Towards climate-smart sustainable management of agricultural soils

SCALE

Managing Sediment Connectivity in Agricultural Landscapes for reducing water Erosion impacts

Deliverable WP1-D1

Report on parameterisation of connectivity and mitigation strategies in the frequently-used soil erosion models

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Abstract

This report provides an overview of the current soil erosion and sediment transport model applications in European countries at various spatiotemporal scales. The analysis was performed on the basis of survey responses from 46 soil erosion model users across 18 European countries. The most widely used model type among the respondents was the Universal Soil Loss Equation and its other versions. About two-thirds of the model applications were used by an authority for soil erosion risk assessment or implementation of mitigation measures. The analysis highlighted the use of different parameters, also between models of the same type, and the prevalence towards use of national or regional datasets. Although the majority of modellers stated to include one or more of the proposed connectivity elements in their modelling procedure, detailed modelling of sediment connectivity was only focused on in a few model applications.

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1 Introduction

This report is compiling the analysis performed within Work Package 1 and Task 1 (WP1-T1) of the SCALE project (Managing Sediment Connectivity in Agricultural Landscapes for reducing water Erosion impacts) under the European Joint Programme EJP SOIL.

Existing, detailed knowledge on the variety of soil erosion and sediment transport models at European level is sparse or does not reflect the different agricultural environments. The aim of the report is to collect systematic information on the variety of the frequent soil erosion modelling applications and their policy relevance in European countries. Moreover, this study aims at gathering information on the diversity of modelling approaches regarding their use of datasets and parameterisation. Finally, we assess the computational implementation of both connectivity elements and soil erosion mitigation measures, which are presumed to be rather diverse within Europe and are thus of particular interest.

The report focuses on answering these following questions:

- Which soil erosion and sediment transport models are used in Europe to assess the risk of soil erosion and the effect of mitigation measures?
- Which parameters are included in the models and which datasets are being used to estimate, calibrate and validate these parameters?
- How are connectivity elements and mitigation measures integrated or applied in the used models?

By answering these questions, this report aims to give an overview of the current use of policy relevant erosion models in European countries at different spatiotemporal scales. The analysis will highlight differences and similarities between model types, at different scales of model use and the application of datasets and parameterisation within the diverse agricultural landscapes of Europe.

The report should serve as a basis for further work within the SCALE project on how to 1) harmonise the use of datasets and parameterisation in soil erosion models, 2) improve modelling approaches across scales and 3) implement connectivity elements and erosion control measures in mitigation scenarios.

2 Methodology and data source

2.1 Data collection

The information for this report was gathered by use of a questionnaire sent out to contacts dealing with erosion modelling throughout Europe. It was attempted to cover all European countries and also regions when approaches differ between regions in a country. Respondents were approached by the SCALE project partners and asked to fill out the questionnaire for the model applied in their country/region. Approached possible respondents included consultants, researchers and officers of a federal or regional authority dealing with soil erosion.

The questionnaire was available online via a survey system, however some respondents also filled out the Excel version of the questionnaire. The online and the Excel versions were identical. For exact questions please see Supplement A.

The questionnaire was composed of four parts:

1. Respondent info (name, institution, country/region, email)
2. Model use - consisted of 5 questions:
   i. Is the model and its results used by an authority for assessment of soil erosion risk or the implementation of mitigation measures? (Yes/No)
      a. If yes: Which authority is using the model results and what is the purpose of the model? Please describe the use of the model within the implementation of regulations or policy.
      b. If no: Who is the end-user of the model results and what is the purpose of the model?
   ii. Please give any references you have that describe the particular use of your specific model application.
   iii. Which model is used? (Choice between 7 different models – specific questions to models using a USLE version, WaTEM/SEDEM, MMF and Other – questions directed at process-based models)
   iv. Please specify the model version used.

3. Model description specific to the chosen model – consisted of four thematic groups:
   i. Model description – Climate data
   ii. Model description – Soil data
   iii. Model description – Topography data
   iv. Model description – Land use and management data

4. Model description common for all models – consisted of seven thematic groups:
   i. Model description – Other data
   ii. Model description – Output data
   iii. Connectivity elements
   iv. Mitigation measures
   v. Calibration
   vi. Validation
   vii. Model user experience

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The questions could be answered in two ways. Some questions could be answered by checking multiple choice options, where one option was always "Other – please specify". The rest of the questions could be answered with freely written answers. It was possible to check several answers in most questions, thereby giving multiple answers per model application. This meant that the total number of answers per question may be larger than the 46 model applications. Thus, percentages were given as number of responses for a specific answer per total number of answers (not per model application/response).

2.2 Method of analysis

All responses to the questionnaire were looked through for completeness. Only fully completed questionnaires describing the use of model applications were used in the analysis. Data were analysed based on all given responses. For questions, which gave the possibility to check several given answer boxes, the percentages are not per model application, but per total number of checked answers. Model applications were organised according to two categories, to see if there were any trends based on these categories:

Model groups:

- Group 1: USLE and all its versions (USLE, RUSLE, RUSLE2, other USLE version).
- Group 2: Models based on or with USLE elements (WaTEM/SEDEM, SWAT, Epic-Grid, VEMALA, MCST-C).
- Group 3: Process-based models, expert judgment/decision tree models and qualitative models (EROSION 3D, MMF, (Open)LISEM, PESERA, FLUSH, WaterSed, MESALES, qualitative model).

Scale at which the model was applied (the precise scale was not specified):

- National scale
- Regional scale
- Catchment scale
- Plot/field scale

2.3 Data harmonisation

In some cases, it was necessary to categorise data in new groups in order to better analyse the data. These cases included:

- In cases, where data/answers were compiled into new categories in order to better classify them e.g. "Other" answers were added to a "None" category.
- In cases, where "Other" was chosen as response, but the description in the elaboration field suggested it could be added to one of the already given categories.

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3 Results

3.1 Analysis of model use

All together 46 usable responses from 18 countries in Europe were received (Table 1). Furthermore, two model applications on a higher spatial scale than national level were received, but these were not included in the general analysis.

Table 1. Number of responses and the described models per country.

Country	Responses	Models
Austria	1	MMF
Belgium	4	RUSLE, WaTEM/SEDEM, Epic-Grid
Czechia	2	USLE, WaTEM/SEDEM
Denmark	1	WaTEM/SEDEM
Finland	4	RUSLE, VEMALA, SWAT, FLUSH
France	5	MESALES, OpenLISEM, WaterSed
Germany	7	USLE, RUSLE, Other USLE version, EROSION 3D, MCST-C
Hungary	3	USLE, LISEM, SWAT+
Italy	4	RUSLE, Other USLE version
Latvia	1	RUSLE
Luxembourg	1	RUSLE
Netherlands	1	LISEM
Norway	1	PESERA
Poland	1	Qualitative model
Portugal	4	MMF, PESERA, RUSLE
Slovenia	1	RUSLE
Spain	3	RUSLE, RUSLE2
Switzerland	2	RUSLE

Twenty-three model applications (50 %) used an USLE version (**Figure 1**). The other models were a mix of models based on or with USLE elements, process-based models, expert judgment/decision tree models and qualitative models. Of the other model applications, the most reported were versions of LISEM (4), WaTEM/SEDEM (3) and PESERA (3).

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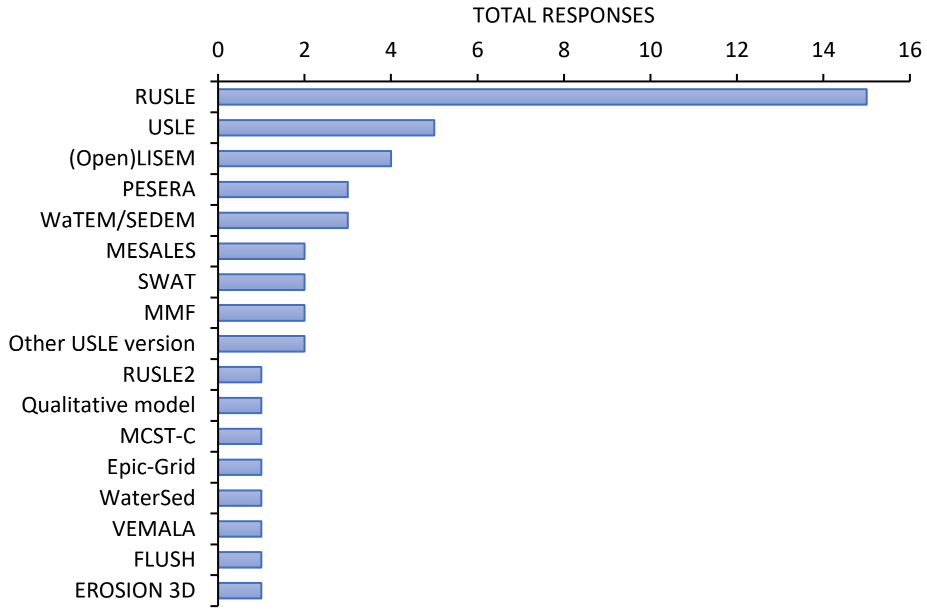

Figure 1. Models used by respondents.

On the question whether the model application was used by an authority or not, 31 responded yes (67 %), while 15 responded no (33 %). When looking at the model applications according to model group or scale of model application (**Figure 2**), the model applications in group 1 and 3 were mainly used by authorities, while the model applications in Group 2 were less used by authorities. For those model applications in Group 1 and 3 used by an authority, the distribution between federal and regional authorities was similar with a majority of regional authorities, while for group 2 it was 50/50. Model applications at national and regional scale were predominantly used by authorities for risk assessment or mitigation measure implementation. At catchment scale most of the model applications were still used by an authority, but at plot/field scale they were not at all used by an authority, as these applications were mostly research related.
The model applications ranged from use as risk assessment of soil erosion for use in CAP measures, to implementation of mitigation measures at local level, to research tools.

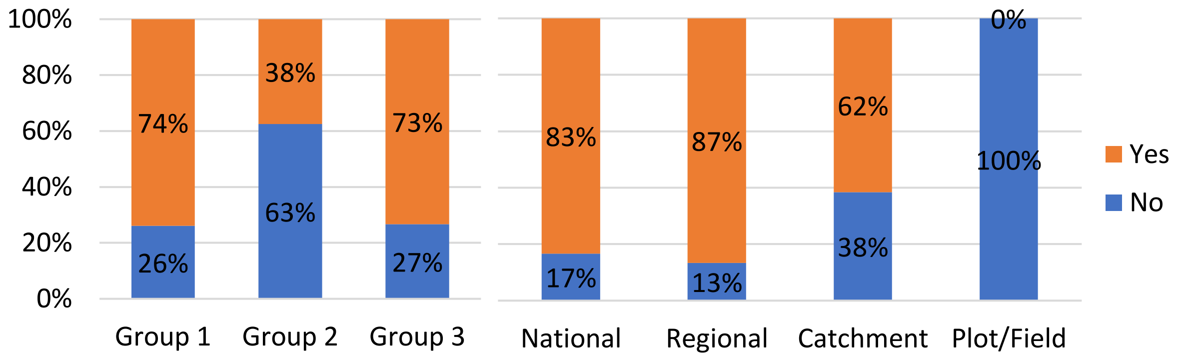

Figure 2. Model application used by an authority according to model group and scale of model application.

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As **Figure 3** shows, model application at national, regional and plot scale were mostly using the USLE and its other versions, whereas modelling applications at catchment scale made use of other models – rather process based ones.

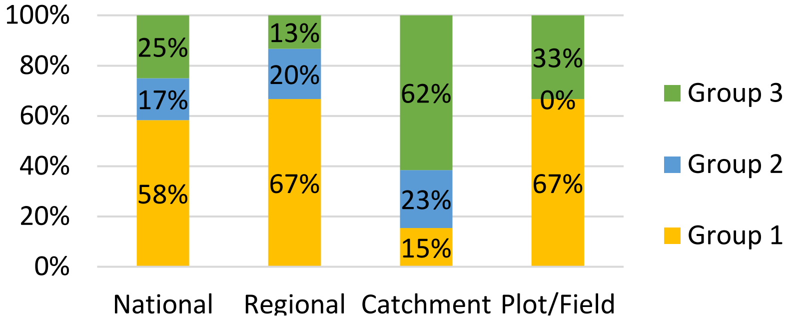

Figure 3. Model application at different scales.

Other models were reported as being used at national scale in: Denmark (WaTEM/SEDEM), Finland (VEMALA –in relation to WFD, and RUSLE for other erosion measures), Norway (PESERA), Poland (qualitative model) and Portugal (MMF).
At regional scale other models were used in: Belgium/Flanders (WaTEM/SEDEM), Belgium/Wallonia (Epic-Grid), Czechia (WaTEM/SEDEM), Germany/Thuringia (Erosion 3D), and France (MESALES).

3.2 Analysis of datasets and parameters

The description of datasets and parameters were divided in four key thematic groups: (1) climate data, (2) soil data, (3) topography data and (4) land use and management data. Further, questions to other data and model output were posed. In the following sections, all questions and answers are listed for each group, as graphs of the answers with multiple choice and descriptions of the written answers. Questions which were only posed to one specific model application have been placed in the Appendix.

3.2.1 Climate data

- Please specify the source of rainfall data.
  The sources of rainfall data were mostly national meteorological institutes, but also a few rain gauge data sources and literature values were mentioned.

- Which type of rainfall input data is used?
  Most model applications used point data as rainfall input data (**Figure 4**). Ten respondents checked both point and grid data as used rainfall input data in their model application.

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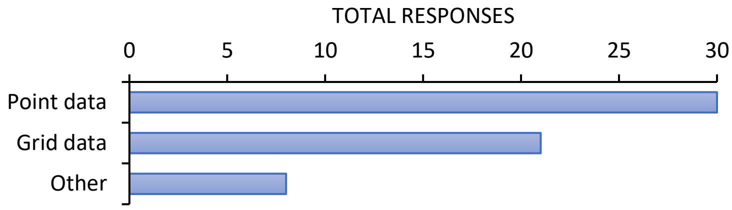

Figure 4. Type of rainfall input data used in model application.

There was no great difference in rainfall input data between model groups (**Figure 5**). Grid data was used more in national and regional scale applications, whereas point data was used more at catchment and plot/field-scale.

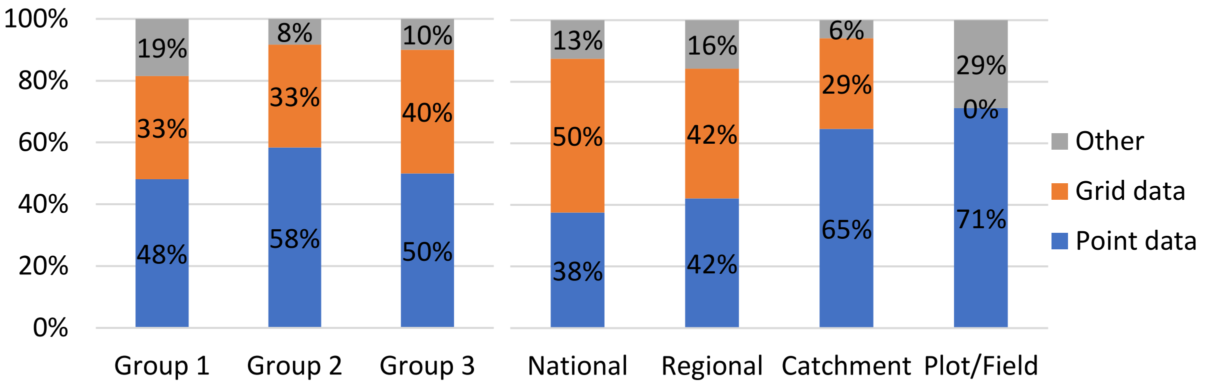

Figure 5. Type of rainfall input data used in each model group and according to the model application scale.

- <u>Please specify the spatial resolution of the rainfall input data.</u>
  The spatial resolution of rainfall input data varied greatly between model applications. Some used point data with a certain number of stations per area, others used grid data in a certain resolution likely derived from a spatialization of point data. Please see Supplement B for exact answers.

- <u>What is the temporal resolution of the rainfall input data?</u>
  The most used temporal resolution of rainfall data was sub-hourly data followed by daily and hourly data (**Figure 6**). Seasonal data were not used at all.

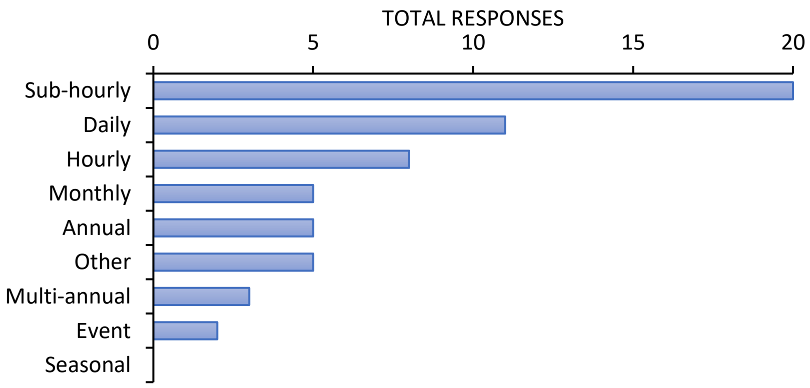

Figure 6. The distribution of total given responses to the temporal resolution of rainfall input data.

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Sub-hourly data was one of the most used data sources, especially for group 3. Group 2 used a majority of daily data. Sub-hourly data had the highest percentage use for all but plot scale applications, where hourly and multi-annual were stated to be equally often applied (**Figure 7**).

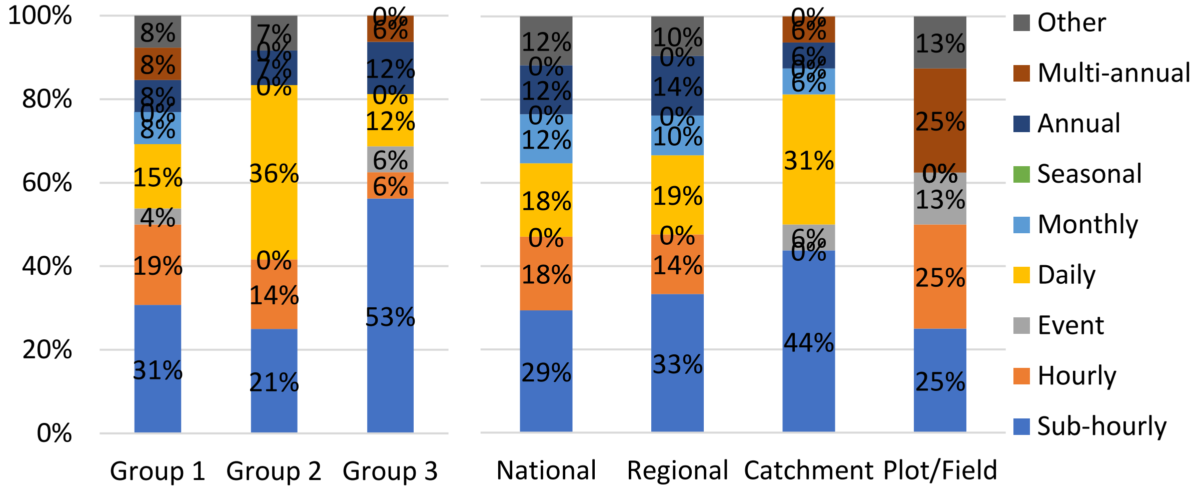

Figure 7. Temporal resolution of rainfall input data per model group and per model application scale.

- Please specify the temporal resolution, if you chose "Sub-hourly" or "Other".
  Twenty of the 46 model applications used sub-hourly rainfall data. Out of all sub-hourly applications the most used time step was 5 and 10 min (both with 30 % of answers) (**Figure 8**).

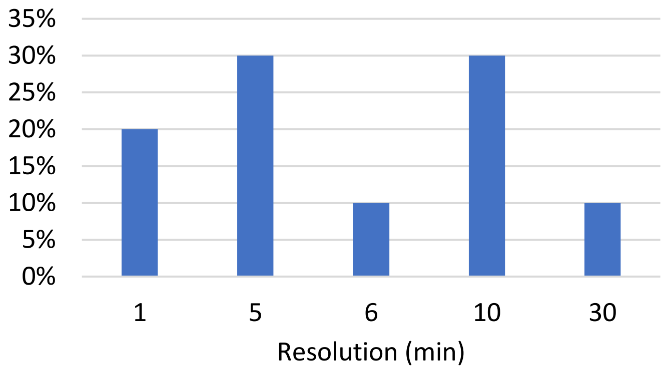

Figure 8. The distribution of sub-hourly rainfall data resolution used by the model applications stating to use sub-hourly rainfall input data.

- Please describe the exact method used to derive the R-factor?
  The calculation of the rainfall parameter or R-factor was done with a wide range of methods ranging from using a fixed value for the entire area to national/regional R-factor maps produced for each area based on rainfall station or radar data, to using the European R-factor map by the Joint Research Centre. Different KE-I equations were used. In Czechia (400 MJ) and Belgium/Flanders (880/1250 MJ) a fixed R-factor value was still used for some modelling applications. All other seemed to have some sort of spatially variable R-factor grid/map.

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- What is the spatial resolution of the final applied R-factor?
  This was not specified by 14 respondents. The most given answer (9) was 1x1 km. The other models applied R-factors of resolutions ranging from 2x2 m to 1:100000.

- Which other climate parameters are included in the model? *Only "Other models"*
  The model applications which included other climate data than rainfall, mostly stated temperature, wind speed and global radiation as the other climate data needed for the model (**Figure 9**).

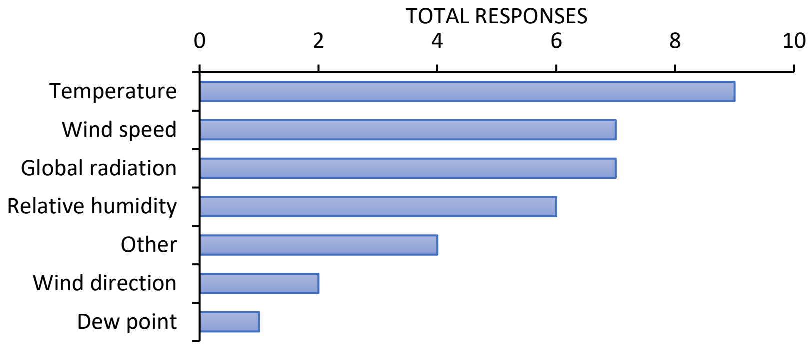

Figure 9. Other climate parameters included in "Other models".

- What is the spatial resolution of the climate input data? *Only "Other models"*
  The majority of other climate input data was from point data (**Figure 10**).

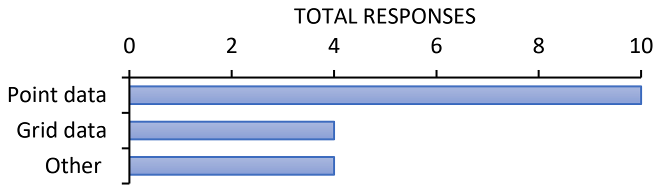

Figure 10. Spatial resolution of other climate input data for "Other models".

- Please specify how each climate parameter is derived and what data are used for the parameterisation. *Only "Other models"*
  Other climate data was mostly from local measurements. A few answered from satellite data or a climate model.

- What is the spatial resolution of the final applied climate parameters? *Only "Other models"*
  Ranged from point data to grids between 1 km and 5 km.

3.2.2 Soil data

- Please specify the data source of soil data.
  Most soil data were stated as being from a regional/national database, followed by "Other", which contained mostly field measurements and local soil surveys (**Figure 11**).

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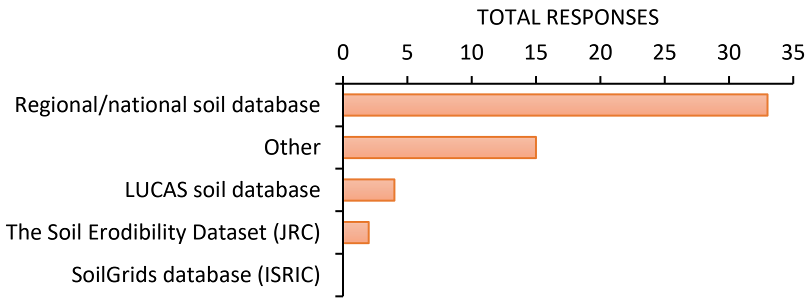

Figure 11. Soil data source.

National, regional and catchment scale applications mostly used a regional/national database for the soil data (**Figure 12**). Plot/field-scale applications of course used in situ data (other).

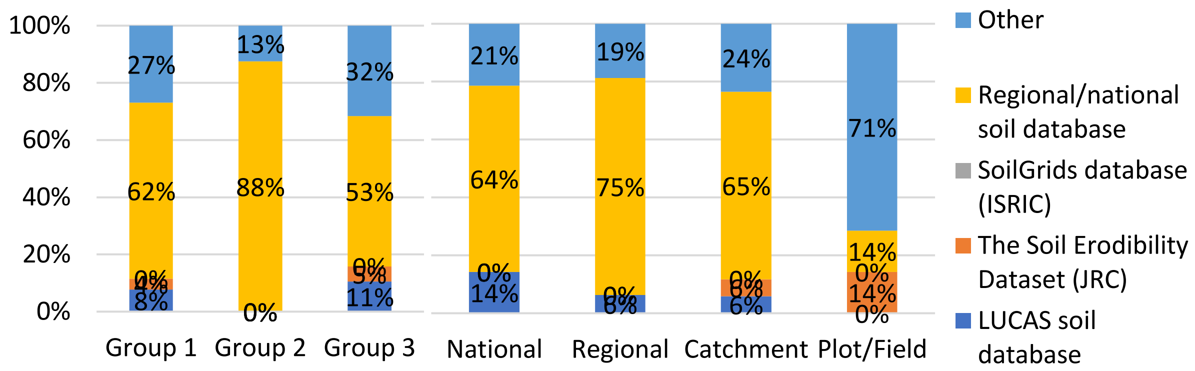

Figure 12. Soil data source per model group and per model application scale.

- <u>Please specify, whether the used soil data is a grid or vector map and state the spatial resolution/scale.</u>
  A mix of grid and vector soil maps of different resolution were used. Some vector soil maps were converted in to raster data containing soil information or K-factors. Please see Supplement B for exact answers.

- <u>Which soil parameters are included in the model?</u>
  Responses given on which soil parameters are used in the model applications, were as seen from **Figure 13**. The most stated parameter was organic matter content followed by the silt, sand and clay content. The "Other" answers were elaborations of the given answers or included more parameters such as the presence of volcanic soils, geometric mean particle size, hydraulic roughness, erosional resistance, adaption of infiltration rate, soil water storage capacity, soil depth, and soil crusting class.
  The possible choices differed between model applications (see Supplement A), so depending on the choice of model at the start of the survey, the possible choices differed.

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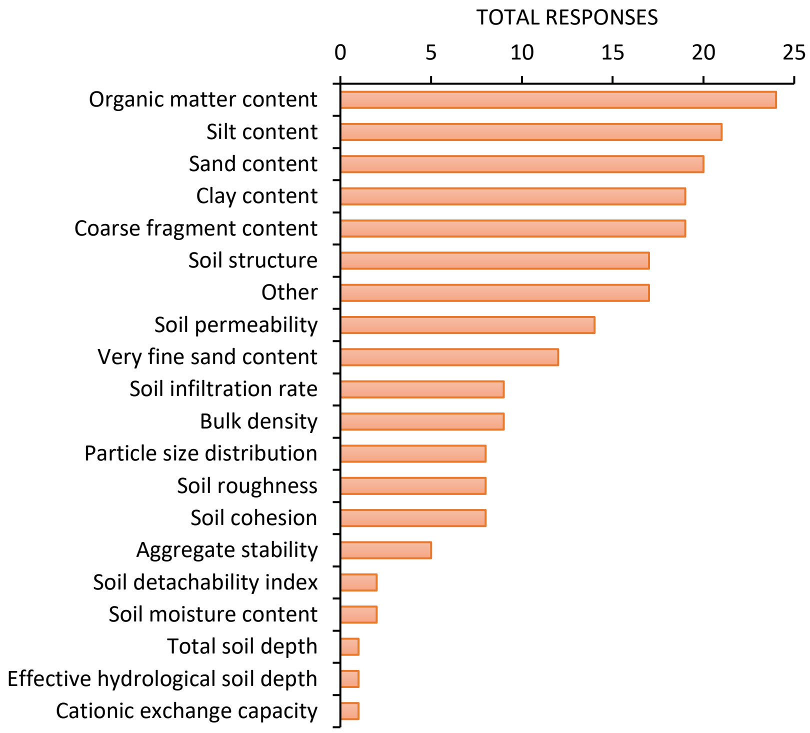

Figure 13. Soil parameters included in the model applications.

- <u>Please specify how each soil parameter is derived and what data are used for the parameterisation.</u>
  Soil parameters were stated as derived from pedotransfer functions, from expert-based method, literature values, directly assessed from measured field data or from soil (polygon) maps. These methods were also sometimes combined within one model application.

- <u>Please describe the method used to model the soil processes. *Only "Other models"*</u>
  See Supplement B for exact answers.

- <u>Which of these methods is used to derive the K-factor? *Only (R)USLE and WaTEM/SEDEM*</u>
  Most answers were given as "Other" (**Figure 14**) and included according to literature values, the norm DIN 19708 (Germany, Switzerland), formula by Bazzoffi (2007), and Declercq, F. & Poesen, J. (1992), etc.

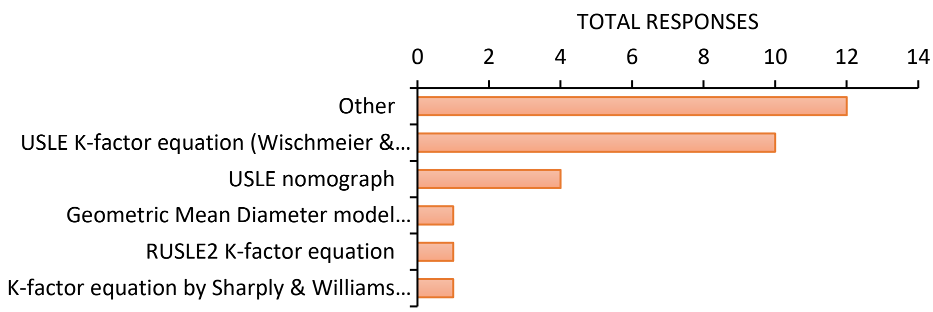

Figure 14. Methods used to derive the K-factor.

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- <u>Please describe the exact method used to derive the K-factor. *Only (R)USLE and WaTEM/SEDEM*</u>
  The methods used were as stated in the above question, plus additional equations with specific parameters and factors. See Supplement B for exact answers.

3.2.3 Topography data

- <u>Which topography parameters are included in the model?</u>
  The main topography parameter included in the model applications was slope gradient (**Figure 15**). This also applied for each model group and application scale (**Figure 16**).

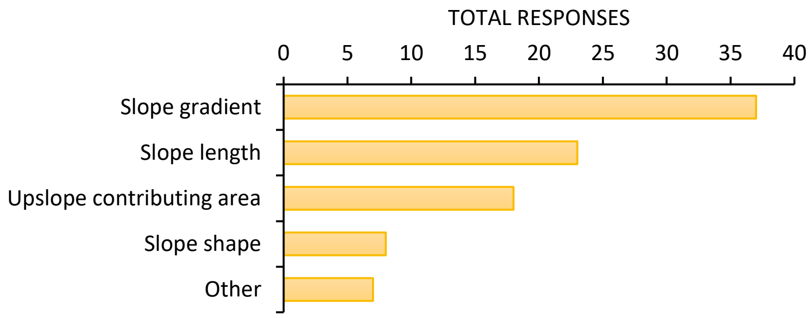

Figure 15. Topography parameters included in the model according to total responses.

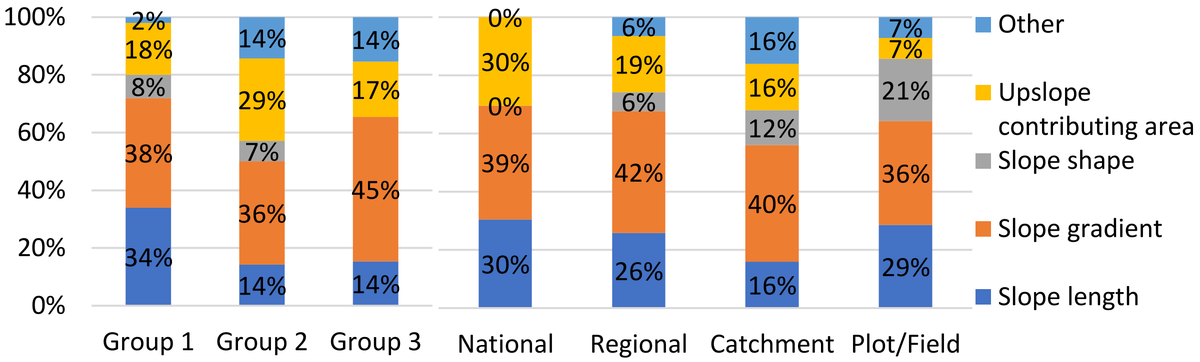

Figure 16. Topography parameters included per model group and per model application scale.

- <u>Please specify DEM resolution and source.</u>
  DEM resolution varied from 1 m to 250 m, with most applications using 5 m and 10 m resolutions (**Figure 17**), and 3 responses stating more than one option of resolution. The number of NA represents the field/plot scale model applications, which do not use a DEM.

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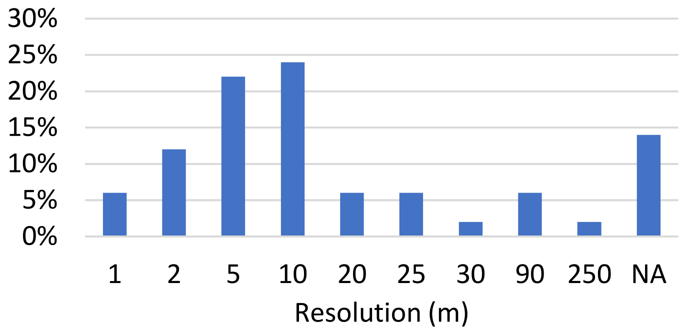

Figure 17. DEM resolution used in the model applications.

- Is correction/filling of the DEM applied? If yes, please state which method and its reference.
  Fifty percent of model applications made use of a filling of the DEM via various methods (26 % No, 24 % NA). For exact methods, see the Supplement B.

- Which flow direction algorithm is used? Please state algorithm name, abbreviation and reference.
  A variety of single and multiple flow direction algorithms were used. For exact methods, see Supplement B.

- Is flow direction affected by tillage direction and oriented roughness? If yes, which method is used to model this?
  The majority of model applications (93%) did not consider the influence of tillage direction and oriented roughness on flow direction. The 3 model applications, that stated to consider tillage direction and oriented roughness all worked at the catchment scale and applied models in group 2 or 3. Some respondents answered that such a function could be activated or was already present in the model, but not used due to lack of data.

- Please specify how each topography parameter is derived, what data are used for the parameterisation and how the topograhy is modelled. *Only "Other models"*
  Through the DEM, calculation of topography parameters by different formulas.

- Please specify which method is used to calculate the L-factor. *Only (R)USLE and WaTEM/SEDEM*
  The L-factor was mostly calculated according to Desmet and Govers (1996), Renard et al. (1997) and Wischmeier and Smith (1978), plus a few other formulas.

- Which of these S-factor equations is used? *Only (R)USLE and WaTEM/SEDEM*
  Most respondents stated to use another S-factor equation than the ones suggested (**Figure 18**). The "Other" answers included a few other formulas, see Supplement B for exact answers.

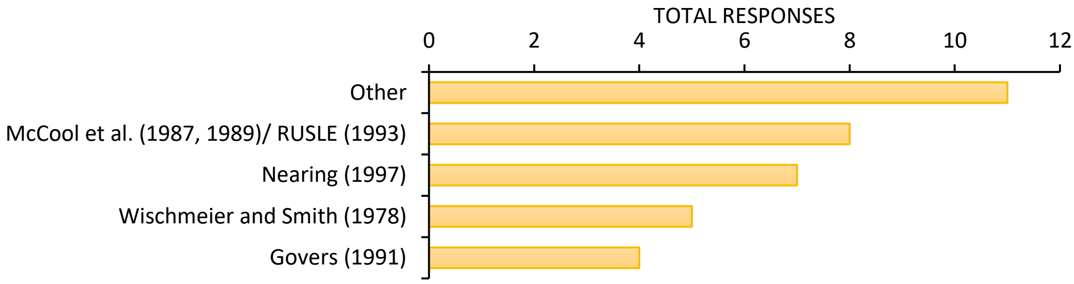

Figure 18. S-factor equations used within USLE type models and WaTEM/SEDEM.

3.2.4 Land use and management data

- <u>Please indicate the modelled land uses.</u>
  The modelled land uses were mainly arable land, grassland forest and permanent crop land (**Figure 19**). "Other" included some specific land uses mentioned by the respondents such as vineyards, olive groves and shrubland.

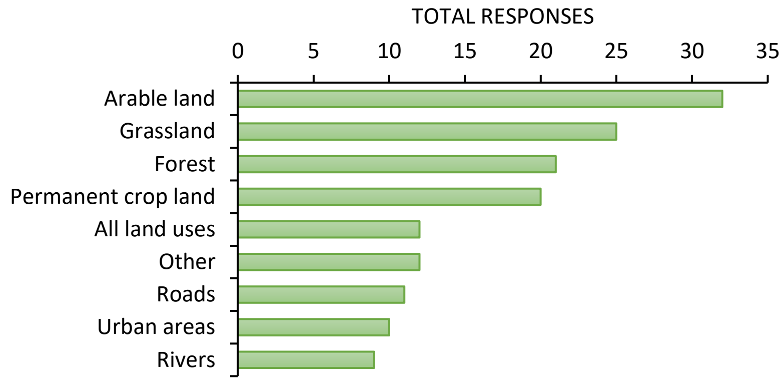

Figure 19. Modelled land uses included in all model applications.

There was not much difference in modelled land uses between model groups or model application scales (**Figure 20**).

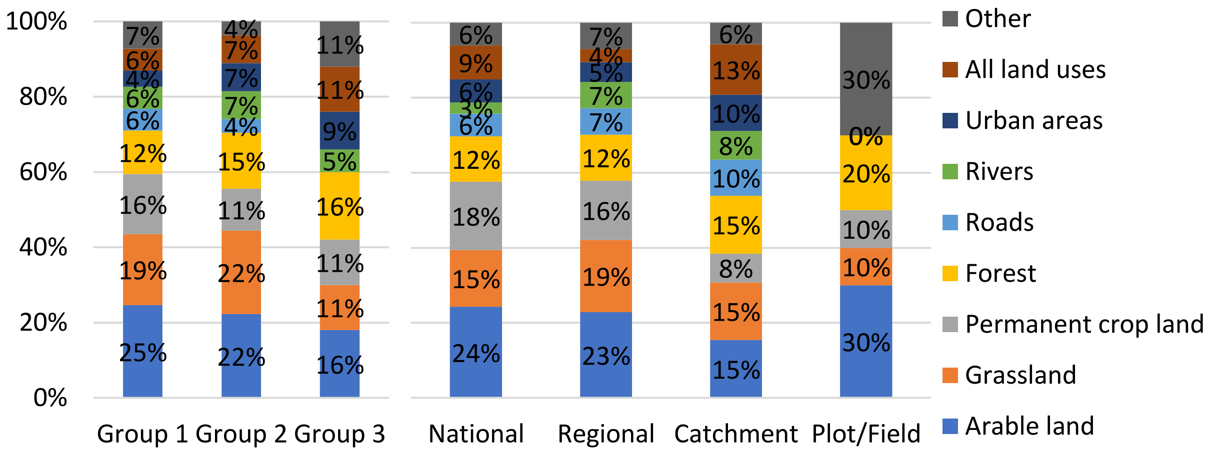

Figure 20. Modelled land uses per model group and per model application scale.

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- <u>Please specify the land use data source.</u>
  The main land use data source was regional/national databases. Field mapping, remote sensing and GIS mapping as well as the CORINE database were also applied in several of the model applications (**Figure 21**).

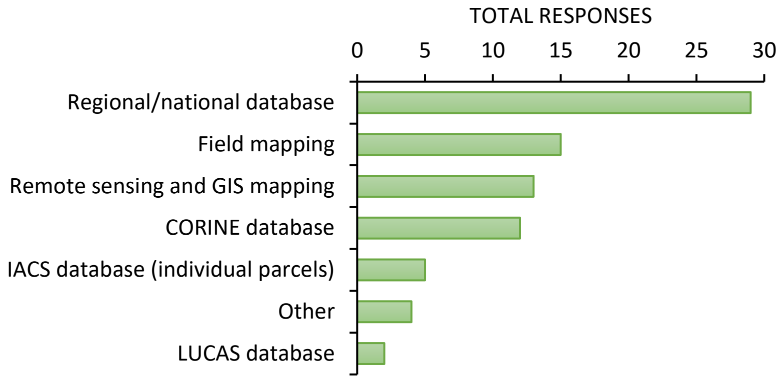

Figure 21. Land use data source used in all model applications.

Group 1 and 3 mainly used regional/national databases as the land use data source (**Figure 22**). For group 2 this source was also dominant, but also field mapping was more often used. The CORINE database was also used more by group 2 and 3. Regional/national databases were also predominantly used at national and regional model application scale. At catchment scale it was a more mixed picture, but with the CORINE database being the most used, whereas at plot/field scale field mapping was the main source of land use data.

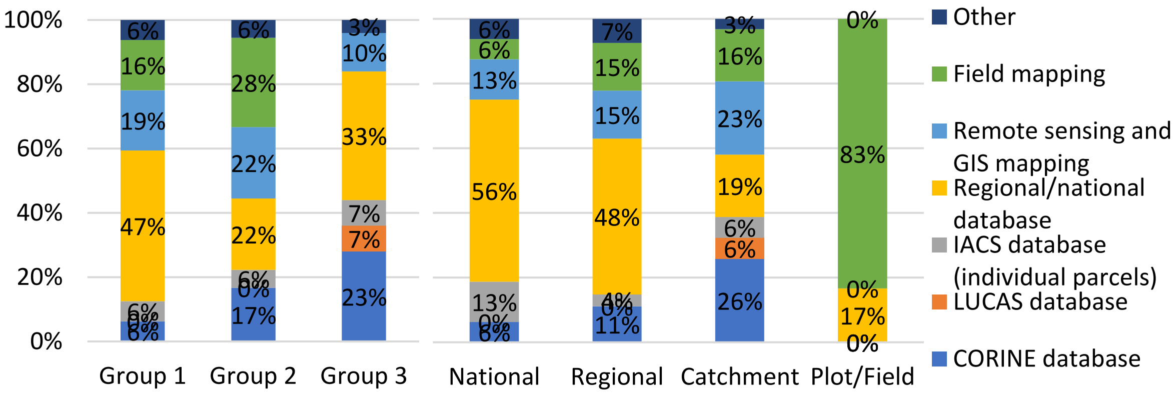

Figure 22. Land use data source per model group and per model application scale.

- <u>Please specify spatial resolution of land use data.</u>
  Many different resolutions from 1x1m to 1:250000 were stated by the respondents.

- <u>Which land use parameters are included in the model (C-factor)?</u>
  Figure 23 shows the combined land use parameters used in all models. Vegetation information was only a given option when respondents chose “Other” as model type. The “Other” category included answers such as land levelling, rockiness, crop sequence,

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intercropping period, just annual C-factor values and specific vegetation information such as plant height or leaf area index. Three respondents did not apply any land use parameters.

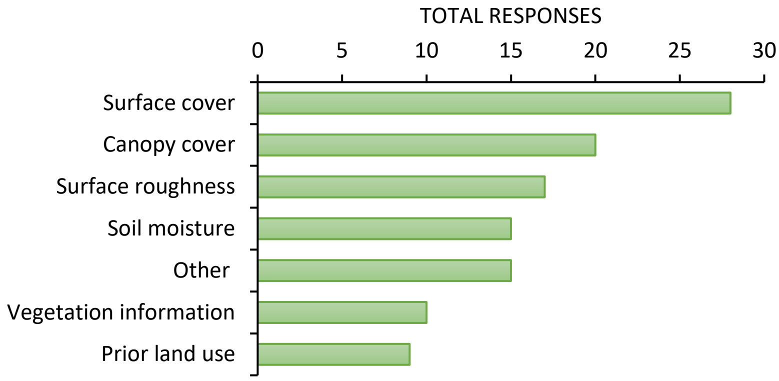

Figure 23. Land use parameters included in the model application.

Figure 24 shows a very mixed use of land use parameters per model group and per model application.

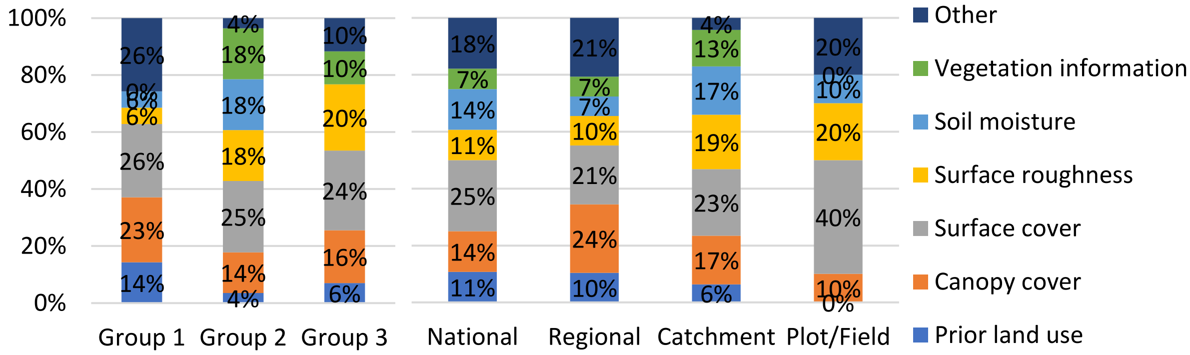

Figure 24. Land use parameters included per model group and per model application scale.

- <u>How are land uses/C-factors applied in the model?</u>
  Land uses or C-factor values for all model types were mainly applied for each individual field (**Figure 25**). Especially as the "Other" category mostly included statements on the land use being applied at field or plot base and at pixel base.

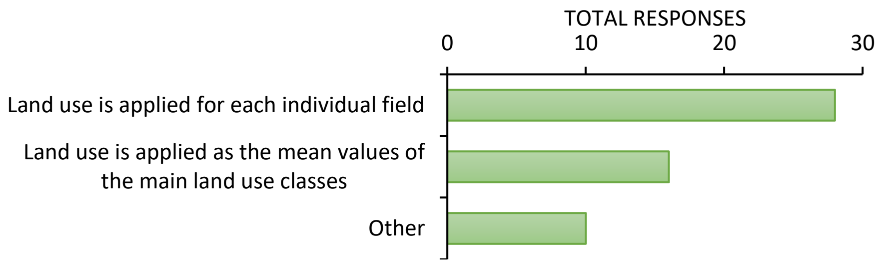

Figure 25. Land use application for all model applications.

At regional scale the land use values were mostly applied as mean values of the main land use classes (**Figure 26**). All other model groups and scale applications mainly applied land use values (C-factors) for each individual field. This includes group 1 and the plot/field scale

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applications, as answers given in the category "Other" could be categorised as "applied for each individual field" for this group and scale application.

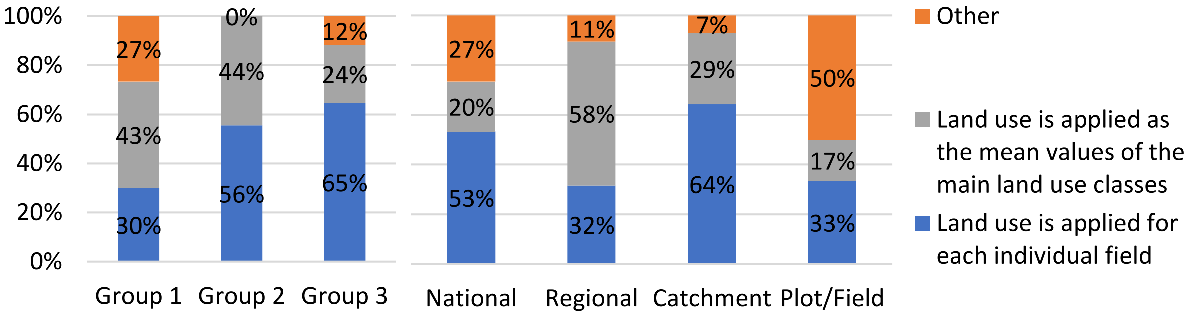

Figure 26. Land use application per model group and per model application scale.

- Land uses/C-factors are applied as (temporal resolution).
  Most model applications made use of average annual values (**Figure 27**). The category "Other" included that no temporal resolution was applied, the use of an annual value plus four seasons, values linked to specific data and values of a worst-case scenario.

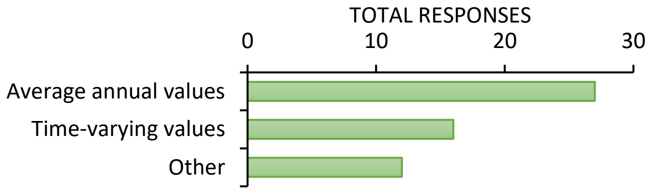

Figure 27. Temporal resolution of land use application.

Group 1 mainly applied average annual land use values, while group 2 used time-varying ones (**Figure 28**). The "Other" category for group 3 included the use of both constant and varying values and a worst-case scenario. National and regional scale applications mainly used average annual values, while catchment and plot/field scale applications rather used time-varying values.

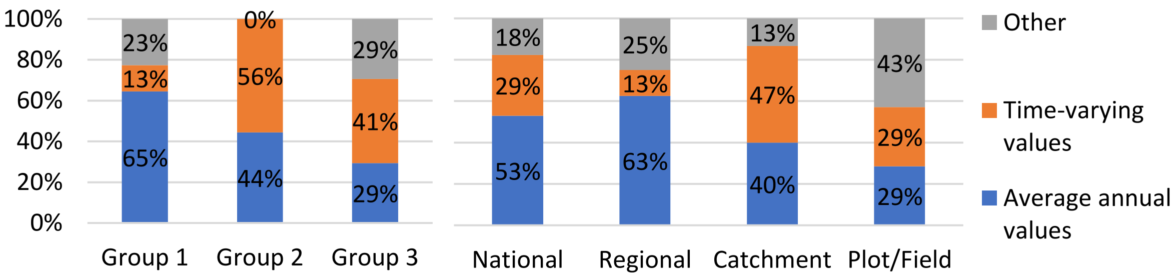

Figure 28. Temporal resolution of land use application per model group and per model application scale.

- For which types of agricultural production is the model applied?
  The main modelled agricultural production was conventional agriculture (**Figure 29**).

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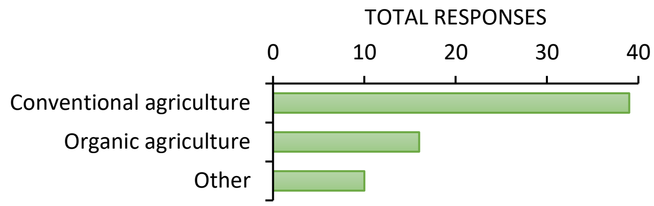

Figure 29. Types of agricultural production for which the model is applied.

Per model group and application scale the most modelled was also conventional production (**Figure 30**). The high percentage in the "Other" category for group 3 and plot/field scale included the use of types of production and not applicable answers.

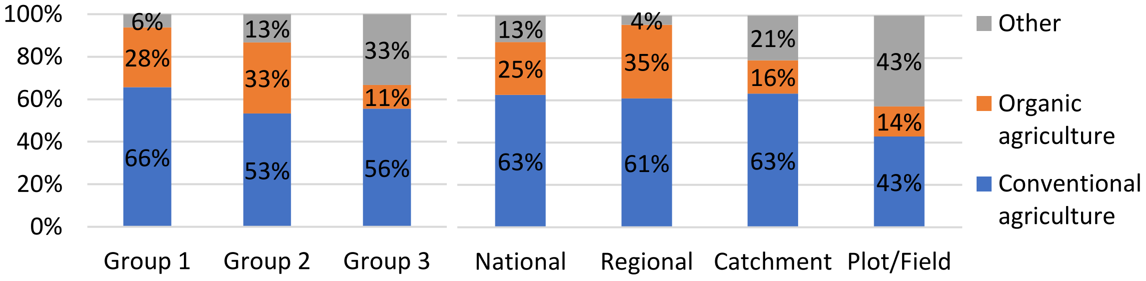

Figure 30. Types of agricultural production applied per model group and per model application scale.

- Which management practices are included in the modelling procedure?
  The most modelled management practices were tillage and crop rotations (**Figure 31**). "Others" include 10 answers of no management practices, and several other answers such as permanent grazing, chemical weeding, carry-over-effects and different intercropping periods.

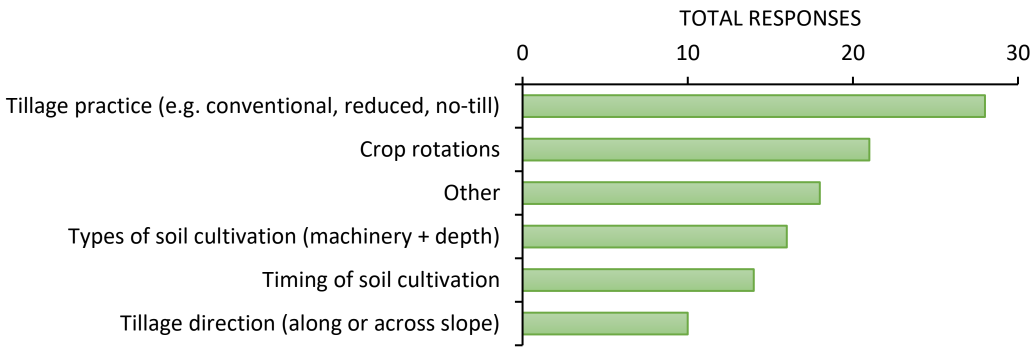

Figure 31. Management practices included in modelling procedure.

Tillage practice and crop rotation were also applied in most model applications per model group and application scale (**Figure 32**). The large percentage in the "Other" category for plot/field scale mainly included not applicable answers.

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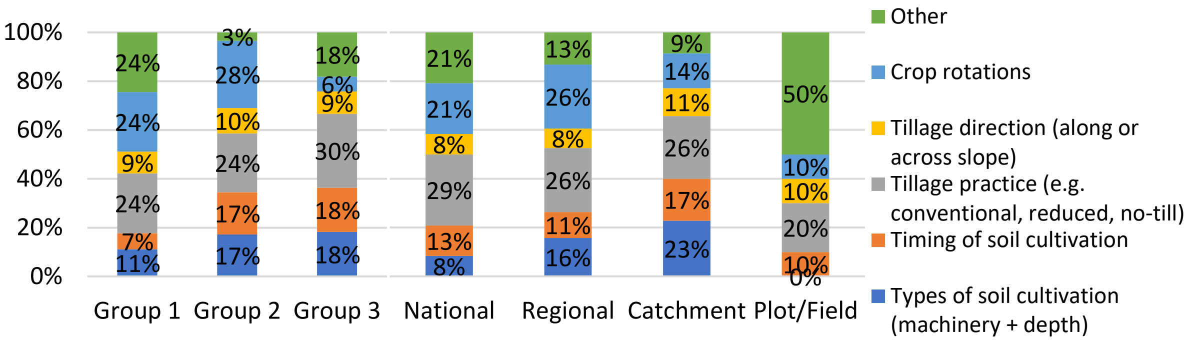

Figure 32. Management practices included in modelling procedure per model group and per model application scale.

- <u>Please specify the source of management data.</u>
  Again, the most applied source of data was a regional or national database (**Figure 33**). The "Other" category included not applicable, field scale data, scenario and research farm.

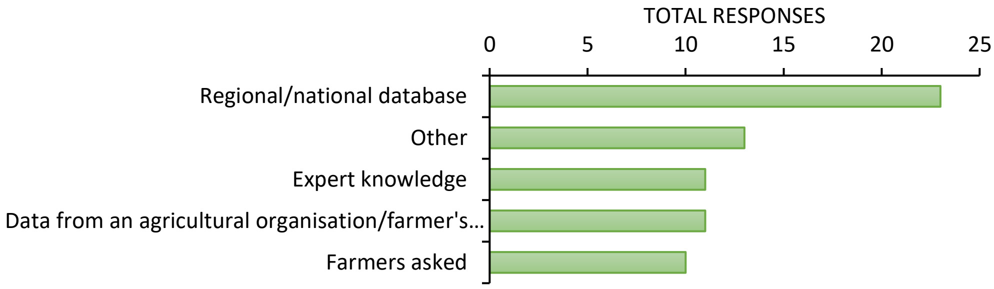

Figure 33. Management data source.

The same applied to the model groups and application scales (**Figure 34**). At plot/field scale the large percentage of "Other" were 'not applicable' answers and one answer of field scale data.

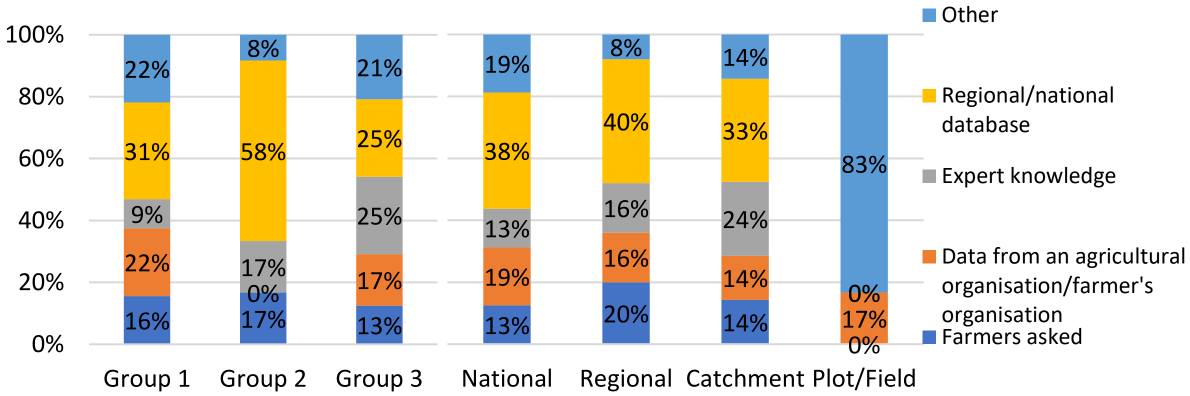

Figure 34. Management data source per model group and per model application scale.

- <u>Please specify how each land use parameter is calculated and what data are used for the parameterisation. *Only "Other models"*</u>
  Expert knowledge plus simple simulation for vegetation parameters, based on agricultural statistics, literature and field measurements or derived from empirical relationships.

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- Please specify if any management support practices are applied and how these are parameterised and modelled. *Only "Other models"*
  Mostly not applicable answers.

- Please specify how each C-factor parameter is calculated and what data are used for the parameterisation.
  Several methods were stated, some were explained in detail. Here some examples are stated: Use of a CP-tool based on Wischmeier and Smith and expert knowledge. The modelling was based on the LANDUM model using national data and adjustment of the algorithm. Land cover types based on orthophotos and field surveys. Field measurements and literature values. Expert knowledge. Mean values derived from general farming statistics. C-factor not used.

- Please specify if any support practices are applied and how the P-factor is calculated for the model, including parameters and data used.
  The P-factor was not included in 15 answers. Otherwise, some examples are stated in the following: map of terraces, 3 tillage methods, measures from LPIS system were considered, reduced soil tillage and cover crops from empirical relationships, literature, directly from measured data, the effect of sub-surface on erosion was considered in the P factor, mulching.

3.2.5 Other data

- Are any other parameters included in the model? If yes, how are they estimated and which data are used?
  Sixteen of the respondents stated to include other parameters in their model applications. These included parameters on fertilization, irrigation, drainage, pesticide use, snowmelt, fire frequency and soil water repellency. Please see Supplement B for further details.

3.2.6 Output data

- Please specify the output of the model.
  The most stated output of the model applications was soil loss (net/gross) (**Figure 35**).

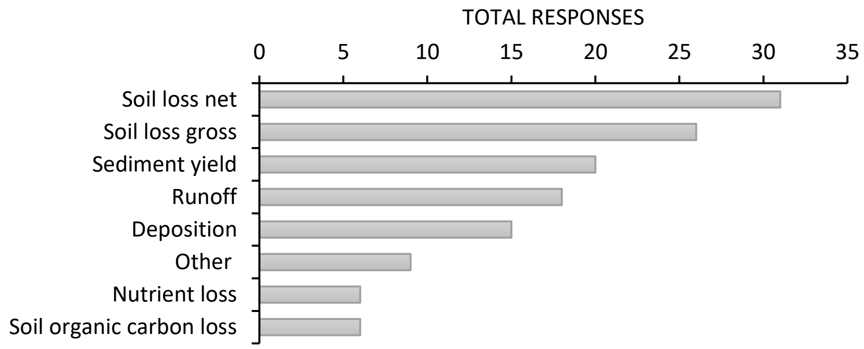

Figure 35. Output of model for all model applications.

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It seems there was not much distinction between net and gross soil loss in group 1, which is curious as USLE and its other versions usually only consider gross erosion (**Figure 36**).

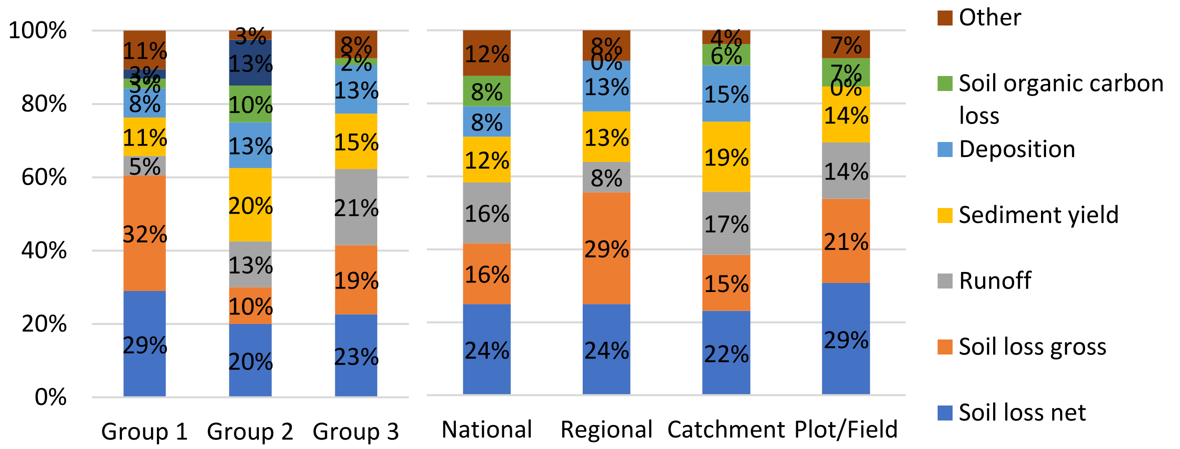

Figure 36. Model output per model group and per model application scale.

- <u>Please specify the spatial scale of the model output.</u>
  The most given answer of spatial scale of the model output was catchment scale followed by parcel (=field), regional and plot scale (**Figure 37**). As the specific scale of each spatial scale category was not defined in the survey, it may be that the respondents have different definitions of e.g. the size of a catchment.

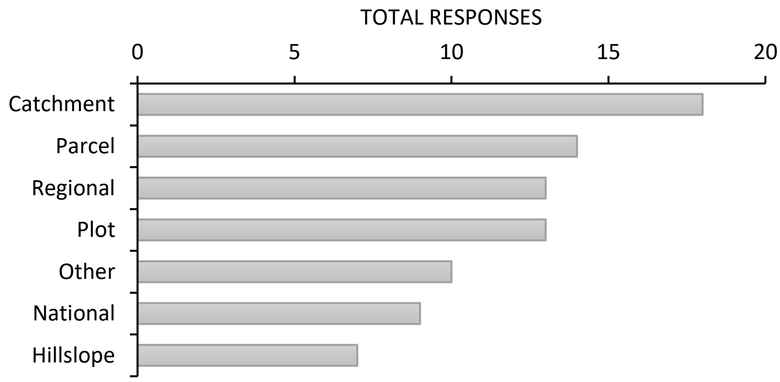

Figure 37. Spatial scale of model output for all model applications.

In group 1 the main spatial scale of the model output was stated as plot or parcel (**Figure 38**). For group 2 and 3 the model output was rather stated to be at catchment scale.

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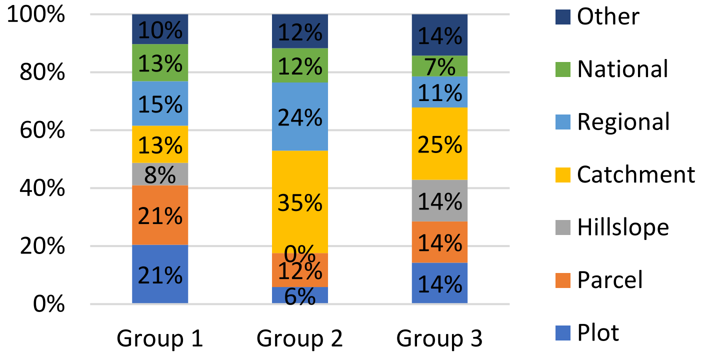

Figure 38. Spatial scale of model output per model group.

- <u>Please specify how the final model output is portrayed (e.g. polygon/raster) and the spatial resolution/scale.</u>
  Most model applications stated to have the final model output as a raster (26 answers), 11 stated polygons, and the rest stated a mix or not applicable. The spatial resolution/scale was not stated for most, but those who did were in a range from 1 m to 10 km or 1:50000.

- <u>Please specify the temporal scale of the model output.</u>
  The most stated temporal scale of the model output was annual followed by multi-annual and event scale (**Figure 39**).

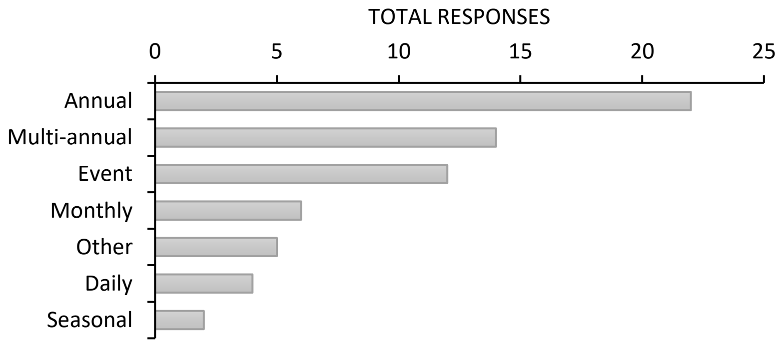

Figure 39. Temporal scale of model output for all model applications.

Group 1 mainly applied annual or multi-annual scale of the model output, while group 2 had a large percentage of annual and daily output scales (**Figure 40**). Group 3 also included a large percentage of event scale model outputs. National and regional application scales also had a large percentage of annual or multi-annual model outputs, while catchment and plot/field scale applications included about 1/3 model outputs at event scale.

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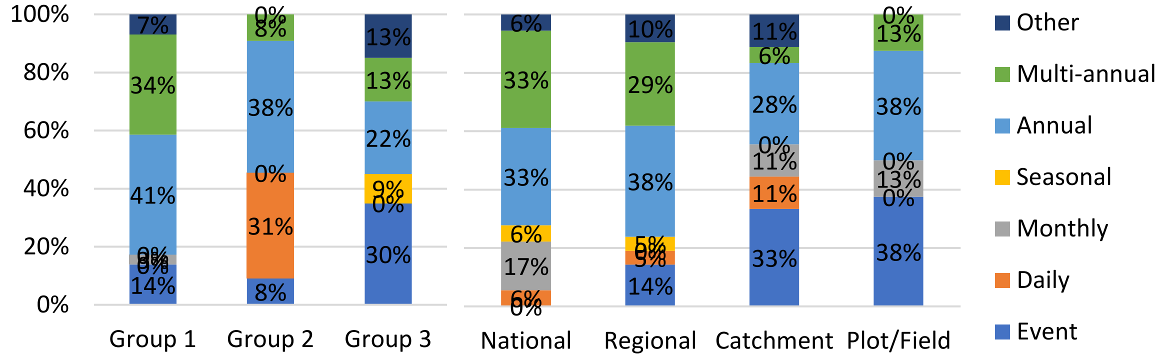

Figure 40. Temporal scale of model output per model group and per model application scale.

3.3 Analysis of connectivity elements

Out of all 46 analysed answers, 30 model applications stated to include connectivity elements, while 16 did not. The majority of model applications in each model group stated to include connectivity elements (**Figure 41**). Plot/field scale model applications included less connectivity elements, which fits with the model application scale.

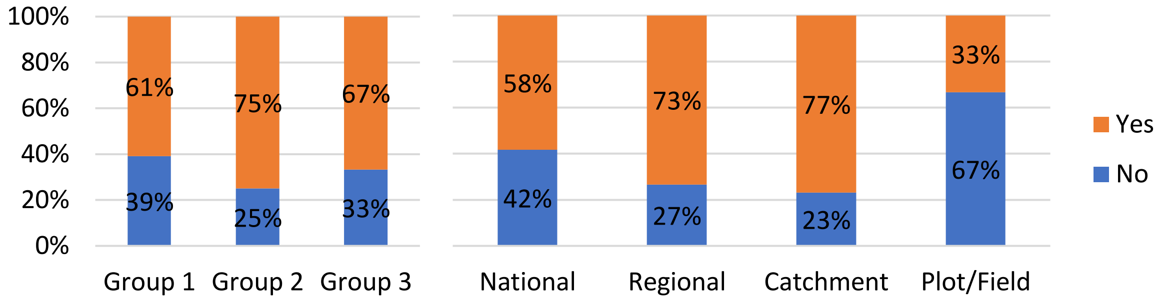

Figure 41. Percentage of model applications, which include connectivity elements or not per model group and per model application scale.

- <u>Which of these connectivity elements are accounted for in the modelling process?</u>
  Out of the 30 model applications that included connectivity, the connectivity elements accounted for in the modelling process were given as in **Figure 42**. The overall most included connectivity elements were roads and land use change, followed by parcel borders and ditches. "Other" included buffering measures such as dams or basins.

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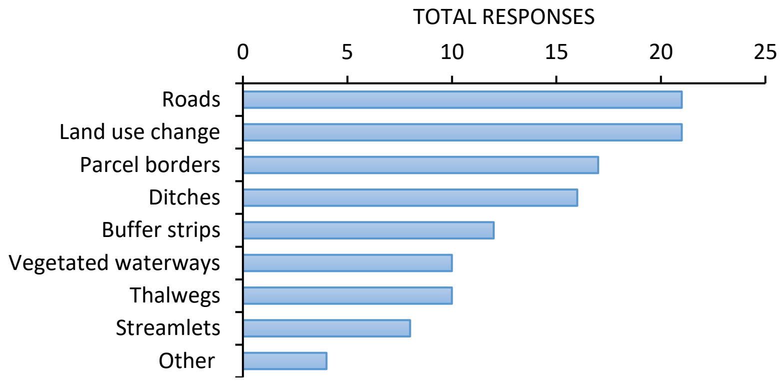

Figure 42. Connectivity elements accounted for in the model.

Looking at the different model groups (**Figure 43**), there was not much difference in included connectivity elements. Plot/field scale had the largest proportion of no connectivity elements – makes sense as one plot is not connected.

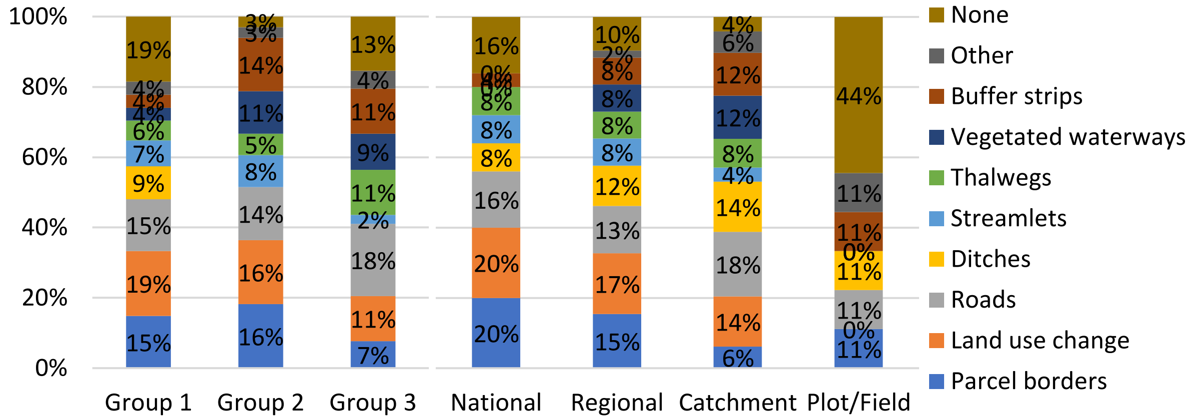

Figure 43. Connectivity elements accounted for per model group and per model application scale.

- <u>Please specify how the effects of (dis)connectivity elements are modelled. Please include how they influence flow (direction) and proportion of runoff.</u>
  The (dis)connectivity elements were modelled in several different ways and to a varying degree of detail. Here some of the answers are presented, for all detailed answers see Supplement B.
  For one model application, an extra connectivity map was produced, where the erosion risk map was combined with the flow distance to a watercourse or drained road. It was calculated if the runoff for every cell of the relevant area could reach the extended drainage network. Cells draining into barriers or cells with a slope of less than 2% were not calculated.
  Another model application stated to include connectivity elements both directly and indirectly. In the latter case, all boundaries between land use elements were assigned a standard parcel connectivity of 80%. Landscape elements other than arable land affected connectivity in the model both via the C factor and the transport capacity factor. Certain land uses (build up areas, roads, water bodies) were considered non-routing in the model and act as sediment sinks.

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In several other model applications, the focus of connectivity seemed to rather be on the disconnecting features e.g. by:

- Modelling each field parcel separately, assuming there is no flow from one parcel to another.
- Letting the LS factor accumulate until a barrier is reached. The barriers used in the model were roads, built up areas and surface water bodies.
- Having soil loss stop at borders, roads and ditches.
- Allowing the flow to follow the parcel border until no adjacent lower grid cell can be reached in the same parcel. At that point parcel borders are crossed.
- Integrating terraces in the P-factor.

Other model applications integrated connectivity effects by:

- Modifying the DEM to change flow direction.
- Modelling connectivity elements by modifying input maps at their location, and not modifying the flow direction (flow direction is obtained from the DEM).
- Using curve numbers to implement different transport capacities in the model.

- Does the erosion model use a sediment transport model? If yes, which model and how?

  Thirty-three respondents answered no to the use of a sediment transport model, while 11 answered yes. Sediment transport models were not included in USLE at all, but in the process-based models to an extent (**Figure 44**). Sediment transport models were mainly included in the models used at catchment scale. This was also the scale where the more process-based models were used, and at catchment scale it would be more feasible to consider sediment transport within the investigated area. For details of the used sediment transport models see Supplement B.

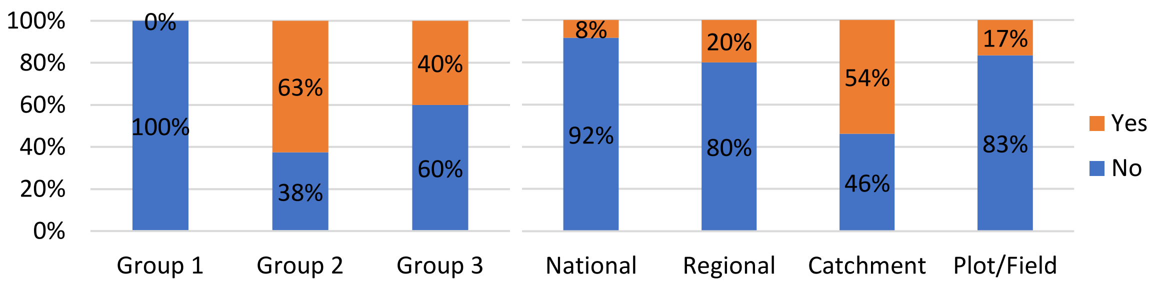

Figure 44. Percentage of models including a sediment transport model per model group and per model application scale.

- How are the parameters in the sediment transport model assessed and which data are needed for this?

  As only few of the model applications included a sediment transport model, only few elaborations of the use of them were given. Here are some examples, for all answers see Supplement B.

  - Model parameters are assessed by calibration/validation procedure using discharge and suspended sediment concentration time series recorded at monitoring station.
  - Transport capacity was based on momentum flux approach.
  - Settling velocity of different grain size classes (Stokes parameters).

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- Texture: soil map and database. Cohesion and aggregate stability: derived from measurements and stored in lookup tables as a function of soil and/or land use.
- The chosen formula for the S-factor gave negative values for slope gradients, so that those lands were considered as flat and depositional areas.

- Does the erosion model use a connectivity index? If yes, which index and how?
  Only 1 respondent stated to use a connectivity index, all others did not use an index.
  A few respondents commented further on this question stating that:
  - They did not use an index, but used the flow distance of each raster cell to the watercourse or drained road as a measure of connectivity.
  - Sediment and water connectivity are results (as retention, deposition and transfers are simulated).
  - Connectivity is incorporated in the model.
  - Connectivity will be assessed by field visits.

- How are the parameters in the connectivity index assessed and which data are needed for this?
  The one respondent did not elaborate much, only stated that the connectivity index was applied through the annual sediment flux in a model under development.

3.4 Analysis of mitigation measures

- Which mitigation measures are modelled?
  Out of all 46 answers, 33 said they applied some sort of mitigation measure in the modelling, while 13 did not. The most applied mitigation measure was cover crops followed by no-till and mulch-till farming (**Figure 45**).

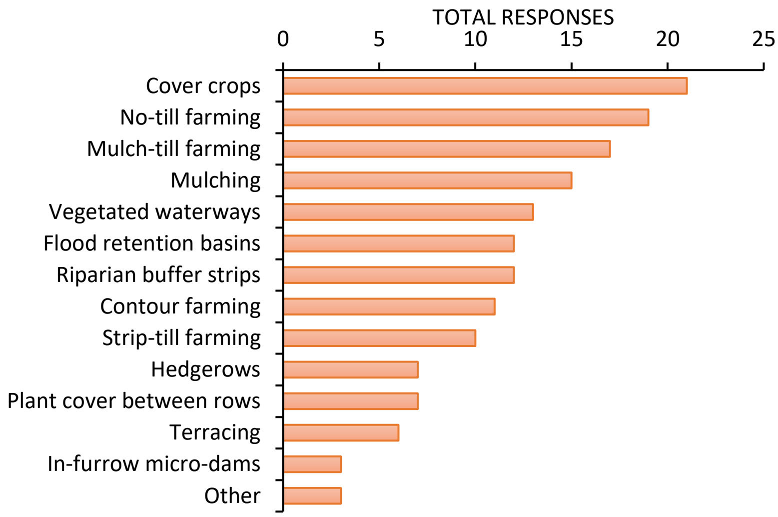

Figure 45. Mitigation measures modelled in all model applications.

There was no immediate difference in modelled mitigation measures between model groups or at model application scale, except for at plot/field scale (**Figure 46**). At this scale the main used mitigation measure was mulching, although the majority of model applications did not apply any mitigation measure.

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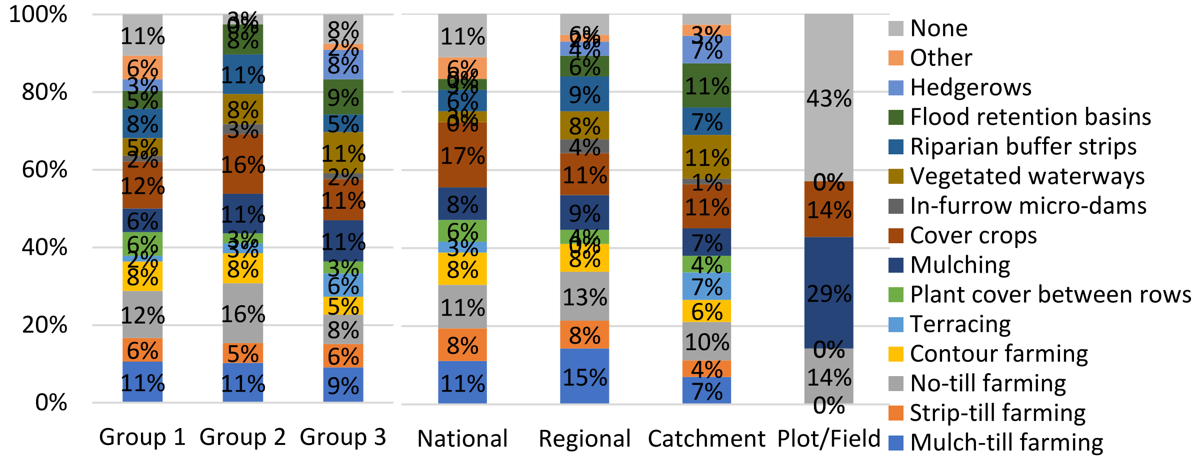

Figure 46. Mitigation measures modelled per model group and per model application scale.

- <u>Please describe how the mitigation measure parameters are estimated and which data are used.</u>
  For all detailed answers see the Supplement B. In the following some of the answers given are listed:
  - The processes are rather simple, different cultivation practices are possible to model, since model includes a lot of different practices. The problem is often that there is no measured information about the required parameters, but the modeler often has to use the so-called default values. There is also no measured output data on cultivation practices, so it is often necessary to trust that field experiments conducted in the US describe processes with sufficient accuracy.
  - Subsidized measures are known by the government. Some measures are registered by the farmers to receive financial support or can be assumed to be applied based on information about regulation and questionnaires.
  - The mitigation measures are calculated using the CP-Factor-tool. The corresponding data for a field or a crop rotation can be entered there. Finally, the calculated CP factor can be linked to the potential erosion risk from the erosion risk map of Switzerland using another tool and visualised in the GIS.
  - The agricultural practices that help reduce erosion from data of measures from the LPIS system.
  - Mitigation measure parameters are defined from experimental studies.
  - Buffer strip rows described through field surveys.
  - They are derived from Land Use Map (DUSAF).
  - Literature.

- <u>Please describe how the mitigation measures are modelled.</u>
  For all detailed answers see Supplement B. In the following some of the answers given are listed:
  - The mitigation measures are translated to the input data for land use and the C-factor. For vegetated waterways and riparian buffer strips, parcel borders are crossed directly and not only at the lowest point. In flood retention basins the flow is directed to the outlet and both the upstream area and sediment load are reduced when the flow leaves the outlet.

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- Changes in surface properties cause a reduction of transport capacity. Thereby, sedimentation is forced at filter strips. Runoff follows tillage direction until water depth exceeds the roughness.
- Basically with combined C*P factors; Flood retention basins can only be modelled as runoff/sediment traps (INLETS/OUTLETS), no real runoff retention calculation with restricted drainage.
- By changing the above-mentioned parameters based on field measurements and scientific literature. Knowledge is put into lookup tables to prepare input maps for OpenLISEM.
- Empirical relationships derived from experimental studies are incorporated to model sediment deposition or infiltration.
- There are specific soil loss ratios values for the various tillage practices, which are stored in the CP tool.
- As weights limiting potential water erosion risk, estimated for bare soil in black follow, based on literature.
- Through the selection of the most appropriate C factors in the RUSLE equation.
- By changing the land use or management or influencing the DEM.

3.5 Analysis of calibration and validation

- <u>Is the model or single model elements calibrated? If yes, please specify which model elements, the data, parameters and method used.</u>
  Out of the 46 answers, 19 responded to calibrate the model, while 27 did not calibrate.
  In the following, some examples of the calibration methods used are given. For further detailed answers see the Supplement B.

  - We used a part the mapped soil loss rates (sheet and rill erosion) over 20 years of 203 fields of a test area for calibration. The model overestimated the long-term measured soil loss by a factor of 5 to 8. We applied corresponding adjustments to the L- and S-factor
  - Typically flow, nutrients and sediment are calibrated. Automatic calibration and uncertainty analysis with SWAT-CUP software (SUFI-2 programme) were carried out (Abbaspour et al. 2004). Kling-Gupta efficiency (KGE) number was adopted as the goodness-of-fit criterion (Gupta et al. 2009). Sometimes Nash-sutcliffe efficiency is also used.
  - The erosion model has been calibrated mainly manually (data used: sediment transport data from subsurface drains and surface runoff)
  - Models parameters are assessed by calibration / validation procedure using discharge and ssc time series recorded at monitoring station. Calibration is realised on runoff volume and sediment load.
  - statistical tests, train and test data, multiply runs (Multilevel-B-splines), experiments in the field
  - C values were calibrated for main crops and management types using data from seven experimental fields. Least squares method.

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- hydrology is calibrated thanks to regional monitoring networks. Nutrient loss is calibrated using the regional survey of APL (potentially leacheable nitrate)
- The model is calibrated based on data of sediment concentrations in watercourses or sediment accumulation in ponds or retention basins. The calibrated parameters are kTChigh and kTClow. The methodology is based on Van Rompaey et al. (2001).
- The R factor we used was calibrated by Bartolini et al. (2004) for a similar RUSLE modelling in Emilia-Romagna (North of Italy).
- The USLE does not require calibration; if calibration becomes necessary, the model parameters were wrong and should not be used
- The model (runoff and sediment phase) was calibrated with bare soil erosion plot data from CZ, AT, HU, ITA; for crop parameters, C, P, etc., it relies on methodology from models with parameters of similar function (RUSLE, EUROSEM, original MMF)
- The model is calibrated for KTc_high and KTc_low parameters, respectively arable land and vegetated other land, based on riverine sediment export in 25 catchments across Denmark.

Thirty percent of USLE applications (group 1) were applying calibration, whereas it was more for group 2 and 3 (**Figure 47**). At national and plot scale it was 50/50 whether calibration was performed, while at regional and catchment scale about 1/3 of model applications were calibrated in some way.

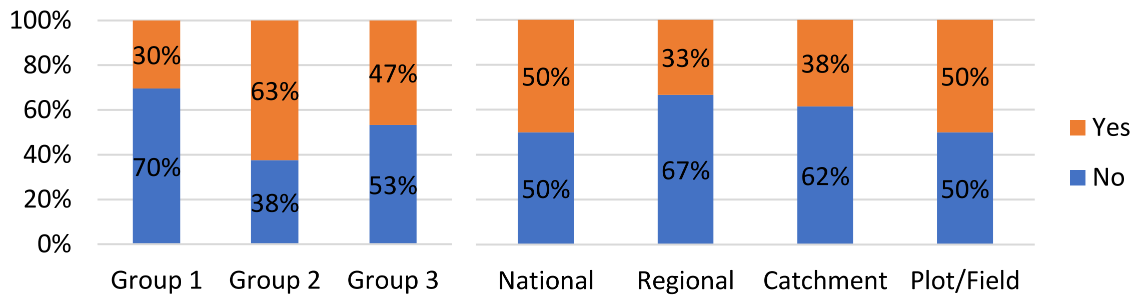

Figure 47. Model calibration per model group and per model application scale.

- <u>Which of these methods is used to validate the model or single model elements?</u>
  For validation 35 responded yes, while 11 respondents answered to not validate the model. However, out of those 11 respondents, 5 of them also checked other response options. This likely meant they validated certain aspect of the model, but not the whole model. For all model applications the most used validation method was expert knowledge, followed by measured erosion rates and field mapping (**Figure 48**). The “Other” category mostly included measured runoff.

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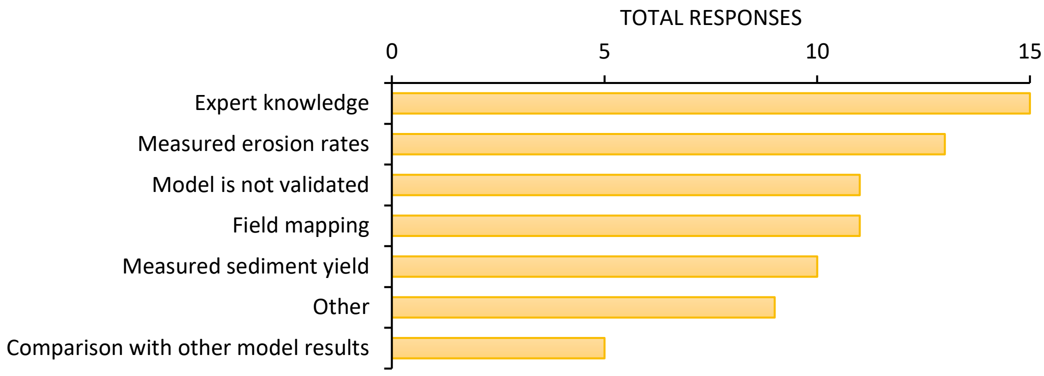

Figure 48. Model validation methods applied in models.

Group 1 (USLE) had the highest number of answers to the model not being validated (**Figure 49**). Group 2 had measured sediment yield as the most answered validation method. For group 3 the methods were more mixed. Models applied at catchment scale had the lowest replies of no validation, and had field mapping and measured sediment yield as the most reported validation method. Plot and field scale model applications mostly validated through measured erosion rates.

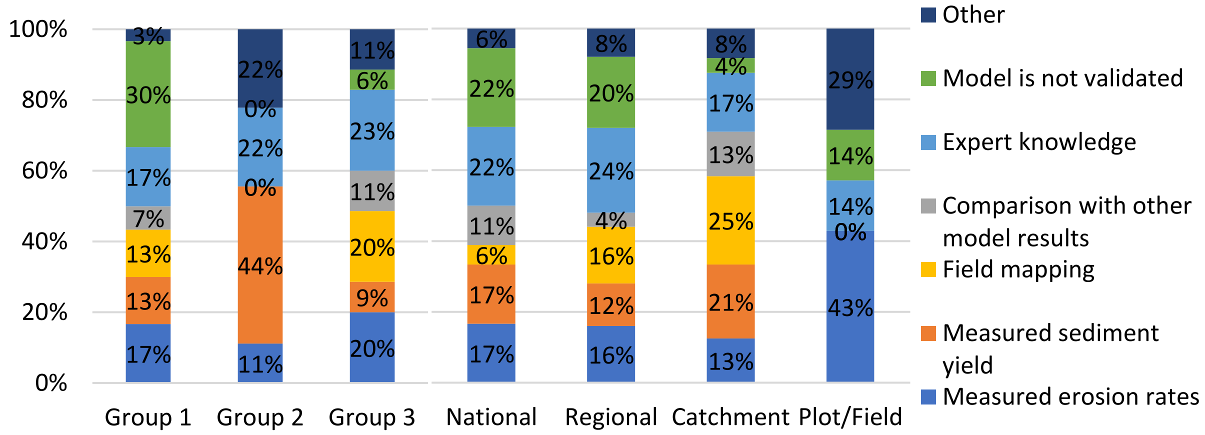

Figure 49. Model validation per model group and per model application scale.

- Please specify which model elements are validated, the used data, parameters and method. For all detailed answers see Supplement B. In the following some of the answers given are listed:
    - R factor validation passed through the comparison with JRC Global Rainfall Erosivity Dataset. K factor was validated through the comparison with other values derived from Rusle application in similar pedoclimatic contexts. C factor was validated through comparison with values provide by bibliography.
    - The core of the model use is the lookup table which links the inputs to the hazard index. This lookup table is modified through a feedback from technicians of the local authority who know the field very well, and the use of their archives (localized pictures, memories, orthophotos, etc.) used as proxies.
    - The model is being validated by split-sampling of the calibration dataset described above; additional validation steps are possible with appropriate data (catchment data,

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field mapping, other models); some model parts (sedimentation, in- and outlets) will require field mapping for validation.

- After calibration model was tested at small catchment and river basin scale against TSS measurements from rivers and streams. The testing provides indication of model performance at larger spatial scales. RUSLE erosion and TSS measurements are not directly comparable.
- Estimated rill erosion rates are compared with averaged measured multi-annual rill erosion rates for a large number of hill slopes at a regionally aggregated level. Rill erosion rates were measured by means of a rill erosion survey.
- Based on photo material and locations of water erosion effects around Slovenia gathered in the past years we did the field validation of RUSLE-SI 2020 model.
- We compared the modelled soil loss corrected due to the calibration with the measured soil loss of another part of the fields from the long-term monitoring.
- We use model performance indicators such as RMSE, NSE, R2 and PBIAS at annual and seasonal scale, to evaluate runoff and soil erosion predictions.
- The results of modelling were compared with the data on sediment load from gully catchments carried by temporary streams.
- Spatial extent of soil erosion risk classes versus physical modelling at catchment scale was validated.
- Usually sediment budgets in reservoirs, rarely sediment concentrations from continuous measurement.
- According to field engineers, the relative ranking of fields makes sense.
- Runoff according to measured data and other model results.
- Model is mostly validated against gauging stations.
- The model output is shared with experts.

3.6 Model user experience and opinion

At the end of the survey we asked the respondents about their opinion of the model they used and to describe the advantages, limitations and possible improvements of the model. Their answers to each of the five questions have been summarised in the following.

- In your experience, what are the most sensitive parameters of the model? (e.g. if a sensitivity analysis was performed).
  Most respondents claimed that the C-factor was one of the most sensitive parameters. This was followed by the LS-factor, the R-factor, K-factor and lastly the P-factor. Other sensitive parameters stated were soil water content, infiltration rate, runoff threshold, transport capacity equation and the quality of the DEM. Only few respondents stated to actually have performed a sensitivity analysis.

- In your opinion, what are the advantages of this model to other models?
  Simplicity and ease of use of the model was the major advantage to most respondents. Moreover, that the required data were available at the needed specific scale and that the model could be integrated in GIS were also recognised as advantageous. For versions of USLE, comparability of results was also mentioned, as the model is widely used.

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- In your opinion, what are the limitations of the model?
  Concerning (R)USLE model applications, the following limitations were specified: only modelling erosion and not sedimentation, the model is empirical, it is a simplified description of erosion processes using general, long-term mean values and the soil loss estimates should not be used as absolute values, but only for comparative or indicative purposes such as risk classes.
  For other models, a limitation such as too many parameters, which may lead to the use of default values, was mentioned. The models require a lot of data and calibration, which is computationally demanding and complex. The accuracy of actual flow paths dependant on quality of DEM and the choice of surface flow algorithm can highly affect the outcome.
  Furthermore, a lack of connectivity within the model and the fact that the quality of the input reflects the quality of the prediction were mentioned.

- In your opinion, which model features should be improved first? E.g. modelling equations, user interface, etc.
  Respondents recommended improvements such as a revision and update of the modelling equations, integration of connectivity, improvement of the spatial resolution e.g. of the DEM resolution, which impacts the LS-factor and the accuracy of the modelling of land use and mitigation measures. Moreover, the issues of uncertainty mapping of the model approaches and the availability, processing and harmonisation of input data were raised.

- In your opinion, what are the most important questions to be tackled for the future of soil erosion and sediment transport modelling?
  Several respondents proposed the need for measured data to calibrate and validate models at different scales as an important future aspect to be dealt with. Connectivity of sediment when leaving the field, quantifying the impact of mitigation measures, climate change impacts and were also stated. Model solutions should be scalable and use better data to improve predictions. Also choosing the right models for the right purposes and understanding and communicating their uncertainty is highly important. It was also expressed that increasing the public awareness towards soil erosion as a problem and that mitigation measures exist to tackle it, should be given more attention.

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4 Limitations of the report

This report is based on a survey of soil erosion and sediment transport model application throughout Europe. We intended the report to provide insight into the various model types used in Europe, their parameterisation and data sources, as well as focus on the implementation of connectivity and mitigation measures in modelling applications. The report is based solely on the 46 responses we received from various practitioners from research institutions, consultancy firms and federal or regional authorities. It is therefore important to point out the limitations of the analysis by enumerating the following points:

- The report is not an exhaustive representation of modelling applications in the whole of Europe due to lack of answers from certain countries.

- The report does not claim to give the complete picture of each country or region we did receive a response from, as it is possible that there are model applications that were not described in the acquired responses.

- The analysis of the reported model applications may not be representative for all other model applications using the same model type.

- The level of detail provided by respondents differed. Some respondents gave extensive explanations of their model application, while others provided incomplete answers. Incomplete answers included some answers filled as ‘not applicable’ or with no or little elaboration, making it difficult to know the exact answer or what was meant with a certain answer.

- The previous point may also be a result of the way questions were posed in the survey. Some questions may not have been asked in a way that was clear to all respondents, and they may thus have answered in different or unclear ways.

- This report provides an overview of the model applications in Europe and cannot cover the full details of the obtained information from every single model application.

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5 Conclusions

This report presents an overview of the current use of erosion and sediment transport model applications in European countries at various spatiotemporal scales. The analysis was based on a survey on the use of model applications from which 46 responses from 18 countries were received. In the following, we list some of the major conclusions to be drawn from the analysis.

- Fifty percent of all reported model applications used the Universal Soil Loss Equation (USLE) or one of its other versions. The other half of the model applications were using models based on or with USLE elements, process-based models, expert judgment/decision tree models and qualitative models.

- About two-thirds of the model applications had policy relevance as they were used by an authority for soil erosion risk assessment or implementation of mitigation measures. The rest were mainly research applications.

- The analysis clearly showed a prevalent use of national or regional datasets. Parameterisation differed between model applications, also between models of the same model type. Harmonisation of datasets and parameterisation would be beneficial to unify some of the modelling approaches.

- Although 30 out of 46 model applications stated to include one or more of the proposed connectivity elements in their modelling procedure, detailed modelling of connectivity seemed to only be a focus of a few model applications. The majority of the models (33 out of 46) did not include sediment transport process descriptions. Only one respondent stated to apply a connectivity index. An increased focus on modelling of sediment connectivity in agricultural landscapes would improve erosion risk assessment and implementation of mitigation measures.

- Mitigation measures were applied in 33 of the model applications. The most applied mitigation measure was cover crops followed by no-till and mulch-till farming.

- Calibration of the model or model elements was carried out by less than half of the reported model applications (19 out of 46). Various parameters were calibrated using soil loss rates, sediment concentrations and other field experiments.

- Validation of the model or model elements was performed for 35 of the model applications. The two mostly used validation methods were expert knowledge and measured erosion rates.

- Modellers were generally well aware of the advantages and limitations of their model and that it is important to choose the right model for the right purposes. They also raised the issues of availability, processing and harmonisation of input data, model uncertainty and integration of connectivity as well as public awareness towards soil erosion and the possible mitigation strategies.

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Appendix

Appendix A. Model specific questions

MMF:

Two respondents stated to use MMF for their modelling application. The specific questions addressed to MMF only are listed below. The respondents' answers can be seen in the answered questionnaire (Supplement B) for full details.

Model description – land use and management:

- Please specify how the proportion of rainfall intercept is estimated and which data are used.
- Please specify how the ratio of actual to potential evapotranspiration is estimated and which data are used.
- Please specify how the percentage canopy cover is estimated and which data are used.
- Please specify how the percentage ground cover is estimated and which data are used.
- Please specify how the plant height is estimated and which data are used.

WaTEM/SEDEM:

Three respondents stated to use the WaTEM/SEDEM for their modelling application. The specific questions addressed only to WaTEM/SEDEM are listed below. The respondents' answers can be seen in the answered questionnaire (Supplement B) for full details.

Model description – topography:

- Please specify how the tillage transport coefficient (ktil) is estimated?
- Please specify how the parcel border trap efficiency values are estimated.
- Please specify how the parcel connectivity values are estimated.
- Please specify how the pond map is created, including the pond map data source, scale and precision.
- Please specify the method used to determine the sediment trap efficiency, and how the parameters within the method are derived.
- Please specify which transport capacity equation is used (+ reference).
- Please specify how the transport capacity coefficient (kTc) is calculated for each land use class and which data is used.
- Please specify how the C-factor threshold given as the kTc limit is determined and which data is used.

Model description – Land use and management data:

- Please specify how the parcel/land use map is created.
- Please specify which type of river routing map is applied.
- Please describe by which method the river routing map is created, including the river map data source, scale and precision.

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Supplementary Material

Supplement A: SCALE_WP1-D1_Supplement_A (Excel file with all survey questions)

Supplement A related to this report is available online at: https://scale-ejpsoil.eu/project_results

Supplement B: SCALE_WP1-D1_Supplement_B (Excel file with all questions and answers)

Supplement B is available only to SCALE project partners.

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