios were tested but only those corresponding to the following crops are presented and discussed here (sugar beet, winter wheat, winter oilseed rape and potato, each of these crops are selected as the main crop in the crop rotations).

10.1 Input parameters

A series of test runs were conducted using the Dummy substances C and D as described in FOCUS (2000). The main parameters of these two substances are summarized in Table 46. It was in addition assumed that the Dummy C metabolite is not a relevant metabolite. For each tested crop, the Dummy substances C and D were applied at emergence of that crop only (e.g., when sugar beet is chosen, the substance is only applied to sugar beet and not to the other crops of the sugar beet rotations). Two exceptions were done for (i) winter wheat and winter barley as in that situation the substance was always applied to the two crops in the rotations, and (ii) maize as in that situation the substance was applied to grain maize and fodder maize.

The FOCUS scenarios using the FOCUS-PEARL 4.4.4 were also run with the same input parameters and considering an annual application of the product (i.e., simulating a monoculture), however at a different application rate than in the standard FOCUS test runs (0.35 and 0.2 kg a.s /ha for Dummy C and D respectively, compared to 1 kg a.s./ha in the standard FOCUS test runs). The application rates were modified compared to that of the standard FOCUS runs to obtain a plausible distribution of PECgw around the trigger value of 10 µg/L for the metabolite of compound C (metC) and around 0.1 µg/L for compound D. This was deemed more representative of the type of case that would require FROGS higher-tier simulations and more relevant to illustrate the potential effect of mitigation. It is highlighted that the PECgw calculated with the FOCUS scenarios and FROGS scenarios differ with regards to:

- target depth: FOCUS-PECgw are calculated at 1-m depth whereas FROGS-PECgw are calculated at the bottom of the soil profile, which varies from 40 to 140 cm, depending on soil-type;
- rotations: FOCUS-PECgw values as calculated in this document are based on a monoculture with annual application whereas FROGS-PECgw are based on typical crop rotation in the 31 Agronomic Unit (mostly with an application pattern once every two or three years and in some instances annual application for maize monoculture or a few 4-year rotations) with simulations conducted over a 26-year, 46-year, 66- or 86-year period, depending on the duration of the rotation period. The 80th temporal percentile of the FROGS runs were calculated as described in Chapter 9, with averaging done over the rotation period (1, 2, 3 or 4 years).

The calculated 80th temporal FROGS-PECgw were systematically plotted versus:
- the sand content, the organic carbon content and the pH-$CaCl_2$ of the first horizon;
- the available water content over the entire soil profile (AWC)[10] and
- the soil ID and the AUID[11].

To characterize the effect of the amendmends implemented in FROGS 3.3.3.3, the corresponding results obtained with former FROGS 2.2.2.2 are also included. The graphs

[10] The calculation of the AWC is detailed in Appendix 21.

[11] AUID: identification code (number) of the Agronomic Unit, therefore considering the specific weather and typical crop rotation of each AU.

were obtained using the Microsoft Excel® template (“FROGS_Template_Mitigation.xls”) included with the FROGS package. Examples of possible mitigation measures based on the sand content of the first soil horizon, the organic carbon content of the first soil horizon or the AWC are also presented.

Table 46 Main input parameters used for the test runs using Dummy substance C (with metabolite) and Dummy substance D

	Dummy C	Dummy C metabolite	Dummy D
DT50 (days)	20	100	20
ffM (-)	-	0.71 from parent	-
Kom/Koc (dm^3/kg)	100 / 172	30 / 52	35 / 60
1/n (-)	0.9	0.9	0.9
MW (g/mol)	200	150	300
Crop uptake factor (-)	0.5	0.5	0.5
Q10	2.58	2.58	2.58
Application rate (g/ha)	350	-	200
Application date/stage	emergence	-	emergence

10.2 Results for the Dummy Substance C and its metabolite

10.2.1 Sugar beet

The results of the test runs for the Dummy substance C and its metabolites using the FOCUS scenarios are presented in Table 47. The leaching of substance C is very limited whereas the PECgw for the metabolite indicate a high leaching potential.

Table 47 80th percentile concentrations for Substance C and its metabolite following application to sugar beet obtained with FOCUS-PEARL 4.4.4

FOCUS scenario	PECgw (µg/L)	
	Substance C	Metabolite C
Chateaudun	<0.001	10.922
Hamburg	<0.001	11.798
Jokioinen	<0.001	9.426
Kremsmünster	<0.001	8.582
Okehampton	<0.001	9.056
Piacenza	<0.001	6.466
Porto	<0.001	5.226
Sevilla	<0.001	3.509
Thiva	<0.001	6.501

The results of the test runs using FROGS for sugar beet are presented as cumulative areal distribution of the 80th percentile in time of PECgw (Figure 48 and Figure 49). They represent a total area of 338436 ha. The detailed results of the corresponding 46 scenarios are presented in Appendix 18.

The FROGS PECgw also indicate a very low leaching potential of Substance C, the maximum PECgw being 0.0021 µg/L. The PECgw of FOCUS scenarios are all below 0.001 µg/L (Figure 48).

For the metabolite of substance C, the 80th temporal percentile of PECgw calculated with the FROGS-scenarios are in the same range as calculated with the FOCUS scenarios (from 1.244 to 8.921 µg/L). The 80th spatial percentile of the 80th temporal percentile PECgw for Metabolite C, corresponding to a joint 90th vulnerability percentile, is 5.008 µg/L (Figure 49). The 80th temporal PECgw for Metabolite C are < 10 µg/L for all scenarios, i.e. for the whole sugar beet surface.

Looking at which parameters could be considered as the most critical for Metabolite C, a sand content of the 1st soil horizon above 80 % seems to be the best and simplest pedological parameter to characterise the FROGS scenarios with the highest PECgw (Figure 50 to Figure 53*)*. The climatic variation and different rotations between the AUs do not lead to any obvious difference in the calculated PECgw as illustrated by the random distribution of the PECgw vs. the AUID (***Figure 55***).

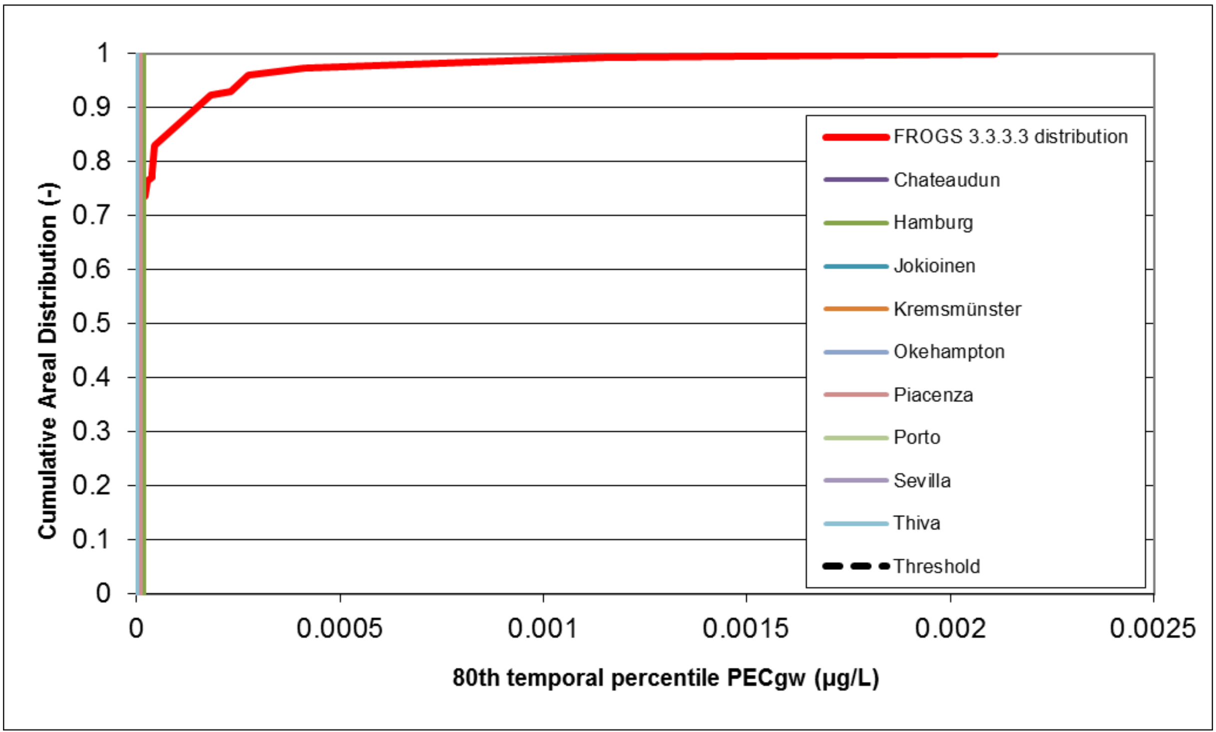


Figure 48 Cumulative aerial distribution of FROGS-PECgw (80th temporal percentile) for Substance C following application to sugar beet

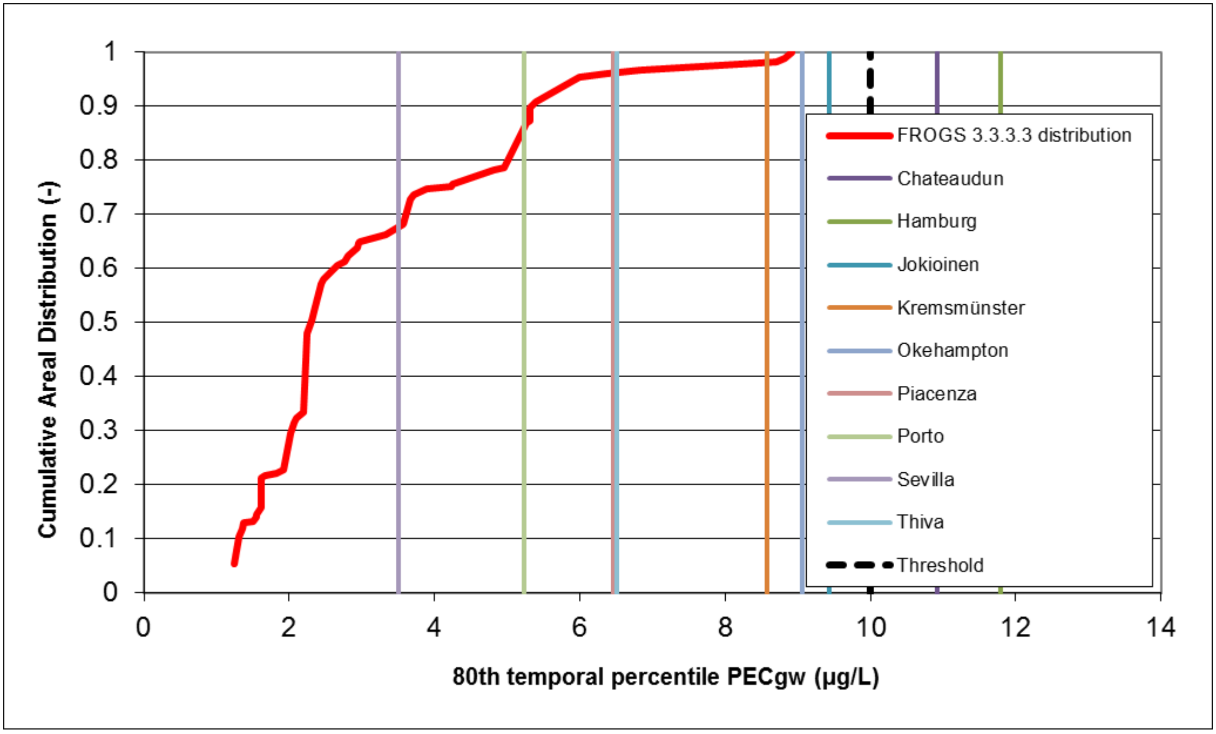


Figure 49 Cumulative aerial distribution of FROGS-PECgw (80th temporal percentile) for Metabolite C following application of Substance C to sugar beet

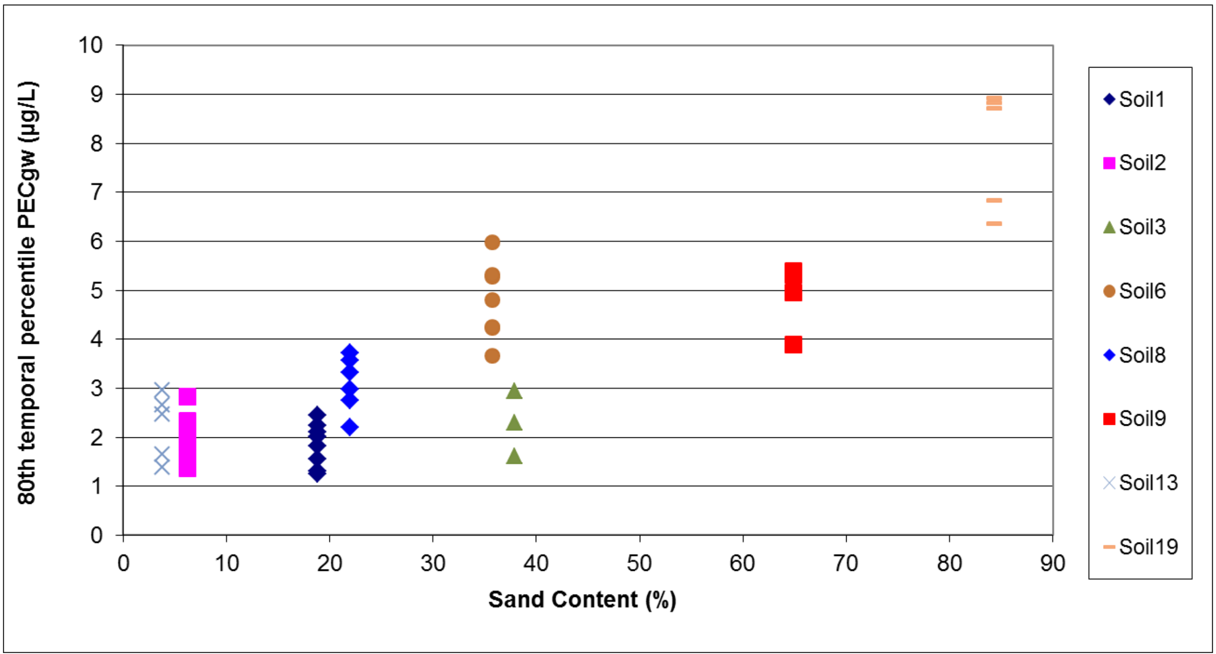


Figure 50 80th temporal percentile PECgw vs. sand content of the 1st soil horizon properties (MetC – Sugar beet)

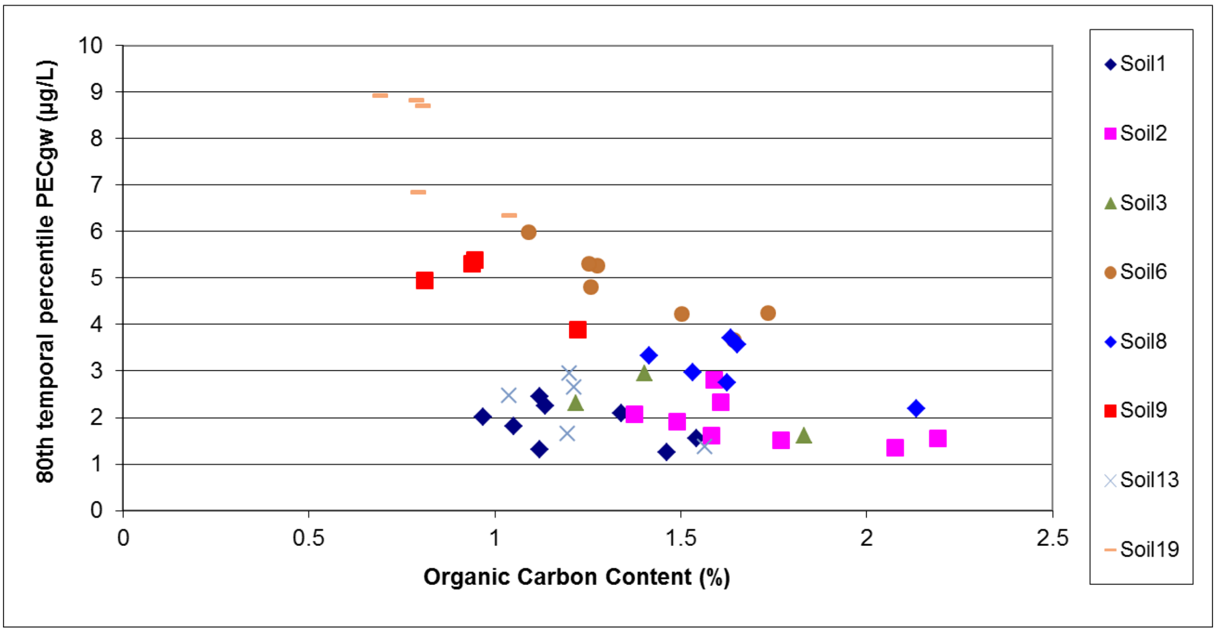


Figure 51 ***80th temporal percentile PECgw vs. organic carbon content of the 1st soil horizon properties (MetC – Sugar beet)***

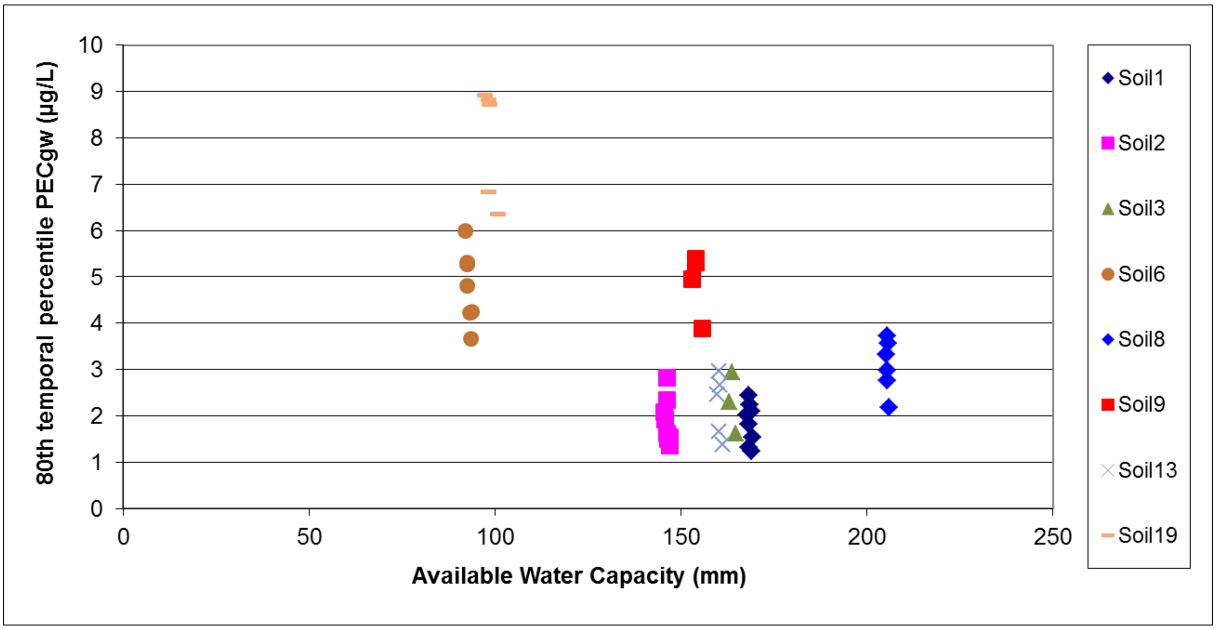


Figure 52 ***80th temporal percentile PECgw vs. the Available Water Capacity of the soil profile (MetC – Sugar beet)***

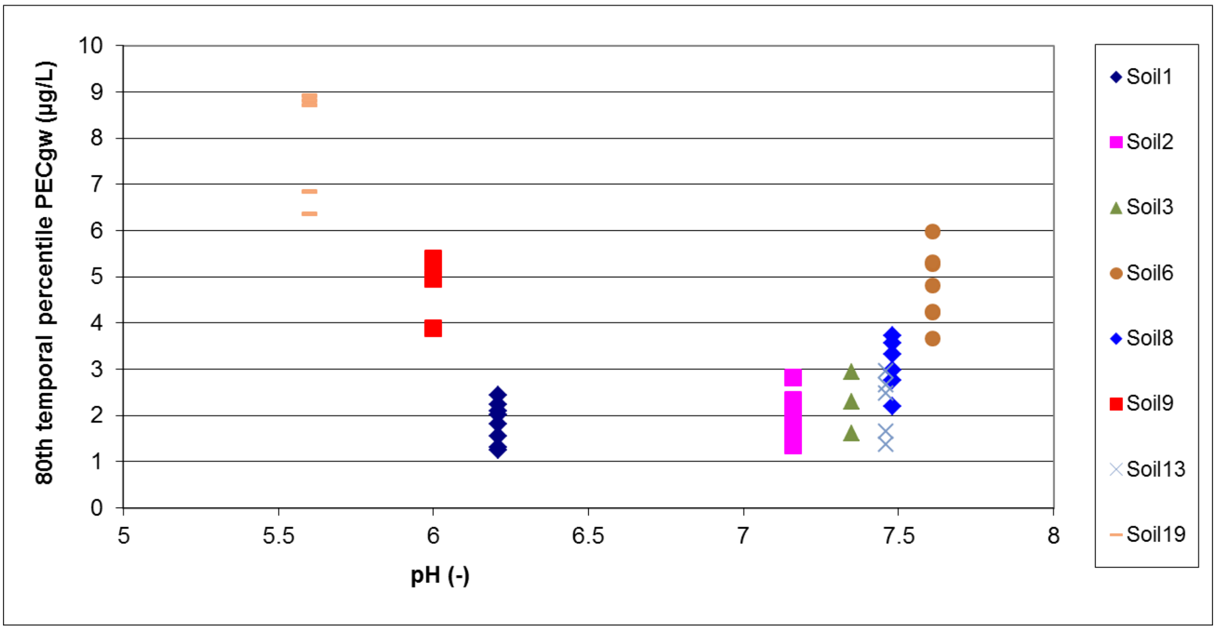


Figure 53 80th temporal percentile PECgw vs. the pH-CaCl2 of the 1st soil horizon properties (MetC – Sugar beet)

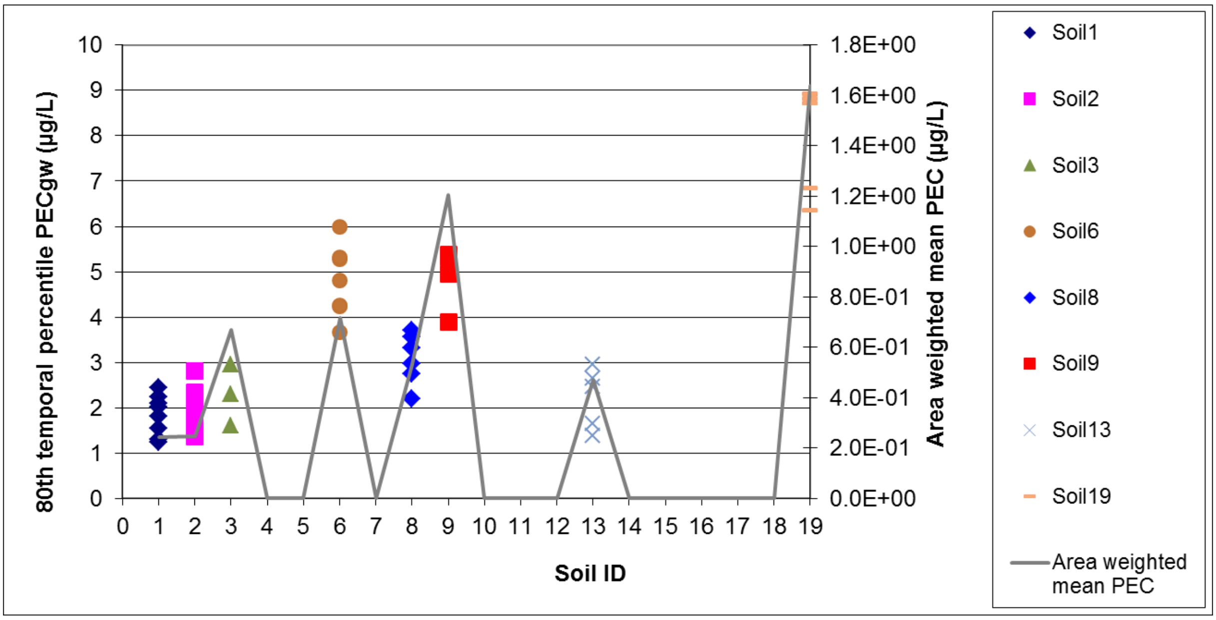


Figure 54 80th temporal percentile PECgw vs. soil ID (MetC – Sugar beet)

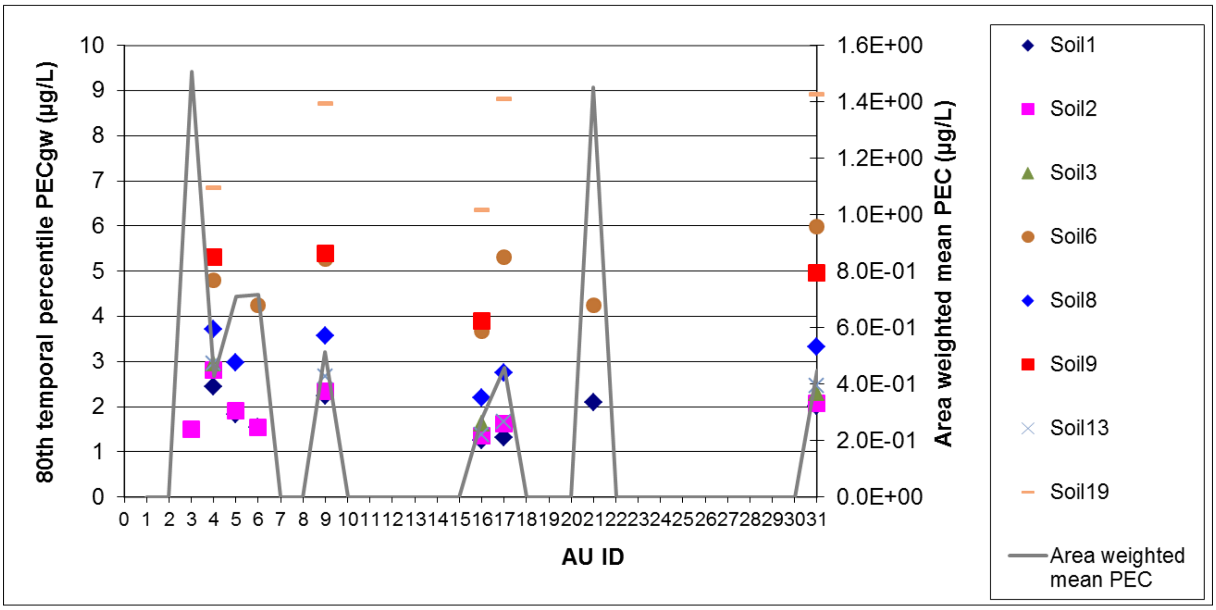


Figure 55 80th temporal percentile PECgw vs. AU ID (MetC – Sugar beet)

10.2.2 Winter wheat

The results of the test runs for the Dummy substance C and its metabolites using the FOCUS scenarios are presented in Table 48. Similar to the scenarios in sugar beets the leaching of substance C is very limited whereas the PECgw for the metabolite indicate a high leaching potential.

Table 48 80th percentile concentrations for Substance C and its metabolite following application to winter wheat (FOCUS crop winter cereals) obtained with FOCUS-PEARL 4.4.4

FOCUS scenario	PECgw (µg/L)	
	Substance C	Metabolite C
Chateaudun	<0.001	7.777
Hamburg	<0.001	13.092
Jokioinen	<0.001	10.215
Kremsmünster	<0.001	9.238
Okehampton	<0.001	10.966
Piacenza	<0.001	7.086
Porto	<0.001	6.837
Sevilla	<0.001	0.253
Thiva	<0.001	4.946

The results of the test runs using the FROGS scenarios for winter wheat (also including application to winter barley as rotational crop) are presented as cumulative areal distribution in Figure 56 and Figure 57. They represent an overall area of 4 691 679 ha. The detailed results of the corresponding 219 scenarios are included in the electronic distribution of the tool.

The FROGS PECgw also indicate a very low leaching potential of Substance C. The maximum PECgw is 0.095 µg/L. The 80th spatial percentile of the 80th temporal percentile PECgw for Substance C, corresponding to an overall 90th vulnerability percentile, is <0.001 µg/L (Figure 56*).*

For Metabolite C, the 80th temporal percentile of PECgw calculated with the FROGS-scenarios are in the same range as those calculated with the FOCUS scenarios (from 1.645 to 15.156 µg/L). The 80th spatial percentile of the 80th temporal percentile PECgw for Metabolite C, corresponding to a joint 90th vulnerability percentile, is 7.046 µg/L (Figure 57). The 80th temporal PECgw is less than 10 µg/L for scenarios representing altogether 92 % of the winter cereals surface. Only 24 scenarios out of 219 resulted in PECgw >10 µg/L, corresponding to the soil 19, soil 12, soil 9 and soil 6 (see detailed results in Appendix 19). Since the overall 90th percentile PECgw is <10 µg/L, mitigations would not be necessary.

Looking at what would be the most critical parameters regarding Metabolite C leaching potential, an available water capacity (AWC) below 100 mm for the entire soil profile appears to be the main pedological parameter to characterise most of the FROGS scenarios with a PECgw above 10 µg/L (Figure 58 to Figure 63). The climatic variation and rotation differences between AUs do not lead to any obvious difference for the calculated PECgw as illustrated by the random distribution of the PECgw vs. the AUID.

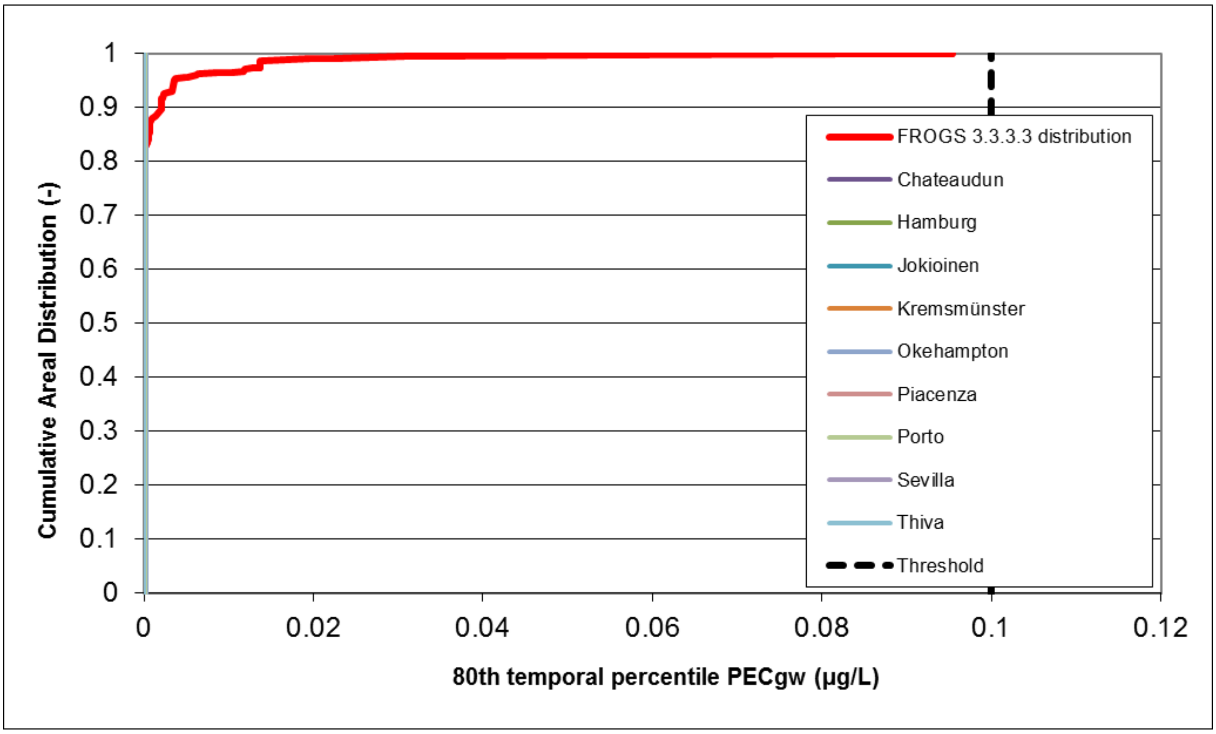


***Figure 56** Cumulative aerial distribution of FROGS-PECgw (80[th] temporal percentile) for Substance C following application to winter wheat as main crop and winter barley as rotational crop*

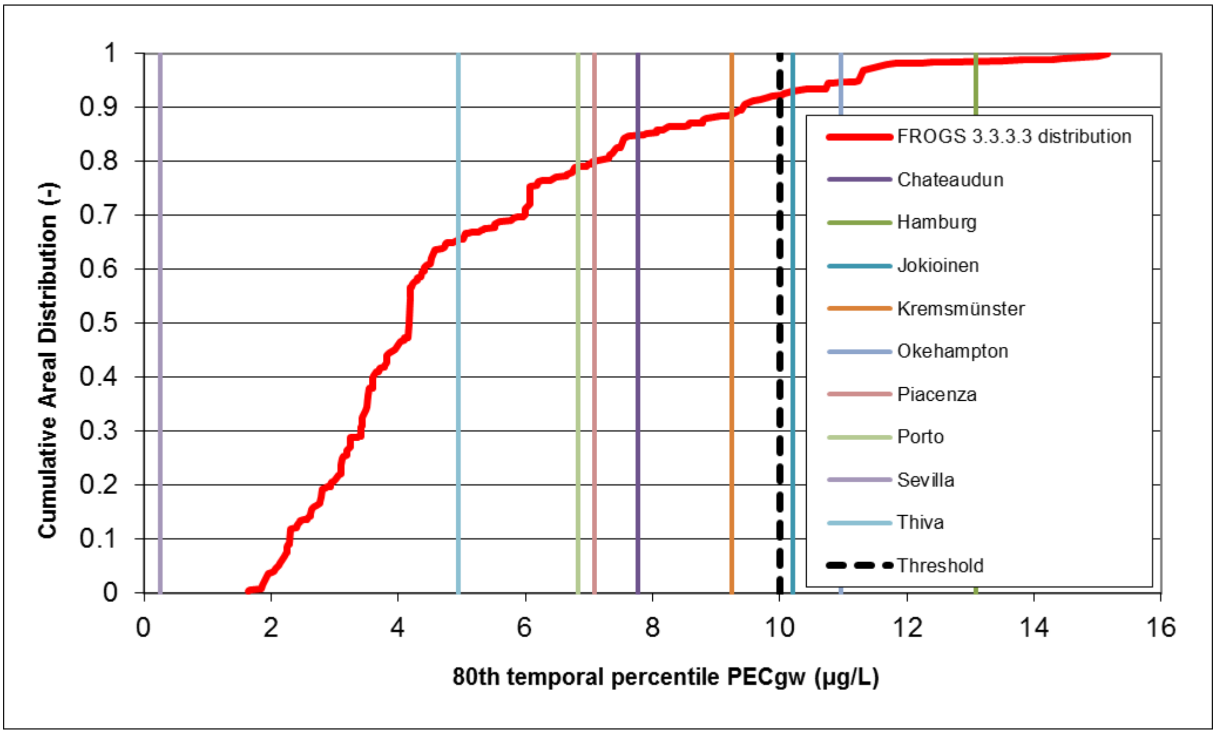


***Figure 57** Cumulative aerial distribution of FROGS-PECgw (80[th] percentile) for Metabolite C following application of Substance C to winter wheat as main crop and winter barley as rotational crop*

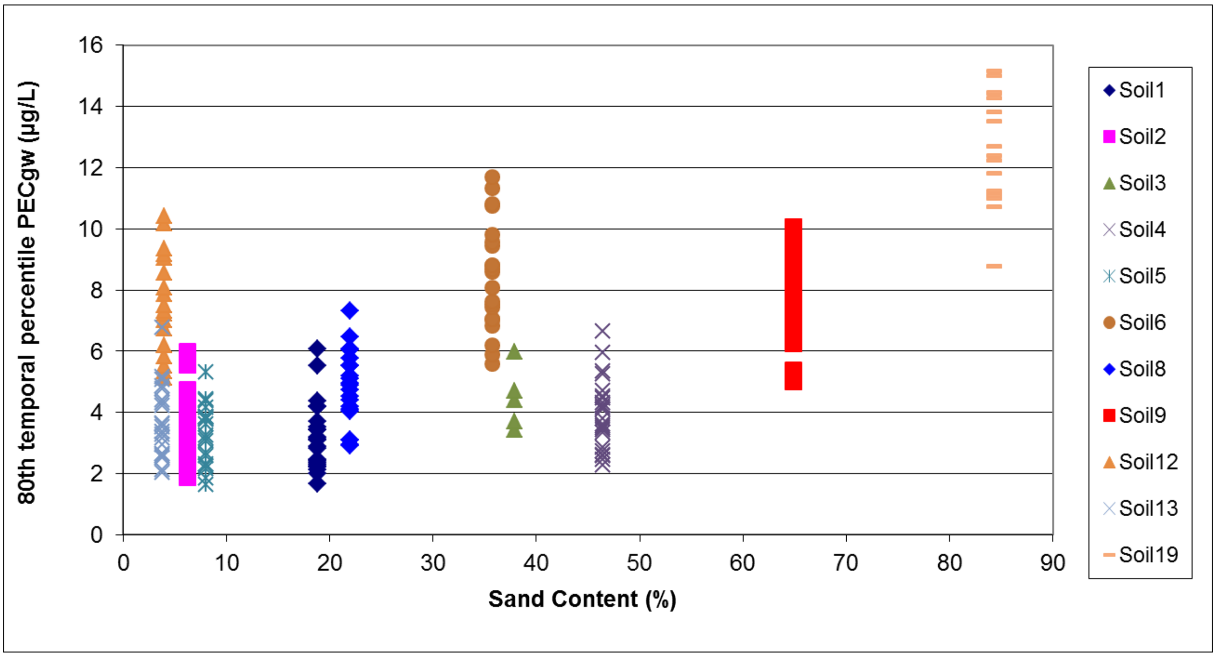


***Figure 58** 80th temporal percentile PECgw vs. sand content of the 1st soil horizon properties (MetC – Winter wheat)*

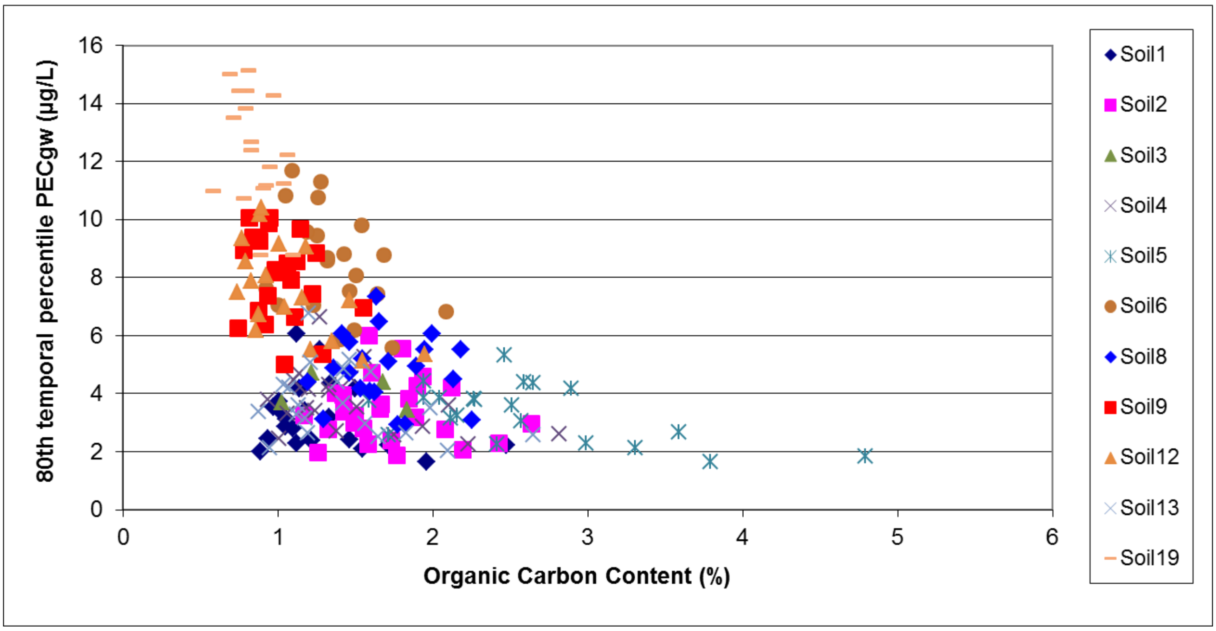


***Figure 59** 80th temporal percentile PECgw vs. organic carbon content of the 1st soil horizon properties (MetC – Winter wheat)*

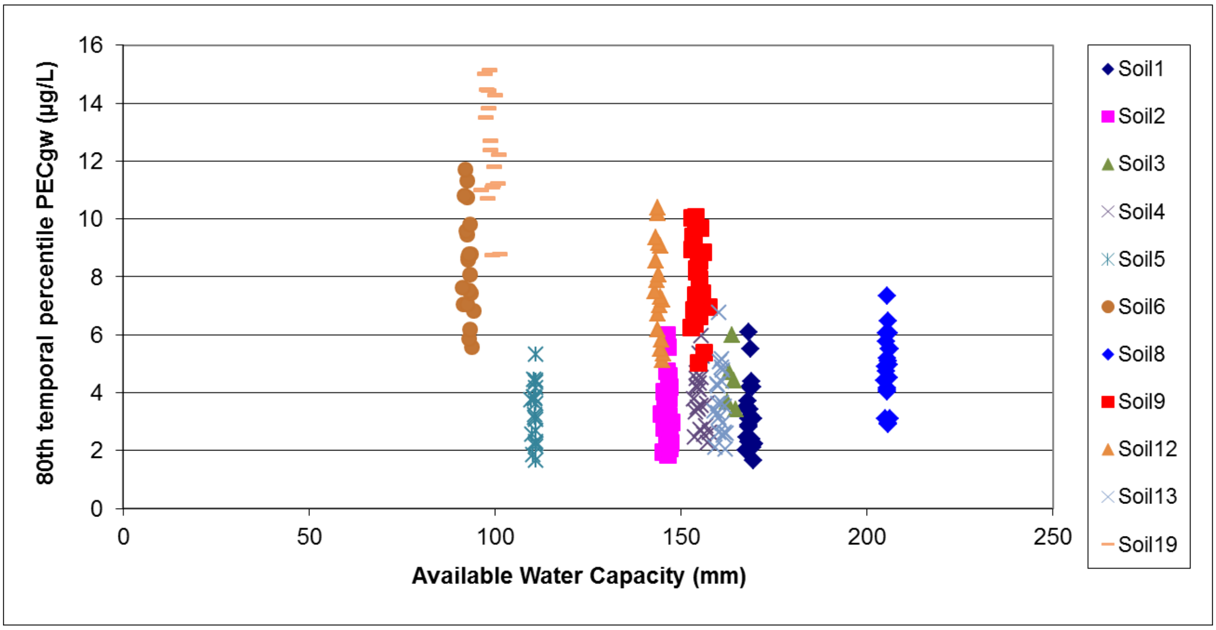


Figure 60 80th temporal percentile PECgw vs. the Available Water Capacity of the soil profile (MetC – Winter wheat)

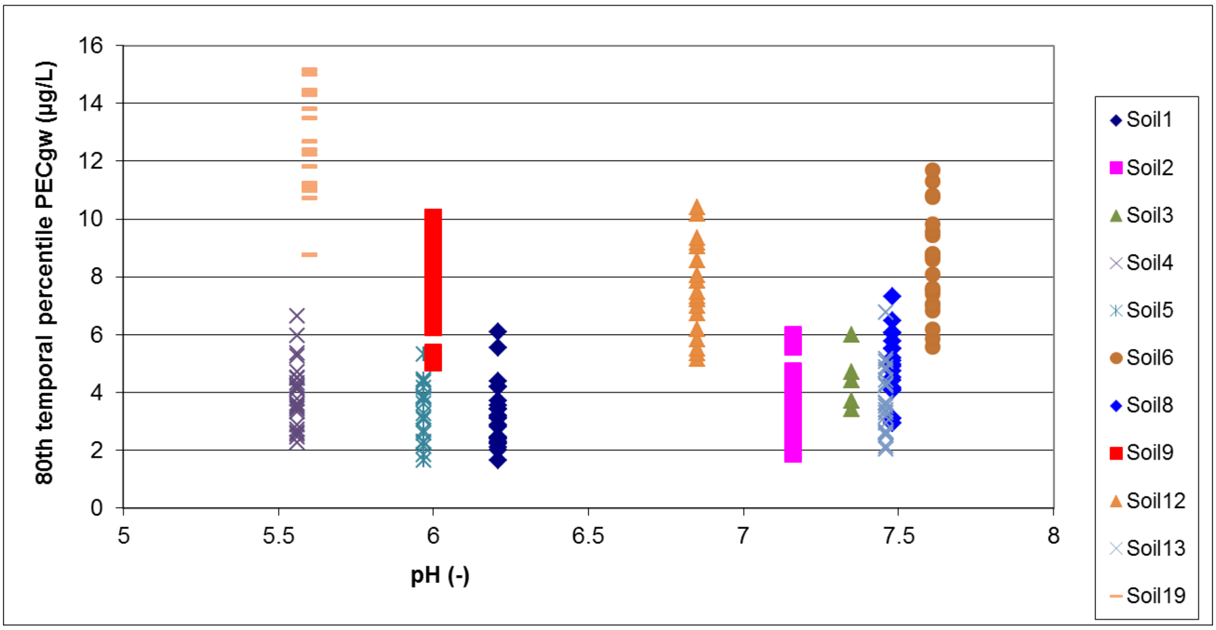


Figure 61 80th temporal percentile PECgw vs. pH-CaCl2 of the 1st soil horizon properties (MetC – Winter wheat)

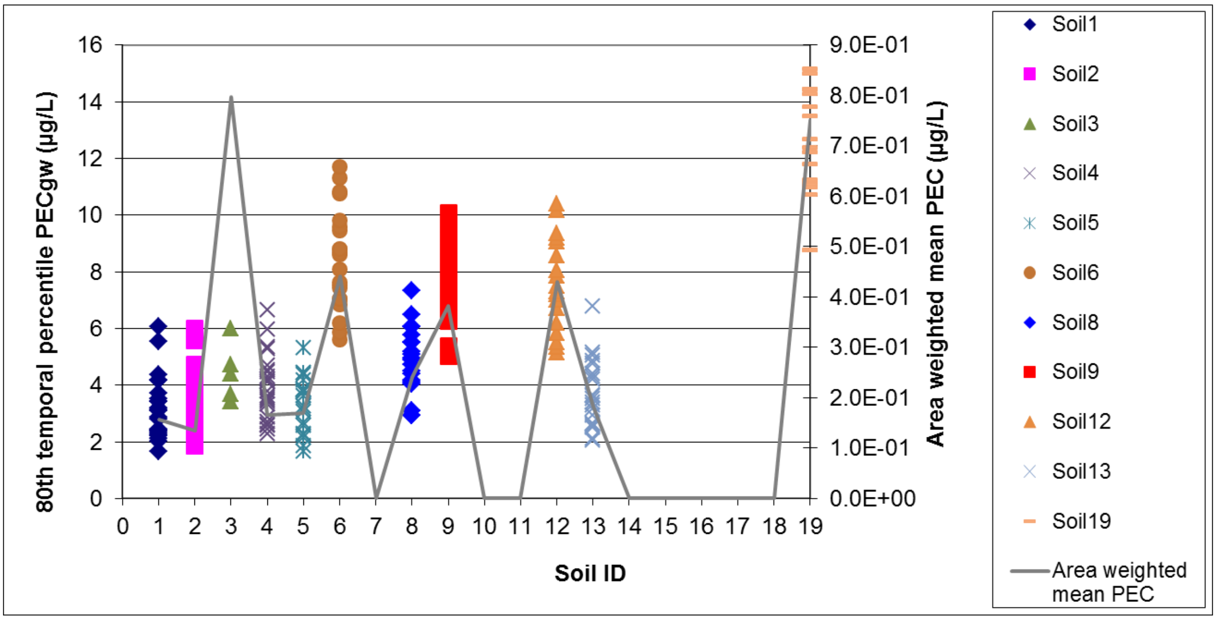


Figure 62   80th temporal percentile PECgw vs. Soil ID (MetC – Winter wheat)

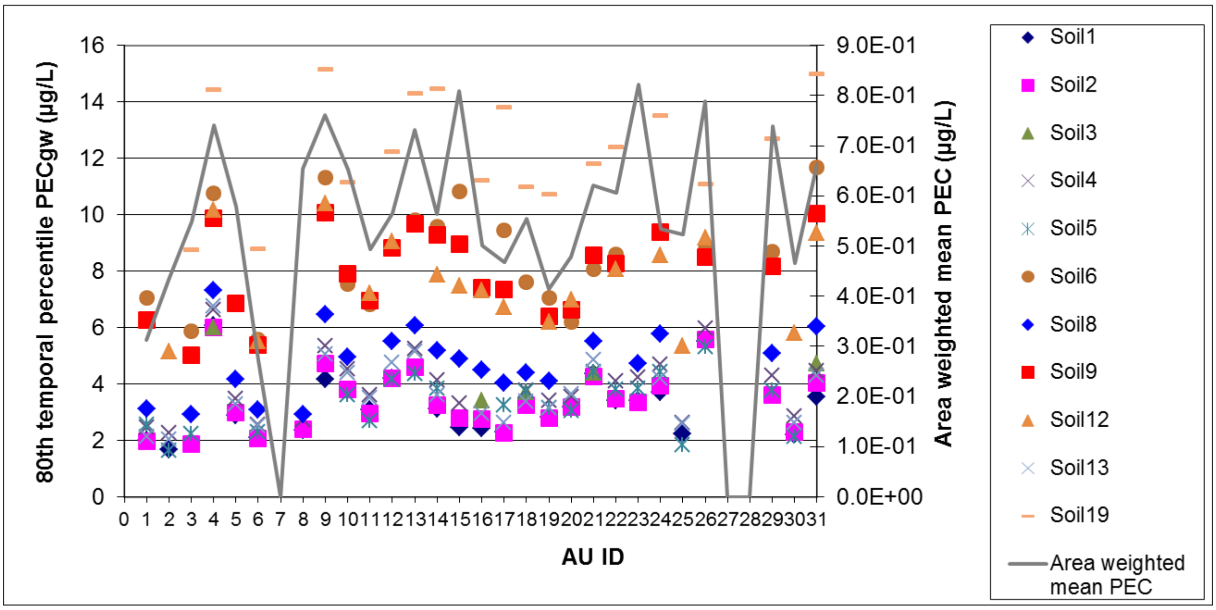


Figure 63   80th temporal percentile PECgw vs. AU ID (MetC – Winter wheat)

10.2.3 Winter oilseed rape

The results of the test runs for the Dummy substance C and its metabolite using the FOCUS scenarios are presented in Table 49. The leaching of substance C is very limited whereas the PECgw for the metabolite indicate a high leaching potential.

***Table 49** 80th percentile concentrations for Substance C and its metabolite applied annually to winter oilseed rape obtained with FOCUS-PEARL 4.4.4*

FOCUS scenario	PECgw (µg/L)	
	Substance C	Metabolite C
Chateaudun	<0.001	9.539
Hamburg	<0.001	14.416
Jokioinen	-	-
Kremsmünster	<0.001	10.192
Okehampton	<0.001	10.775
Piacenza	<0.001	7.597
Porto	<0.001	8.686
Sevilla	-	-
Thiva	-	-

The results of the test runs using the FROGS scenarios for winter oilseed rape are presented as cumulative areal distribution in Figure 64 and Figure 65. They represent an overall area of 1 321488 ha. The detailed results of the corresponding 162 scenarios are included in the FROGS package.

The FROGS PECgw also indicate a very low leaching potential of Substance C. For Metabolite C, the 80^{th} temporal percentile of PECgw calculated with the FROGS-scenarios are in the same range as calculated with the FOCUS scenarios (from 0.944 to 7.060 µg/L). The 80^{th} spatial percentile of the 80^{th} temporal percentile PECgw for Metabolite C, corresponding to an overall 90^{th} percentile, is 4.154 µg/L. The FROGS-scenarios indicate that for 100 % of winter oilseed rape area, the 80^{th} temporal PECgw would be less than 10 µg/L.

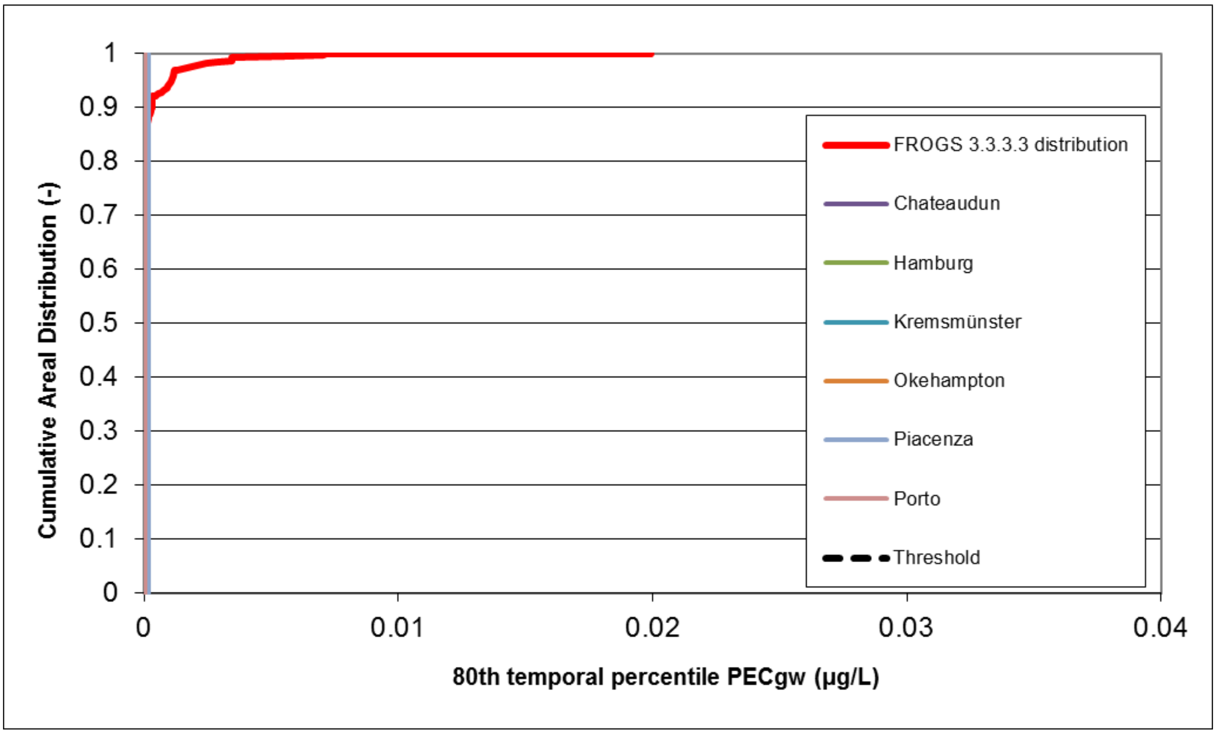


***Figure 64** Cumulative aerial distribution of FROGS-PECgw (80th temporal percentile) for Substance C following application to winter oilseed rape*

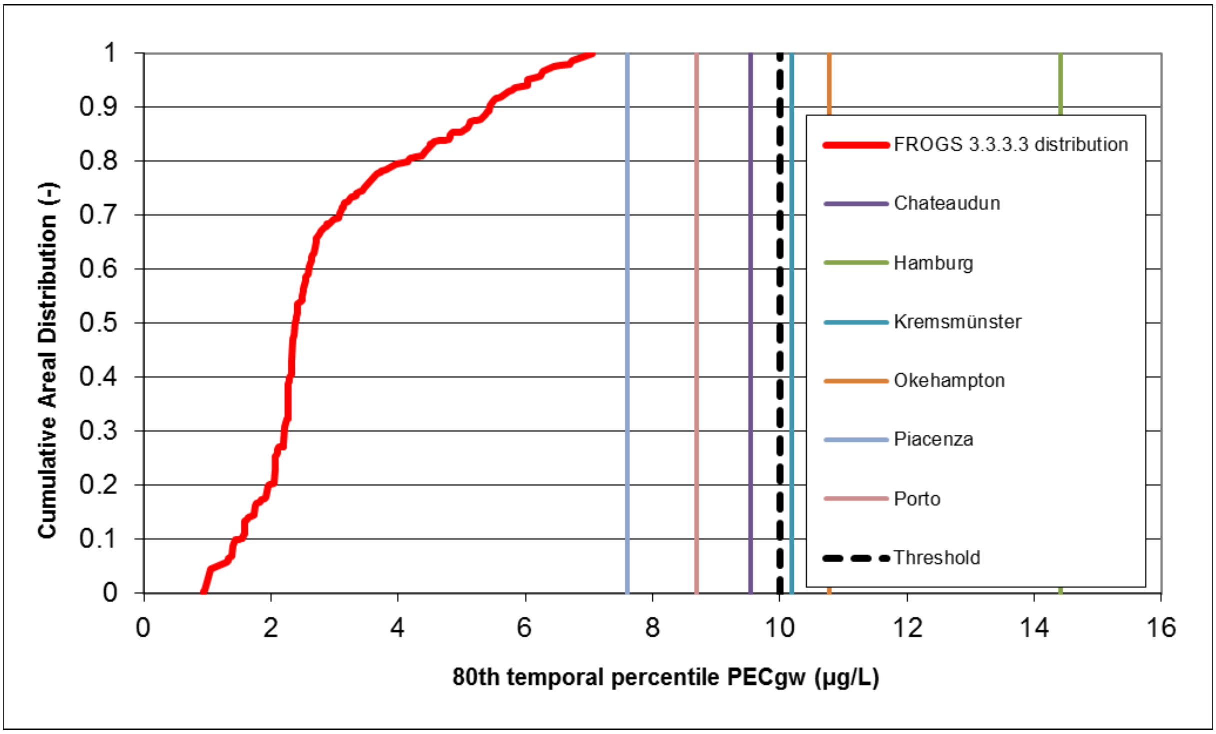


Figure 65 Cumulative aerial distribution of FROGS-PECgw (80th temporal percentile) for Metabolite C following application of Substance C to winter oilseed rape

Looking at the most critical parameters regarding the leaching potential of Metabolite C, several graphs (Figure 66 to Figure 71) indicate that soils 6, 9 and 12 result in the highest PECgw values.. The climatic variation and rotation differences between AUs do not lead to any obvious difference for the calculated PECgw as illustrated by the random distribution of the PECgw vs. the AUID.

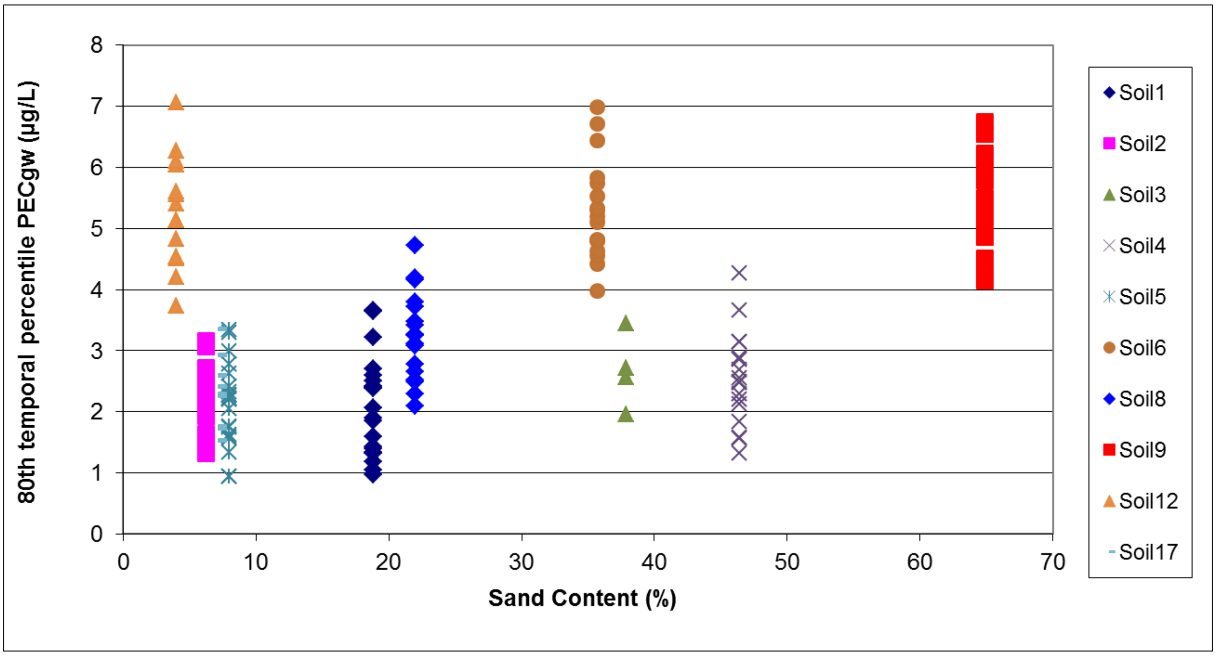


Figure 66 80th temporal percentile PECgw vs. sand content of the 1st soil horizon properties (MetC – Winter oilseed rape)

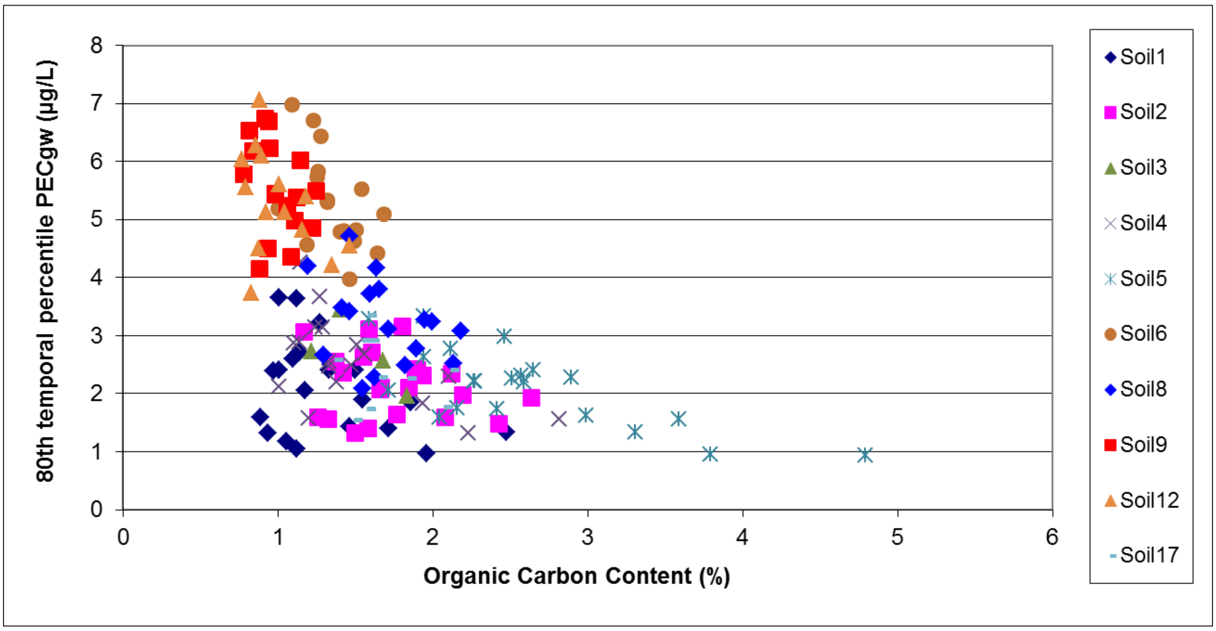


***Figure 67** 80th temporal percentile PECgw vs. organic carbon content of the 1st soil horizon properties (MetC – Winter oilseed rape)*

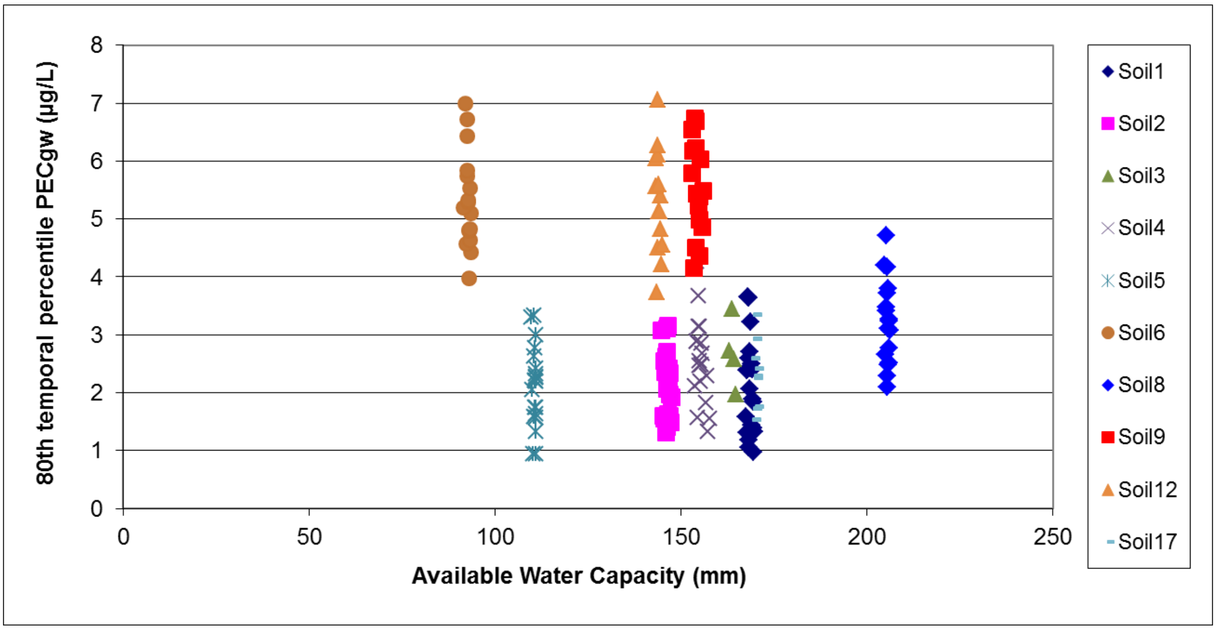


***Figure 68** 80th temporal percentile PECgw vs. the Available Water Capacity of the soil profile (MetC – Winter Oilseed rape)*

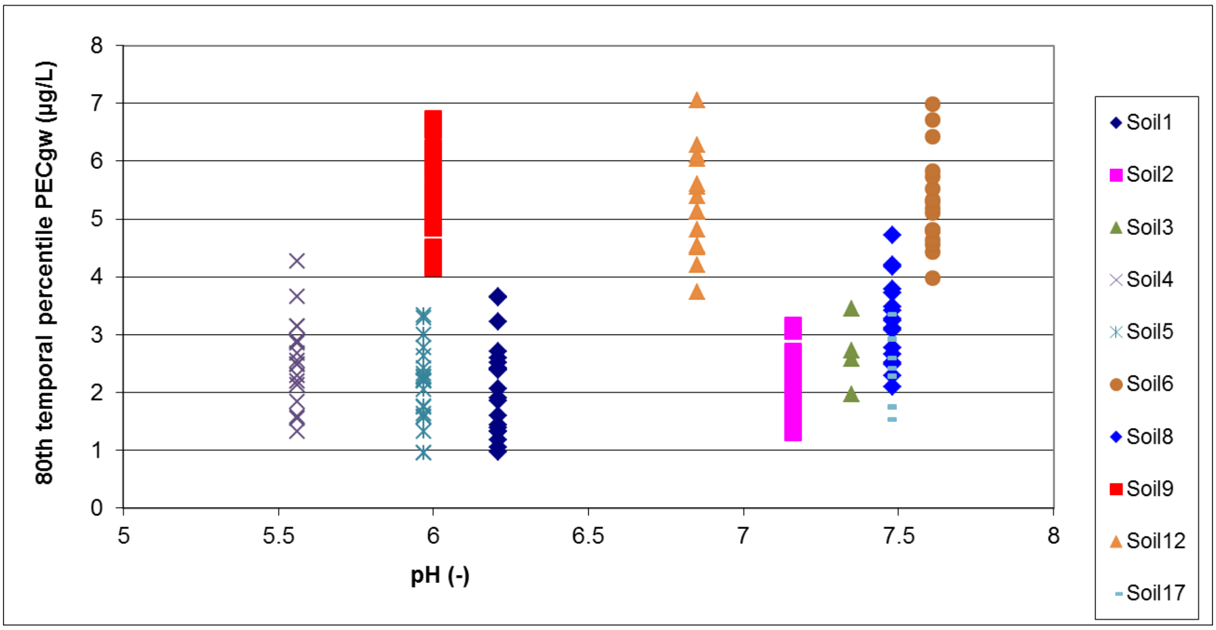


Figure 69 80[th] temporal percentile PECgw vs. the pH of the 1[st] soil horizon properties (MetC – Winter Oilseed rape)

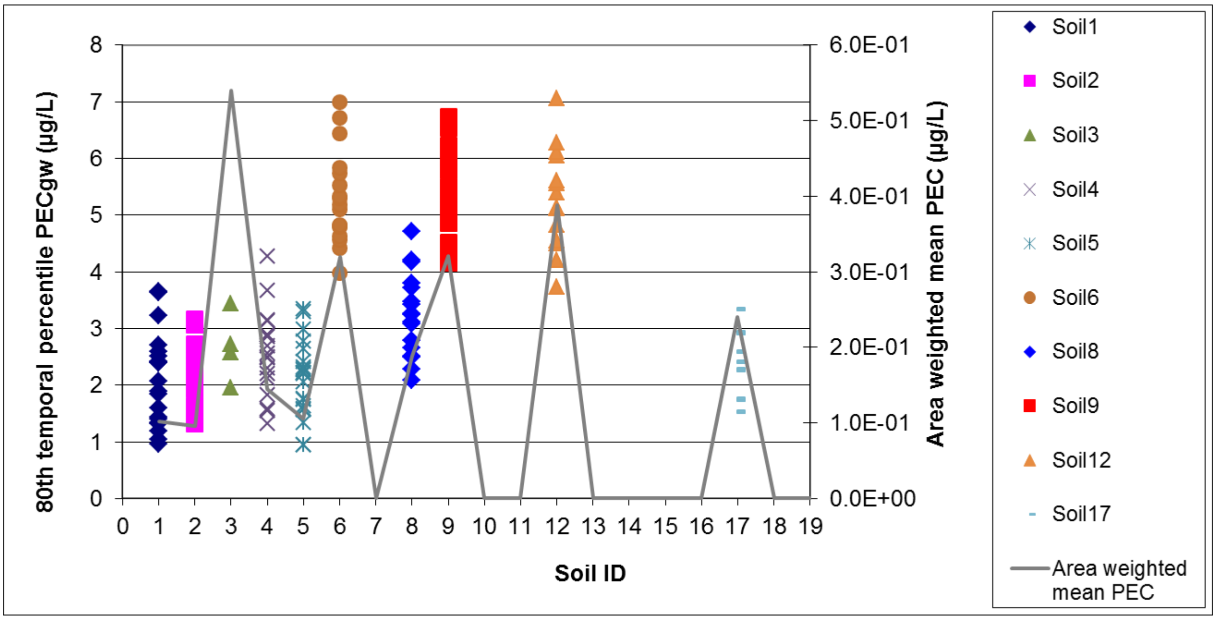


Figure 70 80[th] temporal percentile PECgw vs. Soil ID (MetC – Winter Oilseed rape)

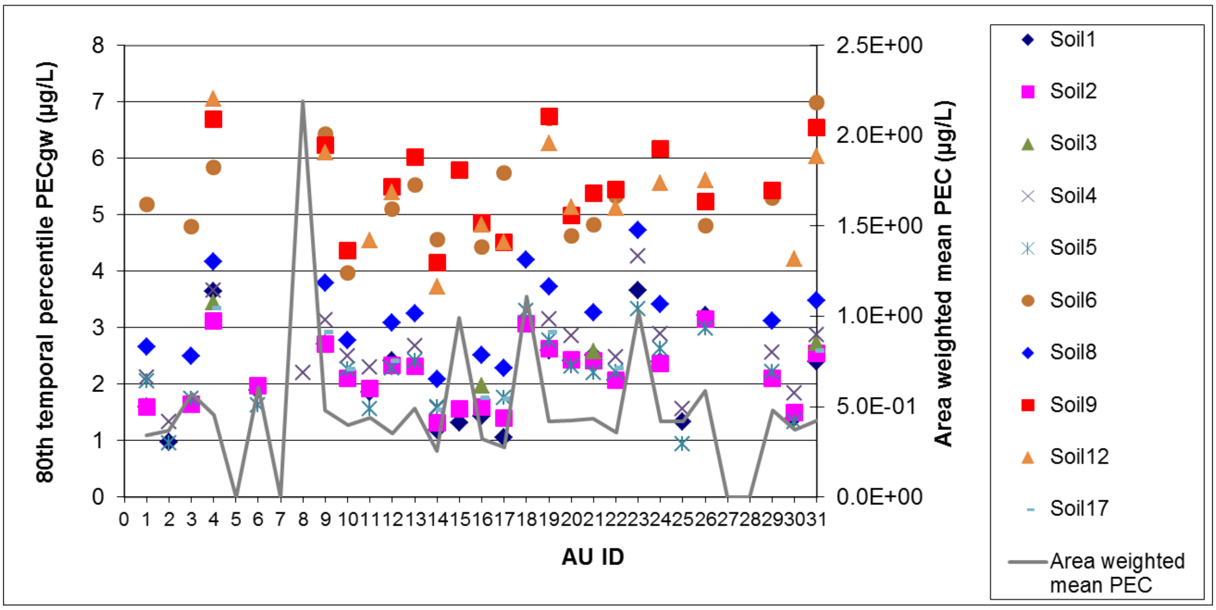


Figure 71   80th temporal percentile PECgw vs. AU ID (MetC – Winter Oilseed rape)

10.3 Results for the Dummy Substance D

10.3.1 Winter Wheat

The results of the test runs for the Dummy substance D using the FOCUS scenarios are presented in Table 50.

Table 50 ***80th percentile concentrations for Substance D following application to winter barley (FOCUS crop winter cereals) obtained with FOCUS-PEARL 4.4.4***

FOCUS scenario	PECgw (µg/L)
	Substance D
Chateaudun	0.009
Hamburg	0.256
Jokioinen	0.042
Kremsmünster	0.074
Okehampton	0.315
Piacenza	0.116
Porto	0.238
Sevilla	<0.001
Thiva	0.003

The results of the test runs using the FROGS scenarios for winter wheat as primary crop and also including application to winter barley as rotational crop are presented as cumulative areal distribution of the 80th percentile in time of PECgw (Figure 72). They represent an area of 4 691 679 ha.

The 80th temporal percentile of PECgw calculated with the FROGS-scenarios are between <0.001 and 3.057 µg/L. The 80th spatial percentile of the 80th temporal percentile PECgw for Substance D, corresponding to an overall 90th percentile, is 0.098 µg/L and thus, only marginally below the threshold of 0.1 µg/L. The FROGS-scenarios indicate that for 80.3 % of winter wheat surface, the 80th temporal PECgw is less than 0.1 µg/L. A total of 57 scenarios out of 219 resulted in PECgw >0.1 µg/L (see details in *Appendix 20)*. Looking at the critical parameters for leaching potential of Substance D, an available water capacity (AWC) below 100 mm appears to be the main pedological parameters to characterise the FROGS scenarios with a PECgw above 0.1 µg/L (Figure 73 to Figure 78). Applying a mitigation measure to avoid application of substance D on soils having an AWC < 100 mm would decrease the surface with PECgw above 0.1 µg/L from 907 kha to 265 kha. The resulting cumulative distribution indicates that the PECgw would be less than 0.1 µg/L for 93.0 % of mitigated winter wheat surface (Figure 79). The climatic variation and rotation differences between AUs do not lead to any obvious difference for the calculated PECgw as illustrated by the random distribution of the PECgw vs. the AUID.

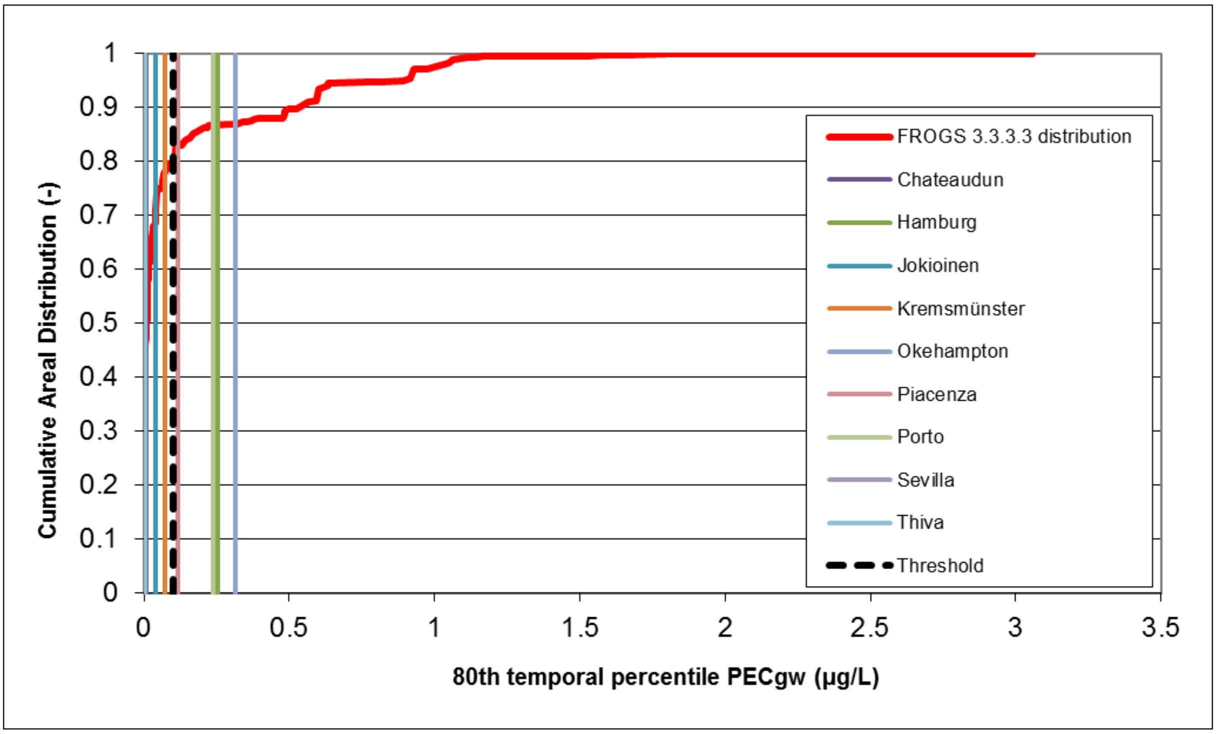


Figure 72 Cumulative aerial distribution of FROGS-PECgw (80th temporal percentile) for Substance D following application to winter wheat as primary crop and winter barley as rotational crop

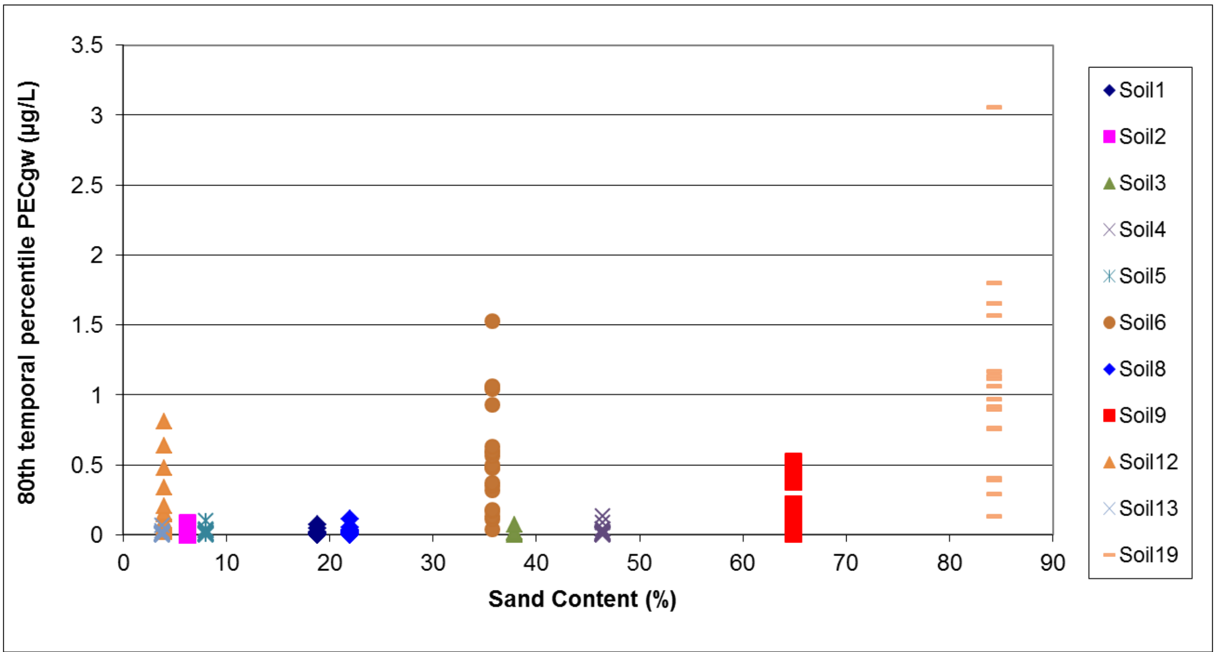


Figure 73 80th temporal percentile PECgw vs. sand content of the 1st soil horizon properties (SubD – Winter wheat)

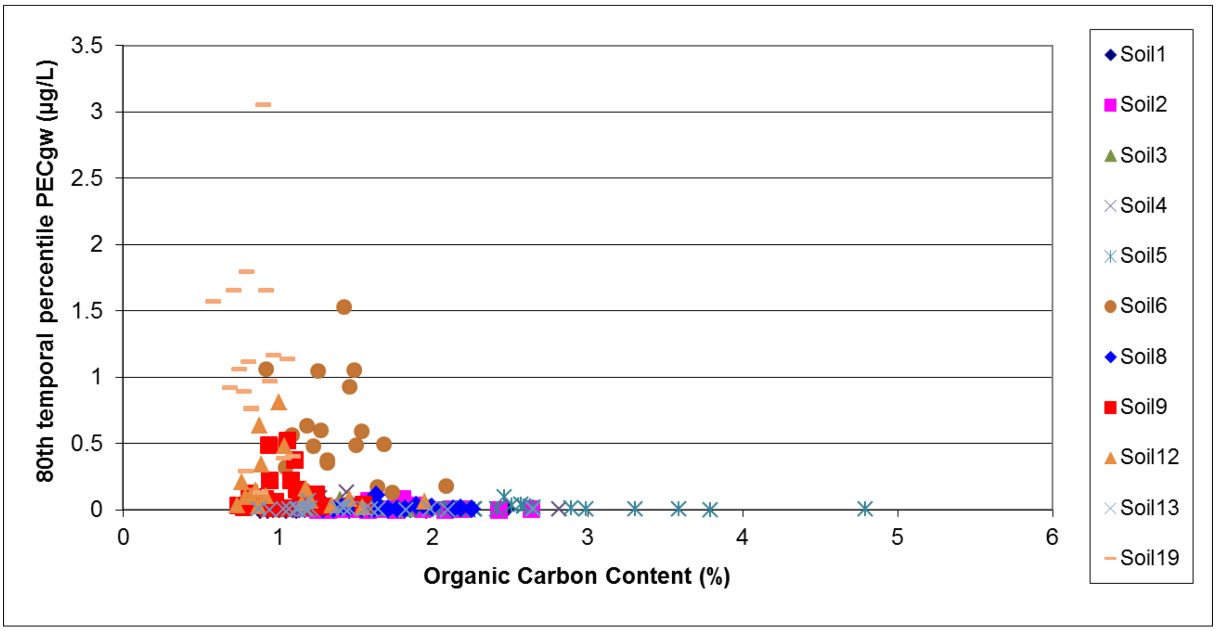


Figure 74 ***80th temporal percentile PECgw vs. organic carbon content of the 1st soil horizon properties (SubD – Winter wheat)***

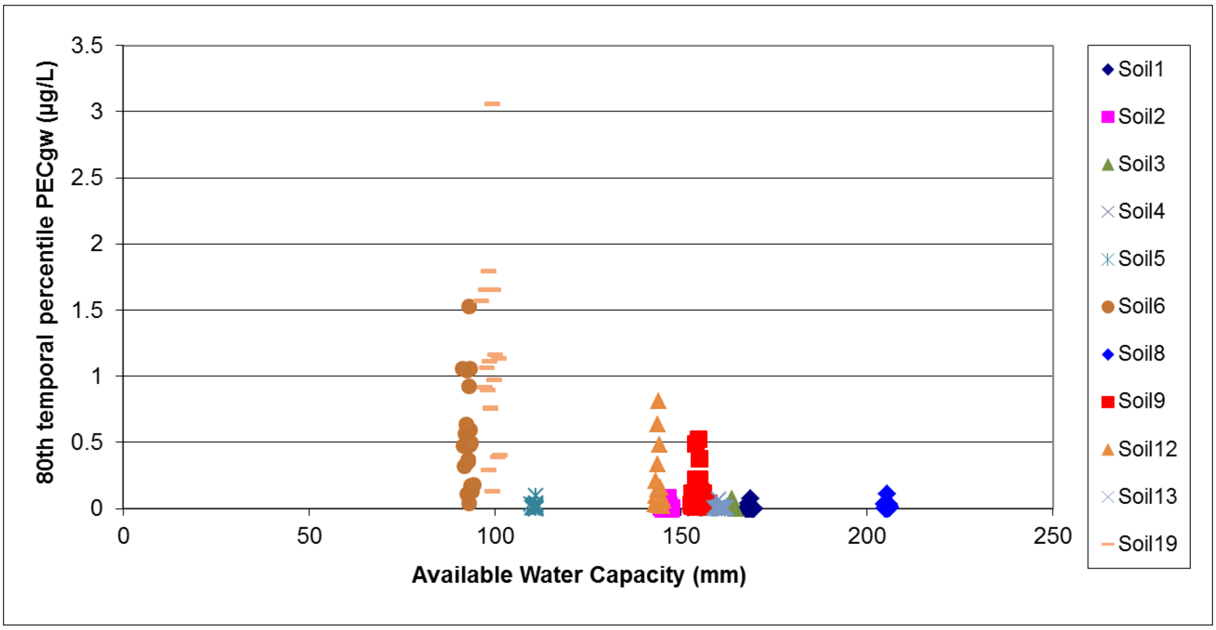


Figure 75 ***80th temporal percentile PECgw vs. the Available Water Capacity of the soil profile (SubD – Winter wheat)***

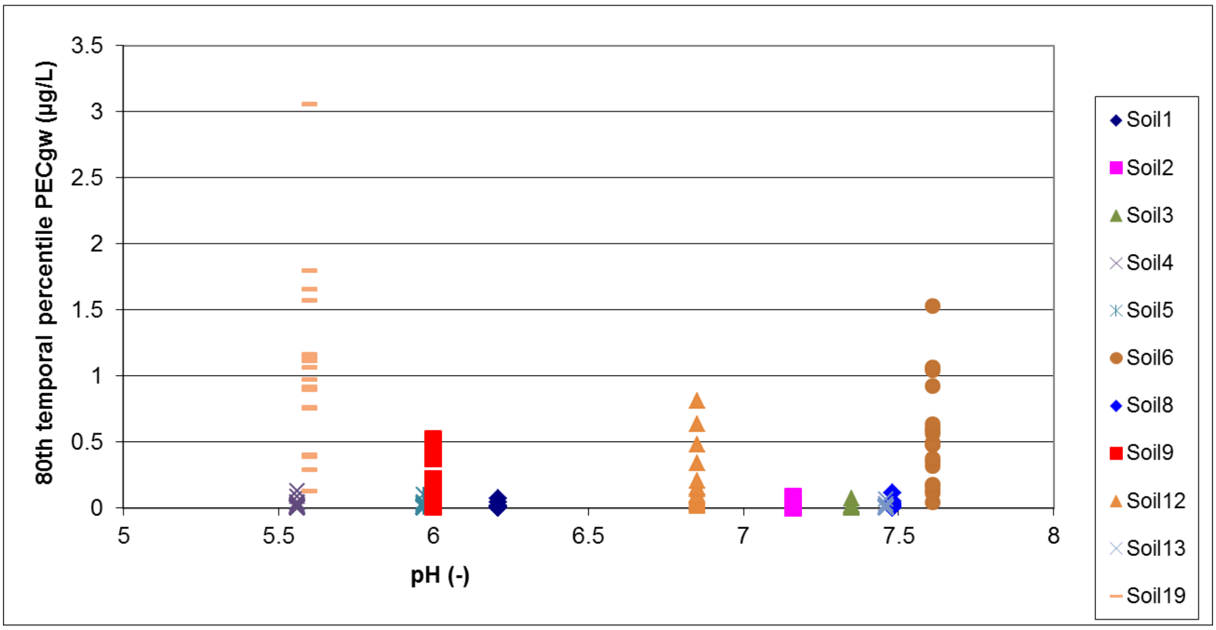


Figure 76 80[th] temporal percentile PECgw vs. the pH-CaCl2 value of the 1[st] soil horizon properties (SubD – Winter wheat)

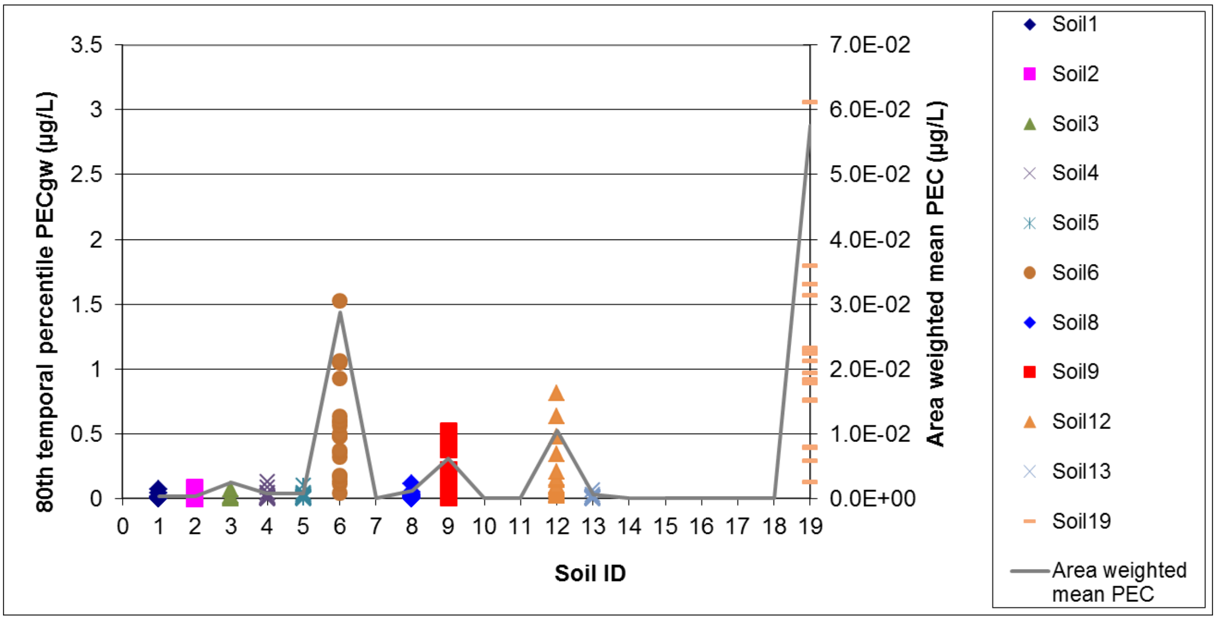


Figure 77 80[th] temporal percentile PECgw vs. Soil ID (SubD – Winter wheat)

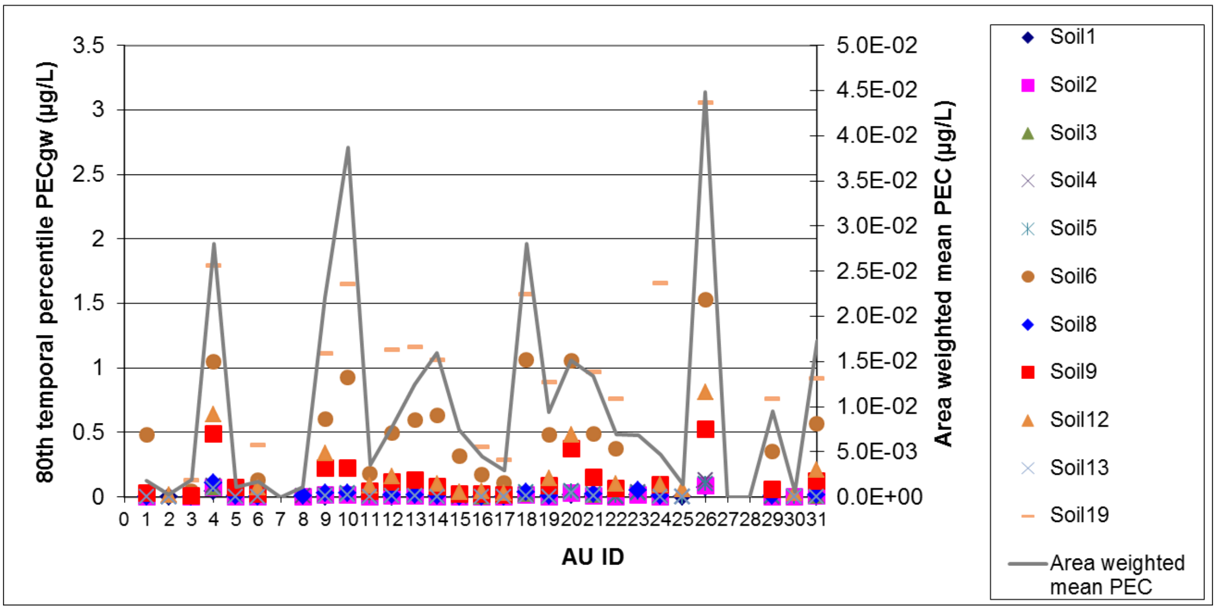


Figure 78 80th temporal percentile PECgw vs. AU ID (SubD – Winter wheat)

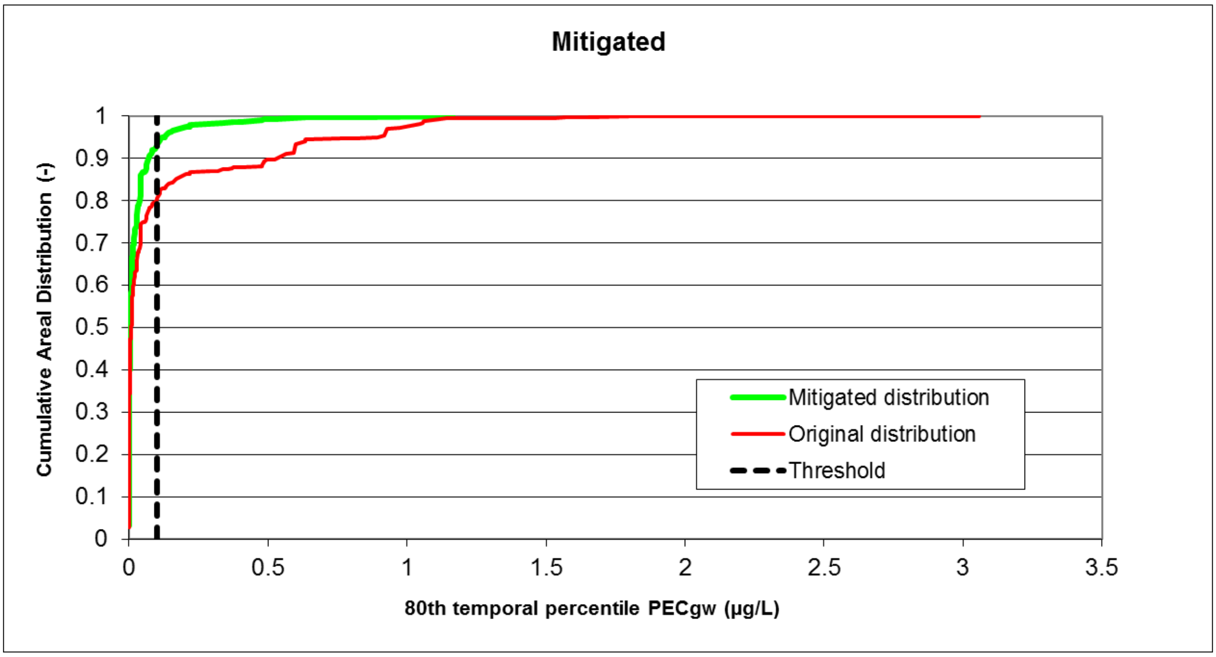


Figure 79 Cumulative aerial distribution of FROGS-PECgw (80th temporal percentile) for Substance D following application to winter wheat as primary crop and winter barley as rotational crop considering a mitigation to eliminate application on soils having an AWC < 100 mm

10.3.2 Potato

The results of the test runs for the Dummy substance D using the FOCUS scenarios are presented in Table 51.

Table 51 80^{th} percentile concentrations for Substance D applied annually to potato obtained with FOCUS-PEARL 4.4.4

FOCUS scenario	PECgw (µg/L)
	Substance D
Chateaudun	0.008
Hamburg	0.033
Jokioinen	0.005
Kremsmünster	0.022
Okehampton	0.039
Piacenza	0.018
Porto	0.004
Sevilla	<0.001
Thiva	<0.001

The results of the test runs using the FROGS scenarios for potato are presented as cumulative areal distribution of the 80^{th} percentile in time of PECgw (*Figure 80*). They represent an area of 126 328 ha. The detailed results of the corresponding 21 scenarios are available with the FROGS package.

The 80^{th} temporal percentile of PECgw calculated with the FROGS-scenarios are between <0.001 and 0.146 µg/L. The 80^{th} spatial percentile of the 80^{th} temporal percentile PECgw for Dummy substance D, corresponding to an overall 90^{th} percentile, is 0.020 µg/L. The 80^{th} temporal PECgw is less than 0.1 µg/L for FROGS-scenarios representing 94.56 % of the total potato surface. Looking at the most critical parameters for the leaching potential of Substance D, an available water capacity (AWC) below 100 mm appears to be the main pedological parameter to characterise the FROGS scenarios with a PECgw above 0.1 µg/L (*Figure 83*). The climatic variation and rotation differences between AUs do not lead to any obvious difference for the calculated PECgw as illustrated by the random distribution of the PECgw vs. the AUID.

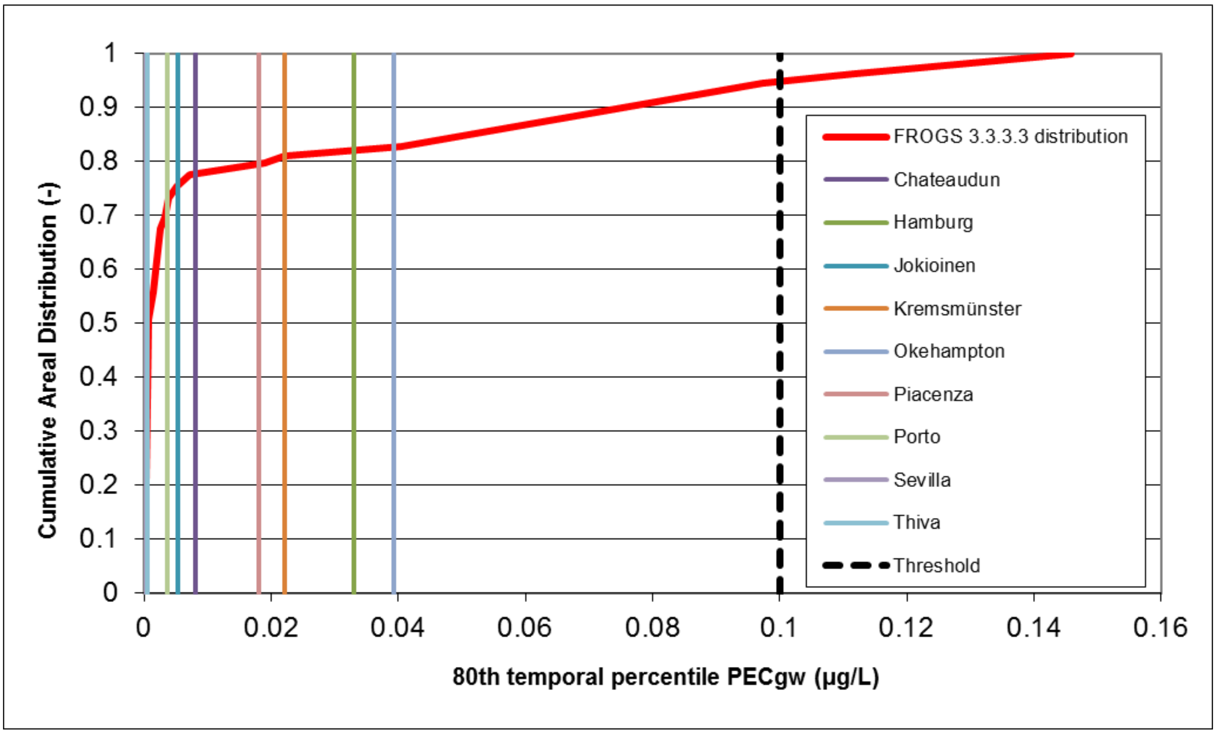


***Figure 80** Cumulative aerial distribution of FROGS-PECgw (80^{th} temporal percentile) for Substance D applied on potato*

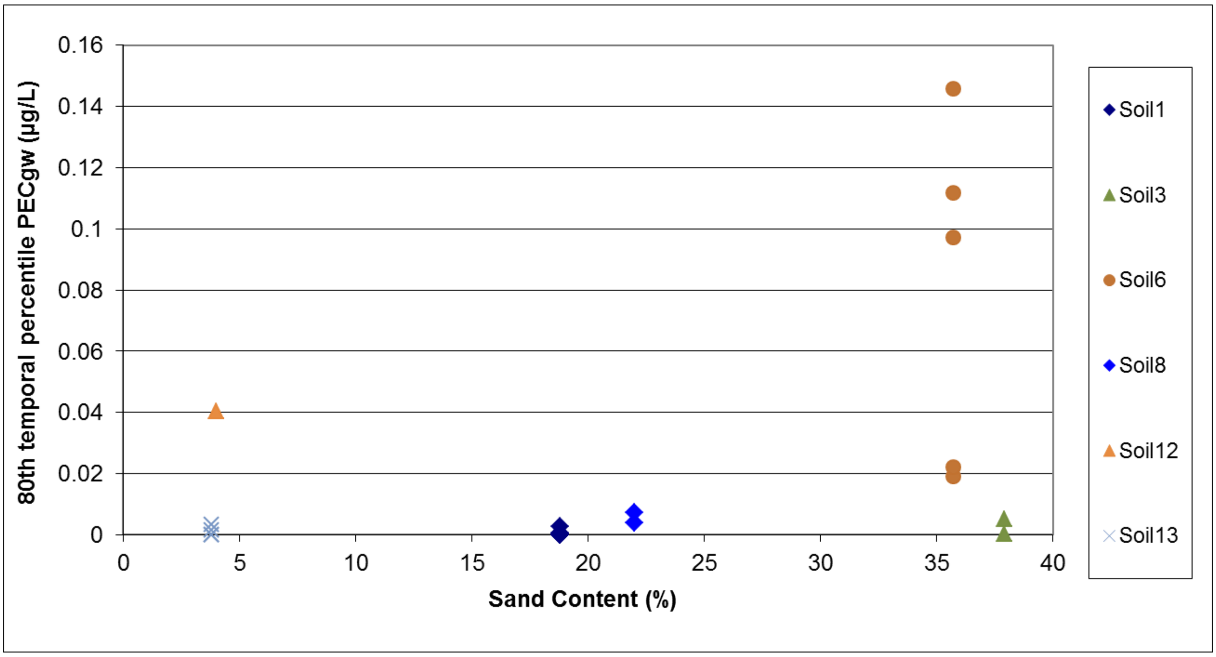


Figure 81 ***80th temporal percentile PECgw vs. sand content of the 1st soil horizon properties (SubD – Potato)***

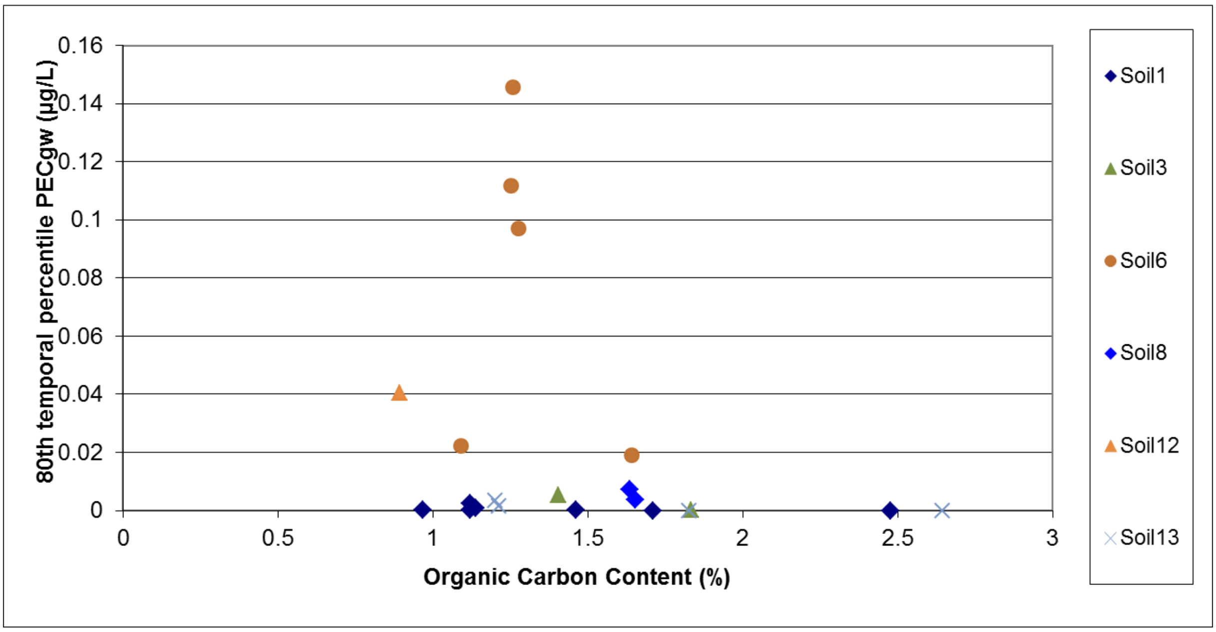


Figure 82 ***80th temporal percentile PECgw vs. organic carbon content of the 1st soil horizon properties (SubD – Potato)***

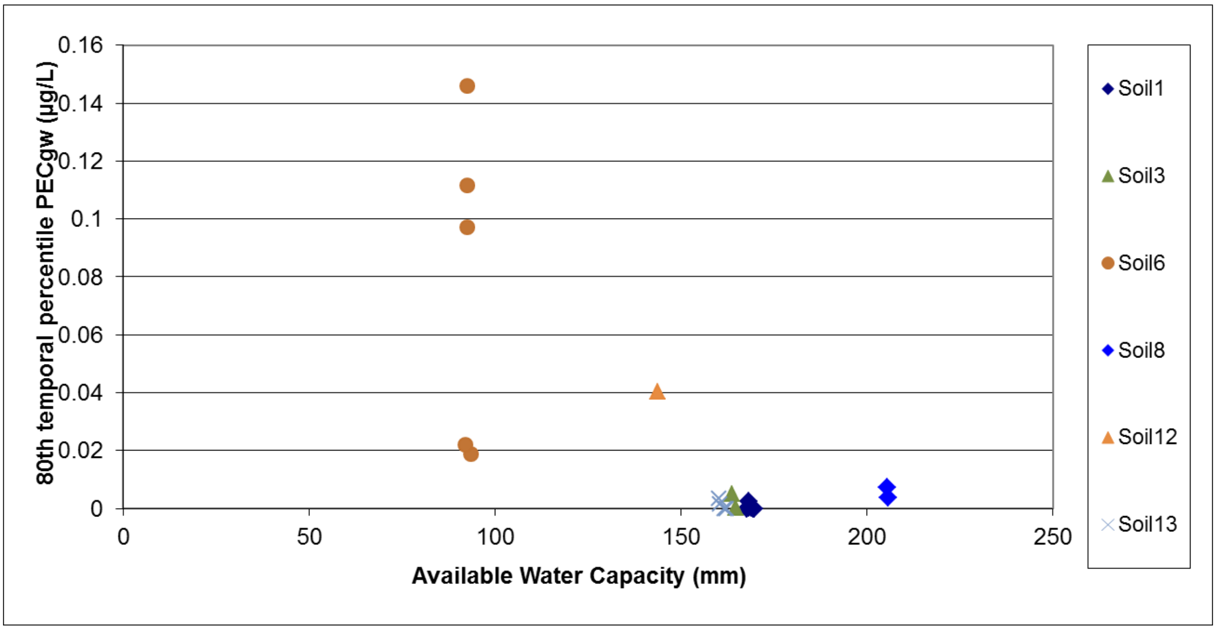


Figure 83 ***80th temporal percentile PECgw vs. the Available Water Capacity of the soil profile (SubD – Potato)***

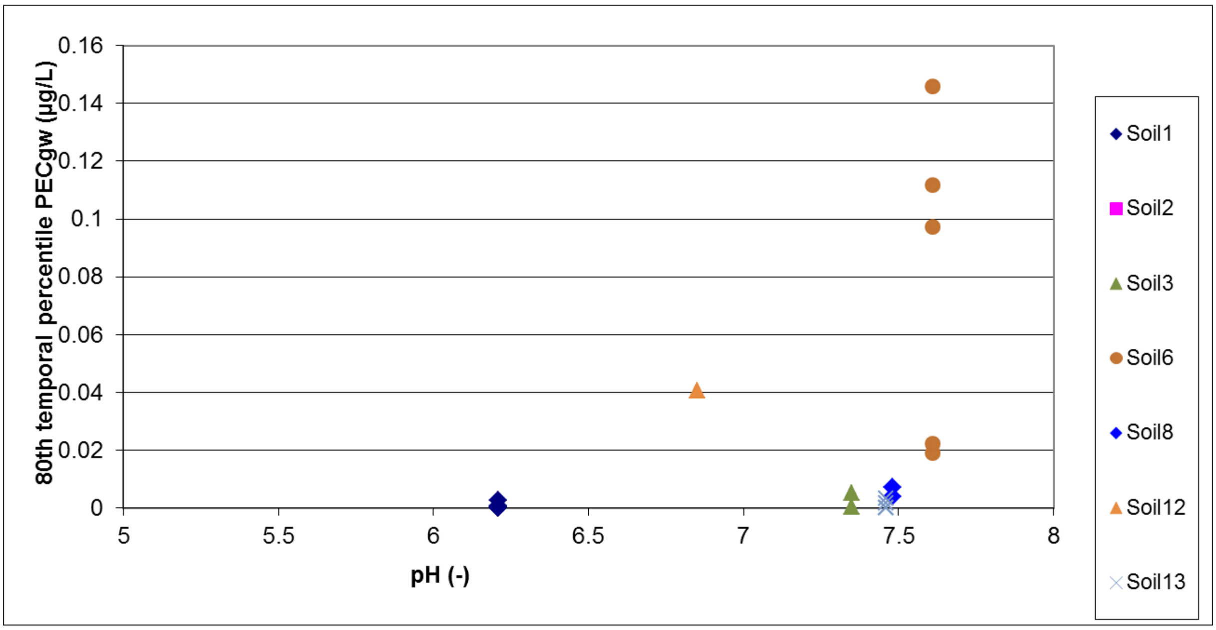


Figure 84 ***80th temporal percentile PECgw vs. the pH-CaCl2 of the 1st soil horizon properties (SubD – Potato)***

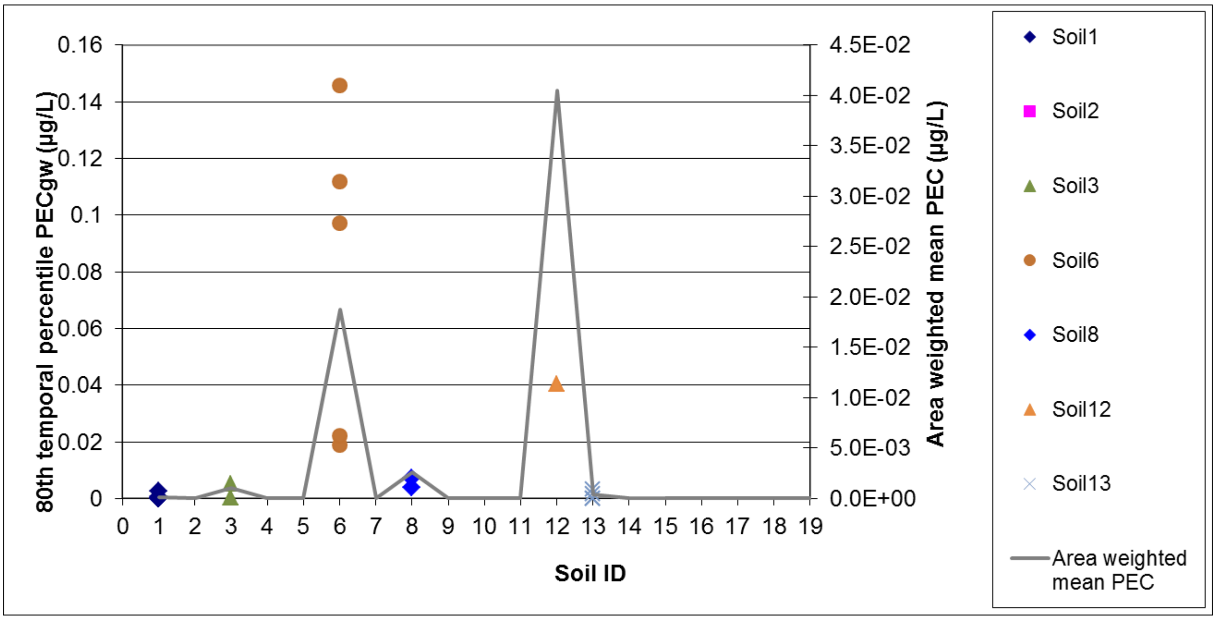


Figure 85 80th temporal percentile PECgw vs. Soil ID (SubD – Potato)

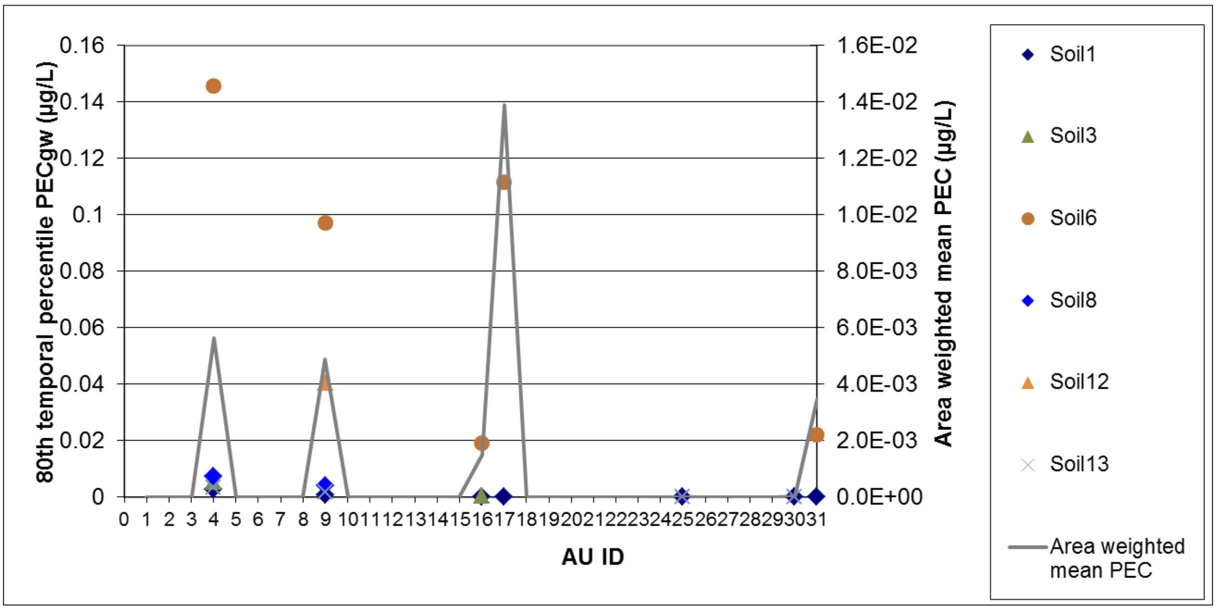


Figure 86 80th temporal percentile PECgw vs. AU ID (SubD – Potato)

10.4 Conclusions

Test runs were conducted with two dummy substances (Substance C + Metabolite C and Substance D) to compare results with the standard FOCUS scenarios and evaluate potential mitigation measure proposals. The results of these reference runs are provided with the FROGS package.

The five examples presented in this chapter demonstrate that FROGS can provide useful information to determine the most critical parameters for a given substance and application scenario and to propose mitigation measures based on simple soil characteristics if the target protection goal is not met.

Soils 19, 12, 9 and 6 appear to be the most vulnerable soils. Soil 19 and 9 are both characterized by a high sand content (83.8% for soil 19 and 64.9 % for soil 9) leading to the highest hydraulic conductivities (Ksat) of the 19 FROGS soils. Soil 12 is characterized by an organic carbon content below 1% in 19 AUs out of 31, and soil 6 is characterized by an available water capacity below 100 mm.

The results obtained also indicate that climate variation and different rotations (represented by the different AUs) are much less critical than the inherent soil properties as there was no clear relation seen between the AUID and the PECgw.

However, these conclusions are based on a limited number of test runs and additional work is needed to investigate the overall sensitivity of the FROGS scenarios.

Finally, Table 52 provides an overview on results in terms of 90th percentile PECgw values from the full set of demonstrative test runs conducted with FROGS 3.3.3.3 in comparison to results obtained with FROGS 2.2.2.2.

Table 52 Overall 90th percentile PECgw obtained with FROGS 3.3.3.3 in comparison to former FROGS 2.2.2.2 for FOCUS Dummy test substances Substance C, Metbolite of Substance C and Substance D

		overall 90th percentile PECgw (µg/L)		
	FROGS	**Dummy C**	**metabolite Dummy C**	**Dummy D**
SB	2.2.2.2	1.444E-07	3.760	0.0077
	3.3.3.3	3.634E-05	5.008	0.0262
WW	2.2.2.2	1.452E-05	6.178	0.0825
	3.3.3.3	4.217E-05	7.046	0.0980
OSR	2.2.2.2	2.014E-05	4.234	0.0393
	3.3.3.3	1.981E-06	4.154	0.0276
MF	2.2.2.2	4.126E-07	4.452	0.0077
	3.3.3.3	6.594E-08	3.857	0.0032
MG	2.2.2.2	1.337E-06	5.129	0.0130
	3.3.3.3	1.529E-07	6.772	0.0065
WB	2.2.2.2	2.167E-05	7.432	0.1150
	3.3.3.3	1.423E-05	7.467	0.0844
PO	2.2.2.2	5.300E-06	3.326	0.0112
	3.3.3.3	1.453E-05	3.840	0.0198
SF	2.2.2.2	1.162E-06	3.921	0.0095
	3.3.3.3	3.902E-06	3.299	0.0080

slightly red colour indicates higher PECgw obtained with FROGS 3.3.3.3 whereas slightly green colour indicates lower results obtained with FROGS 3.3.3.3 in comparison to FROGS 2.2.2.2

11 FROGS 3.3.3.3 - Performances and Limitations

The objective of this chapter is to give an overview of the performances and limitations of the FROGS 3.3.3.3 system resulting from the choices made during the construction and parameterization of the national scenarios, from the choice of groundwater model associated to the scenarios, and from the FROGS tools themselves. The advantages and drawbacks inherent to the data collection and use decisions made in the different domains of interest for building the scenarios (soil, crops, weather), and advantages and drawbacks of the various modeling tools are explored. This review is also aiming at clarifying the tasks to undertake in priority to enhance the capabilities of the FROGS system.

11.1 Data collection and use

The performances and limitations of the FROGS system are directly related to the availability and quality of information used to construct the scenarios, regarding land use, soils and weather. In addition, the temporal variability of this information needs to be addressed, in particular regarding how often the databases are updated and whether this would warrant an update of the scenarios themselves.

11.1.1 Land use

The concept of agronomic unit (AU) refers to geographic areas considered as homogeneous with regard to soil occupation by agricultural activities and environmental conditions. It is similar to the concept of cropping basin except that it is defined in the strict context of groundwater risk assessment.

The rationale used to build the agronomic units is two-fold since it uses statistics of land use by crops and information on environmental conditions, both domains being not independent one from the other. The zoning of agronomic units was achieved without a considerable investment in data acquisition, by making use and consolidating existing zoning information on various criteria (weather, environment, crops, etc.).

AU zoning represents a simplification of reality with unavoidable information loss. What is lost in this process is the range of variation of crop and environmental characteristics which is already partly hidden in the zoning used in the AU construction. A set of 722 PRAs (PRA: “Petite Région Agricole”, “Small Agricultural Region”) forms the building blocks of this construction. PRAs are grouped into AUs using similarity criteria for land use and weather pattern. The number of PRAs is indicative of the diversity of agricultural and environmental conditions at county scale. PRA grouping according to environmental criteria is achieved using the Hydro-ecoregion zoning (Wasson et al. 2002), which is based on robust geomorphology determinants. One assumes that this necessary simplification resulting from PRA aggregation can be overlooked compared to the differences which discriminate the AUs between themselves. In other words, the AU zoning is based on the assumption that the intra-AU variation is significantly lower than the inter-AU variation.

The geographic contours of the agronomic units do not need to be accurate since what matters is the description of representative agricultural activities and environmental conditions. The delineation of the agronomic units could be improved in certain areas where uncertainties are remaining. However, such corrections are considered as minor and are not likely to induce significant changes in the overall system.

The agronomic units are effectively representative of typical situations, which are mostly the result of expert judgment rather than the output of data processing techniques. The range of conditions included in an agronomic unit made of a set of PRAs is difficult to apprehend and quantify since the PRA zoning itself results from expert judgment. As a result, one cannot be sure that the difference between two adjacent agronomic units is significantly greater than the range of variation within the AUs or within the PRAs that constitute these AUs. Better understanding and more accurate determination of the range of parameter variation within the AU should help in estimating to which degree the risk is covered when assessed using only a limited number or typical situations. It would also give hints on whether a refined assessment may be needed using more accurate information.

Information on representative soil types is not directly part of the agronomic unit concept, although geological and pedogenesis homogeneity are inherent to the PRA and Hydro-ecoregion zoning and therefore to the AU zoning. Nevertheless, a large and systematic variation in the agronomic units comes from the soil description, i.e. AU are not supposed to be homogeneous regarding soil types. The soil selection process was handled separately by experts in the domain (INRA Infosol), and it is clear from the number of selected soil types allocated to each AU that soil heterogeneity is accounted for. While contrasted situations present within the AUs like plateaus and alluvial plains are not apparent anymore from the scenarios (there are no plateau or alluvial plains scenarios), such situations are still taken into account in the risk assessment through the corresponding soil types, provided they represent a significant cultivated surface in the AU. For example, there are 2 fluvisols among the 18 representative soil types, which would cover alluvial plains.

Given the geographical nature of the AUs, the AU zoning as homogeneous entities is expected to remain stable in time, at least on the short-term and mid-term (decades). Environmental characteristics should remain fairly stable, unless significant climate changes occur, which could in turn affect land use (based on hydrology and temperature condition changes). Cropping characteristics do evolve in time based on technological and economical trends, but this is unlikely to affect the AU zoning at any significant extent in the short to mid-term. Indeed, the PRA zoning dates from 1946, and following some initial administrative modifications, has not changed since 1987. Similarly, the hydro-ecoregion zoning is considered as a stable zoning based on homogeneous and stable geological, relief and climatic parameters.

11.1.2 Soils

11.1.2.1 Selection of soil types and profiles

A strong constraint in the construction of national scenarios is the availability of soil descriptive information covering the entire cultivated area. The only available data fulfilling this requirement at this time is the soil map at a scale 1/1000 000 (BDGSF). The limitations of the soil description are outlined in the Discussion section (page 19) of the INRA document describing the soil selection process (Morvan and Le Bas, 2006).

The limitations result both from the content of the BDGSF database itself and from the soil selection process: simplified soil description using five texture classes only and inability to locate the Soil Type Units (STUs) within the Soil Mapping Units (SMUs). Nevertheless, the method used by INRA to select the soil types is fully justified considering the material available. In line with the initial objectives, the result is a set of 19 soils, which is a considerable simplification of the overall diversity of soil types but still should cover most of the variation of typical agricultural soil characteristics.

Consequently, each selected soil-type represents a set of STUs, which is then covered by a single representative soil profile. The choice of the profiles in the INRA database is another important step in the scenario parameterization process. The profiles which correspond to a particular STU show variations in terms of thickness of the horizons and texture composition. The selection of one profile among a set of available profiles from different STUs was made in a rather empirical way, aiming for average rather than extreme characteristics. The selected profile is certainly representative of the population of available profiles, however one may not assert that it corresponds to an actual average situation since 1) the set of available soil profiles was relatively limited and not evenly distributed geographically, and 2) the selection was performed based on expert opinion rather than statistical distributions of the relevant soil parameters.

The selection process also implied that selected soil types and corresponding soil profiles are the same in the different agronomic units. To better reflect the major soil types of each agronomic unit, one could consider using a different representative soil profile per agronomic unit, however this was not possible due to the limited number of soil profiles in DONESOL and disparity of their geographical distribution. One step in the direction of proposing different soil profiles depending on the AUs was made by further looking at the critical parameter of organic carbon content, as discussed below.

While soil types are set and soil characteristics do not evolve significantly on the short to mid-term (apart maybe from surface organic carbon content, which is discussed later), the databases used for the selection of soil profiles are continuously updated with new data. The new Agricultural census (Agreste, 2010) highlighted no major changes in the crop acreage and distribution and does not lead to a need to update the soil selection. More importantly, the soil databases were updated, and in particular DONESOL, which at the time of INRA Orléans work for SSM / ComTox contained about 7000 soil profiles, has in the meanwhile been extended to over 13000 soil profiles. This may still not be sufficient for a comprehensive selection of representative soil profiles in the different AUs, but could warrant a re-evaluation of the soil profiles in the short-term.

11.1.2.2 Location of soils in the agronomic units

The location of the soils within the agronomic units is not known. The surface of the soils in the agronomic units was estimated by INRA. As stated above, the location of the STUs within the SMUs is not possible. In addition, since each selected soil represents a number of STUs, sometimes large, the delineation of the contours would be in any case misleading. This is also true for more accurate soil maps, which most often describe associations of soils, not single soils. A direct implication of the fact that the selected soil types cannot be located is that no direct link can be established between STUs and land use. Nevertheless, the method of selection minimized the selection of soils which are not significantly cultivated, thanks to the use of agricultural statistics (Agreste, 2010) and soil occupation (CORINE Land Cover 2000), so it is clear that selected soils are representative of cultivated land.

Another direct implication of the impossibility to locate the soil types within the AUs is that it makes the link with aquifers rather difficult. Consequently, the link with aquifers (regarding presence and type) is not covered in FROGS, but may be considered in a higher-tier refinement if necessary.

11.1.2.3 Soil organic carbon

As already mentioned and as noted by INRA (Morvan and Le Bas, 2006), the geographic distribution of the available soil profiles corresponding to the selected soil types is not homogeneous. A high number of these profiles are located in the Centre region where the organic carbon content (OC) is depleted by intensive farming practices, the decline of the OC content being mostly the result of tilling practices (deep ploughing). Consequently, the OC content of the selected soil profiles is relatively low compared to the real situation in agronomic units located outside the area of depleted OC. For realism purposes, there was a clear need for correction of the OC content of the top soil layer, especially considering the importance of this factor in the retention and mobility of pesticide substances.

The procedure for adjustment of the OC content of the top soil layer is described in details in Chapter 8.1 of this document. A correction factor is calculated for each agronomic unit and applied to all soils in the unit, so that the global OC concentration at this scale matches the average OC content determined using data of soil analysis in the same geographic zone (BDAT). The correction is based on actual measurements of characteristics of cultivated soils, independent from the database used to select the soils.

Although this correction might appear artificial, it is justified thanks to the realism of the BDAT data and the rationale of the procedure. Among various possible methods, the corrections use OC median values to minimize the influence of extreme data. The data are weighted by surface, in order to best estimate average values as characteristics of typical situations.

The OC correction is achieved at the scale of individual agronomic units using a specific correction factor per unit. The correction is the same for each soil in the unit since a specific correction factor could not be estimated for each soil individually. After OC correction, soils are defined specifically for each agronomic unit, even though the soils of the same type differ only on the OC adjusted content.

Considering this new set of soils, it would have been more logical to select profiles of the different soil types specifically within each agronomic unit, in order to avoid smoothing of the variation of characteristics between the agronomic units and the need for OC correction. Once again, this was not possible at the time since the availability of soil profiles for each agronomic unit is the limiting step of the method.

The OC correction was conducted using the data from the 2000-2004 period. Surface organic carbon content is known to evolve with time, as it is very much affected by the farming practices, as discussed above regarding the Orléans region. The BDAT OC data from 2000-2004 were compared to the latest available data from 2005-2009 (INRA, 2013). As the distribution of the OC content from 200-2004 and 2005-2009 are very similar, the use of the 2000-2004 data is still considered adequate.

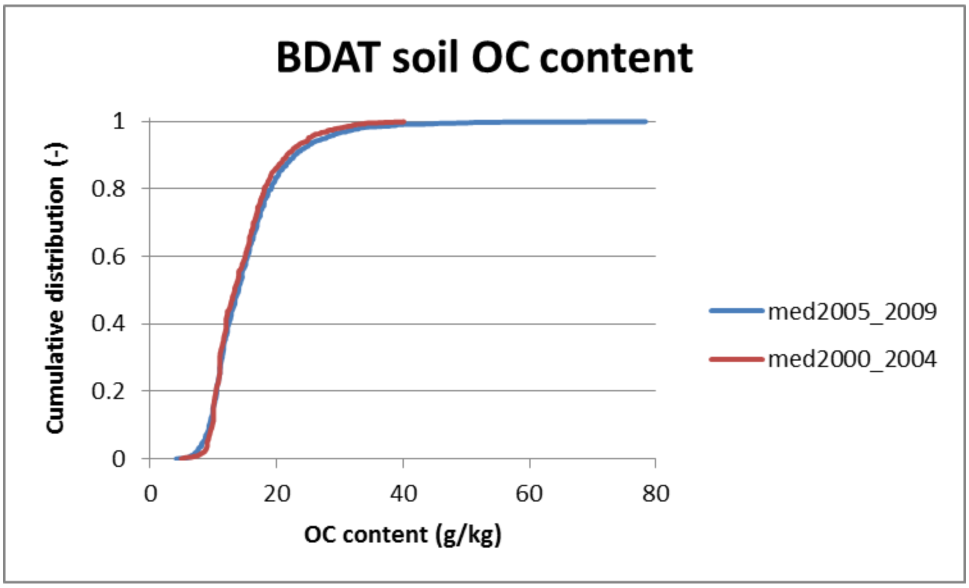


Figure 87 Comparison of BDAT soil OC content from 2000-2004 period and 2005-2009 period

11.1.2.4 Soil types and crops

The proportion of the total surface covered by each of the 8 crops is known for the 19 soils at national level. However, the surface of crop cultivated on each soil in the agronomic units may currently only be estimated as explained in Appendix 15 and the relationship between crops and soil type was also considered as an exclusion criteria, to eliminate unrealistic crop-soil combinations.

The relationship between crops and soils might originate from specific physiology requirements. For instance, water supply is a key factor in sugar beet cultivation so that the crop is excluded from areas where the water holding capacity of soil is not sufficiently high, except if irrigated. Furthermore, stony soils are not suitable for all crops for quality purposes. Concurrently, the presence of certain crops is more likely on soils responding to specific characteristics. The typical rotation oilseed rape – winter wheat – barley is frequently found on soils which suffer from summer drought, the crops being harvested at the time the soil water storage is totally depleted. Local soil – crop relationships are known by agronomists but are not taken into account in the system. Hence, particular combinations of soils and crops could be not representative for particular AUs. Hence caution should be exercised when such combinations appear that would in addition represent conditions conducive to leaching.

Cropping characteristics do evolve in time based on technological (e.g. oilseed rape for biofuel) and economical (market pricing) trends. This is true at national level (overall surface associated to a given crop), but also at local or AU level, with some crops becoming more or less predominant regionally. The overall proportion of surface covered by the crops was obtained based on the 2000 CORINE Land Cover database, which has since been updated with the 2006 CLC, but the 2000 data were deemed more relevant for use in association with the 2000 agricultural census. Changes in cropping characteristics compared to the 2000 data were monitored vs. the 2010 census data and no implemented in the FROGS database.

11.1.3 Weather

Meteorological data in FROGS are taken from the MARS database, which is widely accepted in the European scientific and regulatory community. The selection of a representative tile for each AU was performed based on agricultural occupation as primary selection criteria, meaning that the tile representing the most agricultural surface in the AU was selected. Additional criteria such as variability of climatic conditions within the AUs and proximity to mountains or sea were also considered. Keeping in mind that one of the underlying principles of the scenario construction process was to cover a variety of normal, realistic conditions rather than worst-case situations and given the limiting step of the soil selection, which prevented true GIS scenarios, the selection of a single MARS tile per AU is justified and the variability of weather situations considered with the 31 different weather tiles corresponding to the 31 AUs is deemed sufficient for the level of detail considered in FROGS. In case preferential flow is included in a future FROGS version the current implementation of the meteo data may need to be reevaluated. The system is also flexible enough that additional MARS tiles may be taken into account if refined modeling is required in a higher-tier to further evaluate particular vulnerable conditions highlighted with the FROGS 3.3.3.3 scenarios.

The scenarios cover a 26-year period of meteorological data, from January 1, 1981 to December 31, 2006, with the first 6 years for the warm-up of the model regarding soil hydrology, and pesticide applications over the next 20 years (or 40, 60 or 80 for 2-, 3 or 4-year rotations, with the same 20 years of data repeated). This time period is sufficiently recent and long to be considered representative and include a wide variety of conditions. Unless major climate changes are documented, it is not deemed necessary to update these data in the short to mid-term. The weather files were not updated in FROGS 3.3.3.3.

11.1.4 Crops

The FROGS system is developed for 8 major arable crops in France. It is the intention of the work group to explore the inclusion of further crops into FROGS, the primary focus being put on the major perennial crops, vineyards and orchards. The extension to other minor arable crops could also be contemplated on a longer term.

Thanks to a versatile design, new arable crops can be easily included by documenting the relevant tables of the Access® FROGS.mdb database. The system architecture makes the inclusion of perennial crops also possible. Once again, the difficulties are on the side of scenario construction: data collection, definition of typical situations and corresponding parameterization. The method used for the first 8 crops as described in this document is applicable to other crops, providing sufficient information is available. However, the development of scenarios for perennial crops, vineyards and orchards, is likely to call for specific information, particularly soils, considering the particular environmental conditions of vines and tree cultivation. It is not clear whether the soil selection method used for arable crops is applicable to perennial crops.

With the possibility to define rotations with one or several target crops, product use can be evaluated in very realistic conditions. The crop rotations at AU level were selected based on local expert knowledge and backed up by probabilistic calculations based on AGRESTE information. These are therefore considered realistic enough even though some variability within the AUs may be lost.

Although a particular effort was devoted to the collection of crop data at the scale of AUs, comprehensive information could not be achieved for all AUs. Hence, FOCUS information was used in the parameterization of crop parameters for a number of crop – AU combinations. According to the AU considered, data from the Châteaudun or Piacenza FOCUS scenarios were used for crop dates (emergence, harvest dates in tblCropDates). Complementary information on crop dates may be accessible in the short term to replace these default FOCUS values. Modeling calls for a number of crop parameters which values are not accurately known unless by default (e.g. LAI, Crop factor, Rooting depth in tblCropPar). Unfortunately, specific information for these parameters is scarce and could not be adequately customized as a function of AUs and soils. Quality improvement of these crop parameters is strongly dependent on information availability.

Some local changes in rotation trends with time may occur depending on socio-economic considerations (e.g. increase of acreage of industrial crops for biofuel). Such changes may over time result in different typical rotations than selected in FROGS 3.3.3.3 on the basis of local expert knowledge and 2001 AGRESTE data. It is therefore recommended that the selected rotations be checked again in the mid-term against updated AGRESTE information. If changes are warranted, these could easily be implemented in a further version of the FROGS tools.

11.2 Modeling tools

The FROGS tools were designed in a way that all available options of the selected leaching model may be used, that all parameters specific to the FROGS scenarios may be accessible to the user through the Access® FROGS.mdb database, and that additional scenarios may be implemented within the tool. The FROGS tools are therefore flexible and versatile, and the scenario parameterization fully transparent.

In terms of modeling capabilities, the technical performances and limitations of the FROGS system are for the most part directly linked to performances and limitations of the leaching model to which it is associated.

11.2.1 Choice of associated leaching model

The selection of representative weather, soil, crops and crop rotations for the FROGS scenarios is not model-specific. The limiting step in the current scenarios is the description and parameterization of the soil hydrological processes. Description of the soil hydrology processes is also one of the major points of distinction between leaching models, e.g. preferential flow vs. chromatographic flow, tipping-bucket vs. Richard's equation. Based on the available soil data, the FROGS scenarios could be implemented in any chromatographic-type leaching model. The current parameterization of FROGS 3.3.3.3 was performed for the Richard's based model PEARL 4.4.4, including the relevant Mualem-van Genuchten parameters, but parameters for tipping-bucket models (PRZM / PELMO) may be relatively easily determined. In this version of the FROGS system, no parameters were determined for preferential flow, and it is not clear if sufficient information would be available from the DONESOL database to determine such parameters. Pedotransfer functions could potentially be used to estimate some or all of the preferential flow parameters required for macroporous flow models such as MACRO or the upcoming version of PEARL, but these should first be tested and validated on representative French soils to make sure they are applicable before including in FROGS.

The current version of the PEARL model as used in FOCUS, FOCUS_PEARL_4.4.4, includes a fully flexible pesticide metabolism scheme working for any number of metabolites and any route, and options such as pH-dependent sorption or aged sorption. All these features of the PEARL model are also fully operational in the FROGS system. Any new options or changes implemented in a new future version of PEARL may first require testing and implementation in a future version of FROGS, especially if new parameters are required.

The use of the PEARL model also means that some limitations of this model also apply to FROGS:

- The use of a crop calendar and agricultural year concept in PEARL implies that some of the emergence and/or harvest dates in the FROGS crop rotation scenarios had to be adapted as described in chapter 3.4.

Some other restrictions (splitting of rainfall due to collapsing of the former version of PEARL's hydrologic modul SWAP in case of extraordinariy high rainfall events combined with soil characterized by low hydraulic conductivity or the former restriction to maximum 3-year crop rotations due to a limit of maximum 70 simulation years in the former SWAP) that applied to the former FROGS 2.2.2.2 could now be avoided.

11.2.2 Specificities of the FROGS tools

While in the standard FOCUS scenarios the selected output is the average predicted concentration in leaching water at a reference depth of 1 meter, the output in the FROGS scenarios is the concentration in the leaching water at the bottom of the soil profile, which range from 40 to 140 cm depending on the soil. In both cases, these output concentrations at target depths should only be viewed as indicator of the exposure to ground water and are not to be confused with actual concentrations in the saturated zone or groundwater table.

One feature of the FROGS interface that is in addition to the standard FOCUS parameterization is the scheduling of pesticide applications relative to the crop development. This feature allows to describe the pesticide application scenario in full accordance with the BBCH growth stages as specified in the GAP, and to take into account spatial (from 1 AU to the other) and temporal (from 1 year to the other) variations in function of the meteorological conditions, where the application would be performed every year at the same time in FOCUS.

The FROGS GUI offers limited post-processing of the output concentrations, such as a graphical depiction of the surface aerial distribution of the 80th percentile average concentration at the bottom of the profiles. Further post processing, e.g. output concentration in function of specific critical scenario parameters (surface OC content, pH, available water content, sand content, AUID or soil ID) is possible using the Microsoft Excel® template ("FROGS_Template_ Mitigation.xls") included with the FROGS package which has been updated for FROGS 3.3.3.3 compared to earlier versions to include pH as a potential mitigation. Furthermore, this tool enables the user identify key characteristics which are responsible for e.g. extraordinary high PECgw values. Consequently, the user can test different mitigation strategies that support safe use of a PPP.

11.3 Perspectives

The construction of national scenarios was moved by a constant concern for realism in the description of the agronomic, soil and climate situations. Consequently, evaluations can be made in conditions reflecting faithfully the product use pattern. Simulations using these scenarios provide a distribution of the PEC_{gw} which cover a diversity of typical situations in the cultivated area. These results, weighted by surface, represent an estimate of the degree of safety of a product use.

Considering the characteristics of certain soils, and in case of products exhibiting a significant potential for movement in soil, combinations with weather conditions are probably conducive to PEC_{gw} values higher than 0.1 µg/L. Expressing and interpreting the distribution of the PEC_{gw} as a function of factors of influence on leaching, such as organic carbon content of the top soil layer, water holding capacity of the profile, etc. also gives the possibility to define workable risk mitigation measures. The efficacy of these measures can also be evaluated with the system.

Sensitivity and uncertainty analyses of leaching model and scenarios may prove useful in order to determine which scenario parameters have the most impact on the calculated PEC_{gw} and should therefore be refined in priority. Dubus & Brown (2002) and Dubus et al. (2003) performed sensitivity analyses of the four pesticide leaching models originally used in FOCUS, including PESTLA, a precursor of the model PEARL, and performed a first-step uncertainty analysis for the model MACRO. These studies showed that water flow as predicted by the models were mostly affected by meteorological variables, while pesticide losses were most sensitive to pesticide input parameters related to sorption and degradation, and in some cases could also be very largely affected by the soil hydrological properties. These conclusions should likely also apply to PEARL. Sensitivity and uncertainty analyses specific to FROGS were not performed, as these evaluations were beyond the scope of the working group. Care was taken to reduce uncertainty regarding critical parameters, such as the soil organic carbon content, or sensitive areas, such as application timing, by use of refined data and models. However, there are many model parameters of which impact on calculated PECgw is not yet explored. Therefore the workgroup welcomes scientific initiatives to quantifiy sensitivity and uncertainty associated with the generic approaches used in modelling systems like FROGS.

Some of the above-mentioned limitations of the FROGS 3.3.3.3 system can reasonably be overcome thanks to an improved parameterization based on descriptive information of better quality in the domains of interest for scenarios. Many weaknesses result mainly from the soil part which already needed to be fixed (OC content). About five years after the start of the national scenarios project, information of better quality has become available, which offers serious perspectives to overcome some of the present limitations regarding soil selection and enhance the system performances. These can be foreseen in the context of a future version of the system.

11.4 References

Base de Données Analyse des Terres (BDAT): INRA Unité Infosol, Orléans. http://www.gissol.fr/programme/bdat/bdat.php

CORINE Land Cover (CLC) database:
http://www.ifen.fr/bases-de-donnees/occupation-des-sols-corine-land-cover.html
http://www.eea.europa.eu/themes/landuse

DONESOL database: INRA Unité Infosol, Orléans.
http://www.gissol.fr/outil/donesol/donesol.php

Dubus I., Brown C. and Beulke S. (2003). Sensitivity analyses for four pesticide leaching models. *Pest Manag Sci* 59:962-982.

Dubus I. and Brown C. (2002). Sensitivity and first-step uncertainty analyses for the preferential flow model MACRO. *J. Environ. Qual.* 31 :227-240.

INRA (2013) Base de Données Analyse des Terres, version 3.3.2.0, 23 Juillet 2013 : http://www.gissol.fr/programme/bdat/bdat.php

Morvan X. and Le Bas C. (2006) Détermination de profils types de sols par regions de culture. INRA Infosol, Orléans.

Wasson J.G., Chandesris A., Pella H., Blanc. L. (2002). Les hydro-écorégions de France métropolitaine. Approche régionale de la typologie des eaux courantes et éléments pour la définition des peuplements de référence d'invertébrés. Programme de recherche HYDRECO (LHQ), Contrat n° 2001 06 9 084 U. Cemagref.

Appendix 1. Number of scenarios per crop, AU and soil profile

Table 53 Number of scenarios per Agronomic Unit

AUID	Agronomic Unit	Number of scenarios
1	Collines molassiques - Lauragais	50
2	Bretagne sud	28
3	Limagnes - Plaine du Forez	30
4	Bordure Nord - Picardie - Normandie	52
5	Alsace - Sundgau	23
6	Plaine normande - Bessin	29
7	Aquitaine - Landes	5
8	Bassin de l'Adour	25
9	Picardie - Nord - Pas-de-Calais	53
10	Charentes	48
11	Bocage normand	33
12	Barrois - Plateaux bourguignons	37
13	Plateau lorrain	27
14	Gâtines - Vallées de Loire	52
15	Sologne - Orléanais	19
16	Champagne crayeuse	47
17	Beauce - Drouais - Gâtinais	46
18	Bordelais - Périgord - Coteaux du Lot	41
19	Perche - Pays d'Auge - Pays d'Ouche	47
20	Bocages de l'ouest	46
21	Ardenne - Argonne - Champagne H.	38
22	Champagne berrichonne - Boischaut	45
23	Bas Dauphiné - Vallée du Rhône	31
24	Fossé bressan	47
25	Bretagne centrale	30
26	Plateaux de Haute-Saône	31
27	Provence	1
28	Plaine du Languedoc-Roussillon	1
29	Boischaut du sud	29
30	Bretagne nord	36
31	Ile-de-France	47
	Grand Total	1074

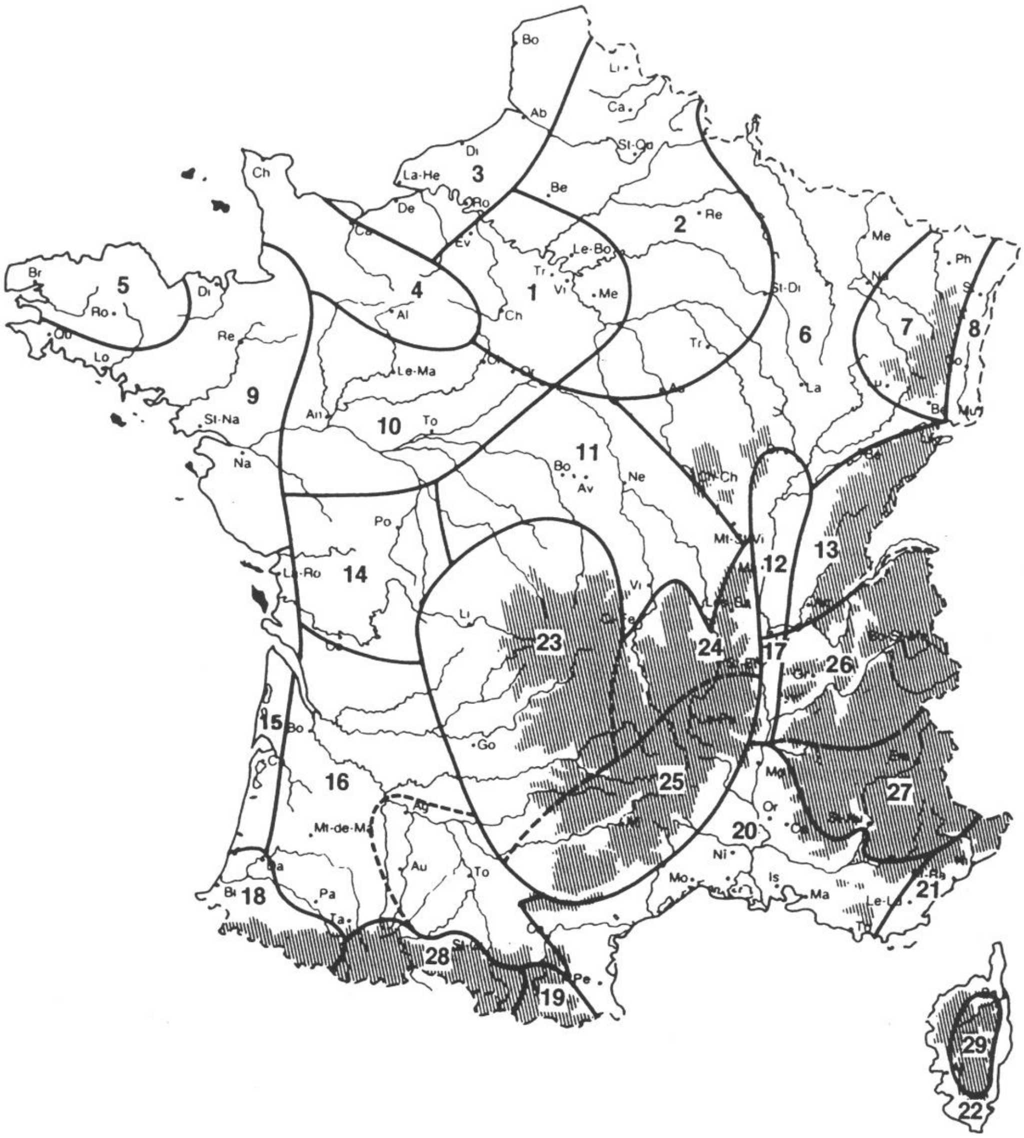
Table 54 Number of scenarios per Soil Type

Soil ID	Number of scenarios
1	129
2	144
3	19
4	94
5	106
6	79
7	2
8	86
9	73
10	2
11	54
12	72
13	81
14	42
15	55
16	3
17	10
19	23
Grand Total	**1074**

Table 55 Number of scenarios per Crop

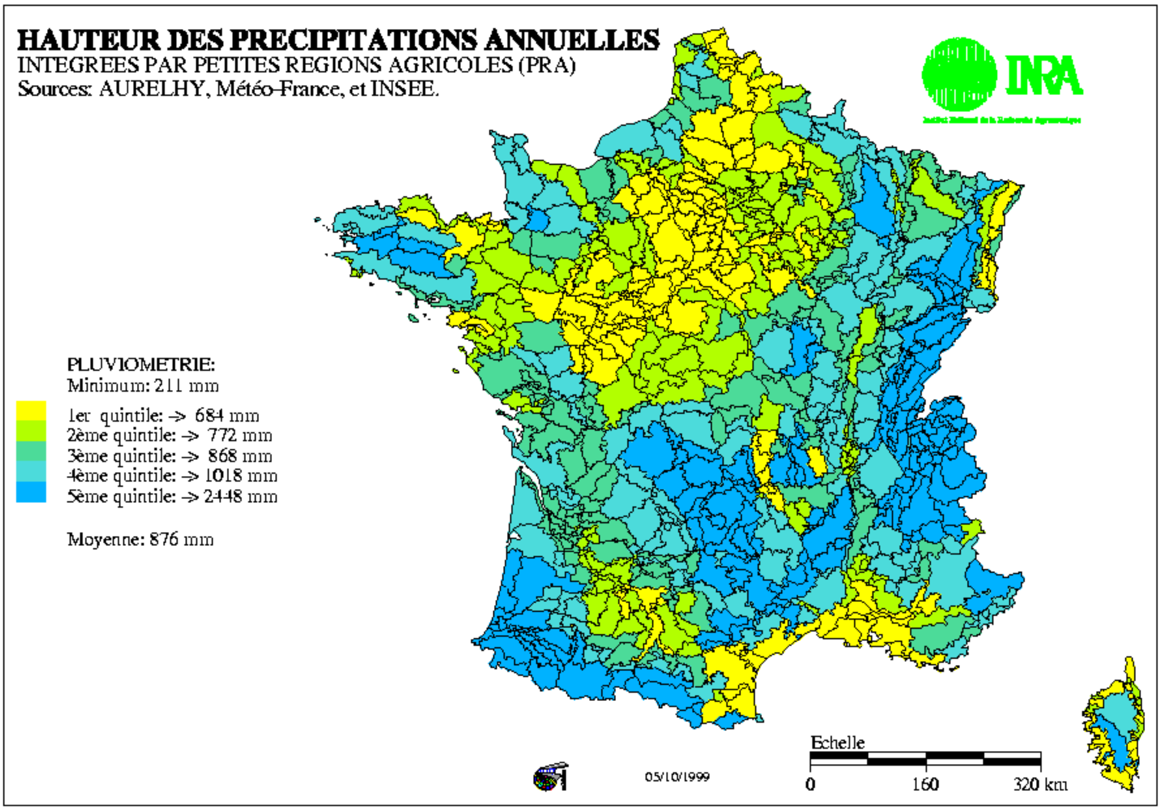
Crop	Number of scenarios
Sugar beet	**46**
Winter Wheat	**219**
Oilseed rape	**162**
Maize fodder	**173**
Maize grain	**200**
Winter Barley	**162**
Potato	**21**
Sunflower	**91**
Grand Total	**1074**

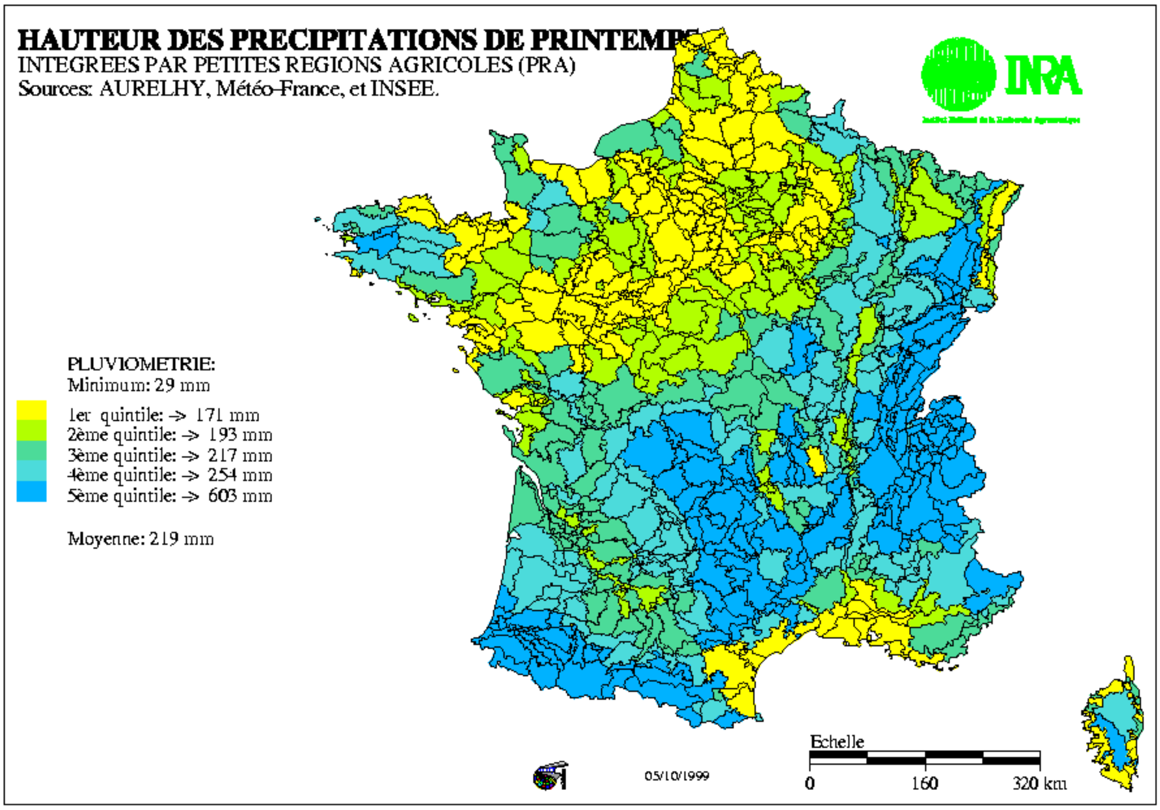
Appendix 2. Agro-climatic Regions

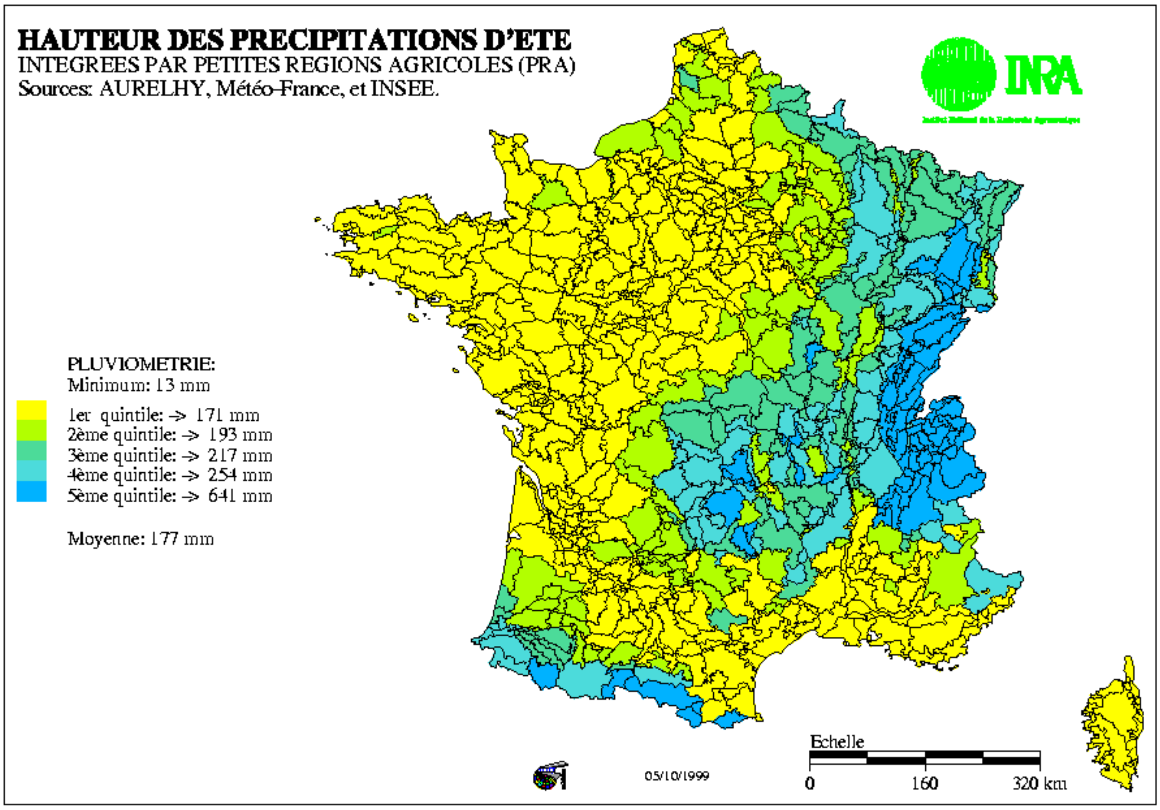


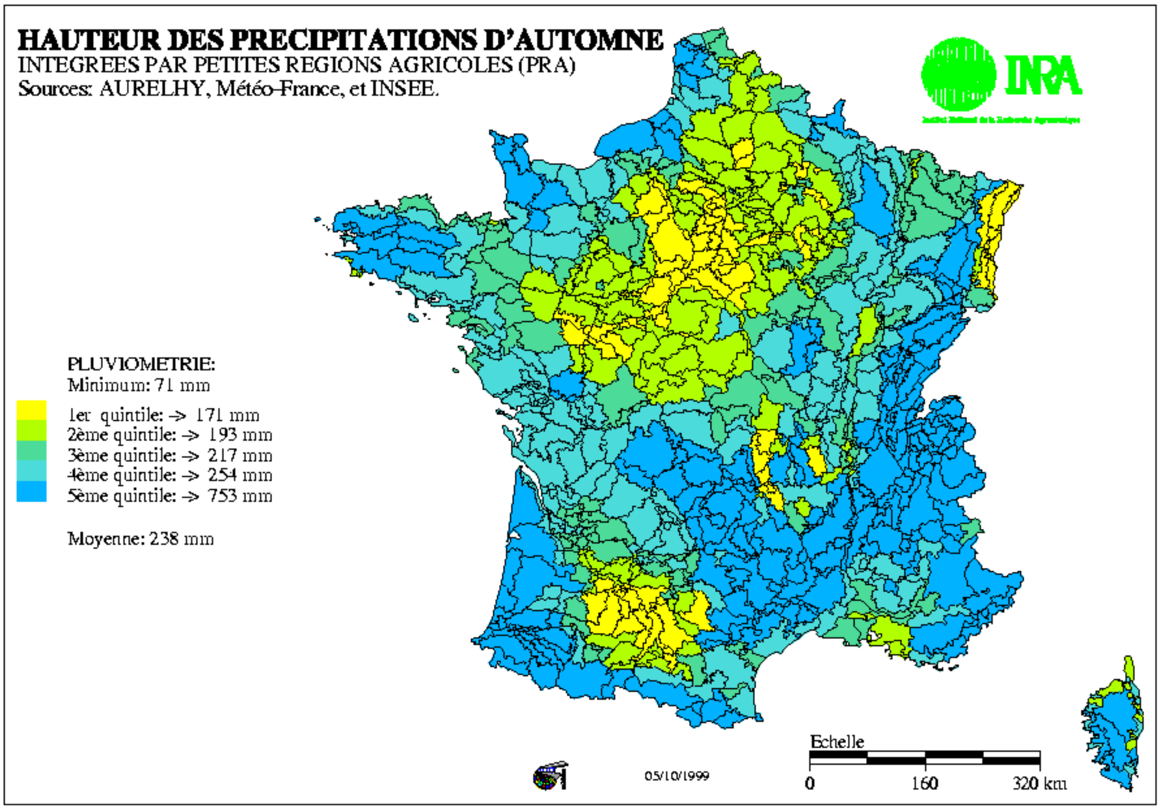
Reference: E. Choisnel (Météo-France) - Agrométéorologie, Techniques de l’ingénieur.

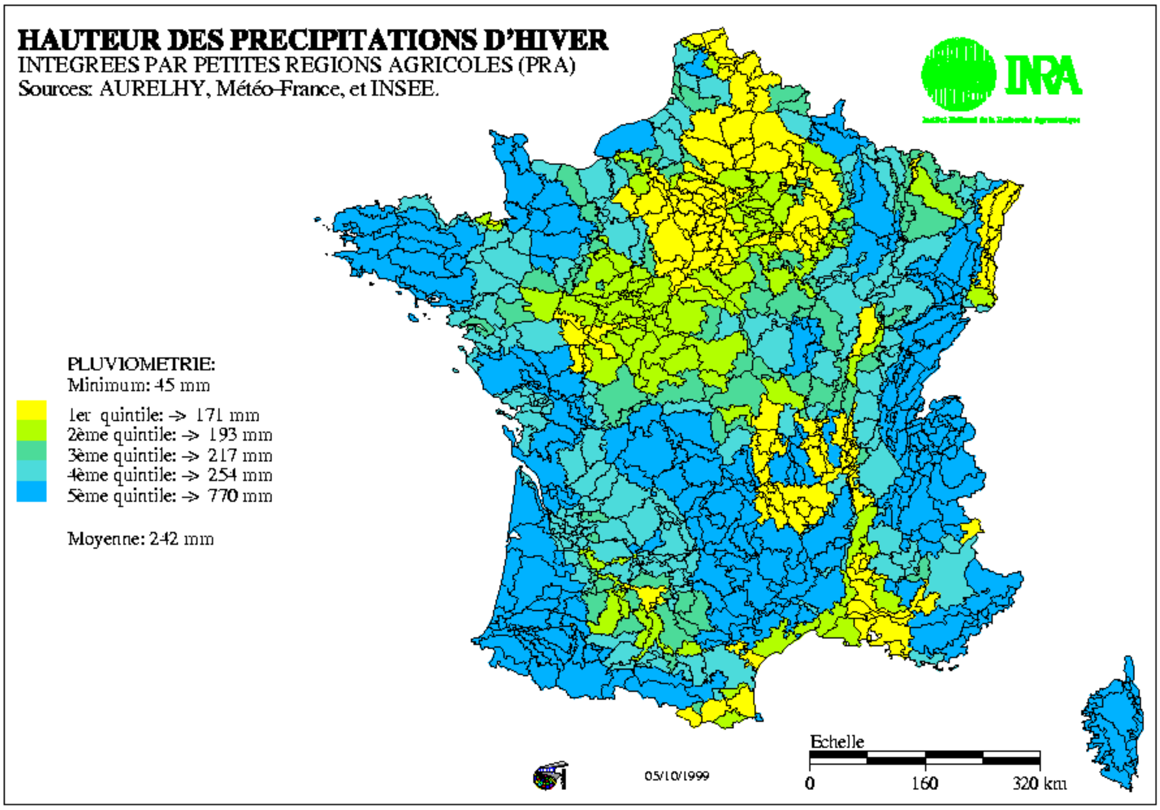
Appendix 3. Map of annual Precipitation Classes agregated by PRA


HAUTEUR DES PRECIPITATIONS ANNUELLES
INTEGREES PAR PETITES REGIONS AGRICOLES (PRA)
Sources: AURELHY, Météo-France, et INSEE.
INRA
PLUVIOMETRIE:
Minimum: 211 mm
1er quintile: -> 684 mm
2ème quintile: -> 772 mm
3ème quintile: -> 868 mm
4ème quintile: -> 1018 mm
5ème quintile: -> 2448 mm
Moyenne: 876 mm
05/10/1999
Echelle
0
160
320 km


HAUTEUR DES PRECIPITATIONS DE PRINTEMPS
INTEGREES PAR PETITES REGIONS AGRICOLES (PRA)
Sources: AURELHY, Météo-France, et INSEE.
INRA
PLUVIOMETRIE:
Minimum: 29 mm
1er quintile: -> 171 mm
2ème quintile: -> 193 mm
3ème quintile: -> 217 mm
4ème quintile: -> 254 mm
5ème quintile: -> 603 mm
Moyenne: 219 mm
05/10/1999
Echelle
0
160
320 km


HAUTEUR DES PRECIPITATIONS D'ETE
INTEGREES PAR PETITES REGIONS AGRICOLES (PRA)
Sources: AURELHY, Météo-France, et INSEE.
INRA
PLUVIOMETRIE:
Minimum: 13 mm
1er quintile: -> 171 mm
2ème quintile: -> 193 mm
3ème quintile: -> 217 mm
4ème quintile: -> 254 mm
5ème quintile: -> 641 mm
Moyenne: 177 mm
Echelle
0
160
320 km
05/10/1999


HAUTEUR DES PRECIPITATIONS D'AUTOMNE
INTEGREES PAR PETITES REGIONS AGRICOLES (PRA)
Sources: AURELHY, Météo-France, et INSEE.
INRA
PLUVIOMETRIE:
Minimum: 71 mm
1er quintile: -> 171 mm
2ème quintile: -> 193 mm
3ème quintile: -> 217 mm
4ème quintile: -> 254 mm
5ème quintile: -> 753 mm
Moyenne: 238 mm
Echelle
0
160
320 km
05/10/1999



HAUTEUR DES PRECIPITATIONS D'HIVER
INTEGREES PAR PETITES REGIONS AGRICOLES (PRA)
Sources: AURELHY, Météo-France, et INSEE.
INRA
PLUVIOMETRIE:
Minimum: 45 mm
1er quintile: -> 171 mm
2ème quintile: -> 193 mm
3ème quintile: -> 217 mm
4ème quintile: -> 254 mm
5ème quintile: -> 770 mm
Moyenne: 242 mm
Echelle
0
160
320 km
05/10/1999

Appendix 4. List of Hydro-ecoregions of Levels 1 and 2

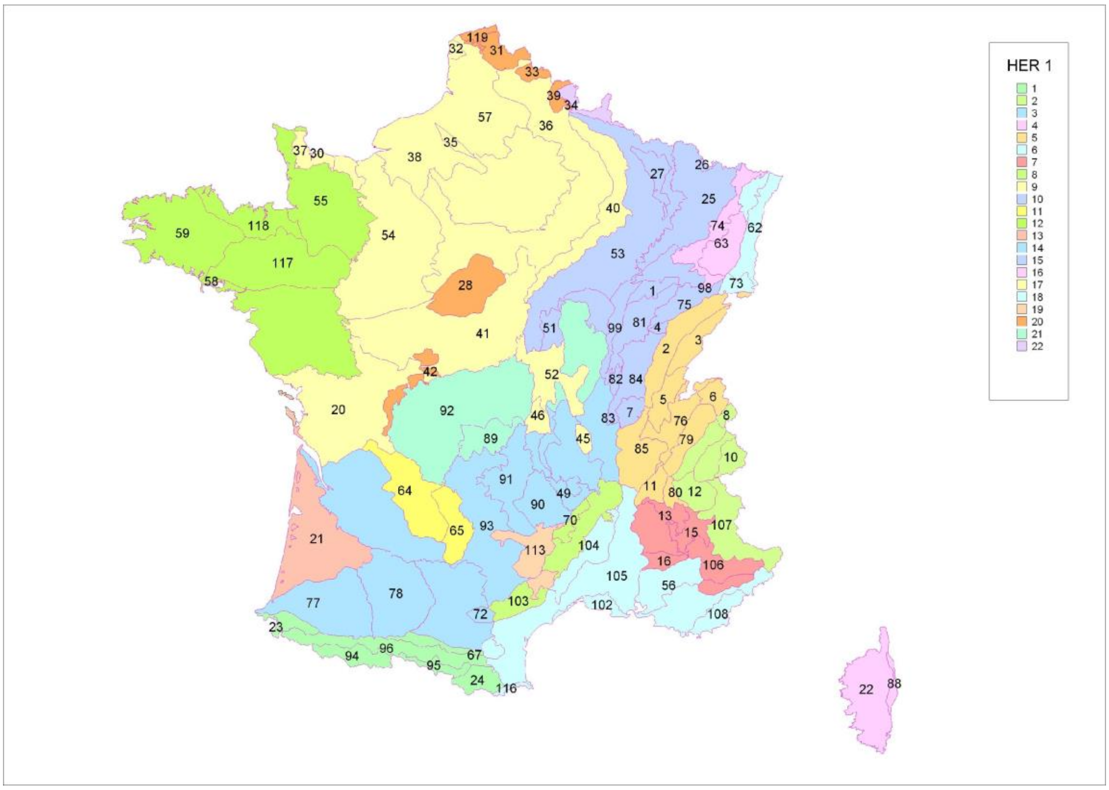
N° HER-1	HER-1	N°HER-2	HER 2
1	Pyrénées	23	Cf. 96 Pyrénées étage montagnard
		24	Pyrénées orientales
		67	Bordure Pyrénéenne centrale
		69	Bordure Pyrénéenne atlantique
		94	Pyrénées étage alpin et sub-alpin occ.
		95	Pyrénées étage alpin et sub-alpin
		96	Pyrénées étage montagnard
2	Alpes internes	8	Massif du Mont Blanc
		9	Massif schisteux Maurienne
		10	Massif de la Vanoise
		12	Massif de l'Oisans
		101	Massif Beaufortain Belledonne
		107	Alpes internes du sud
3	Massif Central Sud	43	MC-Dépressions internes
		44	MC-Terres granitiques orientales
		47	MC-Dépression du Puy
		49	Hautes Terres volcaniques
		50	Hautes Terres granitiques orientales
		72	Montagne noire
		86	Mont du Lyonnais - Pilat
		90	Hautes Terres granitiques
		91	Hautes Terres volcaniques humides
		93	MC versant occidental
4	Vosges	63	Vosges granitiques
		74	Vosges gréseuses

N° HER-1	HER-1	N°HER-2	HER 2
5	Jura - Préalpes Nord	2	Jura premier plateau
		3	Jura nord
		5	Jura sud
		6	Massif Chablais Giffre
		11	Vercors nord
		76	Piedmont Alpes Jura
		79	Massifs calcaires Chartreuse Aravis
		80	Vallée du Drac
		85	Collines du Bas Dauphiné
6	Méditerranée	56	Collines de Basse Provence
		102	Plaine littorale méditerranéenne
		104	Garrigues sub-cévenoles
		105	Plaine méditerranéenne
		108	Maures Esterel
		112	Collines calcaires de Basse Provence
		114	Corbières
		116	Bordure orientale des Pyrénées
7	Préalpes du Sud	13	Dévoluy Vercors sud
		14	Préalpes drômoises - Baronnies
		15	Gapençais Embrunais
		16	Plateau calc. de Provence - Ventoux
		17	Plateaux calcaires de Provence
		106	Préalpes Digne - Haute vallée du Var
8	Cévennes	70	Haute Loire cévenole
		71	Cévennes
		103	Montagne Noire climat cévenol
		115	Causses cévenoles

N° HER-1	HER-1	N°HER-2	HER 2
9	Tables calcaires	30	Pays de Caen
		32	Boulonnais
		35	Pays de Bray
		36	BP-Ile de France
		37	Cotentin est
		38	TC-auréole crétacé
		40	Champagne humide
		41	Tables calcaires sud Loire
		54	TC-nord Loire-Perche
		57	TC-Haute Normandie Picardie
		97	TC-Charentes Poitou
10	Côtes calcaires Est	1	Plateau calcaire Haute Saône
		25	Plateau lorrain
		26	Bassin de Forbach
		27	Plaine de Woëvre
		51	Bazois Auxois
		53	BP-Côtes calcaires
		75	Collines de Haute-Saône
		82	Côtes de Macon
		98	Collines sous-Vosgiennes
		99	Côtes de Bourgogne
11	Causses calcaires	64	Collines Calcaires de Dordogne
		65	Causses du Quercy
12	Armoricain	55	MA-nord est
		58	MA-sud intérieur
		59	MA-ouest
		60	MA-est intérieur
13	Landes	21	Landes

N° HER-1	HER-1	N°HER-2	HER 2
14	Coteaux aquitains	66	Coteaux molassiques nord Aquitaine
		68	Coteaux molassiques est Aquitaine
		77	Coteaux molassiques bassin Adour
		78	Coteaux molassiques centre
15	Plaine Saône	4	Forêt de Chaux
		7	Dombes
		81	Plaine de Bourgogne
		84	Bresse
16	Corse	22	Corse
		88	Corse plaine d'Aléria
17	Dépressions sédimentaires	45	Plaine du Forez
		46	Limagne de l'Allier
		52	Fossés tectoniques
18	Alsace	61	Alsace - collines
		62	Alsace - plaine
		73	Collines du Sundgau
19	Grands Causses	113	Grands Causses
20	Dépôts argilo-sableux	28	Sologne - Forêt d'Orléans
		31	Flandres intérieure
		33	Douai - Condé
		39	Thiérache
		42	Epandages éluviaux
21	Massif Central Nord	48	Montagne bourbonnaise
		87	Morvan - Charollais
		89	Hautes Terres limousines
		92	MC Plateau limousin
22	Ardennes	34	Ardennes

Map of Hydro-ecoregions of Levels 1 et 2



Appendix 5. List of PRA in the Agronomic Units

Agronomic Unit n°1: Collines molassiques - Lauragais

N° UA	N° PRA	PRA
1	147	Haut-Armagnac
1	149	Ténarèze
1	151	Gaillacois
1	152	Coteaux molassiques
1	153	Plaine de l'Albigeois et du Castrais
1	154	Bas-Quercy de Monclar
1	383	Astarac
1	384	Lomagne
1	385	Coteaux du Gers
1	389	Coteaux de Gascogne
1	390	Vallées et terrasses de la Garonne supérieure
1	391	Lauragais
1	392	Volvestre et Razès
1	395	Causses du Quercy
1	398	Coteaux néracois

Agronomic Unit n°2: Bretagne sud

N° UA	N° PRA	PRA
2	103	Zone légumière de la Pénéplaine Sud
2	363	Pénéplaine bretonne Sud
2	364	Littoral breton Sud

Agronomic Unit n°3: Limagnes - Plaine du Forez

N° UA	N° PRA	PRA
3	165	Périphérie des Dômes
3	175	Plaine de la Dore
3	176	Limagne viticole
3	177	Brivadois
3	180	Entre Loire et Allier
3	189	Plateau de Neulise
3	190	Plaine roannaise
3	191	Côte roannaise
3	193	Plaine du Forez
3	426	Limagne agricole
3	427	Limagne de Lembron et de Brioude
3	429	Sologne bourbonnaise

Agronomic Unit n°4: Bordure maritime Nord - Picardie - Normandie

N° UA	N° PRA	PRA
4	023	Pays Aire
4	024	Collines guinoises
4	029	Boulonnais
4	030	Haut-Pays d'Artois
4	032	Ternois
4	036	Ponthieu
4	037	Marquenterre
4	038	Vimeu
4	039	Pays de Montreuil
4	040	Bas-Champs picards
4	041	Pays de Thelle
4	044	Vexin normand
4	046	Pays de Caux
4	047	Petit Caux
4	048	Entre Bray et Picardie
4	049	Entre Caux et Vexin
4	050	Pays de Lyons
4	051	Marais Vernier
4	052	Roumois
4	077	Lieuvin
4	078	Plateau de Neubourg
4	325	Flandre maritime
4	331	Pays de Bray
4	332	Vallée de la Seine

Agronomic Unit n°5: Alsace - Sundgau

N° UA	N° PRA	PRA
5	001	Hardt
5	002	Ochsenfeld
5	301	Plaine du Rhin
5	302	Ried
5	303	Sundgau
5	304	Région sous-vosgienne

Agronomic Unit n°6: Plaine normande - Bessin

N° UA	N° PRA	PRA
6	085	Bessin
6	355	Plaine normande

Agronomic Unit n°7: Aquitaine - Landes

N° UA	N° PRA	PRA
7	130	Pays de Born
7	131	Marensin
7	132	Marenne
7	133	Marsan
7	134	Petites Landes de Roquefort
7	135	Petites Landes de Villandraut
7	137	Landes du Médoc
7	378	Grandes Landes

Agronomic Unit n°8: Bassin de l’Adour

N° UA	N° PRA	PRA
8	138	Côte basque
8	139	Coteaux du Pays basque
8	141	Coteaux entre les Gaves
8	143	Vallée de l'Adour
8	144	Seignanx
8	145	Pays de Gosse
8	148	Coteaux de Bigorre
8	150	Haute vallée de l'Adour
8	379	Vallée du Gave d'Oloron
8	380	Vallée du Gave de Pau
8	381	Coteaux du Béarn
8	382	Chalosse
8	386	Vic-Bilh
8	387	Tursan et Rivière basse
8	388	Bas-Armagnac

Agronomic Unit n°9: Picardie - Nord - Pas de Calais

N° UA	N° PRA	PRA
9	025	Flandre intérieure
9	026	Région de Lille
9	027	Pévèle
9	028	Plaine de la Scarpe
9	031	Béthunois
9	033	Hainaut
9	034	Saint-Quentinois et Laonnois
9	035	Santerre
9	042	Clermontois
9	043	Noyonnais
9	324	Plaine de la Lys
9	326	Artois-Cambrésis
9	327	Plateau picard

Agronomic Unit n°10: Charentes

N° UA	N° PRA	PRA
10	109	Plateau mellois
10	111	Marais de Rochefort et Marennes
10	113	Angoumois-Ruffecois
10	366	Entre plaine, Bocage et Gâtine
10	367	Plaine de la Mothe-Lezay
10	369	Marais poitevin desséché
10	370	Marais poitevin mouillé
10	371	Plaines vendéenne et niortaise
10	372	Terre rouge à châtaigniers
10	374	Aunis
10	375	Saintonge agricole
10	377	Saintonge viticole
10	438	Brandes et Brenne

Agronomic Unit n°11: Bocage normand

N° UA	N° PRA	PRA
11	081	La Hague
11	082	Bocage de Valognes
11	083	Val de Saire
11	084	Cotentin
11	086	Bocage de Coutances et Saint-Lô
11	087	Avranchin
11	093	Bocage sabolien
11	095	Région d'embouche de l'Erve
11	354	Bocage normand
11	357	Région de Fougères et de Mayenne

Agronomic Unit n°12: Barrois - Plateaux bourguignons

N° UA	N° PRA	PRA
12	010	Tonnerois
12	011	Vignoble du Barrois
12	186	Plateaux de Bourgogne
12	305	La Haye
12	308	Pays Haut-lorrain
12	311	Plateau langrois, montagne
12	313	Côtes de Meuse
12	314	Barrois
12	316	Woëvre
12	322	Vallées de l'Yonne à la Marne

Agronomic Unit n°13: Plateau lorrain

N° UA	N° PRA	PRA
13	003	Warndt
13	004	Vallée de la Moselle
13	306	Plateau lorrain Sud
13	310	Bassigny-Châtenois
13	473	Plateau lorrain Nord

Agronomic Unit n°14: Gâtines - Vallées de Loire

N° UA	N° PRA	PRA
14	069	Région de Sainte-Maure
14	070	Champeigne
14	071	Région viticole à l'Est de Tours
14	072	Forêt d'Amboise
14	073	Plateau de Mettray
14	074	Bassin de Savigné
14	344	Val de Loire (Anjou et Touraine)
14	345	Beaugeois
14	346	Gâtine tourangelle
14	347	Saumurois
14	348	Plaine de Loudun, Richelieu et Châtellerault
14	349	Plaine de Thouars

Agronomlic Unit n°15: Sologne - Orléanais

N° UA	N° PRA	PRA
15	063	Orléanais
15	065	Sologne viticole
15	067	Val de Loire (Loiret)
15	068	Vallée et coteaux de la Loire
15	343	Sologne

Agronomic Unit n°16: Champagne crayeuse

N° UA	N° PRA	PRA
16	013	Vallée de la Champagne crayeuse
16	015	Plaine de Troyes
16	016	Vallée de la Marne
16	018	Pays rémois
16	019	Vallée du Nogentais
16	317	Champagne crayeuse
16	319	Pays d'Othe
16	320	Bassée et Basse-Yonne

Agronomic Unit n°17: Beauce - Drouais - Gâtinais

N° UA	N° PRA	PRA
17	064	Pays de Bière et forêt de Fontainebleau
17	079	Plateau d'Evreux Saint-André
17	334	Drouais
17	338	Gâtinais pauvre
17	339	Gâtinais riche
17	341	Beauce dunoise
17	342	Beauce

Agronomic Unit n°18: Bordelais - Périgord - Coteaux du Lot

N° UA	N° PRA	PRA
18	112	Montmorélien
18	114	Médoc
18	115	Bas-Médoc
18	116	Ilot de Polyculture de Civrac
18	117	Blayais

Agronomic Unit n°18: Bordelais - Périgord - Coteaux du Lot (continued)

18	118	Libournais
18	119	Vallée de l'Isle
18	120	Région de polyculture de Saint-Ciers
18	121	Entre-deux-Mers viticole
18	122	Ouest Entre-deux-Mers
18	123	Ilot de Polyculture de Baron
18	124	Benauge boisée
18	125	Benauge (polyculture)
18	126	Ceinture laitière et légumière de Bordeaux
18	127	Ilot de Polyculture de Pujols
18	128	Côtes du Bordelais
18	129	Graves
18	136	Petites Landes du Bazadais
18	155	Bas-Quercy de Montpezat
18	156	Coteaux nord du Lot-et-Garonne
18	157	Coteaux bordure Landes
18	158	Ribéracois
18	376	Saintonge boisée
18	396	Quercy blanc
18	399	Pays de Serres
18	400	Vallée de la Garonne
18	401	Bergeracois
18	402	Duras
18	403	Périgord blanc
18	404	Périgord noir
18	405	Double périgourdine
18	406	Landais

Agronomic Unit n°19: Perche - Pays d'Auge - Pays d'Ouche

N° UA	N° PRA	PRA
19	075	Perche Vendômois
19	076	Faux Perche
19	088	Merlerault
19	089	Vallée de la Sarthe et Région mancelle
19	090	Belinois
19	091	Plateau calaisien
19	092	Champagne mancelle
19	094	Saosnois
19	350	Vallée du Loir
19	351	Perche
19	352	Pays d'Ouche
19	353	Pays d'Auge

Agronomic Unit n°20: Bocages de l'ouest

N° UA	N° PRA	PRA
20	104	Pays de Châteaubriant
20	105	Plateaux boisés nantais
20	106	Estuaire de la Loire
20	107	Région urbaine et maraîchère de Nantes
20	108	Pays de Retz
20	110	Bocage de Chantonnay
20	356	Bocage angevin
20	365	Marais breton
20	368	Bas-Bocage et Gâtine
20	373	Haut-Bocage

Agronomic Unit n°21: Ardenne - Argonne - Champagne humide

N° UA	N° PRA	PRA
21	012	Vallage
21	014	Plaine de Brienne
21	020	Vallée de la Champagne humide
21	022	Crêtes pré-ardennaises
21	315	Argonne
21	318	Champagne humide
21	321	Perthois
21	323	Thiérache

Agronomic Unit n°22: Champagne berrichonne - Boischaut

N° UA	N° PRA	PRA
22	340	Puisaye
22	434	Champagne berrichonne
22	435	Boischaut du Nord
22	439	Sancerrois
22	066	Val de Loire (Cher)
22	179	Vallée de Germigny
22	185	Bourgogne nivernaise
22	188	Nivernais central

Agronomic Unit n°23: Bas Dauphiné - Vallée du Rhône

N° UA	N° PRA	PRA
23	196	Zone maraîchère de Lyon
23	199	Bas-Dauphiné
23	200	Zone fruitière et viticole du Lyonnais
23	217	Vallée du Grésivaudan
23	221	Région de Royans
23	240	Plaines rhodaniennes
23	241	Valloire
23	242	Gallaure et Herbasse
23	243	Pays de Bourdeaux
23	464	Tricastin
23	465	Vallée du Rhône

Agronomic Unit n°24: Fossé bressan

N° UA	N° PRA	PRA
24	195	Vallée de la Saône
24	197	Zone de grande culture entre Saône et Beaujolais
24	198	Dombes
24	201	Coteaux en bordure des Dombes
24	202	Bresse chalonnaise
24	203	Val d'Amour et forêt de Chaux
24	204	Val de Saône
24	205	Plaine grayloise
24	206	Finage
24	440	Plaine viticole de Bourgogne
24	444	Beaujolais viticole-Mâconnais
24	446	Bresse

Agronomic Unit n°25: Bretagne centrale

N° UA	N° PRA	PRA
25	101	Zone de Plougastel-Daoulas
25	102	Presqu'île de Crozon
25	360	Landes des Monts d'Arrée et du Méné
25	362	Landes de Châteaulin et Pontivy

Agronomic Unit n°26: Plateaux de Haute-Saône

N° UA	N° PRA	PRA
26	005	Région sous-vosgienne de Haute-Saône
26	006	Région vosgienne de Haute-Saône
26	007	Région des Plateaux
26	008	Plateau langrois-Apance
26	009	Plateau langrois-Amance
26	312	Vingeanne
26	447	Plaines et basses vallées de la Saône, du Doubs et de l'Ognon
26	448	Trouée de Belfort

Agronomic Unit n°27: Provence

N° UA	N° PRA	PRA
27	246	Crau
27	466	Val de Durance
27	467	Comtat
27	468	Coteaux de Provence
27	469	Littoral de Provence

Agronomic Unit n°28: Plaine du Languedoc-Roussillon

N° UA	N° PRA	PRA
28	252	Plaine du Roussillon
28	254	Crû Banyuls
28	415	Soubergues
28	416	Garrigues
28	471	Plaine viticole du Bas-Languedoc

Agronomic Unit n°29: Boischaut du sud

N° UA	N° PRA	PRA
29	178	Bocage bourbonnais
29	436	Boischaut du Sud
29	437	Bas-Berry

Agronomic Unit n°30: Bretagne nord

N° UA	N° PRA	PRA
30	096	Région de polyculture de Laval
30	097	Région centrale
30	098	Polders du Mont-Saint-Michel
30	099	Marais de Dol
30	100	Zone côtière de Brest
30	358	Littoral breton Nord
30	359	Bretagne centrale
30	361	Pénéplaine bretonne nord

Agronomic Unit n°31: Ile de France

N° UA	N° PRA	PRA
31	017	Vignoble
31	045	Butte de Dammartin
31	053	Plaine de Versailles
31	054	Yvelines
31	055	Hurepoix
31	056	Orxois
31	057	Brie boisée
31	058	Brie centrale
31	059	Montois
31	060	Brie Est
31	061	Vallée de la Marne et du Morin
31	062	Brie humide
31	080	Plateau de Madrie
31	328	Soissonnais
31	329	Valois
31	330	Vexin
31	333	Ceinture de Paris
31	335	Brie champenoise
31	336	Tardenois
31	337	Brie française

Appendix 6. List of Cantons in the Agronomic Units

N°AU	Département	Canton
1	09	0906 0908 0910 0912 0917 0919 0922 0999
	11	1101 1105 1109 1110 1111 1116 1120 1129 1199
	31	3102 3103 3106 3107 3108 3109 3110 3111 3112 3113 3114 3115 3116 3117 3118 3119 3120 3121 3122 3123 3124 3125 3126 3127 3130 3131 3137 3138 3139 3143 3144 3148 3149 3150 3151 3152 3153 3199
	32	3202 3203 3205 3206 3207 3208 3209 3210 3211 3212 3213 3215 3216 3217 3218 3219 3220 3221 3225 3226 3227 3228 3229 3230 3231 3299
	47	4703 4712 4715 4725
	65	6508 6510
	81	8105 8107 8109 8110 8112 8113 8116 8117 8118 8124 8125 8126 8127 8129 8130 8134 8135 8137 8138 8139 8140 8143 8144 8145 8146 8196 8198
	82	8201 8202 8206 8207 8210 8213 8217 8219 8220 8221 8223 8224 8225 8227 8297 8299
2	29	2901 2902 2906 2910 2913 2915 2926 2932 2933 2934 2936 2937 2941 2948 2949 2952 2998
	35	3503 3514 3516 3521 3525 3527 3528 3540
	44	4410 4413 4414 4431 4436 4440 4457
	56	5601 5602 5604 5606 5608 5610 5611 5613 5614 5619 5621 5622 5625 5627 5628 5629 5630 5631 5632 5635 5637 5638 5640 5642 5698
3	03	0304 0306 0307 0308 0310 0311 0323 0325 0326 0328 0333 0396 0397 0399
	42	4205 4209 4212 4214 4216 4223 4226 4227 4231 4232 4234 4298
	43	4304 4305 4310 4311 4316 4334 4397
	58	5810 5822 5830 5832
	63	6301 6306 6308 6309 6314 6315 6317 6319 6322 6324 6330 6332 6333 6334 6337 6340 6343 6346 6347 6348 6349 6355 6356 6358 6359 6361 6398 6399
	71	7103 7117 7120 7122 7128

N°AU	Département	Canton
4	27	2701 2702 2704 2705 2706 2707 2709 2711 2715 2716 2718 2719 2720 2722 2723 2724 2727 2728 2729 2730 2733 2734 2738 2739 2741 2743 2796 2797 2798
	59	5912 5925 5926 5927 5972 5973 5990
	60	6002 6004 6010 6026 6035 6040
	62	6201 6202 6205 6206 6207 6208 6210 6213 6214 6215 6216 6218 6221 6222 6223 6224 6225 6226 6227 6229 6234 6236 6237 6238 6239 6241 6242 6243 6244 6254 6261 6262 6263 6265 6269 6297 6298 6299
	76	7601 7602 7603 7604 7605 7606 7607 7608 7609 7610 7611 7612 7613 7614 7615 7616 7617 7618 7619 7620 7621 7622 7623 7624 7625 7626 7633 7634 7635 7636 7637 7638 7639 7640 7641 7648 7649 7650 7652 7653 7654 7655 7660 7661 7663 7665 7666 7669 7692 7693 7694 7695 7698 7699
	78	7801 7802 7814 7833
	80	8001 8002 8004 8011 8012 8019 8020 8021 8022 8023 8025 8029 8031 8032 8039 8040 8046 8098
5	67	6701 6702 6703 6704 6705 6707 6708 6709 6710 6711 6712 6713 6716 6718 6721 6722 6724 6725 6726 6731 6733 6735 6742 6743 6744 6799
	68	6801 6802 6803 6805 6806 6809 6810 6811 6812 6813 6817 6819 6820 6821 6824 6826 6827 6828 6831 6898 6899
	90	9002 9003 9013
6	14	1402 1403 1406 1407 1408 1409 1413 1414 1418 1420 1425 1428 1432 1433 1440 1443 1444 1446 1448 1493 1497 1498
	61	6103 6111 6112 6124 6131 6135 6138 6139 6197 6199
	72	7218 7229
7	33	3302 3305 3318 3320 3327 3329 3333 3342 3345 3349 3350 3359 3361 3363 3397
	40	4003 4004 4005 4007 4009 4010 4011 4013 4015 4017 4019 4020 4024 4025 4026 4027 4030 4098 4099
	47	4707 4714

N°AU	Département	Canton
8	32	3201 3204 3214 3222 3223 3224
	40	4001 4002 4006 4008 4012 4014 4016 4018 4021 4022 4023 4028 4029 4097
	64	6403 6405 6407 6409 6410 6411 6412 6413 6414 6415 6417 6418 6419 6420 6421 6422 6423 6424 6425 6426 6427 6428 6429 6431 6432 6434 6436 6437 6438 6440 6441 6445 6446 6447 6448 6451 6452 6490 6491 6492 6495 6496 6497 6498 6499
	65	6509 6514 6516 6517 6518 6521 6522 6523 6524 6525 6533 6534 6599
9	02	0203 0206 0209 0213 0216 0218 0219 0220 0225 0227 0229 0233 0237 0239 0240 0242 0297 0298
	59	5901 5902 5905 5906 5907 5908 5909 5910 5911 5913 5914 5915 5916 5917 5918 5919 5920 5921 5922 5923 5924 5928 5929 5930 5931 5933 5938 5940 5942 5943 5944 5945 5946 5947 5948 5949 5950 5951 5954 5955 5956 5957 5958 5960 5961 5962 5963 5965 5966 5967 5968 5969 5970 5971 5974 5977 5978 5984 5985 5987 5988 5989 5991 5993 5994 5995 5996 5997 5998 5999
	60	6006 6008 6009 6011 6013 6014 6015 6016 6017 6018 6019 6020 6021 6022 6024 6027 6028 6029 6031 6032 6033 6039 6041 6099
	62	6203 6204 6209 6211 6212 6217 6219 6220 6228 6230 6231 6232 6233 6235 6240 6245 6246 6248 6249 6250 6251 6252 6253 6255 6256 6257 6259 6260 6264 6267 6268 6270 6271 6272 6273 6274 6275 6277 6288 6289 6290 6291 6292 6296
	80	8003 8005 8006 8007 8008 8009 8010 8013 8014 8015 8016 8017 8018 8024 8026 8027 8028 8030 8033 8034 8035 8036 8037 8038 8041 8042 8044 8045 8099

N°AU	Département	Canton
10	16	1601 1605 1606 1607 1612 1613 1616 1617 1618 1622 1623 1624 1625 1627 1629 1630 1631 1633 1635 1697 1698
	17	1701 1702 1703 1704 1705 1706 1707 1708 1709 1710 1711 1712 1713 1714 1715 1716 1717 1720 1721 1725 1726 1727 1728 1729 1730 1731 1732 1733 1734 1735 1736 1737 1738 1739 1740 1743 1744 1746 1749 1750 1751 1796 1797 1798 1799
	36	3602 3619
	79	7903 7905 7906 7908 7910 7911 7912 7913 7914 7916 7919 7920 7921 7923 7925 7926 7928 7998 7999
	85	8502 8507 8509 8511 8512 8513 8517 8527 8528
	86	8601 8602 8603 8604 8605 8606 8608 8613 8614 8617 8620 8624 8625 8626 8628 8629 8633 8634 8635 8636 8699
11	14	1401 1404 1411 1412 1416 1417 1430 1431 1436 1437 1438
	35	3512 3513 3520 3535 3536 3597
	50	5001 5002 5003 5004 5005 5006 5007 5008 5009 5010 5012 5013 5014 5015 5016 5017 5018 5019 5020 5021 5022 5023 5024 5025 5026 5027 5028 5029 5030 5031 5032 5033 5034 5035 5036 5037 5038 5039 5040 5041 5042 5043 5044 5045 5046 5047 5048 5050 5051 5052 5095 5097 5098 5099
	53	5301 5303 5305 5308 5310 5311 5312 5313 5314 5315 5316 5320 5321 5322 5323 5324 5326 5327 5399
	61	6102 6104 6107 6108 6110 6114 6115 6117 6122 6127 6129 6133 6140 6196
	72	7212 7227 7230

N°AU	Département	Canton
12	10	1003 1004 1010 1015 1019 1025
	21	2101 2104 2108 2116 2117 2118 2122 2128 2130 2132 2135 2139 2143
	52	5201 5202 5203 5206 5207 5208 5210 5211 5213 5214 5216 5221 5222 5223 5224 5227 5229 5285
	54	5402 5407 5408 5411 5412 5415 5416 5426 5427 5428 5430 5431 5432 5434 5437 5499
	55	5501 5502 5503 5505 5506 5507 5508 5509 5510 5511 5512 5513 5514 5515 5516 5517 5518 5519 5520 5524 5525 5526 5527 5528 5529 5530 5531 5592 5593
	57	5711 5713 5715 5722 5737 5742 5744 5748
	88	8809 8818
	89	8902 8903 8907 8909 8912 8913 8914 8915 8916 8918 8919 8920 8921 8925 8928 8932 8934 8935 8938 8939 8941 8942 8995 8998
13	52	5205 5209 5219 5220 5226
	54	5401 5403 5405 5406 5410 5413 5414 5417 5418 5423 5424 5425 5429 5433 5435 5438 5440 5441 5442 5443 5496 5497 5498
	57	5701 5703 5704 5705 5706 5707 5708 5709 5710 5714 5720 5721 5723 5725 5726 5727 5728 5729 5730 5731 5733 5734 5735 5738 5739 5741 5743 5745 5747 5749 5750 5751 5796 5797 5799
	67	6706 6720
	88	8803 8804 8805 8806 8807 8810 8811 8812 8815 8816 8821 8828 8830 8899
14	37	3701 3702 3703 3704 3705 3706 3707 3709 3710 3711 3712 3714 3716 3717 3719 3720 3724 3729 3730 3731 3732 3734 3736 3737 3798 3799
	41	4106
	49	4901 4902 4904 4905 4913 4914 4915 4917 4920 4922 4927 4928 4929 4931 4933 4936 4998 4999
	79	7901 7924 7931 7932 7995 7997
	86	8607 8610 8611 8612 8615 8616 8618 8619 8621 8622 8623 8627 8631 8632 8637 8638 8697

N°AU	Département	Canton
15	18	1802 1803 1830 1899
	41	4102 4103 4104 4107 4109 4115 4117 4120 4122 4129 4130 4197 4199
	45	4502 4506 4510 4513 4515 4520 4527 4531 4534 4535 4536 4537 4538 4539 4540 4599
16	02	0221 0230
	08	0801 0802 0806 0813 0814 0817 0823
	10	1001 1002 1008 1011 1013 1014 1018 1020 1022 1023 1028 1029 1031 1032 1033 1096 1097 1099
	51	5101 5104 5105 5108 5110 5113 5116 5119 5122 5126 5127 5134 5135 5136 5138 5140 5141 5143 5196 5198 5199
	77	7701 7720
	89	8908 8922 8929 8931 8936 8937 8940 8999
17	27	2708 2713 2717 2725 2732 2735 2737 2799
	28	2801 2802 2804 2805 2807 2809 2810 2812 2813 2815 2816 2818 2819 2821 2824 2825 2826 2827 2828 2829 2830 2897 2899
	41	4101 4108 4110 4116 4119 4123 4127 4128
	45	4501 4503 4504 4507 4511 4512 4516 4517 4518 4519 4526 4528 4529 4530 4532 4533
	77	7703 7704 7713 7716 7721 7724 7732 7799
	78	7808
	89	8901 8910 8911 8926 8930
	91	9107 9108 9109 9111 9117 9118

N°AU	Département	Canton
18	16	1604 1608 1610 1621 1628 1632
	17	1718 1719
	24	2401 2402 2404 2405 2407 2408 2409 2410 2412 2413 2414 2416 2417 2419 2420 2421 2422 2423 2424 2425 2426 2428 2429 2430 2431 2432 2434 2435 2436 2437 2438 2439 2440 2442 2443 2444 2445 2446 2447 2448 2449 2450 2496 2497
	33	3303 3304 3306 3307 3315 3316 3317 3319 3321 3322 3323 3324 3325 3326 3328 3330 3331 3332 3334 3336 3337 3338 3339 3340 3341 3343 3344 3346 3347 3348 3352 3354 3355 3357 3358 3360 3398
	46	4603 4605 4614 4621
	47	4702 4704 4705 4706 4708 4709 4710 4711 4713 4716 4717 4718 4719 4720 4721 4722 4723 4724 4726 4727 4728 4729 4730 4731 4732 4734 4735 4736 4737 4738 4739 4740 4797 4798 4799
	82	8203 8205 8208 8209 8211 8212 8214 8215 8218 8222 8226 8298
19	14	1405 1410 1415 1419 1421 1422 1423 1424 1426 1427 1429 1434 1435 1447 1449 1499
	27	2703 2710 2712 2731
	28	2803 2806 2811 2814 2817 2820 2822 2823
	41	4105 4111 4112 4114 4121 4124 4198
	61	6105 6106 6109 6113 6116 6118 6119 6120 6121 6123 6125 6126 6128 6130 6132 6134 6136 6137 6198
	72	7201 7202 7203 7204 7205 7206 7207 7208 7209 7210 7211 7213 7214 7215 7216 7217 7222 7223 7224 7225 7226 7228 7231 7232 7233 7234 7235 7236 7237 7238 7240 7299

N°AU	Département	Canton
20	44	4401 4402 4403 4404 4405 4406 4407 4408 4409 4411 4412 4415 4416 4417 4418 4419 4427 4428 4429 4430 4432 4433 4434 4435 4437 4438 4441 4442 4443 4444 4445 4446 4447 4450 4451 4454 4459 4496 4497 4498 4499
	49	4906 4907 4908 4909 4910 4911 4912 4916 4918 4919 4921 4923 4924 4925 4926 4930 4932 4934 4935 4938 4939 4940 4941 4997
	53	5304 5306 5307 5309 5325 5331 5332 5397
	79	7902 7904 7907 7909 7915 7917 7918 7922 7927 7929 7930
	85	8501 8503 8504 8505 8506 8508 8510 8514 8515 8516 8518 8519 8520 8521 8522 8523 8524 8525 8526 8529 8530 8531 8598
	86	8630
21	02	0202 0205 0217 0223 0226 0234
	08	0803 0804 0807 0808 0809 0812 0815 0818 0819 0820 0821 0825 0828 0830 0831 0833 0898 0899
	10	1005 1006 1007 1009 1012 1017 1021
	51	5115 5123 5124 5128 5132 5133
	52	5218 5228 5230 5231 5232 5286
	55	5504 5521 5522 5523
	59	5903 5904 5932 5959 5964 5986
22	18	1801 1804 1806 1807 1808 1810 1812 1813 1814 1815 1816 1817 1819 1820 1821 1823 1824 1825 1826 1828 1835 1898
	36	3605 3606 3608 3610 3612 3613 3614 3615 3618 3621 3622 3623 3624 3625 3698 3699
	37	3708 3713 3715 3718
	41	4113 4118
	45	4505 4508 4509 4514
	58	5801 5802 5804 5805 5806 5807 5808 5809 5817 5818 5819 5820 5821 5823 5824 5825 5826 5827 5828 5829 5831 5898 5899
	89	8906 8924 8927 8933

N°AU	Département	Canton
23	01	0117
	07	0719 0731
	26	2601 2602 2604 2608 2610 2611 2612 2613 2615 2616 2619 2621 2623 2624 2625 2626 2628 2632 2633 2634 2635 2696 2697 2698 2699
	30	3006 3023 3040
	38	3802 3804 3807 3808 3810 3811 3815 3819 3821 3823 3824 3825 3826 3827 3828 3830 3832 3833 3834 3835 3837 3838 3839 3840 3842 3843 3844 3846 3850 3853 3855 3856 3858 3860 3894 3896 3897 3899
	69	6908 6910 6926 6935 6937 6938 6940 6943 6944 6945 6946 6948 6949 6950 6951 6997 6999
	84	8404 8406 8416 8421 8422
24	01	0102 0108 0110 0111 0119 0120 0121 0125 0126 0127 0129 0130 0132 0134 0135 0139 0140 0142 0143 0199
	21	2103 2106 2109 2110 2114 2120 2124 2125 2129 2134 2138 2199
	39	3904 3907 3908 3909 3915 3917 3923 3930 3931 3933
	69	6902 6904 6905 6906 6925 6932 6939
	70	7009 7010 7019
	71	7102 7107 7108 7115 7116 7123 7125 7126 7127 7134 7135 7139 7142 7143 7145 7147 7149 7151 7153 7155 7157 7198 7199
25	22	2203 2205 2209 2210 2215 2222 2223 2226 2227 2234 2238 2241 2243 2246 2248
	29	2907 2908 2909 2911 2914 2916 2925
	56	5603 5605 5607 5609 5612 5616 5624 5626 5633 5634

N°AU	Département	Canton
26	21	2113
	25	2502 2503 2504 2507 2510 2513 2514 2518 2522 2523 2528 2530 2531 2534 2535 2595 2599
	39	3912 3913 3914 3918 3924 3996
	52	5204 5212 5215 5217
	70	7001 7002 7003 7004 7005 7006 7008 7011 7012 7013 7014 7015 7016 7017 7018 7020 7021 7022 7023 7024 7025 7026 7027 7028 7029 7030 7031 7032 7093 7094 7095 7096
	90	9006 9010 9011 9015 9099
27	04	0413 0419 0432 0498
	13	1301 1302 1303 1305 1306 1307 1308 1309 1310 1311 1312 1326 1327 1329 1331 1332 1333 1334 1335 1336 1348 1349 1350 1351 1352 1353 1395 1396 1397 1399
	83	8302 8303 8304 8305 8306 8309 8311 8312 8316 8317 8318 8320 8321 8323 8336 8338 8340 8341 8342 8397 8398 8399
	84	8402 8405 8409 8410 8411 8413 8417 8423 8497 8498 8499
28	11	1114 1133 1197
	30	3001 3005 3007 3009 3014 3015 3016 3020 3021 3022 3024 3026 3027 3028 3030 3031 3032 3035 3037 3038 3041 3045 3046 3099
	34	3401 3402 3403 3405 3406 3407 3409 3410 3411 3412 3413 3414 3415 3416 3417 3418 3419 3420 3421 3423 3425 3426 3428 3429 3430 3432 3435 3438 3439 3444 3446 3447 3448 3449 3497 3498 3499
	66	6601 6603 6605 6612 6614 6617 6619 6620 6624 6627 6628 6629 6630 6631 6699

N°AU	Département	Canton
29	03	0301 0302 0303 0312 0313 0316 0319 0324 0327 0331 0334 0398
	18	1809 1811 1818 1822 1827
	23	2306 2308 2310 2314 2325
	36	3601 3603 3604 3609 3611 3616 3617 3620
30	22	2201 2202 2204 2206 2207 2208 2211 2212 2213 2214 2216 2217 2218 2219 2220 2221 2224 2225 2228 2229 2230 2231 2232 2233 2235 2236 2237 2239 2240 2242 2247 2249 2250 2251 2298 2299
	29	2903 2912 2917 2918 2919 2920 2921 2922 2923 2924 2927 2928 2929 2930 2931 2938 2939 2940 2942 2943 2944 2946 2951 2999
	35	3501 3502 3504 3505 3506 3507 3508 3509 3510 3511 3515 3517 3518 3519 3522 3523 3524 3526 3531 3533 3534 3538 3539 3541 3542 3543 3546 3547 3549 3552 3553 3596 3598 3599
	53	5302 5317 5319 5328 5398
	56	5615 5620 5623 5636

N°AU	Département	Canton
31	02	0201 0204 0207 0208 0210 0211 0212 0214 0215 0222 0224 0231 0232 0235 0236 0238 0241 0299
	10	1016 1026
	27	2714 2721 2726 2736 2740 2742
	51	5102 5103 5107 5109 5112 5114 5117 5118 5125 5129 5130 5131 5137 5197
	60	6001 6005 6007 6012 6023 6025 6030 6034 6036 6037 6097 6098
	77	7702 7705 7706 7707 7708 7709 7710 7711 7712 7714 7715 7717 7718 7719 7722 7723 7725 7726 7727 7728 7729 7731 7733 7734 7735 7737 7740 7741 7742 7743 7797 7798
	78	7804 7805 7806 7807 7809 7810 7811 7813 7815 7816 7817 7818 7819 7820 7821 7822 7823 7825 7828 7829 7830 7832 7834 7835 7836 7838 7839 7897 7898 7899
	91	9101 9102 9103 9104 9110 9113 9114 9116 9120 9121 9122 9123 9124 9128 9129 9130 9132 9133 9134 9135 9138 9140 9143 9196
	92	9210 9236 9238 9285 9286 9287 9296 9299
	93	9306 9310 9314 9315 9331 9332 9333 9340 9392 9393 9395 9396 9398
	94	9402 9415 9426 9438 9442 9444 9446 9493 9494 9495 9497 9499
	95	9503 9505 9506 9507 9508 9509 9511 9513 9514 9515 9516 9517 9518 9519 9520 9521 9522 9524 9525 9526 9527 9528 9529 9530 9531 9534 9535 9537 9538 9539 9596 9598 9599

Appendix 7. Cultivated Surfaces in the Agronomic Units (ha) – based on Agreste (2010)

AU	Agronomic Unit	SAU (ha)	Sugar beet (ha)	Winter wheat (ha)	Oil seed rape (ha)	Maize fodder (ha)
0	Territoire non pris en compte	5626790	237	165468	27046	109376
1	Collines molassiques - Lauragais	1195140	70	193127	33358	11855
2	Bretagne sud	438287	0	64608	8834	74076
3	Limagnes - Plaine du Forez	595726	3535	78629	9008	14371
4	Bordure maritime Nord - Picardie - Normandie	1193697	43901	392000	74849	100852
5	Alsace - Sundgau	275511	5077	41246	1512	8981
6	Plaine normande - Bessin	243785	6737	66052	13968	20973
7	Aquitaine - Landes	154346	0	2185	63	451
8	Bassin de l'Adour	556590	0	15083	2826	22471
9	Picardie - Nord - Pas-de-Calais	1120612	108057	460924	65265	44193
10	Charentes	1296032	0	292454	62397	36307
11	Bocage normand	1059617	741	150214	16005	212523
12	Barrois - Plateaux bourguignons	1050220	137	282951	185398	34161
13	Plateau lorrain	640498	0	132790	64936	42428
14	Gâtines - Vallées de Loire	619776	11	185187	37439	18114
15	Sologne - Orléanais	145243	425	30033	9542	2328
16	Champagne crayeuse	722653	69601	229293	86734	2497
17	Beauce - Drouais - Gâtinais	942631	36067	329642	145998	3093
18	Bordelais - Périgord - Coteaux du Lot	856375	134	104598	9682	21025
19	Perche - Pays d'Auge - Pays d'Ouche	840368	1325	211644	71384	61408
20	Bocages de l'ouest	1315006	0	209916	29904	169989
21	Ardenne - Argonne - Champagne humide	546726	7583	117515	47526	33165
22	Champagne berrichonne - Boischaut	1037667	236	276383	151862	12576
23	Bas Dauphiné - Vallée du Rhône	416557	0	54358	7159	10599
24	Fossé bressan	537747	0	108289	34162	17103
25	Bretagne centrale	415801	0	67567	5359	69685
26	Plateaux de Haute-Saône	344665	0	53686	25553	15907
27	Provence	179438	0	716	531	0
28	Plaine du Languedoc-Roussillon	323767	0	1561	260	0
29	Boischaut du sud	511189	0	49728	19269	12027
30	Bretagne nord	813290	0	165305	16385	152339
31	Ile-de-France	916168	66548	348857	106346	4253
	Surface AU (1-31) (ha)	21305128	350185	4716541	1343514	1229750
	Total Surface AU (0-31) (ha)	26931918	350422	4882009	1370560	1339126
	Surface AU / Total Surface (%)	79.1	99.9	96.6	98.0	91.8

AU	Agronomic Unit	SAU (ha)	Maize Grain (ha)	Winter barley (ha)	Potato (ha)	Sunflower (ha)
0	Territoire non pris en compte	5626790	63548	119705	1856	17007
1	Collines molassiques - Lauragais	1195140	91076	39569	113	199422
2	Bretagne sud	438287	30991	15016	523	85
3	Limagnes - Plaine du Forez	595726	37185	13970	207	7838
4	Bordure maritime Nord - Picardie - Normandie	1193697	15548	93552	28769	58
5	Alsace - Sundgau	275511	126440	3696	1075	229
6	Plaine normande - Bessin	243785	5014	14530	982	1676
7	Aquitaine - Landes	154346	71396	207	774	2005
8	Bassin de l'Adour	556590	229579	2161	32	7620
9	Picardie - Nord - Pas-de-Calais	1120612	45678	70902	64981	179
10	Charentes	1296032	150703	68209	340	146748
11	Bocage normand	1059617	17534	21962	600	2277
12	Barrois - Plateaux bourguignons	1050220	11875	203834	120	5630
13	Plateau lorrain	640498	4963	55222	113	332
14	Gâtines - Vallées de Loire	619776	44736	32420	118	61338
15	Sologne - Orléanais	145243	16619	10530	496	2837
16	Champagne crayeuse	722653	20464	140310	14411	9745
17	Beauce - Drouais - Gâtinais	942631	42885	128794	10524	12816
18	Bordelais - Périgord - Coteaux du Lot	856375	103000	22245	769	64510
19	Perche - Pays d'Auge - Pays d'Ouche	840368	45476	42046	351	8651
20	Bocages de l'ouest	1315006	41859	28588	668	14977
21	Ardenne - Argonne - Champagne humide	546726	25168	55908	601	3463
22	Champagne berrichonne - Boischaut	1037667	40999	107476	28	26953
23	Bas Dauphiné - Vallée du Rhône	416557	58105	17579	868	16118
24	Fossé bressan	537747	78091	31245	927	15635
25	Bretagne centrale	415801	35311	22132	2745	0
26	Plateaux de Haute-Saône	344665	17165	20028	39	2852
27	Provence	179438	816	698	293	2881
28	Plaine du Languedoc-Roussillon	323767	460	2296	205	2224
29	Boischaut du sud	511189	7474	19996	8	7198
30	Bretagne nord	813290	63801	39276	5689	75
31	Ile-de-France	916168	52310	93685	8743	3032
	Surface AU (1-31) (ha)	21305128	1532721	1418082	146112	629404
	Total Surface AU (0-31) (ha)	26931918	1596269	1537787	147968	646411
	Surface AU / Total Surface (%)	79.1	96.0	92.2	98.7	97.4

Appendix 8. Crop Density in the Agronomic Units (% Farmland) – based on Agreste (2010)

AU	Agronomic Unit	Sugar beet	Winter wheat	Oil seed rape	Maize fodder
0	Territoire non pris en compte	0.00	2.94	0.48	1.94
1	Collines molassiques - Lauragais	0.01	16.16	2.79	0.99
2	Bretagne sud	0.00	14.74	2.02	16.90
3	Limagnes - Plaine du Forez	0.59	13.20	1.51	2.41
4	Bordure maritime Nord - Picardie - Normandie	3.68	32.84	6.27	8.45
5	Alsace - Sundgau	1.84	14.97	0.55	3.26
6	Plaine normande - Bessin	2.76	27.09	5.73	8.60
7	Aquitaine - Landes	0.00	1.42	0.04	0.29
8	Bassin de l'Adour	0.00	2.71	0.51	4.04
9	Picardie - Nord - Pas-de-Calais	9.64	41.13	5.82	3.94
10	Charentes	0.00	22.57	4.81	2.80
11	Bocage normand	0.07	14.18	1.51	20.06
12	Barrois - Plateaux bourguignons	0.01	26.94	17.65	3.25
13	Plateau lorrain	0.00	20.73	10.14	6.62
14	Gâtines - Vallées de Loire	0.00	29.88	6.04	2.92
15	Sologne - Orléanais	0.29	20.68	6.57	1.60
16	Champagne crayeuse	9.63	31.73	12.00	0.35
17	Beauce - Drouais - Gâtinais	3.83	34.97	15.49	0.33
18	Bordelais - Périgord - Coteaux du Lot	0.02	12.21	1.13	2.46
19	Perche - Pays d'Auge - Pays d'Ouche	0.16	25.18	8.49	7.31
20	Bocages de l'ouest	0.00	15.96	2.27	12.93
21	Ardenne - Argonne - Champagne humide	1.39	21.49	8.69	6.07
22	Champagne berrichonne - Boischaut	0.02	26.64	14.63	1.21
23	Bas Dauphiné - Vallée du Rhône	0.00	13.05	1.72	2.54
24	Fossé bressan	0.00	20.14	6.35	3.18
25	Bretagne centrale	0.00	16.25	1.29	16.76
26	Plateaux de Haute-Saône	0.00	15.58	7.41	4.62
27	Provence	0.00	0.40	0.30	0.00
28	Plaine du Languedoc-Roussillon	0.00	0.48	0.08	0.00
29	Boischaut du sud	0.00	9.73	3.77	2.35
30	Bretagne nord	0.00	20.33	2.01	18.73
31	Ile-de-France	7.26	38.08	11.61	0.46
	Upper Class Limits	≥ 8 %	≥ 30 %	≥ 10 %	≥ 15 %
	Medium Class Limits	[4-8 %[	[20-30 %[	[5-10 %[	[5-15 %[
	Lower Class Limits	[1-4 %[	[10-20 %[	[1-5 %[	[1-5 %[

AU	Agronomic Unit	Maize grain	Winter barley	Potato	Sunflower
0	Territoire non pris en compte	1.13	2.13	0.03	0.30
1	Collines molassiques - Lauragais	7.62	3.31	0.01	16.69
2	Bretagne sud	7.07	3.43	0.12	0.02
3	Limagnes - Plaine du Forez	6.24	2.35	0.03	1.32
4	Bordure maritime Nord - Picardie - Normandie	1.30	7.84	2.41	0.00
5	Alsace - Sundgau	45.89	1.34	0.39	0.08
6	Plaine normande - Bessin	2.06	5.96	0.40	0.69
7	Aquitaine - Landes	46.26	0.13	0.50	1.30
8	Bassin de l'Adour	41.25	0.39	0.01	1.37
9	Picardie - Nord - Pas-de-Calais	4.08	6.33	5.80	0.02
10	Charentes	11.63	5.26	0.03	11.32
11	Bocage normand	1.65	2.07	0.06	0.21
12	Barrois - Plateaux bourguignons	1.13	19.41	0.01	0.54
13	Plateau lorrain	0.77	8.62	0.02	0.05
14	Gâtines - Vallées de Loire	7.22	5.23	0.02	9.90
15	Sologne - Orléanais	11.44	7.25	0.34	1.95
16	Champagne crayeuse	2.83	19.42	1.99	1.35
17	Beauce - Drouais - Gâtinais	4.55	13.66	1.12	1.36
18	Bordelais - Périgord - Coteaux du Lot	12.03	2.60	0.09	7.53
19	Perche - Pays d'Auge - Pays d'Ouche	5.41	5.00	0.04	1.03
20	Bocages de l'ouest	3.18	2.17	0.05	1.14
21	Ardenne - Argonne - Champagne humide	4.60	10.23	0.11	0.63
22	Champagne berrichonne - Boischaut	3.95	10.36	0.00	2.60
23	Bas Dauphiné - Vallée du Rhône	13.95	4.22	0.21	3.87
24	Fossé bressan	14.52	5.81	0.17	2.91
25	Bretagne centrale	8.49	5.32	0.66	0.00
26	Plateaux de Haute-Saône	4.98	5.81	0.01	0.83
27	Provence	0.45	0.39	0.16	1.61
28	Plaine du Languedoc-Roussillon	0.14	0.71	0.06	0.69
29	Boischaut du sud	1.46	3.91	0.00	1.41
30	Bretagne nord	7.84	4.83	0.70	0.01
31	Ile-de-France	5.71	10.23	0.95	0.33
	Upper Class Limits	≥ 40 %	≥ 10 %	≥ 5 %	≥ 10 %
	Medium Class Limits	[10-40 %[	[6-10 %[	[2-5 %[	[4-10 %[
	Lower Class Limits	[3-10 %[	[1-6 %[	[1-2 %[	[1-4 %[

Appendix 9. Probability of occurrence of twelve 3-year crop rotations based on AGRESTE 2000 data

Table 56 Probability of occurrence of 12 3-year crop rotations

	OWB	OWW	MBO*	MWB	SWB*	MMM	WWW	WBW	MWM	MMW	MWO	SWW
	(%)											
Alsace	0.00	0.00	0.00	0.00	0.00	38.90	0.07	0.00	2.11	9.06	0.00	0.00
Aquitaine	0.00	0.00	0.00	0.00	0.00	59.27	0.22	0.00	0.06	0.97	0.00	0.00
Auvergne	0.00	0.00	0.00	0.00	0.00	7.95	3.93	0.00	3.90	4.41	0.00	0.00
Basse Normandie	0.00	0.00	0.00	0.00	0.00	6.89	0.22	0.00	8.00	8.20	0.00	0.00
Bourgogne	28.92	3.59	0.09	1.02	0.00	8.52	0.69	7.23	0.42	0.81	0.42	0.00
Bretagne	0.00	0.00	0.00	4.06	0.00	4.67	0.13	4.60	5.85	7.02	0.00	0.00
Centre	9.40	5.48	0.15	1.13	0.00	2.98	1.76	10.61	2.75	1.85	0.89	0.00
Champagne Ardenne	15.88	1.59	0.00	0.00	10.84	0.00	0.22	22.29	0.00	0.00	0.00	3.24
France Comté	13.87	1.66	0.87	4.50	0.00	5.93	0.05	3.59	2.33	3.37	3.09	0.00
Haute Normandie	7.32	2.96	0.57	3.26	0.00	1.06	1.22	18.07	4.61	2.11	2.46	0.00
ile de France	7.45	3.26	0.22	1.16	7.79	0.17	1.38	24.28	6.74	1.12	0.84	6.57
Lorraine	25.06	4.63	0.72	2.02	0.00	3.93	0.93	2.59	2.35	1.95	1.06	0.00
midi Pyrénées	0.00	0.00	0.00	0.16	0.00	30.08	0.58	0.58	0.11	0.78	0.00	0.00
Nord pas de calais	0.00	0.00	0.00	2.89	12.32	0.27	0.22	45.52	7.94	1.76	0.00	5.81
pays de la loire	0.00	0.00	0.00	0.00	0.00	7.41	0.27	0.00	3.50	5.44	0.00	0.00
Picardie	4.28	0.96	0.32	2.12	6.22	0.34	0.80	40.22	3.37	0.95	1.21	9.69
Poitou charentes	2.96	2.42	0.20	0.37	0.00	18.52	0.17	1.84	0.53	1.38	0.55	0.00
Rhones Alpes	0.00	0.00	0.00	0.00	0.00	23.83	0.93	0.00	0.90	3.27	0.00	0.00

O = Oilseed rape, W = Winter Wheat, B = Winter Barley, M = Maize (fodder and grain), S = Sugar beet

Appendix 10. Overlap of the 31 Agronomic Units and administrative Régions and Cantons

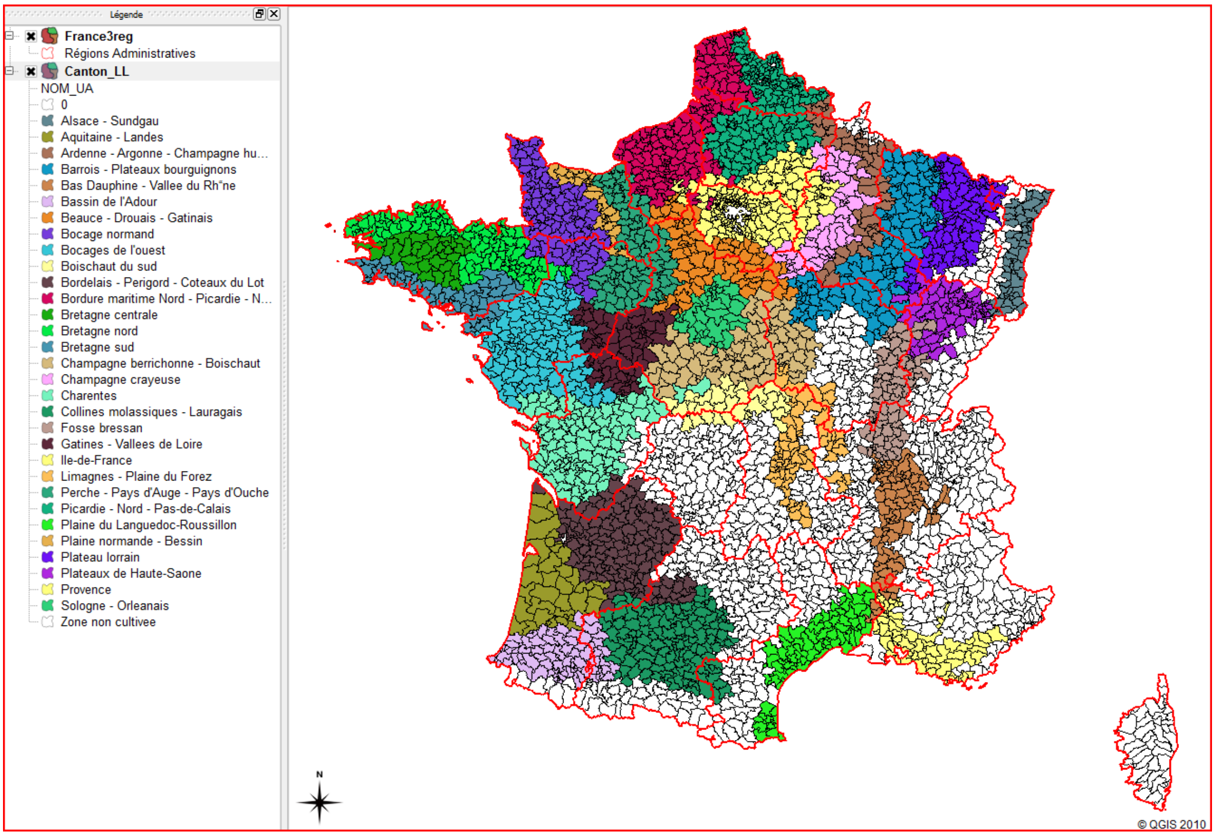


Figure 88 Overlap of the 31 Agronomic Units (colored blocks) and the "Régionadministratives" (red lines) - Small units (black lines) represent the "Cantons"

Appendix 11. Emergence and harvest dates for each crop/AU combination

Table 57 Emergence and harvest dates for each crop/AU combination (with source and remarks on changes due to the crop calendar (CC)). Changed dates are marked in bold

CID	**AUID**	**Emergence**	**Harvest**	**Comment_Emergence**	**Comment_Harvest**
1	3	20-03	15-09	FOCUS Piacenza	FOCUS Piacenza
1	4	25-04	15-10	Local expert	Local expert
1	5	10-04	20-10	Local expert	Local expert
1	6	20-04	**31-10**	Local expert	Local expert (changed due to CC)
1	9	25-04	15-10	Local expert	Local expert
1	16	21-04	25-10	Local expert	Local expert
1	17	15-04	15-10	Local expert	Local expert
1	21	23-04	31-10	Agreste	Agreste
1	24	16-04	15-10	FOCUS chateaudun	FOCUS chateaudun
1	31	05-04	20-10	Local expert	Local expert
2	1	25-11	03-07	Local expert	Local expert
2	2	10-11	25-07	Local expert	Local expert
2	3	15-11	20-07	Local expert	Local expert
2	4	01-11	15-08	Local expert	Local expert
2	5	25-10	20-07	Local expert	Local expert
2	6	01-11	15-08	Local expert	Local expert
2	8	15-11	08-07	Agreste	Agreste
2	9	01-11	10-08	Local expert	Local expert
2	10	01-11	14-07	Local expert	Local expert
2	11	01-11	15-08	Local expert	Local expert
2	12	05-10	**31-07**	Local expert	Local expert (changed due to CC)
2	13	05-10	**31-07**	Local expert	Local expert (changed due to CC)
2	14	25-10	25-07	Local expert	Local expert
2	15	**01-11**	23-07	Local expert (changed due to CC)	Local expert
2	16	**01-11**	05-08	Local expert (changed due to CC)	Local expert
2	17	**01-11**	20-07	Local expert (changed due to CC)	Local expert
2	18	25-11	03-07	Local expert	Local expert
2	19	01-11	15-08	Local expert	Local expert
2	20	**01-11**	15-07	Local expert (changed due to CC)	Local expert
2	21	**01-11**	05-08	Local expert (changed due to CC)	Local expert
2	22	**01-11**	10-07	Local expert (changed due to CC)	Local expert
2	23	05-11	10-07	Local expert	Local expert
2	24	**01-11**	20-07	Local expert (changed due to CC)	Local expert
2	25	10-11	25-07	Local expert	Local expert
2	26	20-10	20-07	Local expert	Local expert
2	28	01-12	01-07	FOCUS Piacenza	FOCUS Piacenza

2	29	07-11	23-07	Agreste	Agreste
2	30	01-12	10-08	Local expert	Local expert
2	31	**01-11**	25-07	Local expert (changed due to CC)	Local expert
3	1	08-09	08-07	Agreste	Agreste
3	2	08-09	08-07	Agreste	Agreste
3	3	08-09	08-07	Agreste	Agreste
3	4	09-09	14-07	Local expert	Local expert
3	5	07-09	10-07	FOCUS chateaudun	FOCUS chateaudun
3	6	12-09	14-07	Local expert	Local expert
3	9	09-09	14-07	Local expert	Local expert
3	10	10-09	01-07	Local expert	Local expert
3	11	15-09	23-07	Agreste	Agreste
3	12	27-08	12-07	Local expert	Local expert
3	13	27-08	12-07	Local expert	Local expert
3	14	01-10	**08-07**	Agreste	Agreste (changed due to CC)
3	15	08-09	08-07	Agreste	Agreste
3	16	**01-09**	15-07	Agreste (changed due to CC)	Local expert
3	17	05-09	15-07	Local expert	Local expert
3	18	10-09	01-07	Local expert	Local expert
3	19	09-09	14-07	Local expert	Local expert
3	20	08-09	08-07	Agreste	Agreste
3	21	**01-10**	15-07	Agreste (changed due to CC)	Local expert
3	22	05-09	01-08	Local expert	Local expert
3	23	05-09	01-07	Local expert	Local expert
3	24	01-09	05-07	Local expert	Local expert
3	25	08-09	08-07	Agreste	Agreste
3	26	**01-10**	15-07	Agreste (changed due to CC)	Agreste
3	27	05-10	20-06	FOCUS Piacenza	FOCUS Piacenza
3	28	05-10	20-06	FOCUS Piacenza	FOCUS Piacenza
3	29	08-09	08-07	Agreste	Agreste
3	30	05-09	15-07	Local expert	Local expert
3	31	05-09	15-07	Local expert	Local expert
4	1	10-05	30-09	Agreste	Agreste
4	2	10-05	**31-08**	Local expert	Local expert (changed due to CC)
4	3	10-05	23-09	Agreste	Agreste
4	4	25-05	20-09	Local expert	Local expert
4	5	01-05	20-09	Local expert	Local expert
4	6	18-05	08-10	Agreste	Agreste
4	8	18-05	30-09	Agreste	Agreste
4	9	25-05	20-09	Local expert	Local expert
4	10	10-05	23-09	Agreste	Agreste
4	11	05-05	10-10	Local expert	Local expert

4	12	10-05	15-09	Local expert	Local expert
4	13	10-05	15-09	Local expert	Local expert
4	14	10-05	15-09	Agreste	Agreste
4	17	10-05	**31-08**	Agreste	Agreste (changed due to CC)
4	18	18-05	30-09	Agreste	Agreste
4	19	05-05	10-10	Local expert	Local expert
4	20	05-05	25-09	Local expert	Local expert
4	21	10-05	20-08	Local expert	Local expert
4	22	10-05	**31-08**	Agreste	Agreste (changed due to CC)
4	23	05-05	**31-08**	Local expert	Local expert (changed due to CC)
4	24	18-05	**30-09**	Agreste	Agreste (changed due to CC)
4	25	10-05	20-09	Local expert	Local expert
4	26	18-05	23-09	Agreste	Agreste
4	29	15-05	23-09	FOCUS Piacenza	Agreste
4	30	20-05	**31-08**	Local expert	Local expert (changed due to CC)
4	31	01-05	**30-09**	FOCUS chateaudun	FOCUS chateaudun (changed due to CC)
5	1	01-05	15-10	Local expert	Local expert
5	2	10-05	15-10	Local expert	Local expert
5	3	10-05	31-10	Agreste	Agreste
5	4	18-05	31-10	Agreste	Agreste
5	5	01-05	**30-09**	Local expert	Local expert (changed due to CC)
5	6	10-05	**31-10**	Local expert	Local expert (changed due to CC)
5	7	08-05	20-10	Local expert	Local expert
5	8	08-05	20-10	Local expert	Local expert
5	9	21-05	20-10	Local expert	Local expert
5	10	01-05	15-10	Local expert	Local expert
5	11	18-05	01-10	Agreste	FOCUS chateaudun
5	12	10-05	**30-09**	Local expert	Local expert (changed due to CC)
5	13	10-05	**30-09**	Local expert	Local expert (changed due to CC)
5	14	10-05	**30-09**	Agreste	Agreste (changed due to CC)
5	15	10-05	23-10	Agreste	Agreste
5	16	03-05	20-09	Agreste	Local expert
5	17	10-05	10-10	Local expert	Local expert
5	18	01-05	15-10	Local expert	Local expert
5	19	18-05	01-10	Agreste	FOCUS chateaudun
5	20	18-05	23-10	Agreste	Agreste
5	21	03-05	23-10	Agreste	Agreste
5	22	10-05	23-10	Agreste	Agreste
5	23	30-04	10-10	Local expert	Local expert
5	24	01-05	05-10	Local expert	Local expert

5	25	10-05	15-10	Local expert	Local expert
5	26	18-05	**30-09**	Agreste	Agreste (changed due to CC)
5	27	15-05	30-10	FOCUS Piacenza	FOCUS Piacenza
5	29	15-05	31-10	FOCUS Piacenza	Agreste
5	30	20-05	10-11	Local expert	Local expert
5	31	10-05	10-10	Local expert	Local expert
6	1	25-11	03-07	Local expert	Local expert
6	2	10-11	25-07	Local expert	Local expert
6	3	15-11	20-07	Local expert	Local expert
6	4	01-11	15-08	Local expert	Local expert
6	5	25-10	20-07	Local expert	Local expert
6	6	01-11	15-08	Local expert	Local expert
6	9	01-11	10-08	Local expert	Local expert
6	10	01-11	14-07	Local expert	Local expert
6	11	01-11	15-08	Local expert	Local expert
6	12	05-10	21-07	Local expert	Local expert
6	13	05-10	21-07	Local expert	Local expert
6	14	25-10	25-07	Local expert	Local expert
6	15	20-10	23-07	Local expert	Local expert
6	16	**01-11**	05-08	Local expert (changed due to CC)	Local expert
6	17	**01-11**	20-07	Local expert (changed due to CC)	Local expert
6	18	25-11	03-07	Local expert	Local expert
6	19	01-11	15-08	Local expert	Local expert
6	20	20-10	10-07	Local expert	Local expert
6	21	**01-11**	05-08	Local expert (changed due to CC)	Local expert
6	22	**01-11**	10-07	Local expert (changed due to CC)	Local expert
6	23	05-11	10-07	Local expert	Local expert
6	24	**01-11**	20-07	Local expert (changed due to CC)	Local expert
6	25	10-11	25-07	Local expert	Local expert
6	26	20-10	20-07	Local expert	Local expert
6	29	**01-11**	08-07	Agreste (changed due to CC)	Agreste
6	30	01-12	10-08	Local expert	Local expert
6	31	**01-11**	25-07	Local expert (changed due to CC)	Local expert
7	4	22-04	10-07	Local expert	Local expert
7	9	21-05	15-09	Local expert	Local expert
7	16	11-05	**30-08**	Local expert	Local expert (changed due to CC)
7	17	06-05	15-08	Local expert	Local expert
7	25	22-04	10-07	Local expert	Local expert
7	30	22-04	10-07	Local expert	Local expert
7	31	06-05	10-08	Local expert	Local expert

8	1	01-05	**31-08**	Local expert	Local expert (changed due to CC)
8	3	06-05	15-09	Agreste	Agreste
8	10	01-05	31-08	Local expert	Local expert
8	12	06-05	15-09	Agreste	Agreste
8	14	20-04	31-08	Local expert	Local expert
8	15	06-05	15-09	Agreste	Agreste
8	16	25-04	25-09	Local expert	Local expert
8	17	06-05	**31-08**	Agreste	Agreste (changed due to CC)
8	18	01-05	**31-08**	Local expert	Local expert (changed due to CC)
8	19	06-05	15-09	Agreste	Agreste
8	20	20-04	**31-08**	Local expert	Local expert (changed due to CC)
8	22	01-05	**31-08**	Local expert	Local expert (changed due to CC)
8	23	20-04	10-09	Local expert	Local expert
8	24	06-05	15-09	Agreste	Agreste
8	26	20-04	20-09	FOCUS Piacenza	FOCUS Piacenza
8	27	20-04	20-09	FOCUS Piacenza	FOCUS Piacenza
8	28	06-05	15-09	Agreste	Agreste
8	29	06-05	15-09	Agreste	Agreste
9	8	08-05	**30-09**	Local expert (Maize grain)	Local expert (Maize grain)(changed due to CC)
9	20	05-05	**31-08**	Local expert (Maize fodder)	Local expert (Maize fodder)(changed due to CC)
9	29	15-05	31-10	FOCUS Piacenza	Agreste (Maize grain)

Appendix 12. Method of selection of most representative MARS tile for each AU

Method of selection of most representative MARS tile for each AU

The selection of the most appropriate MARS tile was based on agricultural area. Corresponding data were taken from the Agreste database, where for each Canton in France the agricultural area is given. The areas corresponding to fruit trees and vines were excluded, so that only arable land was considered.

The tile with the largest occupation of agricultural area within the corresponding AU was selected by default. However, it was then checked if more than one major agricultural area existed in the AU and if the variability of weather conditions within the AU is acceptably small. In such cases, it was decided based on expert's opinion if other tiles might be more suitable as weather scenario (e.g. by relative geographic location to mountain ranges, the sea,…).

<u>Calculation of the agricultural area per tile/AU combination:</u>

- The administrative map of the cantons was intersected with the map of the AUs and a map of the location of the MARS-tiles. For each of the generated polygons the area was calculated.
- The area of each polygon (as an intersection of canton/AU/MARS tile) is multiplied with the agricultural occupation of its corresponding cantons. This gives an "Area Index" (I_a) of how much agricultural area is located within this polygon.
- The single I_a`s of each polygon located in each tile/AU combination were summed up, so that for each AU the tiles can be ranked by their agricultural occupation. A tile with the "Agricultural Area Index" (I_i) is in the following denoted as $T_{i,AU}$, where *i* is the rank of the tile within one AU. $T_{1,AU}$ denotes the tile with the largest agricultural occupation.

<u>Calculation of threshold for acceptance of variability:</u>
The underlying assumption for an acceptable variability is that the level of variability over time is also acceptable over space.

- For each MARS- tile in France the rainfall sum (r) and the average mean temperature (t) was calculated over the 30 years (1971-2001).
- For each of the 31 $T_{1,AU}$ tiles the standard deviation of the annual rainfall sum and annual average temperature is calculated and devided by the mean, indicating the temporal variability within each AU as the coefficient of variation (CV). The mean of the 2 data sets consisting each of 31 entries (1 CV per AU), gives the average coefficient of variation (CV_{temp} and CV_{rain}) of the $T_{1,AU}$ tiles in average over all AUs (CVrain = 0.19 and CVtemp = 0.06).
- For all tiles in France the mean of the rainfall sum and the temperature was calculated over the 30 years. Multiplied by the CV's this identifies the acceptable differences X_{ac} in rainfall sum and average temperature within one AU (4800 mm rainfall sum [160 mm/a] and 0.7 °C).

<u>Selection of most representative tile for each AU:</u>

STEP 1. It is tested whether there are AUs in which two geographically separate agricultural areas exist. Therefore the location of the two tiles within the AU which inherit the largest agricultural occupation ($T_{1,AU}$ and $T_{2,AU}$) is compared with GIS.

a. Are they neighbored, go to STEP 2
b. Are they not neighbored, go to STEP 4a

STEP 2. The difference X_{AU} of the parameters rainfall sum and average temperature of the most representative tiles $T_{1,AU}$ and $T_{2,AU}$ is compared with the acceptable difference (X_{ac} of the corresponding parameter), to test whether the variability in the climatic conditions between the two main tiles is acceptable small.

a. If $X_{AU} < X_{ac}$, select $T_{1,AU}$
b. If $X_{AU} > X_{ac}$, go to STEP 3

STEP 3. Calculate differences in agricultural occupation ($D = \frac{(I_1 - I_2)}{I_1} * 100$) between $T_{1,AU}$ and $T_{2,AU}$ (indicating if $T_{1,AU}$ is much more representative for the agricultural conditions than $T_{2,AU}$). I_1 and I_2 are the agricultural occupation of $T_{1,AU}$ and $T_{2,AU}$ respectively.

a. If D > 25, select $T_{1,AU}$
b. If D < 25, go to STEP 4b

STEP 4. Case-by-case decision:

a. If the two tiles with largest agricultural area occupation are not neighbored, this indicates that there might be at least two not-connected areas of agricultural interest. By local knowledge the area of highest interest for the most important crops is selected. If no preference is obvious, select $T_{1,AU}$
b. Based on STEPS 1-3 no decision can be made. This means that the two most representative MARS-tiles are located close to each other and occupy a similar area of agricultural land, but their rainfall sum or average temperature vary significantly. As a final check before accepting $T_{1,AU}$ major orographic influences (as given by the tiles' position in the landscape) should be checked. If $T_{1,AU}$ is located close to a mountain range or to the sea, and $T_{2,AU}$ is more representative for most of the AU, then select $T_{2,AU}$, otherwise select $T_{1,AU}$.

Example: confirmation of the tile selection for temperature in AU 6

The two tiles 55044 and 54044 are the tiles with largest agricultural occupation (Table 58). Tile 55044 is $T_{1,AU}$ and tile 54044 is $T_{2,AU}$.

STEP 1: Both tiles are neighbored. No two separate main agricultural areas can be observed ➔ follow STEP2

STEP 2: The difference in mean temperature within the main agricultural area is 11.2°C-10.5°C = 0.7 °C. This is exactly the acceptable threshold for the temperature ($X_{ac,temp}$ = 0.7). In this borderline case it was decided to go on with STEP 3.

STEP 3: The difference in agricultural occupation D is calculated by $D = \frac{(13648662 - 8846267)}{13648662} * 100 = 35$. This indicates that the agricultural area of $T_{1,AU}$ is 35% larger than the agricultural area of $T_{2,AU}$. It is therefore assumed to be much more relevant (> 25%) for agriculture in AU 6 and is selected for the weather scenario.

Table 58: Agricultural area, rainfall sum, and mean temperature of 30 years of all MARS tiles in AU 6

AU	MARS tile	Area (-)	Rainfall sum (mm)	Mean Temp. (°C)
6	55044	13648662	23327	11.2
6	54044	8846267	23421	10.5
6	55043	6457459	23325	11.1
6	53044	3538510	23157	10.8
6	53045	2357885	23016	11.0
6	54045	1435458	23406	10.3
6	56043	305168	27808	11.4

Results

STEP 1: All AUs passed, except AU 22 ➔ STEP 4a
STEP 2: rain: All AUs passed, except AU 2, 25, 26 ➔ STEP 3
temp: All AUs passed, except AU 6, 21, 23, 27, 28 ➔ STEP 3
STEP 3: rain: All AUs passed
temp: All AUs passed, except AU 23, 27, 28 ➔ STEP 4b
STEP 4a: for AU 22: Tile 55046 and 50048 are not neighbored, but are located in the same area. No significant differences in agriculture can be identified in these areas ➔ T_1 is selected
STEP 4b: AU23, all 3 tiles are influenced by mountains (either Jura or Massif Central) as is the whole AU ➔ T_1 is selected; AU27, the AU is influenced by mountains and by the sea. Tile 42052 is closer to the mountains, Tile 42051 closer to the sea, hence no preference identified ➔ T_1 is selected; AU28, the AU is strongly influenced by the sea. Tile 42050 is located at the sea and therefore preferred ➔ T_1 is selected.

For all AUs the tiles with the largest agricultural area were selected. Their MARS-ID and their location within the AUs are given in *Table 15* and *Figure 27*.

Appendix 13. Irrigation acreage per Agronomic Unit for the FROGS irrigated crops

Table 59 Irrigation acreage of the crops included in FROGS for the 31 Agronomic Units (expressed in ha)

AU name	AUID	Sum of SAU	Total FROGS Crops Irrigated	Sugarbeet irrigated	Wheat irrigated	Hard wheat irrigated	Oilseed crop irrigated	Grain maize irrigated	Fodder maize iirigated	Other cereals irrigated	Potato irrigated	Sunflower irrigated
Collines molassiques - Lauragais	1	1243320	154609	22	24	395	11382	120494	10118	10286	107	1781
Charentes	10	1322839	151400	0	2622	1750	10380	116376	11092	7575	516	1089
Beauce - Drouais - Gatinais	17	958676	108899	23327	2175	1949	17514	46751	693	9504	6562	424
Bordelais - Perigord - Coteaux du Lot	18	921868	100474	30	177	60	2127	81783	11372	2589	1612	724
Bassin de l'Adour	8	589991	94154	0	11	0	243	90025	3319	226	31	299
Aquitaine - Landes	7	157250	70271	38	34	0	41	68235	669	177	930	147
Bocages de l'ouest	20	1353504	55366	0	478	298	4944	19537	29236	118	617	138
Alsace - Sundgau	5	276558	50726	916	1622	0	5	46496	1226	158	303	0
Bas Dauphine - Vallee du Rhône	23	450219	50672	0	599	233	5375	36076	1643	4211	652	1883
Gatines - Vallees de Loire	14	636638	39878	0	1142	693	3941	26945	5029	1707	94	327
Champagne berrichonne - Boischaut	22	1059459	36827	260	1309	364	2091	25717	1991	4327	241	527
Limagnes - Plaine du Forez	3	612973	27407	1503	1152	0	955	19315	4028	136	239	79
Perche - Pays d'Auge - Pays d'Ouche	19	871648	24106	52	525	136	2001	16101	4519	553	180	39
Picardie - Nord - Pas-de-Calais	9	1141433	22674	845	520	0	174	348	122	0	20665	0
Sologne - Orleanais	15	157615	19395	336	663	109	678	14497	844	1273	808	187
Fosse	24	55943	1526	2236	92	1	124	1104	419	770	552	27

bressan		9	1					0				
Champagne crayeuse	16	732977	13101	1562	92	0	47	1912	70	78	9334	6
Plaine du Languedoc-Roussillon	28	375316	11160	0	215	3437	337	1582	45	4090	445	1009
Ile-de-France	31	931602	10502	1858	511	21	196	2665	87	127	5037	0
Provence	27	192698	7423	0	25	2950	189	2022	4	489	694	1050
Boischaut du sud	29	521777	4937	56	101	27	437	3159	995	111	16	35
Bordure maritime Nord - Picardie - Normandie	4	1224365	4877	324	65	0	20	270	220	10	3968	0
Bocage normand	11	1112296	3356	0	75	0	377	1938	850	28	76	12
Bretagne sud	2	459222	1771	0	0	0	59	595	996	5	116	0
Ardenne - Argonne - Champagne humide	21	556896	1392	131	30	0	4	641	21	10	551	4
Bretagne nord	30	841643	1169	10	14	0	88	245	591	2	219	0
Plaine normande - Bessin	6	251501	1151	227	77	0	93	496	88	46	124	0
Barrois - Plateaux bourguignons	12	1046559	926	130	17	0	108	485	132	16	38	0
Bretagne centrale	25	430730	700	0	0	0	0	56	35	0	609	0
Plateaux de Haute-Saone	26	350511	347	3	0	0	0	289	48	5	2	0
Plateau lorrain	13	640234	80	0	0	0	0	78	0	0	2	0
Territoire non pris en compte	0	5872415	66364	391	815	4955	2844	24783	14583	15204	1084	1705
Total		27854172	1151375	34257	15182	17378	66774	780952	105085	63831	56424	11492

Table 60 Density of irrigation for the crops included in FROGS in the 31 Agronomic Units (expressed in % of irrigated crop surface vs. crop surface)

AU name	AUID	Sum of SAU	Total FROGS Crops Irrigated	Sugarbeet irrigated	Wheat irrigated	Hard wheat irrigated	Oilseed crop irrigated	Grain maize irrigated	Fodder maize iirigated	Other cereals irrigated	Potato irrigated	Sunflower irrigated
Collines molassiques - Lauragais	1	1243320	154609	84.6	0.0	0.3	-	85.4	52.6	-	55.4	-
Charentes	10	1322839	151400	0.0	0.9	8.8	-	66.7	26.1	-	73.5	-
Beauce - Drouais - Gatinais	17	958676	108899	65.9	0.5	4.8	-	83.6	15.9	-	95.2	-
Bordelais - Perigord - Coteaux du Lot	18	921868	100474	76.9	0.2	2.3	-	61.1	38.1	-	90.4	-
Bassin de l'Adour	8	589991	94154	0.0	0.1	0.0	-	36.6	11.2	-	36.5	-
Aquitaine - Landes	7	157250	70271	100.0	2.8	0.0	-	90.7	60.8	-	99.3	-
Bocages de l'ouest	20	1353504	55366	0.0	0.3	15.9	-	39.9	16.8	-	75.8	-
Alsace - Sundgau	5	276558	50726	17.2	4.6	0.0	-	37.0	11.5	-	28.0	-
Bas Dauphine - Vallee du Rhône-	23	450219	50672	0.0	1.2	2.4	-	56.0	14.5	-	53.8	-
Gatines - Vallees de Loire	14	636638	39878	0.0	0.7	4.1	-	46.2	23.9	-	51.1	-
Champagne berrichonne - Boischaut	22	1059459	36827	69.7	0.4	6.3	-	61.5	13.5	-	91.3	-
Limagnes - Plaine du Forez	3	612973	27407	44.7	1.5	0.0	-	53.3	25.1	-	47.2	-
Perche - Pays d'Auge - Pays d'Ouche	19	871648	24106	3.4	0.2	4.0	-	31.8	7.1	-	39.5	-
Picardie - Nord - Pas-de-Calais	9	1141433	22674	0.7	0.1	0.0	-	1.2	0.3	-	32.0	-
Sologne - Orleanais	15	157615	19395	77.1	2.1	4.1	-	77.1	33.3	-	92.2	-
Fosse bressan	24	559439	15261	52.8	0.1	4.3	-	13.2	2.4	-	52.3	-
Champagne	16	732977	13101	2.2	0.0	0.0	-	9.3	1.8	-	51.1	-

crayeuse												
Plaine du Languedoc-Roussillon	28	375316	11160	0.0	13.5	10.3	-	93.9	86.5	-	90.8	-
Ile-de-France	31	931602	10502	2.3	0.1	1.3	-	5.1	1.3	-	41.4	-
Provence	27	192698	7423	0.0	1.9	12.6	-	74.7	26.7	-	92.5	-
Boischaut du sud	29	521777	4937	23.0	0.2	14.1	-	49.1	8.8	-	51.6	-
Bordure maritime Nord - Picardie - Normandie	4	1224365	4877	0.6	0.0	0.0	-	2.7	0.2	-	17.3	-
Bocage normand	11	1112296	3356	0.0	0.1	0.0	-	11.1	0.4	-	4.4	-
Bretagne sud	2	459222	1771	0.0	0.0	0.0	-	1.9	1.4	-	14.9	-
Ardenne - Argonne - Champagne humide	21	556896	1392	1.1	0.0	0.0	-	2.8	0.1	-	36.3	-
Bretagne nord	30	841643	1169	90.9	0.0	0.0	-	0.4	0.4	-	2.2	-
Plaine normande - Bessin	6	251501	1151	3.9	0.1	0.0	-	9.9	0.4	-	14.1	-
Barrois - Plateaux bourguignons	12	1046559	926	7.4	0.0	0.0	-	3.9	0.4	-	11.2	-
Bretagne centrale	25	430730	700	0.0	0.0	0.0	-	0.2	0.1	-	20.6	-
Plateaux de Haute-Saone	26	350511	347	7.0	0.0	0.0	-	1.6	0.3	-	3.3	-
Plateau lorrain	13	640234	80	0.0	0.0	0.0	-	1.3	0.0	-	1.5	-
Territoire non pris en compte	0	5872415	66364	40.8	0.5	9.7	-	33.6	11.6	-	34.5	-
Total		27854172	1151375				-	85.4	52.6	-	55.4	-

Appendix 14. Soil Surfaces in the Agronomic Units (ha)

AU	Agronomic Unit	Soil N°				
		1	2	3	4	5
1	Collines molassiques - Lauragais	7304	497548		116406	3341
2	Bretagne sud	34510	162		97956	61212
3	Limagnes - Plaine du Forez		89149			7195
4	Bordure Nord - Picardie - Normandie	570785	102723	17930	8388	
5	Alsace - Sundgau	5881	187469		37361	
6	Plaine normande - Bessin	61427	38110		1837	56303
7	Aquitaine - Landes		10991	1441	7316	
8	Bassin de l'Adour	5156	65789		252777	1367
9	Picardie - Nord - Pas-de-Calais	569729	12652		6233	
10	Charentes	5	36180		77061	120665
11	Bocage normand	234787	8999		131061	178777
12	Barrois - Plateaux bourguignons	5711	326487		91	670275
13	Plateau lorrain	548	246363		2924	24045
14	Gâtines - Vallées de Loire	201117	124871		3066	22721
15	Sologne - Orléanais	36811	16317		2832	891
16	Champagne crayeuse	31541	45654	467583		
17	Beauce - Drouais - Gâtinais	411028	118809		988	67424
18	Bordelais - Périgord - Coteaux du Lot		286750	18900	48432	18580
19	Perche - Pays d'Auge - Pays d'Ouche	341573	212639		6547	41564
20	Bocages de l'ouest	52102	2858		269480	161552
21	Ardenne - Argonne - Champagne H.	96884	69699	10962		41590
22	Champagne berrichonne - Boischaut	161704	174544		26450	229677
23	Bas Dauphiné - Vallée du Rhône	17828	1784		213237	38527
24	Fossé bressan	40661	72789		52386	52746
25	Bretagne centrale	53439			57669	58793
26	Plateaux de Haute-Saône	15916	112829		4735	144703
27	Provence	6850	109		27173	145
28	Plaine du Languedoc-Roussillon			14043	1337	
29	Boischaut du sud		57091		105928	1392
30	Bretagne nord	254693	1860		102526	112175
31	Ile-de-France	330684	181783	17742	5303	
	Total Surface	3548676	3103007	548602	1667498	2115661

AU	Agronomic Unit	Soil N°				
		6	7	8	9	10
1	Collines molassiques - Lauragais	5348	239096	181607	4364	
2	Bretagne sud					5667
3	Limagnes - Plaine du Forez	21080		70519	25244	
4	Bordure Nord - Picardie - Normandie	105367		149572	27605	25821
5	Alsace - Sundgau			87261	14288	22953
6	Plaine normande - Bessin	1779		3447	3613	2355
7	Aquitaine - Landes		7	48475	20339	
8	Bassin de l'Adour		24670	101993		
9	Picardie - Nord - Pas-de-Calais	221188		59900	32066	7240
10	Charentes	117962		22298	4301	60140
11	Bocage normand	15320		505	2572	
12	Barrois - Plateaux bourguignons	18113		54810	62018	18088
13	Plateau lorrain	14568		56976	24845	16279
14	Gâtines - Vallées de Loire	140221		1080	99618	785
15	Sologne - Orléanais	13885		4634	60120	
16	Champagne crayeuse	123057		29948	71754	9486
17	Beauce - Drouais - Gâtinais	99095		46570	4861	16435
18	Bordelais - Périgord - Coteaux du Lot	41288	127269	96921		126
19	Perche - Pays d'Auge - Pays d'Ouche	38502		28885	11559	
20	Bocages de l'ouest	10079			18135	9002
21	Ardenne - Argonne - Champagne H.	33531		9593	59615	438
22	Champagne berrichonne - Boischaut	8826			118314	4094
23	Bas Dauphiné - Vallée du Rhône		1874	124370		
24	Fossé bressan			50248	6324	
25	Bretagne centrale					
26	Plateaux de Haute-Saône	9477			22479	
27	Provence	685		84072		
28	Plaine du Languedoc-Roussillon	120991		89254	24510	808
29	Boischaut du sud	6602		16145	16818	
30	Bretagne nord	251				
31	Ile-de-France	175462		95345	7728	19164
	Total Surface	1342679	392916	1514428	743093	218881

AU	Agronomic Unit	Soil N°				
		11	12	13	14	15
1	Collines molassiques - Lauragais	42604		34487	293070	56618
2	Bretagne sud	204917	17255	101396	67333	6670
3	Limagnes - Plaine du Forez	34853			214748	29577
4	Bordure Nord - Picardie - Normandie	44607	21237	117608	5672	2185
5	Alsace - Sundgau	1471		3430		4926
6	Plaine normande - Bessin	12387	6823	2874	1761	9911
7	Aquitaine - Landes				19546	502
8	Bassin de l'Adour	51854		17346	91247	183841
9	Picardie - Nord - Pas-de-Calais	96157	17408	104529	7124	7445
10	Charentes	328486	1	11026	35515	63689
11	Bocage normand	161441	93358	247763	47745	81743
12	Barrois - Plateaux bourguignons	117670	6272	7294	10586	45772
13	Plateau lorrain	12806		3158		17530
14	Gâtines - Vallées de Loire	66018	53160	3000	137	42925
15	Sologne - Orléanais	6269	4446		1207	141
16	Champagne crayeuse	54326	23140	28848	9361	54335
17	Beauce - Drouais - Gâtinais	58512	62381	16939	15025	6742
18	Bordelais - Périgord - Coteaux du Lot	131496		6766	159475	52794
19	Perche - Pays d'Auge - Pays d'Ouche	25156	283212	4325	19791	3961
20	Bocages de l'ouest	24993	26051	133448	129726	496427
21	Ardenne - Argonne - Champagne H.	26121		8281	127949	18284
22	Champagne berrichonne - Boischaut	16930	45514		50956	3551
23	Bas Dauphiné - Vallée du Rhône	159463				61377
24	Fossé bressan	38646	3672	5148	3752	63559
25	Bretagne centrale	102831	26720	116111	18040	121597
26	Plateaux de Haute-Saône	34107	13667			12519
27	Provence	214006		55209		
28	Plaine du Languedoc-Roussillon	149829				44876
29	Boischaut du sud	189522			58704	16286
30	Bretagne nord	136701	102355	278212	31251	31896
31	Ile-de-France	73994	158290	16408	14285	23146
	Total Surface	2618173	964962	1323606	1434005	1564829

AU	Agronomic Unit	Soil N°				Total
		16	17	18	19	
1	Collines molassiques - Lauragais	92851				1574644
2	Bretagne sud					597079
3	Limagnes - Plaine du Forez				4041	496406
4	Bordure Nord - Picardie - Normandie		167218		40930	1407648
5	Alsace - Sundgau				151	365190
6	Plaine normande - Bessin				1526	204153
7	Aquitaine - Landes				16555	125172
8	Bassin de l'Adour				904	796944
9	Picardie - Nord - Pas-de-Calais		8325		55226	1205222
10	Charentes	21810	3039	113497	2639	1018315
11	Bocage normand				109	1204181
12	Barrois - Plateaux bourguignons	57692	3318		6904	1411101
13	Plateau lorrain	18274			2112	440428
14	Gâtines - Vallées de Loire		8629		8553	775901
15	Sologne - Orléanais				928	148482
16	Champagne crayeuse		62459		7526	1019019
17	Beauce - Drouais - Gâtinais		46409		24761	995980
18	Bordelais - Périgord - Coteaux du Lot	32638			24821	1046255
19	Perche - Pays d'Auge - Pays d'Ouche		10915		4530	1033157
20	Bocages de l'ouest	1377		369		1335599
21	Ardenne - Argonne - Champagne H.	68			15677	518692
22	Champagne berrichonne - Boischaut		5436		31843	877838
23	Bas Dauphiné - Vallée du Rhône					618461
24	Fossé bressan				2179	392111
25	Bretagne centrale					555201
26	Plateaux de Haute-Saône				3018	373449
27	Provence					388250
28	Plaine du Languedoc-Roussillon					445647
29	Boischaut du sud				3807	472296
30	Bretagne nord					1051921
31	Ile-de-France		38738		109946	1268018
	Total Surface	224711	354486	113865	368683	24162762

Appendix 15. Calculation of the soil surface for each crop within each Agronomic Unit – based on Agreste (2010)

The procedure detailed below aims to allocate soils to the surface defined by the acreage of a specific crop in a specific AU (Appendix 7). In a first step the soils are selected on which the crop is cultivated and the acreage for a specific soil is calculated using the general relation between crop and soil (Table 38). Normally these acreages do not match with the surface of specific soil in an AU (as defined in Appendix 14). At the level of the AU, the surface of some soils is smaller then the acreage derived in the first step whereas the surface is bigger. Therefore, in a second step additional surface is allocated to those soils which have a greater surface than allocated in the first step to compensate for those which have a smaller surface. This method allows to combine both the relation between crop and soil (Table 38) and the relation between AU and soil surface (Appendix 14) in a consistent manner.

However, it is emphasized that these calculations still provide a maximum estimation of the crop surface that can be attributed to one specific soil in one specific AU. Indeed, each crop is considered separately from each other and the methodology does not take into account the possibility that a second crop could be grown on a proportion of the same soil.

Procedure:

The procedure implies two main steps as described below and is repeated.

Step 1 calculates the surface of the 19 soils (i) associated to each crop (crop_x) for each AU (AU_y), called soil(i, AU_y, crop_x)

a- is soil(i,AU_y)>0 ? (from Appendix 14)

b- if yes, the soil surface associated to the crop is calculated by multiplying the cultivated surfaces in the AU (from Appendix 7) with the distribution of soil in the cropping region (from Table 38)

   soil(i, AU_y, crop_x)[ha] = crop_acreage(AU_y, crop_x) * soil_distribution(i, crop_x)

c- it is then checked if the calculated surface soil(i, AU_y, crop_x) is higher or not than the surface of that soil within the AU (soil(i, AU_y)). If the calculated soil surface associated to the crop_x within the AU_y is higher than the surface of that soil within the AU, then it is limited to that surface of that soil within the AU.

   if soil(i, AU_y, crop_x) > soil(i, AU_y),
   then soil(i, AU_y, crop_x) = soil(i, AU_y)

d- from step 1c, if soil(i, AU_y, crop_x) > soil(i, AU_y), the methodology generates "non-allocated" crop surfaces to soils in each AU. This "non-allocated" crop surfaces are calculated as follows and are managed in the Step-2 of the methodology

   non-allocated_crop(i, AU_y, crop_x) = soil(i, AU_y, crop_x) - soil(i, AU_y)

Step 2 aims to distribute the "non-allocated" crop surfaces of each AU to the soils that are present in the AU according to their relative distribution within the AU, and excluding soils that already reached 100% of their "capacity" in step 1.

a- the total "non-allocated" crop surfaces within each AU is calculated as Total non-allocated_crop(i, AU_y, crop_x) = $\sum_{(i=1,19)}$ non-allocated_crop(i, AU_y, crop_x)

b- calculate the relative surface of each "non-full" soil (*i.e.*, soil(I, AU_y, crop_x) < soil(I, AU_y)) to the surface of the subregion made by all "non-full" soils only within the AU

%non-full_soil(i, AU_y, crop_x) = soil(i, AU_y) / $\sum_i$ soil(i, AU_y)

c- the non-allocated crop surfaces of each AU are distributed to soils according to their relative surface within the subregion

distributed_crop(i, AU_y, crop_X) = Total non-allocated_crop(i, AU_y, crop_x) * %non-full_soil(i, AU_y, crop_x)

d- the final surface of soil associated to one crop for each AU is the sum of the calculated soil surface from step 1 and the additional distributed crop from step 2

Final_ soil(i, AU_y, crop_x) = soil(i, AU_y, crop_x) + distributed_crop(i, AU_y, crop_X)

Examples for Step 1

Example 1 – sugar beet_soil1_AU1:

a- first it is checked that Soil(1) is present in AU_1, here soil(1, AU_1) = 7304 ha

b- as soil(1, AU_1) > 0, then soil(1, AU_1, sugar beet) = 26 ha x 25.4% = 7 ha

c- as soil(1, AU_1, sugar beet) < soil(1, AU_1), stop here

Example 2 – sugar beet_soil3_AU3 :

a- first it is checked that soil(3) is present in AU_3, here soil(3, AU_3) = 0 ha

b- as soil(3, AU_3) = 0, then soil(3, AU_3, sugar beet) = 0 ha, despite that at national level soil(3) represents 11.5% of sugar beet soils

Example 3 – winter wheat_soil1_AU1 :

a- first it is checked that soil(1) is present in AU_1, here soil(1, AU_1) = 7304 ha

b- as soil(1, AU_1) > 0, then soil(1, AU_1, winter wheat) = 193128 x 16.9% = 32639 ha

c- as soil(1, AU_1, winter wheat) > soil(1, AU_1), then soil(1, AU_1, winter wheat) = soil(1, AU_1). *i.e.* 7304 ha

d- non-allocated_winter wheat(1, AU_1, winter wheat) = Soil(1, AU_1, winter wheat) - soil(1, AU_1) = 32639 – 7304 = 25335 ha

The overall results of Step 1 are summarised in *Table 61*.

Table 61 Results of Step 1 method to calculate scenarios surfaces

	SB	WW	WOSR	MF	MG	WB	PO	SF
Total crop AU 0-31 (ha)	350422	4882009	1370560	1339126	1596269	1537787	147968	646411
Total crop AU 1-31 (ha)	350185	4716541	1343514	1229750	1532721	1418082	146112	629404
Total crop allocated to soils (ha)	238070	2188874	623048	765079	1064979	639417	83869	379639
Total crop allocated to soil of AU 1-31 (%)	68.0	46.4	46.4	62.2	69.5	45.1	57.4	60.3
Total crop allocated to soil of AU 1-31 (ha)	112115	2527667	720466	464671	467742	778665	62243	249765
Total crop non-allocated to soil of AU 1-31 (%)	32.0	53.6	53.6	37.8	30.5	54.9	42.6	39.7

Example for Step 2:

It is emphasized that the numbers presented in the example below may slightly differ from the one in the database due to the use of rounded values in the example compared to what was done in the calculation for the database.

Continuing example 3 – winter wheat_soil1_AU1:

a- by repeating step 1a, b and c of example 3 for the 19 soils of AU_1, the total non-allocated crop is

Total non-allocated_winter wheat(1, AU_1, winter wheat) = 132522 ha

b- from Step 1, soil(1), soil(5) and soil(6) in AU_1 are already “full” (7304, 3341 and 5348 ha) and cannot receive more winter wheat. However soil(2), soil(4), soil(8), soil(9) and soil(13) are not full and can be cultivated with more winter wheat. The relative surface of soil(2), soil(4), soil(8), soil(9) and soil(13) to the subregion made by soil(2, 4, 8, 9, 13) is calculated as being

%non-full_soil(2, AU_1, winter wheat) = 497 548 / (497 548 + 116 406 + 181 607 + 4364 + 34 487) = 59.6 %
%non-full_soil(4, AU_1, winter wheat) = 14.0%
%non-full_soil(8, AU_1, winter wheat) = 21.8%
%non-full_soil(9, AU_1, winter wheat) = 0.5%
%non-full_soil(13, AU_1, winter wheat) = 4.1%

c- the non-allocated winter wheat of AU_1 in redistributed to soil(2), soil(4), soil(8), soil(9) and soil(13) as

distributed_winter wheat(2, AU_1, winter wheat) = 132522 x 59.6% =78983 ha
distributed_winter wheat(4, AU_1, winter wheat) = 18553 ha
distributed_winter wheat(8, AU_1, winter wheat) = 28890 ha
distributed_winter wheat(9, AU_1, winter wheat) = 663 ha
distributed_winter wheat(13, AU_1, winter wheat) = 5433 ha

d- the final surface of soil(2), soil(4), soil(8) soil(9) and soil(13) associated to winter wheat in AU1 are calculated as

Final_soil(2, AU_1, winter wheat) = 19699 + 78983 = 98682 ha
Final_soil(4, AU_1, winter wheat) = 6180 + 18553 = 24733 ha
Final_soil(8, AU_1, winter wheat) = 6759 + 28890 = 35649 ha
Final_soil(9, AU_1, winter wheat) = 3863 + 663 = 4526 ha
Final_soil(13, AU_1, winter wheat) = 8111 + 5433 = 13544 ha

The overall results of Step 1 are summarised in *Table 62*.

Table 62 Results of Step 2 method to calculate scenarios surfaces

	SB	WW	WOSR	MF	MG	WB	PO	SF
Total crop AU 0-31 (ha)	350422	4882009	1370560	1339126	1596269	1537787	147968	646411
Total crop AU 1-31 (ha)	350185	4716541	1343514	1229750	1532721	1418082	146112	629404
Total crop allocated to soils (ha)	350185	4702482	1343510	1229467	1529380	1418066	146112	629404
Total crop allocated to soil of AU 1-31 (%)	100.0	99.7	100.0	100.0	99.8	100.0	100.0	100.0
Total crop non-allocated to soil of AU 1-31 (ha)	0	14059	4	283	3341	16	0	0
Total crop non-allocated to soil of AU 1-31 (%)	0.0	0.3	0.0	0.0	0.2	0.0	0.0	0.0

Appendix 16. Selected scenarios per Crop and associated surfaces (ha) – based on Agreste (2010)

Crop: Sugar Beet

AU	Soil ID	1	2	3	4	5	6	7
1	Collines molassiques - Lauragais	0	0	0	0	0	0	0
2	Bretagne sud	0	0	0	0	0	0	0
3	Limagnes - Plaine du Forez	0	1192	0	0	0	0	0
4	Bordure Nord - Picardie - Normandie	16926	3322	5230	0	0	8837	0
5	Alsace - Sundgau	1345	2039	0	0	0	0	0
6	Plaine normande - Bessin	3091	1206	0	0	0	1232	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	49381	6106	0	0	0	27642	0
10	Charentes	0	0	0	0	0	0	0
11	Bocage normand	0	0	0	0	0	0	0
12	Barrois - Plateaux bourguignons	0	0	0	0	0	0	0
13	Plateau lorrain	0	0	0	0	0	0	0
14	Gâtines - Vallées de Loire	0	0	0	0	0	0	0
15	Sologne - Orléanais	0	0	0	0	0	0	0
16	Champagne crayeuse	18390	4648	18544	0	0	15093	0
17	Beauce - Drouais - Gâtinais	16881	4107	0	0	0	8245	0
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	0	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0	0	0
20	Bocages de l'ouest	0	0	0	0	0	0	0
21	Ardenne - Argonne - Champagne H.	2556	0	0	0	0	1560	0
22	Champagne berrichonne - Boischaut	0	0	0	0	0	0	0
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0	0	0
24	Fossé bressan	0	0	0	0	0	0	0
25	Bretagne centrale	0	0	0	0	0	0	0
26	Plateaux de Haute-Saône	0	0	0	0	0	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	0	0	0	0	0	0
30	Bretagne nord	0	0	0	0	0	0	0
31	Ile-de-France	23046	6837	7983	0	0	15038	0

Crop: Sugar Beet

AU	Soil ID	8	9	10	11	12	13	14
1	Collines molassiques - Lauragais	0	0	0	0	0	0	0
2	Bretagne sud	0	0	0	0	0	0	0
3	Limagnes - Plaine du Forez	0	0	0	0	0	0	0
4	Bordure Nord - Picardie - Normandie	3313	1377	0	0	0	3034	0
5	Alsace - Sundgau	1034	0	0	0	0	0	0
6	Plaine normande - Bessin	0	0	0	0	0	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	6737	3936	0	0	0	8563	0
10	Charentes	0	0	0	0	0	0	0
11	Bocage normand	0	0	0	0	0	0	0
12	Barrois - Plateaux bourguignons	0	0	0	0	0	0	0
13	Plateau lorrain	0	0	0	0	0	0	0
14	Gâtines - Vallées de Loire	0	0	0	0	0	0	0
15	Sologne - Orléanais	0	0	0	0	0	0	0
16	Champagne crayeuse	3529	3357	0	0	0	3573	0
17	Beauce - Drouais - Gâtinais	2353	0	0	0	0	1833	0
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	0	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0	0	0
20	Bocages de l'ouest	0	0	0	0	0	0	0
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0	0	0
22	Champagne berrichonne - Boischaut	0	0	0	0	0	0	0
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0	0	0
24	Fossé bressan	0	0	0	0	0	0	0
25	Bretagne centrale	0	0	0	0	0	0	0
26	Plateaux de Haute-Saône	0	0	0	0	0	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	0	0	0	0	0	0
30	Bretagne nord	0	0	0	0	0	0	0
31	Ile-de-France	4499	1807	0	0	0	3100	0

Crop: Sugarbeet

AU	Soil ID	15	16	17	18	19	-	-
1	Collines molassiques - Lauragais	0	0	0	0	0		
2	Bretagne sud	0	0	0	0	0		
3	Limagnes - Plaine du Forez	0	0	0	0	0		
4	Bordure Nord - Picardie - Normandie	0	0	0	0	1863		
5	Alsace - Sundgau	0	0	0	0	0		
6	Plaine normande - Bessin	0	0	0	0	0		
7	Aquitaine - Landes	0	0	0	0	0		
8	Bassin de l'Adour	0	0	0	0	0		
9	Picardie - Nord - Pas-de-Calais	0	0	0	0	5692		
10	Charentes	0	0	0	0	0		
11	Bocage normand	0	0	0	0	0		
12	Barrois - Plateaux bourguignons	0	0	0	0	0		
13	Plateau lorrain	0	0	0	0	0		
14	Gâtines - Vallées de Loire	0	0	0	0	0		
15	Sologne - Orléanais	0	0	0	0	0		
16	Champagne crayeuse	0	0	0	0	2466		
17	Beauce - Drouais - Gâtinais	0	0	0	0	1655		
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	0		
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0		
20	Bocages de l'ouest	0	0	0	0	0		
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0		
22	Champagne berrichonne - Boischaut	0	0	0	0	0		
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0		
24	Fossé bressan	0	0	0	0	0		
25	Bretagne centrale	0	0	0	0	0		
26	Plateaux de Haute-Saône	0	0	0	0	0		
27	Provence	0	0	0	0	0		
28	Plaine du Languedoc-Roussillon	0	0	0	0	0		
29	Boischaut du sud	0	0	0	0	0		
30	Bretagne nord	0	0	0	0	0		
31	Ile-de-France	0	0	0	0	4238		

Crop: Winter wheat

AU	Soil ID	1	2	3	4	5	6	7
1	Collines molassiques - Lauragais	7304	98720	0	24668	3341	5348	0
2	Bretagne sud	15620	0	0	15411	12085	0	0
3	Limagnes - Plaine du Forez	0	29995	0	0	6334	12194	0
4	Bordure Nord - Picardie - Normandie	151112	55257	14818	8388	0	50554	0
5	Alsace - Sundgau	5881	18808	0	4230	0	0	0
6	Plaine normande - Bessin	22027	13478	0	1837	13789	1779	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	2645	2757	0	5166	0	0	0
9	Picardie - Nord - Pas-de-Calais	216738	12652	0	6233	0	94925	0
10	Charentes	0	36180	0	46856	75677	83428	0
11	Bocage normand	44600	8999	0	15532	23342	14623	0
12	Barrois - Plateaux bourguignons	5711	81423	0	0	124321	18113	0
13	Plateau lorrain	0	69507	0	2924	13164	14568	0
14	Gâtines - Vallées de Loire	58240	35618	0	3066	13785	35267	0
15	Sologne - Orléanais	8790	4710	0	1247	0	4074	0
16	Champagne crayeuse	31541	29825	73041	0	0	37759	0
17	Beauce - Drouais - Gâtinais	125176	53703	0	0	30514	46086	0
18	Bordelais - Périgord - Coteaux du Lot	0	43623	5415	8913	8202	14054	0
19	Perche - Pays d'Auge - Pays d'Ouche	67512	41349	0	6547	16138	22415	0
20	Bocages de l'ouest	45066	2858	0	56317	41910	10079	0
21	Ardenne - Argonne - Champagne H.	34313	22384	5278	0	13020	15461	0
22	Champagne berrichonne - Boischaut	76997	60884	0	13799	59050	8826	0
23	Bas Dauphiné - Vallée du Rhône	10842	1784	0	21546	6731	0	0
24	Fossé bressan	25987	24805	0	13368	16251	0	0
25	Bretagne centrale	19051	0	0	10398	12315	0	0
26	Plateaux de Haute-Saône	10320	14317	0	2089	14452	5521	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	14412	0	18921	1392	5506	0
30	Bretagne nord	60046	1860	0	18215	23730	0	0
31	Ile-de-France	105781	61324	13327	5303	0	55893	0

Crop: Winter wheat

AU	Soil ID	8	9	10	11	12	13	14
1	Collines molassiques - Lauragais	35602	4364	0	0	0	13589	0
2	Bretagne sud	0	0	0	0	4805	16525	0
3	Limagnes - Plaine du Forez	20135	7795	0	0	0	0	0
4	Bordure Nord - Picardie - Normandie	35958	11944	0	0	18054	33950	0
5	Alsace - Sundgau	8240	1938	0	0	0	1999	0
6	Plaine normande - Bessin	2921	1960	0	0	3717	2874	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	2417	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	30730	17033	0	0	17408	44832	0
10	Charentes	21086	4301	0	0	0	11026	0
11	Bocage normand	0	2572	0	0	13348	26584	0
12	Barrois - Plateaux bourguignons	18727	15643	0	0	6272	7294	0
13	Plateau lorrain	17590	8299	0	0	0	3158	0
14	Gâtines - Vallées de Loire	1080	17049	0	0	14159	3000	0
15	Sologne - Orléanais	1519	6668	0	0	1590	0	0
16	Champagne crayeuse	12248	14704	0	0	11976	13698	0
17	Beauce - Drouais - Gâtinais	19408	4861	0	0	23069	16708	0
18	Bordelais - Périgord - Coteaux du Lot	14799	0	0	0	0	5171	0
19	Perche - Pays d'Auge - Pays d'Ouche	10092	5307	0	0	34363	4325	0
20	Bocages de l'ouest	0	7536	0	0	12772	33379	0
21	Ardenne - Argonne - Champagne H.	5544	11243	0	0	0	6171	0
22	Champagne berrichonne - Boischaut	0	27689	0	0	19028	0	0
23	Bas Dauphiné - Vallée du Rhône	13455	0	0	0	0	0	0
24	Fossé bressan	13288	3361	0	0	3672	5148	0
25	Bretagne centrale	0	0	0	0	6383	19420	0
26	Plateaux de Haute-Saône	0	2835	0	0	3111	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	4382	3746	0	0	0	0	0
30	Bretagne nord	0	0	0	0	19186	42017	0
31	Ile-de-France	25711	7728	0	0	35670	16408	0

Crop: Winter wheat

AU	Soil ID	15	16	17	18	19	-	-
1	Collines molassiques - Lauragais	0	0	0	0	0		
2	Bretagne sud	0	0	0	0	0		
3	Limagnes - Plaine du Forez	0	0	0	0	2176		
4	Bordure Nord - Picardie - Normandie	0	0	0	0	11965		
5	Alsace - Sundgau	0	0	0	0	0		
6	Plaine normande - Bessin	0	0	0	0	1261		
7	Aquitaine - Landes	0	0	0	0	0		
8	Bassin de l'Adour	0	0	0	0	0		
9	Picardie - Nord - Pas-de-Calais	0	0	0	0	20372		
10	Charentes	0	0	0	0	2639		
11	Bocage normand	0	0	0	0	0		
12	Barrois - Plateaux bourguignons	0	0	0	0	5356		
13	Plateau lorrain	0	0	0	0	2112		
14	Gâtines - Vallées de Loire	0	0	0	0	3924		
15	Sologne - Orléanais	0	0	0	0	0		
16	Champagne crayeuse	0	0	0	0	4501		
17	Beauce - Drouais - Gâtinais	0	0	0	0	9129		
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	4421		
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	3596		
20	Bocages de l'ouest	0	0	0	0	0		
21	Ardenne - Argonne - Champagne H.	0	0	0	0	4101		
22	Champagne berrichonne - Boischaut	0	0	0	0	10110		
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0		
24	Fossé bressan	0	0	0	0	2036		
25	Bretagne centrale	0	0	0	0	0		
26	Plateaux de Haute-Saône	0	0	0	0	1042		
27	Provence	0	0	0	0	0		
28	Plaine du Languedoc-Roussillon	0	0	0	0	0		
29	Boischaut du sud	0	0	0	0	1369		
30	Bretagne nord	0	0	0	0	0		
31	Ile-de-France	0	0	0	0	20801		

Crop: Oilseed rape

AU	Soil ID	1	2	3	4	5	6	7
1	Collines molassiques - Lauragais	4363	14599	0	3576	3341	1685	0
2	Bretagne sud	2068	0	0	2984	2701	0	0
3	Limagnes - Plaine du Forez	0	3552	0	0	1232	1025	0
4	Bordure Nord - Picardie - Normandie	29026	11910	2337	2608	0	7135	0
5	Alsace - Sundgau	0	0	0	0	0	0	0
6	Plaine normande - Bessin	4077	3002	0	0	3716	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	1074	0	0	0
9	Picardie - Nord - Pas-de-Calais	30674	7808	0	2269	0	11783	0
10	Charentes	0	10669	0	9773	19387	14931	0
11	Bocage normand	4660	1894	0	1972	3837	0	0
12	Barrois - Plateaux bourguignons	5711	52427	0	0	86138	10470	0
13	Plateau lorrain	0	34774	0	2339	10087	4678	0
14	Gâtines - Vallées de Loire	9848	7379	0	1239	4848	5337	0
15	Sologne - Orléanais	2437	1616	0	0	0	0	0
16	Champagne crayeuse	12746	12344	28933	0	0	11166	0
17	Beauce - Drouais - Gâtinais	51339	25874	0	0	22048	14804	0
18	Bordelais - Périgord - Coteaux du Lot	0	4595	0	0	1331	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	20143	14936	0	2427	9494	4612	0
20	Bocages de l'ouest	5251	2858	0	8596	8007	1692	0
21	Ardenne - Argonne - Champagne H.	13513	10736	1944	0	8648	4838	0
22	Champagne berrichonne - Boischaut	34210	33281	0	7174	38725	7960	0
23	Bas Dauphiné - Vallée du Rhône	1092	0	0	2498	1227	0	0
24	Fossé bressan	6870	8419	0	4364	7223	0	0
25	Bretagne centrale	1664	0	0	1233	1699	0	0
26	Plateaux de Haute-Saône	3841	7269	0	0	8566	1571	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	5882	0	7507	1392	1336	0
30	Bretagne nord	6078	1860	0	2124	3636	0	0
31	Ile-de-France	32077	22178	3448	3596	0	14909	0

Crop: Oilseed rape

AU	Soil ID	8	9	10	11	12	13	14
1	Collines molassiques - Lauragais	4866	0	0	0	0	0	0
2	Bretagne sud	0	0	0	0	0	0	0
3	Limagnes - Plaine du Forez	2255	0	0	0	0	0	0
4	Bordure Nord - Picardie - Normandie	7156	2819	0	0	4472	0	0
5	Alsace - Sundgau	0	0	0	0	0	0	0
6	Plaine normande - Bessin	0	0	0	0	0	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	4123	2895	0	0	3949	0	0
10	Charentes	3953	1997	0	0	0	0	0
11	Bocage normand	0	0	0	0	1851	0	0
12	Barrois - Plateaux bourguignons	10321	10649	0	0	6272	0	0
13	Plateau lorrain	8113	4397	0	0	0	0	0
14	Gâtines - Vallées de Loire	1038	3478	0	0	3228	0	0
15	Sologne - Orléanais	0	2254	0	0	0	0	0
16	Champagne crayeuse	4067	6302	0	0	5670	0	0
17	Beauce - Drouais - Gâtinais	7674	4040	0	0	12300	0	0
18	Bordelais - Périgord - Coteaux du Lot	1448	0	0	0	0	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	2870	2162	0	0	12813	0	0
20	Bocages de l'ouest	0	1264	0	0	2237	0	0
21	Ardenne - Argonne - Champagne H.	2028	5818	0	0	0	0	0
22	Champagne berrichonne - Boischaut	0	14827	0	0	11836	0	0
23	Bas Dauphiné - Vallée du Rhône	1521	0	0	0	0	0	0
24	Fossé bressan	4093	1253	0	0	1940	0	0
25	Bretagne centrale	0	0	0	0	0	0	0
26	Plateaux de Haute-Saône	0	1517	0	0	1812	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	1573	1579	0	0	0	0	0
30	Bretagne nord	0	0	0	0	2432	0	0
31	Ile-de-France	8257	3095	0	0	14258	0	0

Crop: Oilseed rape

AU	Soil ID	15	16	17	18	19	-	-
1	Collines molassiques - Lauragais	0	0	0	0	0		
2	Bretagne sud	0	0	0	0	0		
3	Limagnes - Plaine du Forez	0	0	0	0	0		
4	Bordure Nord - Picardie - Normandie	0	0	7387	0	0		
5	Alsace - Sundgau	0	0	0	0	0		
6	Plaine normande - Bessin	0	0	0	0	0		
7	Aquitaine - Landes	0	0	0	0	0		
8	Bassin de l'Adour	0	0	0	0	0		
9	Picardie - Nord - Pas-de-Calais	0	0	1764	0	0		
10	Charentes	0	0	1682	0	0		
11	Bocage normand	0	0	0	0	0		
12	Barrois - Plateaux bourguignons	0	0	3318	0	0		
13	Plateau lorrain	0	0	0	0	0		
14	Gâtines - Vallées de Loire	0	0	1044	0	0		
15	Sologne - Orléanais	0	0	0	0	0		
16	Champagne crayeuse	0	0	5506	0	0		
17	Beauce - Drouais - Gâtinais	0	0	6932	0	0		
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	0		
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	1927	0	0		
20	Bocages de l'ouest	0	0	0	0	0		
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0		
22	Champagne berrichonne - Boischaut	0	0	3848	0	0		
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0		
24	Fossé bressan	0	0	0	0	0		
25	Bretagne centrale	0	0	0	0	0		
26	Plateaux de Haute-Saône	0	0	0	0	0		
27	Provence	0	0	0	0	0		
28	Plaine du Languedoc-Roussillon	0	0	0	0	0		
29	Boischaut du sud	0	0	0	0	0		
30	Bretagne nord	0	0	0	0	0		
31	Ile-de-France	0	0	4528	0	0		

Crop: Fodder Maize

AU	Soil ID	1	2	3	4	5	6	7
1	Collines molassiques - Lauragais	1606	2360	0	1530	0	0	0
2	Bretagne sud	11334	0	0	10874	7666	0	0
3	Limagnes - Plaine du Forez	0	2838	0	0	1169	0	0
4	Bordure Nord - Picardie - Normandie	43854	8706	0	8388	0	0	0
5	Alsace - Sundgau	1294	3444	0	1437	0	0	0
6	Plaine normande - Bessin	4933	2001	0	1837	3391	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	3051	1516	0	5085	1367	0	0
9	Picardie - Nord - Pas-de-Calais	17558	1674	0	4105	0	0	0
10	Charentes	0	2111	0	5289	5633	0	0
11	Bocage normand	41438	7306	0	26480	24481	0	0
12	Barrois - Plateaux bourguignons	4609	4845	0	0	10026	0	0
13	Plateau lorrain	0	21194	0	2924	4821	0	0
14	Gâtines - Vallées de Loire	4773	2048	0	1666	1499	0	0
15	Sologne - Orléanais	0	0	0	0	0	0	0
16	Champagne crayeuse	0	0	0	0	0	0	0
17	Beauce - Drouais - Gâtinais	0	0	0	0	0	0	0
18	Bordelais - Périgord - Coteaux du Lot	0	4833	0	2595	1699	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	16938	7425	0	5695	5243	0	0
20	Bocages de l'ouest	24855	2858	0	26919	18525	0	0
21	Ardenne - Argonne - Champagne H.	8072	3695	0	0	3827	0	0
22	Champagne berrichonne - Boischaut	2917	1745	0	1335	2622	0	0
23	Bas Dauphiné - Vallée du Rhône	1603	0	0	3268	1139	0	0
24	Fossé bressan	2928	1716	0	2381	2010	0	0
25	Bretagne centrale	11582	0	0	8769	7284	0	0
26	Plateaux de Haute-Saône	2463	2969	0	1535	4237	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	1357	0	2885	0	0	0
30	Bretagne nord	32561	1860	0	18662	15776	0	0
31	Ile-de-France	1232	0	0	0	0	0	0

Crop: Fodder Maize

AU	Soil ID	8	9	10	11	12	13	14
1	Collines molassiques - Lauragais	0	0	0	1154	0	1572	1522
2	Bretagne sud	0	0	0	14950	3704	13318	5114
3	Limagnes - Plaine du Forez	0	0	0	2122	0	0	6159
4	Bordure Nord - Picardie - Normandie	0	0	0	10750	5167	18475	3328
5	Alsace - Sundgau	0	0	0	0	0	1144	0
6	Plaine normande - Bessin	0	0	0	2173	1077	2638	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	2493	0	2929	1780
9	Picardie - Nord - Pas-de-Calais	0	0	0	5639	2125	7490	1472
10	Charentes	0	0	0	11628	0	4682	2021
11	Bocage normand	0	0	0	26697	13739	39615	9054
12	Barrois - Plateaux bourguignons	0	0	0	4188	1439	4217	1146
13	Plateau lorrain	0	0	0	4553	0	3158	0
14	Gâtines - Vallées de Loire	0	0	0	2280	1349	2227	0
15	Sologne - Orléanais	0	0	0	0	0	0	0
16	Champagne crayeuse	0	0	0	0	0	0	0
17	Beauce - Drouais - Gâtinais	0	0	0	0	0	0	0
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	3653	0	2642	2944
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	5743	9728	4325	2350
20	Bocages de l'ouest	0	0	0	15187	7923	26323	10694
21	Ardenne - Argonne - Champagne H.	0	0	0	3740	0	4326	5830
22	Champagne berrichonne - Boischaut	0	0	0	1174	0	0	0
23	Bas Dauphiné - Vallée du Rhône	0	0	0	2610	0	0	0
24	Fossé bressan	0	0	0	2040	0	2152	0
25	Bretagne centrale	0	0	0	10237	3944	13460	2872
26	Plateaux de Haute-Saône	0	0	0	2064	0	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	0	0	4224	0	0	1360
30	Bretagne nord	0	0	0	19246	11036	31868	6079
31	Ile-de-France	0	0	0	0	0	0	0

Crop: Fodder Maize

AU	Soil ID	15	16	17	18	19	-	-
1	Collines molassiques - Lauragais	1292	0	0	0	0		
2	Bretagne sud	6670	0	0	0	0		
3	Limagnes - Plaine du Forez	2082	0	0	0	0		
4	Bordure Nord - Picardie - Normandie	2185	0	0	0	0		
5	Alsace - Sundgau	0	0	0	0	0		
6	Plaine normande - Bessin	2233	0	0	0	0		
7	Aquitaine - Landes	0	0	0	0	0		
8	Bassin de l'Adour	4250	0	0	0	0		
9	Picardie - Nord - Pas-de-Calais	4130	0	0	0	0		
10	Charentes	4938	0	0	0	0		
11	Bocage normand	23713	0	0	0	0		
12	Barrois - Plateaux bourguignons	3600	0	0	0	0		
13	Plateau lorrain	5230	0	0	0	0		
14	Gâtines - Vallées de Loire	2135	0	0	0	0		
15	Sologne - Orléanais	0	0	0	0	0		
16	Champagne crayeuse	0	0	0	0	0		
17	Beauce - Drouais - Gâtinais	0	0	0	0	0		
18	Bordelais - Périgord - Coteaux du Lot	2658	0	0	0	0		
19	Perche - Pays d'Auge - Pays d'Ouche	3961	0	0	0	0		
20	Bocages de l'ouest	36705	0	0	0	0		
21	Ardenne - Argonne - Champagne H.	3676	0	0	0	0		
22	Champagne berrichonne - Boischaut	1159	0	0	0	0		
23	Bas Dauphiné - Vallée du Rhône	1620	0	0	0	0		
24	Fossé bressan	2560	0	0	0	0		
25	Bretagne centrale	11537	0	0	0	0		
26	Plateaux de Haute-Saône	1705	0	0	0	0		
27	Provence	0	0	0	0	0		
28	Plaine du Languedoc-Roussillon	0	0	0	0	0		
29	Boischaut du sud	1360	0	0	0	0		
30	Bretagne nord	15251	0	0	0	0		
31	Ile-de-France	0	0	0	0	0		

Crop: Grain Maize

AU	Soil ID	1	2	3	4	5	6	7
1	Collines molassiques - Lauragais	7304	25452	0	14901	2190	0	0
2	Bretagne sud	14053	0	0	4769	1233	0	0
3	Limagnes - Plaine du Forez	0	8942	0	0	1208	0	0
4	Bordure Nord - Picardie - Normandie	6796	1893	0	1973	0	0	0
5	Alsace - Sundgau	5881	51494	0	23221	0	0	0
6	Plaine normande - Bessin	2171	0	0	0	0	0	0
7	Aquitaine - Landes	0	10991	0	7316	0	0	0
8	Bassin de l'Adour	5156	37571	0	65014	1367	0	0
9	Picardie - Nord - Pas-de-Calais	19913	5610	0	5797	0	0	0
10	Charentes	0	21825	0	26143	14433	0	0
11	Bocage normand	7838	2159	0	2256	0	0	0
12	Barrois - Plateaux bourguignons	5277	1704	0	0	0	0	0
13	Plateau lorrain	0	1853	0	0	0	0	0
14	Gâtines - Vallées de Loire	21771	6687	0	3066	1244	0	0
15	Sologne - Orléanais	7610	2147	0	2128	0	0	0
16	Champagne crayeuse	9291	2814	0	0	0	0	0
17	Beauce - Drouais - Gâtinais	20493	5695	0	0	1225	0	0
18	Bordelais - Périgord - Coteaux du Lot	0	30244	0	16049	3508	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	19763	5327	0	5767	0	0	0
20	Bocages de l'ouest	18734	2858	0	6082	1422	0	0
21	Ardenne - Argonne - Champagne H.	11925	3635	0	0	0	0	0
22	Champagne berrichonne - Boischaut	18698	5576	0	5288	1645	0	0
23	Bas Dauphiné - Vallée du Rhône	17828	1784	0	14736	2666	0	0
24	Fossé bressan	34605	9485	0	9831	1709	0	0
25	Bretagne centrale	16283	0	0	5137	1478	0	0
26	Plateaux de Haute-Saône	7723	2836	0	2210	1324	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	1376	0	1796	0	0	0
30	Bretagne nord	30632	1860	0	9030	2482	0	0
31	Ile-de-France	23463	6564	0	5303	0	0	0

Crop: Grain Maize

AU	Soil ID	8	9	10	11	12	13	14
1	Collines molassiques - Lauragais	11668	1127	0	3770	0	3447	14222
2	Bretagne sud	0	0	0	2610	1696	1699	2556
3	Limagnes - Plaine du Forez	6095	1646	0	2749	0	0	12902
4	Bordure Nord - Picardie - Normandie	1076	0	0	0	0	0	0
5	Alsace - Sundgau	25707	4130	5539	1471	0	3430	0
6	Plaine normande - Bessin	0	0	0	0	0	0	0
7	Aquitaine - Landes	26719	9869	0	0	0	0	13299
8	Bassin de l'Adour	30768	0	0	13784	0	8659	27637
9	Picardie - Nord - Pas-de-Calais	3204	0	0	1217	2273	1166	2919
10	Charentes	12727	2049	6822	34075	0	5071	12873
11	Bocage normand	0	0	0	0	0	0	1133
12	Barrois - Plateaux bourguignons	0	0	0	0	0	0	0
13	Plateau lorrain	0	0	0	0	0	0	0
14	Gâtines - Vallées de Loire	1080	1437	0	1879	2741	1236	0
15	Sologne - Orléanais	1209	0	0	0	0	0	1071
16	Champagne crayeuse	1648	0	0	0	1174	0	1371
17	Beauce - Drouais - Gâtinais	3209	0	0	1408	2365	1218	2798
18	Bordelais - Périgord - Coteaux du Lot	13253	0	0	10944	0	3196	16367
19	Perche - Pays d'Auge - Pays d'Ouche	3193	0	0	1242	1919	1222	2886
20	Bocages de l'ouest	0	0	0	1243	2167	1510	3048
21	Ardenne - Argonne - Champagne H.	1861	0	0	0	0	0	2601
22	Champagne berrichonne - Boischaut	0	0	0	1200	2189	0	2780
23	Bas Dauphiné - Vallée du Rhône	8416	0	0	7129	0	0	0
24	Fossé bressan	5462	0	0	2123	3672	2100	3752
25	Bretagne centrale	0	0	0	2153	2068	2268	2464
26	Plateaux de Haute-Saône	0	0	0	0	0	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	0	0	1724	0	0	0
30	Bretagne nord	0	0	0	3023	4116	4239	4366
31	Ile-de-France	3782	0	0	1518	2729	1424	3358

Crop: Grain Maize

AU	Soil ID	15	16	17	18	19	-	-
1	Collines molassiques - Lauragais	6995	0	0	0	0		
2	Bretagne sud	1885	0	0	0	0		
3	Limagnes - Plaine du Forez	3643	0	0	0	0		
4	Bordure Nord - Picardie - Normandie	0	0	0	0	0		
5	Alsace - Sundgau	4926	0	0	0	0		
6	Plaine normande - Bessin	0	0	0	0	0		
7	Aquitaine - Landes	0	0	0	0	0		
8	Bassin de l'Adour	39624	0	0	0	0		
9	Picardie - Nord - Pas-de-Calais	2690	0	0	0	0		
10	Charentes	14680	0	0	0	0		
11	Bocage normand	1053	0	0	0	0		
12	Barrois - Plateaux bourguignons	0	0	0	0	0		
13	Plateau lorrain	0	0	0	0	0		
14	Gâtines - Vallées de Loire	3047	0	0	0	0		
15	Sologne - Orléanais	0	0	0	0	0		
16	Champagne crayeuse	1561	0	0	0	0		
17	Beauce - Drouais - Gâtinais	2554	0	0	0	0		
18	Bordelais - Périgord - Coteaux du Lot	9313	0	0	0	0		
19	Perche - Pays d'Auge - Pays d'Ouche	2678	0	0	0	0		
20	Bocages de l'ouest	3881	0	0	0	0		
21	Ardenne - Argonne - Champagne H.	1626	0	0	0	0		
22	Champagne berrichonne - Boischaut	2430	0	0	0	0		
23	Bas Dauphiné - Vallée du Rhône	5546	0	0	0	0		
24	Fossé bressan	4503	0	0	0	0		
25	Bretagne centrale	3460	0	0	0	0		
26	Plateaux de Haute-Saône	1093	0	0	0	0		
27	Provence	0	0	0	0	0		
28	Plaine du Languedoc-Roussillon	0	0	0	0	0		
29	Boischaut du sud	0	0	0	0	0		
30	Bretagne nord	4053	0	0	0	0		
31	Ile-de-France	3103	0	0	0	0		

Crop: Barley

AU	Soil ID	1	2	3	4	5	6	7
1	Collines molassiques - Lauragais	5703	17637	0	0	3341	3710	0
2	Bretagne sud	3794	0	0	0	4304	0	0
3	Limagnes - Plaine du Forez	0	5302	0	0	1507	2194	0
4	Bordure Nord - Picardie - Normandie	36948	13290	6927	0	0	12840	0
5	Alsace - Sundgau	0	1953	0	0	0	0	0
6	Plaine normande - Bessin	4477	2919	0	0	3487	1379	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	32287	7305	0	0	0	15090	0
10	Charentes	0	11697	0	0	22971	22928	0
11	Bocage normand	6246	2231	0	0	4298	2185	0
12	Barrois - Plateaux bourguignons	5711	54856	0	0	89771	18113	0
13	Plateau lorrain	0	28913	0	0	6998	6366	0
14	Gâtines - Vallées de Loire	9353	6121	0	0	3303	6297	0
15	Sologne - Orléanais	2905	1650	0	0	0	1491	0
16	Champagne crayeuse	22191	17361	49110	0	0	23115	0
17	Beauce - Drouais - Gâtinais	48624	21244	0	0	15987	18998	0
18	Bordelais - Périgord - Coteaux du Lot	0	10428	2015	0	2428	3196	0
19	Perche - Pays d'Auge - Pays d'Ouche	13008	8496	0	0	4446	4592	0
20	Bocages de l'ouest	5842	2847	0	0	8223	2934	0
21	Ardenne - Argonne - Champagne H.	15105	10643	4520	0	7900	7570	0
22	Champagne berrichonne - Boischaut	27820	24222	0	0	27431	8826	0
23	Bas Dauphiné - Vallée du Rhône	3565	1784	0	0	3917	0	0
24	Fossé bressan	7470	8597	0	0	6712	0	0
25	Bretagne centrale	6401	0	0	0	5539	0	0
26	Plateaux de Haute-Saône	3316	5698	0	0	6544	2120	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	1092	0
29	Boischaut du sud	0	10109	0	0	1392	2747	0
30	Bretagne nord	14336	1860	0	0	7248	0	0
31	Ile-de-France	28742	17635	7027	0	0	16772	0

Crop: Barley

AU	Soil ID	8	9	10	11	12	13	14
1	Collines molassiques - Lauragais	6119	1071	0	0	0	1988	0
2	Bretagne sud	0	0	0	0	1349	5406	0
3	Limagnes - Plaine du Forez	3510	1457	0	0	0	0	0
4	Bordure Nord - Picardie - Normandie	8800	3403	0	0	3978	7366	0
5	Alsace - Sundgau	0	0	0	0	0	0	0
6	Plaine normande - Bessin	0	0	0	0	0	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	4273	2964	0	0	3025	5959	0
10	Charentes	5015	2249	0	0	0	3343	0
11	Bocage normand	0	0	0	0	1994	3941	0
12	Barrois - Plateaux bourguignons	11428	11595	0	0	6272	6088	0
13	Plateau lorrain	6952	3706	0	0	0	1738	0
14	Gâtines - Vallées de Loire	0	3179	0	0	2351	0	0
15	Sologne - Orléanais	0	2606	0	0	0	0	0
16	Champagne crayeuse	6341	9483	0	0	6602	6107	0
17	Beauce - Drouais - Gâtinais	6958	3454	0	0	8913	4615	0
18	Bordelais - Périgord - Coteaux du Lot	3404	0	0	0	0	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	1741	1252	0	0	7328	1184	0
20	Bocages de l'ouest	0	1336	0	0	1878	5528	0
21	Ardenne - Argonne - Champagne H.	2236	5854	0	0	0	2080	0
22	Champagne berrichonne - Boischaut	0	12004	0	0	7172	0	0
23	Bas Dauphiné - Vallée du Rhône	8297	0	0	0	0	0	0
24	Fossé bressan	4708	1236	0	0	1313	1208	0
25	Bretagne centrale	0	0	0	0	2393	7799	0
26	Plateaux de Haute-Saône	0	1233	0	0	1118	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	2856	2892	0	0	0	0	0
30	Bretagne nord	0	0	0	0	4863	10718	0
31	Ile-de-France	7062	2616	0	0	10616	3216	0

Crop: Barley

AU	Soil ID	15	16	17	18	19	-	-
1	Collines molassiques - Lauragais	0	0	0	0	0		
2	Bretagne sud	0	0	0	0	0		
3	Limagnes - Plaine du Forez	0	0	0	0	0		
4	Bordure Nord - Picardie - Normandie	0	0	0	0	0		
5	Alsace - Sundgau	0	0	0	0	0		
6	Plaine normande - Bessin	0	0	0	0	0		
7	Aquitaine - Landes	0	0	0	0	0		
8	Bassin de l'Adour	0	0	0	0	0		
9	Picardie - Nord - Pas-de-Calais	0	0	0	0	0		
10	Charentes	0	0	0	0	0		
11	Bocage normand	0	0	0	0	0		
12	Barrois - Plateaux bourguignons	0	0	0	0	0		
13	Plateau lorrain	0	0	0	0	0		
14	Gâtines - Vallées de Loire	0	0	0	0	0		
15	Sologne - Orléanais	0	0	0	0	0		
16	Champagne crayeuse	0	0	0	0	0		
17	Beauce - Drouais - Gâtinais	0	0	0	0	0		
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	0		
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0		
20	Bocages de l'ouest	0	0	0	0	0		
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0		
22	Champagne berrichonne - Boischaut	0	0	0	0	0		
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0		
24	Fossé bressan	0	0	0	0	0		
25	Bretagne centrale	0	0	0	0	0		
26	Plateaux de Haute-Saône	0	0	0	0	0		
27	Provence	0	0	0	0	0		
28	Plaine du Languedoc-Roussillon	0	0	0	0	0		
29	Boischaut du sud	0	0	0	0	0		
30	Bretagne nord	0	0	0	0	0		
31	Ile-de-France	0	0	0	0	0		

Crop: Potato

AU	Soil ID	1	2	3	4	5	6	7
1	Collines molassiques - Lauragais	0	0	0	0	0	0	0
2	Bretagne sud	0	0	0	0	0	0	0
3	Limagnes - Plaine du Forez	0	0	0	0	0	0	0
4	Bordure Nord - Picardie - Normandie	14933	0	2659	0	0	4800	0
5	Alsace - Sundgau	0	0	0	0	0	0	0
6	Plaine normande - Bessin	0	0	0	0	0	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	37112	0	0	0	0	14869	0
10	Charentes	0	0	0	0	0	0	0
11	Bocage normand	0	0	0	0	0	0	0
12	Barrois - Plateaux bourguignons	0	0	0	0	0	0	0
13	Plateau lorrain	0	0	0	0	0	0	0
14	Gâtines - Vallées de Loire	0	0	0	0	0	0	0
15	Sologne - Orléanais	0	0	0	0	0	0	0
16	Champagne crayeuse	4753	0	4618	0	0	2748	0
17	Beauce - Drouais - Gâtinais	6290	0	0	0	0	2077	0
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	0	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0	0	0
20	Bocages de l'ouest	0	0	0	0	0	0	0
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0	0	0
22	Champagne berrichonne - Boischaut	0	0	0	0	0	0	0
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0	0	0
24	Fossé bressan	0	0	0	0	0	0	0
25	Bretagne centrale	1317	0	0	0	0	0	0
26	Plateaux de Haute-Saône	0	0	0	0	0	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	0	0	0	0	0	0
30	Bretagne nord	3075	0	0	0	0	0	0
31	Ile-de-France	4031	0	0	0	0	1810	0

Crop: Potato

AU	Soil ID	8	9	10	11	12	13	14
1	Collines molassiques - Lauragais	0	0	0	0	0	0	0
2	Bretagne sud	0	0	0	0	0	0	0
3	Limagnes - Plaine du Forez	0	0	0	0	0	0	0
4	Bordure Nord - Picardie - Normandie	2726	0	0	0	0	2683	0
5	Alsace - Sundgau	0	0	0	0	0	0	0
6	Plaine normande - Bessin	0	0	0	0	0	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	4421	0	0	0	2200	6379	0
10	Charentes	0	0	0	0	0	0	0
11	Bocage normand	0	0	0	0	0	0	0
12	Barrois - Plateaux bourguignons	0	0	0	0	0	0	0
13	Plateau lorrain	0	0	0	0	0	0	0
14	Gâtines - Vallées de Loire	0	0	0	0	0	0	0
15	Sologne - Orléanais	0	0	0	0	0	0	0
16	Champagne crayeuse	0	0	0	0	0	0	0
17	Beauce - Drouais - Gâtinais	0	0	0	0	0	0	0
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	0	0	0
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0	0	0
20	Bocages de l'ouest	0	0	0	0	0	0	0
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0	0	0
22	Champagne berrichonne - Boischaut	0	0	0	0	0	0	0
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0	0	0
24	Fossé bressan	0	0	0	0	0	0	0
25	Bretagne centrale	0	0	0	0	0	1129	0
26	Plateaux de Haute-Saône	0	0	0	0	0	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	0	0	0	0	0	0
30	Bretagne nord	0	0	0	0	0	1698	0
31	Ile-de-France	0	0	0	0	0	0	0

Crop: Potato

AU	Soil ID	15	16	17	18	19	-	-
1	Collines molassiques - Lauragais	0	0	0	0	0		
2	Bretagne sud	0	0	0	0	0		
3	Limagnes - Plaine du Forez	0	0	0	0	0		
4	Bordure Nord - Picardie - Normandie	0	0	0	0	0		
5	Alsace - Sundgau	0	0	0	0	0		
6	Plaine normande - Bessin	0	0	0	0	0		
7	Aquitaine - Landes	0	0	0	0	0		
8	Bassin de l'Adour	0	0	0	0	0		
9	Picardie - Nord - Pas-de-Calais	0	0	0	0	0		
10	Charentes	0	0	0	0	0		
11	Bocage normand	0	0	0	0	0		
12	Barrois - Plateaux bourguignons	0	0	0	0	0		
13	Plateau lorrain	0	0	0	0	0		
14	Gâtines - Vallées de Loire	0	0	0	0	0		
15	Sologne - Orléanais	0	0	0	0	0		
16	Champagne crayeuse	0	0	0	0	0		
17	Beauce - Drouais - Gâtinais	0	0	0	0	0		
18	Bordelais - Périgord - Coteaux du Lot	0	0	0	0	0		
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0		
20	Bocages de l'ouest	0	0	0	0	0		
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0		
22	Champagne berrichonne - Boischaut	0	0	0	0	0		
23	Bas Dauphiné - Vallée du Rhône	0	0	0	0	0		
24	Fossé bressan	0	0	0	0	0		
25	Bretagne centrale	0	0	0	0	0		
26	Plateaux de Haute-Saône	0	0	0	0	0		
27	Provence	0	0	0	0	0		
28	Plaine du Languedoc-Roussillon	0	0	0	0	0		
29	Boischaut du sud	0	0	0	0	0		
30	Bretagne nord	0	0	0	0	0		
31	Ile-de-France	0	0	0	0	0		

Crop: Sunflower

AU	Soil ID	1	2	3	4	5	6	7
1	Collines molassiques - Lauragais	6919	57528	0	21541	3341	5348	22034
2	Bretagne sud	0	0	0	0	0	0	0
3	Limagnes - Plaine du Forez	0	2050	0	0	0	0	0
4	Bordure Nord - Picardie - Normandie	0	0	0	0	0	0	0
5	Alsace - Sundgau	0	0	0	0	0	0	0
6	Plaine normande - Bessin	0	0	0	0	0	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	1573	0	1594	0	0	0
9	Picardie - Nord - Pas-de-Calais	0	0	0	0	0	0	0
10	Charentes	0	27875	0	17186	14461	16476	0
11	Bocage normand	0	0	0	0	0	0	0
12	Barrois - Plateaux bourguignons	0	1538	0	0	1394	0	0
13	Plateau lorrain	0	0	0	0	0	0	0
14	Gâtines - Vallées de Loire	10711	16005	0	3066	3558	9553	0
15	Sologne - Orléanais	0	0	0	0	0	0	0
16	Champagne crayeuse	0	2213	0	0	0	1977	0
17	Beauce - Drouais - Gâtinais	2833	2914	0	0	0	1312	0
18	Bordelais - Périgord - Coteaux du Lot	0	17682	0	6327	3132	4616	6442
19	Perche - Pays d'Auge - Pays d'Ouche	1803	2441	0	0	0	0	0
20	Bocages de l'ouest	0	2606	0	2607	1465	0	0
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0	0	0
22	Champagne berrichonne - Boischaut	3220	7179	0	2564	4443	1664	0
23	Bas Dauphiné - Vallée du Rhône	0	1784	0	4172	1195	0	0
24	Fossé bressan	1237	3995	0	2195	1591	0	0
25	Bretagne centrale	0	0	0	0	0	0	0
26	Plateaux de Haute-Saône	0	0	0	0	0	0	0
27	Provence	0	0	0	0	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	1603	0	1247	0	0	0
30	Bretagne nord	0	0	0	0	0	0	0
31	Ile-de-France	0	0	0	0	0	0	0

Crop: Sunflower

AU	Soil ID	8	9	10	11	12	13	14
1	Collines molassiques - Lauragais	17978	3792	0	16131	0	0	24931
2	Bretagne sud	0	0	0	0	0	0	0
3	Limagnes - Plaine du Forez	0	0	0	0	0	0	2118
4	Bordure Nord - Picardie - Normandie	0	0	0	0	0	0	0
5	Alsace - Sundgau	0	0	0	0	0	0	0
6	Plaine normande - Bessin	0	0	0	0	0	0	0
7	Aquitaine - Landes	0	0	0	0	0	0	0
8	Bassin de l'Adour	0	0	0	0	0	0	0
9	Picardie - Nord - Pas-de-Calais	0	0	0	0	0	0	0
10	Charentes	8577	2937	0	33007	0	0	10807
11	Bocage normand	0	0	0	0	0	0	0
12	Barrois - Plateaux bourguignons	0	0	0	0	0	0	0
13	Plateau lorrain	0	0	0	0	0	0	0
14	Gâtines - Vallées de Loire	1080	5407	0	7207	0	0	0
15	Sologne - Orléanais	0	0	0	0	0	0	0
16	Champagne crayeuse	0	1005	0	1320	0	0	0
17	Beauce - Drouais - Gâtinais	0	0	0	1253	0	0	0
18	Bordelais - Périgord - Coteaux du Lot	5301	0	0	7571	0	0	7304
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0	0	0
20	Bocages de l'ouest	0	0	0	1193	0	0	1525
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0	0	0
22	Champagne berrichonne - Boischaut	0	2191	0	2158	0	0	2271
23	Bas Dauphiné - Vallée du Rhône	2446	0	0	3288	0	0	0
24	Fossé bressan	1641	0	0	1795	0	0	0
25	Bretagne centrale	0	0	0	0	0	0	0
26	Plateaux de Haute-Saône	0	0	0	0	0	0	0
27	Provence	0	0	0	1372	0	0	0
28	Plaine du Languedoc-Roussillon	0	0	0	0	0	0	0
29	Boischaut du sud	0	0	0	1699	0	0	0
30	Bretagne nord	0	0	0	0	0	0	0
31	Ile-de-France	0	0	0	0	0	0	0

Crop: Sunflower

AU	Soil ID	15	16	17	18	19	-	-
1	Collines molassiques - Lauragais	11594	8286	0	0	0		
2	Bretagne sud	0	0	0	0	0		
3	Limagnes - Plaine du Forez	0	0	0	0	0		
4	Bordure Nord - Picardie - Normandie	0	0	0	0	0		
5	Alsace - Sundgau	0	0	0	0	0		
6	Plaine normande - Bessin	0	0	0	0	0		
7	Aquitaine - Landes	0	0	0	0	0		
8	Bassin de l'Adour	1054	0	0	0	0		
9	Picardie - Nord - Pas-de-Calais	0	0	0	0	0		
10	Charentes	10983	4435	0	0	0		
11	Bocage normand	0	0	0	0	0		
12	Barrois - Plateaux bourguignons	0	0	0	0	0		
13	Plateau lorrain	0	0	0	0	0		
14	Gâtines - Vallées de Loire	4614	0	0	0	0		
15	Sologne - Orléanais	0	0	0	0	0		
16	Champagne crayeuse	1066	0	0	0	0		
17	Beauce - Drouais - Gâtinais	0	0	0	0	0		
18	Bordelais - Périgord - Coteaux du Lot	4104	2032	0	0	0		
19	Perche - Pays d'Auge - Pays d'Ouche	0	0	0	0	0		
20	Bocages de l'ouest	3242	0	0	0	0		
21	Ardenne - Argonne - Champagne H.	0	0	0	0	0		
22	Champagne berrichonne - Boischaut	1264	0	0	0	0		
23	Bas Dauphiné - Vallée du Rhône	1550	0	0	0	0		
24	Fossé bressan	1830	0	0	0	0		
25	Bretagne centrale	0	0	0	0	0		
26	Plateaux de Haute-Saône	0	0	0	0	0		
27	Provence	0	0	0	0	0		
28	Plaine du Languedoc-Roussillon	0	0	0	0	0		
29	Boischaut du sud	0	0	0	0	0		
30	Bretagne nord	0	0	0	0	0		
31	Ile-de-France	0	0	0	0	0		

Appendix 17. Soil hydraulic parameterization

1/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 1

Table 63 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 1

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.29	20	6.21	0.4170	0.01	0.0185	1.2093	0.1199	-2.4903	1459.2
	2	0.01	1	6.70	0.4067	0.01	0.0187	1.1493	0.1129	-3.5634	1522.2
2	1	0.29	20	6.21	0.4596	0.01	0.0234	1.1887	0.1340	-2.5147	1306.6
	2	0.01	1	6.70	0.4424	0.01	0.0229	1.1470	0.1370	-3.5287	1395.5
4	1	0.29	20	6.21	0.4283	0.01	0.0198	1.2055	0.1256	-2.5347	1419.1
	2	0.01	1	6.70	0.4162	0.01	0.0199	1.1497	0.1206	-3.5908	1489.1
5	1	0.29	20	6.21	0.4250	0.01	0.0194	1.2067	0.1240	-2.5252	1430.9
	2	0.01	1	6.70	0.4134	0.01	0.0196	1.1496	0.1184	-3.5860	1498.8
6	1	0.29	20	6.21	0.4453	0.01	0.0217	1.1973	0.1315	-2.5457	1358.0
	2	0.01	1	6.70	0.4305	0.01	0.0216	1.1489	0.1305	-3.5790	1438.4
8	1	0.29	20	6.21	0.4324	0.01	0.0203	1.2037	0.1273	-2.5431	1404.3
	2	0.01	1	6.70	0.4196	0.01	0.0203	1.1496	0.1232	-3.5934	1476.8
9	1	0.29	20	6.21	0.4289	0.01	0.0199	1.2052	0.1258	-2.5361	1417.1
	2	0.01	1	6.70	0.4167	0.01	0.0200	1.1497	0.1210	-3.5914	1487.4
11	1	0.29	20	6.21	0.4562	0.01	0.0230	1.1909	0.1336	-2.5248	1318.8
	2	0.01	1	6.70	0.4396	0.01	0.0226	1.1475	0.1356	-3.5436	1405.7
12	1	0.29	20	6.21	0.4436	0.01	0.0215	1.1983	0.1310	-2.5472	1364.4
	2	0.01	1	6.70	0.4290	0.01	0.0214	1.1490	0.1295	-3.5829	1443.7
13	1	0.29	20	6.21	0.4386	0.01	0.0210	1.2008	0.1296	-2.5484	1382.2
	2	0.01	1	6.70	0.4248	0.01	0.0210	1.1494	0.1268	-3.5906	1458.5
14	1	0.29	20	6.21	0.4254	0.01	0.0195	1.2066	0.1242	-2.5264	1429.6
	2	0.01	1	6.70	0.4137	0.01	0.0196	1.1496	0.1187	-3.5866	1497.7
15	1	0.29	20	6.21	0.4194	0.01	0.0188	1.2086	0.1212	-2.5026	1450.7
	2	0.01	1	6.70	0.4087	0.01	0.0190	1.1494	0.1146	-3.5718	1515.2
16	1	0.29	20	6.21	0.4423	0.01	0.0214	1.1989	0.1307	-2.5479	1368.8
	2	0.01	1	6.70	0.4279	0.01	0.0213	1.1491	0.1289	-3.5852	1447.4
17	1	0.29	20	6.21	0.4281	0.01	0.0198	1.2056	0.1255	-2.5341	1420.0
	2	0.01	1	6.70	0.4160	0.01	0.0199	1.1497	0.1204	-3.5905	1489.8
19	1	0.29	20	6.21	0.4271	0.01	0.0197	1.2059	0.1250	-2.5314	1423.6
	2	0.01	1	6.70	0.4151	0.01	0.0198	1.1497	0.1198	-3.5893	1492.8
20	1	0.29	20	6.21	0.4371	0.01	0.0208	1.2016	0.1290	-2.5479	1387.7
	2	0.01	1	6.70	0.4235	0.01	0.0208	1.1495	0.1260	-3.5920	1463.1
21	1	0.29	20	6.21	0.4374	0.01	0.0208	1.2014	0.1291	-2.5480	1386.6
	2	0.01	1	6.70	0.4238	0.01	0.0208	1.1494	0.1261	-3.5917	1462.1
22	1	0.29	20	6.21	0.4305	0.01	0.0200	1.2046	0.1265	-2.5396	1411.4
	2	0.01	1	6.70	0.4180	0.01	0.0201	1.1497	0.1220	-3.5926	1482.7
23	1	0.29	20	6.21	0.4229	0.01	0.0192	1.2075	0.1230	-2.5177	1438.3
	2	0.01	1	6.70	0.4117	0.01	0.0194	1.1496	0.1170	-3.5816	1504.9
24	1	0.29	20	6.21	0.4229	0.01	0.0192	1.2075	0.1230	-2.5175	1438.5
	2	0.01	1	6.70	0.4116	0.01	0.0193	1.1496	0.1170	-3.5815	1505.1
25	1	0.29	20	6.21	0.4748	0.01	0.0253	1.1783	0.1342	-2.4526	1251.2
	2	0.01	1	6.70	0.4551	0.01	0.0243	1.1438	0.1421	-3.4417	1349.1
26	1	0.29	20	6.21	0.4347	0.01	0.0205	1.2027	0.1282	-2.5460	1396.1

	2	0.01	1	6.70	0.4216	0.01	0.0206	1.1496	0.1246	-3.5933	1470.0
27	1	0.29	20	6.21	0.4164	0.01	0.0184	1.2095	0.1195	-2.4867	1461.5
	2	0.01	1	6.70	0.4062	0.01	0.0187	1.1492	0.1124	-3.5608	1524.1
30	1	0.29	20	6.21	0.4512	0.01	0.0224	1.1939	0.1328	-2.5366	1336.7
	2	0.01	1	6.70	0.4354	0.01	0.0222	1.1482	0.1334	-3.5621	1420.6
31	1	0.29	20	6.21	0.4212	0.01	0.0190	1.2080	0.1222	-2.5109	1444.2
	2	0.01	1	6.70	0.4102	0.01	0.0192	1.1495	0.1159	-3.5773	1509.8

Table 64 Subsoil horizons parameters for soil-type 1

AU ID	**Horizon ID**	**Horizon Thickness (m)**	**Numerical layers (-)**	**pH $CaCl_2$ (-)**	**Saturated water content (m^3/m^3)**	**Residual water content (m^3/m^3)**	**Alpha (1/cm)**	**n (-)**	**Saturated conductivity (m/day)**	**L (-)**	**Rho (g/cm^3)**
all	3	0.11	4	6.70	0.4220	0.01	0.0191	1.1195	0.117	-3.5842	1501.53
	4	0.19	4	6.89	0.4188	0.01	0.0187	1.1157	0.1095	-3.6399	1514.58
	5	0.15	3	6.89	0.4188	0.01	0.0187	1.1157	0.1095	-3.6399	1514.58
	6	0.25	5	6.99	0.3987	0.01	0.0169	1.1105	0.0896	-3.5579	1584.45
	7	0.25	5	6.89	0.3992	0.01	0.0195	1.0696	0.0387	-4.2722	1603.79
	8	0.1	10	6.89	0.3992	0.01	0.0195	1.0696	0.0387	-4.2722	1603.79
	9	0.65	8	6.89	0.3992	0.01	0.0195	1.0696	0.0387	-4.2722	1603.79

2/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 2

Table 65 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 2

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.2	8	7.16	0.4417	0.01	0.0195	1.1457	0.1045	-3.4859	1398.5
	2	0.1	4	6.96	0.4054	0.01	0.0150	1.1333	0.0823	-3.7378	1536.5
3	1	0.2	8	7.16	0.4606	0.01	0.0217	1.1410	0.1100	-3.3418	1329.3
	2	0.1	4	6.96	0.4189	0.01	0.0166	1.1347	0.0911	-3.7544	1489.6
4	1	0.2	8	7.16	0.4545	0.01	0.0210	1.1428	0.1086	-3.3960	1352.0
	2	0.1	4	6.96	0.4145	0.01	0.0161	1.1344	0.0884	-3.7560	1505.0
5	1	0.2	8	7.16	0.4507	0.01	0.0206	1.1437	0.1075	-3.4255	1365.6
	2	0.1	4	6.96	0.4118	0.01	0.0158	1.1341	0.0866	-3.7538	1514.3
6	1	0.2	8	7.16	0.4736	0.01	0.0232	1.1365	0.1119	-3.2084	1281.2
	2	0.1	4	6.96	0.4281	0.01	0.0176	1.1349	0.0963	-3.7311	1456.7
7	1	0.2	8	7.16	0.4392	0.01	0.0193	1.1461	0.1035	-3.4995	1407.5
	2	0.1	4	6.96	0.4037	0.01	0.0148	1.1330	0.0810	-3.7305	1542.5
8	1	0.2	8	7.16	0.4592	0.01	0.0215	1.1414	0.1097	-3.3554	1334.8
	2	0.1	4	6.96	0.4178	0.01	0.0164	1.1346	0.0904	-3.7554	1493.3
9	1	0.2	8	7.16	0.4551	0.01	0.0211	1.1426	0.1087	-3.3905	1349.6
	2	0.1	4	6.96	0.4149	0.01	0.0161	1.1344	0.0887	-3.7562	1503.4
10	1	0.2	8	7.16	0.4630	0.01	0.0220	1.1402	0.1105	-3.3192	1320.6
	2	0.1	4	6.96	0.4206	0.01	0.0168	1.1348	0.0921	-3.7521	1483.6
11	1	0.2	8	7.16	0.4857	0.01	0.0248	1.1316	0.1124	-3.0655	1236.1
	2	0.1	4	6.96	0.4368	0.01	0.0185	1.1345	0.1006	-3.6874	1425.6
12	1	0.2	8	7.16	0.4716	0.01	0.0230	1.1372	0.1117	-3.2303	1288.6
	2	0.1	4	6.96	0.4267	0.01	0.0174	1.1349	0.0956	-3.7363	1461.8
13	1	0.2	8	7.16	0.4661	0.01	0.0223	1.1392	0.1110	-3.2886	1309.2
	2	0.1	4	6.96	0.4228	0.01	0.0170	1.1348	0.0934	-3.7477	1475.8
14	1	0.2	8	7.16	0.4512	0.01	0.0206	1.1436	0.1076	-3.4224	1364.1
	2	0.1	4	6.96	0.4121	0.01	0.0158	1.1342	0.0868	-3.7542	1513.2
15	1	0.2	8	7.16	0.4444	0.01	0.0199	1.1452	0.1055	-3.4695	1388.7
	2	0.1	4	6.96	0.4073	0.01	0.0153	1.1336	0.0836	-3.7443	1529.8
16	1	0.2	8	7.16	0.4703	0.01	0.0228	1.1377	0.1116	-3.2452	1293.7
	2	0.1	4	6.96	0.4257	0.01	0.0173	1.1349	0.0950	-3.7396	1465.3
17	1	0.2	8	7.16	0.4542	0.01	0.0209	1.1429	0.1085	-3.3983	1353.0
	2	0.1	4	6.96	0.4143	0.01	0.0160	1.1344	0.0882	-3.7560	1505.7
18	1	0.2	8	7.16	0.4378	0.01	0.0191	1.1464	0.1029	-3.5064	1412.5
	2	0.1	4	6.96	0.4027	0.01	0.0147	1.1328	0.0803	-3.7260	1545.9
19	1	0.2	8	7.16	0.4531	0.01	0.0208	1.1432	0.1082	-3.4074	1357.1
	2	0.1	4	6.96	0.4135	0.01	0.0160	1.1343	0.0877	-3.7555	1508.5
20	1	0.2	8	7.16	0.4644	0.01	0.0221	1.1398	0.1107	-3.3060	1315.6
	2	0.1	4	6.96	0.4215	0.01	0.0169	1.1348	0.0927	-3.7504	1480.2
21	1	0.2	8	7.16	0.4647	0.01	0.0222	1.1397	0.1108	-3.3024	1314.3
	2	0.1	4	6.96	0.4218	0.01	0.0169	1.1348	0.0928	-3.7499	1479.3
22	1	0.2	8	7.16	0.4569	0.01	0.0213	1.1421	0.1092	-3.3751	1343.0
	2	0.1	4	6.96	0.4162	0.01	0.0163	1.1345	0.0895	-3.7562	1498.9

23	1	0.2	8	7.16	0.4484	0.01	0.0203	1.1443	0.1068	-3.4428	1374.2
	2	0.1	4	6.96	0.4101	0.01	0.0156	1.1339	0.0855	-3.7512	1520.1
24	1	0.2	8	7.16	0.4483	0.01	0.0203	1.1443	0.1068	-3.4433	1374.4
	2	0.1	4	6.96	0.4101	0.01	0.0156	1.1339	0.0855	-3.7511	1520.2
26	1	0.2	8	7.16	0.4617	0.01	0.0218	1.1406	0.1102	-3.3313	1325.2
	2	0.1	4	6.96	0.4196	0.01	0.0167	1.1347	0.0916	-3.7534	1486.8
29	1	0.2	8	7.16	0.4570	0.01	0.0213	1.1421	0.1092	-3.3744	1342.7
	2	0.1	4	6.96	0.4163	0.01	0.0163	1.1345	0.0895	-3.7561	1498.7
30	1	0.2	8	7.16	0.4802	0.01	0.0241	1.1339	0.1123	-3.1324	1256.7
	2	0.1	4	6.96	0.4329	0.01	0.0181	1.1347	0.0988	-3.7097	1439.8
31	1	0.2	8	7.16	0.4465	0.01	0.0201	1.1447	0.1062	-3.4560	1381.1
	2	0.1	4	6.96	0.4088	0.01	0.0154	1.1338	0.0846	-3.7482	1524.7

Table 66 Subsoil horizons parameters for soil-type 2

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.2	8	6.96	0.4210	0.01	0.0149	1.1034	0.0835	-3.7528	1516.8
	4	0.1	2	6.96	0.4149	0.01	0.0137	1.0994	0.0740	-3.7747	1540.5
	5	0.2	4	6.96	0.4149	0.01	0.0137	1.0994	0.0740	-3.7747	1540.5
	6	0.2	4	6.67	0.4019	0.01	0.0128	1.0784	0.0455	-3.9787	1597.1
	7	0.15	15	6.67	0.4019	0.01	0.0128	1.0784	0.0455	-3.9787	1597.1
	8	0.85	10	6.67	0.4019	0.01	0.0128	1.0784	0.0455	-3.9787	1597.1

3/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 3

Table 67 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 3

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
4	1	0.25	10	7.35	0.4438	0.01	0.0409	1.1635	0.3510	-3.5135	1377.0
	2	0.05	2	7.55	0.4119	0.01	0.0397	1.1632	0.3133	-3.6907	1493.5
7	1	0.25	10	7.35	0.4291	0.01	0.0399	1.1677	0.3339	-3.5554	1429.6
	2	0.05	2	7.55	0.4007	0.01	0.0383	1.1630	0.2894	-3.6364	1532.5
16	1	0.25	10	7.35	0.4590	0.01	0.0417	1.1575	0.3619	-3.4269	1321.6
	2	0.05	2	7.55	0.4235	0.01	0.0408	1.1621	0.3344	-3.7042	1452.4
18	1	0.25	10	7.35	0.4278	0.01	0.0398	1.1680	0.3321	-3.5569	1434.3
	2	0.05	2	7.55	0.3997	0.01	0.0381	1.1629	0.2871	-3.6293	1535.9
21	1	0.25	10	7.35	0.4536	0.01	0.0414	1.1598	0.3589	-3.4617	1341.1
	2	0.05	2	7.55	0.4194	0.01	0.0405	1.1626	0.3275	-3.7040	1466.9
28	1	0.25	10	7.35	0.4218	0.01	0.0393	1.1691	0.3230	-3.5577	1455.8
	2	0.05	2	7.55	0.3952	0.01	0.0375	1.1625	0.2762	-3.5911	1551.7
31	1	0.25	10	7.35	0.4361	0.01	0.0405	1.1659	0.3429	-3.5412	1404.6
	2	0.05	2	7.55	0.4060	0.01	0.0390	1.1632	0.3012	-3.6678	1514.0

Table 68 Subsoil horizons parameters for soil-type 3

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.2	8	7.55	0.4142	0.01	0.0396	1.1342	0.1695	-3.6784	1505.8
	4	0.1	2	7.65	0.4059	0.01	0.0423	1.1431	0.1773	-3.5273	1528.4
	5	0.1	2	7.65	0.4059	0.01	0.0423	1.1431	0.1773	-3.5273	1528.4
	6	0.25	5	7.55	0.3967	0.01	0.0508	1.1394	0.1653	-3.6869	1553.3
	7	0.1	10	7.55	0.3967	0.01	0.0508	1.1394	0.1653	-3.6869	1553.3
	8	0.95	10	7.55	0.3967	0.01	0.0508	1.1394	0.1653	-3.6869	1553.3

4/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 4

Table 69 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 4

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.25	10	5.56	0.4221	0.01	0.0405	1.2093	0.3801	-2.8509	1438.4
	2	0.05	2	6.53	0.3942	0.01	0.0409	1.1650	0.3067	-3.5976	1552.6
2	1	0.25	10	5.56	0.4668	0.01	0.0426	1.1841	0.4141	-2.7981	1277.5
	2	0.05	2	6.53	0.4266	0.01	0.0443	1.1639	0.3788	-3.7133	1438.9
4	1	0.25	10	5.56	0.4340	0.01	0.0413	1.2042	0.3958	-2.8733	1396.1
	2	0.05	2	6.53	0.4028	0.01	0.0421	1.1657	0.3291	-3.6639	1523.0
5	1	0.25	10	5.56	0.4305	0.01	0.0411	1.2058	0.3917	-2.8701	1408.5
	2	0.05	2	6.53	0.4002	0.01	0.0417	1.1656	0.3228	-3.6476	1531.7
6	1	0.25	10	5.56	0.4519	0.01	0.0420	1.1941	0.4103	-2.8528	1331.6
	2	0.05	2	6.53	0.4157	0.01	0.0435	1.1653	0.3584	-3.7123	1477.4
7	1	0.25	10	5.56	0.4198	0.01	0.0403	1.2101	0.3765	-2.8425	1446.6
	2	0.05	2	6.53	0.3925	0.01	0.0406	1.1648	0.3021	-3.5810	1558.3
8	1	0.25	10	5.56	0.4383	0.01	0.0415	1.2020	0.4004	-2.8737	1380.4
	2	0.05	2	6.53	0.4059	0.01	0.0425	1.1657	0.3367	-3.6810	1511.9
9	1	0.25	10	5.56	0.4346	0.01	0.0413	1.2039	0.3965	-2.8736	1393.9
	2	0.05	2	6.53	0.4032	0.01	0.0421	1.1657	0.3302	-3.6665	1521.4
10	1	0.25	10	5.56	0.4419	0.01	0.0416	1.2000	0.4037	-2.8713	1367.5
	2	0.05	2	6.53	0.4085	0.01	0.0428	1.1657	0.3428	-3.6924	1502.8
11	1	0.25	10	5.56	0.4633	0.01	0.0424	1.1866	0.4138	-2.8136	1290.3
	2	0.05	2	6.53	0.4240	0.01	0.0442	1.1643	0.3743	-3.7159	1448.1
13	1	0.25	10	5.56	0.4448	0.01	0.0418	1.1984	0.4059	-2.8676	1357.1
	2	0.05	2	6.53	0.4106	0.01	0.0430	1.1657	0.3475	-3.6999	1495.5
14	1	0.25	10	5.56	0.4309	0.01	0.0411	1.2056	0.3922	-2.8705	1407.1
	2	0.05	2	6.53	0.4005	0.01	0.0418	1.1656	0.3235	-3.6495	1530.7
15	1	0.25	10	5.56	0.4246	0.01	0.0407	1.2083	0.3838	-2.8584	1429.4
	2	0.05	2	6.53	0.3960	0.01	0.0412	1.1652	0.3117	-3.6142	1546.3
17	1	0.25	10	5.56	0.4337	0.01	0.0413	1.2043	0.3955	-2.8731	1397.0
	2	0.05	2	6.53	0.4026	0.01	0.0421	1.1657	0.3286	-3.6628	1523.6
18	1	0.25	10	5.56	0.4185	0.01	0.0402	1.2105	0.3744	-2.8373	1451.0
	2	0.05	2	6.53	0.3916	0.01	0.0405	1.1647	0.2995	-3.5714	1561.4
19	1	0.25	10	5.56	0.4326	0.01	0.0412	1.2048	0.3943	-2.8724	1400.8
	2	0.05	2	6.53	0.4018	0.01	0.0420	1.1656	0.3267	-3.6580	1526.3
20	1	0.25	10	5.56	0.4432	0.01	0.0417	1.1993	0.4047	-2.8699	1362.9
	2	0.05	2	6.53	0.4094	0.01	0.0429	1.1657	0.3449	-3.6959	1499.6
22	1	0.25	10	5.56	0.4362	0.01	0.0414	1.2030	0.3983	-2.8740	1387.9
	2	0.05	2	6.53	0.4044	0.01	0.0423	1.1657	0.3331	-3.6733	1517.2
23	1	0.25	10	5.56	0.4283	0.01	0.0409	1.2068	0.3889	-2.8667	1416.3
	2	0.05	2	6.53	0.3987	0.01	0.0415	1.1655	0.3187	-3.6361	1537.1
24	1	0.25	10	5.56	0.4282	0.01	0.0409	1.2068	0.3889	-2.8666	1416.5
	2	0.05	2	6.53	0.3986	0.01	0.0415	1.1655	0.3186	-3.6357	1537.3
25	1	0.25	10	5.56	0.4829	0.01	0.0433	1.1723	0.4104	-2.7143	1219.3
	2	0.05	2	6.53	0.4383	0.01	0.0449	1.1612	0.3963	-3.6817	1397.1

26	1	0.25	10	5.56	0.4407	0.01	0.0416	1.2007	0.4026	-2.8723	1371.7
	2	0.05	2	6.53	0.4077	0.01	0.0427	1.1657	0.3408	-3.6889	1505.8
27	1	0.25	10	5.56	0.4214	0.01	0.0405	1.2095	0.3790	-2.8485	1440.8
	2	0.05	2	6.53	0.3937	0.01	0.0408	1.1649	0.3054	-3.5928	1554.3
28	1	0.25	10	5.56	0.4127	0.01	0.0397	1.2123	0.3642	-2.8077	1471.6
	2	0.05	2	6.53	0.3875	0.01	0.0399	1.1639	0.2873	-3.5218	1575.7
29	1	0.25	10	5.56	0.4363	0.01	0.0414	1.2030	0.3984	-2.8740	1387.6
	2	0.05	2	6.53	0.4045	0.01	0.0423	1.1657	0.3333	-3.6736	1517.0
30	1	0.25	10	5.56	0.4581	0.01	0.0423	1.1901	0.4128	-2.8335	1309.2
	2	0.05	2	6.53	0.4202	0.01	0.0439	1.1649	0.3673	-3.7166	1461.5
31	1	0.25	10	5.56	0.4265	0.01	0.0408	1.2075	0.3866	-2.8631	1422.6
	2	0.05	2	6.53	0.3974	0.01	0.0414	1.1653	0.3154	-3.6260	1541.6

Table 70 Subsoil horizons parameters for soil-type 4

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.2	8	6.53	0.4049	0.01	0.0421	1.1365	0.1652	-3.6426	1534.1
	4	0.1	2	7.12	0.3965	0.01	0.0388	1.1063	0.1051	-4.0991	1575.8
	5	0.4	8	7.12	0.3965	0.01	0.0388	1.1063	0.1051	-4.0991	1575.8
	6	0.15	3	7.12	0.3965	0.01	0.0388	1.1063	0.1051	-4.0991	1575.8
	7	0.1	10	7.12	0.3965	0.01	0.0388	1.1063	0.1051	-4.0991	1575.8
	8	0.75	8	7.12	0.3965	0.01	0.0388	1.1063	0.1051	-4.0991	1575.8

5/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 5

Table 71 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 5

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.1	4	5.97	0.4551	0.01	0.0206	1.1609	0.1020	-3.0627	1336.5
	2	0.18	8	5.28	0.4335	0.01	0.0181	1.1638	0.0954	-3.2228	1417.0
	3	0.02	1	5.58	0.4233	0.01	0.0191	1.1377	0.1110	-3.7524	1472.0
2	1	0.1	4	5.97	0.5091	0.01	0.0291	1.1330	0.1004	-2.5881	1136.8
	2	0.18	8	5.28	0.4798	0.01	0.0238	1.1462	0.1036	-2.9263	1247.7
	3	0.02	1	5.58	0.4640	0.01	0.0235	1.1320	0.1296	-3.4661	1324.6
3	1	0.1	4	5.97	0.4765	0.01	0.0234	1.1510	0.1040	-2.9034	1257.9
	2	0.18	8	5.28	0.4518	0.01	0.0202	1.1585	0.1008	-3.1474	1350.7
	3	0.02	1	5.58	0.4394	0.01	0.0209	1.1368	0.1204	-3.6837	1414.5
6	1	0.1	4	5.97	0.4912	0.01	0.0256	1.1431	0.1032	-2.7671	1203.5
	2	0.18	8	5.28	0.4644	0.01	0.0217	1.1535	0.1029	-3.0607	1304.6
	3	0.02	1	5.58	0.4504	0.01	0.0221	1.1351	0.1253	-3.6005	1374.3
8	1	0.1	4	5.97	0.4748	0.01	0.0232	1.1519	0.1039	-2.9178	1264.1
	2	0.18	8	5.28	0.4504	0.01	0.0200	1.1590	0.1005	-3.1557	1355.9
	3	0.02	1	5.58	0.4381	0.01	0.0208	1.1369	0.1197	-3.6915	1419.0
10	1	0.1	4	5.97	0.4792	0.01	0.0238	1.1496	0.1039	-2.8797	1247.9
	2	0.18	8	5.28	0.4542	0.01	0.0205	1.1576	0.1013	-3.1334	1342.3
	3	0.02	1	5.58	0.4414	0.01	0.0211	1.1365	0.1214	-3.6705	1407.1
11	1	0.1	4	5.97	0.5049	0.01	0.0282	1.1354	0.1012	-2.6308	1152.6
	2	0.18	8	5.28	0.4762	0.01	0.0233	1.1480	0.1036	-2.9604	1261.2
	3	0.02	1	5.58	0.4608	0.01	0.0232	1.1328	0.1288	-3.5008	1336.4
12	1	0.1	4	5.97	0.4889	0.01	0.0253	1.1443	0.1034	-2.7889	1211.8
	2	0.18	8	5.28	0.4625	0.01	0.0215	1.1543	0.1026	-3.0755	1311.6
	3	0.02	1	5.58	0.4488	0.01	0.0219	1.1354	0.1246	-3.6149	1380.4
13	1	0.1	4	5.97	0.4827	0.01	0.0243	1.1477	0.1038	-2.8480	1235.1
	2	0.18	8	5.28	0.4571	0.01	0.0208	1.1565	0.1018	-3.1140	1331.4
	3	0.02	1	5.58	0.4440	0.01	0.0214	1.1362	0.1226	-3.6520	1397.6
14	1	0.1	4	5.97	0.4658	0.01	0.0220	1.1563	0.1034	-2.9905	1297.4
	2	0.18	8	5.28	0.4427	0.01	0.0191	1.1615	0.0984	-3.1937	1384.1
	3	0.02	1	5.58	0.4313	0.01	0.0200	1.1375	0.1160	-3.7266	1443.4
15	1	0.1	4	5.97	0.4582	0.01	0.0210	1.1597	0.1025	-3.0437	1325.3
	2	0.18	8	5.28	0.4362	0.01	0.0184	1.1632	0.0963	-3.2163	1407.6
	3	0.02	1	5.58	0.4256	0.01	0.0194	1.1377	0.1125	-3.7468	1463.8
17	1	0.1	4	5.97	0.4692	0.01	0.0224	1.1546	0.1037	-2.9640	1284.7
	2	0.18	8	5.28	0.4456	0.01	0.0195	1.1606	0.0993	-3.1806	1373.4
	3	0.02	1	5.58	0.4339	0.01	0.0203	1.1373	0.1175	-3.7146	1434.2
18	1	0.1	4	5.97	0.4508	0.01	0.0201	1.1626	0.1011	-3.0872	1352.4
	2	0.18	8	5.28	0.4298	0.01	0.0176	1.1646	0.0939	-3.2293	1430.4
	3	0.02	1	5.58	0.4200	0.01	0.0187	1.1376	0.1088	-3.7576	1483.5
19	1	0.1	4	5.97	0.4680	0.01	0.0222	1.1552	0.1036	-2.9740	1289.4
	2	0.18	8	5.28	0.4445	0.01	0.0193	1.1609	0.0990	-3.1857	1377.4
	3	0.02	1	5.58	0.4329	0.01	0.0202	1.1374	0.1169	-3.7193	1437.6

20	1	0.1	4	5.97	0.4807	0.01	0.0240	1.1488	0.1039	-2.8660	1242.3
	2	0.18	8	5.28	0.4555	0.01	0.0206	1.1572	0.1015	-3.1251	1337.5
	3	0.02	1	5.58	0.4426	0.01	0.0212	1.1364	0.1219	-3.6626	1403.0
21	1	0.1	4	5.97	0.4811	0.01	0.0241	1.1486	0.1039	-2.8623	1240.8
	2	0.18	8	5.28	0.4558	0.01	0.0207	1.1570	0.1016	-3.1228	1336.2
	3	0.02	1	5.58	0.4429	0.01	0.0213	1.1363	0.1221	-3.6605	1401.9
22	1	0.1	4	5.97	0.4723	0.01	0.0228	1.1531	0.1039	-2.9389	1273.3
	2	0.18	8	5.28	0.4483	0.01	0.0198	1.1597	0.0999	-3.1674	1363.8
	3	0.02	1	5.58	0.4362	0.01	0.0206	1.1371	0.1187	-3.7024	1425.8
23	1	0.1	4	5.97	0.4627	0.01	0.0216	1.1577	0.1031	-3.0133	1308.8
	2	0.18	8	5.28	0.4400	0.01	0.0188	1.1622	0.0976	-3.2041	1393.7
	3	0.02	1	5.58	0.4290	0.01	0.0198	1.1376	0.1146	-3.7360	1451.8
24	1	0.1	4	5.97	0.4626	0.01	0.0216	1.1577	0.1031	-3.0138	1309.1
	2	0.18	8	5.28	0.4399	0.01	0.0188	1.1622	0.0976	-3.2043	1393.9
	3	0.02	1	5.58	0.4289	0.01	0.0198	1.1376	0.1145	-3.7362	1452.0
25	1	0.1	4	5.97	0.5284	0.01	0.0341	1.1224	0.0956	-2.4041	1065.8
	2	0.18	8	5.28	0.4963	0.01	0.0264	1.1376	0.1025	-2.7604	1186.6
	3	0.02	1	5.58	0.4783	0.01	0.0251	1.1275	0.1321	-3.2905	1270.9
26	1	0.1	4	5.97	0.4778	0.01	0.0236	1.1503	0.1040	-2.8924	1253.3
	2	0.18	8	5.28	0.4529	0.01	0.0203	1.1581	0.1010	-3.1410	1346.8
	3	0.02	1	5.58	0.4403	0.01	0.0210	1.1367	0.1208	-3.6777	1411.0
29	1	0.1	4	5.97	0.4724	0.01	0.0228	1.1531	0.1039	-2.9382	1273.0
	2	0.18	8	5.28	0.4483	0.01	0.0198	1.1597	0.1000	-3.1670	1363.5
	3	0.02	1	5.58	0.4363	0.01	0.0206	1.1371	0.1188	-3.7020	1425.6
30	1	0.1	4	5.97	0.4986	0.01	0.0270	1.1389	0.1023	-2.6933	1175.8
	2	0.18	8	5.28	0.4708	0.01	0.0225	1.1506	0.1034	-3.0081	1281.0
	3	0.02	1	5.58	0.4561	0.01	0.0227	1.1339	0.1273	-3.5486	1353.7

Table 72 Subsoil horizons parameters for soil-type 5

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	4	0.1	4	5.58	0.4395	0.01	0.0191	1.1071	0.1054	-3.7317	1447.8
	5	0.2	8	5.77	0.4193	0.01	0.0166	1.0819	0.0584	-4.1068	1535.6
	6	0.05	1	5.77	0.4193	0.01	0.0166	1.0819	0.0584	-4.1068	1535.6
	7	0.1	10	5.77	0.4193	0.01	0.0166	1.0819	0.0584	-4.1068	1535.6
	8	0.25	5	5.77	0.4193	0.01	0.0166	1.0819	0.0584	-4.1068	1535.6
	9	1	10	5.77	0.4193	0.01	0.0166	1.0819	0.0584	-4.1068	1535.6

6/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 6

Table 73 **Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 6**

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.2	8	7.61	0.4239	0.01	0.0327	1.1927	0.2687	-3.0055	1440.1
	2	0.1	4	7.80	0.4116	0.01	0.0323	1.1965	0.2643	-2.9571	1483.3
3	1	0.2	8	7.61	0.4414	0.01	0.0343	1.1861	0.2848	-3.0100	1377.5
	2	0.1	4	7.80	0.4273	0.01	0.0340	1.1924	0.2846	-3.0135	1427.6
4	1	0.2	8	7.61	0.4357	0.01	0.0338	1.1886	0.2804	-3.0159	1398.0
	2	0.1	4	7.80	0.4221	0.01	0.0334	1.1940	0.2787	-3.0025	1445.9
6	1	0.2	8	7.61	0.4535	0.01	0.0352	1.1801	0.2916	-2.9776	1333.8
	2	0.1	4	7.80	0.4381	0.01	0.0349	1.1883	0.2950	-3.0160	1388.7
9	1	0.2	8	7.61	0.4363	0.01	0.0338	1.1883	0.2809	-3.0156	1395.8
	2	0.1	4	7.80	0.4227	0.01	0.0335	1.1939	0.2794	-3.0040	1444.0
10	1	0.2	8	7.61	0.4436	0.01	0.0345	1.1851	0.2863	-3.0060	1369.5
	2	0.1	4	7.80	0.4293	0.01	0.0341	1.1917	0.2868	-3.0159	1420.6
11	1	0.2	8	7.61	0.4648	0.01	0.0361	1.1735	0.2947	-2.9270	1292.7
	2	0.1	4	7.80	0.4483	0.01	0.0357	1.1834	0.3020	-2.9965	1352.0
12	1	0.2	8	7.61	0.4517	0.01	0.0351	1.1811	0.2908	-2.9842	1340.5
	2	0.1	4	7.80	0.4365	0.01	0.0348	1.1890	0.2936	-3.0173	1394.7
13	1	0.2	8	7.61	0.4465	0.01	0.0347	1.1837	0.2881	-2.9995	1359.2
	2	0.1	4	7.80	0.4318	0.01	0.0344	1.1908	0.2894	-3.0177	1411.4
14	1	0.2	8	7.61	0.4326	0.01	0.0335	1.1898	0.2777	-3.0163	1409.0
	2	0.1	4	7.80	0.4194	0.01	0.0332	1.1948	0.2752	-2.9938	1455.7
15	1	0.2	8	7.61	0.4264	0.01	0.0329	1.1919	0.2715	-3.0105	1431.2
	2	0.1	4	7.80	0.4138	0.01	0.0325	1.1960	0.2676	-2.9695	1475.4
16	1	0.2	8	7.61	0.4504	0.01	0.0350	1.1817	0.2902	-2.9884	1345.2
	2	0.1	4	7.80	0.4353	0.01	0.0347	1.1894	0.2926	-3.0178	1398.8
17	1	0.2	8	7.61	0.4354	0.01	0.0338	1.1887	0.2802	-3.0160	1399.0
	2	0.1	4	7.80	0.4219	0.01	0.0334	1.1941	0.2784	-3.0019	1446.7
18	1	0.2	8	7.61	0.4204	0.01	0.0323	1.1937	0.2645	-2.9955	1452.7
	2	0.1	4	7.80	0.4084	0.01	0.0319	1.1970	0.2594	-2.9366	1494.5
19	1	0.2	8	7.61	0.4344	0.01	0.0337	1.1891	0.2793	-3.0163	1402.7
	2	0.1	4	7.80	0.4210	0.01	0.0333	1.1943	0.2772	-2.9991	1450.1
20	1	0.2	8	7.61	0.4449	0.01	0.0346	1.1845	0.2871	-3.0033	1365.0
	2	0.1	4	7.80	0.4304	0.01	0.0343	1.1913	0.2879	-3.0169	1416.5
21	1	0.2	8	7.61	0.4452	0.01	0.0346	1.1843	0.2873	-3.0026	1363.8
	2	0.1	4	7.80	0.4307	0.01	0.0343	1.1912	0.2882	-3.0171	1415.5
22	1	0.2	8	7.61	0.4380	0.01	0.0340	1.1876	0.2823	-3.0144	1389.8
	2	0.1	4	7.80	0.4242	0.01	0.0337	1.1934	0.2811	-3.0077	1438.6
26	1	0.2	8	7.61	0.4424	0.01	0.0344	1.1856	0.2855	-3.0083	1373.8
	2	0.1	4	7.80	0.4282	0.01	0.0340	1.1921	0.2856	-3.0147	1424.3
27	1	0.2	8	7.61	0.4232	0.01	0.0326	1.1929	0.2679	-3.0038	1442.5
	2	0.1	4	7.80	0.4110	0.01	0.0322	1.1966	0.2634	-2.9534	1485.5
28	1	0.2	8	7.61	0.4146	0.01	0.0316	1.1950	0.2571	-2.9719	1473.2
	2	0.1	4	7.80	0.4032	0.01	0.0312	1.1975	0.2510	-2.8958	1512.6

29	1	0.2	8	7.61	0.4381	0.01	0.0340	1.1876	0.2823	-3.0143	1389.6
	2	0.1	4	7.80	0.4242	0.01	0.0337	1.1934	0.2812	-3.0079	1438.4
31	1	0.2	8	7.61	0.4283	0.01	0.0331	1.1913	0.2735	-3.0132	1424.4
	2	0.1	4	7.80	0.4155	0.01	0.0327	1.1957	0.2700	-2.9779	1469.4

Table 74 Subsoil horizons parameters for soil-type 6

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.1	4	7.80	0.4251	0.01	0.0347	1.1675	0.2289	-2.9893	1460.0
	4	0.15	15	8.00	0.3935	0.01	0.0238	1.1340	0.1286	-3.2087	1586.3
	5	0.05	1	8.00	0.3935	0.01	0.0238	1.1340	0.1286	-3.2087	1586.3
	6	0.4	8	8.00	0.3935	0.01	0.0238	1.1340	0.1286	-3.2087	1586.3
	7	1	10	8.00	0.3935	0.01	0.0238	1.1340	0.1286	-3.2087	1586.3

7/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 7

Table 75 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 7

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.15	6	7.48	0.4661	0.01	0.0268	1.1161	0.1811	-3.6852	1333.3
8	1	0.15	6	7.48	0.4854	0.01	0.0282	1.1120	0.1870	-3.3646	1260.4
18	1	0.15	6	7.48	0.4618	0.01	0.0265	1.1167	0.1790	-3.7478	1349.3
23	1	0.15	6	7.48	0.4735	0.01	0.0273	1.1147	0.1840	-3.5692	1305.5

Table 76 Subsoil horizons parameters for soil-type 7

AU ID	Horizon ID	Horizon Thickness (cm)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	2	0.2	8	7.67	0.4328	0.01	0.0209	1.1020	0.1425	-4.0183	1476.9
	3	0.1	10	7.67	0.4458	0.01	0.0182	1.0712	0.0447	-3.9373	1453.1
	4	0.15	3	7.67	0.4458	0.01	0.0182	1.0712	0.0447	-3.9373	1453.1
	5	0.4	8	7.67	0.4458	0.01	0.0182	1.0712	0.0447	-3.9373	1453.1
	6	1	10	7.67	0.4458	0.01	0.0182	1.0712	0.0447	-3.9373	1453.1

8/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 8

Table 77 **Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 8**

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.2	8	7.48	0.4337	0.01	0.0201	1.2239	0.1322	-2.1620	1393.4
	2	0.1	4	7.48	0.3919	0.01	0.0162	1.2456	0.1190	-1.6841	1539.6
3	1	0.2	8	7.48	0.4531	0.01	0.0223	1.2111	0.1368	-2.1797	1323.5
	2	0.1	4	7.48	0.4051	0.01	0.0178	1.2432	0.1301	-1.8672	1493.3
4	1	0.2	8	7.48	0.4468	0.01	0.0216	1.2156	0.1358	-2.1812	1346.4
	2	0.1	4	7.48	0.4008	0.01	0.0173	1.2443	0.1267	-1.8151	1508.5
5	1	0.2	8	7.48	0.4429	0.01	0.0211	1.2182	0.1349	-2.1789	1360.2
	2	0.1	4	7.48	0.3982	0.01	0.0169	1.2448	0.1246	-1.7802	1517.7
6	1	0.2	8	7.48	0.4666	0.01	0.0239	1.2007	0.1375	-2.1582	1274.8
	2	0.1	4	7.48	0.4143	0.01	0.0189	1.2401	0.1365	-1.9560	1460.8
7	1	0.2	8	7.48	0.4311	0.01	0.0198	1.2253	0.1312	-2.1543	1402.5
	2	0.1	4	7.48	0.3901	0.01	0.0160	1.2457	0.1174	-1.6544	1545.6
8	1	0.2	8	7.48	0.4516	0.01	0.0221	1.2122	0.1366	-2.1806	1329.0
	2	0.1	4	7.48	0.4041	0.01	0.0177	1.2435	0.1293	-1.8553	1497.0
9	1	0.2	8	7.48	0.4475	0.01	0.0216	1.2151	0.1359	-2.1813	1343.9
	2	0.1	4	7.48	0.4012	0.01	0.0173	1.2442	0.1271	-1.8210	1506.9
10	1	0.2	8	7.48	0.4556	0.01	0.0226	1.2092	0.1371	-2.1775	1314.6
	2	0.1	4	7.48	0.4068	0.01	0.0180	1.2427	0.1314	-1.8856	1487.4
11	1	0.2	8	7.48	0.4793	0.01	0.0255	1.1903	0.1365	-2.1211	1229.2
	2	0.1	4	7.48	0.4230	0.01	0.0198	1.2362	0.1415	-2.0158	1430.0
12	1	0.2	8	7.48	0.4646	0.01	0.0236	1.2023	0.1376	-2.1629	1282.3
	2	0.1	4	7.48	0.4129	0.01	0.0187	1.2406	0.1356	-1.9441	1465.8
13	1	0.2	8	7.48	0.4588	0.01	0.0229	1.2068	0.1374	-2.1734	1303.1
	2	0.1	4	7.48	0.4090	0.01	0.0182	1.2420	0.1329	-1.9079	1479.7
14	1	0.2	8	7.48	0.4434	0.01	0.0212	1.2179	0.1350	-2.1793	1358.6
	2	0.1	4	7.48	0.3984	0.01	0.0170	1.2447	0.1248	-1.7842	1516.7
15	1	0.2	8	7.48	0.4364	0.01	0.0204	1.2223	0.1331	-2.1689	1383.5
	2	0.1	4	7.48	0.3937	0.01	0.0164	1.2454	0.1207	-1.7147	1533.1
16	1	0.2	8	7.48	0.4631	0.01	0.0234	1.2035	0.1375	-2.1658	1287.5
	2	0.1	4	7.48	0.4119	0.01	0.0186	1.2410	0.1349	-1.9356	1469.3
17	1	0.2	8	7.48	0.4465	0.01	0.0215	1.2158	0.1357	-2.1811	1347.4
	2	0.1	4	7.48	0.4006	0.01	0.0172	1.2443	0.1266	-1.8126	1509.2
18	1	0.2	8	7.48	0.4297	0.01	0.0197	1.2261	0.1307	-2.1494	1407.5
	2	0.1	4	7.48	0.3892	0.01	0.0158	1.2458	0.1165	-1.6376	1548.9
19	1	0.2	8	7.48	0.4453	0.01	0.0214	1.2166	0.1355	-2.1806	1351.6
	2	0.1	4	7.48	0.3998	0.01	0.0171	1.2445	0.1259	-1.8023	1512.0
21	1	0.2	8	7.48	0.4574	0.01	0.0228	1.2079	0.1373	-2.1754	1308.2
	2	0.1	4	7.48	0.4080	0.01	0.0181	1.2423	0.1322	-1.8981	1483.1
23	1	0.2	8	7.48	0.4405	0.01	0.0209	1.2197	0.1343	-2.1761	1368.8
	2	0.1	4	7.48	0.3965	0.01	0.0167	1.2451	0.1232	-1.7568	1523.4
24	1	0.2	8	7.48	0.4405	0.01	0.0209	1.2198	0.1343	-2.1760	1369.1
	2	0.1	4	7.48	0.3965	0.01	0.0167	1.2451	0.1231	-1.7561	1523.6

27	1	0.2	8	7.48	0.4329	0.01	0.0200	1.2243	0.1319	-2.1599	1396.1
	2	0.1	4	7.48	0.3914	0.01	0.0161	1.2457	0.1185	-1.6754	1541.4
28	1	0.2	8	7.48	0.4233	0.01	0.0189	1.2293	0.1279	-2.1211	1430.4
	2	0.1	4	7.48	0.3849	0.01	0.0153	1.2458	0.1121	-1.5544	1563.9
29	1	0.2	8	7.48	0.4494	0.01	0.0219	1.2138	0.1363	-2.1813	1336.9
	2	0.1	4	7.48	0.4026	0.01	0.0175	1.2438	0.1282	-1.8375	1502.3
31	1	0.2	8	7.48	0.4386	0.01	0.0206	1.2210	0.1337	-2.1731	1375.8
	2	0.1	4	7.48	0.3952	0.01	0.0166	1.2452	0.1220	-1.7370	1528.1

Table 78 Subsoil horizons parameters for soil-type 8

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.3	6	7.48	0.4072	0.01	0.0183	1.2183	0.2132	-1.7700	1520.2
	4	0.4	8	7.48	0.3809	0.01	0.0148	1.1971	0.1500	-1.5435	1615.4
	5	0.15	2	7.48	0.3809	0.01	0.0148	1.1971	0.1500	-1.5435	1615.4
	6	0.1	10	7.48	0.3809	0.01	0.0148	1.1971	0.1500	-1.5435	1615.4
	7	0.75	8	7.48	0.3809	0.01	0.0148	1.1971	0.1500	-1.5435	1615.4

9/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 9

Table 79 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 9

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.25	10	6.00	0.4015	0.01	0.0491	1.2898	0.5694	-1.7894	1487.1
	2	0.05	2	6.00	0.3816	0.03	0.0520	1.3051	0.5676	-1.4856	1551.7
3	1	0.25	10	6.00	0.4170	0.01	0.0495	1.2807	0.6093	-1.9336	1432.0
	2	0.05	2	6.00	0.3943	0.03	0.0529	1.3016	0.6211	-1.6984	1507.4
4	1	0.25	10	6.00	0.4119	0.01	0.0494	1.2841	0.5978	-1.8944	1450.1
	2	0.05	2	6.00	0.3901	0.03	0.0527	1.3030	0.6048	-1.6366	1522.0
5	1	0.25	10	6.00	0.4089	0.01	0.0494	1.2859	0.5901	-1.8671	1461.0
	2	0.05	2	6.00	0.3876	0.03	0.0525	1.3038	0.5944	-1.5958	1530.7
6	1	0.25	10	6.00	0.4279	0.01	0.0493	1.2725	0.6288	-1.9950	1393.5
	2	0.05	2	6.00	0.4032	0.03	0.0531	1.2974	0.6519	-1.8078	1476.3
7	1	0.25	10	6.00	0.3994	0.01	0.0490	1.2907	0.5631	-1.7648	1494.2
	2	0.05	2	6.00	0.3800	0.03	0.0518	1.3054	0.5597	-1.4521	1557.4
9	1	0.25	10	6.00	0.4125	0.01	0.0494	1.2837	0.5991	-1.8989	1448.2
	2	0.05	2	6.00	0.3906	0.03	0.0527	1.3029	0.6066	-1.6435	1520.4
10	1	0.25	10	6.00	0.4190	0.01	0.0495	1.2793	0.6134	-1.9469	1425.0
	2	0.05	2	6.00	0.3959	0.03	0.0530	1.3009	0.6271	-1.7205	1501.7
11	1	0.25	10	6.00	0.4381	0.01	0.0490	1.2636	0.6411	-2.0297	1357.2
	2	0.05	2	6.00	0.4115	0.03	0.0531	1.2924	0.6762	-1.8870	1446.8
12	1	0.25	10	6.00	0.4262	0.01	0.0493	1.2739	0.6262	-1.9873	1399.5
	2	0.05	2	6.00	0.4018	0.03	0.0531	1.2981	0.6475	-1.7928	1481.1
13	1	0.25	10	6.00	0.4216	0.01	0.0494	1.2775	0.6183	-1.9627	1415.9
	2	0.05	2	6.00	0.3980	0.03	0.0530	1.3000	0.6346	-1.7477	1494.4
14	1	0.25	10	6.00	0.4092	0.01	0.0494	1.2857	0.5910	-1.8703	1459.8
	2	0.05	2	6.00	0.3879	0.03	0.0525	1.3037	0.5956	-1.6004	1529.7
15	1	0.25	10	6.00	0.4037	0.01	0.0492	1.2887	0.5759	-1.8146	1479.3
	2	0.05	2	6.00	0.3834	0.03	0.0521	1.3048	0.5759	-1.5204	1545.4
16	1	0.25	10	6.00	0.4251	0.01	0.0494	1.2748	0.6244	-1.9817	1403.6
	2	0.05	2	6.00	0.4009	0.03	0.0531	1.2986	0.6444	-1.7820	1484.4
17	1	0.25	10	6.00	0.4117	0.01	0.0494	1.2842	0.5972	-1.8924	1450.9
	2	0.05	2	6.00	0.3900	0.03	0.0526	1.3031	0.6040	-1.6336	1522.6
19	1	0.25	10	6.00	0.4108	0.01	0.0494	1.2848	0.5949	-1.8844	1454.2
	2	0.05	2	6.00	0.3892	0.03	0.0526	1.3033	0.6009	-1.6215	1525.3
20	1	0.25	10	6.00	0.4201	0.01	0.0494	1.2785	0.6156	-1.9540	1421.0
	2	0.05	2	6.00	0.3968	0.03	0.0530	1.3005	0.6304	-1.7326	1498.5
21	1	0.25	10	6.00	0.4204	0.01	0.0494	1.2783	0.6161	-1.9559	1420.0
	2	0.05	2	6.00	0.3971	0.03	0.0530	1.3004	0.6313	-1.7357	1497.7
22	1	0.25	10	6.00	0.4140	0.01	0.0495	1.2828	0.6025	-1.9109	1442.9
	2	0.05	2	6.00	0.3918	0.03	0.0528	1.3025	0.6114	-1.6621	1516.2
24	1	0.25	10	6.00	0.4069	0.01	0.0493	1.2870	0.5849	-1.8481	1468.0
	2	0.05	2	6.00	0.3860	0.03	0.0524	1.3042	0.5875	-1.5679	1536.3
26	1	0.25	10	6.00	0.4180	0.01	0.0495	1.2801	0.6112	-1.9399	1428.8
	2	0.05	2	6.00	0.3951	0.03	0.0529	1.3012	0.6239	-1.7088	1504.8

28	1	0.25	10	6.00	0.3932	0.01	0.0486	1.2931	0.5425	-1.6798	1516.0
	2	0.05	2	6.00	0.3749	0.03	0.0513	1.3057	0.5344	-1.3404	1574.9
29	1	0.25	10	6.00	0.4140	0.01	0.0495	1.2827	0.6027	-1.9114	1442.7
	2	0.05	2	6.00	0.3919	0.03	0.0528	1.3025	0.6116	-1.6629	1516.0
31	1	0.25	10	6.00	0.4054	0.01	0.0493	1.2879	0.5807	-1.8327	1473.3
	2	0.05	2	6.00	0.3848	0.03	0.0523	1.3045	0.5821	-1.5460	1540.6

Table 80 Subsoil horizons parameters for soil-type 9

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.3	6	6.00	0.3904	0.03	0.0590	1.2811	0.3362	-1.5839	1533.1
	4	0.4	8	6.39	0.3446	0.03	0.0785	1.3419	0.2804	-0.4070	1655.2
	5	0.15	2	6.48	0.3305	0.03	0.0802	1.4794	0.2920	1.4114	1687.3
	6	0.1	10	6.48	0.3305	0.03	0.0802	1.4794	0.2920	1.4114	1687.3
	7	0.75	8	6.48	0.3305	0.03	0.0802	1.4794	0.2920	1.4114	1687.3

10/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 10

Table 81 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 10

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
2	1	0.15	6	7.38	0.5598	0.01	0.0155	1.0940	0.0800	1.2913	995.1
	2	0.15	6	7.28	0.5482	0.01	0.0157	1.0940	0.0800	0.5088	1045.5
4	1	0.15	6	7.38	0.5206	0.01	0.0131	1.0990	0.0800	-0.3668	1168.0
	2	0.15	6	7.28	0.5101	0.01	0.0139	1.0991	0.0800	-1.0492	1209.3
5	1	0.15	6	7.38	0.5163	0.01	0.0130	1.0995	0.0800	-0.5505	1186.4
	2	0.15	6	7.28	0.5058	0.01	0.0138	1.0995	0.0800	-1.2135	1226.8
6	1	0.15	6	7.38	0.5424	0.01	0.0140	1.0962	0.0800	0.5701	1073.2
	2	0.15	6	7.28	0.5313	0.01	0.0146	1.0965	0.0800	-0.1885	1119.6
9	1	0.15	6	7.38	0.5214	0.01	0.0131	1.0989	0.0800	-0.3343	1164.7
	2	0.15	6	7.28	0.5108	0.01	0.0139	1.0990	0.0800	-1.0201	1206.2
10	1	0.15	6	7.38	0.5305	0.01	0.0134	1.0978	0.0800	0.0549	1125.6
	2	0.15	6	7.28	0.5196	0.01	0.0141	1.0981	0.0800	-0.6670	1169.3
12	1	0.15	6	7.38	0.5402	0.01	0.0139	1.0965	0.0800	0.4749	1083.0
	2	0.15	6	7.28	0.5291	0.01	0.0145	1.0968	0.0800	-0.2780	1128.9
13	1	0.15	6	7.38	0.5340	0.01	0.0135	1.0974	0.0800	0.2059	1110.4
	2	0.15	6	7.28	0.5230	0.01	0.0142	1.0976	0.0800	-0.5282	1154.9
14	1	0.15	6	7.38	0.5167	0.01	0.0130	1.0994	0.0800	-0.5300	1184.4
	2	0.15	6	7.28	0.5063	0.01	0.0138	1.0994	0.0800	-1.1952	1224.8
16	1	0.15	6	7.38	0.5387	0.01	0.0138	1.0967	0.0800	0.4086	1089.8
	2	0.15	6	7.28	0.5276	0.01	0.0144	1.0970	0.0800	-0.3400	1135.3
17	1	0.15	6	7.38	0.5203	0.01	0.0131	1.0991	0.0800	-0.3805	1169.3
	2	0.15	6	7.28	0.5098	0.01	0.0139	1.0991	0.0800	-1.0615	1210.6
20	1	0.15	6	7.38	0.5320	0.01	0.0135	1.0976	0.0800	0.1210	1119.0
	2	0.15	6	7.28	0.5211	0.01	0.0142	1.0979	0.0800	-0.6063	1163.0
22	1	0.15	6	7.38	0.5235	0.01	0.0132	1.0987	0.0800	-0.2452	1155.8
	2	0.15	6	7.28	0.5128	0.01	0.0139	1.0988	0.0800	-0.9398	1197.8
28	1	0.15	6	7.38	0.4931	0.01	0.0127	1.1007	0.0800	-1.4661	1281.3
	2	0.15	6	7.28	0.4835	0.01	0.0135	1.1001	0.0800	-2.0134	1316.1
31	1	0.15	6	7.38	0.5112	0.01	0.0129	1.0999	0.0800	-0.7585	1207.5
	2	0.15	6	7.28	0.5010	0.01	0.0137	1.0998	0.0800	-1.3979	1246.6

Table 82 Subsoil horizons parameters for soil-type 10

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.1	4	7.48	0.4509	0.01	0.0119	1.0642	0.0850	-3.4105	1453.1
	4	0.2	4	7.28	0.4422	0.01	0.0116	1.0640	0.0850	-3.5949	1483.1
	5	0.4	8	7.28	0.4422	0.01	0.0116	1.0640	0.0850	-3.5949	1483.1
	6	0.15	2	7.28	0.4422	0.01	0.0116	1.0640	0.0850	-3.5949	1483.1
	7	0.1	10	7.28	0.4422	0.01	0.0116	1.0640	0.0850	-3.5949	1483.1
	8	0.75	8	7.28	0.4422	0.01	0.0116	1.0640	0.0850	-3.5949	1483.1

11/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 11

Table 83 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 11

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.15	6	6.26	0.4470	0.01	0.0452	1.2180	0.4977	-2.5553	1339.7
	2	0.15	6	6.94	0.3930	0.01	0.0424	1.2563	0.4173	-2.0569	1528.2
2	1	0.15	6	6.26	0.5023	0.01	0.0464	1.1715	0.4764	-2.3683	1141.3
	2	0.15	6	6.94	0.4281	0.01	0.0448	1.2415	0.4941	-2.3537	1404.1
3	1	0.15	6	6.26	0.4687	0.01	0.0453	1.2007	0.5017	-2.5093	1261.6
	2	0.15	6	6.94	0.4067	0.01	0.0437	1.2524	0.4541	-2.2203	1479.9
4	1	0.15	6	6.26	0.4616	0.01	0.0452	1.2066	0.5024	-2.5304	1287.1
	2	0.15	6	6.94	0.4022	0.01	0.0434	1.2540	0.4430	-2.1746	1495.8
5	1	0.15	6	6.26	0.4573	0.01	0.0452	1.2101	0.5019	-2.5406	1302.6
	2	0.15	6	6.94	0.3995	0.01	0.0431	1.2548	0.4359	-2.1436	1505.3
6	1	0.15	6	6.26	0.4838	0.01	0.0455	1.1876	0.4944	-2.4513	1207.5
	2	0.15	6	6.94	0.4163	0.01	0.0443	1.2482	0.4745	-2.2956	1446.1
8	1	0.15	6	6.26	0.4670	0.01	0.0453	1.2021	0.5020	-2.5148	1267.8
	2	0.15	6	6.94	0.4057	0.01	0.0437	1.2528	0.4515	-2.2099	1483.8
9	1	0.15	6	6.26	0.4624	0.01	0.0452	1.2060	0.5024	-2.5284	1284.4
	2	0.15	6	6.94	0.4027	0.01	0.0434	1.2538	0.4442	-2.1798	1494.1
10	1	0.15	6	6.26	0.4715	0.01	0.0453	1.1983	0.5009	-2.4999	1251.7
	2	0.15	6	6.94	0.4085	0.01	0.0439	1.2517	0.4581	-2.2362	1473.8
11	1	0.15	6	6.26	0.4979	0.01	0.0461	1.1753	0.4814	-2.3882	1156.9
	2	0.15	6	6.94	0.4253	0.01	0.0447	1.2432	0.4900	-2.3430	1414.1
12	1	0.15	6	6.26	0.4814	0.01	0.0454	1.1897	0.4960	-2.4610	1215.8
	2	0.15	6	6.94	0.4148	0.01	0.0443	1.2489	0.4717	-2.2858	1451.3
13	1	0.15	6	6.26	0.4750	0.01	0.0453	1.1953	0.4995	-2.4868	1238.9
	2	0.15	6	6.94	0.4108	0.01	0.0440	1.2508	0.4631	-2.2552	1465.8
14	1	0.15	6	6.26	0.4578	0.01	0.0452	1.2097	0.5020	-2.5396	1300.8
	2	0.15	6	6.94	0.3998	0.01	0.0432	1.2547	0.4367	-2.1472	1504.3
15	1	0.15	6	6.26	0.4501	0.01	0.0452	1.2157	0.4994	-2.5525	1328.6
	2	0.15	6	6.94	0.3949	0.01	0.0427	1.2559	0.4231	-2.0847	1521.4
16	1	0.15	6	6.26	0.4799	0.01	0.0454	1.1911	0.4970	-2.4677	1221.5
	2	0.15	6	6.94	0.4138	0.01	0.0442	1.2494	0.4696	-2.2787	1454.9
17	1	0.15	6	6.26	0.4613	0.01	0.0452	1.2069	0.5024	-2.5313	1288.3
	2	0.15	6	6.94	0.4020	0.01	0.0434	1.2540	0.4425	-2.1724	1496.5
18	1	0.15	6	6.26	0.4426	0.01	0.0452	1.2212	0.4946	-2.5567	1355.5
	2	0.15	6	6.94	0.3902	0.01	0.0421	1.2567	0.4089	-2.0146	1537.9
19	1	0.15	6	6.26	0.4600	0.01	0.0452	1.2079	0.5023	-2.5345	1293.0
	2	0.15	6	6.94	0.4012	0.01	0.0433	1.2543	0.4403	-2.1633	1499.4
20	1	0.15	6	6.26	0.4730	0.01	0.0453	1.1970	0.5004	-2.4943	1246.1
	2	0.15	6	6.94	0.4095	0.01	0.0439	1.2513	0.4603	-2.2447	1470.3
21	1	0.15	6	6.26	0.4734	0.01	0.0453	1.1966	0.5002	-2.4927	1244.6
	2	0.15	6	6.94	0.4097	0.01	0.0440	1.2512	0.4609	-2.2469	1469.4
22	1	0.15	6	6.26	0.4645	0.01	0.0452	1.2043	0.5023	-2.5226	1277.0
	2	0.15	6	6.94	0.4040	0.01	0.0435	1.2534	0.4475	-2.1937	1489.5
23	1	0.15	6	6.26	0.4547	0.01	0.0452	1.2122	0.5012	-2.5458	1312.3

	2	0.15	6	6.94	0.3978	0.01	0.0430	1.2552	0.4312	-2.1227	1511.3
24	1	0.15	6	6.26	0.4546	0.01	0.0452	1.2123	0.5012	-2.5460	1312.5
	2	0.15	6	6.94	0.3978	0.01	0.0430	1.2552	0.4311	-2.1221	1511.5
25	1	0.15	6	6.26	0.5224	0.01	0.0486	1.1551	0.4492	-2.2867	1070.6
	2	0.15	6	6.94	0.4409	0.01	0.0449	1.2326	0.5082	-2.3815	1358.6
26	1	0.15	6	6.26	0.4700	0.01	0.0453	1.1996	0.5013	-2.5050	1257.0
	2	0.15	6	6.94	0.4076	0.01	0.0438	1.2521	0.4560	-2.2278	1477.1
27	1	0.15	6	6.26	0.4462	0.01	0.0452	1.2187	0.4972	-2.5559	1342.8
	2	0.15	6	6.94	0.3925	0.01	0.0424	1.2564	0.4157	-2.0491	1530.0
28	1	0.15	6	6.26	0.4354	0.01	0.0451	1.2260	0.4877	-2.5518	1381.2
	2	0.15	6	6.94	0.3857	0.01	0.0415	1.2571	0.3943	-1.9380	1553.5
29	1	0.15	6	6.26	0.4646	0.01	0.0452	1.2042	0.5023	-2.5223	1276.6
	2	0.15	6	6.94	0.4041	0.01	0.0435	1.2534	0.4477	-2.1943	1489.3
30	1	0.15	6	6.26	0.4914	0.01	0.0458	1.1809	0.4880	-2.4174	1180.0
	2	0.15	6	6.94	0.4212	0.01	0.0446	1.2456	0.4834	-2.3239	1428.7
31	1	0.15	6	6.26	0.4525	0.01	0.0452	1.2139	0.5004	-2.5494	1320.1
	2	0.15	6	6.94	0.3964	0.01	0.0428	1.2556	0.4274	-2.1049	1516.1

Table 84 Subsoil horizons parameters for soil-type 11

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.2	8	6.94	0.4037	0.01	0.0474	1.2301	0.2971	-2.1345	1508.0
	4	0.1	10	6.94	0.4037	0.01	0.0474	1.2301	0.2971	-2.1345	1508.0
	5	0.4	8	6.94	0.4037	0.01	0.0474	1.2301	0.2971	-2.1345	1508.0
	6	1	10	6.94	0.4037	0.01	0.0474	1.2301	0.2971	-2.1345	1508.0

12/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 12

Table 85 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 12

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
2	1	0.2	8	6.85	0.4429	0.01	0.0148	1.2077	0.0230	-2.2650	1358.3
	2	0.05	2	6.85	0.4429	0.01	0.0148	1.2077	0.0230	-2.2650	1358.3
4	1	0.2	8	6.85	0.4144	0.01	0.0117	1.2204	0.0230	-2.1856	1459.9
	2	0.05	2	6.85	0.4144	0.01	0.0117	1.2204	0.0230	-2.1856	1459.9
6	1	0.2	8	6.85	0.4299	0.01	0.0134	1.2145	0.0230	-2.2520	1404.7
	2	0.05	2	6.85	0.4299	0.01	0.0134	1.2145	0.0230	-2.2520	1404.7
9	1	0.2	8	6.85	0.4150	0.01	0.0118	1.2202	0.0230	-2.1889	1458.0
	2	0.05	2	6.85	0.4150	0.01	0.0118	1.2202	0.0230	-2.1889	1458.0
11	1	0.2	8	6.85	0.4398	0.01	0.0145	1.2094	0.0230	-2.2649	1369.3
	2	0.05	2	6.85	0.4398	0.01	0.0145	1.2094	0.0230	-2.2649	1369.3
12	1	0.2	8	6.85	0.4283	0.01	0.0132	1.2152	0.0230	-2.2479	1410.5
	2	0.05	2	6.85	0.4283	0.01	0.0132	1.2152	0.0230	-2.2479	1410.5
14	1	0.2	8	6.85	0.4118	0.01	0.0115	1.2211	0.0230	-2.1675	1469.3
	2	0.05	2	6.85	0.4118	0.01	0.0115	1.2211	0.0230	-2.1675	1469.3
15	1	0.2	8	6.85	0.4064	0.01	0.0109	1.2224	0.0230	-2.1238	1488.3
	2	0.05	2	6.85	0.4064	0.01	0.0109	1.2224	0.0230	-2.1238	1488.3
16	1	0.2	8	6.85	0.4272	0.01	0.0131	1.2157	0.0230	-2.2447	1414.5
	2	0.05	2	6.85	0.4272	0.01	0.0131	1.2157	0.0230	-2.2447	1414.5
17	1	0.2	8	6.85	0.4142	0.01	0.0117	1.2205	0.0230	-2.1841	1460.7
	2	0.05	2	6.85	0.4142	0.01	0.0117	1.2205	0.0230	-2.1841	1460.7
19	1	0.2	8	6.85	0.4133	0.01	0.0116	1.2207	0.0230	-2.1782	1463.9
	2	0.05	2	6.85	0.4133	0.01	0.0116	1.2207	0.0230	-2.1782	1463.9
20	1	0.2	8	6.85	0.4224	0.01	0.0126	1.2177	0.0230	-2.2276	1431.6
	2	0.05	2	6.85	0.4224	0.01	0.0126	1.2177	0.0230	-2.2276	1431.6
22	1	0.2	8	6.85	0.4164	0.01	0.0119	1.2198	0.0230	-2.1977	1452.8
	2	0.05	2	6.85	0.4164	0.01	0.0119	1.2198	0.0230	-2.1977	1452.8
24	1	0.2	8	6.85	0.4095	0.01	0.0112	1.2217	0.0230	-2.1503	1477.3
	2	0.05	2	6.85	0.4095	0.01	0.0112	1.2217	0.0230	-2.1503	1477.3
25	1	0.2	8	6.85	0.4568	0.01	0.0165	1.1989	0.0230	-2.2457	1308.0
	2	0.05	2	6.85	0.4568	0.01	0.0165	1.1989	0.0230	-2.2457	1308.0
26	1	0.2	8	6.85	0.4203	0.01	0.0124	1.2185	0.0230	-2.2181	1439.1
	2	0.05	2	6.85	0.4203	0.01	0.0124	1.2185	0.0230	-2.2181	1439.1
30	1	0.2	8	6.85	0.4353	0.01	0.0140	1.2118	0.0230	-2.2615	1385.5
	2	0.05	2	6.85	0.4353	0.01	0.0140	1.2118	0.0230	-2.2615	1385.5
31	1	0.2	8	6.85	0.4080	0.01	0.0111	1.2221	0.0230	-2.1382	1482.4
	2	0.05	2	6.85	0.4080	0.01	0.0111	1.2221	0.0230	-2.1382	1482.4

Table 86 Subsoil horizons parameters for soil-type 12

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.05	2	6.85	0.4233	0.01	0.0120	1.1918	0.0230	-2.1588	1473.4
	4	0.3	6	6.76	0.3743	0.01	0.0089	1.1400	0.0400	-2.1131	1655.2
	5	0.4	8	6.76	0.3422	0.01	0.0373	1.0608	0.0400	0.4496	1759.1
	6	0.35	4	6.76	0.3422	0.01	0.0373	1.0608	0.0400	0.4496	1759.1
	7	0.1	10	6.76	0.3422	0.01	0.0373	1.0608	0.0400	0.4496	1759.1
	8	0.55	8	6.76	0.3422	0.01	0.0373	1.0608	0.0400	0.4496	1759.1

13/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 13

Table 87 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 13

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.2	8	7.46	0.4241	0.01	0.0153	1.1680	0.0768	-3.1543	1448.4
	2	0.1	4	7.17	0.4020	0.01	0.0122	1.1724	0.0625	-3.0007	1524.2
2	1	0.2	8	7.46	0.4674	0.01	0.0205	1.1542	0.0863	-2.9644	1291.5
	2	0.1	4	7.17	0.4375	0.01	0.0162	1.1681	0.0755	-3.0709	1398.4
4	1	0.2	8	7.46	0.4356	0.01	0.0166	1.1657	0.0806	-3.1408	1407.2
	2	0.1	4	7.17	0.4114	0.01	0.0133	1.1724	0.0667	-3.0570	1491.3
5	1	0.2	8	7.46	0.4322	0.01	0.0162	1.1665	0.0796	-3.1481	1419.3
	2	0.1	4	7.17	0.4087	0.01	0.0130	1.1725	0.0655	-3.0439	1501.0
6	1	0.2	8	7.46	0.4530	0.01	0.0187	1.1603	0.0846	-3.0658	1344.4
	2	0.1	4	7.17	0.4256	0.01	0.0149	1.1708	0.0720	-3.0872	1440.9
8	1	0.2	8	7.46	0.4399	0.01	0.0171	1.1646	0.0818	-3.1280	1392.0
	2	0.1	4	7.17	0.4149	0.01	0.0137	1.1722	0.0681	-3.0700	1479.1
9	1	0.2	8	7.46	0.4362	0.01	0.0167	1.1656	0.0808	-3.1392	1405.1
	2	0.1	4	7.17	0.4119	0.01	0.0133	1.1724	0.0669	-3.0591	1489.6
10	1	0.2	8	7.46	0.4433	0.01	0.0175	1.1636	0.0827	-3.1147	1379.3
	2	0.1	4	7.17	0.4177	0.01	0.0140	1.1720	0.0692	-3.0779	1469.0
11	1	0.2	8	7.46	0.4640	0.01	0.0200	1.1557	0.0861	-2.9911	1304.1
	2	0.1	4	7.17	0.4347	0.01	0.0159	1.1689	0.0747	-3.0778	1408.5
12	1	0.2	8	7.46	0.4512	0.01	0.0184	1.1609	0.0843	-3.0762	1350.9
	2	0.1	4	7.17	0.4242	0.01	0.0147	1.1711	0.0715	-3.0868	1446.2
13	1	0.2	8	7.46	0.4461	0.01	0.0178	1.1627	0.0833	-3.1023	1369.2
	2	0.1	4	7.17	0.4200	0.01	0.0142	1.1717	0.0701	-3.0824	1460.9
14	1	0.2	8	7.46	0.4326	0.01	0.0163	1.1664	0.0797	-3.1474	1418.0
	2	0.1	4	7.17	0.4090	0.01	0.0130	1.1725	0.0657	-3.0455	1499.9
16	1	0.2	8	7.46	0.4499	0.01	0.0183	1.1614	0.0841	-3.0831	1355.5
	2	0.1	4	7.17	0.4231	0.01	0.0146	1.1713	0.0712	-3.0861	1449.9
17	1	0.2	8	7.46	0.4354	0.01	0.0166	1.1658	0.0805	-3.1414	1408.1
	2	0.1	4	7.17	0.4112	0.01	0.0133	1.1724	0.0666	-3.0561	1492.0
18	1	0.2	8	7.46	0.4206	0.01	0.0149	1.1685	0.0755	-3.1516	1460.8
	2	0.1	4	7.17	0.3992	0.01	0.0119	1.1722	0.0612	-2.9771	1534.0
19	1	0.2	8	7.46	0.4343	0.01	0.0165	1.1660	0.0802	-3.1438	1411.8
	2	0.1	4	7.17	0.4104	0.01	0.0132	1.1725	0.0663	-3.0524	1495.0
20	1	0.2	8	7.46	0.4446	0.01	0.0177	1.1632	0.0829	-3.1094	1374.9
	2	0.1	4	7.17	0.4187	0.01	0.0141	1.1718	0.0696	-3.0800	1465.5
21	1	0.2	8	7.46	0.4449	0.01	0.0177	1.1631	0.0830	-3.1080	1373.7
	2	0.1	4	7.17	0.4190	0.01	0.0141	1.1718	0.0697	-3.0806	1464.5
24	1	0.2	8	7.46	0.4301	0.01	0.0160	1.1670	0.0789	-3.1514	1427.1
	2	0.1	4	7.17	0.4069	0.01	0.0128	1.1725	0.0648	-3.0339	1507.2
25	1	0.2	8	7.46	0.4827	0.01	0.0226	1.1466	0.0866	-2.8281	1234.7
	2	0.1	4	7.17	0.4502	0.01	0.0177	1.1640	0.0782	-3.0197	1352.3
27	1	0.2	8	7.46	0.4234	0.01	0.0152	1.1681	0.0765	-3.1540	1450.8
	2	0.1	4	7.17	0.4015	0.01	0.0122	1.1724	0.0623	-2.9965	1526.0

30	1	0.2	8	7.46	0.4589	0.01	0.0194	1.1579	0.0855	-3.0273	1322.5
	2	0.1	4	7.17	0.4306	0.01	0.0154	1.1699	0.0736	-3.0845	1423.3
31	1	0.2	8	7.46	0.4284	0.01	0.0158	1.1673	0.0783	-3.1531	1433.1
	2	0.1	4	7.17	0.4055	0.01	0.0126	1.1725	0.0642	-3.0256	1511.9

Table 88 Subsoil horizons parameters for soil-type 13

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.2	8	7.17	0.4195	0.01	0.0130	1.1416	0.1137	-3.0397	1503.7
	4	0.1	2	7.17	0.4057	0.01	0.0120	1.0983	0.0661	-3.6902	1572.6
	5	0.4	8	7.17	0.4057	0.01	0.0120	1.0983	0.0661	-3.6902	1572.6
	6	0.1	1	7.17	0.4057	0.01	0.0120	1.0983	0.0661	-3.6902	1572.6
	7	0.15	2	7.56	0.3804	0.01	0.0093	1.1353	0.0767	-2.4475	1637.5
	8	0.1	10	7.56	0.3804	0.01	0.0093	1.1353	0.0767	-2.4475	1637.5
	9	0.65	8	7.56	0.3804	0.01	0.0093	1.1353	0.0767	-2.4475	1637.5

14/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 14

Table 89 **Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 14**

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.03	1	5.00	0.4770	0.01	0.0188	1.2471	0.0839	-0.9805	1220.6
	2	0.07	4	5.20	0.4770	0.01	0.0187	1.2453	0.0814	-1.0117	1220.6
	3	0.2	8	5.49	0.4000	0.01	0.0113	1.3115	0.0769	-0.6406	1495.9
2	1	0.03	1	5.00	0.5473	0.01	0.0348	1.1716	0.0675	-1.1278	981.2
	2	0.07	4	5.20	0.5472	0.01	0.0349	1.1706	0.0655	-1.1496	981.2
	3	0.2	8	5.49	0.4388	0.01	0.0151	1.2819	0.0876	-1.0274	1358.3
3	1	0.03	1	5.00	0.5042	0.01	0.0231	1.2144	0.0789	-1.0114	1125.5
	2	0.07	4	5.20	0.5042	0.01	0.0230	1.2130	0.0765	-1.0389	1125.5
	3	0.2	8	5.49	0.4152	0.01	0.0128	1.3024	0.0825	-0.8408	1442.3
4	1	0.03	1	5.00	0.4953	0.01	0.0215	1.2249	0.0808	-1.0018	1156.5
	2	0.07	4	5.20	0.4953	0.01	0.0214	1.2233	0.0784	-1.0305	1156.5
	3	0.2	8	5.49	0.4102	0.01	0.0123	1.3058	0.0809	-0.7834	1459.9
6	1	0.03	1	5.00	0.5233	0.01	0.0273	1.1936	0.0741	-1.0424	1060.3
	2	0.07	4	5.20	0.5232	0.01	0.0273	1.1924	0.0719	-1.0674	1060.3
	3	0.2	8	5.49	0.4258	0.01	0.0138	1.2940	0.0853	-0.9403	1404.7
7	1	0.03	1	5.00	0.4735	0.01	0.0184	1.2515	0.0843	-0.9748	1233.2
	2	0.07	4	5.20	0.4735	0.01	0.0183	1.2496	0.0818	-1.0065	1233.2
	3	0.2	8	5.49	0.3980	0.01	0.0111	1.3124	0.0760	-0.6086	1502.8
8	1	0.03	1	5.00	0.5021	0.01	0.0227	1.2169	0.0794	-1.0089	1132.9
	2	0.07	4	5.20	0.5020	0.01	0.0226	1.2154	0.0770	-1.0367	1132.9
	3	0.2	8	5.49	0.4140	0.01	0.0127	1.3032	0.0821	-0.8277	1446.5
9	1	0.03	1	5.00	0.4962	0.01	0.0217	1.2238	0.0807	-1.0028	1153.2
	2	0.07	4	5.20	0.4962	0.01	0.0216	1.2222	0.0782	-1.0314	1153.2
	3	0.2	8	5.49	0.4107	0.01	0.0124	1.3054	0.0810	-0.7899	1458.0
10	1	0.03	1	5.00	0.5077	0.01	0.0238	1.2105	0.0781	-1.0156	1113.5
	2	0.07	4	5.20	0.5076	0.01	0.0237	1.2090	0.0757	-1.0426	1113.5
	3	0.2	8	5.49	0.4171	0.01	0.0130	1.3010	0.0831	-0.8612	1435.4
11	1	0.03	1	5.00	0.5415	0.01	0.0327	1.1764	0.0691	-1.1008	999.8
	2	0.07	4	5.20	0.5414	0.01	0.0328	1.1753	0.0671	-1.1234	999.8
	3	0.2	8	5.49	0.4357	0.01	0.0148	1.2849	0.0872	-1.0098	1369.3
12	1	0.03	1	5.00	0.5203	0.01	0.0266	1.1967	0.0749	-1.0361	1070.2
	2	0.07	4	5.20	0.5203	0.01	0.0265	1.1954	0.0726	-1.0614	1070.2
	3	0.2	8	5.49	0.4242	0.01	0.0137	1.2954	0.0849	-0.9268	1410.5
15	1	0.03	1	5.00	0.4809	0.01	0.0194	1.2424	0.0834	-0.9859	1207.0
	2	0.07	4	5.20	0.4809	0.01	0.0193	1.2406	0.0809	-1.0165	1207.0
	3	0.2	8	5.49	0.4022	0.01	0.0115	1.3104	0.0778	-0.6738	1488.3
16	1	0.03	1	5.00	0.5183	0.01	0.0261	1.1988	0.0754	-1.0321	1077.1
	2	0.07	4	5.20	0.5183	0.01	0.0260	1.1975	0.0732	-1.0577	1077.1
	3	0.2	8	5.49	0.4230	0.01	0.0135	1.2963	0.0847	-0.9171	1414.5
17	1	0.03	1	5.00	0.4949	0.01	0.0215	1.2254	0.0809	-1.0014	1157.9
	2	0.07	4	5.20	0.4949	0.01	0.0214	1.2238	0.0785	-1.0302	1157.9
	3	0.2	8	5.49	0.4100	0.01	0.0123	1.3059	0.0808	-0.7807	1460.7

18	1	0.03	1	5.00	0.4716	0.01	0.0181	1.2539	0.0845	-0.9714	1240.0
	2	0.07	4	5.20	0.4716	0.01	0.0180	1.2520	0.0820	-1.0034	1240.0
	3	0.2	8	5.49	0.3969	0.01	0.0110	1.3129	0.0755	-0.5904	1506.6
19	1	0.03	1	5.00	0.4933	0.01	0.0212	1.2273	0.0813	-0.9998	1163.5
	2	0.07	4	5.20	0.4932	0.01	0.0211	1.2257	0.0788	-1.0287	1163.5
	3	0.2	8	5.49	0.4091	0.01	0.0122	1.3065	0.0805	-0.7693	1463.9
20	1	0.03	1	5.00	0.5096	0.01	0.0242	1.2083	0.0776	-1.0182	1106.7
	2	0.07	4	5.20	0.5096	0.01	0.0241	1.2069	0.0753	-1.0450	1106.7
	3	0.2	8	5.49	0.4182	0.01	0.0131	1.3001	0.0834	-0.8722	1431.6
21	1	0.03	1	5.00	0.5102	0.01	0.0243	1.2077	0.0775	-1.0189	1104.9
	2	0.07	4	5.20	0.5101	0.01	0.0242	1.2063	0.0752	-1.0456	1104.9
	3	0.2	8	5.49	0.4185	0.01	0.0131	1.2999	0.0835	-0.8751	1430.5
22	1	0.03	1	5.00	0.4988	0.01	0.0221	1.2207	0.0801	-1.0055	1144.1
	2	0.07	4	5.20	0.4988	0.01	0.0220	1.2191	0.0777	-1.0337	1144.1
	3	0.2	8	5.49	0.4122	0.01	0.0125	1.3045	0.0815	-0.8072	1452.8
24	1	0.03	1	5.00	0.4865	0.01	0.0201	1.2355	0.0825	-0.9926	1187.3
	2	0.07	4	5.20	0.4865	0.01	0.0201	1.2338	0.0800	-1.0225	1187.3
	3	0.2	8	5.49	0.4053	0.01	0.0118	1.3088	0.0791	-0.7189	1477.3
25	1	0.03	1	5.00	0.5741	0.01	0.0477	1.1534	0.0605	-1.3240	898.0
	2	0.07	4	5.20	0.5740	0.01	0.0479	1.1525	0.0587	-1.3425	898.0
	3	0.2	8	5.49	0.4529	0.01	0.0166	1.2670	0.0886	-1.0867	1308.0
29	1	0.03	1	5.00	0.4990	0.01	0.0221	1.2205	0.0801	-1.0056	1143.7
	2	0.07	4	5.20	0.4989	0.01	0.0221	1.2190	0.0777	-1.0338	1143.7
	3	0.2	8	5.49	0.4123	0.01	0.0125	1.3044	0.0816	-0.8080	1452.6
30	1	0.03	1	5.00	0.5332	0.01	0.0300	1.1839	0.0714	-1.0694	1027.3
	2	0.07	4	5.20	0.5331	0.01	0.0300	1.1828	0.0693	-1.0931	1027.3
	3	0.2	8	5.49	0.4312	0.01	0.0143	1.2892	0.0864	-0.9807	1385.5
31	1	0.03	1	5.00	0.4839	0.01	0.0198	1.2388	0.0829	-0.9896	1196.6
	2	0.07	4	5.20	0.4838	0.01	0.0197	1.2370	0.0804	-1.0198	1196.6
	3	0.2	8	5.49	0.4038	0.01	0.0117	1.3096	0.0785	-0.6982	1482.4

Table 90 Subsoil horizons parameters for soil-type 14

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	4	0.06	2	5.49	0.4180	0.01	0.0135	1.2857	0.2317	-0.7340	1473.4
	5	0.24	5	5.39	0.3836	0.01	0.0093	1.2667	0.1587	-0.3847	1597.1
	6	0.04	1	5.39	0.3836	0.01	0.0093	1.2667	0.1587	-0.3847	1597.1
	7	0.16	4	5.59	0.3733	0.01	0.0065	1.2581	0.1138	-0.0540	1633.4
	8	0.15	3	5.68	0.3828	0.01	0.0127	1.1538	0.1081	-2.3019	1621.7
	9	0.05	1	5.88	0.3979	0.01	0.0216	1.0649	0.0311	-4.3403	1607.2
	10	0.25	4	5.88	0.3979	0.01	0.0216	1.0649	0.0311	-4.3403	1607.2
	11	0.07	7	5.88	0.3979	0.01	0.0216	1.0649	0.0311	-4.3403	1607.2
	12	0.03	3	5.88	0.4000	0.01	0.0131	1.0583	0.0207	-4.0262	1617.9
	13	0.65	8	5.88	0.4000	0.01	0.0131	1.0583	0.0207	-4.0262	1617.9

15/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 15

Table 91 **Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 15**

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.25	10	5.82	0.4230	0.01	0.0287	1.2063	0.2326	-2.6973	1439.5
	2	0.05	2	5.82	0.4218	0.01	0.0264	1.2158	0.2106	-2.4904	1441.0
2	1	0.25	10	5.82	0.4675	0.01	0.0330	1.1820	0.2540	-2.6571	1279.1
	2	0.05	2	5.82	0.4663	0.01	0.0308	1.1899	0.2298	-2.4913	1281.1
3	1	0.25	10	5.82	0.4405	0.01	0.0305	1.1986	0.2460	-2.7249	1376.8
	2	0.05	2	5.82	0.4393	0.01	0.0282	1.2075	0.2227	-2.5346	1378.5
4	1	0.25	10	5.82	0.4348	0.01	0.0300	1.2014	0.2424	-2.7234	1397.4
	2	0.05	2	5.82	0.4336	0.01	0.0276	1.2106	0.2194	-2.5277	1399.0
5	1	0.25	10	5.82	0.4313	0.01	0.0296	1.2030	0.2398	-2.7191	1409.8
	2	0.05	2	5.82	0.4301	0.01	0.0273	1.2123	0.2171	-2.5202	1411.3
6	1	0.25	10	5.82	0.4526	0.01	0.0316	1.1918	0.2515	-2.7079	1333.1
	2	0.05	2	5.82	0.4514	0.01	0.0294	1.2002	0.2276	-2.5288	1334.9
7	1	0.25	10	5.82	0.4207	0.01	0.0285	1.2071	0.2303	-2.6882	1447.7
	2	0.05	2	5.82	0.4195	0.01	0.0261	1.2167	0.2086	-2.4790	1449.1
8	1	0.25	10	5.82	0.4391	0.01	0.0304	1.1993	0.2452	-2.7251	1381.8
	2	0.05	2	5.82	0.4379	0.01	0.0281	1.2083	0.2220	-2.5336	1383.5
9	1	0.25	10	5.82	0.4354	0.01	0.0300	1.2011	0.2428	-2.7238	1395.2
	2	0.05	2	5.82	0.4342	0.01	0.0277	1.2103	0.2198	-2.5288	1396.8
10	1	0.25	10	5.82	0.4427	0.01	0.0307	1.1974	0.2473	-2.7237	1368.8
	2	0.05	2	5.82	0.4415	0.01	0.0284	1.2063	0.2238	-2.5355	1370.6
11	1	0.25	10	5.82	0.4640	0.01	0.0327	1.1845	0.2538	-2.6716	1291.9
	2	0.05	2	5.82	0.4628	0.01	0.0305	1.1925	0.2297	-2.5027	1293.9
12	1	0.25	10	5.82	0.4508	0.01	0.0315	1.1929	0.2509	-2.7121	1339.8
	2	0.05	2	5.82	0.4495	0.01	0.0292	1.2014	0.2270	-2.5313	1341.6
13	1	0.25	10	5.82	0.4456	0.01	0.0310	1.1959	0.2487	-2.7208	1358.5
	2	0.05	2	5.82	0.4444	0.01	0.0287	1.2046	0.2251	-2.5353	1360.3
14	1	0.25	10	5.82	0.4317	0.01	0.0297	1.2028	0.2401	-2.7197	1408.4
	2	0.05	2	5.82	0.4305	0.01	0.0273	1.2121	0.2174	-2.5212	1410.0
16	1	0.25	10	5.82	0.4495	0.01	0.0313	1.1936	0.2504	-2.7147	1344.5
	2	0.05	2	5.82	0.4483	0.01	0.0291	1.2022	0.2266	-2.5327	1346.3
17	1	0.25	10	5.82	0.4345	0.01	0.0299	1.2015	0.2422	-2.7231	1398.3
	2	0.05	2	5.82	0.4333	0.01	0.0276	1.2107	0.2193	-2.5273	1399.9
18	1	0.25	10	5.82	0.4194	0.01	0.0283	1.2075	0.2291	-2.6826	1452.2
	2	0.05	2	5.82	0.4182	0.01	0.0260	1.2171	0.2074	-2.4722	1453.6
19	1	0.25	10	5.82	0.4335	0.01	0.0298	1.2020	0.2414	-2.7221	1402.0
	2	0.05	2	5.82	0.4323	0.01	0.0275	1.2112	0.2186	-2.5252	1403.7
20	1	0.25	10	5.82	0.4440	0.01	0.0308	1.1968	0.2479	-2.7226	1364.3
	2	0.05	2	5.82	0.4428	0.01	0.0285	1.2056	0.2244	-2.5356	1366.1
21	1	0.25	10	5.82	0.4443	0.01	0.0309	1.1966	0.2481	-2.7223	1363.1
	2	0.05	2	5.82	0.4431	0.01	0.0286	1.2054	0.2245	-2.5356	1364.9
22	1	0.25	10	5.82	0.4371	0.01	0.0302	1.2003	0.2439	-2.7248	1389.2
	2	0.05	2	5.82	0.4358	0.01	0.0279	1.2094	0.2208	-2.5313	1390.8

23	1	0.25	10	5.82	0.4291	0.01	0.0294	1.2039	0.2381	-2.7151	1417.5
	2	0.05	2	5.82	0.4279	0.01	0.0270	1.2133	0.2156	-2.5141	1419.1
24	1	0.25	10	5.82	0.4291	0.01	0.0294	1.2039	0.2380	-2.7149	1417.7
	2	0.05	2	5.82	0.4279	0.01	0.0270	1.2133	0.2155	-2.5139	1419.3
25	1	0.25	10	5.82	0.4835	0.01	0.0346	1.1706	0.2521	-2.5769	1221.0
	2	0.05	2	5.82	0.4823	0.01	0.0325	1.1778	0.2279	-2.4251	1223.3
26	1	0.25	10	5.82	0.4415	0.01	0.0306	1.1981	0.2466	-2.7244	1373.1
	2	0.05	2	5.82	0.4403	0.01	0.0283	1.2070	0.2232	-2.5351	1374.8
28	1	0.25	10	5.82	0.4136	0.01	0.0277	1.2091	0.2227	-2.6509	1472.6
	2	0.05	2	5.82	0.4125	0.01	0.0253	1.2189	0.2018	-2.4348	1474.0
29	1	0.25	10	5.82	0.4371	0.01	0.0302	1.2003	0.2440	-2.7248	1388.9
	2	0.05	2	5.82	0.4359	0.01	0.0279	1.2094	0.2209	-2.5314	1390.6
30	1	0.25	10	5.82	0.4588	0.01	0.0322	1.1879	0.2531	-2.6903	1310.7
	2	0.05	2	5.82	0.4576	0.01	0.0300	1.1961	0.2290	-2.5167	1312.6
31	1	0.25	10	5.82	0.4274	0.01	0.0292	1.2046	0.2366	-2.7110	1423.8
	2	0.05	2	5.82	0.4262	0.01	0.0269	1.2140	0.2142	-2.5083	1425.3

Table 92 Subsoil horizons parameters for soil-type 15

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.05	2	5.82	0.4374	0.01	0.0291	1.1867	0.2547	-2.5176	1414.8
	4	0.13	5	6.11	0.4062	0.01	0.0209	1.2070	0.2143	-1.9971	1524.6
	5	0.12	2	6.21	0.3863	0.01	0.0209	1.1958	0.1793	-1.8729	1594.2
	6	0.4	8	6.21	0.3863	0.01	0.0209	1.1958	0.1793	-1.8729	1594.2
	7	0.05	1	6.21	0.3769	0.01	0.0202	1.1759	0.1445	-1.9340	1629.8
	8	0.1	10	6.21	0.3769	0.01	0.0202	1.1759	0.1445	-1.9340	1629.8
	9	0.85	10	6.21	0.3769	0.01	0.0202	1.1759	0.1445	-1.9340	1629.8

16/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 16

Table 93: **Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 16**

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
1	1	0.3	12	7.58	0.4275	0.01	0.0191	1.1520	0.1090	-3.4946	1446.9
10	1	0.3	12	7.58	0.4467	0.01	0.0213	1.1486	0.1176	-3.4153	1377.6
12	1	0.3	12	7.58	0.4546	0.01	0.0222	1.1465	0.1201	-3.3609	1349.1
13	1	0.3	12	7.58	0.4495	0.01	0.0217	1.1479	0.1186	-3.3972	1367.4
18	1	0.3	12	7.58	0.4240	0.01	0.0187	1.1523	0.1071	-3.4992	1459.3
20	1	0.3	12	7.58	0.4480	0.01	0.0215	1.1483	0.1180	-3.4076	1373.1

Table 94 **Subsoil horizons parameters for soil-type 16**

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	2	0.2	8	7.97	0.4113	0.01	0.0211	1.1312	0.1328	-3.3849	1530.7
	3	0.1	10	7.97	0.4113	0.01	0.0211	1.1312	0.1328	-3.3849	1530.7
	4	0.4	8	7.97	0.4113	0.01	0.0211	1.1312	0.1328	-3.3849	1530.7
	5	1	10	7.97	0.4113	0.01	0.0211	1.1312	0.1328	-3.3849	1530.7

17/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 17

Table 95 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 17

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
4	1	0.08	4	7.47	0.4527	0.01	0.0207	1.1521	0.1056	-3.2587	1352.0
	2	0.2	8	7.57	0.4514	0.01	0.0206	1.1507	0.1058	-3.2988	1357.7
	3	0.02	1	7.76	0.4230	0.01	0.0272	1.1544	0.1885	-3.6235	1461.9
9	1	0.08	4	7.47	0.4533	0.01	0.0208	1.1519	0.1057	-3.2542	1349.6
	2	0.2	8	7.57	0.4521	0.01	0.0207	1.1505	0.1059	-3.2944	1355.3
	3	0.02	1	7.76	0.4235	0.01	0.0273	1.1544	0.1890	-3.6233	1460.0
10	1	0.08	4	7.47	0.4612	0.01	0.0217	1.1491	0.1073	-3.1948	1320.6
	2	0.2	8	7.57	0.4599	0.01	0.0216	1.1479	0.1077	-3.2353	1326.6
	3	0.02	1	7.76	0.4298	0.01	0.0280	1.1536	0.1949	-3.6149	1437.5
12	1	0.08	4	7.47	0.4699	0.01	0.0228	1.1457	0.1084	-3.1190	1288.6
	2	0.2	8	7.57	0.4685	0.01	0.0226	1.1447	0.1089	-3.1599	1295.1
	3	0.02	1	7.76	0.4367	0.01	0.0288	1.1525	0.2007	-3.5942	1412.8
14	1	0.08	4	7.47	0.4493	0.01	0.0203	1.1532	0.1047	-3.2802	1364.1
	2	0.2	8	7.57	0.4481	0.01	0.0202	1.1517	0.1049	-3.3200	1369.7
	3	0.02	1	7.76	0.4204	0.01	0.0269	1.1546	0.1858	-3.6234	1471.2
16	1	0.08	4	7.47	0.4685	0.01	0.0226	1.1463	0.1083	-3.1318	1293.7
	2	0.2	8	7.57	0.4671	0.01	0.0224	1.1452	0.1088	-3.1726	1300.1
	3	0.02	1	7.76	0.4356	0.01	0.0286	1.1527	0.1998	-3.5982	1416.7
17	1	0.08	4	7.47	0.4524	0.01	0.0207	1.1522	0.1055	-3.2606	1353.0
	2	0.2	8	7.57	0.4512	0.01	0.0206	1.1508	0.1057	-3.3006	1358.7
	3	0.02	1	7.76	0.4228	0.01	0.0272	1.1544	0.1882	-3.6236	1462.6
19	1	0.08	4	7.47	0.4512	0.01	0.0205	1.1526	0.1052	-3.2681	1357.1
	2	0.2	8	7.57	0.4500	0.01	0.0204	1.1511	0.1054	-3.3080	1362.8
	3	0.02	1	7.76	0.4219	0.01	0.0271	1.1545	0.1873	-3.6237	1465.8
22	1	0.08	4	7.47	0.4551	0.01	0.0210	1.1513	0.1062	-3.2415	1343.0
	2	0.2	8	7.57	0.4539	0.01	0.0209	1.1500	0.1064	-3.2818	1348.8
	3	0.02	1	7.76	0.4250	0.01	0.0275	1.1542	0.1904	-3.6223	1454.9
31	1	0.08	4	7.47	0.4446	0.01	0.0198	1.1545	0.1034	-3.3068	1381.1

Table 96 Subsoil horizons parameters for soil-type 17

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	4	0.1	4	7.76	0.4272	0.01	0.0266	1.1253	0.1474	-3.6228	1475.3
	5	0.2	4	7.96	0.3841	0.01	0.0227	1.1670	0.1529	-2.3712	1607.2
	6	0.15	3	7.96	0.3841	0.01	0.0227	1.1670	0.1529	-2.3712	1607.2
	7	0.25	5	8.15	0.3771	0.01	0.0374	1.1321	0.1212	-3.2103	1629.4
	8	0.15	2	8.15	0.3771	0.01	0.0374	1.1321	0.1212	-3.2103	1629.4
	9	0.1	10	8.15	0.3771	0.01	0.0374	1.1321	0.1212	-3.2103	1629.4
	10	0.75	8	8.15	0.3771	0.01	0.0374	1.1321	0.1212	-3.2103	1629.4

18/ SOIL HYDRAULIC PARAMETERIZATION FOR SOIL-TYPE 19

Table 97 Topsoil horizons parameters for the relevant AU/soil combinations (topsoil parameter values differ for each AU due to OC correction) for soil-type 19

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
3	1	0.28	14	5.60	0.4000	0.03	0.0588	1.4259	1.0710	-0.7517	1459.4
	2	0.02	1	6.08	0.3468	0.03	0.0622	1.5050	0.8577	0.7384	1635.8
4	1	0.28	14	5.60	0.3952	0.03	0.0592	1.4309	1.0494	-0.6862	1476.2
	2	0.02	1	6.08	0.3444	0.03	0.0622	1.5032	0.8214	0.8448	1644.2
6	1	0.28	14	5.60	0.4102	0.03	0.0577	1.4138	1.1088	-0.8684	1423.5
	2	0.02	1	6.08	0.3520	0.03	0.0624	1.5073	0.9288	0.5312	1617.9
7	1	0.28	14	5.60	0.3835	0.03	0.0598	1.4411	0.9858	-0.4916	1517.2
	2	0.02	1	6.08	0.3385	0.03	0.0626	1.4963	0.7227	1.1332	1664.4
8	1	0.28	14	5.60	0.3988	0.03	0.0589	1.4272	1.0660	-0.7366	1463.4
	2	0.02	1	6.08	0.3462	0.03	0.0622	1.5046	0.8492	0.7635	1637.9
9	1	0.28	14	5.60	0.3957	0.03	0.0592	1.4304	1.0518	-0.6935	1474.4
	2	0.02	1	6.08	0.3447	0.03	0.0622	1.5034	0.8254	0.8332	1643.3
10	1	0.28	14	5.60	0.4018	0.03	0.0586	1.4238	1.0787	-0.7752	1452.8
	2	0.02	1	6.08	0.3478	0.03	0.0623	1.5056	0.8713	0.6988	1632.6
12	1	0.28	14	5.60	0.4086	0.03	0.0579	1.4158	1.1037	-0.8523	1429.0
	2	0.02	1	6.08	0.3512	0.03	0.0624	1.5071	0.9183	0.5615	1620.7
13	1	0.28	14	5.60	0.4042	0.03	0.0584	1.4211	1.0882	-0.8041	1444.4
	2	0.02	1	6.08	0.3490	0.03	0.0623	1.5062	0.8884	0.6487	1628.4
14	1	0.28	14	5.60	0.3927	0.03	0.0594	1.4334	1.0368	-0.6480	1485.2
	2	0.02	1	6.08	0.3431	0.03	0.0623	1.5020	0.8011	0.9043	1648.6
15	1	0.28	14	5.60	0.3875	0.03	0.0597	1.4380	1.0091	-0.5635	1503.3
	2	0.02	1	6.08	0.3405	0.03	0.0624	1.4991	0.7580	1.0305	1657.6
16	1	0.28	14	5.60	0.4075	0.03	0.0580	1.4171	1.1001	-0.8408	1432.9
	2	0.02	1	6.08	0.3507	0.03	0.0623	1.5069	0.9110	0.5828	1622.6
17	1	0.28	14	5.60	0.3950	0.03	0.0592	1.4311	1.0484	-0.6831	1476.9
	2	0.02	1	6.08	0.3443	0.03	0.0622	1.5031	0.8197	0.8497	1644.6
18	1	0.28	14	5.60	0.3825	0.03	0.0599	1.4418	0.9794	-0.4717	1520.8
	2	0.02	1	6.08	0.3380	0.03	0.0627	1.4954	0.7132	1.1609	1666.2
19	1	0.28	14	5.60	0.3941	0.03	0.0593	1.4320	1.0441	-0.6703	1480.0
	2	0.02	1	6.08	0.3439	0.03	0.0623	1.5027	0.8129	0.8698	1646.1
21	1	0.28	14	5.60	0.4032	0.03	0.0585	1.4223	1.0840	-0.7914	1448.2
	2	0.02	1	6.08	0.3484	0.03	0.0623	1.5059	0.8808	0.6709	1630.3
22	1	0.28	14	5.60	0.3971	0.03	0.0591	1.4290	1.0583	-0.7132	1469.5
	2	0.02	1	6.08	0.3454	0.03	0.0622	1.5040	0.8361	0.8017	1640.9
24	1	0.28	14	5.60	0.3905	0.03	0.0595	1.4354	1.0255	-0.6137	1492.8
	2	0.02	1	6.08	0.3420	0.03	0.0623	1.5009	0.7833	0.9564	1652.4
26	1	0.28	14	5.60	0.4009	0.03	0.0587	1.4250	1.0747	-0.7628	1456.3
	2	0.02	1	6.08	0.3473	0.03	0.0623	1.5053	0.8641	0.7199	1634.3
29	1	0.28	14	5.60	0.3972	0.03	0.0591	1.4289	1.0586	-0.7141	1469.3
	2	0.02	1	6.08	0.3454	0.03	0.0622	1.5040	0.8366	0.8002	1640.8
31	1	0.28	14	5.60	0.3891	0.03	0.0596	1.4366	1.0179	-0.5905	1497.8
	2	0.02	1	6.08	0.3413	0.03	0.0623	1.5001	0.7715	0.9909	1654.8

Table 98 Subsoil horizons parameters for soil-type 19

AU ID	Horizon ID	Horizon Thickness (m)	Numerical layers (-)	pH $CaCl_2$ (-)	Saturated water content (m^3/m^3)	Residual water content (m^3/m^3)	Alpha (1/cm)	n (-)	Saturated conductivity (m/day)	L (-)	Rho (g/cm^3)
all	3	0.08	4	6.08	0.3439	0.03	0.0738	1.4894	0.3690	0.9309	1650.6
	4	0.18	4	6.47	0.3352	0.03	0.0754	1.4938	0.3016	1.5401	1681.3
	5	0.04	1	5.89	0.3231	0.03	0.0852	1.6778	0.5780	1.6328	1681.3
	6	0.3	6	5.89	0.3231	0.03	0.0852	1.6778	0.5780	1.6328	1681.3
	7	0.1	2	6.38	0.3077	0.03	0.1003	1.6560	0.4409	2.2306	1715.6
	8	0.25	5	6.38	0.3077	0.03	0.1003	1.6560	0.4409	2.2306	1715.6
	9	0.1	10	6.38	0.3077	0.03	0.1003	1.6560	0.4409	2.2306	1715.6
	10	0.65	10	6.38	0.3077	0.03	0.1003	1.6560	0.4409	2.2306	1715.6

Appendix 18. Test results for Substance C and its metabolite applied to sugar beet

Table 99 80th percentile concentrations for Substance C and its metabolite applied to sugar beet

AUID	AU	SID	Soil	Area (kha)	Substance C 80th percentile PECgw	Metabolite C 80th percentile PECgw
4	Bordure Nord - Picardie - Normandie	1	Luvisol 3 >80 cm	16926	< 0.001	2.444
5	Alsace - Sundgau	1	Luvisol 3 >80 cm	1345	< 0.001	1.820
6	Plaine normande - Bessin	1	Luvisol 3 >80 cm	3091	< 0.001	1.546
9	Picardie - Nord - Pas-de-Calais	1	Luvisol 3 >80 cm	49381	< 0.001	2.243
16	Champagne crayeuse	1	Luvisol 3 >80 cm	18390	< 0.001	1.244
17	Beauce - Drouais - Gâtinais	1	Luvisol 3 >80 cm	16881	< 0.001	1.309
21	Ardenne - Argonne - Champagne H.	1	Luvisol 3 >80 cm	2556	< 0.001	2.095
31	Ile-de-France	1	Luvisol 3 >80 cm	23046	< 0.001	2.011
3	Limagnes - Plaine du Forez	2	Cambisol 4 >80 cm	1192	< 0.001	1.508
4	Bordure Nord - Picardie - Normandie	2	Cambisol 4 >80 cm	3322	< 0.001	2.817
5	Alsace - Sundgau	2	Cambisol 4 >80 cm	2039	< 0.001	1.914
6	Plaine normande - Bessin	2	Cambisol 4 >80 cm	1206	< 0.001	1.548
9	Picardie - Nord - Pas-de-Calais	2	Cambisol 4 >80 cm	6106	< 0.001	2.335
16	Champagne crayeuse	2	Cambisol 4 >80 cm	4648	< 0.001	1.355
17	Beauce - Drouais - Gâtinais	2	Cambisol 4 >80 cm	4107	< 0.001	1.612
31	Ile-de-France	2	Cambisol 4 >80 cm	6837	< 0.001	2.073
4	Bordure Nord - Picardie - Normandie	3	Rendzine 2 >80 cm	5230	< 0.001	2.944
16	Champagne crayeuse	3	Rendzine 2 >80 cm	18544	< 0.001	1.613
31	Ile-de-France	3	Rendzine 2 >80 cm	7983	< 0.001	2.301
4	Bordure Nord - Picardie - Normandie	6	Rendzine 2 60 cm	8837	< 0.001	4.806
6	Plaine normande - Bessin	6	Rendzine 2 60 cm	1232	< 0.001	4.253
9	Picardie - Nord - Pas-de-Calais	6	Rendzine 2 60 cm	27642	< 0.001	5.268
16	Champagne crayeuse	6	Rendzine 2 60 cm	15093	< 0.001	3.666
17	Beauce - Drouais - Gâtinais	6	Rendzine 2 60 cm	8245	< 0.001	5.314
21	Ardenne - Argonne - Champagne H.	6	Rendzine 2 60 cm	1560	< 0.001	4.236
31	Ile-de-France	6	Rendzine 2 60 cm	15038	< 0.001	5.984
4	Bordure Nord - Picardie - Normandie	8	Fluvisol 2 >80 cm	3313	< 0.001	3.716
5	Alsace - Sundgau	8	Fluvisol 2 >80 cm	1034	< 0.001	2.977
9	Picardie - Nord - Pas-de-Calais	8	Fluvisol 2 >80 cm	6737	< 0.001	3.564
16	Champagne crayeuse	8	Fluvisol 2 >80 cm	3529	< 0.001	2.190
17	Beauce - Drouais - Gâtinais	8	Fluvisol 2 >80 cm	2353	< 0.001	2.755
31	Ile-de-France	8	Fluvisol 2 >80 cm	4499	< 0.001	3.325
4	Bordure Nord - Picardie - Normandie	9	Fluvisol 1 >80 cm	1377	< 0.001	5.313
9	Picardie - Nord - Pas-de-Calais	9	Fluvisol 1 >80 cm	3936	< 0.001	5.387
16	Champagne crayeuse	9	Fluvisol 1 >80 cm	3357	< 0.001	3.893
31	Ile-de-France	9	Fluvisol 1 >80 cm	1807	< 0.001	4.958
4	Bordure Nord - Picardie - Normandie	13	Cambisol 3 >80 cm	3034	< 0.001	2.955
9	Picardie - Nord - Pas-de-Calais	13	Cambisol 3 >80 cm	8563	< 0.001	2.657
16	Champagne crayeuse	13	Cambisol 3 >80 cm	3573	< 0.001	1.380
17	Beauce - Drouais - Gâtinais	13	Cambisol 3 >80 cm	1833	< 0.001	1.657
31	Ile-de-France	13	Cambisol 3 >80 cm	3100	< 0.001	2.471
4	Bordure Nord - Picardie - Normandie	19	Arenosol 1 >80 cm	1863	0.002	6.839
9	Picardie - Nord - Pas-de-Calais	19	Arenosol 1 >80 cm	5692	0.001	8.713
16	Champagne crayeuse	19	Arenosol 1 >80 cm	2466	< 0.001	6.358
17	Beauce - Drouais - Gâtinais	19	Arenosol 1 >80 cm	1655	< 0.001	8.821
31	Ile-de-France	19	Arenosol 1 >80 cm	4238	< 0.001	8.921

Appendix 19. FROGS scenarios presenting a 80th temporal PECgw > 10 µg/L for MetC on Winter wheat

Table 100 FROGS scenarios presenting a 80th temporal PECgw > 10 μg/L for MetC – Winter wheat

AU ID	AU name	Soil ID	Soil name	Area of the scenario (kha)	Crop Rotation	80th temporal PECgw (μg/L)
24	4	Bordure Nord - Picardie - Normandie	6	Rendzine 2 60 cm	50554	WWHEAT-BARLEY-
53	9	Picardie - Nord - Pas-de-Calais	6	Rendzine 2 60 cm	94925	WWHEAT-BARLEY-
105	15	Sologne - Orléanais	6	Rendzine 2 60 cm	4074	WWHEAT-BARLEY-
214	31	Ile-de-France	6	Rendzine 2 60 cm	55893	WWHEAT-BARLEY-
55	9	Picardie - Nord - Pas-de-Calais	9	Fluvisol 1 >80 cm	17033	WWHEAT-BARLEY-
216	31	Ile-de-France	9	Fluvisol 1 >80 cm	7728	WWHEAT-BARLEY-
27	4	Bordure Nord - Picardie - Normandie	12	Podzoluvisol 3 >80 cm	18054	WWHEAT-BARLEY-
56	9	Picardie - Nord - Pas-de-Calais	12	Podzoluvisol 3 >80 cm	17408	WWHEAT-BARLEY-
29	4	Bordure Nord - Picardie - Normandie	19	Arenosol 1 >80 cm	11965	WWHEAT-BARLEY-
58	9	Picardie - Nord - Pas-de-Calais	19	Arenosol 1 >80 cm	20372	WWHEAT-BARLEY-
66	10	Charentes	19	Arenosol 1 >80 cm	2639	WWHEAT-BARLEY-
83	12	Barrois - Plateaux bourguignons	19	Arenosol 1 >80 cm	5356	WWHEAT-WOSR-
91	13	Plateau lorrain	19	Arenosol 1 >80 cm	2112	WWHEAT-WOSR-
101	14	Gâtines - Vallées de Loire	19	Arenosol 1 >80 cm	3924	WWHEAT-BARLEY-
117	16	Champagne crayeuse	19	Arenosol 1 >80 cm	4501	WWHEAT-WOSR-
126	17	Beauce - Drouais - Gâtinais	19	Arenosol 1 >80 cm	9129	WWHEAT-BARLEY-
134	18	Bordelais - Périgord - Coteaux du Lot	19	Arenosol 1 >80 cm	4421	WWHEAT-SUNFL
144	19	Perche - Pays d'Auge - Pays d'Ouche	19	Arenosol 1 >80 cm	3596	WWHEAT-MAIZEF
161	21	Ardenne - Argonne - Champagne H.	19	Arenosol 1 >80 cm	4101	WWHEAT-WOSR-
169	22	Champagne berrichonne - Boischaut	19	Arenosol 1 >80 cm	10110	WWHEAT-BARLEY-
183	24	Fossé bressan	19	Arenosol 1 >80 cm	2036	WWHEAT-WOSR-
196	26	Plateaux de Haute-Saône	19	Arenosol 1 >80 cm	1042	WWHEAT-WOSR-
203	29	Boischaut du sud	19	Arenosol 1 >80 cm	1369	WWHEAT-BARLEY-
219	31	Ile-de-France	19	Arenosol 1 >80 cm	20801	WWHEAT-BARLEY-

Appendix 20. FROGS scenarios presenting a 80th temporal PECgw > 0.1 μg/L for Substance D on Winter wheat

Table 101 FROGS scenarios presenting a 80th temporal PECgw > 0.1 µg/L for Substance D – Winter wheat

AU ID	AU name	Soil ID	Soil name	Area of the scenario (kha)	Crop Rotation	80th temporal PECgw (µg/L)
22	Champagne berrichonne - Boischaut	12	Podzoluvisol 3 >80 cm	19028	WWHEAT-BARLEY-WOSR	0.102
17	Beauce - Drouais - Gâtinais	6	Rendzine 2 60 cm	46086	WWHEAT-BARLEY-WOSR	0.110
4	Bordure Nord - Picardie - Normandie	8	Fluvisol 2 >80 cm	35958	WWHEAT-BARLEY-MAIZEF	0.111
12	Barrois - Plateaux bourguignons	9	Fluvisol 1 >80 cm	15643	WWHEAT-WOSR-BARLEY	0.114
31	Ile-de-France	9	Fluvisol 1 >80 cm	7728	WWHEAT-BARLEY-WOSR	0.120
26	Plateaux de Haute-Saône	4	Luvisol 2 >80 cm	2089	WWHEAT-WOSR-BARLEY	0.129
13	Plateau lorrain	9	Fluvisol 1 >80 cm	8299	WWHEAT-WOSR-BARLEY	0.130
3	Limagnes - Plaine du Forez	19	Arenosol 1 >80 cm	2176	WWHEAT-MAIZEF	0.131
6	Plaine normande - Bessin	6	Rendzine 2 60 cm	1779	WWHEAT-MAIZEF	0.133
19	Perche - Pays d'Auge - Pays d'Ouche	12	Podzoluvisol 3 >80 cm	34363	WWHEAT-MAIZEF	0.142
21	Ardenne - Argonne - Champagne H.	9	Fluvisol 1 >80 cm	11243	WWHEAT-WOSR-BARLEY	0.153
12	Barrois - Plateaux bourguignons	12	Podzoluvisol 3 >80 cm	6272	WWHEAT-WOSR-BARLEY	0.157
16	Champagne crayeuse	6	Rendzine 2 60 cm	37759	WWHEAT-WOSR-BARLEY	0.170
11	Bocage normand	6	Rendzine 2 60 cm	14623	WWHEAT-MAIZEF-BARLEY	0.177
31	Ile-de-France	12	Podzoluvisol 3 >80 cm	35670	WWHEAT-BARLEY-WOSR	0.206
10	Charentes	9	Fluvisol 1 >80 cm	4301	WWHEAT-BARLEY-WOSR	0.220
9	Picardie - Nord - Pas-de-Calais	9	Fluvisol 1 >80 cm	17033	WWHEAT-BARLEY-SBEET	0.220
17	Beauce - Drouais - Gâtinais	19	Arenosol 1 >80 cm	9129	WWHEAT-BARLEY-WOSR	0.291
15	Sologne - Orléanais	6	Rendzine 2 60 cm	4074	WWHEAT-BARLEY-WOSR	0.318
9	Picardie - Nord - Pas-de-Calais	12	Podzoluvisol 3 >80 cm	17408	WWHEAT-BARLEY-SBEET	0.338
29	Boischaut du sud	6	Rendzine 2 60 cm	5506	WWHEAT-BARLEY-WOSR	0.353
22	Champagne berrichonne - Boischaut	6	Rendzine 2 60 cm	8826	WWHEAT-BARLEY-WOSR	0.371
20	Bocages de l'ouest	9	Fluvisol 1 >80 cm	7536	WWHEAT-MAIZEF	0.375
16	Champagne crayeuse	19	Arenosol 1 >80 cm	4501	WWHEAT-WOSR-BARLEY	0.391
6	Plaine normande - Bessin	19	Arenosol 1 >80 cm	1261	WWHEAT-MAIZEF	0.402
1	Collines molassiques - Lauragais	6	Rendzine 2 60 cm	5348	WWHEAT-SUNFL	0.478
20	Bocages de l'ouest	12	Podzoluvisol 3 >80 cm	12772	WWHEAT-MAIZEF	0.479

AU ID	AU name	Soil ID	Soil name	Area of the scenario (kha)	Crop Rotation	80th temporal PECgw (µg/L)
19	Perche - Pays d'Auge - Pays d'Ouche	6	Rendzine 2 60 cm	22415	WWHEAT-MAIZEF	0.483
21	Ardenne - Argonne - Champagne H.	6	Rendzine 2 60 cm	15461	WWHEAT-WOSR-BARLEY	0.485
4	Bordure Nord - Picardie - Normandie	9	Fluvisol 1 >80 cm	11944	WWHEAT-BARLEY-MAIZEF	0.486
12	Barrois - Plateaux bourguignons	6	Rendzine 2 60 cm	18113	WWHEAT-WOSR-BARLEY	0.496
26	Plateaux de Haute-Saône	9	Fluvisol 1 >80 cm	2835	WWHEAT-WOSR-BARLEY	0.523
31	Ile-de-France	6	Rendzine 2 60 cm	55893	WWHEAT-BARLEY-WOSR	0.566
13	Plateau lorrain	6	Rendzine 2 60 cm	14568	WWHEAT-WOSR-BARLEY	0.593
9	Picardie - Nord - Pas-de-Calais	6	Rendzine 2 60 cm	94925	WWHEAT-BARLEY-SBEET	0.600
14	Gâtines - Vallées de Loire	6	Rendzine 2 60 cm	35267	WWHEAT-BARLEY-WOSR	0.633
4	Bordure Nord - Picardie - Normandie	12	Podzoluvisol 3 >80 cm	18054	WWHEAT-BARLEY-MAIZEF	0.636
22	Champagne berrichonne - Boischaut	19	Arenosol 1 >80 cm	10110	WWHEAT-BARLEY-WOSR	0.758
29	Boischaut du sud	19	Arenosol 1 >80 cm	1369	WWHEAT-BARLEY-WOSR	0.764
26	Plateaux de Haute-Saône	12	Podzoluvisol 3 >80 cm	3111	WWHEAT-WOSR-BARLEY	0.811
19	Perche - Pays d'Auge - Pays d'Ouche	19	Arenosol 1 >80 cm	3596	WWHEAT-MAIZEF	0.893
31	Ile-de-France	19	Arenosol 1 >80 cm	20801	WWHEAT-BARLEY-WOSR	0.917
10	Charentes	6	Rendzine 2 60 cm	83428	WWHEAT-BARLEY-WOSR	0.927
21	Ardenne - Argonne - Champagne H.	19	Arenosol 1 >80 cm	4101	WWHEAT-WOSR-BARLEY	0.972
4	Bordure Nord - Picardie - Normandie	6	Rendzine 2 60 cm	50554	WWHEAT-BARLEY-MAIZEF	1.045
20	Bocages de l'ouest	6	Rendzine 2 60 cm	10079	WWHEAT-MAIZEF	1.055
18	Bordelais - Périgord - Coteaux du Lot	6	Rendzine 2 60 cm	14054	WWHEAT-SUNFL	1.061
14	Gâtines - Vallées de Loire	19	Arenosol 1 >80 cm	3924	WWHEAT-BARLEY-WOSR	1.062
9	Picardie - Nord - Pas-de-Calais	19	Arenosol 1 >80 cm	20372	WWHEAT-BARLEY-SBEET	1.116
12	Barrois - Plateaux bourguignons	19	Arenosol 1 >80 cm	5356	WWHEAT-WOSR-BARLEY	1.139
13	Plateau lorrain	19	Arenosol 1 >80 cm	2112	WWHEAT-WOSR-BARLEY	1.165
26	Plateaux de Haute-Saône	6	Rendzine 2 60 cm	5521	WWHEAT-WOSR-BARLEY	1.527
18	Bordelais - Périgord - Coteaux du Lot	19	Arenosol 1 >80 cm	4421	WWHEAT-SUNFL	1.569
10	Charentes	19	Arenosol 1 >80 cm	2639	WWHEAT-BARLEY-WOSR	1.653
24	Fossé bressan	19	Arenosol 1 >80 cm	2036	WWHEAT-WOSR-BARLEY	1.656
4	Bordure Nord - Picardie - Normandie	19	Arenosol 1 >80 cm	11965	WWHEAT-BARLEY-MAIZEF	1.797
26	Plateaux de Haute-Saône	19	Arenosol 1 >80 cm	1042	WWHEAT-WOSR-BARLEY	3.057

Appendix 21. Calculation of Available Water Capacity

Calculation of Available Water Capacity

Conceptually the available water capacity (AWC) is the amount of water accessible to a crop. This is determined by the storage properties of the soil which are closely related to texture and the root depth. As a convention the root depth is assumed to reach down to 1 m unless the profile is not developed down to this depth or there are other restrictions to root growth (e.g. stagnant water, massive soil layers). For the soils considered here the profile depth is exclusively used as potential restriction to root growth.

Available water in a certain soil layer of thickness Δz is defined as the difference between the water content Θ_F at field capacity (pF = 2) and the water content Θ_{WP} at the wilting point (pF = 4.2) multiplied by Δz, as can be calculated using the hydraulic parameters (see Appendix 17) and the water retention function of Van Genuchten [1980][12] which is implemented in PEARL. The total available water AWC is the sum for n layers representing the root depth z_r as

$$AWC = \sum_n^{i=1} \left(\theta_{F\,i} - \theta_{WP\,i} \right) \Delta z_i, \qquad \sum_n^{i=1} \Delta z_i = z_r$$

were z_r = 1 m or the development depth of the soil profile if smaller than 1 m.

[12] Van Genuchten, M. T. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of American Journal 44: 892 - 898.