
# Deliverable 13:

# The SNOWMAN Research Programme

# A basis for cooperation between European countries in funding research

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# Summary

To define the scope of the research programme on soil and groundwater, discussions have commenced with "visionaries" from different partner countries of SNOWMAN about future relevant societal developments that will have an impact on soil and groundwater. Based on these developments, the knowledge questions asked by stakeholders of soil and groundwater use and management have been accumulated. These developments and questions are described in Chapter 2 and also presented in Annex 1.
During a workshop with experts, the step from knowledge questions to research needs was made. For the purpose of this workshop, knowledge questions were categorised into soil functions and various questions relating to driving forces, pressures, impact, response and state (DPSIR). The results of this step are described in Chapter 4 and also presented in Annexes 2 and 3.

Other sources of information about research needs have been consulted, from recent national programmes implemented by the SNOWMAN partners, recent discussions and the workshop by the European Commission and other soil and groundwater projects, such as SoilCritZone, SOWA and the ERANET projects IWRM and CREU. This information is described in Chapter 5, 6 and 7 and Annex 4.

Finally all of this input has been used in order to define a comprehensive soil and groundwater research programme, which is described in Chapter 8.
The main elements of this programme are:

- The function of the research programme
  The research programme should, therefore, not be considered to be a fixed framework, but a concrete and stable programme which will be implemented during the next decade. It should be a flexible "á la carte menu" from which SNOWMAN partners are able to select areas of research for cooperation in research funding and the definition of coordinated calls.
  The programme must also be flexible in terms of timing. New societal developments, policy priorities and new knowledge questions during the implementation of policies and technologies, must lead to a continuous adaptation of the programme. A structure, plus procedures for this adaptation should be developed.
- Depth and detail in formulated research needs
  It has proven to be difficult to translate knowledge questions into research needs and potential research projects up to the level of scientific disciplines or research groups.
  The experience gained with calls for research proposals in the partner countries and in the coordinated calls of SNOWMAN, shows that a well-defined scope of knowledge needs and research issues will help to ensure that adequate proposals are received for research projects. The advantage of defining a programme in not too much detail is that researchers are given room and flexibility to propose research on issues of which stakeholders and funders are unaware. The development of a research programme can be considered to be a top-down process, controlled by stakeholders and funders, and the call procedure as a bottom-up process controlled by researchers and scientists. The interaction between the top-down and bottom-up processes will achieve more innovative research that would actually be relevant in practice.

This process resulted in a number of research needs in the complex relations in terms of driving forces, soil functions and type, aspects of research. In order to construct a comprehensive programme, 7 fields of research have been distinguished.

1. Transformation processes

This research area focuses on the function of the soil transformation processes, such as physical, chemical and biological processes required for the soil to function as a system

2. Biodiversity

Biodiversity is an important characteristic of the soil, because of the soil's important role in the functioning of the biosphere.

3. The impact of several driving forces on the hydrological system and responses

A specific characteristic of the soil system is its role in the hydrological system, the interaction between soil and groundwater, and between groundwater and surface water.

4. Climate change and sustainable energy

Climate change and the policy to increase the use of sustainable energy is a driving force that has an influence on several soil functions. For this reason, many research projects need to relate to the impact of these driving forces on soil functions. The effects of this on the carbon cycle is an issue that arises in several research needs

5. The impact of sustainable agriculture

There is a common awareness in a number of countries that we need to change the way in which we produce agricultural products (dairy products and crops) in order to maintain fertile soil with a high yield, without this

resulting in long-term negative effects on the environment. This issue is growing in importance because of the growing need for food and changes in consumption throughout the world.

6. Contamination

Contamination remains a general field of research; this is not specifically related to soil functions, but to the risk to human health and ecological effects and approaches and the technologies required in order to reduce these risks

7. The relationship between soil functions and the role and responses of the socio-economic system.

There are several research needs to change soil quality management from a specific sectoral policy and management issue into an integrated factor in social and economic decision processes

The research programme is based on the aforementioned seven fields of research. The content of the research needs in these fields are described in Chapter 8.4.

# 1 Introduction

SNOWMAN is the ERA-Net for Soil and Groundwater research under the pressure of contamination. SNOWMAN is now an EU contracted project that will terminate mid 2009. The participants of the SNOWMAN consortium intend to continue their cooperation in funding research as a self-supporting network. The network will operate on the basis of an agreement described in two documents:

- The Constitution Paper, concerning the organisation and funding of the network.
- The SNOWMAN Research Programme, which forms the basis for the joint calls of the network.

This report deals with the SNOWMAN Research Programme (SNRP). This SNRP should:

- Represent the research needs towards the sustainable management of soil and groundwater.
- Attract a larger number of funders from European countries, among them the present partners of SNOWMAN, who would commit themselves to fund (parts of) this programme.

In order to create a multinational research programme, various approaches can be followed:

- To use as a basis the threats of the EU strategy on soil;
- To ask for the opinions of researchers;
- To use the societal developments related to soil and groundwater as a starting point.

The latter approach was chosen for the SNRP. This approach has involved the following steps:

- An initial draft of the programme was created, based on discussions with “visionaries” from countries of the present partners of SNOWMAN. The discussion dealt with the relevant societal developments. (Annex 3 outlines the participants of these discussions). This draft focused on the scope and outline of a programme
- In March 2008, a workshop was held in Amsterdam for research funders from several European countries. The relevant knowledge questions relating to the scope of the draft programme that ensued from this workshop have been listed.
- This draft and the results of the workshop, have been discussed with funders based in EU countries that are potentially interested in joining the SNOWMAN project, and with stakeholders, researchers and ministries in the different countries, the NICOLE-network, the Common Forum and representatives of DGR and DGE of the European Commission.
- The knowledge questions have been analysed and structured in accordance with the DPSIR system (Driving Forces, Pressure, State, Impact and Response).
- These results formed the input for the discussion during a workshop with experts, which was held in Gouda in December 2008. The discussion focused on the definition of research needs, based on the knowledge questions.
- All this information formed the input of this second draft of the Research Programme.

In addition to this approach, other sources have also been used for the research programme such as:

- The national research programmes of the countries participating in SNOWMAN.
- The results of the Working Group Research of the EU Soil Thematic Strategy.
- The input of FP6 projects that have identified research needs, such as Joint, Sowa and Risk base.
- The results of projects funded as a result of the first coordinated call of SNOWMAN.

# 2 Scope of the research programme

In the Vision Paper regarding the R&D process[1], a distinction is made between fundamental, strategic and applied research. The scope of these types of research, in terms of timelines (short, medium-term or long-term) and scale (local, regional or national) differs. For international programmes, it seems unlikely that short-term and local problems will be the subject of research projects. In terms of an international programme, the focus will be on more strategic and fundamental research. Sustainable soil management is an activity that has to be implemented in practice, mostly on a regional or national scale with medium-term and long-term perspectives. It is for this reason that it is likely that a research programme has to focus more on strategic research than on fundamental research.

The first coordinated call of SNOWMAN showed that the research projects that have been selected and executed also relate to practical cases and problems. These projects can be considered as being strategic and applied research. This experience shows that a research programme acts as a framework. Within this framework, relevant research projects can be proposed, selected and executed which also include applied research.

Taking into consideration this experience, plus the discussions during the preparation of the programme, a detailed research programme up to the level of research items or projects is not an effective tool for executing coordinated research. The main goal for the programme is to formulate the knowledge questions of stakeholders, policymakers and researchers in an explicit, detailed and structured manner. The programme must be able to function as a clear framework, on the basis of which research consortia of different countries can propose research projects that fit within this framework, that are relevant for research funders in several countries and also relevant for the partners of the project consortia itself.

The scope of the SNOWMAN project is sustainable soil and groundwater management *under the pressure of soil pollution and contamination.* The research programme focuses on the research issues for the next 5 to 10 years. We have to be aware of the fact, that during this period, pollution and contamination is predicted to no longer be the main issue, but instead just one of a number of concerns relating to sustainable soil and groundwater management in several European countries over the next 5 to 10 years. Also, DGEnvironment and DGResearch of the EU must direct their efforts by including soil contamination in upcoming issues that relate to climate change, water management and spatial development.

A consequence of this change in terms of where attention is focussed, will be that soil is no longer a separate issue in itself with its own policy and own problems to solve. In these new issues, soil is an element that contributes to these, or that is affected by these developments. Sustainable soil management will support other relevant societal issues, such as sustainable agriculture, water management, urban and rural development and sustainable energy. Sustainable soil management is to preserve functions of soil that are relevant for supporting sustainability in different societal developments.

Based on these presumptions, discussions have been held with ‘visionaries’ from several countries about relevant societal developments and their relation to soil functions. The results of these discussions are presented in Chapter 3.

[1] Vision paper SNOWMAN, May 2006

# 3 Societal developments and soil functions

Soil quality management and soil policy are not stand-alone activities. Soil quality and soil policy are supportive aspects and activities and are relevant to the development of societies. To define the needs of soil research in the future, we have to discuss the need for knowledge about soil functions and processes that is of relevance to future societal developments.

Figure 1 shows examples of societal activities, supported by soil and soil functions.

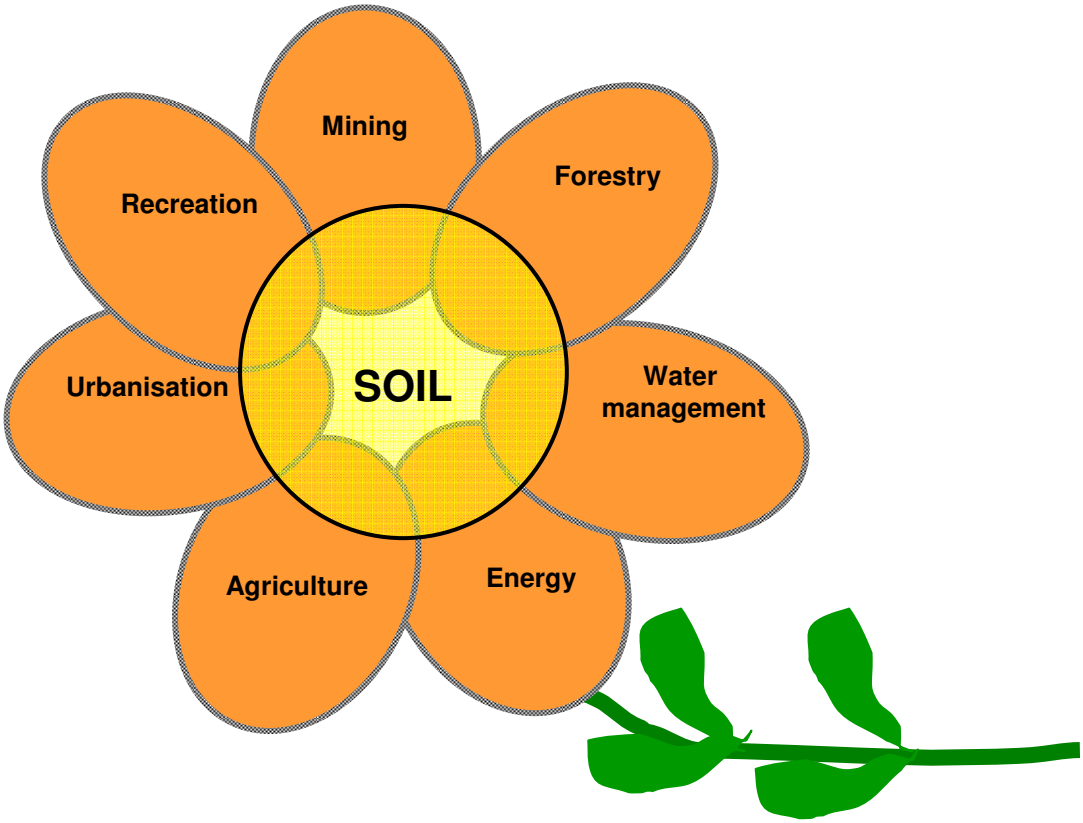



***Figure 1: Examples of societal activities supported by soil and soil functions.***

Not all developments are as relevant in the discussions about future developments and research needs. In the discussion with visionaries, we identified four mainstreams that play an important role in societal discussions, politics and policy making:

- Sustainable energy and climate change. On account of the activities of Al Gore and Bill Clinton, the attention being focused on sustainable energy has grown enormously.
- Sustainable water management. The effect of climate change will cause the hydrological circumstances to change in all European countries.
- Sustainable agriculture. Also induced by climate change and sustainable energy, the growth of products for biofuels will result in a sudden shortage of agricultural land and competition between food and biofuel crops. Also the growth in consumption throughout the world, especially of meat, is a problem for sustainable agriculture.
- Urbanisation. The growth of urbanisation (today more than 50% of the world's population lives in the cities) is creating numerous societal problems.

The knowledge questions that relate to these mainstreams came out of the discussions during the workshop with research funders[2]. The knowledge questions have been organised into several sub-themes as shown below. The detailed information about the knowledge questions is presented in the tables of Annex 1

## 3.1 Sustainable energy and climate change

The subject of this theme is to increase the role of soil for renewable energy production and reduction of the emission of greenhouse gases. There will be an increase in heat and cold storage for cooling and heating to achieve energy savings in soil and groundwater. Thermal heat will be used as a source of renewable energy. To mitigate climate change, there is a policy to reduce the emission of greenhouse gases, such as $CO_2$, $NO_2$ and $CH_4$ or even $CO_2$ will be stored in the subsoil. To influence the carbon cycle, there is a need to increase the fixation of carbon in organic materials (plant roots, vegetation, peat formation).

Knowledge questions relating to these phenomena are:

- Energy saving and sustainable production.
  - What is the potential contribution of soil and groundwater to energy storage and sustainable energy production?
  - Which factors influence soil functions and soil processes?
  - What are the other effects of energy storage on the soil and groundwater?
  - Which strategies should be applied to heat and cold storage in the soil and groundwater?
- Reduction in emissions of greenhouse gasses:
  - What is the present state of the role of soil in the production and reduction of greenhouse gases such as $CO_2$, $NO_2$ and $CH_4$?
  - How does climate change influence soil functions?
  - How does the storage of $CO_2$ and natural gas influence soil functions?
  - How can the fixation of carbon in organic materials (plant roots, vegetation, peat formation) be increased?
  - How can we influence the emission of greenhouse gases?
  - How do we exchange knowledge between countries to accelerate learning?
- Bio fuel crop production:
  - How can we produce bio fuel crops in a sustainable way? What effect does this have on soil functions?
  - How can we respond to bio fuel crop production with management strategies and procedures?
- The effect of climate change on soil quality:
  - What is the effect of climate change on soil functions?
  - How can we respond to climate change effects with management strategies and procedures?

Also related to climate change is the increasing need for attention to be focussed on water management.

## 3.2 Sustainable water management

The increasing need for attention to be focussed on water management, on account of climate change, is caused by several consequences for the hydrological circumstances creating new problems for water management. Changes are also occurring in runoff and the transportation of surface and groundwater due to urbanisation (sealing), compaction and the building of subsurface constructions. There will be a need for areas for inundation and storage of surface water. This will affect the quality of groundwater. Changes in the intensity of rainfall will result in a fall or rise of the groundwater table, that in turn increases the oxidation of peat with $CO_2$ emission or the emission of $NO_2$.

Knowledge questions relating to these phenomena are:

- Retention and flooding:
  - What is the soil's capacity for water storage, infiltration and retention?
  - What is the effect of flooding on soil functions?
  - Which effects can influence the retention capacity of soil?
  - How can soil functions reduce the effects of flooding
- Groundwater quality:
  - What is the state of groundwater quality?
  - Which factors influence groundwater quality?
  - How does groundwater quality support other relevant developments?
  - How can we respond to improve groundwater quality with management strategies and procedures?
- Soil as a water filter:
  - What is the contribution of soil as a function for relevant aspects?
  - Which effects influence the function of soil as a filter?

[2] Workshop Research funders, March 2008 Amsterdam

- Water management strategies:
    - Which developments influence water management strategies?
    - How can we respond to improve retention capacity and reduce the effects of flooding with management strategies and procedures?
    - Management of sediments

## 3.3 Sustainable agriculture

There is increasing interest in the sustainable production of food and bio fuels. The increase of plant and animal disease caused by the intensive use of soil and monocultures raises questions about the sustainability of the present agricultural production. People are showing a growing interest in food safety and the sustainable production of food. Methods are being sought to reduce the use of pesticides. The fast growing production of bio fuels is creating a strong competition in terms of land use, but the sustainability of the production is becoming an urgent issue. Climate change has increased the salinisation of soils caused by evaporation or the rise in sea level. The risk of erosion is increasing due to heavier rainfall. The loss of organic carbon is a problem all over the world. Today's agricultural practises are resulting in a decrease of production owing to compaction and loss of organic compounds. The biodiversity of the soil is also decreasing on account of agricultural production practices.

Knowledge questions relating to these phenomena are:
- What is the role of ecosystem services:
    - What is soil system ecology?
    - What is the role of soil ecosystem services?
    - What impacts soil ecosystem services?
    - How can we respond to improve ecosystem services with management strategies and procedures
- What is the relation between agriculture and soil quality:
    - State of soil quality?
    - Influence of types of agricultural production methods on soil quality?
    - Role of soil functions to support sustainable agriculture?
- What is the role of soil in mineral cycles:
    - What is the influence of land use and soil quality on mineral cycles?
    - How can we respond to improve agriculture and soil quality with management strategies and procedures?
- What is the relation between soil quality and agricultural practises:
    - What is the role of farmers?
    - What is the effect of agricultural policies?
    - What is the effect of agricultural practices on soil quality?
- Role of landslides and erosion:
    - Increasing risks of landslides due to climate change and land use
    - Risk and prevention of erosion
- Relation to urban planning:
    - What aspects influence land use and regional planning?
    - How can we respond to improve agriculture and soil quality with management strategies and procedures?

## 3.4 Sustainable urbanisation

In the future, the process of urbanisation will continue in all countries throughout the world, which includes in the European countries. This means that the emission of contaminants into the soil and groundwater will also continue. During the next decade, questions about risks and remediation of contaminants will remain relevant. Costs of remediation and risk reduction will be compared to investments and the effects of other environmental pollution.
Apart from contamination, the ongoing urbanisation will consume increasingly more green areas, which will lead to redevelopment of existing urban and industrial areas and intensification of the use of urban space. On the one hand, the practice of sealing soils in urban areas will grow and this will have an effect on soil quality. On the other hand, the importance of urban green is growing due to urban leisure, wellbeing, but also due to its positive effects on urban climate (temperature) and air quality.

Knowledge questions relating to these phenomena are:
- Contamination:
    - Risk and risk perception
    - Management of contaminations
    - Remediation
- Urban ecology:
    - Soil as an urban resource
    - Sealing

- Urban planning:
    - Redevelopment of urban and industrial areas
    - Urban spoil, land consumption
    - Urbanisation and soil quality
    - Urban planning

## 3.5 General questions

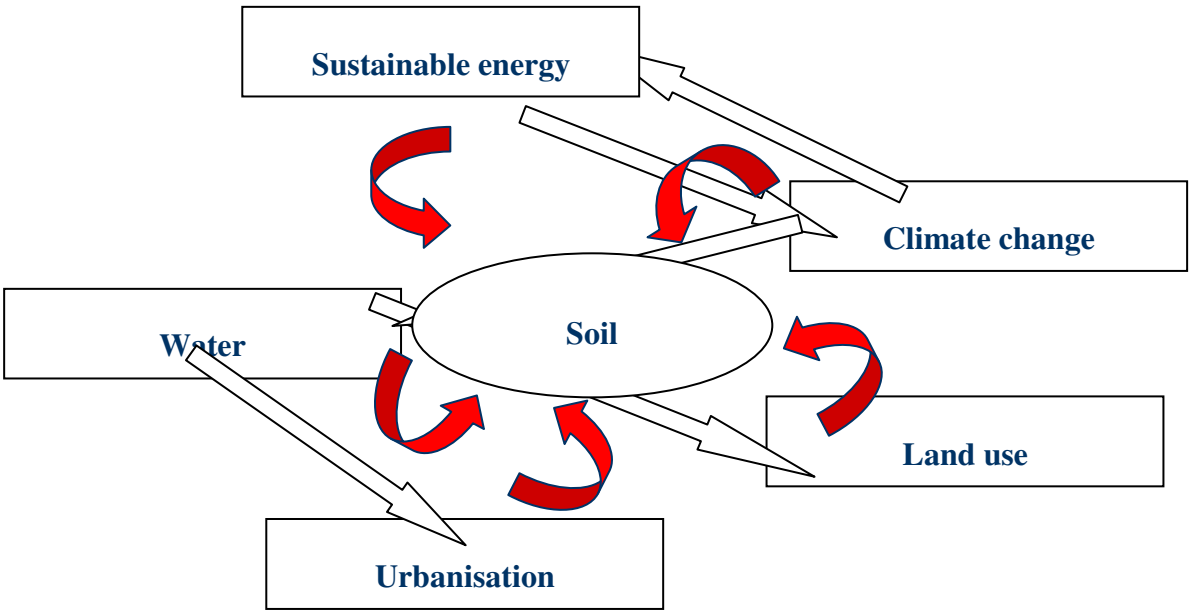
Apart from the knowledge questions concerning the four main societal developments mentioned above, there are also general questions relating to soil quality management:

*Awareness:* To maintain public support for the investments required from public funding for soil remediation, there must be an increased awareness of the role of soil and groundwater in human welfare. A high level of awareness will influence public and industrial behaviour in terms of preventing emissions of contaminants into the soil, as has been the case in the past. The role of soil and groundwater in energy saving and production is underestimated. Soil, groundwater and the subsurface play an insignificant role in the spatial planning decision-making process, because the value of the soil and groundwater and their possible contribution to solving problems is an unknown entity. As many of the decisions in the spatial planning process are based on economic evaluations, the economic value of soil functions must be clarified. This means that tools which can assess the economic value of soil must be developed.

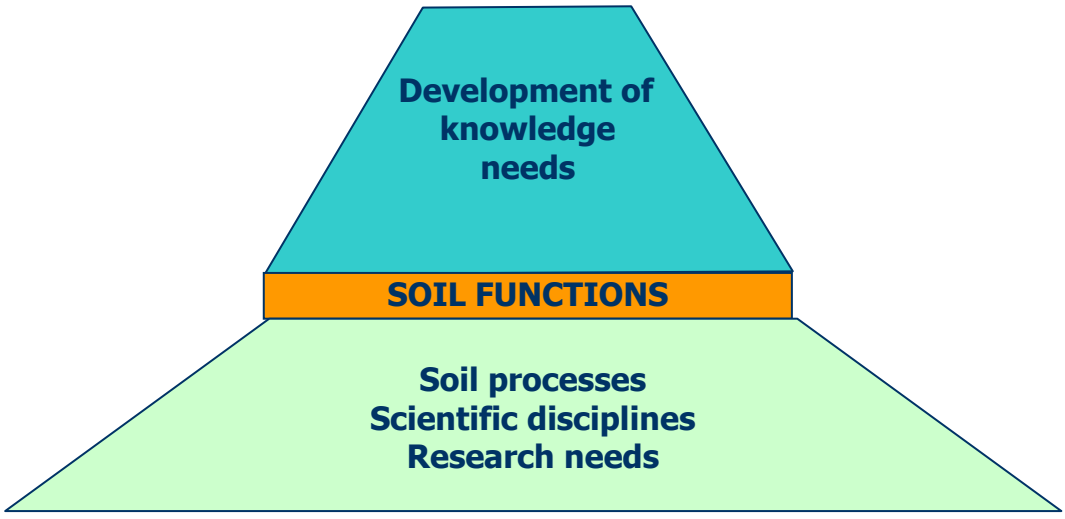
# 4 From questions to research needs

## 4.1 Soil functions as a bridge to research needs

In order to develop a research programme, the knowledge questions of stakeholders and funders have to be translated into research needs. This means that research is required when the answers to the questions cannot be given on the basis of existing knowledge. New knowledge has to be developed to answer these questions.
Research mostly relates to scientific disciplines: hydrology, chemistry, geo chemistry, biology, microbiology, soil science, economy, etc. The knowledge questions cannot be linked to scientific disciplines.
Another problem is that the impact of a variety of pressures from developments on soil is interrelated. Even the main developments described in chapter 3 are interrelated.




For this reason, we have introduced soil function as the bridge between societal developments and knowledge questions on the one hand, and research needs on the other hand.



Soil functions are influenced by several impacts and pressures from numerous societal developments. Pressures and impacts on soil functions can relate to (physical, chemical and biological) processes in the soil. In this way, a link can be made to specific scientific disciplines and fields of research.

There are several ways of defining the functions of the soil. A number of the functions of soil relate to the threats mentioned in the work of the Working Group Research of the EU Soil Thematic Strategy. In this structure, groundwater is considered to be a raw material for the production of drinking water, for enabling agricultural production, etc. In terms of the storage function, this also includes the storage of carbon .

1. Production (of biomass through agriculture and forestry)
2. Source of biodiversity (habitats, species, genes)
3. Filtering and transformation (of nutrients, other components)
4. Source for raw materials: groundwater
5. Storage (including carbon)
6. Physical and cultural environment (for human activities)
7. Archive for geological and archaeological heritage

## 4.2 Driving Forces, Pressures and Impacts

In environmental policy, the DPSIR cause-effect chain is often used. The research needs are analysed according to this system of Driving Forces (D), Pressures (P), State (S), Impact (I) and Response (R). This system is also used in the report published by the Working Group Research of the Soil Thematic Strategy[3].

The main societal developments mentioned in Chapter 3 can be considered to be driving forces, thus creating pressures on soil functions. Research will focus on the impact of these pressures on soil functions, the way we can respond to these impacts, and again, the impact of these responses on the functions of the soil. As a result of impacts, responses and the effects of these responses, the state of the soil and soil functions will change. Research can also focus on monitoring and analysing the developments of the state of soil functions.
In this respect, it is possible to categorise the knowledge questions into questions relating to impacts, responses and the state of soil functions. The result of this analysis is presented in the tables of Annex 2.

## 4.3 Research needs

Based on the knowledge questions structured according to the DPSIR tables, during a workshop, experts were asked to express the need for research in order for these questions to be answered. The participants of this workshop are named in Annex 3.
Based on the results of this workshop, the main fields of research needs relating to soil functions can be identified. It also clarified the fact that there are knowledge questions relating to issues for which no research needs are mentioned. This could mean that sufficient knowledge is available regarding this issue, or that there is no scientific interest in research relating to these knowledge questions in the expert group.

The results of the expert meeting, relating to the various soil functions, can be summarised as follows:

### 4.3.1 Production

- There is an awareness that the production of food has to increase by 40% before 2040. This means an increase in the use of soil for food production, however that results in strong pressure on the intensification of food production. There is a need for data about the growth of the area of land used for food production and an increase of production capacity on national and global bases.
- There is a need for research about the impact of the production of biomass for biofuel production on soil functions and quality, plus on the impact of the use of organic residues from biofuel production on soil quality and the carbon cycle, which differ on account of residues from food production.
  There is a similar need for research on the effects of the production of transgenic crops on soil quality.
- Most of the research needs relate to the way in which we are able to respond to the pressures and impacts mentioned above and the effects of this response.
  - How can we increase the societal awareness about the main dilemmas relating to food production.

[3] Winfried E.H. Blum: European Union Soil thematic strategy, Working Group Research, March 2004.

    - On the one hand, there is a societal resistance against intensive agricultural production methods, but on the other hand, will the growth of demand for food imply intensification of production methods. How do we cope with this dilemma?
    - There has been a change in the foods consumed by people in the world that has led to an exponential growth of meat consumption. Meat, as a source of protein, requires a considerably greater amount of land (and water) than other sources. This change in diet is an additional pressure on the use of land for food production. How can we make people aware of the consequences of their changing diet?
  - How can we reduce the loss of valuable agricultural land through urbanisation, or the loss of quality through contamination, salinisation or desertification?
  - How can we develop more resilient, high-productive land in a way that intensification of production will have less negative effects and will not degrade valuable productive land?
  - Are we able to make a cost benefit analysis of the complete chain of growing biofuel crop, from sewing to harvesting, the production of bio fuels and end waste?
  - What are the potentials of growing bio fuel crops on contaminated or marginal land?
  - How can we achieve sustainable food production, using less pesticides and fertilizers, without an increase in the use of land?
  - Can we make a cost-benefit analysis about the different forms of adding nutrients like manure, compost, sewage sludge, fertilizers and the addition of contaminants related to those forms of nutrient sources?

No research needs were identified in relation to:
- forestry and forestry practices
- the production of bio fuels as such (the type of crops, suitable land) or the combination of bio fuel crop production and soil remediation and phytoremediation
- the production of greenhouse gases
- the relation between production and erosion
- the effects of agricultural production methods on other soil functions including biodiversity
- Methods to enhance soil processes to increase the amount of organic material in the soil.

### 4.3.2 Biodiversity

Most research needs that are identified relate to the questions about the meaning of biodiversity, how to measure and monitor biodiversity and about the role and importance of biodiversity. A statement has been made that, without this knowledge, it is not worth carrying out research about the impacts or response to those impacts.

Research needs that have been identified relate to:
- What is the definition of a “healthy soil” with respect to biodiversity?
- Which parameters are relevant in terms of measuring and monitoring biodiversity?
- Which organisms are active and why?
- What is the role and value (economical, societal) of biodiversity/? How can we make people aware of this value in spatial planning and changes in land use?
- What is the role of biodiversity in mineral cycles?
- What is the biodiversity in “hot spots” in the rhizosphere?

Regarding the impacts, a research need is indicated about the effects of climate change on ecological changes and changes in biodiversity of the soil.

Furthermore, there are different needs which relate to responses to changes in or the use of biodiversity. One research question relates to the improvement of quality of urban soil which is relevant for knowledge questions about the role of soil and green areas in the urban environment. According to the general statement that was made, while we have insufficient knowledge about the principles of biodiversity, these needs are irrelevant. This also explains why no research has been identified in relation to questions about the way in which we can use biodiversity for sustainable agriculture, reduction of pathogens and decision support tools to manage biodiversity.

Nevertheless we cannot ignore the numerous knowledge questions about the impact of pressures on biodiversity, which include:
- The effects of climate change and water management, such as temporary flooding
- The effects of agricultural practices, such as intensive production of monocultures, compaction
- The relation between biodiversity of the soil and biodiversity on the soil and in water, the role in the ecological infrastructure, corridors and stepping stones

- The role in the formation and preservation of natural areas.

### 4.3.3 Transformation and Filtering

Many soil processes play a role in this soil function. A general remark has been made that we mostly respond to one single process (e.g. remediate contamination) and that we monitor the quality of the soil for that particular parameter (contaminants). However, we are not aware of the effects of this response on all other soil processes. We should start to conceptualise a model for an integrated holistic approach to soil as a physical, chemical and biological system.
Some research needs relate to the state and role of transformation processes in the soil:
- What are the key parameters to defining a healthy, properly functioning soil? Is that dependent on the way in which the land is used? Can we make people aware of the soils state of health ?
- How can we valorise the transformation function of the soil?
- Can we bridge models from micro-scale to macro-scale for specific parameters?

There are research needs to study the impact of several pressures on the transformation function of soil:
- What are the effects in terms of time and resilience towards the buffering capacity of greenhouse gasses, such as $CO_2$, $CH_4$ and $NO_2$?
- What are the effects of climate change, such as temperature changes and flooding, on the binding of components, pH changes, oxidation of organic matter and other changes involved in the transformation processes?
- What is the fate and what are the effects of emerging components, such as antibiotics?
- What is the effect of soil remediation technologies on soil functions, such as the transformation processes?
- What is the fate and what are the effects of pesticides. Are models for breakdown and fate reliable? Are the specifications of admissible pesticides reliable?
- What are the effects of different kinds of land use on transformation processes?

Research needs relating to responses towards these impacts are:
- How can we enhance transformation processes that play a role in the emission of greenhouse gasses?
- Restoration of transformation processes after soil remediation or replacement of contaminated soil by clean soil (dig and dump)?
- How can we improve transformation processes in urban environments (perhaps by artificial soils)?
- Can we modify models in such a way that decision makers can use them?

No research needs were indicated in areas in which several knowledge questions have been identified:
- About the importance of the role of transformation processes in the emission of greenhouse gasses and the monitoring of changes in that role
- About the impact of heat and cold and energy storage on transformation processes
- About the impact of changes in land use on the transformation of organic material and emission of $CO_2$
- About the impact of agricultural practises on transformation processes
- About responses in water management, forestry and agriculture to reduce mineral transfer to water and air, to reduce acidification and to increase the amount of organic material in the soil
- About the regional management of nutrients, biomass and water
- About the relation between global development and effects and responses on a regional and local scale.

### 4.3.4 Source for raw materials: Groundwater

As a source of raw material, soil can deliver sand, stones, clay, peat, oil and natural gas. However, in this research agenda we focus on groundwater, a valuable “raw material“ for drinking water production, for growing forests and food and the production of food and beverages. It has been suggested to split this item into quantitative and qualitative aspects, but there is too much interaction between quality and quantity to do so.

There is only one issue concerning the state of groundwater, which is that there is a lack of data concerning the relation between the quality of groundwater and the quality of surface water.

The other research needs concern dealing with impacts on groundwater and the effect of responses.

Research needs to study the impact of several pressures on groundwater:
- Effects of energy storage on temperature changes, groundwater level and chemical equilibrium of components in the groundwater
- Models to calculate distribution of heat and cold
- Effect of monoculture production of biofuel crops on groundwater quality and quality

- Use of groundwater for bio fuel production
- The effects of climate change and the use of land on groundwater quality and quantity
- The effects of (temporary) flooding
- The effects of agricultural practices on quality and quantity, such as:
    - Buffer zones between land and surface water
    - Run off and infiltration of nitrate and phosphate
    - Erosion
    - Effect on groundwater level and reverse effects on agricultural production
- Effects of sediments on groundwater quality.
- Sources and effects of diffuse contamination including pathogens
- Effects of land use on quality

Research needs relating to the effect of responses:
- Decision support systems for decisions about using groundwater or surface water
- Effect of geomorphologic changes (mining) on quality
- Enhancement of transformation processes to improve quality
- Removal of phosphate by mining or reduction of sources
- Development of risk assessment tools for mixed contaminants and holistic risk assessment
- Development of tools for budgeting remediation of mixed contaminants
- Managing the groundwater resource with respect to:
    - Land use
    - Sealing
    - Infiltration
    - Filtering
    - Models on catchments scale and connections with local and intermediate scale for decision making purposes
- Development of management options to deal with historical contaminations that cannot be remediated.

There are also a lot of knowledge questions that have been formulated, which are not addressed by research needs:
- Definition of sustainable groundwater quality and ecology
- The role and importance of groundwater in development and preservation of natural areas and agriculture
- The need for strategic clean groundwater reservoirs
- The interactions between energy storage (heat and cold) and drinking water production
- The creation of pollution pathways by the construction of infiltration and extracting wells
- The effect of peat oxidation on drinking water quality
- The pressures and impacts of urbanisation on groundwater quantity and quality caused by sealing, compaction, underground constructions, growing consumption and use
- Effect of hazards in polluted areas
- Interaction between upstream and downstream interests
- Transfer of organic compounds from upland soil
- The consequences of the water framework directive
- Management strategies for improvement of retention capacity
- Management strategies for groundwater in urban areas related to water surplus, quality, reduction of diffuse contamination, soil quality, planning of use.

### 4.3.5 Storage (including carbon)

Included in the soil function of storage, we also consider the storage of carbon in different forms ($CO_2$, organic material bio char). The general opinion is that the research into the storage of $CO_2$ is completely covered and no additional research is needed.

Identified research needs are:
- The capacity and the limits for storing heat and cold
- Using data from artic ice layers to study what has happened to $CO_2$ and using labelled $CO_2$ to study the uptake in plants, the atmosphere and soil

Considering the general opinion, this research does not have a high priority.
With relation to the impacts:
- The effects of storage of energy on soil quality
- The effect of long droughts on the storage capacity of groundwater

With relation to responses:

- Management options to reduce oxidation of peat
- Effect of land use on the binding or emission of $CO_2$
- The effects of storing carbon in the form of bio char: stability, effect of accumulation of other components
- The role and effects of sub-surface storage of water
- The relation between urban planning and river basin management
- Management of sealing to minimise storage capacity for water
- Need for storage capacity in the sub-surface in cities; planning of capacity
- Advantages and disadvantages of the storage of contaminants (phosphate, metals) in soil
- Possibilities and effects of disposal of sediments in brownfields

Formulated knowledge questions that are not addressed by research needs, are:
- Improvement of spatial planning and characteristics of soil for energy storage and energy savings
- The role of soil in the carbon cycle in general: is there a negative or positive balance, what are the long term dynamics, what is the heterogenic spread in being a sink or source for carbon
- Effects of climate change, erosion and soil conditions on retention and infiltration of water
- Strategies to improve the storage capacity of soil and retention of rainwater
- Strategies, capacity and combination with other functions and remediation of storage of heat and cold

### 4.3.6 Physical and cultural environment (for human activities) Archive for geological and archaeological heritage

There are research questions about the meaning of cultural aspects of the soil as a physical part of our environment relating to geomorphology, colour and smell as physical evidences of history and cultural heritage.

There is also a need for more data and information about erosion, deforestation and reforestation and the development of reclaimed land, contamination and erosion of reclaimed land.

Regarding the impact on the physical characteristics of soil research, the needs are:
- Effects of different kinds of sealing
- Interactions between soil and the atmosphere
- Relation between erosion sensitive areas and soil use

Regarding the responses to these impacts, research needs have been formulated with regard to:
- Reducing or improving permeability on a small scale
- Effects of sub-surface constructions on soil and the effect of soil on constructions
- Using GIS to predict urban sealing
- Compensation of sealing (green roofs)
- How to deal with archaeological relics
- Effects of changes in soil functions (transformation) on archaeological relics

No research needs were formulated for knowledge questions:
- The effects of compaction and the development of models and strategies to reduce compaction
- Relation between climate change and the occurrence of land slides, tools and strategies to predict land slides, early warning systems
- The effect of climate change on erosion, tools (risk maps) and strategies to reduce the risks of erosion

### 4.3.7 General

Not many knowledge questions related to soil functions, so we included these in a table under the heading of General.
Only a few research needs have been identified relating to the general questions, although research needs formulated within the soil function tables also reflect general questions.
The research needs which have been identified point to the following:
- Meetings with experts to start an awareness process about the value of soil processes
- An explanation to the public about the role of soil and effects of contamination
- How to connect the environmental and social value of soil with the economic system
- Development of information and tools to link soil issues with spatial planning
- Assessment of sustainability of development of brownfields relating to the development of green fields.

No research needs have been formulated relating to:

- Effective strategies and methods for raising awareness by public and policy makers
- Public and private practices relating to land use changes and the land market
- The economic value of soil functions, dealing with conflicts in soil use and integrate soil functions into decision making about soil use
- Tools for economic evaluation of soil remediation measures, effects on value of real estate, cost benefit analyses, internalisation of costs
- Mechanisms to shift from short term aspects in decision making to long-term effects and sustainable use of soil
- The relation between soil quality and health and food safety
- The role of soil and soil characteristics in sustainable agriculture. Harmonisation of risk assessment tools
- Management, evaluation of soil remediation technologies and approaches
- Management of contaminated sites and areas
- Integration of soil characteristics in urban planning

**Contamination**

SNOWMAN started off as a network of research funders in the field of contaminated soil and groundwater. Since that time, in some of the SNOWMAN countries, the policy created to manage the problem of contamination has matured in such a way that no further national research funding is available in this field. In some other countries, however, contamination is still a research issue.
This results in a transition phase where some SNOWMAN partners will launch research calls in the field of contaminated soil and groundwater.

Existing research that has been identified are:

- *The role of the filtering capacity of soil for the attenuation and storage of contaminants:*
    - Which soil types are good and which are bad in filtering and storing pollution? What are the possible long-term releases of which contaminants?
    - How does soil work, what kind of soil interfaces with different pollutants?
    - How resilient is the soil filter capacity in the long term? Can you improve resilience? What is destroying the filtering capacity?
    - What is the behaviour of heavy metals in the unsaturated soil? Which processes effect mobilisation and demobilisation?
    - How does the soil ecosystem influence the filtering capacity and groundwater quality?
    - How can we change scale: from the local scale (site scale) to the regional scale: which tools, extrapolation methods, models? How should soil (local) models be linked to water catchment models?
    - How can we value the function of soil filtering?

- *Risk assessment of contaminants:*
    - Improvement of risk assessment methods
    - Quantification of risks from contaminated areas (cancer/TDI). How many individuals are affected, which individuals are they, can they avoid being affected?
    - How great is the impact on ecosystems (ecosystem services)?
    - How do the risks change over time? What is the effect of remediation measures?
    - The interaction between contaminated land – groundwater - recipients – catchments areas
    - Methods for validation of exposure and load
    - A tool for comparison of the sustainability of different remediation solutions
    - Tools for risk evaluation concerning ecological, economical and social/cultural aspects
    - Tools for decision support/consequence analysis/prioritisation
    - Fill gaps in knowledge for important parameters in risk assessment models (human and eco toxicology of pollutants, physical/chemical data, abundance/behaviour of exposed organisms etc)
    - What relation is there between risks from soil pollution and other environmental risks
    - Which part of human and ecosystem exposure is coming from contaminated land vs. other sources
    - How to estimate the total pollution load on a recipient

- *Regional management of contaminations:*
    - How do we shift from a site-specific approach to an area approach.
    - Sustainable management of contaminated land in urban areas
    - Management of multiple pollution sources
    - Discrimination of sources of pollution in a specific area

- What are the costs for management of diffuse polluted land What are the economical aspects of risk evaluation /risk management
- How to calculate the societal costs for land use restrictions?
- Methods for comparison between different investments: remediation projects/environmental projects/other societal projects

Due to the fact that there is a lot of knowledge within Europe about contaminated soil and groundwater, but the distribution of this knowledge is limited SNOWMAN should encourage the dissemination of knowledge between the different countries.

# 5 Recent research needs from SNOWMAN partners

During the workshop held in Gouda, the Netherlands, in December 2008, experts who had been invited from the countries of the SNOWMAN partners, gave an overview of the research needs The main issues are indicated below.

## 5.1 Austria

In Austria a programme is still under way about remediation technologies and on-site investigation and risk assessment for so-called "Altlast" sites.
Additionally, large portion of research funds are invested in climate and energy. In Pfeil 10, a programme which is running from 2006 until 20120, the research items concerning climate change and soil are:
- Climate change and adaptation
- Resource management of soil and water
- Organic farming
- Biodiversity and ecosystems
- Rural development

## 5.2 Flanders (Belgium)

In Flanders, research on soil and groundwater is funded by the Flemish government. The research budget is divided between several institutions and governmental organisations, which are responsible for the execution of the policy regarding the different aspects of soil and groundwater.

As an example, OVAM's research agenda,is restricted to soil and groundwater contamination and remediation. Research initiated by the OVAM focuses on two themed areas: policy-supporting research and technical-scientific research. This latter themed area focuses on research about risk assessment and the development of standards, developing alternative methods for soil investigation (measurement techniques and characterisation methods) and new remediation techniques (testing, development of methodologies etc, with a special focus on diffuse contamination).

The policy-oriented research is focussed on the strategic priorities of the ruling government and the strategic plans which derive from it. Over the past years, special attention has been paid to the management of soil contamination, investigation and remediation of polluted sediments, development of alternative ways of financing soil remediation, brownfield redevelopment and the management of polluted urbanised or regions suffering from diffuse pollution.

Other governmental organisations, such as VMM, VLM and LNE, also have research agendas oriented towards, respectively, water and sediments, fertilisation of soil and monitoring/evaluation of soil data, erosion and the use/management of natural resources.

Every year, a common research agenda is drawn up (Technical-Scientific Research for the Environment) which includes all research projects that have been planned for soil and groundwater. In 2009, the focus, relating to soil and groundwater, has been on:
- The management of soil data
- Integral water management
- Climate change
- Salinisation
- Fertilisation
- Soil pollution
- Pollution of surface water.

## 5.3 France

In France, the main issues for research are:
- Contamination on a regional scale (water bodies)
- Emerging contaminants

- Climate change impacts

**Remediation:** there is a need for a more holistic approach towards remediation. Which remediation approaches are sustainable? How do we balance remediation approaches with respect to other environmental investments (water, air) or economic aspects? There is a need for a standardisation of assessment tools for the sustainability of remediation approaches.

In terms of remediation, the focus is still on source pollution and remediation. Research issues are:
- 3D spatial heterogeneity
- the balance between characterisation (less) and remediation (more)
- fate of dense phases in chalk spreading of DNAPLs and LNAPLs
- quantification and prediction of natural attenuation
- improving the application of and confidence in in-situ remediation
- demonstration and verification of remediation technologies
- dissemination of knowledge

In terms of brownfield redevelopment, the specific research needs are:
- multi-criteria analyses tools
- public participation in redevelopment
- drivers and constraints in redevelopment
- data for redevelopment alternatives
- raising confidence in existing methods
- efficiency assessment of remediation technologies

With respect to the effects of climate change, there are still many uncertainties. The climate scenarios are uncertain, as is the effect of climate changes on soil. The effects depend on regional circumstances and also on political situations. In Eastern Europe, the economical restoration is more important than climate change. Research issues relating to agriculture are:
- the production of non food on degredated soils
- the effect of antibiotics
- the role of soil in the carbon cycle
- parameters and indicators for healthy soil
- non-invasive characterisation technologies
- dynamic characterisation and prediction
- the impact of future policies

In terms of climate change, agriculture as well as brown field redevelopment, the application of socio-economic sciences is of importance.

## 5.4 The Netherlands

In the Netherlands, two new research programmes are under preparation. The first one is an applied research programme. It aims at the four research issues listed below:

- Soil and energy:
  - The storage of heat and cold in aquifers: potential and effects
- Soil and climate change:
  - Effects on hydrology and the soil ecosystem
  - Consequences for drinking water production from groundwater, groundwater need for agriculture and natural developments
  - Droughts, salinisation, peat oxidation, emission of greenhouse gasses
- Sustainable agriculture:
  - Role of biodiversity in sustainable agriculture and the development of natural areas
  - Carbon cycle, increase of organic compounds
  - Mineral cycles, fertility of soil
  - Retention of rainwater
- Sustainable urbanisation:
  - Subsurface constructions and infrastructure: the effect on soil functions
  - The development of metropolitan parks
  - Urban ecology: role and development
  - Urban spatial planning of the subsurface
  - Brown field redevelopment

The second programme in the list is a more strategic/fundamental research programme. It aims at the pressures and impacts on soil functions. In this approach, soil functions are combined in three different research areas. Apart from that, there are two more general research areas. The main research issues are:

- Soil biodiversity and the related function and service in the context of historical development ('memory') and current environmental change. Organisms, food web interactions and ecosystem services, in which research focuses on the crucial role of the biosphere within the sub-surface in regulating the fluxes by transforming energy and matter;
- The interplay between physical, chemical, and biological processes that determine the functioning of the subsurface. Fluxes, transformations and interfaces, providing the framework for studying the sub-surface as a dynamic system that reacts to changes and inputs as a result of natural processes and human intervention.
- Dynamic processes in the heterogeneous multiple scale sub-surface focusing on the effects of these fluxes, biotic and a-biotic transformations and interfaces as they manifest themselves throughout the sub-surface over a wide range of scales ranging from molecular reactions on mineral surfaces and within micro-organisms to the continental scale in which ocean landmass interactions are studied;
- Integrated measurement and monitoring, in order to understand and visualise. Measurement, monitoring and research methodology providing the new developments required for carrying out experiments which provide information about the processes occurring in the sub-surface to which access is very limited and in which the timescales of change can be very large
- Identification and understanding of (un)known forms of metabolism in the subsurface
- The consequences of Economic globalisation and the consequences for regional and local socio-economical drivers for land-use change and soil quality. Social, legal, economic and political aspects of utilisation of the sub-surface is an essential research theme within the programme, focusing on understanding the economical, political and social aspects related to the sub-surface as driving factors for utilisation of the new insights by society

## 5.5 Sweden

Sweden still needs to focus research on contamination and remediation.
A Swedish knowledge programme called "Sustainable Remediation", which has been running from 2004 to date shows that there is a need for research and knowledge in the area of contamination.
Some of the research needs:
Site investigation

- New investigation and analytical methods
- Methods for measuring actual exposure

Risk assessment

- Improved risk assessment methods
- Fill gaps in knowledge for important parameters in risk assessment models

Diffuse pollution vs. contaminated land

- Part of human and ecosystem exposure coming from contaminated land vs. other sources
- How to estimate the total pollution load on a recipient
- The interaction between contaminated land – groundwater - recipients – catchment areas
- Methods for validation of exposure and load

Risk management/risk evaluation

- Tool to compare the sustainability of different remediation solutions
- Tools for risk evaluation concerning ecological, economical and social/cultural aspects
- Tools for decision support/consequence analysis/prioritisation

Remedial solutions

- Demonstration and validation of innovative solutions and/or solutions with uncertainties in the long-term effectiveness
- Low cost methods for contaminated areas with low interest from all parties
- Organisational aspects of remediation projects
- How to measure effects of remediation (local and regional scale, environmental, health, impact on society etc)

Economy (Environmental and societal)

- Effects of remediation vs. costs of remediation
- Costs for management of diffuse polluted land
- How to calculate the societal costs for land use restrictions?

- Economical aspects of risk evaluation /risk management
- Methods for comparison between different investments: remediation projects/environmental projects/other societal projects
- Impact on competitiveness for companies with responsibilities for contaminated land

There is also a research programme at the North Sweden Remediation Centre (MCN), which aims at advancing soil remediation and science, which will run until 2011. Risk assessment, the source, path- receptor approach are just a few of the important issues. Today, in Sweden, ex-situ treatment is the main approach and there is a clear need for the development of remedial technologies adapted for cold climate. Among the more than 10,000 sites estimated in risk classes 1 and 2, which are of most concern, contamination related to wood-paper industrial activities are of importance. Here, chlorophenols (dioxins), creosote and CCA are important compounds (wood preservation) and diffuse pollution is receiving more attention. Specific climate factors found in the Nordic countries, as well as other Alpine countries, are of particular relevance and the effects of the climate and climate change are gathering more attention. For example the impact of the spring flood (now and in future scenarios) is important because of the accumulation of several contaminants through long-range transport (i.e. diffuse pollution) and subsequent atmospheric depositions in snow. Considering a wider perspective, there is an urgent need to quantify the importance of different sources and their relative contribution to the environment, in order to gain optimal effect of different remedial activities. Land to sea transport are especially relevant for the protection and recovery of the Baltic Sea.
Some research topics are:

- Transport and fate of contaminants in direct and indirect pathways
- Exposures and effects
- Risk assessment tools
- Tools for prioritisation
- New remediation alternatives

## 5.6 The United Kingdom

Research topics in the United Kingdom are:

- With respect to water management:
    - Competition between agricultural and urban demand
    - Loss of aquatic biodiversity (due to irrigation)
    - Phosphate and nitrate in surface water
    - Pathogen sources, transfer and risks
- With respect to agriculture:
    - Decline of organic carbon (colder and wetter soils)
    - Methane and nitrous oxide emission from grasslands
    - Carbon sequestration in lowland soils
    - Quality of organic wastes and return to land (biochar)
    - Acceleration of erosion
    - Increased surface water run off, flooding, sediment transfer
- With respect to urbanisation:
    - Reduction of green land for urbanisation
    - Urban food production: marginal or intensive

Many research projects are still underway concerning soil contamination and remediation. There is also a focus on knowledge dissemination (Cl:aire) and brown field redevelopment.
In respect of the European soil strategy research needs are:

- Effects of and adaptation to climate change
- Declining quality due to agriculture and contaminated land
- Sustainable remediation or sustainable regeneration of land

# 6 Research needs from other sources and projects

## 6.1 European research agenda on soil

In a consultation with DG Environment (Luca Marmo and Niek de Wit), it seems that there is no current specific research agenda on soil and groundwater. Climate change has a high priority and, in that respect, the contribution of soil to mitigate climate change, or the contribution to the adaptation to climate change are of interest. A symposium held by DG Research in May 2008 was dedicated entirely to this subject. In addition to the role of soil as a carbon sink, changes in biodiversity, soil degradation and the prevention of land slides due to heavy rainfall and flooding as effects of climate change, are on the research agenda. There is still a lack of data about the role of soil as a carbon sink, which is a barrier to accounting for the contribution of soil in the post-Kyoto targets for $CO_2$ reduction.

Nevertheless a workshop was organised, which also took place in May 2008, to discuss the need for research with regard to the implementation of the Soil Thematic Strategy and the Soil Framework Directive which is still under discussion.
During that workshop, a considerable number of gaps in soil research were highlighted:

1. Inability to adequately perform multi-, inter- and trans-disciplinary research as we move from soil-research to soil-system research and considering soil in the context of sustainable development.
2. Our knowledge about soil is highly fragmented along disciplinary lines and focuses too much on static properties rather than on dynamic processes. Modelling is, of course, used for characterising dynamic properties, but models only work well when validated by field measurements and these are often lacking.
3. A “perception gap” in terms of current developments likely to have a major effect on soil studies of the future.
4. Our inability or inaction to express soil functions in financial terms, as this is needed in order to communicate with the policy arena.
5. We don’t have an operational definition of soil quality (or soil health), which hampers communication with third parties.
6. Many projects dealing with various aspects of soil management are in progress within the EU. The lack of common indicators and evaluation procedures leads to a highly confusing array of recommendations.
7. We appear to ignore education as we focus on research.
8. Lack of basic soil information in major areas of the EU and the associated question whether data gathering represents a “research” activity. New digital and remote sensing data-gathering techniques have been developed, but are not yet widely available.
9. Large and often unknown variability in the quality of available soil data.
10. We are unable to define the carbon cycle in soils and landscapes: there are currently unexplained gaps.
11. We are, as yet, unable to answer common questions for the EU, e.g. how much C is lost each year by erosion, how much fertile soil is lost or degraded, how much biofuel could potentially be produced, what will the likely effects of climate change be, etc. etc
12. Too much research is still based on disruptive sampling in the field, followed by laboratory analysis. Non-disruptive monitoring with innovative in-situ sensing techniques is possible but not yet widely applied.

Two main recommendations were made in support of the implementation of the European Soil Thematic Strategy:

- The establishment of a number of soil observatories to collect soil data and study soil processes under field conditions
- The development of a framework to define the role of soils in a comprehensive scheme for sustainable development. This scheme should be developed on the basis of soil functions.

During a recent visit in March Niek de Wit from DG Environment stated that there are three main issues related to soil:

- Climate change
- Biodiversity
- Healthy food and sustainable agriculture

## 6.2 SoilCritZone

SoilCritZone, is a Specific Support Action that aims to mobilise the scientific and engineering community to develop a European research and innovation strategy on soil science in line with the aims of this Thematic Strategy.

The discussion about the research needs in the SoilCritZone project focuses on 4 fields of research:
- Weathering
- Biodiversity and cross-cutting issues
- Degradation
- Lifecycle analyses

So-called 'overarching research questions' have been formulated:
- Weathering:
  - How can the dominant factors controlling chemical weathering be identified and their effects be quantified in a given environment and at various scales?
  - In what ways are physical, chemical, and biological weathering processes coupled, and how can these couplings be elucidated and quantified?
  - How can we advance our ability to predict weathering processes over the range of pertinent spatial scales, including mineral surfaces, laboratory reactors, soil profiles, catchments, and global systems?
- Biodiversity and cross-cutting issues:
  - What is the influence of physical and chemical perturbations, both short and long-term, on soil biodiversity and biological function?
  - What are the roles of soil biodiversity and biological processes in soil formation and soil sustainability?
  - What are the practical uses of soil biodiversity and function?
  - What are the gaps in our knowledge of C cycling in wetland soils?
- Degradation
  - What is the methodology that can be developed to increase soil organic matter and at the same increase fertility?
  - What is the most effective methodology to sequester carbon in soil and increase fertility?
  - Are extreme events more important for soil than average annual events?
  - Are organic or permaculture agricultural practices better for fertile soil preservation than conventional practices?
- Lifecycle analyses
  - Can we ground truth in the new models?
  - Can we delineate risk areas?
  - Can we define appropriate management measures to alleviate the threats (restoration measures and achieve soil sustainability?

## 6.3 SOWA

The SOWA project aims to integrate soil and water research in Europe. There is a large-scale thematic focus i.e. diffuse pollution of soils from e.g. atmospheric deposition and agricultural practices and the associated risk of groundwater pollution.
The objective is to pull together the critical mass needed in order to integrate available and emerging scientific knowledge from various disciplines such as soil science, soil chemistry, soil physics, hydrogeology, water resources, agriculture, atmospheric deposition of pollutants, environmental analysis and engineering as well as management and remediation of contaminated soil and groundwater.
SOWA provides a multidisciplinary forum for the identification of research needs and strategies for integrated soil and water protection.

Successful policies to abate and control diffuse pollution and to manage large-scale polluted soil require an integrated system understanding including socio-economic factors and driving forces. However, the behaviour and fate of large-scale diffuse pollution of soils and waters, the effects of such large-scale pollution on ecosystem functions and life-supporting services is rather poorly understood. In particular, our knowledge of interactions between the different environmental compartments and the anthroposphere needs to be improved. Sectoral solutions for specific problems taking inadequate account of societal factors are not sufficient in the

long-term. They can even be counterproductive. Integrative approaches are needed, as shown, for example, by the nitrate problem. Specific knowledge gaps are:

- There is a lack of adequate quantitative system understanding and pertinent models. For this reason, indirect effects of large-scale pollution are difficult or even impossible to predict.
- Little is known about the quantitative role of preferential and particle-bound transport processes or the role of vegetation on the transfer of metals and other chemicals in the root zone on field to river basin scales.
- Knowledge about the effects of mixed pollution ("cocktail pollution") is sparse.
- Many pathways of pollutant transport and transformation in the environment have not yet been sufficiently identified or quantified, for example pollutant transfer from soil to plant due to re-suspension of contaminated soils by wind and rainwater splash or the uptake of pollutants by humans and animals through dermal soil contact.
- Little is known about the effects of climate and land use changes on soil functions and potentials on a large scale.
- Despite much progress in recent years, there is still a considerable lack of uniform approaches and standardised procedures to assess and evaluate ecotoxicological effects of diffuse soil and water pollution.
- Emerging techniques for a gentle remediation of already polluted agricultural soils, e.g. plant-based risk-reduction, clean-up and site-stabilisation schemes, are still not operational at field level.

There is a great need for theoretical knowledge about how stakeholder decisions and actions affecting soil and water quality can be influenced to achieve the goals of pollution reduction and sustainable land-use and how respective policies can be implemented in practice. Given these gaps and the potential risks arising from the accumulation of large-scale diffuse pollution in soils and water bodies, the following tasks need to be addressed urgently in order to cope effectively and in a sustainable way with this challenging problem:

- Investigation of driving forces, magnitude and dynamics of diffuse pollutant fluxes at field, farm, regional and larger scales, between soil, water, other environmental compartments and the anthroposphere, in particular agriculture; methods of assessment (such as mapping and mass flux analysis), controlling factors, options for active management.
- Evaluation of long-term effects of diffuse soil and water pollution on life-supporting ecosystem services and goods, climate, biodiversity, and health, including pathway-specific evaluation of risks due to pollutant transfer from soil and water into food chains and other exposure pathways.
- Identification of consistent long-term goals for soil and water quality, compatible with an ecologically, socially and economically sustainable development.
- Design of adequate strategies (e.g. in spatial and land use planning) and instruments (policies, regulations, management procedures, technical processes etc.) to prevent further diffuse soil and water pollution.
- Development of techniques to eliminate or control risks arising from existing diffuse pollution, compatible with the goals of sustainable development: studies on natural attenuation, potential for stabilisation, possible ways for large-scale amelioration of low-to medium level polluted soils and waters, in particular by using "green" techniques such as phytoremediation.
- Harmonisation of methods and procedures to survey and monitor diffuse soil and water pollution, to assess hazards and risks emanating from such pollution, and regulations regarding present and future diffuse soil and water pollution.
- Improvement of the knowledge transfer between the various actors and stakeholders (e.g. scientists, farmers, administrators, planners, politicians, general public). To accomplish these tasks, it is important to take adequate account of the specific difficulties arising from the diffuse, long-term and – due to the involved uncertainties – ill-defined nature of the problem. First of all, the spatial heterogeneity of soils and aquifers at the scale of interest must be considered. Effective control of diffuse pollution requires coordination with land-use planning and thus should be based on policies and action plans which take account of the uneven spatial distributions of, as well as the interrelationships between, the various potential uses, ecosystem functions and vulnerabilities of the soil and water resources to be managed. Then, the disparity of time scales must be taken into account. Because of the low rate of accumulation, the delay until adverse effects become manifest and the even longer times – in certain cases this may take generations – until counter-measures become effective, it is necessary to intervene early against diffuse pollution, long before the pollution exceeds thresholds above which negative impacts on ecosystem functions become manifest. Not only the time constants of the biophysical system need to be considered, but also of the socio-economic processes involved. Finally, historical experience shows that human impacts on the environment always include risks which nobody has been able to think about in the beginning. To cope with such uncertainty, basic strategies based on the precautionary principle must be developed and established in a politically responsible approach to maintain the multi-functionality of soils and the quality of waters.

# 7 Relationship to other ERA-Net programmes

## 7.1 IWRM-Net

IWRM-Net, an ERA-Net on Integrated Water Resources Management, focuses on research to support the implementation of the Water Framework Directive. Much of the identified research needs relate to surface water management, but there are also issues which relate to groundwater.

Aquifers recharge and aquifer discharge

- Develop a tool for identification, tool for pollution migration (dispersion)
- Research needed on techniques, how much money can you afford to spend on removal?

Relation to the Drinking Water Directive:

- How can Member States achieve the European standards if well below natural contamination levels?

Improving groundwater management capabilities:

- Improve modelling and planning methods
- Develop methods for estimating background pollutant content
- Creation of an integrative database for unsaturated and saturated soil zone (cover soil) including pF (retention), porosity, structure
- Improve our knowledge of the movement of pollutants through soil and groundwater
- Assess the effectiveness of measures to reduce pollution
- How do you stimulate chemical/physical changes to reduce pollution?
- Developing new management strategies to deal with the above issues
- Arsenic removal from groundwater

## 7.2 CRUE

CRUE is an ERA-Net project which aims at the prediction of floods, early warning systems and risk assessment on floods. There are no links between the research needs of the CRUE network and the research agenda on soil and groundwater. On the other hand, in the discussions about the SNOWMAN research agenda impacts, the impact of floods on soil and groundwater quality have been identified.

# 8 The SNOWMAN Research Programme

## 8.1 Function of the research programme

Taking into consideration the research needs and issues formulated in several projects, networks and countries there is on one hand quite a lot of similarity, but on the other hand a difference in focus between some networks and countries. This difference in focus likely results from the broad scope of the issues involved and the differences in policies that are being developed in the different countries. The research programme should, therefore, not be considered to be a fixed framework but a concrete and stable programme which will be implemented during the next decade. I should be a flexible "á la carte menu" from which SNOWMAN partners are able to select areas of research for cooperation in research funding and the definition of coordinated calls. Different combinations of partners and countries can focus on different research areas of the programme.
The programme must also be flexible in terms of timing. New societal developments, policy priorities and new knowledge questions during the implementation of policies and technologies, must lead to a continuous adaptation of the programme. A structure, plus procedures for this adaptation should be developed.

## 8.2 Depth and detail in formulated research needs

It has proven to be difficult to translate knowledge questions into research needs and potential research projects up to the level of scientific disciplines or research groups.
The experience gained with calls for research proposals in the partner countries and in the coordinated call of SNOWMAN, shows that a well-defined scope of knowledge needs and research issues will help to ensure that adequate proposals are received for research projects. The advantage of defining a programme in not too much detail is that researchers are given room and flexibility to propose research on issues of which stakeholders and funders are unaware. The development of a research programme can be considered to be a top-down process, controlled by stakeholders and funders, and the call procedure as a bottom-up process controlled by researchers and scientists. The interaction between the top-down and bottom-up processes will achieve more innovative research that would actually be relevant in practice.

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## 8.3 Scope of the programme

It is not easy to construct a comprehensive research programme based on the knowledge questions and research needs that have resulted from discussions and other projects. The number of driving forces and pressures on seven soil functions and their impact, possible responses and the resulting state gives a number of research needs that is very hard to get an overview. It is for that reason that it has become necessary to concentrate on a number of fields of research in which many research needs are related. Therefore, the soil functions that will be considered are as follows:

1. Production (of organic matter) for agriculture, forestry, bio fuel.
2. Physical space: physical characteristics of soil relating to storage (the use of the sub-surface), preservation space for cultural and archaeological heritage, sealing, compaction and land slides.
3. Transformation processes: The interplay between physical, chemical, and biological processes that determine the functioning of the subsurface.
4. Biodiversity and related functioning and services.
5. Hydrological system of rainwater, groundwater, surface water and the interaction with soil

The main driving forces that are relevant for research needs are:

1. Climate and energy
2. Water management
3. Sustainable agriculture
4. Urbanisation.

Finally, contamination still plays a role in almost all of the functions and land use: sources of contamination, fate of pollutants, effects and risks, and (evaluation) of remediation technologies. Contamination can be seen as being a driver:

5. Contamination

Another driver is how the socio-economic system has an impact on soil. The socio-economic system, the social, legal, economical and political aspects of utilisation of the sub-surface is an essential research theme within the programme, focusing on understanding the economical, political and social aspects relating to the sub-surface as driving factors for utilisation of the new insights by society:

6. Socio economic system

Table 1 displays several areas of research needs:

1. The state of transformation processes, the impact of several driving forces on transformation processes and possibilities of responding in urban areas and the relation to contamination.
2. The state, role and importance of soil biodiversity and ecosystem services and the impact of several driving forces on biodiversity. There is still a lot unknown about the state and impact, so it is too early to carry out research into responses.
3. The impact of several driving forces on the hydrological system and responses.
4. The relation between climate change and sustainable energy on all soil functions regarding state, impact and responses.
5. The impact of sustainable agriculture on almost all soil functions.
6. Contamination: state, impact and responses.
7. The relation between soil functions and the role and responses of the socio-economic system.

We are thus able to relate the research needs to seven areas, four of which are more focussed on the functioning of the soil and groundwater system and three of which are more focussed on the use of soil and the effects of that use on soil quality.

**Table 1: Research priorities relating to driving forces and soil functions**

| | | Production | Physical space | Transformation | Biodiversity | Hydrology |
|---|---|---|---|---|---|---|
| **Climate and energy** | Impact | | | | | |
| | Response | | | | | |
| | State | | | | | |
| **Water management** | Impact | | | | | |
| | Response | | | | | |
| | State | | | | | |
| **Sustainable agriculture** | Impact | | | | | |
| | Response | | | | | |
| | State | | | | | |
| **Urbanisation** | Impact | | | | | |
| | Response | | | | | |
| | State | | | | | |
| **Contamination** | Impact | | | | | |
| | Response | | | | | |
| | State | | | | | |
| **Socio-economic system** | Impact | | | | | |
| | Response | | | | | |
| | State | | | | | |

Hot: significant research needs

Medium

Fewer or no research needs

## 8.4 General description of the seven areas of research

In Chapters 4, 5, 6 and 7 and the tables in Annexes 3 and 4, a number of specific research needs are mentioned. In this paragraph, we summarise these needs according to the seven fields of research indicated above. It is inevitable that some research needs appear in more then one research field. The specific research needs are still relevant if we want to look in more detail at the needs in a specific area.

### 8.4.1 Transformation processes

This research area focuses on the function of the soil transformation processes, such as physical, chemical and biological processes, which are relevant to the functioning of the soil as a system. Research needs are related to:
*State*
- Do we have good indicators about the state and functioning of the transformation processes to evaluate whether there is a "healthy" soil ?
- Can we bridge models about transformation processes from micro to macro scale?

*Impact*
- What is the impact of climate change on the transformation processes, such as the mineral cycles of carbon and methane?
- What are the effects of changes in land use on transformation processes?
- What is the role of transformation processes in the fate of persistent and emerging pollutants?
- What effect do different remediation technologies have on the transformation processes?

*Response*
- How can we restore and enhance transformation processes in urban areas (i.e. make a soil "healthy" again) or restore the functions after different remediation activities?
- Can we strengthen transformation functions with respect to climate change?
- Can we improve models for decision making towards responses of the transformation processes of the soil?
- Can we develop technology assessment tools with respect to the destruction or restoration of transformation processes?

### 8.4.2 Biodiversity

Biodiversity is an important characteristic of the soil because of the important role of soil in the functioning of the biosphere. Most research needs relate to a better understanding of the role and state of biodiversity.
*State*
- What are the key parameters in determining the state of biodiversity for a healthy soil?
- How can we monitor these parameters?
- How can we determine the activity of relevant organisms?
- What is the heterogeneity of the biodiversity, especially with regard to the rhizosphere
- What is the role of biodiversity in mineral cycles or the transformation processes in general ?
- What is the role of the soil as a gene pool and how can we make use of or explore the potentials of this gene pool?

*Impact*
- What are the impacts of climate change, changes in land use or sealing on the biodiversity?

### 8.4.3 The impact of several driving forces on the hydrological system and responses

A specific characteristic of the soil system is its role in the hydrological system, the interaction between soil and groundwater and between groundwater and surface water. There is a tendency that the use of groundwater for different purposes is growing and also the competition between the different purposes of use is growing.
*State*
- We require more data about the relation between groundwater and surface water quality
- What is the role of groundwater in drinking water production/

*Impact*
There are significant research needs regarding the effects of several pressures on the hydrological system and groundwater quality, such as :
- Energy storage (heat, cold) on the chemical equilibrium of groundwater and the groundwater level
- The use of geothermal energy
- Monoculture production (of biofuels) including secondary effects (use of pesticides) on groundwater quality and use of groundwater
- Climate change resulting in extreme variation in the intensity of rainfall (also droughts) and temporary flooding on soil and groundwater quantity and quality

- Agricultural practices on groundwater quality (phosphate, ammonia, nitrate) and changes in groundwater level
- Mining activities on groundwater level and flow and quality
- Sediments on groundwater quality
- Filtration of rainwater on groundwater quality
- Long droughts on the filtering capacity of the soil

*Response*

- We need decision support systems for using groundwater or surface water for different purposes
- Possibilities and effects of storage of water in deep aquifers
- Preservation and enhancement of storage of rainwater in aquifers in urban areas
- Methods for the enhancement of infiltration capacity
- Methods for the enhancement of biological processes to improve groundwater quality
- Management systems of resources and impacts, such as land use, sealing, infiltration, filtering and models to support management
- Decision support systems related to the competition of different groundwater usages
- Development of legal instruments to manage the use of groundwater for different purposes
- Approaches to improve the relation between river basin management and urban planning

### 8.4.4 Climate change and sustainable energy

Climate change and the policy to increase the use of sustainable energy is a driving force that influences several soil functions. For this reason, many research needs relate to the impact of these driving forces on soil functions. The effects on the carbon cycle is an issue that arises in several research needs. The effect of climate change on soil quality depends a lot on regional circumstances and are quit different in coastal zones, wetlands, hill sides or permafrost areas.

*State*

- What is the potential of soil and groundwater to store heat and cold
- Can we use historical data of soil and groundwater to study the long-term changes in carbon cycle
- What is the buffering capacity of soil to cope with climate change?
- Can we use labelled carbon to study the carbon cycle

*Impact*

- Of biomass and monoculture production on soil quality
- Of the use of organic residues of biofuel production on soil quality
- Of storing carbon in the form of biochar: stability, effect of accumulation of other components
- Of storage of heat and cold on groundwater quality and groundwater level
- Of the use of thermal energy on biodiversity and groundwater quality
- Effects in terms of time of buffering of greenhouse gasses in soil
- Of climate change on carbon cycle and pH changes
- Of heavy rainfalls and temporary flooding on groundwater quality and erosion
- Of increasing sediment transport due to erosion
- On soil ecology and biodiversity, growth and fate of pathogens
- What is the impact of climate change in wetlands and permafrost areas?

*Response*

- We need to develop economic and lifecycle analyses of the use of different bio fuel crops and the complete chain of production, also with respect to the impact on soil functions
- Can we change soils and areas from a carbon source into a carbon sink
- We need to develop management options of wetlands to reduce peat oxidation and enhance the formation of organic material
- Reduction of emission of greenhouse gasses like $NO_2$
- Models to predict the spread of heat and cold in groundwater
- LCA of production of bio fuels on contaminated land or combined with phytoremediation
- How to deal with the competition between the use of hydro power and restore natural rivers?
- How to adapt to climate change in coastal zones?

### 8.4.5 The impact of sustainable agriculture

There is a common awareness in many countries that we need to change the way in which we produce agricultural products (dairy products and crops) to maintain a fertile soil with a high yield without negative long-term effects on the environment. This issue is growing in importance because of the growing need for food and changes in consumption throughout the world. A specific aspect is the way we can involve farmers and agricultural practices into the development of sustainable agriculture.

*State*

- Can biodiversity be used as a parameter for sustainable agriculture

- Data about the loss of agricultural land due to urbanisation and contamination
- Robust methods to measure soil status by farmers

*Impact*

- Of changes in diet: increased consumption of meat and the effect on the need for agricultural land
- Of the production of transgenic crops
- Use and fate of pesticides
- Of compaction on soil quality and yield
- What is the impact of land use change on flooding

*Response*

- Development of more resilient and highly productive land and prevention of degradation of land by agricultural production
- Reduction of the use of pesticides and fertilizers through the role of biodiversity of soil
- Comparison and environmental impact assessment of different sources of nutrients (fertilisers, manure, compost, sewage sludge)
- Development of agricultural practices to reduce the emission of phosphate and nitrate and changes in groundwater quality
- Mining of phosphate from soil and groundwater
- Best practices to prevent soil deterioration or to reduce compaction
- The use of minor land with high input and output strategies
- How do we manage the competition between organic and conventional farming?

### 8.4.6 Contamination

Contamination is still a generalised field of research, not specifically in relation to soil functions, but to the risk to human health and ecological effects and approaches and technologies to reduce these risks.

*Risk assessment of contaminants:*

- Improvement of risk assessment methods
- Quantification of risks for human health from contaminated areas (cancer/TDI). How many individuals are affected, which individuals, can they avoid being affected?
- How large is the impact on ecosystems (ecosystem services)?
- How do the risks change over time? What is the effect of remediation measures?
- Development of methods for validation of exposure and load
- Tools for risk evaluation concerning ecological, economical and social/cultural aspects
- Fill the gaps in knowledge about important parameters in risk assessment models (human and eco toxicology of pollutants, physical/chemical data, abundance/behaviour of exposed organisms, etc.)
- What is the relation between risks from soil pollution and other environmental risks:
- Which part of human and ecosystem exposure is coming from contaminated land vs. other sources

*Impact*

- Of diffuse contaminations from agricultural practices
- What is the interaction between contaminated land – groundwater - recipients – catchments areas
- Fate of pesticides and emerging components
- Transfer of pathogens to groundwater
- How to estimate the total pollution load on a recipient
- What are long term effects on health?

*The role of the filtering capacity of soil for the attenuation and storage of contaminants:*

- Which soil types are good and which are bad in terms of filtering and storing pollution? What are the potential long-term releases of which contaminants?
- How does soil work, which kind of soil interfaces with different pollutants?
- How resilient is the soil filter capacity in the long term? Can you improve resilience? What is destroying the filtering capacity?
- What is the behaviour of heavy metals in the unsaturated soil? Which processes effect mobilisation and demobilisation?
- How does the soil ecosystem influence the filtering capacity and groundwater quality?
- How can we change the scale : from the local scale (site scale) to the regional scale : which tools, extrapolation methods, models ? How do we link soil (local) models to water catchment models?

*Remediation*

- New remediation alternatives
- Enhancement of the implementation of remediation technologies
- Tools for comparison of the sustainability of different remediation solutions

*Regional management of contaminations:*

- How do we shift from a site-specific approach to an area approach.
- Development of sustainable management systems of contaminated land in urban areas
- Management of brownfield sites

- How to deal with contaminated sediments?
- Management of multiple pollution sources
- How to manage historical contaminations that cannot be removed
- Development of tools for prioritisation of remediation
- Methods for the discrimination of sources of pollution in a specific area
- What are the costs for management of diffuse polluted land? What are the economical aspects of risk evaluation /risk management?
- How do we calculate the societal costs for land use restrictions?
- The development of methods for comparison between different investments: remediation projects/environmental projects/other societal projects

#### 8.4.7 Relationship between soil functions and the role and responses of the socio-economic system.

There are several research needs to change soil quality management from a specific sectoral policy and management issue into an integrated factor in social and economic decision processes.

- Approaches to improve the awareness of citizens and policy makers about the value of soil transformation processes
- Methods to improve the awareness of the value of biodiversity and environmental services of the soil
- How can we increase the societal awareness about the main dilemmas relating to food production
- How do we express environmental and social quality in economic assessments
- Methods to determine the value of soil transformation processes depending on land use
- Methods to determine the value of biodiversity
- What are the societal costs of land use restrictions
- Development and implementation of administrative systems for soil contaminations and restrictions of land use
- Integration of soil and groundwater quality management into spatial planning
- Regional management of all related approaches, aspects and interests in soil quality

## 8.5 Final remarks

**The soil system as a whole**

In spite of describing the programme in 7 lines we must not forget that all functions of the soil and processes that are going on in the soil are interrelated. When studying one line we must be aware of the relation with other lines of the programme. There is a need to study and describe the system of the soil as a whole and understanding all the interrelations. We think this is more an scientific or strategic issue than a goal for more applied research. That means, that apart from the SNOWMAN research programme which is more strategic and applied research, we must underline the need for fundamental research on an European level. We hope that the SoilCritZone-project will underpin the need for fundamental research on soil.

**It is not all research**

To improve the management of soil quality for all the reasons mentioned in the research programme and to gain all the benefits to a sustainable use of soil and groundwater we must realize that only research is not enough. To implement sustainable soil quality management in practice stakeholders, policy makers and citizens have to be involved in all phases of development and research. Communication about the socio-economic aspects of soil quality management is essential to realize interest of all relevant stakeholders. The SNOWAN-partners should contribute to this need for communication and awareness rising each of them in there home country and as a group in the whole European society.

# Annex I

## Knowledge questions shown in themes and sub-themes

| Theme | Questions | Knowledge needs |
|---|---|---|
| **ENERGY AND CLIMATE CHANGE** | | |
| **Sub-theme: Energy saving and sustainable production** | | |
| Sustainable energy: energy saving | What is the potential contribution of soil and groundwater to energy storage and sustainable energy production? | - What are the options for storage in the soil and groundwater of heat and cold for cooling and heating?<br>- Options for sustainable city developments<br>- Relation to urban and rural planning because of the characteristics of soil and groundwater in relation to possibilities of sustainable energy and energy savings<br>- |
| Sustainable energy: energy saving | Which factors influence soil functions and soil processes? | - What is the long term impact?<br>- What is the impact on resilience of soil and water systems?<br>- What is the likely impact on groundwater, soil, chemical processes?<br>- The effect of cold on geological formation<br>- Heat as a pollutant:<br>o Thermal effect on ecosystems<br>o Thermal effect on chemical solutions<br>o Thermal effect on drinking water production<br>- Cumulative effects potential for upscaling spreading of heat and cold<br>- What are the effects of upscaling heat storage for soil diversity? |
| Sustainable energy: energy saving | What are the other effects of energy storage on the soil and groundwater? | - Do we create pollution pathways? |
| Sustainable energy: energy saving | Which strategies should be applied to heat and cold storage in the soil and groundwater? | - How do we combine the storage of heat and cold and the use of thermal energy and other soil functions and remediation goals?<br>- Who owns, or is responsible “deep down”? |
| **Sub-theme: Reduction in emissions of greenhouse gases** | | |
| | What is the present state of the role of the soil in the production and reduction of greenhouse gases such as, $CO_2$, $NO_2$ and $CH_4$ ? | - Collation of data on the role and magnitude of soil as a factor<br>- Is soil currently losing carbon, is soil a source or a sink?<br>- Is soil a sink or source for carbon, or a red herring?<br>- What is the heterogenic spread of areas of sink or source of $CO_2$?<br>- Emission from cattle |
| | How does climate change influence soil functions? | - What is the influence of climate on the balance of emission and fixation?<br>- How does climate change affect the release of stored CH4?<br>- Oxidation of organic matter (peat)<br>- Relation between changes in groundwater level and oxidation of peat |

| | | |
|---|---|---|
| | | - Nitrification and denitrification<br>- Transformation of minerals<br>- Anaerobic organic breakdown |
| | How does the storage of $CO_2$ and natural gas influence soil functions? | - Effect on geological formation<br>- Interaction of $CO_2$ with soil/groundwater<br>- Risks of leakage<br>- Comparison between natural fixation of $CO_2$ or technological liquid storage<br>- What are the long-term dynamics of soils as a sink source of $CO_2$? |
| | How can the fixation of carbon in organic materials (plant roots, vegetation, peat formation) be increased? | - What is the role of soil in the production of biomass through agriculture and forestry?<br>- What is the effect of wetlands restoration on the emission of greenhouse gases?<br>- How can we enhance:<br>o Assimilation processes<br>o Production of organic material<br>o Peat formation<br>o Root formation |
| | How can we influence the emission of green house gases? | - What is the effect of agricultural practices on the emission of greenhouse gases? (Different cultivation methods)<br>- What is the impact of flooding on the emission of greenhouse gases? |
| | How do we exchange knowledge between countries to accelerate learning? | |
| **Sub-theme: Biofuel crop production** | | |
| | How can we produce biofuel crops in a sustainable way? What effect does this have on soil functions? | - What is the effect of high input forestry and intensification in forestry?<br>- What is the effect on soil quality and biodiversity?<br>- What is the impact of biomass production in terms of compaction, structure?<br>- What are the long-term effects on soil quality?<br>- What are the effects of changes in land use (waste land/nature/pasture or forest) on biofuel production? |
| | How can we respond to biofuel crop production with management strategies and procedures to biofuel crop production? | - Which areas are suitable for biofuel crop production? How do we decide on the different uses of land?<br>- How do we choose the different biofuel crops?<br>- What are the effects of the second generation of biofuel crops?<br>- What are the advantages/disadvantages of woody energy carriers? What is the relation between the production of biofuels and food production?<br>- Is there a win-win situation from biofuel production (landscape, leisure, etc)?<br>- How can we combine phytoremediation and biofuel production: what are the barriers? How do we improve these?<br>- How can we connect land remediation with biomass production?<br>- Are there alternatives for protein production, cattle farms or fish farms? |
| **Sub-theme: The effect of climate change on soil quality** | | |
| | What is the effect of climate change on soil functions? | - What is the effect of organic matter, fertility, biodiversity, erosion? Can we model these effects? |

| | | |
|---|---|---|
| | | - To what extent is mathematical modelling useful to decision makers? In which ways can it be utilised?<br>- What is the influence on the resilience of soil and water systems?<br>- What is the impact on upland peat moors, will these be lost?<br>- What is the impact of enhanced peat oxidation on drinking water production (colour)?<br>- What is the effect of climate change on (ground)water flow?<br>- How do we monitor soil quality changes due to climate change? |
| | How can we respond to climate change effects with management strategies and procedures? | - How do we make a shift from global developments and effects to local and regional scales?<br>- Are there future land use scenarios under climate change conditions?<br>- How do we connect the climate change community and the soil community? |

| Theme | Questions | Knowledge needs |
|---|---|---|
| **SUSTAINABLE WATER MANAGEMENT** | | |
| **Sub-theme: Retention and Flooding** | | |
| | What is the soil's capacity for water storage, infiltration and retention? | - Does the soil have sufficient capacity to be able to contribute?<br>- Can you improve capacity and the impact (e.g. contamination?)<br>- What are the potential different soil types which could mitigate the risk of flood? |
| | What is the effect of flooding on soil functions? | - How can flooding impact soil quality?<br>- What is the impact of flooding on land/soil use and water?<br>- What are the effects of flooding on soil ecosystems? |
| | Which effects can influence the retention capacity of soil? | - How does erosion influence retention?<br>- What is the effect of climate change on retention?<br>- How do soil and vegetation enforce soil retention capacity, balance of vegetation type and soil type?<br>- Effect of sealing and compaction on retention?<br>- How does the condition of soil influence retention quality?<br>- What is the role of soil in terms of attenuation in rainfall in climate change particularly in the urban context (increasing intensities of rainfall events)? |
| | How can soil functions reduce the effects of flooding | - What is the effect of changes in climate and land use on flooding? |
| | How can we respond to improve retention capacity and reducing flooding effects with management strategies and procedures? | - Development of flood management strategies that work with nature?<br>- What are the costs /benefits of flooding?<br>- How to manage water surplus in urban areas, what kind of policy tools are needed (sealing problem)?<br>- How do we create a win/win situation by increasing water retention and improving ecosystems?<br>- How do we maintain water supplies during droughts and an increase in demand, making use of groundwater storage?<br>- How does the way in which we manage soils in rural areas affect the flood risk at catchment level?<br>- How do we increase storage capacity in catchments and groundwater<br>- How can the soil best be managed in order to optimise retention? |
| **Sub-theme: Groundwater Quality** | | |
| | What is the state of groundwater quality | - What is sustainable groundwater quality?<br>- What is groundwater ecology?<br>- What is the need for strategic clean groundwater reservation? |
| | Which factors influence groundwater quality? | - Demographic development relating to the use of groundwater<br>- Do we understand the long-term effects on groundwater?<br>- Understanding the groundwater pathway timescales |

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|---|---|---|
| | | - Long-term effects of today's contamination, is there a timescale for these effects?<br>- What is the relation of spatial timescale effects to groundwater quality?<br>- How is groundwater quality affected by pollution concentrated in sources or diffuse via air and soil?<br>- What are the effects of emissions on groundwater quality?<br>- What are the effects of land use on groundwater quality?<br>- What is the effect of transformation of soil usage?<br>- What is the response time of groundwater quality related to land use change?<br>- Influence of flooding on groundwater quality/surface water?<br>- Transfer of contaminants to groundwater, specifically for emerging contaminants?<br>- Effects of hazard on polluted areas?<br>- Groundwater management<br>- Sub-surface constructions<br>- Other usage of groundwater<br>- Thermal heating remediation |
| | How does groundwater quality support other relevant developments? | - What is the role of groundwater level and quality in the development or preservation of natural areas and agricultural production?<br>- Can we improve water/soil safety against pathogens?<br>- Persistence and quantity of pathogens in relation to water quality management. |
| | How can we respond to improve groundwater quality with management strategies and procedures? | - How does soil management use affect long-term (and short-term) groundwater quality?<br>- How can habits that influence groundwater quality surface water be changed?<br>- How can the water surplus in urban areas be managed, what kind of policy tools are needed (sealing problem)?<br>- Are there measures to reduce effects of diffused contaminations on quality? |
| **Sub-theme: Soil as a Water Filter** | | |
| | What is the contribution of soil as a function for relevant aspects? | - How does soil work, what kind of soil interfaces are there with different pollutants?<br>- What is the cost/benefit of filtering upstream in wetlands?<br>- Soil as an immobiliser<br>- How can we value the function of soil filtering? |
| | Which effects influence the function of the soil as a filter? | - How resilient is the long-term soil filter capacity?<br>- Is it possible to improve resilience?<br>- What is destroying the filtering capacity?<br>- Influence of flooding on soil function filtering |

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| **Sub-theme: Water Management Strategy** | | |
| | Which developments influence water management strategies? | - What is the effect of climate change on seawater intrusion and groundwater recharge?<br>- What are the effects of more pressure on drinking water stock?<br>- What changes will there be to runoff of rainwater and transportation of groundwater when increased by urbanisation (sealing, compaction and building of subsurface constructions)? |
| | How can we respond to improve retention capacity and reduce the effects of flooding with management strategies and procedures? | - Effects of planning on groundwater<br>- Is it possible to develop catchment management without soil/water management?<br>- How can international water management be implemented in the most cost effective manner? Tools are needed.<br>- How to link soil (local) models to water catchments models.<br>- Relationship between groundwater quality and surface water quality<br>- How do we balance upstream and downstream interests?<br>- What is the relation of groundwater quality management to groundwater quality?<br>- How to link soil use/practice to make water quality meet WFD? |
| **Sub-theme: Sediments** | | |
| | Management of sediments | - How can we control, prevent or intercept the erosion of sediments?<br>- What is the influence of climate change on erosion?<br>- Are sediment balances influenced by climate change? |

| Theme | Questions | Knowledge needs |
|---|---|---|
| **SUSTAINABLE AGRICULTURE** | | |
| **Sub-theme: Ecosystem services** | | |
| | What is soil system ecology | - What is healthy soil?<br>- Is soil part of the ecosystem or water?<br>- Ecosystem. What species are "normal"/what degree of diversity is normal?<br>- Soil ecology function<br>- What is the relation with soil biodiversity?<br>- Research on new and improved methods to determine soil biodiversity, at the micro-organism level and at the functional (mRNA) and the protein levels |
| | What is the role of soil ecosystem services | - How can we use ecosystem services for sustainable agriculture?<br>- How can we use the soil ecosystem to optimise agriculture fertiliser input and pesticide input.<br>- What is the relationship between biodiversity and soil and plant health?<br>- What is the relationship between above-ground and below-ground biodiversity?<br>- What is the relationship between biodiversity in soil and biodiversity in ecosystem "on top of soil" and water?<br>- What is the role of soil biodiversity as a "pool" for white biotechnology?<br>- How important is biodiversity of/in soil (incl. gene pool)?<br>- What is the impact of soil biodiversity on human health?<br>- What is the role of soil ecosystem services in spatial planning, agriculture etc.?<br>- What is the role in ecological infrastructure: corridors / stepping stones?<br>- Soils in an ecosystem approach |
| | What impacts soil ecosystem services? | - What is the impact of different agricultural production methods (machinery, pesticides, fertilisers, crops) on the emission of greenhouse gasses, food safety, biodiversity in soil / groundwater, erosion, human/animal health?<br>- What are the long-term effects of agriculture on soil services/the ecosystem?<br>- How will soil ecological functions change with climate change?<br>- What is the effect of contamination on biodiversity?<br>- Long-term use of waste land.<br>- Relationship between soil ecology, biodiversity and the formation of natural areas and agriculture.<br>- Development of risk assessments for the concepts "Real" contamination (cocktails chemical contamination, medication and elements in waste/sludges) |
| | How can we respond to improve ecosystem services with management strategies and procedures | - Ecosystem goods and services (pricing/valuation) How to quantify the ecological value of soil?<br>- Instruments to value services (agricultural, € , others)<br>- The use of ecosystem services in sustainable agriculture and nature development (biodiversity)<br>- How do we combine ecological (soil) services with other (physical) integrated soil services (use of sub soil) ? |

| | | |
|---|---|---|
| | | - Protection and ecological reconstruction of critical areas<br>- Integrated management of natural resources<br>- Dissolved organic compounds transfer from upland soils, management/audification, recovery |
| **Sub-theme: Relationship between agriculture and soil functions** | | |
| | State of soil quality | - Do we protect soil functions or biodiversity for its own sake?<br>- What form should a monitoring system for evaluation of soil/groundwater quality take?<br>- How do we recognise that a certain soil function is in jeopardy? Early warning system?<br>- How do we evaluate changes in (in a reasonable way) methods and references? |
| | Influence of agriculture on soil quality? | - Make long-term effects visible and understandable<br>- Long-term effects of measures and pressures (e.g. use of sludge on soil)<br>- Effects of compaction? We know compaction is a problem, but do we have data about the scale at which this is problematic? What is the impact on the ecosystem?<br>- What is the potential for phytoremediation to help resolve contamination problems?<br>- Potential reduction in soil of carbon stocks and organic material<br>- How should degradation be avoided?<br>- Increasing plant and animal illness caused by intensive use of soil and growing of monocultures<br>- Agricultural impact on C-storing / C-cycle "Natural" areas<br>- Forestry: water household in mountainous areas<br>  - Methods to reduce acidification<br>  - Alternative forestry practices |
| | Role of soil functions to support sustainable agriculture | - Modern agriculture is no longer related to the natural soil quality. Agricultural soils have an artificial quality leading to other threats<br>- Impact of soil contamination on food safety.<br>- How can biodiversity be used to reduce the use of fertilisers and pesticides?<br>- Decrease of production due to compaction and loss of organic compounds<br>- |
| | | - Decision support tool kits for soil, groundwater, surface water and biodiversity management at landscape/catchment scale<br>- Interdisciplinary research<br>- Awareness of upcoming instruments (as long as I can grow crops, the soil is ok)<br>- Incentives for "good behaviour" vs. punishment for "bad behaviour"<br>- Increasing awareness of food safety |
| **Sub-theme: Role of soil in Mineral cycles** | | |
| | What is the influence of land use and soil quality on mineral cycles? | - What impact does a change in land use (e.g. energy crops) have on the carbon cycle?<br>- What plays the most important role on the mineral cycle: land use or site-specific measures? |

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| | | - What is the effect of contamination on mineral cycle/biodiversity?<br>- How should the mid-term or long-term effects of land use change on nutrient release be estimated? Show the benefit to the farmer<br>- Nutrient transfer from land to water (especially P) |
| | How can we respond to improve agriculture and soil quality with management strategies and procedures? | - Integrated regional (urban + rural) management of substances (nutrients, biomass, water) |
| **Sub-theme: Agricultural practices and soil functions** | | |
| | What is the role of farmers | - Influence of agricultural practices on soil and groundwater (diffuse pollution)<br>- What is the impact of changing "roles" of the farmer e.g. energy supplier?<br>- Can the farmer play a beneficial role? How should such roles be encourage?<br>- How can farmers be taught to change agricultural methods? Being taught by the father is much stronger than messages from science or policy. |
| | What is the effect of agricultural policies | - How should conflicting EU policies be implemented?<br>- How should conflicting scales be met (Top: EU-policymakers, bottom: agriculture)? |
| | What is the effect of agricultural practices on soil quality | - Impact of irrigation/salinisation on soil functions?<br>- Relationship between production and compaction and organic material<br>- Methods to reduce compaction<br>- New models for stress transmission and soil deformation<br>- Better models for predicting the effects of compaction on soil processes, such as water flow, transport of solutes and crop growth<br>- Development of strategies to reduce compaction, including technical measures and decision support systems<br>- Measure to increase organic material |
| **Sub-theme: Landslides and erosion** | | |
| | Increasing risks of landslides due to climate change and land use | - Understanding the relationship between climate and landslides and the development of better models for fast landslides<br>- Predicting future behaviour of landslides under different a climate and land use<br>- Design of reliable early-warning systems<br>- Living with landslides and sustainable development in landslide-prone regions, using both land use changes and technical measures |
| | Risk and prevention of erosion | - How can we map out the risks to soil, such as erosion?<br>- How do changes in climate and land use effect erosion?<br>- Development of integrated strategies for addressing erosion<br>- Development of tailor-made conservation strategies |
| **Sub-theme: Spatial planning** | | |
| | What aspects influence land use and regional planning? | - What are the effects of climate change?<br>- Effects of forest management: effects on soil?<br>- Relationship between the rising seawater level and salinisation?<br>- Production of crops on saline soil?<br>- Role of groundwater level and quality in development or preservation of natural areas and agricultural production? |

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| | | - Sustainable food production under climate change pressure<br>- What is the impact of aerial contamination of industry, traffic, emerging contaminant (e.g. hormone disturbance) on soil quality and land use? |
| | How can we respond to improve agriculture and soil quality with management strategies and procedures? | - Instruments for rural planning (e.g. crop selection) soil properness<br>- We must match crop/agricultural land use to the environment better on account of climate change. Which crops prefer which soil types? This will change as the climates changes.<br>- Reservation of connected wetlands (to groundwater)<br>- Instruments to link soil types to optimal land use<br>- Do agriculture and nature go hand in hand?<br>- Can a combination of agricultural/natural areas help to migrate potential negative effects on agriculture?<br>- How should we link crop choice in an improved manner to soil type/properties<br>- Can agriculture help to tackle problems of diffuse contamination? (phytoremediation?)<br>- How can we better use the knowledge of soil properties in rural planning?<br>- How can we integrate soil/groundwater aspects in rural planning?<br>- What are the expectations of stakeholders in terms of rural planning? |

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| Theme | Questions | Knowledge needs |
|---|---|---|
| **SUSTAINABLE URBANISATION** | | |
| **Sub-theme: Contamination** | | |
| | Risk and risk perception | - Risk perception and communication with citizens/soil contamination<br>- Soil health and diffuse contamination (long term: agriculture and private gardens)<br>- Harmonisation of risk assessment, modelling for decision making<br>- Consensus on standards (risk, models, concentrations)<br>- Attitude of people towards waste/water/pollution<br>- Cost-effective reduction of risk<br>- Reduce risks caused by contaminated soil and groundwater for human and ecosystems.<br>- Relationship between soil contamination and health<br>- Accumulation in food chance/effect modelling<br>- Relationship between sources (where, how much, rate) and effects<br>- Relationship between soil contamination and land use<br>- Food chain transfer of contaminants, eco-toxicological effects, effects on human health and on animal health<br>- Communication about risks/measures (or not) on health/stress<br>- Integrated approach/assessment of economy/social communication/risk<br>- Discrimination of risk effects from soil, air, water etc |
| | Management of contaminations | - Management of diffuse contamination (transfers to water, ecosystem, food chains)<br>- Effects (integration?) on soil and groundwater quality (sludge) accumulation<br>- Soil as a storer and attenuator of pollution: the role of soil types (which are good, which are bad) in filtering and alternating pollution from the surface and its role in storing pollution, with potential for long-term release (e.g. policy)<br>- Integration of soil contamination with other effects<br>- Need to know how many contaminated sites or potential contaminated sites there are in our state<br>- Getting closer to the end of remediation of old environmental damage.<br>- Management of contaminated sites<br>- Concepts for contaminated land management in relation “to safe land use” + effective “polishing concepts”<br>- Management of multiple pollution sources<br>- Emerging contaminants in groundwater(detection, removal, control)<br>- Spreading of contaminants<br>- Bioavailability<br>- Relationship between land use and changes in land use and contamination<br>- Relationship of (also diffuse) contamination with the river basin, water quality, (small attachments)<br>- Waste-water management |

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| | | - Discrimination of sources of pollution in a specific area<br>- Site specific approach to area approach |
| | Remediation | - Remediation of sites: consolidation of sites management tools<br>- Technologies evaluation and demonstrations, knowledge dissemination<br>- Rehabilitation of contaminated land using sustainable technology<br>- New innovative remediation technologies<br>- Diffuse groundwater pollution (control) point pollution<br>- Reduction of diffuse contamination |
| **Sub-theme: Urban Ecology** | | |
| | Soil as an urban resource | - How do we make the best use of soil in an urban environment?<br>- Functions of soil in cities: support for greening of cities (ecosystem, filtering pollution rainfall, prevention and capturing dust, reduce warming, improve health, climate, wellbeing, humidity, flooding )<br>- How do urban soils function?<br>- What is the positive effect of soil: do we know and understand it?<br>- What is the value of biodiversity?<br>- Effects on urban ecology of soil/soil functions<br>- Effect of green roofs<br>- Effect on temperature, air quality<br>- Evaluation of services<br>- Bioparameters for determining quality<br>- Influence of contamination on bioparameters ecology<br>- Positive effects on air quality/temperature<br>- Integrated management air and soil quality, in urban and surrounding areas |
| | Sealing | - What is the quality of and how do we mitigate soil sealing? What functions remain in permeable surface soils?<br>- How useful are artificial urban soils? (green roof)<br>- Impact urbanisation flood risk/water management<br>- Effects of sealing (groundwater management)<br>- Solutions to reduce sealing |
| **Sub-theme: Spatial Planning** | | |
| | Redevelopment of urban and industrial areas | - Brownfield redevelopment<br>- Sealing/soil use of quality Brown fields<br>- Green areas and redevelopment of brown fields<br>- Soil management in relation to rehabilitation in a cost-effective way<br>- Brownfield redevelopment: soil quality/land use<br>- What is a Brownfield |
| | Urban spoil, land consumption | - How do we prevent the incorrect use of high-quality agricultural land?<br>- How do we combine soil opportunities with spatial planning?<br>- Land use, environmental aspects of spatial planning |
| | Urbanisation and soil quality | - The influence of large infrastructure on soil functionality<br>- Urbanisation and geological properties<br>- The impact on soils of waste stream diversion from landfill. Waste diversion |

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| | | from landfill: what are the implications for soil of diversion of waste from landfill? What is/is not appropriate? |
| | Urban planning | - Integration with organisation, economy, decision-making<br>- Circumstantial aspects<br>- Integration with planning scenarios (LT)<br>- Cost-benefit analyses<br>- Method/tool for societal cost in developments (to internalise the cost)<br>- Carbon neutral communities<br>- Demographic developments/migration use of land/soil<br>- Urban functions in the right place<br>- Integrate at the right time/inclusion in the process<br>- Tools for facilitating flow of information<br>- Integrate in administrative procedures (real estate info)<br>- Economic value of houses/buildings |

| Theme | Questions | Knowledge needs |
|---|---|---|
| **GENERAL** | | |
| **Sub theme: Awareness** | | |
| | Increasing public awareness about the role of soil and groundwater | - What items relating to soil have the attention of the public?<br>- Which methods can be used to raise awareness or to make soil visible (soil profiles/organisms)<br>- Awareness perception governance<br>- Social learning<br>- Science policy interfacing (knowledge brokering)<br>- How to keep an interest and investment in "soil and groundwater" knowledge<br>- Why is "nobody" interested in soil protection/sustainable management? How to integrate this into national and regional and individual strategies<br>- Dissemination<br>- The main need: General education of policymakers + the public about the role of soil/groundwater |
| | Effects of Public behaviour | - Effects of public and private practices, tools and instruments on soil dynamics in the way these are connected to land use changes and land market |
| **Sub theme: Economy** | | |
| | Assessment of economic value of soil functions | - Monetising soil services<br>- Economic value of soils and soil servings<br>- What is the "new" market value of soil and groundwater<br>- Soil conflict of use (food, bioenergy, urbanism/tourism)<br>- How should soil services be translated into decision-making tools?<br>- How should the value of soil (services)and cost (prevention/decontamination) be translated?<br>- Overall economic evaluation of environmental measures (soil, air, water etc) |
| **Sub theme: Soil quality management** | | |
| | Supporting soil quality management | - Resource management: (soil/water/ecosystem)<br>o Monitoring<br>o Data provision<br>o Assessment<br>o Planning<br>- Standards: What is acceptable for soil? What is acceptable in terms of materials that are spread on soil?<br>- Funding a common definition of good soil "quality"<br>- What is the mechanism behind ignoring negative effects and shifting the costs of soil and groundwater use to future generations?<br>- What is the innovative policy response to a change in use of soil and groundwater services to sustainable use. |

# Annex 2: Knowledge questions per soil function categorised in DPIRS order

## 1. Production

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Bio fuel production | Competition with other land uses, suitability for production | - What is the effect of high input forestry and intensification in forestry?<br>- What is the impact in terms of compaction, soil structure?<br>- What are the long-term effects on soil quality?<br>- What are the effects of changes in land use (waste land/nature/pasture or forest)?<br>- What is the effect of biofuel production ~~fuels on food production?~~ | - Which areas are suitable for biofuel crop production? How do we decide on the different uses of land?<br>- How do we choose the different biofuel crops?<br>- What are the effects of second generation of biofuel crops?<br>- What are the advantages/disadvantages of woody energy carriers?<br>- Is there a win-win situation from biofuel production (landscape, leisure, etc)?<br>- How can we combine phytoremediation and biofuel production: what are the barriers? How do we improve these?<br>- How can we connect land remediation with biomass production? | - What is the role of soil in the production of biomass through agriculture and forestry? |
| Reduction in the emission of greenhouse gases | How to increase the fixation of carbon in organic materials (plant roots, vegetation, peat formation)? | - What is the effect of wetlands restoration on the emission of greenhouse gases?<br>- What is the effect of agricultural practices on the emission of greenhouse gases? (Different cultivation methods)? | | |
| | ~~Erosion~~ | | - What are the possibilities of production of crop on saline soil? | |
| Climate change | | - How can we control, prevent intercept erosion of sediments?<br>- What is influence of climate change on erosion? | - How can we enhance:<br>- Assimilation processes<br>- Production of organic material<br>- Peat formation<br>- Root formation | |
| | ~~Different agricultural products~~ | | | ~~Increasing awareness of food safety~~ |
| Development of ecosystem services | | - What is the impact of different agricultural production methods (machinery, pesticides, fertilizers, crops) on the emission of greenhouse gases, food safety, biodiversity in soil/groundwater, erosion, human/animal health?<br>- What are the long-term effects of agriculture on soil services/ecosystem? | - Are there alternatives for protein production, cattle farms or fish farms? | |

# 2. Biodiversity (Habitat/gene pool, eco-system)

| Driving forces | Pressures | Impacts | Responses | State |
|---|---|---|---|---|
| Energy saving<br><br>Biofuel production | Warming and cooling of soil and groundwater<br><br>Mono cultures of biofuel crop | - What are the effects of up scaling heat storage on soil diversity?<br>- What is the effect on ecosystem health, biodiversity?<br>- Increasing plant and animal illness caused by intensive use of soil and growing of monocultures | - How to quantify the ecological value of soil in relation to ecosystem goods and services (pricing/valuation)<br>- How to combine ecological (soil) services with other (physical) soil services (use of sub soil)?<br>- Protection and ecological reconstruction of critical areas. | - What is a healthy soil?<br>- Is soil part of the ecosystem?<br>- What species are “normal”/what diversity is normal?<br>- How do urban soils function?<br>- What is the value of biodiversity?<br>- How important is biodiversity of/in soil (incl. gene pool)? |
| Climate change | Temperature changes<br>Flooding | - How will soil ecological functions change with climate change?<br>- What are the effects of flooding on soil ecosystems? | - How can you create a win/win situation by increasing water retention and improving ecosystems? | - What is the role of soil biodiversity as a “pool” for biotechnology?<br>- What is the role of soil ecosystem services in spatial planning, agriculture, etc. |
| Sustainable agriculture | Reducing use of herbicides and pesticides<br>Changing agricultural production methods | - What is the relationship between biodiversity and soil and plant health?<br>- What is the impact of compaction on the ecosystem? | - How can we use ecosystem services for sustainable agriculture?<br>- How can we use the soil ecosystem to optimise agriculture fertiliser input, pesticide input? | - Bioparameters for determining quality - How to monitor biodiversity?<br>- Research on new and improved methods to determine soil biodiversity, at the micro-organism level and at the functional (mRNA) and at the protein levels |
| Development of ecosystem services | Changes in land use | - Persistence and quantity of pathogens related to water quality management.<br>- What is the relationship between biodiversity in soil to biodiversity in the ecosystem “on top of soil” and water?<br>- Role in ecological infrastructure: corridors / stepping stones<br>- Relationship between soil ecology, biodiversity and formation of natural areas and agriculture | - How to teach farmers to change agricultural methods? Being taught by the father is much stronger than messages from science or policy?<br>- Can we improve water/soil safety against pathogens? | |
| Urbanisation<br>Urban ecology | Improving role of urban green and ecosystems | - What is the impact of soil biodiversity on human health?<br>- Functions of soil in cities: support for greening of cities (ecosystem, filtering pollution rainfall, prevention and capture of dust, reduce warming, improve health, climate, well being, humidity, flooding, etc. )<br>- What is the effect of contamination on biodiversity? | - Decision support tool kits for soil, groundwater, surface water and biodiversity management at landscape/catchment scale<br>- Integrated management of air and soil quality, in urban and surrounding areas.<br>- How to make the best use of soil in urban environment?<br>- Effect of green roofs on temperature, air quality | |

# 3. Transformation processes: physical, chemical, biological

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Energy saving | Warming and cooling of soil and groundwater | - What is the long-term impact?<br>- What is the impact on resilience of soil and water systems?<br>- Thermal effect on ecosystems<br>- Thermal effect on chemical solutions<br>- Effect of cold on geological formation | | |
| Reduction of emission of greenhouse gasses | How to achieve a reduction in emission? | - Reduction of $NO_2$ by nitrification/denitrification,<br>- Reduction of methane production | - What is the impact of changes in land use (e.g. energy crops) on carbon-cycle?<br>- Measure to increase organic material | - The role of the soil in the production and reduction of greenhouse gases such as $CO_2$, $NO_2$ and $CH_4$ ? |
| Climate change | Temperature changes<br><br>Flooding | - Balance of emission and fixation of carbon?<br>- Release of stored CH4<br>- Oxidation of organic matter (peat)<br>- Impact of irrigation/salinisation on soil functions<br>- Relationship between changes in groundwater level and oxidation of peat<br>- Influence of flooding on soil function filtering.<br>- How resilient is the soil filter capacity in the long term? | - How to shift from global developments and effects to local and regional scales?<br>- To what extent is mathematical modelling useful to decision makers? In which ways can it be utilised? | - How to monitor soil quality changes due to climate change? |
| Urbanisation | Contaminations from different sources | - Soil as an immobiliser.<br>- Effect of contaminations on mineral cycle? | | |
| Development of ecosystem services | Agricultural production methods | - Influence of agricultural practices on soil and groundwater (diffuse pollution)<br>- Transformation of minerals<br>- Anaerobic organic breakdown<br>- What is the influence on resilience of soil and water systems? | - Incentives for “good behaviour” vs. punishment for “bad behaviour”<br>- (especially P)role?<br>- How to stimulate nutrients transfer from land to water<br>- Measure to increase organic material<br>- Methods to reduce acidification<br>- Alternative forestry practices | |
| Change in land use | | | - How to estimate mid-term or long-term effects of land use change on nutrient release. How can the benefit be shown to farmers?<br>- Integrated regional management of substances (nutrients, biomass, water) | |

# 4. Source of raw material: Groundwater

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Energy saving | Pollution of groundwater<br>Temperature changes | - Interactions between energy storage and drinking water production.<br>- Thermal effects on drinking water production.<br>- Creation of pollution pathways by energy storage | - How can international water management and tools be implemented most cost effectively?<br>- How should soil (local) models be linked to water catchment models?<br>- How should upstream be balanced with downstream interests? | - What is sustainable groundwater quality?<br>- What is groundwater ecology?<br>- What is the need for strategic clean groundwater reservation? |
| Climate change | Seawater intrusion | - What is the impact of enhanced peat oxidation on drinking water?<br>- What is the effect of climate change on (ground)water flow?<br>- What is the influence of flooding on groundwater quality? | - Management/audification, recovery of dissolved organic compounds transfer from upland soils,<br>- Relationship between groundwater quality and surface water quality | - What is the role of groundwater level and quality in the development or preservation of natural areas and agricultural production? |
| Sustainable agriculture | Implementation of sustainable agriculture | - What is the effect on agricultural groundwater use? | - How to link soil use and practice, to make water quality meet WFD? | |
| Urbanisation | Demographic developments<br>Changes in land use<br>Contaminations from different sources | - What changes will there be in runoff of rainwater and transportation of groundwater (sealing, compaction and building of subsurface constructions)?<br>- How do spatial and timescale effects affect surface of groundwater quality?<br>- What are the effects of more pressure on drinking water stock?<br>- Effects of land use and transformation of use on groundwater quality?<br>- What is the response time of groundwater quality related to land use changes?<br>- Do we understand the long-term effects on groundwater?<br>- How is groundwater quality affected by pollution concentrated in sources or diffuse via air and soil?<br>- Transfer of emerging contaminants to groundwater?<br>- What are the effects of hazards on polluted areas?<br>- What is the effect of thermal heating remediation? | - How to change habits that influence groundwater quality and surface water?<br>- How to manage water surplus in urban areas, what kind of policy tools are needed?<br>- Effects of planning on groundwater<br>- What measures could there be to reduce the effects of diffused contaminations on quality?<br>- Development of risk assessment concepts “Real” contamination (cocktails chemical contamination, medication and elements in waste / sludges)<br>- What is the potential for phytoremediation to help solve contamination problems?<br>- How does soil management use affect long-term (and short-term) groundwater quality? | |

# 5. Storage (including carbon)

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Energy saving | Heating and cooling | - | - What strategies are there to apply the storage of heat and cold in the soil and groundwater?<br>- How can the storage of heat and cold and use of thermal energy and other soil functions and remediation goals be combined?<br>- Can you improve capacity and the impact (e.g. contamination?) | - What are the possibilities and capacity for energy storage?<br>- What are the possibilities for storage in the soil and groundwater of heat and cold for cooling and heating?<br>- What is the relation between urban and rural planning and the characteristics of soil and groundwater in relation to possibilities for sustainable energy and energy savings?<br>- Capacity to contribute, differences in soil type |
| Reduction of emission of greenhouse gasses | Storage of $CO_2$ and natural gas | - Effect on geological formation<br>- Interaction of $CO_2$ with soil/groundwater<br>- Risks of leakage<br>- Comparison between natural fixation of $CO_2$ or technological liquid storage<br>- What is the long-term dynamic of soils as a sink source of CO2? | | - Is soil currently losing carbon, is soil a source or a sink?<br>- What is the heterogenic spread of areas of sink or source of CO2? |
| Climate change | Infiltration<br>Retention | - Effect on infiltration<br>- What is the effect of climate change on retention?<br>- How does erosion influence retention?<br>- How does the condition of soil influence<br>- retention quality? | - How do we increase storage capacity in catchments and groundwater?<br>- What is the cost/benefit of filtering upstream in wetlands.<br>- How can we value the function of soil filtering?<br>- Can you improve resilience?<br>- How can you create a win/win situation by increasing water retention and improving ecosystems?<br>- How can the soil best be managed to optimise retention? | - What is the role of soil in attenuating rainfall in climate change, particularly in the urban context (increasing intensities of rainfall events)? |
| | Temperature change | Effect on organic matter, fertility, erosion. Can these effects be modelled? | - How do soil and vegetation enforce soil retention capacity, balance of vegetation type and soil type? | |
| Urbanisation | Sealing | - What is the effect of sealing and compaction on retention? | | |

## 6. Physical and cultural environment
## 7. Archive for geological and archaeological heritage

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Development of ecosystem services | Agricultural production methods | - Effects of compaction? We know compaction is a problem, but do we have data on the scale of this?<br>- Decrease of production due to compaction and loss of organic compounds<br>- What is the impact of changing "roles" of the farmer e.g. energy supplier? | - New models for stress transmission and soil deformation<br>- Better models for predicting the effects of compaction on soil processes such as water flow, transport of solutes and crop growth<br>- Development of strategies to reduce compaction, including technical measures and decision support systems | - Quantity and mitigate soil sealing? |
| Climate change | Landslides and erosion | - Understanding the relationship between climate and landslides and the development of better models for fast landslides<br>- Predicting future behaviour of landslides under different climate and land use. | - Design of reliable early-warning systems<br>- Living with landslides and sustainable development in landslide-prone regions, using both land use changes and technical measures<br>- How can we map risks to soil, such as erosion?<br>- What is the effect of changes in climate and land use on erosion?<br>- Development of integrated strategies for addressing erosion | |
| Build environment | Sealing | - What functions remain in permeable surface soils?<br>- How useful are artificial urban soils? (green roof)<br>- Impact of urbanisation flood risk/water management.<br>- Effects of sealing on groundwater management | - Solutions to reduce sealing | |

# 8. General

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Awareness | Increasing public awareness about the role of soil and groundwater | - Which items relating to soil have public attention?<br>- What methods can be used to raise awareness?<br>- Science policy interfacing (knowledge brokering)<br>- How to keep interest and investment in "soil and groundwater" knowledge?<br>- How to integrate awareness for soil in national and regional and individual strategies? | - The main need: General education of policymakers + public about the role of soil/groundwater<br>- Dissemination | |
| | Effects of Public behaviour | - Effects of public and private practices, tools and instruments on soil dynamics as linked to land use changes and land market | - | |
| Economy | Assessment of economic value of soil functions | - Economic value of soil and soil services<br>- Soil conflict of use (food, bio energy, urbanism/tourism)<br>- How should soil services be translated into decision-making tools? | - Overall economic evaluation of environmental measures (soil, air, water etc)<br>- Cost-benefit analyses. | |
| Effective land use | Improvement of rural planning | - Can a combination of agricultural and natural areas help to mitigate potential negative effects on agriculture?<br>- Matching crop/agricultural land use to the environment on account of the changing climate.<br>- Which crops are better to grow with which soil types?<br>- Can agriculture help tackle the problems of diffuse contamination? (phytoremediation?) | - Instruments for rural planning<br>- Instruments to link soil types to optimal land use<br>- How can we make better use of the knowledge about soil properties in rural planning?<br>- How can we integrate soil/groundwater aspects in rural planning?<br>- How can we link crop choice to soil type/properties in an improved manner? | - |
| Soil quality management | Supporting soil quality management | - What is acceptable in terms of materials that are spread on soil?<br>- ? | - What is the mechanism behind ignoring negative effects and shifting the costs of soil and groundwater use to future generations?<br>- What is the innovative policy response to a change in use of soil and groundwater services to sustainable use? | - Funding a common definition of good soil "quality"<br>- Resource management: (soil/water/ecosystem)<br>- Monitoring<br>- Data provision<br>- Assessment |
| Contamination | Risk and risk perception | - Long-term effects on soil health and diffuse contamination<br>- Relationship between soil contamination and health<br>- Relationship between sources and effects<br>- Relationship between soil contamination, risks and land use<br>- Food chain transfer of contaminants, eco-toxicological effects, effects on human health and on animal health | - Communication about risks/measures (or not) on health/stress<br>- Harmonisation of risk assessment, modelling for decision making<br>- Consensus on standards<br>- Site-specific approach to area approach | - Need to know how many contaminated sites or potential contaminated sites are in our region<br>- Discrimination of sources of pollution in a specific area |

| | | | | |
|---|---|---|---|---|
| | | - Discrimination of risk effects from soil, air, water, etc.<br>- Emerging contaminants in groundwater (detection, removal, control)<br>- Spreading of contaminants<br>- Bioavailability | | |
| | Reducing risks | - Soil as a storer and attenuator of pollution: the role of soil types (which are good, which are bad) in filtering and alternating pollution from the surface and its role in storing pollution which has a potential for long-term release (e.g. policy) | - Cost-effective reduction of risk<br>- Management of diffuse contamination (transfers to water, ecosystem, food chains)<br>- Management of contaminated sites<br>- Management of multiple pollution sources<br>- Evaluation and demonstration of technologies, knowledge dissemination<br>- Rehabilitation of contaminated land using sustainable technology<br>- New innovative remediation technologies<br>- Reduction of diffuse contamination | - |
| Urban planning | | - Influence of large infrastructure on soil functionality | - How do we prevent the incorrect use of high-quality agricultural land?<br>- How do we combine soil opportunities with spatial planning?<br>- Integration with organisation, economy, decision-making<br>- Integration with planning scenarios (LT)<br>- Method/tool for societal cost in developments (to internalise cost)<br>- Tools for facilitating the flow of information.<br>- Integration into administrative procedures (real estate info).<br>- Economic value of houses/buildings. | - Demographic developments/migration use of land/soil. |
| Redevelopment of urban and industrial areas | | - | - Brownfield redevelopment | - What is a Brownfield |

# Annex 3

# Expert workshop December 2008 in Gouda, the Netherlands

**PARTICIPANTS OF EXPERT WORKSHOP**

**ANNEX 3**

**Participant**

| Name | Organisation |
|---|---|
| Dr. Ir. H.H.M. Rijnaarts | Deltares |
| Dr. N. Hartog | Deltares |
| B. van Breukelen | Vrije Universiteit Amsterdam |
| Prof. A. Laboudigue | Mines de Douai |
| C. Mouvet | Brgm Geoscience for a sustainable earth |
| Prof. Dr. F. Buscot | Helmholtz Centre for environmental research - ufz |
| Prof. Dr. F. Rück | Fachhochschule Osnabruck University of Applied Sciences |
| M. Kibblewhite | Cranfield University |
| S. Le Roy | Jacobs |
| M. Schamann | Umwelt Budesamt GmbH |
| Dr. Ir. P. Spanoghe | Ugent |
| K. Adriaensen | Uhasselt |
| M. Bergknut, PhD | Swedish University of Agricultural Sciences, SLU |
| B. Barnes | Environment Agency, Science Dept |

The tables below contain a summary of the results of the discussion with experts about the research needs, which is categorised according to soil function.

The research items are shown in red
The knowledge questions are shown in black that relate to the research need
The knowledge questions for which no research needs were indicated are shown in black bold type.

# 1. Production

# Annex 4 Research questions per soil function

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Biofuel production | Competition with other land uses, suitability for production | - **What is the effect of high input forestry and intensification in forestry?**<br>- **What is the impact in terms of compaction, soil structure?**<br>- What are the long term effects on soil quality?<br>- What are the effects of changes in land use (waste land/nature/pasture or forest)?<br>- What is the effect of biofuel production on food production?<br>- What is impact of biomass production on soil (including biodiversity), is this different from food production?<br>- Carbon cycle: residue of biofuel/food is different: effects on soil functions | - **Which areas are suitable for biofuel crop production? How do we decide on the different uses of land?**<br>- **How do we choose the different biofuel crops?**<br>- **What are the effects of second generation of biofuel crops?**<br>- **What are the advantages/disadvantages of woody energy carriers?**<br>- **Is there a win-win situation from biofuel production (landscape, leisure, etc)?**<br>- Budget the greenhouse gases of the different production systems of biomass (food/biofuel) e.g. harvest plants with or without roots.<br>- **How can we combine phytoremediation and biofuel production: what are the barriers? How do we improve these?**<br>- **How can we connect land remediation with biomass production?**<br>- What are the possibilities of production of crop on saline soil?<br>- Make a cost-benefit analysis of the complete chain from sewing to harvest, the use of the biomass and the end wastes;<br>- Can biofuel crops grow on contaminated or marginal land? | Increase of production of food 40% in 2040: intensification and pressure on soil use<br>- What is the role of soil in the production of biomass through agriculture and forestry? |
| Reduction in the emission of greenhouse gasses | How to increase the fixation of carbon in organic materials (plant roots, vegetation, peat formation)? | - **What is the effect of wetlands restoration on the emission of greenhouse gases?**<br>- **What is the effect of agricultural practices on the emission of greenhouse gases? (Different cultivation methods)?** | | |
| Climate change | Erosion | - **What is the effect on organic matter, fertility, erosion? Can these effects been modelled?**<br>- **How can we control, prevent intercept erosion of sediments?**<br>- **What is influence of climate change on erosion?** | - Discrepancy between societal values and intensive production<br>- Changes in diet: meat instead of other food<br>- Loss of agricultural land (urbanisation), loss of quality (by contamination)<br>- Development of more resilient/highly productive land, (intensification without negative effects) and prevention of degradation of valuable land<br>- Using less pesticides, more land is needed<br>- Any nutrient addition to the land brings contamination: fertiliser, manure, compost, sewage sludge, what is the cost benefit of nutrients; can we reduce contaminant load including emerging contaminants<br>- **How can we enhance:**<br>º **Assimilation processes**<br>º **Production of organic material**<br>º **Peat formation**<br>º **Root formation**<br>- **Are there alternatives for protein production, cattle farms or fish farms?** | - Increasing awareness of food safety |
| Development of ecosystem services | Different agricultural products | - **What is the impact of different agricultural production methods (machinery, pesticides, fertilisers, crops) on the emission of greenhouse gasses, food safety, biodiversity in soil/groundwater, erosion, human/animal health?**<br>- **What are the long-term effects of agriculture on soil services / ecosystem?**<br>- Use of transgenic crops | | |

# 2. Biodiversity (Habitat/gene pool, eco-system)

| Driving forces | Pressures | Impacts | Responses | State |
|---|---|---|---|---|
| Energy saving | Warming and cooling of soil and groundwater | - **What are the effects of up scaling heat storage on biodiversity and ecosystem health?** | - How to combine ecological (soil) services with other (physical) soil services (use of sub soil)?<br>- Protection and ecological reconstruction of critical areas. | State of knowledge is insufficient to respond. SNOWMAN should organise a process (e.g. conference) to start answering these questions. |
| Biofuel production | Mono cultures of biofuel crop | - **Increasing plant and animal illness caused by intensive use of soil and growing of monocultures** | - Buffering and stability | - What is a healthy soil?<br>- Is soil part of the ecosystem?<br>- What species are "normal"/what diversity is normal? |
| Climate change | Temperature changes<br>Flooding | - How will soil ecological functions change with climate change? | - How can you create a win/win situation by increasing water retention and improving ecosystems? | - How do urban soils function? |
| Sustainable agriculture | Reducing use of herbicides and pesticides<br>Changing agricultural production methods | - Climate change > ecological changes > growth of (new) pathogens. We don't know what will happen nor how to manage it.<br>- **What are the effects of flooding on soil ecosystems?**<br>- **What is the relationship between biodiversity and soil and plant health?**<br>- **What is the impact of compaction on the ecosystem?** | - Use of minor land (mining) – high input strategy<br>- How can we use ecosystem services for sustainable agriculture?<br>- Can we use biodiversity as a parameter for "green" agriculture? | - How to quantify the ecological value of soil related to ecosystem goods and services (pricing / valuation)<br>- What is the value of biodiversity?<br>- How important (to us) is biodiversity of/in soil (incl. gene pool)?<br>- Increase soil awareness in planning: use biodiversity when there are changes in the use of the soil<br>- What is the role of soil ecosystem services in spatial planning, agriculture etc |
| Development of ecosystem services | Changes in land use | - **What is the relationship between biodiversity in soil to biodiversity in the ecosystem "on top of soil" and water?**<br>- **Role in ecological infrastructure: corridors/stepping stones** | - **How can we use the soil ecosystem to optimise agriculture fertilizer input, pesticide input?**<br>- **How to teach farmers to change agricultural methods (Being taught by the father is much stronger than messages from science or policy)?**<br>- **Can we improve water/soil safety against pathogens?**<br>- **Decision support tool kits for soil, groundwater, surface water and biodiversity management at landscape/catchment scale** | - Role in land use, nitrogen cycle, carbon cycle<br>- Hot spots rhizosphere<br>- **What is the role of soil biodiversity as a "pool" for biotechnology?** |
| Urbanisation<br>Urban ecology | Improving role of urban green and ecosystems | - **Relationship between soil ecology, biodiversity and formation of natural areas and agriculture**<br>- What is the impact of soil biodiversity on human health?<br>- **Functions of soil in cities: support for greening of cities (ecosystem, filtering pollution rain fall, prevention and capture of dust, reduce warming, improve health, climate, wellbeing, humidity, flooding, etc.)**<br>- **What is the effect of contamination on biodiversity?** | - **Integrated management of air and soil quality, in urban and surrounding areas.**<br>- **How to make the best use of soil in urban environment?**<br>- **Effect of green roofs on temperature, air quality**<br>- Phytoremediation<br>- How to improve the quality of urban soil to fulfil more soil functions with higher biodiversity; | - Bioparameters for determining quality. How to monitor biodiversity?<br>- Research on new and improved methods to determine soil biodiversity, at the micro-organism level and at the functional (mRNA) and at the protein levels<br>- Biodiversity and biological processes: which organisms are active? Why?<br>- Data (DNA/RNP) - theoretical system to interpret (knowledge from plant and animal research) – basis for practical use |

# 3. Transformation processes: physical, chemical, biological

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Energy saving | Warming and cooling of soil and groundwater | - **What is the long-term impact?**<br>- **What is the impact on resilience of soil and water systems?**<br>- **Thermal effect on chemical solutions**<br>- **Effect of cold on geological formation** | - **What is the impact of changes in land use (e.g. energy crops) on carbon-cycle?**<br>- **Measure to increase organic material**<br>- Enhancement of processes | - Bridging models from micro to macro scale (for specific parameters) |
| Reduction of emission of greenhouse gasses | How to achieve a reduction in emission? | - Reduction of $NO_2$ by nitrification/denitrification,<br>- Reduction of methane production<br>- Effects in time: buffering, resilience $CO_2$, $CH_4$ etc. | | - **The role of the soil in the production and reduction of greenhouse gases** |
| Climate change | Temperature changes<br><br><br><br><br>Flooding | - Balance of emission and fixation of carbon? Oxidation of organic matter (peat)<br>- Binding of components and carbon (is decreasing)<br>- Changes in processes by flooding<br>- pH decreasing<br>- Release of stored $CH_4$<br>- Relationship between changes in groundwater level and oxidation of peat<br>- Influence of flooding on soil functions such as filtering.<br>- How resilient is the soil filter capacity in the long term? | - **To what extent is mathematical modelling useful to decision makers? In which ways can it be utilised?** | - **How to monitor soil quality changes due to climate change?**<br><br>- **How to shift from global developments and effects to local and regional scales**<br>- |
| Urbanisation | Contaminations from different sources | - Soil as an immobiliser.<br>- Effect of contaminations on mineral cycle?<br>- Fate and effects of emerging components e.g. antibiotics<br>- Effect of soil remediation on soil functions (restoration) | - How to improve transformation in urban environments (artificial soils)<br>- Effect of soil remediation on soil<br>- functions (restoration)<br>- What is the impact of replacement of soil on soil quality | - Value of soil processes<br>- What could we develop as a good indicator for good soil<br>- What is a healthy soil and how do we influence people in such a way that the soil will remain healthy |
| Development of ecosystem services | Agricultural production methods | - **Influence of agricultural practices on soil and groundwater (diffuse pollution)**<br>- **Transformation of minerals**<br>- **Anaerobic organic breakdown**<br>- **What is the influence on resilience of soil and water systems?**<br>- Fate of pesticides (breakdown, validation of models )decisions of specifications | - **How to stimulate nutrients transfer from land to water**<br>- **Measure to increase organic material**<br>- **Methods to reduce acidification**<br>- **Alternative forestry practices**<br>- How can we degrade the modelling tools in such a way that decision-makers use the models? | - How can we value the function of soil filtering? |
| Change in land use | | - Effect of land use on soil processes | - **How to estimate mid-term or long-term effects of land use change on nutrient release.**<br>- **Integrated regional management of substances (nutrients, biomass, water)** | - Valorisation of transformation processes depending on land use |

# 4. Source of raw materials: Groundwater

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Energy saving | Pollution of groundwater<br>Temperature changes | - **Interactions between energy storage and drinking water production.**<br>- **Thermal effects on drinking water production.**<br>- **Creation of pollution pathways by energy storage**<br>- Effect of energy storage on temperature changes, groundwater level, and chemical equilibrium<br>- Models for spreading of heat and cold | - How to link soil (local) models to water catchments models.<br>- Decision support systems for using groundwater or surface water for different purposes<br>- **How should upstream be balanced with downstream interests?**<br>- **Management/audification, recovery of dissolved organic compounds transfer from upland soils,**<br>- Effect of geomorphology changes (mining) on quality<br>- **How to link soil use and practice, to make water quality meet WFD?**<br>- **How can we respond to improve retention capacity and reduce flooding effects with management strategies and procedures?**<br>- Enhancing/engineering biological processes (biodiversity) to improve quality (nitrate)<br>- How do we implement international water management and tools most cost effectively?<br>- Managing of resources:<br>º Local/intermediate/large-scale models and connections (catchments)<br>º Interaction between groundwater and land use<br>º Sealing<br>º Infiltration<br>º Quality<br>º Filtering<br>- Phosphate: removal, mining, reducing sources (agriculture) | **Split this function into quantity and quality. Quantity is most important in southern Europe, quality in eastern Europe**<br>- **What is sustainable groundwater quality?**<br>- **What is groundwater ecology?**<br>- **What is the need for strategic clean groundwater reservation?**<br>- **What is the role of groundwater level and quality in the development or preservation of natural areas and agricultural production?**<br>- How does surface/groundwater interact? Perhaps we understand, but we don't have the data. Is there a solution for the lack of data? |
| | Biofuel crop production | - Effect of monoculture production (biofuels) on quality, additional effects (pesticides)<br>- Use of water during conversion of crops to fuel | | |
| Climate change | | - **What is the impact of enhanced peat oxidation on drinking water?**<br>- What is the effect of climate change on (ground)water flow? | | |
| | Flooding | - What is the effect of changes in climate and land use on flooding?<br>- Influence of flooding on groundwater quality?<br>- Effects of temporary flooding of land on water quality | | |
| | Seawater intrusion | - Impact of irrigation/salinisation | | |
| Sustainable agriculture | Implementation of sustainable agriculture | - Effect on agricultural groundwater use<br>- Effect of agricultural practices:<br>º Buffer zones between surface water<br>º Run off of N/P<br>º Erosion<br>º Quality<br>º Changes in groundwater level on production | | |
| Land use | | - Relationship between groundwater quality and surface water quality<br>- Effect of sediments on surface water and groundwater quality (infiltration) | | |

| | | | | |
|---|---|---|---|---|
| Urbanisation | Demographic developments<br>Changes in land use<br>Contaminations from different sources | - **What changes will there be in runoff of rainwater and transportation of groundwater (sealing, compaction and building of subsurface constructions)?**<br>- **How do spatial and time scale effects affect surface and groundwater quality?**<br>- **What are the effects of more pressure on drinking water stock?**<br>- How is groundwater quality affected by pollution concentrated in sources or diffuse via air and soil?<br>- Transfer of emerging contaminants to groundwater?<br>- There is some diffuse contamination that we do not understand (including pathogenic). e.g. the spread of sediments with contamination during flooding.<br>- Transfer of pathogens to groundwater<br>- **What are the effects of hazards on polluted areas?**<br>- **What is the effect of thermal heating remediation?**<br>- What are the effects of land use and transformation of use on groundwater quality?<br>- What is the response time of groundwater quality in relation to land use changes?<br>- What is the effect of land use on groundwater quality and quantity, planning of land use? | - **How to change habits that influence groundwater quality and surface water?**<br>- **How to manage water surplus in urban areas, what kind of policy tools are needed?**<br>- **Planning of the use of groundwater**<br>- **What measures could there be to reduce the effects of diffused contaminations on quality?**<br>- **How does soil management use affect long-term (and short-term) groundwater quality?**<br>- How should historical pollution (pesticides/nitrate/Cadmium), which is not removable, be managed? How does the soil manage these contaminants by natural processes in the long term?<br>- We need a tool to estimate the risks of mixed contaminants.<br>- How do we budget remediation in a total system approach, taking into account more than just contamination?<br>- Development of risk assessment concepts “Real” contamination (cocktails chemical contamination, medication and elements in waste / sludges)<br>- Developing holistic risk assessment approaches for groundwater/ soil | - Do we study and understand the long-term effects on groundwater? |

# 5. Storage (including carbon)

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Energy saving | Heating and cooling | - What is the effect of energy saving systems (heat/cold storage) on the quality of soil? | - **What strategies are there to apply the storage of heat and cold in the soil and groundwater?**<br>- **How can the storage of heat and cold and use of thermal energy and other soil functions and remediation goals be combined? Can you improve capacity and the impact (e.g. contamination)?** | - What are the possibilities and capacity for energy storage (heat and cold)? Are there differences in soil type?<br>- Available capacity for storing heat/cold. What are the limits?<br>- **What is the relation between urban and rural planning and the characteristics of soil and groundwater in relation to possibilities for sustainable energy and energy savings?** |
| Biofuel production<br><br>Reduction of emission of greenhouse gasses | Change in carbon cycle<br><br>Storage of $CO_2$ and natural gas | - **Effect on geological formation**<br>- **Interaction of $CO_2$ with soil/groundwater**<br>- **Risks of leakage**<br>- **Comparison between natural fixation of $CO_2$ or technological liquid storage** | - Management determines the oxidation, how do you manage the peat (and other soils) in such a way that there is less oxidation?<br>- Which type of land use can change soil from being a $CO_2$ source to a $CO_2$ sink;<br>- Storage of carbon (biochar): stability of carbon in soil, carbon accumulation | - Learn from the past; what happened in the soil 10 – 100 thousand years' ago by the use of historical data archived in arctic ice layers (archive) to observe long-term $CO_2$ developments. |
| Climate change | Infiltration<br>Retention | - **Effect on infiltration**<br>- **What is the effect of climate change on retention?**<br>- **How does erosion influence retention?**<br>- **How does the condition of soil influence**<br>- **retention quality?**<br>- What is the effect of a long drought on the soil storage capacity of groundwater<br>- What is the effect of sealing and compaction on retention? | - Storage of surface water in deep aquifers: state of the art and what are the effects.<br>- Use of subsurface storage of water<br>- How do we increase storage capacity in catchments and groundwater?<br>- **What is the cost/benefit of filtering upstream in wetlands.**<br>- **How can you create a win/win situation by increasing water retention and improving ecosystems?**<br>- How can the soil best be managed to optimise retention? | - Use of labelled $CO_2$ in growing plants and uptake in air.<br>- **Role of soil in the carbon cycle.**<br>- **Is soil currently losing carbon, is soil a source or a sink?**<br>- **What is the long-term dynamic of soil as a sink source of $CO_2$?**<br>- **What is the heterogenic spread of areas of sink or source of $CO_2$?** |
| Urbanisation | Temperature changes<br><br>Sealing<br><br>Contamination<br><br>Disposal of wastes | | - **How do soil and vegetation enforce soil retention capacity, balance of vegetation type and soil type?**<br>- We need a link between river basin management and urban planning.<br>- How can we manage soil sealing to minimise storage capacity?<br>- How do we keep water storage functions alive in urban infrastructure development? What should the storage capacity of cities be? We need instruments.<br>- In the long term: storage of phosphate.<br>- Effects and potentials of accumulation of components (heavy metals, phosphate)<br>- Disposal of sediments/compost in brownfield sites. | - **What is the role of soil in attenuating rainfall in climate change particularly in the urban context (increasing intensities of rainfall events)?** |

# 6. Physical and cultural environment

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Development of ecosystem services | Agricultural production methods | - **What are the effects of compaction? We know compaction is a problem, but do we have data about the scale of this?**<br>- **Decrease of production due to compaction and loss of organic compounds.**<br>- **What is the impact of changing "roles" of the farmer e.g. energy supplier?** | - **New models for stress transmission and soil deformation.**<br>- **Better models for predicting the effects of compaction on soil processes, such as water flow, transport of solutes and crop growth.**<br>- **Development of strategies to reduce compaction, including technical measures and decision support systems.** | - Cultural aspects: geomorphology, colour, smell, awareness. |
| Climate change | Landslides and erosion | - **Understanding the relationship between climate and landslides and the development of better models for fast landslides.**<br>- **Predicting future behaviour of landslides under different climate and land use.** | - **Design of reliable early-warning systems.**<br>- **Living with landslides and sustainable development in landslide-prone regions, using both land use changes and technical measures.**<br>- **How can we map risks to soil, such as erosion?**<br>- **What is the effect of changes in climate and land use on erosion**<br>- **Development of integrated strategies for addressing erosion.** | - Monitoring of erosion (already a lot of research)<br>- How to reduce erosion, reforestation?<br>- Reclaimed land, erosion, contamination, room for the river |
| Build environment | Sealing | - Which functions remain in permeable surface soils?<br>- How useful are artificial urban soils? (green roof)<br>- What is the impact of urbanisation flood risk/water management?<br>- What are the effects of sealing on groundwater management?<br>- What are the effects of different kinds of sealing on soil functions?<br>- What interactions are there between soil and the atmosphere? | - Solutions to reduce sealing.<br>- Reducing permeability on a small scale, benefits of sealing.<br>- Compensation (green roofs).<br>- Can GIS be used to predict sealing of urban settings? | - Quantity and mitigation of soil sealing? |
| | Sub-surface constructions | - Urban planning and sealing | - Effect of soil on structures (wine cellars, tanks, pipelines, heat and cold storage-installations) | |
| Soil use | Sealing | | | |
| Cultural heritage | | - Relationship between erosion-sensitive areas and soil use, use of manure (awareness) | - How to deal with archaeological relics?<br>- Effects of changes in soil functions on relics | |

# 7 General

| Driving force | Pressure | Impact | Response | State |
|---|---|---|---|---|
| Awareness | Increasing public awareness about the role of soil and groundwater | - **Which items relating to soil have the attention of the public?**<br>- **Which methods can be used to raise awareness?**<br>- **Science policy interfacing (knowledge brokering)**<br>- **How to keep interest and investment in "soil and groundwater" knowledge?**<br>- **How to integrate soil knowledge in national and regional and individual strategies?** | - The main need: General education of policymakers and the public about the role of soil/groundwater<br>- Dissemination<br>- Explain about the relevance of soil to the public: what does derelict land mean for the future?<br>- Organise meetings with social, economic and communication experts and those working with soil in order to commence an awareness process. | |
| | Effects of public behaviour | - **Effects of public and private practices, tools and instruments on soil dynamics when linked to land use changes and land market** | | |
| Economy | Assessment of the economic value of soil functions | - **Economic value of soils and soil servings**<br>- **Soil conflict of use (food, bioenergy, urbanism/tourism)**<br>- **How can we translate soil services into decision-making tools?** | - **Overall economic evaluation of environmental measures (soil, air, water, etc)**<br>- **Cost-benefit analyses.**<br>- **Method/tool for societal cost in developments (to internalise cost)**<br>- **Economic value of houses/buildings.** | - The value is more than economic value<br>- How to connect environmental/social quality to the economic system |
| Effective land use | Improvement of rural planning | - **Can a combination of agricultural and natural areas help to mitigate potential negative effects on agriculture?**<br>- **Matching crop/agriculture land use to the environment, with the climate changing.**<br>- **Which crops can best be grown with which soil types?**<br>- **Can agriculture help to tackle problems of diffuse contamination? (phytoremediation?)** | - Instruments for rural planning<br>- Instruments to link soil types to optimal land use<br>- How can we better use the knowledge of soil properties in rural planning?<br>- How can we integrate soil/groundwater aspects in rural planning?<br>- How should we link crop choice in an improved manner to soil type/properties<br>- | - Effective land use has a relative meaning: it depends where you are in Europe |
| Soil quality management | Supporting soil quality management | - What is acceptable in terms of materials that are spread on soil?<br>- | - What is the mechanism behind ignoring negative effects and shifting the costs of soil and groundwater use to future generations?<br>- **What is the innovative policy response to a change in use of soil and groundwater services to sustainable use?** | - Funding a common definition of good soil "quality"<br>- Resource management: (soil/water/ecosystem)<br>  - Monitoring<br>  - Data provision<br>  - Assessment |

| | | | | |
|---|---|---|---|---|
| Contamination | Risk and risk perception | - **Long-term effects on soil health and diffuse contamination**<br>- **Relationship between soil contamination and health**<br>- **Relationship between sources and effects**<br>- **Food chain transfer of contaminants, eco-toxicological effects, effects on human health and on animal health**<br>- Relationship between soil contamination, risks and land use<br>- **Discrimination of risk effects from soil, air, water, etc**<br>- Emerging contaminants in groundwater (detection, removal, control)<br>- Spreading of contaminants<br>- **Bioavailability** | - **Communication about risks/measures (or not) on health/stress**<br>- **Harmonisation of risk assessment, modelling for decision making**<br>- **Consensus on standards**<br>- **Site-specific approach to area approach**<br>- | - **Need to know how many contaminated sites or potential contaminated sites are in our state**<br>- **Discrimination of sources of pollution in a specific area**<br>- |
| | Reducing risks | - Soil as a storer and attenuator of pollution: the role of soil types (which are good, which are bad) in filtering and alternating pollution from the surface and its role in storing pollution, with potential for long-term release (e.g. policy)<br>- | - **Cost-effective reduction of risk**<br>- **Management of diffuse contamination (transfers to water, ecosystem, food chains)**<br>- **Management of contaminated sites**<br>- **Management of multiple pollution sources**<br>- **Evaluation and demonstration of technologies, knowledge dissemination**<br>- **Rehabilitation of contaminated land using sustainable technology**<br>- **New innovative remediation technologies**<br>- **Reduction of diffuse contamination** | |
| Urban planning | | - Influence of large infrastructure on soil functionality | - **How do we prevent the incorrect use of high- quality agricultural land?**<br>- **How do we combine soil opportunities with spatial planning?**<br>- **Integration with organisation, economy, decision-making**<br>- **Integration with planning scenarios (LT)**<br>- **Tools for facilitating flow of information.**<br>- **Integrate in administrative procedures (real estate info).**<br>- Urban planning relating to soil functions: make maps, data collection on right scale<br>- How to link soil issues to planning; | - Demographic developments/migration use of land / soil. |
| Redevelopment of urban and industrial areas | | | - Brownfield redevelopment<br>- Brownfield development has no research questions.<br>- Is Brownfield development really more sustainable than Greenfield? | - What is a Brownfield site? |

# Annex 5: Research questions from the SoilCritZone project

## With respect to weathering:

**Overarching research question 1:** *How can the dominant factors controlling chemical weathering be identified and their effects quantified in a given environment and at various scales?*
Specific research areas within this remit include:

- Cosmogenic isotopes. In parallel to $^{10}Be$ approach (that still poses some problems), we need to develop new cosmogenic measurements. Rare gases are probably good candidates.
- Similarly, techniques with short-lived isotopes need to be developed. Efforts that have been made in oceanography could be tentatively applied to the critical zone.
- Reactive surface areas: Kinetic models still face the reactive surface problem. Tomographic techniques could be used as a cutting-edge technique for determining the reactive surface area, porosity and preferential flow paths in soils. This technique could be applied to key monitoring sites.
- Dissolution rates and clay precipitation rates: Clay precipitation rates are unknown and more experimental work should be done on clay minerals.

**Overarching research question 2:** *In what ways are physical, chemical, and biological weathering processes coupled, and how can these couplings be elucidated and quantified?*
Specific research areas within this remit include:

- Soil hydrology is a crucial component of the critical zone and we should engage soil hydrologists that are interested in the critical zone concept. Soil moisture is a key component of the global change issue.
- Biological factors: How will global change alter the biodiversity of fungi and therefore nutrient release and therefore soil fertility, soil structure, and hydrology? We must quantify carbon fluxes from the soils. The major soil carbon flux is due to primary productivity. Satellites are now providing maps of gross and primary productivity. Chemical weathering uses $CO_2$ that is produced by the decomposition of organic matter, and by roots and their associated micro-organisms.
- The soil is a self-regulating system; in particular, the upper layer of soil recycles its components entirely. We need to develop tools that allow us to understand more closely the behaviour of the first layer of soil. This relates to its biological activity and the status of nutrients. These tools could be isotopes (especially the 'new' isotopes).

**Overarching research question 3:** *How can we advance our ability to predict weathering processes over the range of pertinent spatial scales, including mineral surfaces, laboratory reactors, soil profiles, catchments, and global systems?*
Specific research areas within this remit include:

- Sedimentation versus erosion. At large scales, sediments are being transported from mountains to plains, defining a 'conveyor belt' of sediments. The most cultivated regions of the world are the plain regions where soils are in a sedimentation regime rather than an erosion regime. This conveyor belt has been interrupted by human activities such as dams and erosion of cultivated areas. This problem relates to the vertical versus horizontal transfer of mass in the critical zone.
- Lake records could be used to understand the link between the critical zone behaviour and land used (or climate change).
- Build integrated mechanistic models bridging biological, hydrological and geochemical processes, in order to better predict the response of the Critical Zone to the anthropogenic forcing. The models should aim at all scales, from the microscopic to global level.

## Biodiversity and cross-cutting themes

**Overarching research question 1:** *What is the influence of physical and chemical perturbations, short and long-term, on soil biodiversity and biological function?*
Specific research questions within this remit include:

- How important are the diversity and community composition of soil organisms in creating resilience to perturbation, particularly in relation to climate change (e.g., drought, flood events, frost, heat, changing seasons), soil management (e.g., tillage, agro-chemicals, crops), and air pollution (acid deposition of $SO_x$ and $NO_x$)?
- What impact does the loss of carbon and erosion have on soil biodiversity and function?

- Is the loss of organic matter from soils a major cause of biodiversity decline and does this compound the negative impact of carbon loss on soil functioning?
- What is the influence of atmospheric $CO_2$ changes on soil biodiversity and function?
- What are the roles of plants, fungi, bacteria and archaea and their interactions in greenhouse gas formation, consumption, rates and pathways of release from soil?
- What effects do short-term land use changes have on soil biodiversity and function?
- What is the influence of pollution on soil biodiversity and function?
- What is the effect of soil physical and chemical variables on soil biodiversity and how well can the soil biota (including microbial communities) adapt to changes in their environment?
- How does the loss of biodiversity affect soil functions, and how can these losses be mitigated?
- How does the structure and composition of microbial communities affect soil processes and process rates, and what are the keystone groups of organisms that perform specific functions?
- What are the key components needed to model and reliably predict the impact of certain soil management strategies or climatic changes on soil biodiversity and resulting soil functions?
- What are the major controls on biotic fluxes of greenhouse gases from soils and how are these affected by vegetation and cropping systems?
- What predictions and practical recommendations from this research can be made in terms of sustainable land uses?

**Overarching research question 2:** *What are the roles of soil biodiversity and biological processes in soil formation and soil sustainability?*
Specific research areas within this remit include:
- What is the relative influence and role of different biotic components on soil formation (i.e. prokaryotes, fungi, plants)?
- Are there keystone organisms involved in soil formation in natural ecosystems and forests that are absent or less active in agricultural soils?
- Is the carbon/energy flux to soil organisms the main driver of their activities? Can this flux be managed to restore functions in degraded soil?
- What are the pathways, flux rates, fate and impacts of biotic-driven carbon fluxes in the critical zone?
- What is the nature and effect of microbe–mineral interactions in the mycorrhizosphere/rhizosphere?
- What is the relative importance of surface versus subsurface interactions between biota and soil constituents in the critical zone for soil regeneration?
- What is the mechanistic basis of the effects of biota on the formation and stability of soils and soil regeneration following degradation?
- What are the key interactions between organisms and minerals that lead to the weathering of minerals, release of nutrient elements, building of ion exchange capacity through clays, sesquioxides and humus, which together lead to the formation of soil horizons and structure?
- Can we develop models and trans-disciplinary experiments that enable knowledge transfer of the functioning of organisms in sustainable natural systems to help better manage soil in production systems?
- What is the mechanistic basis of the role of organisms in the creation of soil aggregates and soil structure, and how do we apply this knowledge to reduce soil degradation and losses in cropping systems?
- What is the role of organisms in soil C sequestration and how can we apply this knowledge to inform land use-policies to restore soil organic matter pools and improve soil functioning (resistance to erosion, infiltration capacity, nutrient and water-storage capacity, carbon storage)?
- What are the dynamics of nutrient partitioning and biogeochemistry in the total soil community, and how is this affected by biotic composition?
- Can we restore functions that have been diminished or lost by using selected organisms to facilitate rebuilding soils?
- What are the functional genetic capabilities in the soil system and how do we characterise these?
- How do we minimise the negative impacts of land use and optimise various soil functions?

**Overarching research question 3**: *What are the practical uses of soil biodiversity and function?*
Specific research areas within this remit include:
- What functional capabilities does soil micro biota possess?
- Do these functional capabilities have practical uses?
- Which soils (from which geographical regions and ecosystem types) can be used to harness specific capabilities required (e.g. antibiotic production, degradation of contaminants)?
- What impacts do anthropogenic perturbations have on these functional capabilities?
- Can plants and their specific associated microbial consortia be selected and used to restore damaged soils and rebuild soil carbon stocks?

- Are there new cultivation methods, cropping systems, species or genotype selections of organisms that can be harnessed to provide profitable crops or bio fuel products whilst building soil health, soil carbon stocks and soil sustainability together with reduced greenhouse gas emissions?
- Are there marginal lands that can be safely brought into bio fuel or food cultivation without compromising soil sustainability?
- How to limit accumulation of N (and other nutrients) in bio fuel crops to reduce pollution risks of combustion and requirements for soil nutrient replenishment.
- How to minimise greenhouse gas emissions ($CH_4$, $N_2O$, $CO_2$) from agriculture, forestry and bio fuel cultivation systems.
- What are the practical uses (engineering) and soil functions (more direct benefits) of soil biodiversity and function?
- Can we apply our knowledge of biogeochemistry and soil ecosystem functioning to engineer bio fertilisation systems that are less dependent on man-made fertilisers and which generate sustained nutrient inputs (N,P,K, etc.) and effective nutrient conservation?
- How to manage bio fuel land use and engineer the specific crops to facilitate soil carbon sequestration and soil sustainability?
- Which are the best strategies to follow to harness the enormous reservoir of microbial bio-compounds that are currently unexplored for novel industrial and medical products?
- How can novel culturing approaches as well as metagenomics be efficiently applied to access the metabolic potential of hitherto unculturable soil micro-organisms?

**Overarching research question 4:** *What are the gaps in our knowledge of C cycling in wetland soils?*
Specific research areas within this remit include:

- What is the long-term effect of a combination of droughts with extreme precipitation events on methane (and $CO_2$) emissions from peat lands? Can long-term field and laboratory manipulation studies of the relationship between wetness and methane emission rates be designed which would minimise manipulation artefacts? How to overcome the known large heterogeneity in methane emission rate measurements from peat lands under various moisture regimes?
- Is carbon quality or environmental parameters the primary control of C sequestration in peat lands? Is this site-specific?
- How can we reduce uncertainty in peat accretion dating and thus in estimates of C accumulation rates?
- What will the net effect of changing vegetation in peat lands be on peat C balance with respect to changing proportion of emission rates of different greenhouse gases?
- What is the explanation of these conflicting measurement results?
- Will higher greenhouse gas emissions from wetlands during global warming further accelerate global warming by releasing even more greenhouse gases from these Crich deposits? Or, alternatively, will higher net primary production under higher (pollution-related) N inputs into wetlands in the 21st century counter-balance the negative effect of warmer, drier conditions on microbial activity, and, thus, will peat lands not experience thinning at all? Will inclusion of wetland behaviour into models of future global change significantly change the prediction of rates of global warming for the future?
- What is the effect of permafrost melting, release of methane hydrates on global C balance?
- What is the fate of drained wetland soils, sustainability of these areas following conversion to agricultural land?
- Is there lower biodiversity in wetland soils as a result of global change?
- Soil lifecycle in rich fens and minerotrophic peat lands (these ecosystems have a high input of nutrients, major and trace elements from groundwater and bedrock; how does weathering in these high-ash organic acidic deposits proceed? etc.).