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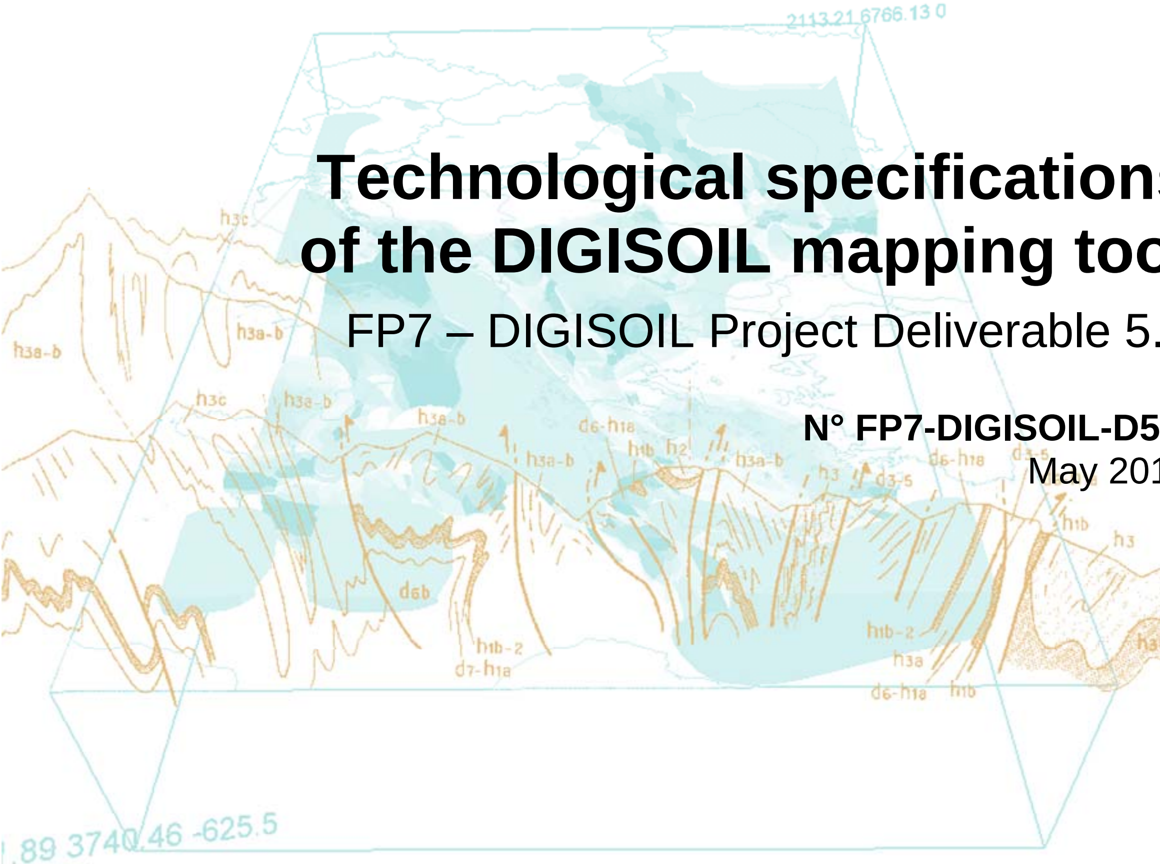

Technological specifications of the DIGISOIL mapping tool

FP7 – DIGISOIL Project Deliverable 5.2

N° FP7-DIGISOIL-D5.2

May 2011

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The DIGISOIL project (FP7-ENV-2007-1 N°211523) is financed by the European Commission under the 7th Framework Programme for Research and Technological Development, Area "Environment", Activity 6.3 "Environmental Technologies".

Geoscience for a sustainable Earth

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The DIGISOIL project (FP7-ENV-2007-1 N°211523) is financed by the European Commission under the 7th Framework Programme for Research and Technological Development, Area "Environment", Activity 6.3 "Environmental Technologies".

Keywords: specifications, geophysical system, soil characteristics, mapping, functional analysis, processing protocols.

In bibliography, this report should be cited as follows:
R. Cochery, M. Thörnelöf, 2011. Technological specifications of the DIGISOIL mapping tool. Report N°BRGM/FP7-DIGISOIL-D5.2, 32 pages.

Synopsis

The purpose of this study concerns the technical specifications of the geophysical system, already set up in previous tasks.

Contents

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1. Introduction

1.1. THE MAPPING PRODUCT

“The multidisciplinary DIGISOIL consortium intends to **integrate and improve *in situ* and proximal measurement technologies for the assessment of soil properties and soil degradation indicators, going from the sensing technologies to their integration and their application in (digital) soil mapping (DSM)**. In addition, our SMEs experience will allow taking **into account the feasibility of such developments based on economic constraints, reliability of the results and needs of the DSM community**.

In order to assess and prevent soil degradation and to benefit from the different ecological, economical and historical functions of the soil in a sustainable way, there is an obvious need for high resolution and accurate maps of soil properties. The core objective of the project is to explore and exploit new capabilities of advanced geophysical technologies for answering this societal demand. To this aim, DIGISOIL addresses four issues covering technological, soil science and economic aspects: (i) the validation of geophysical (in situ, proximal and airborne) technologies and integrated pedo-geophysical inversion techniques (mechanistic data fusion) (ii) the relation between the geophysical parameters and the soil properties, (iii) the integration of the derived soil properties for mapping soil functions and soil threats, (iv) the evaluation, standardization and sub-industrialization of the proposed methodologies, including technical and economic studies.”[1]

As a part of the technical studies within the above-mentioned issue (iv), the hereafter detailed technological specifications present the new mapping product, defined as a solution to issues (i), (ii) and (iii). Those specifications include an analysis of the requirements, which led to the definition of the functions of the product. These functions are studied in term of I/O and interdependences, operating time and needed resources. A Gantt chart sums then all those data up, and key operations are identified. A specific chapter is about the implementation of those functions, with overall needed resources – *sc.*, both equipment and human resources – and their related requirements.

To meet the user’s expectations (see Figure 1), the “product” should be a service, including measurements, treatments, and potentially interpretation for agricultural or environmental purposes. The machine itself is awaited by only 19.5% of the potential end-users.

[1] Cf DoW

However, **it will be assumed hereafter that the product is the mapping system, including hardware and software parts, ready for measurements and treatments**. This is the basic configuration. Services, such as measurement operations or interpretations, can be considered as a subsidiary part.

The analysis would not be very different in the case of services included: the presented functional expectations of the end-user would be shifted to derived to derived functional requirements, and new principal requirements would be considered – *e.g.,* soil risk assessment –.

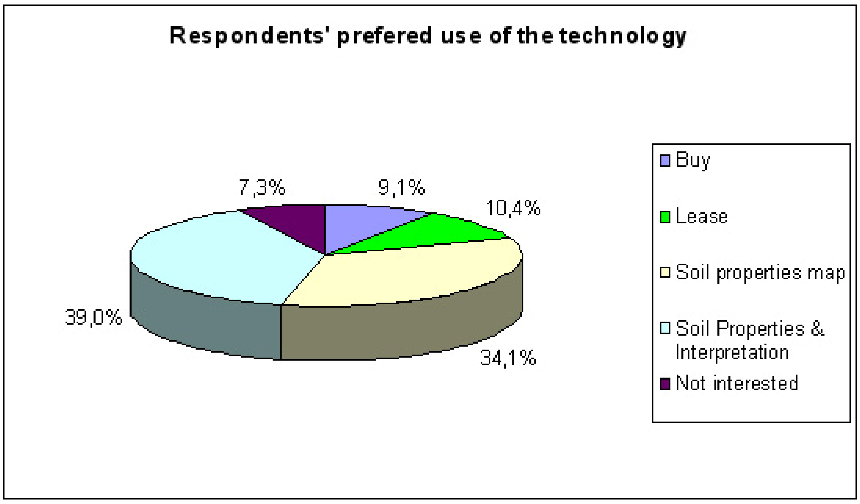

Figure 1: Potential users' expectations (from JRC webpage about the DIGISOIL project[2])

1.2. DEFINITIONS

Geophysical parameters: they are defined as soil physical characteristics which can be determined by geophysical measurements; they are assumed to be independent of the method of measurement.

Soil properties: they are defined as soil characteristics relevant to the functions of the soil (*e.g.*, water absorption). The soil properties of interest are the carbon content, the clay content, the water content, and the bulk density.

[2] http://eusoils.jrc.ec.europa.eu/projects/Digisoil/Survey.html

2. Requirements analysis

2.1. IDENTIFICATION OF REQUIREMENTS

The purpose of the DIGISOIL project is to identify and bridge the technological gap to develop pertinent, reliable and cost-effective geophysical mapping solutions. Consequently, implemented methods must have a proven contribution to the characterization of soil properties related to degradation processes

DIGISOIL requires a strong collaboration between geophysicists, soil scientists and industrial partners for developing a new soil mapping product featured by at least the following characteristics:

- Integrated and efficient technological tools for mapping soil properties from the field up to the catchment scale;
- Innovative quasi-continuous seismic methods adapted for mapping soil properties involved in soil threats and soil functions (compaction, erosion, biomass, production …);
- Highly sensitive/wideband GPR and EMI technologies with full-waveform analyses;
- Ultra-Light Motorised hyperspectral flying sensor campaigns to characterise topsoil organic matter content (and therewith avoiding the use of costly classic airborne campaigns).

One of the aims of this study is to identify what are the hierarchical products the project has to deliver and what are their related constraints and interdependencies. In the following sections, we will focus our attention on what is necessary to produce in terms of geophysical parameters maps and what are the constraints related to them. The first four identified requirements are completed by the following functional set up:

- **Principal functional requirements:** digital soil mapping of soil properties of interest (*viz*. C stock, clay content, bulk density and water content);
- **Derived and secondary functional requirements:** measurement and acquisition of raw geophysical data, treatment of raw geophysical data, mapping of geophysical parameters, intermediate mapping of other soil properties, fusion of maps of different geophysical parameters and/or intermediate other soil properties;
- **Non-functional requirements:** high speed recording, multi-sensor approach, experiments at the scale of parcels, accuracy of the results, accuracy of the measurements, adaptability to the wanted spatial resolution, adapted vertical

resolution, usability on the field, interoperability of different secondary functions, digital rendering.

The principal functional requirements constitute the functional expectations of the end-user. As mentioned in the introduction, the considered product is the mapping system; consequently, the principal requirements are the delivering of the maps.

Derived functional requirements are step requirements to achieve principal functional requirements, or higher-level derived functional requirements.

Non-functional requirements are mainly direct expectations of the end-users (such as accuracy), but they can also be derived from other requirements: *e.g.*, the "usability on the field" requirement is indeed derived from the principal requirements, because concerned soils are located outdoor and off the roads, and from derived requirements, because measurements should be done to obtain the maps, so usage on the field is needed.

2.2. PRINCIPAL FUNCTIONAL REQUIREMENTS

The end user's need is to obtain data to perform an assessment of soil threats, such as soil erosion, organic material decline, compaction, salinization or landslide. Results that should be given to match this need are presented in Table 1, as already presented in the DIGISOIL's DoW.

SOIL THREATS				
Soil erosion	**OM decline**	**Compaction**	**Salinisation**	**Landslide**
SOIL PROPERTIES[1]				
Soil texture	Soil texture/clay content	Soil texture	Soil texture	
Soil density		Soil density		
Soil hydraulic properties		Soil hydraulic properties	Soil hydraulic properties	
	Soil organic Carbon	Soil organic matter		
SOIL-RELATED PARAMETERS				
Topography	Topography	Topography		Topography
Land cover	Land cover	Land cover		Land cover
Land use	Land use	Land use	Irrigation areas	Land use
Climate	Climate	Climate	Climate	Climate
Hydrological conditions				
Agro-ecological zone				
				Occurrence/density of existing landslides
			Groundwater information	
				Bedrock
				Seismic risk

Table 1: Common elements for the identification of risk areas (as presented in DIGISOIL Description of Work)

2.3. DERIVED AND SECONDARY FUNCTIONAL REQUIREMENTS

2.3.1. Measurement, acquisition, treatment and mapping of geophysical data

Geophysical data involved in the mapping tool are: GPR, EMI, geoelectric, hyperspectral and seismic data. The specific requirements for their acquisition and treatment are detailed in previous DIGISOIL deliverables:

- D1.1 for geophysical sensors;
- D3.3 for methods.

2.3.2. Intermediate mapping of soil properties

The specific requirements for mapping of first order soil properties are described in DIGISOIL deliverable D3.3, including workflow, outputs and performances.

2.3.3. Fusion of geophysical parameters and soil properties

General methods for mapping of first order soil properties are presented in DIGISOIL deliverable D2.2. The specific requirements for mapping of first order soil properties are described in DIGISOIL deliverable D3.3, including workflow, outputs and performances.

2.4. NON-FUNCTIONAL REQUIREMENTS

- High speed recording: this condition is necessary to be able to produce a large quantity of data in order to cover the spatial domain of a map (1 to several parcels) with a relatively good resolution (5 to 15 m);

- Multisensor approach: this is the core of the methodology proposed in the project. The basics of this approach concern the possibility to recover soil parameters (density, water content, OM content, bedrock depth, etc) from a multiple interpretation coming from different measuring techniques. Knowing that a particular techniques won't be able to be efficient for all geological and pedological contexts, using several techniques optimize the chance to be successful for mapping a particular parameter;

- Experiments at the field and catchments scales: the investigation dimensions are typically for producing detailed maps of physical parameters in order to estimate risk related to soils at the catchments scale. Several hectares seems to be a reasonable surface dimension for observing large variations of soil parameters, characterizing local features, and being in the good range in terms of experiment costs, knowing that measurements are carried out from ground-based measuring systems. Some measurements – like hyperspectral measurements – are more likely to be done for larger surfaces, at the catchments scale. The DSM must be adapted to those two scales;

- Spatial resolution of around tens of meters: from what is currently performed in precision agriculture or polluted soils mapping, the data acquisition systems are more or less able to deliver reliable measurements with a spatial precision less than 1 m. Taking into account the above cited constraints, a spatial sampling of around 10 to 50 m should be sufficient to cover the domains of investigations with a resolution in good agreement with phenomena needed to be observed;

- Resolution in depth: on the other hand, the needed resolution in the Z dimension should be able to describe the different pedological structures of the soils, and in particular i) the depth of the bedrock that is very important for modelling erosion processes and ii) the frontiers between horizons that are limits between domains of significant different soil properties.

3. Functional analysis and time charts

In the functional analysis hereafter, the principal functions, which are coincident with the principal functional requirements (see chapter 2), will be named:

- F1: digital soil mapping of C stock;
- F2: digital soil mapping of clay content;
- F3: digital soil mapping of bulk density;
- F4: digital soil mapping of water content.

Each of these functions is achieved through the following general steps (see Figure 2).

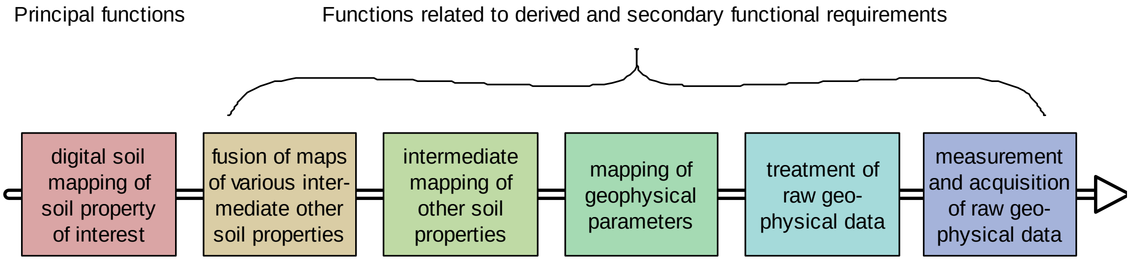

Figure 2: General function chart of digital soil mapping

3.1. PRINCIPAL FUNCTION F1, DIGITAL SOIL MAPPING OF C STOCK

Principal function F1 consists in the digital soil mapping of carbon stock.

The output map of function F1 is obtained by drawing a raster grid. To calculate the carbon stock grid, we extrapolate the surface C content, calculated from hyperspectral measurements, to the whole soil layer. Therefore, the soil thickness is also needed (see Figure 3).

The soil thickness is obtained by calibrated interpretation of seismic data; the calibration requires penetrometry measurements (which, although they are not *s.s.* geophysical measurements, have been associated to them). Seismic data correspond to Vs or Vp velocity; details about the seismic acquisition and treatments are given in

DIGISOIL Project Deliverable 2.3, chapter 6 (pp. 67 to 81). Sub-functions needed to map the soil thickness are presented in Figure 4.

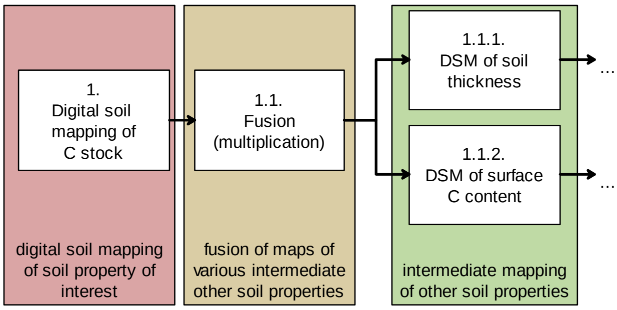

Figure 3: Principal function F1 and its first derived functions

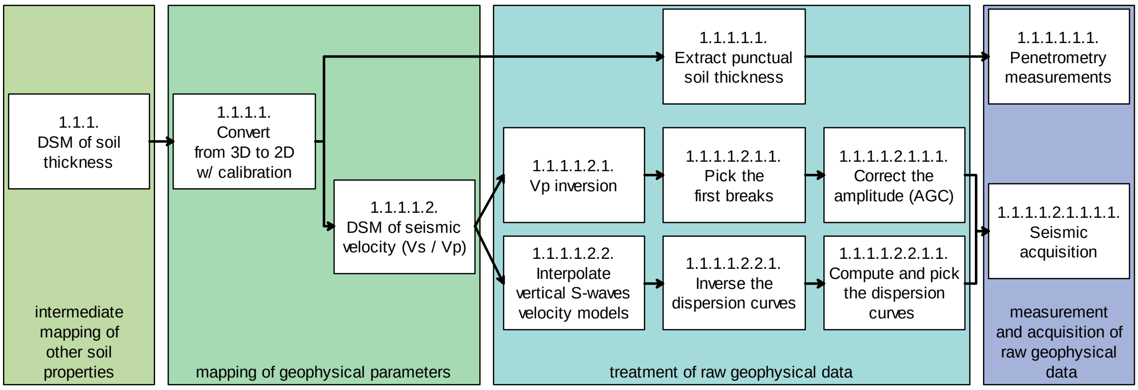

Figure 4: Secondary function 1.1.1. and its antecedent functions

Surface C content is obtained from hyperspectral data. After data processing, these data are correlated with the measurements performed on a few geolocalized samples.

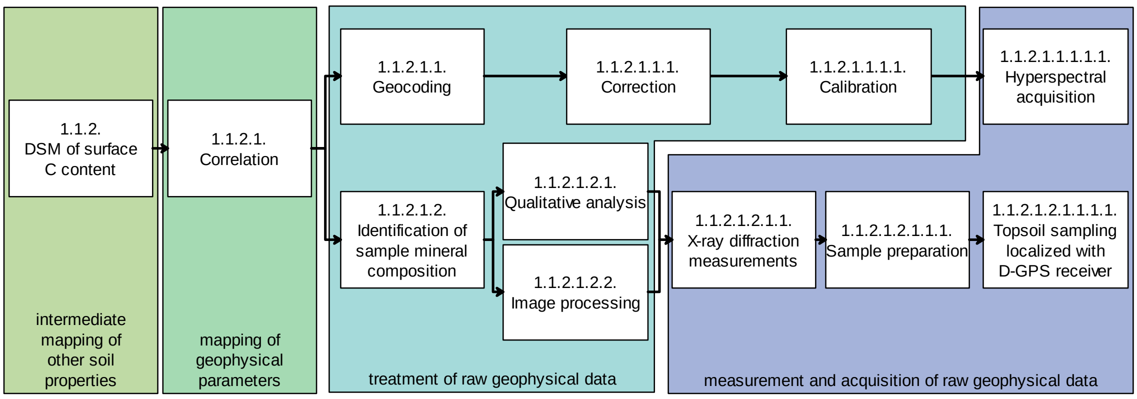

Figure 5: Secondary function 1.1.2. and its antecedent functions

The different derived functions are listed above:

- F1.
  Digital soil mapping of carbon stock; the output is an image representing the carbon stock with a user-friendly layout;

- F1.1.
  Fusion of soil thickness and surface carbon content grids; the output is a carbon stock 2D grid;

- F1.1.1.
  Interpolation of the soil thickness to the expected extension and resolution; the output is a soil thickness 2D grid;

- F1.1.2.
  Interpolation of the surface carbon content to the expected extension and resolution; the output is a 2D grid;

- F1.1.1.1.
  Conversion from seismic velocity 3D data to soil thickness 2D data, using punctual soil thickness data from penetrometry measurements in order to assess the seismic velocity threshold between soil and bedrock; the output is a 2D set of soil thickness;

- F1.1.2.1.
  Conversion from reflectance geocoded maps to surface carbon content maps, using sample mineral composition analysis to correlate hyperspectral reflectance data and carbon content; the output is a surface carbon content grid, with extension and resolution inherited from hyperspectral geocoded maps;

- F1.1.1.1.1.
  Extraction of punctual soil thickness from penetrometry cone resistance data; the output is a limited 2D set of soil thickness (only a few points);

- F1.1.1.1.2.
  3D interpolation of seismic velocity; the output is a 3D grid;

- F1.1.2.1.1.
  Geocoding of corrected hyperspectral data: ortho-rectifying the image overt a digital elevation model;

- F1.1.2.1.2.
  Identification of sample mineral composition;

- F1.1.1.1.1.1.
  Penetrometry measurements are performed with Panda penetrometer, and geolocalized with DGPS; the output is cone resistance data;

Functions interdependences are presented in Table 2. Required outputs of the various functions derived from F1 are presented in Table 3. Their inputs correspond to the output of their respective predecessors.

Function		Predecessors	Successors
1.	DSM of C stock	1.1.	
1.1.	Fusion (multiplication)	1.1.1., 1.1.2.	1.
1.1.1.	DSM of soil thickness	1.1.1.1.	1.1.
1.1.2.	DSM of surface C content	1.1.2.1.	1.1.
1.1.1.1.	Convert from 3D to 2D w/ calibration	1.1.1.1.1., 1.1.1.1.2.	1.1.1.
1.1.2.1.	Correlation	1.1.2.1.1., 1.1.2.1.2.	1.1.2.
1.1.1.1.1.	Extract punctual soil thickness	1.1.1.1.1.1.	1.1.1.1.
1.1.1.1.2.	DSM of seismic velocity (Vp / Vs)	1.1.1.1.2.1. (*), 1.1.1.1.2.2. (*)	1.1.1.1.
1.1.2.1.1.	Geocoding	1.1.2.1.1.1.	1.1.2.1.
1.1.2.1.2.	Identification of sample mineral composition	1.1.2.1.2.1., 1.1.2.1.2.2.	1.1.2.1.
1.1.1.1.1.1.	Penetrometry measurements	-	1.1.1.1.1.
1.1.1.1.2.1.	Vp inversion	1.1.1.1.2.1.1.	1.1.1.1.2.
1.1.1.1.2.2.	Interpolate vertical S-waves velocity models	1.1.1.1.2.2.1.	1.1.1.1.2.
1.1.2.1.1.1.	Correction	1.1.2.1.1.1.1.	1.1.2.1.1.
1.1.2.1.2.1.	Qualitative analysis	1.1.2.1.2.1.1.	1.1.2.1.2.
1.1.2.1.2.2.	Image processing	1.1.2.1.2.1.1.	1.1.2.1.2.
1.1.1.1.2.1.1.	Pick the first breaks	1.1.1.1.2.1.1.1.	1.1.1.1.2.1.
1.1.1.1.2.2.1.	Inverse the dispersion curves	1.1.1.1.2.2.1.1.	1.1.1.1.2.2.
1.1.2.1.1.1.1.	Calibration	1.1.2.1.1.1.1.1.	1.1.2.1.1.1.
1.1.2.1.2.1.1.	X-ray diffraction measurements	1.1.2.1.2.1.1.1.	1.1.2.1.2.1., 1.1.2.1.2.2.
1.1.1.1.2.1.1.1.	Correct the amplitude (AGC)	1.1.1.1.2.1.1.1.1.	1.1.1.1.2.1.1.
1.1.1.1.2.2.1.1.	Compute and pick the dispersion curves	1.1.1.1.2.1.1.1.1.	1.1.1.1.2.2.1.
1.1.2.1.1.1.1.1.	Hyperspectral acquisition	-	1.1.2.1.1.1.1.
1.1.2.1.2.1.1.1.	Sample preparation	1.1.2.1.2.1.1.1.1.	1.1.2.1.2.1.1.
1.1.1.1.2.1.1.1.1.	Seismic acquisition	-	1.1.1.1.2.1.1.1., 1.1.1.1.2.2.1.1.
1.1.2.1.2.1.1.1.1.	Topsoil sampling localized with D-GPS receiver	-	1.1.2.1.2.1.1.1.

Table 2: List of functions derived from F1

(*) *Only either Vp* or *Vs is required, depending on the context (see in text)*

Function	Process	Output
1.	Digital soil mapping of carbon stock	Image representing the C stock with user-friendly layout
1.1.	Fusion of soil thickness and surface carbon content grids	Extrapolated carbon stock 2D grid
1.1.1.	Interpolation	Interpolated soil thickness 2D grid
1.1.2.	Interpolation	Interpolated surface carbon content 2D grid
1.1.1.1.	Determination – with known points – and appliance of bedrock seismic velocity threshold on seismic velocity data	Points (x,y) with punctual soil thickness information
1.1.2.1.	Correlation	Points (x,y) with punctual soil thickness information
1.1.1.1.1.	Determination and appliance of bedrock penetrometry threshold on penetrometry data	Points (x,y) with punctual soil thickness information
1.1.1.1.2.	DSM of seismic velocity (Vp / Vs)	Density distribution
1.1.2.1.1.	Image geocoding	Georeferenced, reflectance orthoimage
1.1.2.1.2.	Identification of sample mineral composition	Presence of minerals of interest and their contents
1.1.1.1.1.1.	Penetrometry measurements	Cone resistance data for calibration.
1.1.1.1.2.1.	Vp inversion	Layering + depth to bedrock
1.1.1.1.2.2.	Interpolate vertical S-waves velocity models	Maps with the vertical distribution of Vs
1.1.2.1.1.1.		
1.1.2.1.2.1.		
1.1.2.1.2.2.		
1.1.1.1.2.1.1.	Pick the first breaks	First arrival time records for Vp inv.
1.1.1.1.2.2.1.	Inverse the dispersion curves	Vs distribution diagrams
1.1.2.1.1.1.1.		
1.1.2.1.2.1.1.		
1.1.1.1.2.1.1.1.	Correct the amplitude (AGC)	Enhanced seismic records
1.1.1.1.2.2.1.1.	Compute and pick the dispersion curves	Dispersion diagrams
1.1.2.1.1.1.1.1.		
1.1.2.1.2.1.1.1.		
1.1.1.1.2.1.1.1.1.	Seismic acquisition	Seismic records
1.1.2.1.2.1.1.1.1.		

Table 3: Outputs of functions derived from F1

3.2. PRINCIPAL FUNCTION F2, DIGITAL SOIL MAPPING OF CLAY CONTENT

Principal function F2 consists in digital soil mapping of clay content.

The method is similar to principal function F1. The output map of function F2 is also obtained by drawing a raster grid. To calculate the clay content, we consider three different parts: surface (or "topsoil"), soil and bedrock. The clay content is estimated for those three different parts, using various geophysical methods. The total clay content is simply obtained by combining the clay content from the three parts.

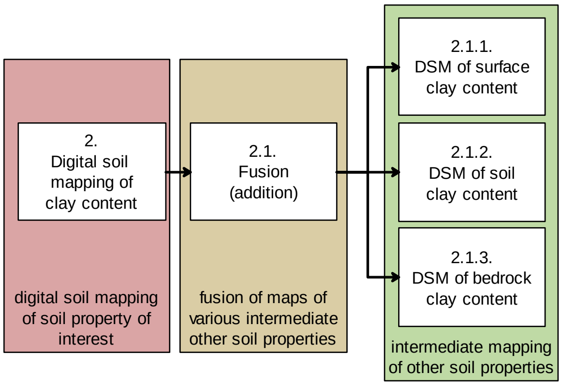

Figure 6: Principal function F2 and its first derived functions

Surface clay content is calculated with statistical processing from reflectance data, which must have been obtained with a hyperspectral acquisition. The reflectance data were already an input to C content calculation; the needed functions to obtain them are inherited from function F1 subfunctions. As for C content estimation, topsoil sampling and analysis must be performed to achieve a correct correlation between reflectance data and surface clay content. Only the correlation function will differ.

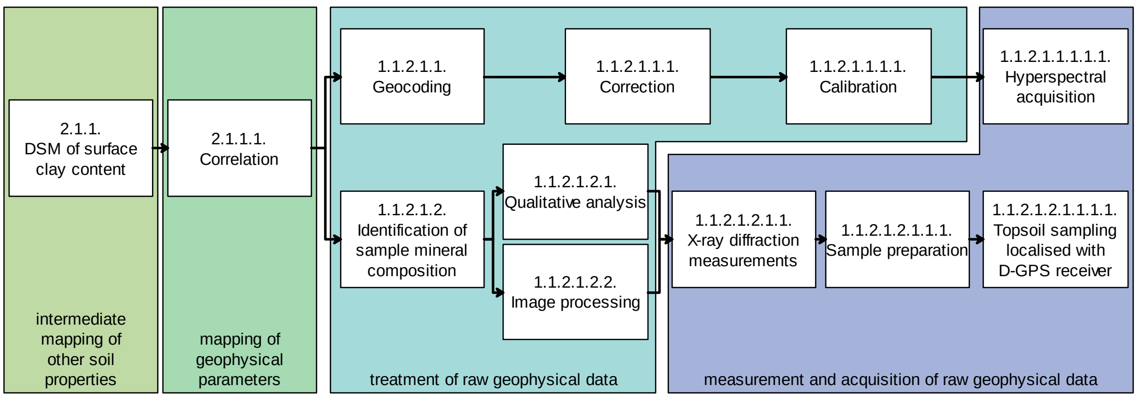

Figure 7: Secondary function 2.1.1. and its antecedent functions

Soil clay content is obtained with conductivity data. Data fusion is performed; the conductivity is sensitive to soil composition and density, and to water saturation. To get the clay content, statistical analysis from samples is performed, and soil map of water content (see function F4) is used.

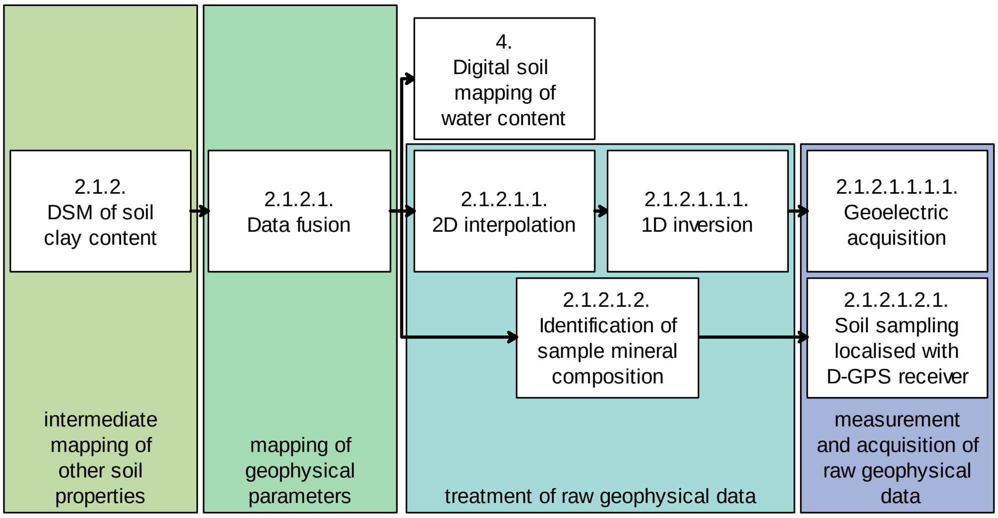

Figure 8: Secondary function 2.1.2. and its antecedent functions

Bedrock clay content is computed with measurements from electromagnetic induction methods. To perform a correct inversion, first measurements must be made on known media prior to the field acquisition, so that they are calibrated.

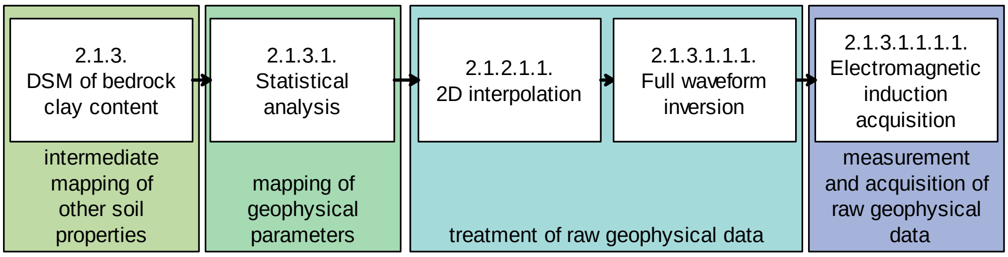

Figure 9: Secondary function 2.1.3. abnd its antecedent functions

Function		Predecessors	Successors
2.	DSM of clay content	2.1.	
2.1.	Fusion (addition)	2.1.1., 2.1.2., 2.1.3.	2.
2.1.1.	DSM of surface clay content	2.1.1.1.	2.1.
2.1.2.	DSM of soil clay content	2.1.2.1.	2.1.
2.1.3.	DSM of bedrock clay content	2.1.1.1.1., 2.1.1.1.2.	2.1.
2.1.1.1.	Correlation	1.1.2.1.1. (*), 1.1.2.1.2. (*)	2.1.1.
2.1.2.1.	Data fusion	2.1.2.1.1., 2.1.2.1.2., 4. (**)	2.1.2.
2.1.3.1.	Statistical analysis	2.1.2.1.1.	2.1.3.
2.1.2.1.1.	2D interpolation	2.1.2.1.1.1.	2.1.2.1.
2.1.2.1.2.	Identification of sample mineral composition	2.1.2.1.2.1.	2.1.2.1.
2.1.3.1.1.	2D interpolation	2.1.3.1.1.1.	2.1.3.1.
2.1.2.1.1.1.	1D inversion	2.1.2.1.1.1.1.	2.1.2.1.1.
2.1.2.1.2.1.	Soil sampling localized with D-GPS receiver	-	2.1.2.1.2.
2.1.3.1.1.1.	Full waveform inversion	2.1.3.1.1.1.1.	2.1.3.1.1.
2.1.2.1.1.1.1.	Geoelectric acquisition	-	2.1.2.1.1.1.
2.1.3.1.1.1.1.	Electromagnetic induction acquisition	-	2.1.3.1.1.1.

Table 4: List of functions derived from F2

(*) Predecessors to F2.1.1.1. are similar to function F1.1.2.1. predecessors; they will be found in Table 2

(**) One of the predecessors to F2.1.2.1. is the main function F4; it will be found in Table 8

Function	Process	Output
2.	DSM of clay content	
2.1.	Fusion (addition)	
2.1.1.	DSM of surface clay content	
2.1.2.	DSM of soil clay content	
2.1.3.	DSM of bedrock clay content	
2.1.1.1.	Correlation	Calibrated compound maps
2.1.2.1.	Data fusion	Compound maps
2.1.3.1.	Statistical analysis	
2.1.2.1.1.	2D interpolation	
2.1.2.1.2.	Identification of sample mineral composition	Soil composition lists
2.1.3.1.1.	2D interpolation	Profile information of Geoph. Param.
2.1.2.1.1.1.	1D inversion	Point information of Geoph. Param.
2.1.2.1.2.1.	Soil sampling localized with D-GPS receiver	Point localized soil samples
2.1.3.1.1.1.	Full waveform inversion	
2.1.2.1.1.1.1.	Geoelectric acquisition	Resistivity/IP records
2.1.3.1.1.1.1.	Electromagnetic induction acquisition	Conductivity records

Table 5: Outputs of functions derived from F2

3.3. PRINCIPAL FUNCTION F3, DIGITAL SOIL MAPPING OF BULK DENSITY

Principal function F3 consists in digital soil mapping of bulk density.

The output map of function F3 is also obtained by drawing a raster grid. To calculate the bulk density, electrical and seismic data, already measured and treated by precedent sub-functions of F1 and F2, are used. To achieve the fusion of those data, the Bayesian maximum entropy (BME) method is used, as presented in DIGISOIL deliverable D2.2.

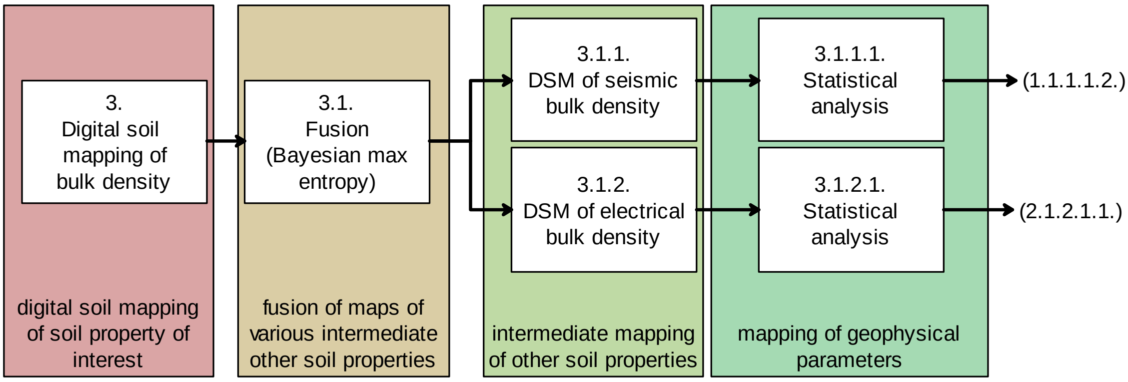

Figure 10: Principal function F3 and its first derived functions

Statistical analyses are performed to get the bulk density from both electrical and seismic data.

Function		Predecessors	Successors
3.	DSM of bulk density	3.1.	
3.1.	Fusion (Bayesian maximum entropy)	3.1.1., 3.1.2.	3.
3.1.1.	DSM of “seismic bulk density”	3.1.1.1.	3.1.
3.1.2.	DSM of “electrical bulk density”	3.1.2.1.	3.1.
3.1.1.1.	Statistical analysis	2.1.1.1.1. (*)	3.1.1.
3.1.2.1.	Statistical analysis	1.1.2.1.1. (*)	3.1.2.

Table 6: List of functions derived from F3

(*) Predecessors to F3.1.1.1. and F3.1.2.1. are similar to functions F1.1.1.1. and F2.1.2.1. predecessors; they will be found in Table 2 and Table 4

Function	Process	Output
3.	DSM of bulk density	
3.1.	Fusion (Bayesian maximum entropy)	
3.1.1.	DSM of “seismic bulk density”	
3.1.2.	DSM of “electrical bulk density”	
3.1.1.1.	Statistical analysis	
3.1.2.1.	Statistical analysis	

Table 7: Outputs of functions derived from F3

3.4. PRINCIPAL FUNCTION F4, DIGITAL SOIL MAPPING OF WATER CONTENT

Principal function F4 consists in digital soil mapping of water content.

The output map of function F4 is, again, obtained by drawing a raster grid. To calculate the water content, dielectric permittivity is used, after inverting the ground penetrating radar (GPR) waveform. It is obtained with GPR acquisition, as presented in DIGISOIL deliverable D2.3.

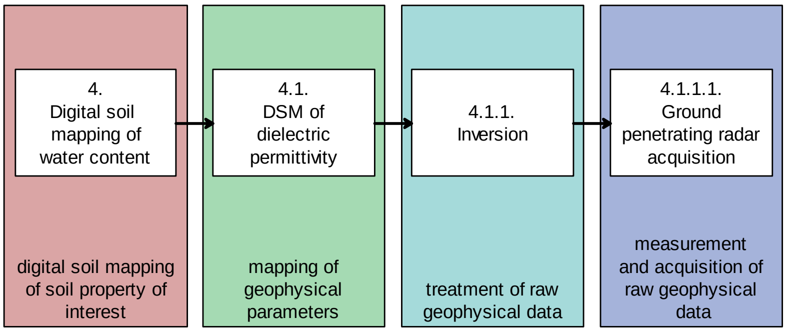

Figure 11: Principal function F4 and its first derived functions

Function		Predecessors	Successors
4.	DSM of water content	4.1.	
4.1.	DSM of dielectric permittivity	4.1.1.	4.
4.1.1.	Inversion of the waveform	4.1.1.1.	4.1.
4.1.1.1.	GPR acquisition	-	4.1.1.

Table 8: List of functions derived from F4

Function	Process	Output
4.	DSM of water content	
4.1.	DSM of dielectric permittivity	
4.1.1.	Inversion of the waveform	
4.1.1.1.	GPR acquisition	

Table 9: Outputs of functions derived from F4

3.5. GLOBAL FUNCTION CHART

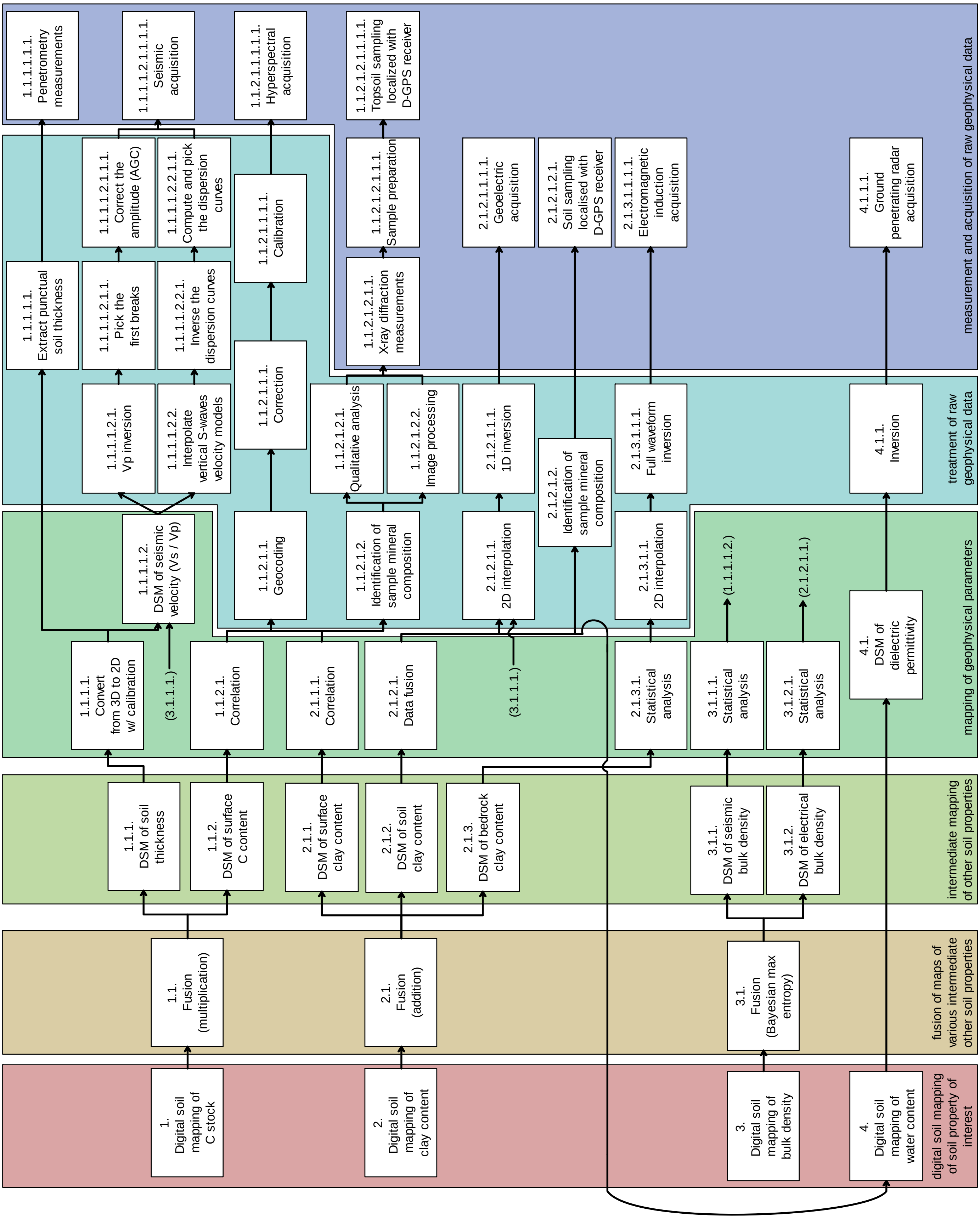

Figure 12: Global function chart

4. Conclusions

This study aimed is to identify what are the hierarchical products the project has to deliver and what are their related constraints and interdependencies in order to specify future industrial works. We focused our attention on what is necessary to produce in terms of geophysical parameters maps and what are the constraints related to them. Results show that the Digisoil's workflows can be described by the following requirements that structure the generation of the final products:

- **Principal functional requirements:** digital soil mapping of soil properties of interest (*viz*. C stock, clay content, bulk density and water content);

- **Derived and secondary functional requirements:** measurement and acquisition of raw geophysical data, treatment of raw geophysical data, mapping of geophysical parameters, intermediate mapping of other soil properties, fusion of maps of different geophysical parameters and/or intermediate other soil properties;

- **Non-functional requirements:** high speed recording, multi-sensor approach, experiments at the scale of parcels, accuracy of the results, accuracy of the measurements, adaptability to the wanted spatial resolution, adapted vertical resolution, usability on the field, interoperability of different secondary functions, digital rendering.

After the functional analysis has been achieved, a synthetic function chart is provided in order to represent the DIGISOIL's workflows.

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