Study on Soil and water in a changing environment

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Soil and water in a changing environment

FINAL REPORT

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Executive summary

Introduction

Soil and water are two key resources that directly or indirectly affect our everyday activities and are closely linked through the capacity of soil to retain water. A better understanding of the SWR-capacity underlying mechanisms and factors of influence is important to ensure and enhance the long-term supply of ecosystem services that are dependent on the soil and water. In particular, the catastrophic flooding that recently occurred in 2002 and 2013 in Central and Eastern Europe, and in 2007 and 2014 in Western Europe, highlights the urgency to better consider the impacts of our economic development on SWR capacity and the resilience of natural ecosystems.

Soil water retention capacity and its services

When water is applied to the soil surface, water naturally seeps down by gravity provided no physical barriers (such as impermeable layers at the soil surface or within the soil profile) impede this process. The “maximum soil water content” is the maximum amount of water a soil can contain. It informs on how much water can infiltrate in the soil before it reaches saturation (i.e. all available space is occupied by water). Even then, infiltration can continue as water drains downwards to the aquifer or is discharged into any outlets such as ditches or streams. As air progressively replaces soil water following drainage and plant evapotranspiration, soil dries and remaining water is held increasingly tightly to the soil. It cannot be drained by gravity nor evapotranspirated anymore. In soils covered with vegetation, water cannot be extracted by the plants anymore and they may wilt permanently.

Through these mechanisms, SWR capacity provides multiple ecosystem services, which sustain human needs from an environmental, health and socio-economic perspective.

Through its capacity to absorb water and slow down water flows at the soil surface (capture), the soil prevents run off. When soils can absorb less water, more runoff may occur depending on precipitation. They therefore play a key role in the control of land erosion and in the mitigation of flooding events by reducing or postponing peak flows.

Through its capacity to store and hold water (storage), the soil acts as a water reservoir where plants extract their water resources, although the water actually available to plants is lower than the maximum soil water content. This capacity ensures a continuous source of water to plants, hence preventing or postponing water deficit during dry periods. In the driest regions, it also helps preventing desertification. By maintaining humid conditions within the soil, this capacity also supports microorganisms and ensures nutrient availability for plants.

Through water drainage (release) within the soil and deep percolation, soils contribute to the replenishment of groundwater aquifers. Groundwater has a key ecological function in sustaining river low flows, wetlands and lakes. It is also a major source for agricultural, industrial and domestic water supply. In this respect, the filtration function of soils may play a key role in the regulation of pollution issues, as soil particles can bind pollutants during water transfer through the soil matrix before it reaches the aquifers.
Executive summary

Through **evapotranspiration** (release), the capacity of soils to release water to the atmosphere allows regulating temperatures and influences precipitation patterns, at the local, regional and global scales. A disruption of this capacity, for instance through soil sealing, may result in massive temperature increases, such as heat waves observed in cities, and in heavy rainfall events.

It is not possible to maximise simultaneously all the assets of SWR capacity. Trade-offs will be necessary depending for instance on the need, in different catchments, for maximising yields, mitigating run off and floods, increasing aquifer replenishment or ensuring water filtration. An “optimal” SWR capacity could however be defined as **the capacity to retain water within the soil yet in a form allowing water and air exchanges and to deal with large water quantities during wet periods**.

- **Parameters governing soil water retention capacity**

Water dynamics in soil is influenced by various physical, chemical, biological, and **geoclimatic parameters**. The inherent capacity of soil to retain water mostly depends on specific soil parameters, such as soil texture, soil structure, and soil organic matter (SOM) content. Soil cover and initial water content also play direct and preponderant roles in various mechanisms governing SWR capacity. Soil biodiversity is another major parameter as it influences soil structure through higher porosity and aggregates stability. Table 1 summarises how they respectively influences the different mechanisms of soil water retention.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Contribution to SWR capacity</th>
<th>Threats to SWR capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infiltration</td>
<td>Storage</td>
</tr>
<tr>
<td>Texture</td>
<td>Coarse</td>
<td>Fine</td>
</tr>
<tr>
<td>Structure</td>
<td>High porosity</td>
<td>Balanced pore-size distribution</td>
</tr>
<tr>
<td>SOM content</td>
<td>High SOM</td>
<td>x</td>
</tr>
<tr>
<td>Soil cover</td>
<td>Vegetated surface or porous materials</td>
<td>x</td>
</tr>
<tr>
<td>Water content (WC)</td>
<td>Low WC</td>
<td>x</td>
</tr>
</tbody>
</table>

Legend: x low or negligible influence
The actual capacity of soils to retain water depends on a combination of parameters, which may vary spatially and temporally. For instance, near saturation, soil structure is determinant for SWR capacity, in particular for infiltration and drainage, and probably even more determinant than soil cover in terms of regulating runoff. In desaturation conditions, however, soil texture and soil organic matter content become more and more important, with an increasing role in the soil capacity to hold water.

Most parameters can be directly enhanced by human activities to prevent the degradation of soil water retention capacity and optimise its services with effects observable in the short term. For those, such as soil texture, which remains inherent to the soil, action can be taken to mitigate their possible detrimental impact on SWR capacity.

A soil water retention capacity optimising infiltration, storage, recharge of the groundwater and exchanges with the atmosphere could be achieved by ensuring soil surface permeability, high porosity and balanced pore-size distribution, as well as soil stability.

**Drivers affecting soil water retention capacity**

Land uses affect SWR capacity through different types of soil cover and associated modifications of biophysical soil properties (e.g. permeability, degree of compaction). Land use changes naturally modify previous SWR capacity conditions. Different management practices may also substantially influence the "average" SWR capacity associated to these land uses. Furthermore, climate change may affects soil water contents by modifying temperatures and precipitation patterns may modify the dynamics of evapotranspiration and infiltration (in case of heavy rainfall events).

**Land use type**

Land uses drive the development of complex mosaics of artificial areas (e.g. buildings and roads), agriculture areas and forests, which have different assets and shortcomings in terms of SWR capacity, as summarised in Table 2.

<table>
<thead>
<tr>
<th>Land use types</th>
<th>Infiltration</th>
<th>Storage</th>
<th>Drainage</th>
<th>Exchange with atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forests</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Agriculture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Arable land</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Artificial areas</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*High variability depending on farming practices*

Forest areas have an excellent infiltration capacity as well as water recycling through its return to the atmosphere. Despite slowing down run-off and desynchronising flows, and unlike usually shared assumptions, their flood mitigation potential at the catchment level is only significant if a substantial share of the catchment area is occupied by continuous forests, unless forested areas are located upstream in the catchment. In large agricultural catchments, run-off from
surrounding farmlands may end up playing a more significant role on water run-off and flows than forested areas.

Within agriculture areas, grasslands have the most balanced SWR capacity compared to arable land, and to forests and artificial land, with high potential for rain interception, infiltration, and storage. SWR capacity of arable land is generally low compared to other types of vegetated areas, especially where agricultural practices may leave the soil bare most of the year and are generally associated with compaction. Yet, the SWR capacity very much depends on the type of agricultural practices.

Artificial areas (housing, industrial and commercial purposes) have substantial local impacts on SWR capacity because associated soil sealing and compaction prevent or drastically decrease the capacity of soils to infiltrate water and to exchange water with the atmosphere, favouring run off and increases in temperatures.

At the catchment scale, the respective influences of different land use types are combined and the overall SWR capacity will depend not only on the types of dominant land uses, but also on their relative location.

### Land use change

Past trends in land use change have raised specific concerns, as they tended to create unfavourable conditions for SWR capacity through the decline of forests and grasslands and the increase in agriculture and urban areas. Most recent trends and projected future trends in land cover are less alarming in this respect, as the most critical conversions (deforestation, grassland to crops, crops to urban land) are projected to be rather limited (Table 3).

**Table 3: Impact of land cover changes on maximum soil water content**

<table>
<thead>
<tr>
<th>Land cover change</th>
<th>Impact on maximum soil water content</th>
<th>Possible future trends in the EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest to grassland</td>
<td>- 5%</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Forest to crops</td>
<td>-10%</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Forest to Urban land</td>
<td>-20 to 25%</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Grassland to forest</td>
<td>+ 9%</td>
<td>+++ in NL, FR, SI, LT, IE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>++ in Scandinavia (DK, SE), PT, EE and parts of Central and Eastern Europe (HU)</td>
</tr>
<tr>
<td>Grassland to crops</td>
<td>- 4%</td>
<td>+ in HU, IE, LV, PL</td>
</tr>
<tr>
<td>Grassland to Urban land</td>
<td>- 10 to 15%</td>
<td>+ in BE, NL, LU, FR and partly in the Baltics countries (EE), central and northern parts of DE (Hamburg). To a least extent in Northern and Southern IT</td>
</tr>
<tr>
<td>Crops to forest</td>
<td>+5%</td>
<td>++ in IE, NL, PT and SI</td>
</tr>
<tr>
<td>Crops to grassland</td>
<td>+4%</td>
<td>+ in IE and NL</td>
</tr>
<tr>
<td>Crops to Urban land</td>
<td>- 1 to 5%</td>
<td>+ in DK, HU, RO, FR, DE and IT</td>
</tr>
<tr>
<td>Others to Urban land</td>
<td>&gt; -25%</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>

Note: +++ to + → significant increase to mild increase in associated land use change
Besides revegetation or afforestation of abandoned farmlands, opportunities for improving SWR capacity through land use changes remain limited in practice, as current land uses respond to socio-economic demands and needs. **Opportunities to maintain or enhance SWR capacity** rather lie in **restoring the ecological functioning of semi-natural areas**, such as wetlands and floodplains and **preventing detrimental land use changes**.

### Farming practices

Within a particular type of land use, modifying practices may significantly affect SWR capacity and associated services. **Adapting plant, soil and water management in agriculture would most likely improve the SWR capacity**, in particular in Member States with large agricultural areas. The modelling exercise conducted for the present study, which considered the impacts of grazing, tillage, crop residue management and composting (organic amendment), showed that some agricultural practices, in particular organic amendment and residue management, have the possibility to increase soil water retention by up to 25% at a 10 km x 10 km resolution (therefore with a higher expected impact locally). Table 4 summarises the impact of different farming practices on the different aspects of SWR capacity, based on the modelling exercise, the literature review and the case studies.

The majority of agricultural practices associated with **intensive farming**, and in particular the use of heavy machinery and tillage operations combined with poor soil cover throughout the year and low restitution of SOM, have negative impacts on the key parameters influencing SWR capacity, such as soil structure, soil organic matter, soil cover, water content and soil biodiversity. They promote soil compaction and crusting, higher susceptibility to erosion, increased mineralisation of SOM, and loss of biodiversity. In particular, the application of mineral fertilisers instead of manure and the increasing removal of crop residues e.g. for bioenergy purposes limit the restitution of stable organic matter to the soil, which progressively loses its resilience to mechanical and climate disturbances. This leads to decreased infiltration, with a degradation of maximum soil water contents, less winter recharge rates to aquifers, and increased run off and debated risks of floods. Intensive agricultural practices are implemented in large areas in the EU, and the conversion to more sustainable and integrated systems, although increasingly promoted, is still at its infancy. In order to cope with the degradation of the capacity of soils to store water or the degradation of their hydrological functioning, changes towards more sustainable practices are not necessarily the first strategy implemented. Irrigation and drainage are often used to artificially modify the soil water content and regulate water deficit and the saturation of soils respectively.

More “extensive” systems may have significant benefits on SWR capacity. Although **organic farming** may also heavily rely on tillage, its negative impacts are relatively mitigated by practices in terms of extensive rotations and adequate management of organic matter, and by the confinement of possible impacts to parcels of smaller sizes. **Conservation farming**, which consists in limiting field operations such as tillage, represents the more balanced asset with regards to SWR capacity. Combining the respective assets of tillage and no tillage, the adoption of reduced tillage has high benefits in terms of run-off reduction and water storage in the long run. In addition to reducing the use of heavy machinery, it allows the development of cover crops and crop residue management, and maximise the SWR functions of soil biodiversity by reducing...
soil disturbance. However, it is often associated with higher use of herbicides for weed control, increasing pressure on water quality. Agroforestry, which is an example of integrated farming system, is also expected to benefit SWR capacity through better infiltration and higher maximum soil water contents by increasing soil organic matter while preventing erosion.
Table 4: Impact of different farming practices on SWR capacity

<table>
<thead>
<tr>
<th>Categories of practices</th>
<th>Types of practices</th>
<th>EU coverage (% of arable land)</th>
<th>Farming systems</th>
<th>Infiltration</th>
<th>Storage</th>
<th>Drainage</th>
<th>Air exchange</th>
<th>Impact of practices on SWR capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intensive</td>
<td>Organic</td>
<td>Conservation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of heavy machinery</td>
<td>Reduced use</td>
<td>Low</td>
<td>√</td>
<td>-</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Use in normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Use in wet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Tillage</td>
<td>Conventional vs. no</td>
<td>&gt;60 %</td>
<td>√</td>
<td>√</td>
<td>++</td>
<td>++</td>
<td>x</td>
<td>++ ST LT</td>
</tr>
<tr>
<td></td>
<td>no tillage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Reduced vs. no</td>
<td>18 %</td>
<td>√</td>
<td>+</td>
<td>+</td>
<td>x</td>
<td>x</td>
<td>+</td>
</tr>
<tr>
<td>Amendment</td>
<td>Mineral fertilisation</td>
<td>High</td>
<td>√</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Organic vs. mineral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>fertilisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Crop residue</td>
<td>Removal</td>
<td>&gt; 80 %</td>
<td>√</td>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>management</td>
<td>Conservation</td>
<td>&lt; 20 %</td>
<td>√</td>
<td>√</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Types of</td>
<td>Monocultures</td>
<td>&lt;15 %</td>
<td>√</td>
<td></td>
<td>--</td>
<td>--</td>
<td></td>
<td>++</td>
</tr>
<tr>
<td>rotation</td>
<td>Rotation vs. Monoculture</td>
<td>&gt; 85 %</td>
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<td>Extensive rotation</td>
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<td>favouring soil cover</td>
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<td>vs. monoculture</td>
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<td>Intensity of grazing</td>
<td>Intensive vs.</td>
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<td>grazing</td>
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<td>- (locally)</td>
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<td>Management of</td>
<td>Conservation (e.g.</td>
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<td>landscape</td>
<td>hedges) vs.</td>
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<td>features</td>
<td>removal</td>
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<tr>
<td>Water management</td>
<td>Irrigation</td>
<td>&gt; 8 %</td>
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<td></td>
<td>Drainage</td>
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<td>- at the catchment scale</td>
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Legend:

--- Negative impact
-- Positive impact
- Indication of practices usually implemented in the different farming systems; ST: Short term; LT: Long term
In general, agricultural practices aiming at covering the soil surface (e.g. cover crops) and returning SOM to the soil (crop residue management, organic amendment) are highly beneficial to SWR capacity. Even a small marginal increase of SOM can have significant impacts on soil porosity, infiltration rate, and maximum soil water content.

High opportunities to maintain or enhance optimal SWR capacity lie at the scale of crop rotations, as they allow optimising soil and water management practices. Appropriate crop rotation practices, which prevent the soil from being left bare in critical periods of time, are usually found in extensive systems, but they can also be introduced in more intensive rotations. In particular, the introduction of legumes, such as beans and peas, or ryegrass, even in short rotations, may enhance SWR capacity through their limited water consumption, appropriate soil cover and structural properties.

Furthermore, maintaining landscape natural features like hedges has been shown to slow down water flows and optimise the delivery of associated ecosystem services (e.g. flood regulation, erosion). Reducing the size of natural patches has also been shown to be able to improve the hydrological functioning of agricultural fields at the catchment level.

**Urban planning and design**

Several factors in the urban planning and design can influence the impact of urban development on the natural water balance. Key factors of influence include the density of development (compactness, fragmentation), and the capacity of cities to infiltrate water (presence of green areas, permeable surfaces, capacity of urban drainage systems).

High urban density may reduce the impacts of urban development on infiltration and runoff, and hence on water balance, by sparing land with natural soil water retention capacity. In residential areas for instance, compact multi-storey stocks can present the same degree of sealing than single and semi-detached housing estate, although they host many more inhabitants. Furthermore, urban sprawl comes along with the development of commercial sites and transport infrastructure (roads) which represent the greatest degree of soil sealing. Yet, the current trends are towards the development of low-density structures, which require more built-up areas per person, and many more cities are expected to have to cope with the problems of low-density settlements.

Water-related ecosystem services can also be safeguarded by restoring the initial ability of urban sites to absorb storm water. This consists in removing all unnecessary soil sealing, replacing complete pavement by permeable surfaces in yards, parks, along streets etc., and restoring urban green spaces that may provide areas within the built environment where infiltration and evapotranspiration can take place. Several initiatives, even at small scale, show successful results with substantial reduction in run off. An efficient measure relates to permeable pavements, which are increasingly used to mimic natural hydrology and cope with the shortcomings of traditional storm water management through continuous infiltration. They require specific attention, however, depending on the associated type of drainage of infiltrated water, as they may favour soil contamination and rapid water discharge. Sustainable urban drainage systems play a major role in flood control, by allowing storm water to be appropriately collected, infiltrated and/or redirected to river streams or infiltration areas. In Copenhagen, such measures were shown to contribute to a net saving of 1 005 million EUR out of the 2 084 million EUR of
total costs of damages for society estimated without taking any actions. The development of green areas is another option proven to reduce run off efficiently, at least locally, and to slow down run off and flooding responses.

These opportunities to maintain or enhance SWR capacity are all the more important in the context of climate change. Reduced infiltration due to uneven and intense precipitations are expected to occur along with higher risks of floods, despite the increase in precipitation in some regions. Furthermore, changes in temperatures are likely to increase the need for irrigation in rural areas, and the demand for water in urbanised areas, with subsequent impacts on water shortages.

**Trends in soil water retention capacity in the EU**

EU trends in SWR capacity were estimated and mapped through maximum soil water contents. This indicator describes the intrinsic capacity of soils to retain water depending on soil characteristics and land use types, but irrespective of infiltration conditions at the soil surface, of water supply from precipitation or irrigation, or of releases to the atmosphere.

**Land use changes (excluding urbanisation) and agricultural practices**

Overall, historical trends show significant decreases (up to 20%) in maximum soil water content in large parts of the EU because of land use changes in rural areas (excluding urbanisation) and associated agricultural practices, notably in Benelux, northern and central parts of France, parts of Iberia (Portugal and Spain) and Central Europe. Although fewer detrimental land use conversions have been recently observed and are expected in the future as projected in Reference scenarios from the Land Use Modelling Platform (Lavalle et al., 2013), their marginal impacts on soil water contents cumulated with the history of degradation of soil water retention capacity will represent a key environmental issue in the next decades. Moreover, further substantial decreases in SWR capacity are still expected in rural areas in France, Portugal and Spain as well as central and southern part of Germany and to a lesser extent in central Member States.

**Urbanisation**

Increasing trends in urbanisation resulted in significant decreases in SWR capacity (up to 25%) in the most densely populated areas in the EU, in particular in Germany, northern Italy, Czech Republic, Denmark, France, parts of Poland, Portugal, and along the coastal areas of Spain. Very low SWR capacity can unsurprisingly be observed in large metropolises, like Paris. Although land take rates now tend to stabilise in the EU, land use changes into artificial areas are still occurring, contributing to add up to the cumulative impacts on SWR capacity.

**Links with water deficiency and the occurrence of floods**

Combined with increased temperature trends, conversions from land uses with high SWR capacity (e.g. forests, grasslands) to land uses with a lower SWR capacity (e.g. croplands, urban areas) create significant increase of precipitation deficiency (as an important drought risk

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1 Based on the currently available datasets, the relationships established through case studies and demonstrated mathematic functions, and relatively simple modelling exercises using geospatial analysis.
indicator) especially in Mediterranean countries (Greece, Cyprus, Italy, Spain, Portugal and Malta), and in some Eastern countries (Bulgaria and Romania).

Combined with increased precipitation patterns, past and current urbanisation trends resulted in significant plausible increase of the surface runoff in the densely populated and industrial regions in Europe notably Germany, Czech Republic, Italy, France which presented significant reductions in maximum soil water contents, as well as in Hungary, Romania, the Netherlands, Ireland and the UK. The flood occurrence evidence shows significant correlation with the risk of increased surface runoff due increased precipitations, urbanisation trends and disruption of SWR capacity. In the next decades, these trends are expecting to slow down because of the decreased pace in urbanisation, but will still raise concerns, in particular in the most densely populated areas, where damages from floods may increase due to the increasing vulnerability and economic value of these areas. Increasing flood damages are particularly expected in large parts of western and central Europe as well as in the UK. To counteract the impacts of climate change, the role of soil water retention as a provider of flood regulation services will therefore become increasingly important in these regions.

**Economic implications of floods and droughts**

Although it has not been possible to quantify it in the context of this study, soil water retention capacity has a direct influence on floods and drought. In fact, soil act as a sponge and can absorb a certain amount of excess water (thus contributing to attenuating flood impacts) and slowly release it to plants (thus contributing to attenuating drought impacts).

Within the scope of this study, effort has been made to quantitatively map the impact of rainfall and SWR capacity on flood through climatic and hydrological models. Taking the example of 2007 summer floods in the UK, our result shows that SWR capacity has been reduced for about 13% between 2000 and 2007 due to the intensive agricultural practices in the area. This series of floods have a tremendous socio-economic impact in the society and has resulted in total damage cost to agriculture alone amounting to around €2.7 million over an area of 23,500 hectares of cropland. The magnitudes of their impacts depend on a set of factors: the location of the flood, the size and duration of the flood, the economic activities disrupted during the flood, the income of affected population, etc. If the SWR had not been decreased to the extent that it was decreased in that area over the past years, one could reasonably have expected that the damage costs could have been lower. This implies that although it is not possible to quantify such cost reduction in this report and although in this specific case, one may assume that even the best SWR capacity may not have prevented that disaster, but it can effectively mitigate the damages to certain extent, even in the case of extreme weather conditions.

Decreasing trends in SWR capacity may eventually counterbalance the benefits of the substantial progress in water efficiency achieved in the EU in the last two decades, as the capacity of soils to store water as a reservoir decreases and as water demands subsequently increase. The agricultural sector, which heavily relies on green water, will face particular challenges.

On the other hand, the results of the analysis show that drought already have prominent impacts on the yields of many climate sensitive crops in Europe. The magnitudes of these impacts may however vary depending on the type of crops, their respective commercial values, and the total
area affected by the drought event. Among others, the highest economic losses are observed for maize, estimated at around 140€/ha, which were directly lost after the 2003 drought event.

Concluding remarks

The consistent declining trends in maximum soil water content in the EU and their possible correlations with recent flooding events, suggest that actions should be taken to maintain or preserve the inherent potential of soils to retain water.

First, knowledge base could be improved through the development of modelling capacity that allows quantifying the specific contribution of SWR capacity on floods and drought, and on other ecosystem services.

Then, the study shows that several opportunities exist in land use planning, urban design and in the agriculture and forestry sectors to preserve or even enhance this function and associated assets, and reduce the costs of associated damages. This is especially important in Mediterranean countries, which are particularly vulnerable, and in areas subject to high soil sealing (e.g. densely populated and industrial areas) or rapid urban sprawl, such as coastal areas. The agricultural sector in particular, through wide variety of agricultural practices that can be implemented within a same land use type, represent a key opportunity and many beneficial practices still show an untapped potential for development across the EU. There is no one-fit-all approach for improving SWR capacity in the EU. A range of possible options exist to better integrate soil and water policies following catchments specificities, in particular in the countries identified as representing a concern through the modelling. However, following key principles have been identified:

At landscape level:

- limiting the conversion of land uses with high SWR capacity (forests, grasslands, wetlands, etc.) to land uses with lower SWR capacity (agricultural land, urban areas, etc.), in particular urban sprawl;
- preventing building development in flood basins and discouraging any construction or works likely to form an obstacle to the natural flow of waterways that cannot be justified by the protection of densely populated areas;
- maintaining semi-natural areas and grasslands within agricultural areas as part of a wider landscape mosaic and as green infrastructures, and promoting re-vegetation where relevant to deliver regulating ecosystem services alongside other land uses;
- restoring floodplains and wetlands to benefit from their flood regulation functions.

In agriculture sector:

- mitigating the impacts of the use of heavy machinery which is a key driver of soil compaction, e.g. through better consideration of environmental conditions (avoid driving on a soil with a water content above the field capacity), avoiding any unnecessary field operation, ensuring the tractor is properly balanced,
Executive summary

avoiding oversized equipment, or ensuring the maintenance of equipment or limiting the load;

- mitigating the impact of tillage, through reduced tillage or tillage adapted to environmental conditions, such as contour tillage on slopes;
- promoting the return of organic matter to the soil, through organic amendment and crop residue management. Yet, the former may be limited by nitrates concentrations and the latter may be difficult in the context of increased biofuels demand;
- better integrating the issue of SWR when designing crop rotations, which remains relatively untapped in the EU and represent great opportunities for inserting alternative crops and soil management practices, in order to:
  - protect soil surfaces through soil cover throughout the year (e.g. winter rye; legumes such as peas and beans) and enhance soil structure through specific root systems, which increases the capacity and duration of infiltration (e.g. alfalfa), and
  - limit evapotranspiration, through the choice of species with limited water demand during periods of limited availability, whenever possible (e.g. winter vs. spring varieties);
  - optimise the use of soil water, through the choice of species with different rooting depths.
- maintaining landscape features such as hedges and buffer strips along rivers, which allow slowing down water flows, and reducing the size of patches to optimise the hydrological functioning of the catchment.

In urban areas, impacts on SWR capacity could be mitigated, in addition to better selecting the development sites, through:

- promoting integrated and compact cities, where green areas are maintained and managed to increase the temporary water storage during heavy precipitation and provide flood retention rooms. The restoration of brownfields or other derelict land into green areas represents a promising opportunity;
- promoting the development of permeable pavements and sustainable drainage systems, which slow down the response to heavy rainfall events.

The concept of SWR capacity and associated good practices could be further promoted at the EU level, in particular through the Common Agricultural Policy (CAP) in the agriculture sector. In both rural and urban areas, the recent Green Infrastructure Strategy also offers promising guidance for valuing the ecological function of green areas, amongst which soil water retention capacity. Furthermore, a communication on "land as a resource", expected to be published by the European Commission in 2015, is thought to tackle both the issues of land take and soil degradation. It will be a great opportunity to better highlight the services dependent on soil water retention.
### List of abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AWC</td>
<td>Available water content</td>
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<tr>
<td>BIOIS</td>
<td>BIO Intelligence Service</td>
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<td>BD</td>
<td>Bulk density</td>
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<td>CC</td>
<td>Climate change</td>
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<td>CEC</td>
<td>Cation Exchange Capacity</td>
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<td>EC</td>
<td>European Commission</td>
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<td>EEA</td>
<td>European Environment Agency</td>
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<td>ESS</td>
<td>Ecosystem services</td>
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<td>ET</td>
<td>Evapotranspiration</td>
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<td>EU</td>
<td>European Union</td>
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<td>FAO</td>
<td>Food and Agriculture Organisation</td>
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<td>LCLU</td>
<td>Land cover/land use change</td>
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<td>MS</td>
<td>Member States</td>
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<td>PTF</td>
<td>Pedotransfer functions</td>
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<td>SOC</td>
<td>Soil organic content</td>
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<td>SOM</td>
<td>Soil organic matter</td>
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<td>SWR</td>
<td>Soil water retention</td>
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<td>SWRC</td>
<td>Soil water retention curve</td>
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<tr>
<td>USDA-NRCS</td>
<td>U.S. Department of Agriculture Natural Resources Conservation Service</td>
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Glossary

**Adsorption** is the ability of soil particles to attract and retain water molecules on their surface.

**Available water content (AWC)** is the water stored within the soil that can be absorbed by plants.

**Blue water** is the fresh surface and groundwater, in other words, the water in freshwater lakes, rivers and aquifers.

**Bulk density (BD)** is defined as the dry weight of the soil particles divided by the total volume of soil. It reflects the degree of soil compaction.

**Capillarity** is the capacity of water to flow throughout narrow spaces, because of intermolecular forces between the liquid and solid surrounding surfaces.

**Capture** is defined in this report as the ability of soil surface to intercept and infiltrate water. 1 m² of soil can generally capture from less than a litre to more than 100 litres of water per hour.

**Cation Exchange Capacity (CEC)** is defined as the degree to which a soil can adsorb and exchange cations with the soil solution.

**Climate change (CC)** is defined by the Intergovernmental Panel on Climate Change (IPCC) as a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

**Degree of saturation** is defined as the fraction of the porosity that is occupied by water. A saturated soil is said for a soil that reached its maximum soil water content (see definition below).

**Drainage** is the action to remove excess water from the soil surface or subsurface, in order to avoid saturation and related impacts (e.g. root asphyxia).

**Drivers** are natural or anthropogenic factors likely to influence soil water retention, through the modification of soil parameters. They include climate change, land cover/spatial planning, urban development, and farming and forestry practices.

**Drought** is a long period of abnormally low rainfall, with adverse effects on growing or living conditions. For instance, soils dry out and cannot supply crops with water, leading to more or less severe water stress and possibly permanent wilting.

**Ecosystem services (ESS)** are the benefits people obtain from the ecosystems. These include provisioning services such as food and water; regulating services such as flood control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.

**Evapotranspiration (ET)** consists in the combination of evaporation from soil surfaces and transpiration by crops (see below the definition of “evaporation” and “transpiration”).
Evaporation is a type of vaporization of a liquid that occurs from the surface of a liquid into a gaseous phase that is not saturated with the evaporating substance. Evaporation of water occurs when the surface of the liquid is exposed, allowing molecules to escape and form water vapor.

**Flood** is the temporary covering by water of land not normally covered by water, as defined in the Flood Directive (2007/60/EC). Three main types of flooding include fluvial flooding, pluvial flooding and urban flooding (due to overflow of sewage).

**Field capacity** is the state of soil after the excess water is drawn away by gravity. Most macropores are empty and water is stored in meso and micropores.

**Free water** is excess water within the soil, which can be drained downwards by gravity.

**Green water** corresponds to the water actually stored within the soil. It corresponds to the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Green water can be made productive for crop growth (although not all green water can be taken up by crops, because there will always be evaporation from the soil and because not all periods of the year or areas are suitable for crop growth).

**Hydraulic conductivity** is a property of vascular soils that describes the ease with which the water can move through pore spaces. Best proxy for measuring hydraulic conductivity is the value of the hydraulic conductivity in conditions of water saturation.

**Infiltration** is the movement of water from the soil surface into the soil profile.

**Macropores** are defined as cavities that are larger than 75 μm, which favor preferential soil solution flow and rapid transport of solutes and colloids.

**Mesopores** are defined as cavities with a size between 75 μm and 20 μm. They are the pores filled with water at field capacity.

**Micropores** are defined as cavities that are smaller than 20 μm. There, water is strongly adsorbed to soil particles.

**Natural capital** refers to Indispensable resources and benefits, essential for human survival and economic activity, provided by the ecosystems.

**Parent material** is the underlying geological material (generally bedrock or a superficial or drift deposit) from which soil horizons form.

**Pedotransfer functions (PTF)** are mathematical functions that predict soil hydraulic properties (such as SWR capacity) based on measured soil properties.

**Percolation** is the natural movement of water from the soil profile downward to groundwater.

**Porosity** is the amount and form of spaces (or voids) within the soil. They are spaces between soil particles or within soil particles. Depending on their size, pores have different hydraulic functions: they conduct water or store them through capillarity and adsorption.

**Residual water** is the water stored within the soil, in the smallest pores (>20 μm diameter), and which is not available for plants or cannot be released through evaporation.
Runoff is the process whereby some share of rainfall, melted snow or irrigation water flows over the soil surface and eventually returns to the nearest surface streams.

Soil is a natural substance composed of weathered rock particles, organic matter, water and air.

Soil depth is the distance from the soil surface to the parent material.

Soil organic carbon (SOC) is the organic fraction of carbon stored within the soil.

Soil organic matter (SOM) is the organic fraction of the soil, excluding undecayed plant and animal residues, their partial decomposition products, and the soil biomass.

Soil profile is a vertical section of the soil showing various layers from the surface to the unaffected parent material.

Soil structure is defined by the way individual particles of sand, silt, and clay are assembled.

Soil texture indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil.

Soil water content is the amount of water contained in a given volume of soil (e.g. cm$^3$ of water per cm$^3$ of soil) at any time. The "maximum soil water content" describes the highest amount of water that a certain volume of soil can contain. This is the indicator used as a proxy for the estimation of past, current and future trends in soil water retention capacity.

Soil water storage is the ability of soils to hold water, after excess water has been drained by gravity. Soil can temporarily store large amounts of rainfall, reducing off-flow into surface waters. It can be a decisive factor in flood protection. In the literature, the maximum amount of water stored within the soil after drainage is called "soil water holding capacity".

Soil water retention (SWR) capacity: in the literature, there is no clear and consistent definition for the concept of "soil water retention", which can reflect a variety of situations. In certain publications, it corresponds to the soil water holding capacity (capacity in the sense of "volume"), at field capacity; in others, it corresponds to the maximum amount of water that a unit of soil can contain, at saturation; lastly, it can also be used to describe the overall amount of water that can infiltrate within the soil before runoff. For the purpose of this study, it is defined in its broad meaning as the "capacity of the soil to capture, store and/or release water". Soil water contents at saturation, at field capacity and at wilting point are used as descriptors of this capacity.

Soil water retention curve (SWRC) is the relationship between the water content and the soil water potential. This curve is characteristic for different types of soil (different textures, structures, etc.). It describes the soil water holding capacity of soils.

Soil water retention parameters are soil and climate properties that determine the characteristics of soil responses to water and its capacity to retain water. Soil parameters can be physical (e.g. soil texture, soil structure), chemical (e.g. soil organic matter content, composition of soil solution), biological (e.g. soil cover, soil biodiversity) or related to water content.

Subsoil is the layer of earth below the topsoil.

Suction is the force that, by a pressure differential, attracts water to the region of lower pressure.

Topsoil is the upper, outermost layer of soil, usually the top 5 to 20 cm.
**Transpiration** is the process of water movement through a plant and its evaporation from aerial parts.

**Unsaturated zone** is the area above the water table where soil pores are not fully saturated with water.

**Water abstraction** refers to the volume of water taken from a natural or modified (e.g. reservoirs) resource over a certain period of time, typically the calendar year.

**Water potential** reflects the difference in potential energy with free water. Water potential helps in the understanding of water movement within plants and soil.

**Water scarcity** occurs where there are insufficient water resources to satisfy long-term average requirements. It refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system.

**Water table** is the upper surface of groundwater below which soil is saturated with water that fills all voids and interstices and where the pressure of water in the soil equals the atmospheric pressure.

**Wilting point** is the minimal point of soil water content the plant requires not to wilt.
Introduction

Soil and water are two key resources that directly or indirectly affect our everyday activities. Until recently, soil has predominantly been perceived in the context of its agricultural production function but healthy soils provide many more goods, services and societal function e.g. for flood protection and maintenance of natural landscapes; and water is necessary for all the provisioning, regulating, supporting and cultural services it provides.

Mismanagement and/or intensive use of soil and water put at risk the maintenance and resilience capacity of our natural capital. Our economies have increasingly relied on technologies and innovations to cope with environmental degradation, rather than on optimising the ecosystem services (ESS) provided by our environment. For example, in the agricultural sector, irrigation and drainage can be used intensively to cope with the degradation of soil hydrological functions. In the urban environment, storm-water channels and other hydraulic works allow tackling the risks of flooding linked to rainwater runoff on impervious surfaces.

The necessity to preserve the important contribution of soil to the water cycle, in particular through the soil water retention (SWR) capacity, is still not fully recognised in EU policies. Soil and water are mostly treated as independent subjects, although an integrated approach of soil and water management is emerging in the EU, as illustrated in the Floods Directive 2007/60/EC, the Communication “Addressing the challenge of water scarcity and droughts”\(^3\), the Thematic Strategy for Soil Protection\(^4\) and the Draft Framework Directive for the protection of soils\(^5\).

Today, a large number of research publications investigate the issue of soil-water dynamics. Although they shed light on some of the scientific aspects, the overall knowledge of SWR remains scattered and there is no clear overview of the trends in SWR at EU and Member State (MS) levels, their causes and environmental, socio-economic and political implications. There is a need to explore these aspects, put in a global perspective and explain to policy makers and public society. In particular, a better understanding of the mechanisms and drivers of SWR will

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empower policy makers and stakeholders to take informed decisions about how to maintain, restore or improve the SWR capacity.

**Objectives**

This study aims to bridge the science-policy gap and enhance the current evidence base about SWR capacity by gathering and synthesising the available information. Through key messages and recommendations, the study further aims to help policy-makers take appropriate actions to maintain or restore SWR.

Overall, it aims to answer the following questions:

- What is SWR capacity and how does it work?
- Why is it important?
- What are the EU major trends?
- What are the environmental and socio-economic implications of a reduction in SWR capacity?
- What are the key drivers behind these trends and which practices allow enhancing SWR capacity?

**Report Structure**

In addition to this introductory chapter, the report presents an analysis divided into five chapters and conclusions.

Chapter 1 defines the concept of SWR capacity and explains its mechanisms through the dynamics occurring at the soil surface and within the soil (storage and releases). It also explains why this soil function is crucial for the environment, human health and well-being, and the economy, through the ecosystem services it provides.

Chapter 2 describes the role of physical, chemical, biological and water-related parameters in the capacity of soil to capture, store and release water. Key threats related to their ability to ensure this function and possible leverages are also pinpointed.

Chapter 3 explains how anthropogenic drivers may alter SWR capacity, by modifying the parameters cited in Chapter 2. In particular, it explores the influence of land use change, farming and forestry practices, urban planning and design, and climate change, in order to identify and highlight best practices.

Chapter 4 presents past, current and future trends in SWR capacity in the EU. These are discussed in light of the trends in water availability and water use in the EU.

Chapter 5 presents economic implications of SWR capacity in the EU, through its influence on the occurrence of floods and droughts, and the related damages in urban, agricultural, forest and grassland areas.
The conclusions highlight key messages, as well as research needs and recommendations of good practices for policy-makers.

Additional details on the analysis and methodology are provided in the annexes to this report.

- Annex 1 provides an overview of the case studies investigated during the study. It will be referred to with the number of the case study in the main text;
- Annex 2 provides further scientific details regarding some parameters and drivers of SWR capacity;
- Annex 3 provides a thorough description of the sources of information, the methodology and key assumptions underlying the estimation of past, current and future trends in SWR capacity;
- Annex 4 provides a description of the sources of information and main approach for the estimation of economic impacts;
- Annex 5 provides the list of experts consulted during the study.
Chapter 1  “Soil water retention capacity” or how soils capture, store and release water

1.1 Soil water retention in the water cycle

Soil water is a key component of the water cycle. Overall, 67 000 km$^3$ of water are globally retained within the soils. Excluding the atmosphere, soils are the environmental compartment with the highest turn-over with regards to the residential time of water (up to 280 days depending on the nature of soils) (Figure 1).

Figure 1: The water cycle – water content and residence time

Legend: Major reservoirs are shown as boxes, with water content given in units of 10$^3$ km$^3$ and turnover times in years (Y) or days (D). Fluxes are given in km$^3$ per yr. The majority of water is available as what is called “blue water”, through groundwater, lakes and rivers. Soil moisture makes up approximately 1.5% of freshwater sources (excluding ice and water contained in the atmosphere).

Source: Chestworth (2008), adapted from Reeburgh (1997)

Several indicators exist in the scientific literature to define the soil water retention (SWR) capacity. In this report, we consider its broadest meaning, i.e. the capacity of soils to capture, store and release water (Figure 2).
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1.2 Mechanisms of soil water retention

1.2.1 Introduction

SWR capacity governs the dynamics between natural infiltration and runoff on the one hand, and storage, evapotranspiration and percolation within the soil profile and down to the groundwater on the other hand. An illustration to understand these processes is to use an analogy of watering a flower pot (Figure 3).

When flowers are watered, the soil absorbs water and gets wet (capture and infiltration). If watering continues, the soil gets progressively saturated with water (storage). Water is not retained by the soil anymore. If there are drainage holes underneath, excess water poured on starts draining out of the pot, sometimes with a slight delay (percolation). If the bottom of the pot is impermeable, water overflows (accumulation of water at the soil surface). Conversely, when water is added on a plate to the bottom of a dry pot of soil, the water is progressively withdrawn up into the pot because of the attraction of water by the soil, increased by plant's...
demand for water (transfer upward). Depending on exposure to sun and wind, temperature and the type of flowers in the pot, flowers start wilting more or less rapidly after a few days without watering, as the soil is drying again (evapotranspiration). On the field, soil behaves in a similar fashion (Figure 4).

**Figure 4: Dynamics of soil water retention**

Soil is a porous material generally composed of weathered rock particles (minerals), organic matter, water and air. Water is stored between (and moves within) the connected network of voids (pores, cracks, and fissures)\(^6\) formed by the soil solid fraction (Figure 5).

**Figure 5: Four components of soil – example of a typical agricultural soil**

\(^6\) The size of these voids can vary from less than 20 µm of diameter for pores (micropores < 20 µm, corresponding to voids within aggregate; 20 µm < mesopores < 75 µm; macropores > 75 µm generally corresponding to voids between aggregates) to more than several mm for cracks and fissures and therefore influence in different ways how water flows within the soil.
Four natural forces apply to water and drive water flows into and within the soil: gravitational forces, matrix forces, osmotic pressure and vapour pressure. Their respective influence on SWR capacity is explained below.

1.2.2 Description of mechanisms

When water is applied to the soil surface, whether by precipitation or irrigation, it naturally seeps downward by gravity, provided infiltration is not impeded by physical barriers or that soil surface does not receive more water than can infiltrate in a given amount of time. The infiltration rate, i.e. the speed at which water seeps into the soil, can vary from less than 1 mm to more than 10 cm per hour (Patriquin, 2003). In other words, 1 m² of soil can generally capture from less than a litre to more than 100 litres of water per hour, until its saturation. Usually high at the beginning of a rainfall event, the infiltration rate progressively declines as the soil water content increases. Water progressively fills all soil pores, cracks and fractures and the soil reaches its “maximum water content”.

As long as the water can move downward into the soil profile and be discharged into the aquifer, as an equivalent rate as the water supplied to the soil surface (e.g. by precipitation or irrigation) (Figure 6), infiltration can continue. Drainage occurs fastest in large voids left by soil cracks and fissures, as well as macropores. There, water is not well bound to soil particles through matrix forces and is conducted easily, resulting in fast water flows along with the transport of chemicals and colloids (clay, soil organic matter). Cracks, fissures and macropores are therefore air-filled under most field conditions. The ease of water to move within the soil is called “hydraulic conductivity”.

Figure 6: Illustration of saturated and unsaturated zones

Water accumulates at the soil surface or runs off when it cannot flow anywhere through the water saturated subsoil, e.g. because of the presence of compacted layers or impermeable

\footnote{1 mm means “1 mm water layer on the soil surface”, which corresponds to 1 L per square meter of soil surface.}
geological material (e.g. rocks, clay) and the absence of outlet such as ditches or streams. In this case, any more rainwater may be lost for the soil (Patriquin, 2003). It will, however, recharge rivers and contribute to sustaining environmental flows in surface water bodies.

When water is not applied to the soil anymore, air replaces water which drained from large soil voids to the water table. The smaller pores (meso and micropores) may still remain filled with water, as a result of water attraction for soil particles that becomes stronger than gravity. These matrix forces, which result from the combined effect of capillarity\(^8\) and surface adsorption\(^9\) are determinant for the capacity of soil to hold water. Once all excess water is drained away, the soil is said to be at “field capacity”. The higher the capacity to store water the more and longer can soil act as a water reservoir for plants.

While capillary water cannot be drained downward anymore, water can be evaporated from the soil surface, through the effects of temperature and wind. Some can also be removed from the soil by plant transpiration. Although osmotic pressure is less significant than gravitational and matrix forces, it is still determinant for the uptake of water by plant roots\(^10\). The amount of water that can be released to the atmosphere through these processes corresponds to the water available to plants. “Plant available water” is an indicator of the amount of water held at field capacity that can be evapotranspirated and theoretically used by plants.

As air progressively replaces soil water, soil dries and remaining water is held increasingly tightly to the soil. The influence of capillarity decreases to be replaced by the prominence of adsorbed water. When it reaches what is called the “wilting point”, residual water is held so tightly to the soil that the plant cannot abstract it anymore. Plant growth stops and if water deficit is extended, the plant may wilt permanently.

The abundance, size and arrangement of voids (pores and fissures) and the specific surface area of soil particles\(^11\) are major determinants of the soil’s ability to infiltrate, distribute and hold water within the soil profile, by modifying the relative influence between gravity and matrix forces (see Chapter 2 about the parameters of SWR capacity).

SWR capacity as meant in this study can be described by several indicators. These include indicators of infiltration (e.g. maximum infiltration rate, cumulative infiltration) and water content (e.g. maximum soil water content at saturation, water content at field capacity, plant available water, and water content at wilting point). Figure 7 sums up the indicators describing the soil water content, at the wilting point, at field capacity and at saturation.

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\(^8\) Resulting from the surface tension of water, and its contact angle with the solid particles.

\(^9\) Corresponding to the formation of hydration envelopes over the particle surfaces through electrostatic binding.

\(^10\) The osmotic potential is attributable to the attraction between a water molecule and various ions (e.g. cations) and solutes (e.g. soluble salts) in the soil solution. The presence of large amounts of soluble salts in the soil solution decreases the soil potential and makes it difficult for plants to remove soil water. This is known as physiological drought and explains why plants wilt and appear stunted in saline soil profiles.

\(^11\) Surface area per unit mass of soil.
The use of each of these indicators usually depends on which ecosystem services the user is interested in (see section 1.3). Water managers will focus for instance on the maximum volume of water infiltrated, in order to anticipate flooding events or to estimate groundwater bodies replenishment. Farmers and agronomists may rather focus on the plant available water, to estimating how soil water content matches crop water requirements. In particular, this indicator allows for the identification of the “refill point” at which plant production begins to decrease as the plant begins to suffer from water deficit and therefore to estimate the complementary amount of water that may need to be brought to the plant, in order to maximise yield (Vico & Porporato, 2010). The degree of water saturation is also an interesting indicator to know e.g. whether the fields need to be drained or whether farmers can use heavy machinery on their fields while limiting soil compaction.

1.3 Ecosystem services dependent on soil water retention capacity

Through the mechanisms described in section 1.2, soil water retention provides multiple services13, which sustain human needs from an environmental, health and socio-economic perspective (Brauman et al. 2007; Dominati et al., 2010). These ecosystem services ensure three main functions, as illustrated in Figure 8:

- **Provisioning services** ensure the production of material goods such as food, feed and fibre, through the storage of water, as well as drinking water, through the groundwater recharge, and through the filtering function of soil, which prevents the contamination of groundwater by surface pollution.

- **Regulating services** ensure the modulation of natural processes, hence indirectly the protection of goods. This includes climate regulation through the process of evapotranspiration and flood and drought mitigation.

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13 As defined in Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis.
Supporting services are necessary for the production of all other ecosystem services; they ensure indirect benefits in the long term. For example, erosion control through a regulation of soil water conditions is necessary to safeguard soil functions and ability to provide ecosystem services in the long run. Similarly, nutrient cycling allowed by the presence of water within the soil and biodiversity are essential to support biomass production and water filtration.

A variety of applications can benefit from a better understanding of SWR mechanisms, which allows enhancing the delivery of these ecosystem services, from optimising water-related practices in urban and rural areas, designing appropriate technologies and developing efficient early-warning systems for floods and drought. These include public water supply (e.g. estimation of water storage coefficients, drinking water quality), engineering (e.g. road and railway embankments), agriculture (e.g. optimal irrigation, design of drainage systems), urban wastewater management (e.g. development of sustainable drainage systems and adequate treatment plants’ capacity, installation of porous pavements) and flood control (e.g. runoff predictions and warning systems). Key ecosystem services and related anthropogenic applications are described in the following sub-sections.
1.3.1 Provisioning services

Storage of green water for biomass production

Water is essential for plant’s growth and structure. It carries out multiple functions, including maintaining cell turgidity, transporting nutrients and organic compounds throughout the plant; and contributing to major chemical processes such as photosynthesis. In average, less than one percent of water absorbed is retained by plants. The rest is transpirated and returns to the atmosphere, which also allows regulating temperatures and offering better conditions for growth (Lambers et al., 2008).

The soil, and particularly the subsoil, acts as a water reservoir where plants extract their water resources, although only part of the water contained in soils is actually available to plants. The more the soil can contain water and make it available to plants, the higher biomass production is likely to be (Sala et al., 1988; Rodriguez-Iturbe & Porporato, 2004). The capacity of soils to store water during wet periods of the year namely ensures a continuous source of water to plants during dry periods, hence preventing or postponing water deficit (Baudena & Provenzale, 2008).

A better understanding of dynamics of SWR may namely have great applications in irrigation scheduling and crop production models, with particular interest in water-scarce regions.

On the other side, too wet conditions may favour anaerobic conditions in the root zone, which most terrestrial plants can deal with only for short periods during the growing season (Bartholomeus et al., 2008).

Groundwater recharge

Drainage, which allows the exchange of water between the soil and the aquifer, influences groundwater recharge. In many EU regions, groundwater is a major source for agricultural, industrial and domestic water supply. Groundwater also has great ecological importance through sustaining rivers, wetlands and lakes, and subterranean ecosystems (e.g. karsts), where it can create micro-environments with subtle ecological changes (Thorburn & Walker, 1994; Snyder & Williams, 2000; Nwankwoala, 2012). In particular, groundwater recharge determines the amount of water that may be extracted from an aquifer without causing depletion or impacting environmental flows.

Water filtration

Soil is a natural filter that neutralises potential water pollutants and may prevent groundwater pollution to a certain extent during infiltration. Soil particles and living organisms may transform or accumulate pollutants and absorb their toxicity (EEA, 2012b; ESA and UCS, non-dated). As soil particles are charged, they can bind pollutants and trap them into the solid matrix, preventing them from being leached into groundwater. For example, clays and organic matter are two
constituents of the soil that form an excellent trap for metals. In addition, soil microorganisms can use organic pollutant for their metabolism, incorporate them into their bodies or transforming them into smaller, non-toxic molecules (BIOSIS, 2010a). However, these processes require time for water to transfer slowly throughout the soil (Van der Zee et al., 1994). They are not effective during fast percolation.

This phenomenon has important consequences for the chemical and ecological status of water bodies, as well as for drinking water quality, by performing a water “pre” treatment. Water filtration by soils is a function expected to take increasing importance in the context of a changing climate, where contamination of groundwater by pollutants washed away may increase following intense rainfall.

1.3.2 Regulation services

- Climate mitigation: floods and droughts

In the context of a changing climate, floods and droughts are extreme events that are expected to occur in the future with increased frequency and intensity.

Soils prevent or limit runoff by capturing part of the rainwater, at least up to their maximum water content and even more if water can keep moving to the aquifer. A reduction of this ability, for instance through soil sealing, compaction or through saturation, can lead to the three main types of flooding that are fluvial flooding, pluvial (i.e. rainfall-generated) flooding and urban flooding. Pluvial and urban flooding are mostly due to local runoff and ponding because of heavy rain, little permeable soils and input of water exceeding the capacity of urban sewage network. The lower the capacity to absorb water, the more runoff may occur following small increases in precipitation. Fluvial flooding (corresponding to river overflowing their banks) results from the accumulation of water running of downstream the catchments and are likely to affect large areas. As rainwater rapidly runs off into river channels due to the inability of soils to capture water after heavy rainfalls, flash floods may occur (EEA, 2012b; Nedkov et Burkhard, 2012), which are still complex to forecast. This type of floods is expected to increase in frequency due to climate change and related increase of rainfall intensity (Frei et al., 2006). Floods linked to western disturbances usually correspond to slow, winter flood events associated to west atmospheric circulation, leading to gradual water-table elevation and relatively long flood duration whereas Mediterranean-type floods typically correspond to flash floods generated by stormy, Mediterranean depressions occurring from the end of summer to the beginning of winter.

Floods can cause significant socio-economic impacts, depending on their scale and whether they threaten inhabited or economic areas (Fisher et al., 2009; Boyd and Banzhaf, 2007 in Nedkov and Burkhard, 2012) (see Chapter 5). A better understanding of soil and water dynamics at the catchment level can help take actions to increase the soil ability to capture water and ultimately to improving the forecast of flooding events.
The capacity of soil to retain water also increases the resilience of crops, forest and biodiversity to drought, by ensuring a continuous supply throughout the dry season (Brouwer C., 1985). Furthermore, the replenishment of groundwater resources through the infiltration of water into the soil also guarantees water availability for human and natural uses. In the driest regions, conserving the ability of soil to retain water overall helps preventing desertification, which is still a threat in the EU, in particular in Mediterranean countries (JRC, 2007).

The economic impacts of floods and droughts associated with a disruption of SWR capacity are estimated in Chapter 5.

**Climate regulation: temperatures, precipitation patterns and CO₂ releases**

Soil water content is a key variable of the climate system, involved in a number of feedbacks with temperatures and precipitation patterns at the local, regional and global scales (Seneviratne et al., 2010).

Exchanges between the soil and the atmosphere are regulated by soil water content variations and evapotranspiration, where water converted to vapour is released to the atmosphere. When temperature increases, evapotranspiration increases too, despite increasingly drier soil conditions. This creates a negative feedback on local temperature through the consumption of energy in the process and therefore buffering hot extremes and regulating heat waves (Hirschi et al., 2011). This process goes on until the soil is dry. Then, temperature increases cannot be damped by any further increases in evapotranspiration (Seneviratne et al., 2010). This important function explains why the limitation of water exchanges between soil and water due to soil sealing can result in massive temperature increases in urban areas (Schwarz, 2012a; Schwarz et al., 2012b).

Furthermore, in the context of a changing climate, soil water content may play a role in the decrease of CO₂ releases, which is an important greenhouse gas. Soil water content limitation can suppress microbial activity regardless of increases in temperature (Suseela et al., 2012).
therefore counteracts the demonstrated effects of temperature on soil organic matter microbial decomposition (Kirschbaum, 2010) and thus reduces CO₂ releases into the atmosphere.

The relationships between precipitations and soil water content are still subject to higher uncertainties, although the role of evapotranspiration in modifying precipitation patterns is acknowledged. Evapotranspiration of soil water has been shown to contribute to the movement of air and cloud formation (Seneviratne et al., 2010).

1.3.3 Supporting services

Biodiversity support/habitat functions

Water is necessary to all forms of life for multiple reasons. In particular, it is involved in metabolism reactions and cell functioning; it contains essential nutrients and it is used by many organisms as a transportation medium.

Soil water content is a structuring element for soil biodiversity. As it creates various hydrological conditions that are more or less suitable depending on organisms. It supports the development of a large diversity of organisms (BIOIS, 2010a) by influencing the distribution and dynamics of animal and plant populations (Wall et al., 1999; Araya et al., 2010) as well as soil microbial communities (Evans et al., 2014, in press). Some species even develop specific adaptations to habitats with extreme conditions, such as deserts and wetlands. For plants, this suitability is mostly determined by root distribution and depth (e.g. deep or shallow, as shown in Figure 10) along with the available water.

Figure 10: Access to soil water and rooting depth

Deep rooting system

Shallow rooting system

The water stored in these layers of soil is directly available to plants

Source: FAO (http://www.fao.org/docrep/r4082e/r4082e05.htm)
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**Nutrient cycling**

Mineral cycles and the natural distribution of minerals in the environmental compartments (soil, water, air, and biota) are naturally regulated by hydrological regimes, temperatures and the activity of biological communities. In particular, SWR processes are fundamental in the nutrient cycling and plant growth. They determine nutrients concentration in the soil solution and their availability to plants in a dissolved form (Nitrogen, Phosphorus, Potassium, etc.) (Janssen et al., 1990). For instance, plants can only directly use N in solution (NH$_4^+$ and NO$_3^-$) to meet their N requirements. Similarly, plant roots absorb P mainly as orthophosphate (H$_2$PO$_4^-$ or HPO$_4^{2-}$) from the soil solution.

**Erosion control**

Soil erosion consists in the removal of soil material by water or wind. It is a natural process, occurring over geological time$^{16}$. Most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased mostly by soil degradation caused by human activity (inappropriate land management, overgrazing, construction, etc.). The natural formation rate for new soil in the EU is very slow. It is generally considered between 1 and 2 t/ha/yr, although it has been reported to range from 0.1 to 2 t/ha/yr, which corresponds to the formation of 1 cm of topsoil every 100-400 years depending on soil density$^{17}$. This means that in some regions, a soil loss of 1 cm can be considered as irreversible within a time span of 50-100 years (Huber et al., 2008). Tolerable rates of erosion in the EU are generally considered to range between 1 and 2 t/ha/yr (Huber et al., 2008). They can however be variable following rates of soil formation under different geoclimatic conditions. Erosion is a widespread issue in the EU, where some soils are already irreversibly eroded. The surface area affected by erosion in the EU-27 is estimated at 1.3 million km$^2$. Out of this area, almost 20% is subject to soil loss in excess of 10 tonnes/ha/yr (JRC, 2012). In the Mediterranean basin, average yearly soil losses even exceed 15 t/ha$^{18}$. Soil erosion rates in the EU have generally been considered to range between 0 and 5 t/ha/yr for water erosion and 0 and 2 t/ha/yr for wind erosion (Huber et al., 2008). In some places, and for extreme events, losses of 20 to 40 t/ha and even up to 100 t/ha can be observed (Lal et al., 1989; Richter, 1983; Arden-Clarke and Evans, 1983 in Huber et al., 2008).

SWR processes plays a key role in controlling erosion. On the one hand, it limits runoff - known as one of the most important direct drivers of soil erosion - through water capture and infiltration (Le Bissonnais and Singer, 1992). This is likely to take increasing importance in the context of climate change, with more intense rainfall. On the other hand, it creates suitable soil water conditions. Soil with a high capacity of holding water are less prone to wind erosion, because they are less likely to dry out following sparse precipitation and because soil water presents a cohesive function (Roseen, undated).

Reduced erosion not only results in a smaller quantity of sediments transported into the air or surface water and reduced loss of nutrients, with benefits for human health (Ebi et al. 2006) and soil fertility. It also allows safeguarding the overall amount of soil and in turn the maximum

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$^{16}$ eusoils.jrc.ec.europa.eu/library/themes/erosion/

$^{17}$ http://ec.europa.eu/agriculture/envir/report/en/inter_en/report.htm#tab2

capacity of soil to hold water, and preserving its functions in the long term, including agricultural productivity and biological diversity (Ecologic Institute & SERI, 2010).

1.4 Synthesis

Through water capture, storage and release, soil water retention (SWR) capacity is a key component of the water cycle. It influences several mechanisms, from water infiltration at the soil surface and storage within the soil, to percolation down to the groundwater and releases to the atmosphere through evapotranspiration. The infiltration, storage and distribution of water within the soil profile are determined by water potentials resulting from the different forces applied to soil water. These include gravitational forces, matrix forces (capillarity and adsorption), vapour pressure and osmotic pressure.

The SWR capacity, as meant in this study, can be described by several indicators.

### Indicators of SWR capacity:

- **Infiltration capacity:**
  - maximum infiltration rate: maximum rate at which water can be absorbed by a given soil per unit area;
  - cumulative infiltration: describes the total amount of water actually infiltrated during a given period.

- **Soil water content:** amount of water present in the soil (in mm of water depth, % of volume, mass, or degree of saturation).

  \[
  \text{Soil water content} = \text{Precipitations & Irrigation} - \text{Runoff} - \text{Evapotranspiration} - \text{Deep percolation}
  \]

  - Maximum soil water content: maximum amount of water a soil can contain, when all pores are filled with water (saturation).
  - Water content at field capacity: maximum amount of water a soil can hold after water has drained to the aquifer by gravity.

  \[
  \text{Soil water holding capacity} = \text{Max Infiltration} - \text{Percolation to the groundwater} = \text{Precipitations & Irrigation} - \text{Runoff} - \text{Percolation to the groundwater}
  \]

  - Plant available water: amount of water that can be used by plants or evaporated. Of this amount, about one half is usually readily available and does not create conditions of water stress.

  \[
  \text{Plant available water} = \text{Water content at field capacity} - \text{Water content at wilting point}
  \]

  - Water content at wilting point (or residual water content): amount of water held so tightly to the soil that it cannot be taken up by plants nor evaporated.
Their use often depends on which ecosystem services the user wishes to focus on. Soil water retention indeed provides multiple goods and services, which sustain human needs from an environmental, health and socio-economic perspective. **Provisioning services** ensure the production of feed and fibre, through the storage of water, and of drinking water, through the groundwater recharge and the filtering function of soil. **Regulating services** ensure the modulation of natural processes and include climate regulation through the process of evapotranspiration and flood and drought mitigation. **Supporting services** are necessary for the production of all other ecosystem services and include e.g. erosion control and nutrient cycling, as nutrients are available to plants and microorganisms in a dissolved form within the soil.

It is not possible to maximise simultaneously all the assets of SWR capacity. Trade-offs will be necessary depending for instance on the need, in different catchments, for maximising yields, mitigating run off and floods, increasing aquifer replenishment or ensuring water filtration. An “optimal” SWR capacity could however be defined as the capacity to retain water within the soil yet in a form allowing water and air exchanges and to deal with large water quantities during wet periods.
Chapter 2 Parameters influencing soil water retention capacity

Water dynamics in soil is influenced by many factors that vary within the soil profile, laterally across land use types and temporally in response to climate (Swarowsky, et al., 2011). These factors can be physical, chemical, biological, water-related and geoclimate-related (Figure 11). Scientific literature shows that the inherent capacity of soil to retain water can generally be described by specific soil parameters (such as soil texture, soil structure, and soil organic matter (SOM) content), soil cover and initial water content.

Figure 11: Parameters affecting soil water retention capacity

Note: key parameters of Soil Water Retention capacity are highlighted in bold.

Together, these parameters determine the ability of soil to capture, hold and release water, either directly or through interactions with each other. For example, soil structure has a direct influence on SWR capacity by allowing preferential flows. Soil biodiversity on the other hand plays a key role on SWR capacity through its influence on soil structure.

The following sections aim to provide relatively concise background information on the most important parameters of SWR capacity, in order to identify whether and how they can be influenced to maintain or enhance this capacity. Where indicated, Annex 2 provides further analysis.
Chapter 2: Parameters determining soil water retention capacity

2.1 Properties of the soil matrix and related parameters

The overall abundance of pores, or “porosity”, determines the maximum volume of water that the soil can contain. However, a high porosity is not enough to maximise the services related to water retention capacity. The balanced arrangement of pores of different sizes, or “pore-size distribution”, is a key property in order to retain water yet in a form available for plants, to deal with large quantities during wet periods, and to ascertain air filled pores during most of the time, in order to provide oxygen to the plant roots (see box below). The specific surface area of soil particles is another important soil property, as it relates to the surfaces that water can bind to, once in the soil.

Influence of pore-size distribution on the SWR capacity:

Natural drainage in soils with a predominance of macropores is an asset in terms of maximising infiltration and respiration of soils, by avoiding saturation and its consequences (e.g. oxygen depletion for plants and microorganisms\(^9\), standing water or flooding events). Drainage into deeper layers of the soil also allows recharging the aquifers. On the other hand, fast and large drainage may be detrimental to water storage within the soil. Such soils tend to dry out quickly, which makes them prone to wind erosion and increases water stress for vegetation, with likely consequences in terms of irrigation requirements. On the other hand, soils should also be able to retain water for extended periods in between rainfalls, and this requires the presence of smaller pores. Soils with a predominance of small pores (meso and micropores), such as fine-textured soils, generally present a high capacity of water retention through prominent matrix forces, which hold water in the soil against the pull of gravity. The risk of soils with a predominance of micropores is a poor drainage, which easily induces water saturation. This results both in poor aeration (Patriquin, 2003), which limits the soil suitability for agricultural purposes, and often results in lower infiltration capacity, which makes them prone to runoff (Nedkov and Burkhard, 2012), increases flood risk as well as water erosion.

These three soil properties are influenced by several parameters, which primarily include soil structure, soil texture, and soil organic matter content. These are key parameters of SWR capacity.

2.1.1 Soil structure

Soil structure reflects the way solid soil particles are aggregated and built together, resulting in an arrangement of macropores and fissures\(^20\). There is no “ideal” soil structure associated to SWR capacity. Each structure presents different characteristics in terms of overall porosity, permeability, stability of aggregates, soil strength (toughness and resilience of structures) and behaviour when dealing with mechanical disturbances. Soil structure therefore represents different assets and shortcomings depending on whether focus is made e.g. on flood prevention,

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\(^9\) About 10 percent of the pores must be large enough for aeration so that root growth is not restricted. Source: passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447039&topicorder=8&maxto=10

\(^20\) There are six main categories of soil structure: single grain, granular, blocky, prismatic, platy and massive. See Annex 2.
on agricultural productivity or on water quality\textsuperscript{21}. Note that although soil structure is particularly determining for the capacity of soils to hold water in conditions near saturation, the less water there is in the soil, the more its distribution within the soil profile is conditioned by soil texture and the presence of organic matter (Malaya and Sreedeep, 2012).

The degradation of soil structure, however, generally goes along with a reduction in SWR capacity. Compaction, in particular, is a key threat as it increases soil bulk density and decreases its porosity, forcing a smaller distribution of pore sizes within the soil. Even a low level of compaction can significantly affect the way in which air and water move through the soil, generating run off along with a decreased hydraulic conductivity within the soil (USDA-NRCS, 2000; Richard et al., 2001; Mueller and Thompson, 2009). Yet, high levels of compaction currently occur in urban and agricultural areas, namely through the use of heavy machinery (Alberthy et al., 1984; Randrup and Dralle, 1996; Alakukku et al., 2003; Chamen et al., 2003; Jones et al., 2003; Hamza and Anderson, 2005; Gregory et al., 2006; Heesmans, 2007; Otoko, 2014). Impact of SWR capacity is even more important as time scales between the “sealing” of soil (relatively short time scales) and macropores formation (seasonal to multi-annual) are very different (Strudley et al., 2008). Other forms of degradation include the facilitated dispersal of soil particles, making the soil erosion-prone, and the formation of fractures or fissures allowing preferential flows down to the water table. The composition of the soil solution\textsuperscript{22}, and in particular sodicity that may result from irrigation and contamination through transfers with saline groundwater, may contribute to degrade soil structure, as excess in sodium prevents soil particles from sticking together (and hence to form both aggregates and macropores). In this respect, organic matter and biodiversity have an important structuring role on the soil.

The impact of structure degradation on SWR capacity can be mitigated to a certain extent through practices preserving the porosity and stability of aggregates. These are developed in Chapter 3. Annex 2 provides further details about the role of soil structure in SWR capacity.

\textsuperscript{21} For instance, an ideal soil structure for agricultural activities would consist of a granular structure with stable aggregates allowing the circulation of air and water while retaining water within the soil. However, this type of structure may not allow very high infiltration rates and would generate run-off in case of long lasting or short but torrential rainfall. Similarly, a soil structure that increases infiltration and therefore reduces runoff (e.g. single grain structure, such as sandy soils) could be suitable for flood mitigation, but percolating water may not be retained within the soil and may favour the deep leaching of contaminants with percolating water, resulting in risk of groundwater contamination. This is the case when fractures or fissures allow preferential flows down to the water table (Gerke, 2006).

\textsuperscript{22} See further details in Annex 2.
2.1.2 Soil texture

Soil texture indicates the relative content of particles smaller than 2mm, such as sand (<2 mm), silt (<0.075 mm) and clay (<0.02 mm) in the soil. It therefore excludes gravels and stones. Because of their influence on pore-size distribution and the overall porosity, each type of soil textures has specific consequences on infiltration, storage, and percolation (see Annex 2 for further details). Overall, the coarser the texture:

- the better the infiltration and the lesser runoff in unsaturated conditions. Note, however, that once saturation is reached, surface runoff will occur regardless of the soil texture (Loague et al., 2010; Church & Woo, 1999);
- the lower the maximum capacity of soils to store water because a coarse soil presents too many macropores, which do not hold water against gravity, and less cumulated pore space than a finer soil;
- the lower the residual water, which means that between field capacity and wilting point a greater amount of water is available to plants.

Because it allows great cumulative porosity, clay is the soil fraction with the most important influence on such soil behaviour as water holding capacity. The mineralogical composition of clays may further influence the capacity of soil to hold water, depending on their capacity to swell with water. Yet, this fraction has a limited interest as water storage for agricultural purposes as it still holds large amount of water at the wilting point.

Soil texture is an inherent soil property, resulting from a combination between the type and mineral composition of parent material, the soil position in the landscape (residual, colluvial, alluvial, loess deposits) and physical and chemical weathering processes involved in soil formation. Soil texture cannot be directly modified to improve SWR capacity in a given area. However, related impacts can be mitigated through appropriate practices preventing the formation of crust and fractures within the soil. These practices are developed in Chapter 3. Annex 2 provides further details about the role of soil texture in SWR capacity.

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23 Twelve major soil texture classes are defined depending on the preponderance of silt, clay or sand. In the field soil texture can be determined by moistening the soil and rolling it in the hands. The stickier the soil is, the more clay there is. The soapier the soil feels the higher the silt content. The crispier it is, the higher the sand content. Coarse soils, like sandy soils, consisting of large particles, leave ample space between particles forming macropores, whereas fine soils, like clay soils, consisting of smaller particles, mostly form micropores.

24 Note that beyond the soil texture, the presence of rock fragments (stoniness) reduces the maximum water content in direct proportion to their volume, unless the rocks are porous (NRCS, 1998). Neglecting the presence of rock fragments in calcareous soil may overestimate the available water content by 39%, because of the induced lower specific surface area and lower cumulated pore volume (Cousin et al., 2003).

25 Deformable minerals such as smectites and vermiculite have stronger capacity to hold water than other clay minerals. More generally, amorphous materials such as allophanes (hydrated aluminosilicate minerals) are characterised with high capacity to hold water (Mile & Mitkova, 2012).
2.1.3 Soil organic matter

Soil organic matter (SOM) is “the organic fraction of the soil, excluding undecayed plant and animal residues, their partial decomposition products, and the soil biomass”\textsuperscript{26,27}. About 45% of soils in Europe are thought to have a low or very low organic content matter (0-2% organic carbon) (JRC, 2012). Estimations reveal that the issue of low and medium carbon content soils particularly concern Southern countries, where 74% of the soil had less than 3.4% organic matter, as well as parts of France, the United Kingdom, Germany and Sweden (Lal, 2004; EC, 2006; Gardi et al., 2011). SOC levels in the EU increase according to a South-East to North-West trend (Toth, 2013). In general, organic matter is greater in areas of higher rainfall, and lower in areas of higher temperature, the rate of decomposition doubling for every 8 or 9°C increase in mean annual temperature\textsuperscript{28}. For instance, in the EU, the SOC pool to 1 meter depth ranges from 30 t/ha in arid climates to 800 t/ha in cold regions (Lal, 2004).

Organic matter plays a key direct role in the capacity of soil to hold water, and indirectly contributes to favouring infiltration and circulation of water within the soil, through increasing the soil cation exchange capacity and stabilising the aggregates\textsuperscript{29}. Increasing soil organic matter contents were positively correlated with an improvement in the capacity of soils to store water, and in particular plant available water irrespective of the texture considered (sand, silt loam, or silty clay loam) (Olu et al., 1987; Hudson, 1994; Wall et al., 2003; Saxton and Rawls, 2006; Singer et al., 2006; Margulies, 2012). It is considered that for each 1% of OM increase, the available water increases by more than 1.5 - 2%, these increases being the most remarkable in silt loams (e.g. up to 4%) (Hudson, 1994; NRCS, 1998). The marginal effect of SOM on SWR capacity is particularly significant where its structuring effects are the most important, i.e. in coarse soils, in soils at low initial C content and in conditions of field capacity. However, quantitative information concerning the water content of soil organic matter and its impact on SWR capacity remains very scarce.

SOM can be naturally lost, as after e.g. fire events. However, land use practices can further influence the losses of SOM content through soil erosion and mineralisation. In order to maintain or improve SWR capacity, several opportunities are provided by appropriate land uses and soil management practices. Crop rotation, crop and forestry residues management, amendment as well as changes in land use (e.g. preserving grasslands, restoring peatlands) are key leverages to influence the amount of soil organic matter. These opportunities are developed in Chapter 3. Annex 2 provides further details about the role of SOM in SWR capacity.


\textsuperscript{27} The amount of organic material stored in the soil can be expressed in two ways, as organic matter or organic carbon. Soil organic matter is a key indicator of soil quality and productivity. Soil organic carbon (SOC) is the main constituent of soil organic matter by weight. It refers to the amount of carbon stored in soils and expressed in g C/kg soil.

\textsuperscript{28} www.dpiw.tas.gov.au/inter.nsf/WebPages/TPRY-5YW6YZ

\textsuperscript{29} In particular, the biodegradation of soil organic matter by microorganisms releases polysaccharides which act like glue, and contribute to the physical and chemical binding of soil particles and microorganisms together into aggregates. It helps form and maintain the air passages and channels, protecting the soil from compaction.
2.1.4 Soil biodiversity

Soil biodiversity has diverse and complex impacts on SWR capacity. It is an important supporting factor in enhancing two key parameters of SWR capacity that are soil structure and soil organic matter.

It has first a physical impact on the soil, through the burrowing activity of earthworms, ants and termites but also mammals, which modifies soil structural features at different scales of soil porosity (Lamandé et al., 2003). At a macro scale, the burrowing activity creates preferential path flows for water, thus increasing the hydraulic conductivity (Chan, 2001). At a smaller scale, earthworms contribute to the formation of granular aggregates and hence to meso-porosity and micro-porosity, namely through the accumulation of casts below the soil surface (Jongmans et al., 2001 in Bottinelli et al., 2010; Pérès et al., 1998). In temperate climates, the abundance of earthworms is generally beneficial to SWR capacity, through the reduction of runoff and the increase in water storage. For example, surface runoff during rain was negatively correlated with Lumbricus terrestris L. dry weight in observations made in the field in Finland (Pitkanen & Nuutinen, 1998 in Blouin, 2013). Ehlers (1975) also reported an increase of water storage of 25% in a field, ten years after the introduction of earthworms.

Some microorganisms (fungi, bacteria) also have chemical impacts on soil, through the degradation of organic carbon and the secretion of sticky substances, which allows reinforcing soil structure through binding soil particles into aggregates. Although some of these secretions are thought to have a water-repellent behaviour by creating coating hydrophobic surfaces, which would reduce in turn the affinity of soils for water, their actual impact on SWR capacity is not quantified in the literature.

The main threats likely to impair the SWR capacity provided by the soil biodiversity include erosion, depletion of organic matter, salinisation, soil compaction and soil sealing, in addition to pollution (EC, 2010; BIOIS, 2010a). Gardi et al. (2013) recently demonstrated that the intensity of land exploitation is the main factor applying pressure on soil biodiversity, both in terms land-use dynamics and farming practices. Sustainable practices can maximise the SWR functions of soil
biodiversity. In particular, earthworms management through appropriate land uses and farming practices represent an excellent potential partner for humans in managing ecosystem services (Byers et al., 2006 in Blouin et al., 2013). The impacts of land use and management practices on SWR through maintenance or loss of biodiversity are detailed in Chapter 3.

2.2 Soil cover

2.2.1 Overview

Soil cover is closely associated to the pattern of land covers, including forests, grasslands, agricultural areas and artificial areas. Compared to bare and sealed surfaces, the coverage of soils by vegetation or permeable materials represents a key asset for the SWR capacity. At the soil surface, both canopies and vegetation residues laying on the soil surface regulate the amount and rate of water supplied to the soil through water interception. For instance, although forest felling is visually very dramatic, its impact on extreme flows is relatively small and difficult to detect at the catchment level, as there is limited change in the interception capacity between the standing forest and that of felled areas covered by large amounts of tree brash (Robinson, 2003). More generally, the presence of permeable soil cover dissipates the kinetic energy of raindrops and reduces the volumes and velocity of run-off, with significant impacts in terms of prevention of erosion and mitigation of flood risks (Cesar Ramos et al., 2013; Nedkov and Burkhard, 2012). The seasonality of soil cover, in particular, is a key factor affecting the formation of a soil crust. An advantage of vegetated cover is that within the soil, roots increase infiltration, through their mechanical action on soil aggregates or through leaving channels or macropores, once they are decayed, as in the case of alfalfa (Kavdir et al., 2005). Schmidt et al. (2011) also reported that root-derived carbon is retained in soils much more efficiently than are above-ground inputs of leaves and needles, therefore influencing soil organic matter content. Through its water demand and related evapotranspiration, vegetation also regulates soil water content. The rooting of crops, from shallow to deep, and with various strength, will influence the extent to which the plant may search for water in deeper soil layers. On the contrary, SWR capacity is likely to be rapidly disrupted in bare soils and even instantly in sealed soils. Besides their negative impacts on the dynamics of infiltration, predominantly bare soils may also progressively lose their capacity for water storage through their vulnerability to wind and water erosion. Although soil stock is more important for infiltration and percolation processes than the slope, topography further influences the risk of run off and soil loss. In particular, on steep slopes (> 15° inclination), water flows have little time to infiltrate, which make these areas particularly vulnerable to run-off and water erosion. Note that erosion does not have to be extended geographically in order to create significant impacts on SWR capacity. In case of gully erosion, gullies concentrate water into narrow channels and accelerate water flows, depriving surrounding areas of water supplies and leading to severe off-site impacts (Valentin et al., 2005).

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30 Annex 2 provides further details about the role of soil stocks and topography in SWR capacity.

34 Gentle slopes (< 5° inclination) may face another issue, with the rapid formation of crust occurs through splashing effect.
2.2.2 Impacts of different land covers

Because of their high interception capacity, forest and shrubs cover are commonly thought of as having important benefits related to water and in particular in the mitigation of run off and flood regulation (Figure 13) [see case study n°20 in Annex 1]. Mature deciduous forests are shown to provide the best conditions for storing storm rainfall, compared to coniferous woodland (Archer et al., 2012).33 As forests tend to have higher infiltration rates than other soils, they are able to reduce peak flows locally (Scanlon et al., 2007; Power, 2010). However, forest cover is shown to have relatively low impact on extreme flows at the catchment level and at larger scales (Robinson et al., 2003). Several studies show that forest present higher infiltration rates than grasslands and a better conductivity within the soil, leading to the better recharge of the aquifers (e.g. up to 5 to 6 times according to an experiment conducted by Archer et al. (2012) in Scotland in mixed forests). As forests are high water users, with high evapotranspiration rate compared to other plants, they may reduce the overall soil water content despite their high infiltration capacity. Soil water measurements generally show drier soil conditions under established forest than nearby grass (Hudson, 1988; Robinson and Cosandey, 2002). In particular, fast growing forest crops (often used for energy purposes) usually require high amounts of water to reach expected yields (IUFRO, 2007), and may reduce the overall water available downstream in case of drier climate. Yet, compared with other forms of land cover, forests is almost twice as efficient at returning water to the atmosphere and thereby contributes back to regional precipitations (Ellison et al., 2012).

Figure 13: Influence of forest on runoff vs. infiltration

![Figure 13: Influence of forest on runoff vs. infiltration](source: COMET Program, 2010)

Although they are less favourable to water infiltration than forest covers, grassland covers represent a more balanced asset to maximise services related to soil water retention. They present a high capacity for rain interception and for slowing down runoff, as well as a high infiltration capacity due to their well-developed capillary soil-pore system, compared to agricultural vegetation and urbanised areas. They are also associated with reduced evapotranspiration compared to forests and cultivated land, and thereby with higher water storage capacity within the soil.

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33 Although the leaves are gone from the fall season, which prevents interception as in spring and summer, the presence of a leaf litter covering the soil in deciduous forests is an asset compared to coniferous forests.
On the contrary, the low capacity of cultivated areas to capture and store water within the soil is often pointed out in comparison to forest and grassland covers, as agricultural activities may leave soils uncovered for parts of the year (Li et al., 2007; Kodesová et al., 2011). This contributes to increased risks of run-off, namely through the formation of crust and erosion rills (reviewed in Green et al., 2003). Hart et al. (2013) for instance reported that in Catalonia (Spain) cropland was estimated to contribute to run-offs of 1884 m$^3$/ha compared to 962 and 643 m$^3$/ha in grasslands and forests respectively. Furthermore, evapotranspiration in cultivated areas during the growing season potentially greatly exceeds the precipitation rates (especially in dry areas), creating a deficit in soil moisture and water stress for crops. That said, the actual risks and opportunities for SWR capacity in agricultural areas, and associated ecosystem services, very much depend on agricultural management practices on a catchment, which play a key role in how much water infiltrates and is stored in agricultural soils. These practices are further discussed in Chapter 3.

Soil sealing, which consists in the covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.), is the most intense form of land take and is essentially an irreversible process. By preventing or drastically decreasing the capacity of soils to infiltrate water, and reducing the overall evapotranspiration, soil sealing modifies the natural water balance. When the soil is sealed, water cannot infiltrate the soil locally (infiltration rate equals 0% on site), unless drainage systems are in place (see section 3.3). Run off from sites with high proportions of sealed surfaces could be two to three times that from predominantly vegetated surfaces (Dunnett and Clayden, 2007). They increase significantly with the degree of imperviousness, as depicted in Figure 14 and illustrated by historical trends in Leipzig [Case study n° 10 in Annex 1], Halle, Leeds [Case study n° 11 in Annex 1] and Brussels.

Figure 14: Water balance components in built-up areas as a function of sealed surfaces

In Brussels, for every 10% increase in impervious surface area, annual cumulated runoff was estimated to increase by 40%, high stream flow by 32% and flood frequency by 2.25 flood events (Hamdi et al., 2010). Depending on the characteristics of the watersheds, the groundwater

33 This also includes corresponding soil types, topography and management practices.
34 For most crops, the water used in transpiration is the equivalent of 2–5 cm of rain under humid conditions, and 3–8 cm under semi-arid conditions for each tonne of dry matter produced per hectare (Brady and Weil, 2002).
recharge can also be impeded, although to a relatively small extent. Taking the case of Leipzig, the groundwater recharge rate had only decreased slightly between 1870 and 2007 (about – 4%), despite substantial urbanisation. This is explained by the fact that water running off will generally end up infiltrating areas of good infiltration capacity within cities or in their close vicinity (Nuisl et al., 2009). Furthermore, the combined effects of the cut down of soil evaporation through sealing and the absence of vegetation impede soil water and atmosphere exchanges and cause a drop in evapotranspiration, along with increasing temperatures. For instance, in Leipzig, evapotranspiration rates in the areas where impervious surfaces cover 80 to 100% of the land surface are decreased by three compared to those in areas with less than 20% and up to 40% impervious cover (Haase et al., 2007) [see case study n°10 in Annex 1].

Like in agricultural areas, management practices (e.g. use of permeable materials) can mitigate to a certain extent the impact of soil sealing. These practices are further discussed in Chapter 3.

2.3 Soil water content

Soil water content counts amongst the key parameters of SWR capacity, along with soil structure, soil texture, soil organic matter, and soil cover. Soil water content is both a consequence and an influencing parameter of SWR capacity. It is strongly dependent upon climate conditions (temperature and precipitations, both in terms of intensity and duration, see section 2.4) as well as upon the soil infiltration and holding capacity, but it can in turn alter SWR capacity.

The degree of saturation of soils influence the additional volume of water that can be absorbed by the soil, and subsequently the infiltration process and generation of run off (Marchi et al., 2010). However, low water contents do not always guarantee high level of water infiltration and or retention within the soil, as the drying of soil after a long period of drought may alter soil physical and chemical properties and impede its water retention abilities, e.g. through the formation of crust and fractures in clayey soils. For example, the flash flood that occurred in Malborghetto-Valbruna (Northern Italy) was explained by the combination of an extreme precipitation event (355mm within 3 to 6 hours) with an anomalous dryness of the soil [see case study n° 23]. Despite a high capacity to hold water, the dryness of the soil impeded infiltration, preventing it to play its flood mitigation role (Borga, 2007; Scolobig, 2008; Norbiato, 2008) (Figure 15). Repellence due to drying can indeed delay wetting of soil for periods ranging from as little as a few seconds to several weeks35. As soil dries, its capacity to store water is increasingly governed by the water content and the influence of texture becomes negligible (Vanapalli et al. 1999; Baker and Frydman, 2009; Malaya and Sreedeep, 2010).

Soil water content may also impact SWR capacity indirectly through its role on chemical and biological processes, in particular on soil biodiversity, and its contribution to the regulation of evapotranspiration processes. Soil water can be actively managed, either directly through water supply via irrigation or water removal via drainage, or indirectly through soil management

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35 This was demonstrated in a more theoretical way by Jeyakumar et al. (2012), which show that after air-drying of soil fractions, 16 to 96% of precipitation could be lost for the soil through run-off (increasing losses from Fluvisol to Histosols).
practices and land cover influencing the natural processes of rainwater infiltration, evapotranspiration and percolation.

Figure 15: Flash flooding in Malborghetto-Valbruna (Northern Italy) in August 2003

Source: www.floodsite.net

2.4 Climate parameters

Beyond the inherent capacity of soils to capture, store and release water, climate parameters (precipitation, temperatures and wind) influence soil water contents and eventually the groundwater replenishment through their influence on water supply and evapotranspiration.

When no water is provided to the soil, soil water is progressively withdrawn to the atmosphere through evapotranspiration until reaching the wilting point. Soil water content is recharged during rainfall events. Across the EU, Member States do not benefit from the same potential from precipitation. For instance, in Spain, the average annual rainfall from 1990-2009 amounted to 605.1 mm/yr, whereas it amounted to 1145.5 mm/yr in the UK. However, the amount of water captured and retained by the soil during a rain event does not only depend on the amount of water supplied, as run off increases with the intensity of rainfall and the degree of saturation. In Europe, the average European intensity of precipitation for a very light rain corresponds to a precipitation rate below 0.25 mm/hour, a moderate rain corresponds to a precipitation rate between 1 and 4 mm/hour, and a heavy rain corresponds to a precipitation rate above 50 mm/hour. These thresholds are highly variable depending on countries and seasons. They are to be compared locally with the infiltration rate of soils, which can range from less than a mm to several cm per hour. Precipitation may also indirectly impede water infiltration through the sealing of soil surfaces resulting from the splashing effect of rain drops on vulnerable soil surfaces, e.g. in bare and fine-textured soils.

Temperature directly influences SWR capacity through the regulation of evapotranspiration processes, and hence of the release of soil water into the atmosphere. An increase in temperature increases evapotranspiration, hence resulting in a decrease in soil water content.

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36 data.worldbank.org/indicator/AG.LND.PRCP.MM

37 For example, if the initial infiltration rate is 20 mm/h, and that a rainfall event supplies 30 mm of water in 1 hour, water will end up running at the surface. If the rainfall event supplies 30 mm in 3 hours, then the intensity of the rainfall is only of about 10 mm/h, which means that the rainfall water should be able to infiltrate into the soil.
Evapotranspiration may then exceed the supply of water through precipitation or irrigation, resulting in water stress for plants and lack of groundwater recharge. However, evapotranspiration is shown to be a significant source of rainfall over land, contributing up to 48% of rainfall at the regional and continental scales and 16% at the local level (Ellison et al., 2012). Reciprocally, lower temperatures inhibit evapotranspiration, and consequently preserve the storage of soil water. This process is, however, subject to many retroactions, since the process of evapotranspiration itself results in a local decrease of temperature, playing in turn on the reduction of evapotranspiration, and so on (Seneviratne et al., 2010).

Beyond its erosive power, likely to impact SWR capacity through soil losses, wind velocity also influences evapotranspiration processes (Liu M. et al., 2012; Liu X. And Zhang, 2012), and therefore modifies the water balance in catchments. Wind has particular impact on wet catchments, where it can even influence stream flows. In dry catchments, its impact on stream flow remains negligible, because the actual evapotranspiration dynamics follow more closely the precipitation patterns (McVicar et al., 2012).

Precipitation, temperatures and wind patterns are relatively inherent to the geographic area. Yet, soil water content can be easily improved by practices increasing infiltration at the soil surface in the case of light to medium rain. However, the potential for improvement decreases with the intensity of rain, until becoming negligible in the case of very heavy rains. It can also be improved by practices reducing evapotranspiration, such as wind breakers or soil coverage (e.g. mulching). These are developed in Chapter 3.

2.5 Synthesis and discussion

Soil water retention capacity depends on a number of physical, chemical, biological parameters and water-related parameters. Together, these parameters determine the ability of soil to capture, hold and release water, either directly or through interactions with each other.

Overall, soil texture, soil structure and soil organic matter play direct and preponderant roles in the mechanisms of SWR as they influence the overall porosity, pore-size-distribution and specific surface area. Soil cover, namely through its action on interception and infiltration, and initial water content are also major parameters. As for soil biodiversity, it is a key supporting factor in enhancing these parameters.

The parameters of SWR can be more or less involved in the different SWR processes, i.e. infiltration, storage, drainage and evapotranspiration.
Table 5 summarises the involvement of main parameters in each stage, with their role, associated threats and related drivers. For instance, infiltration is favored by porous surfaces and interception by soil cover. When soil surface is sealed by impervious materials, by compaction or by the formation of a crust, the soil surface becomes impenetrable. Infiltration can also be impeded when water has not enough time to infiltrate, such as in the case of intense rainfall events. Steep slopes and bare soils tend to further limit infiltration as they, respectively, accelerate water provided to the soil or do not intercept water through vegetation. Furthermore, saturation may further prevent infiltration. Storage is particularly increased by high amount of soil organic matter and high degree of porosity. Drainage is favoured by soil texture and structure allowing macroporosity. The presence of organic matter also stabilises aggregates and allows conserving this porosity. Furthermore, initial water content plays a role in releases of water down into the aquifer. Exchanges with the atmosphere are mostly regulated by soil water content and temperatures.

They can play synergetic or antagonist roles in different processes that are related with SWR capacity. For instance, a sandy texture enhances infiltration but adversely affects the actual retention through lower water content at field capacity.

While these parameters influence soil water retention, soil water content influences in turn their contribution to SWR capacity. For instance, in saturation conditions (high water content), runoff or ponding will occur whatever the texture, structure and soil cover. Near saturation, soil structure is determinant for SWR capacity, in particular for infiltration and releases, and probably even more determinant than soil cover in terms of regulating runoff. In desaturation conditions, however, soil texture and soil organic matter content become more and more important, with an increasing role in the soil capacity to hold water.

SWR capacity is manageable to a certain extent. Most physical, chemical, biological and water parameters can be directly enhanced or degraded by human activities, most of them with effects observable in the short term. This has important consequences in terms of opportunities for soil water retention management for various stakeholders. For other parameters that inherent to the soil type (e.g. texture) or to the geographical area (e.g. temperature and precipitation), actions can be taken to mitigate their impact or further enhance their benefits on SWR capacity. Approaches to maintain or enhance SWR capacity is described in Chapter 3.
### Table 5: Summary of the key parameters influencing SWR capacity

<table>
<thead>
<tr>
<th>Categories</th>
<th>Parameters</th>
<th>Role in SWR capacity</th>
<th>Threats to SWR capacity</th>
<th>Possibility to manage the parameter</th>
<th>Possibility to manage its impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical parameters</strong></td>
<td>Texture</td>
<td>x</td>
<td>x</td>
<td>The coarser the texture: $\Rightarrow$ infiltration; $\Rightarrow$ storage capacity; $\Rightarrow$ residual water $\Rightarrow$ aquifer recharge due to its reduced effective porosity and surface specific area.</td>
<td>For fine-textured soils: crust, impermeable layers, high amount of residual water, cracks and fractures. For coarse-textured soils: large porosity with low specific areas resulting in rapid percolation to the aquifer.</td>
</tr>
<tr>
<td></td>
<td>Structure</td>
<td>x</td>
<td>x</td>
<td>Influences the water capture, storage and release by determining the overall porosity, pore-size distribution, permeability, soil strengths and responses to disturbances.</td>
<td>Soil structure degradation resulting in reduced surface permeability through crusting and compaction; reduced infiltration in case of compaction; rapid percolation in case of fractures and fissures due to wetting-drying cycles; increase water erosion due to aggregates instability.</td>
</tr>
<tr>
<td></td>
<td>Soil depth</td>
<td>x</td>
<td></td>
<td>Determines the maximum volume of water a soil can absorb and store.</td>
<td>Loss of soil through wind and water erosion</td>
</tr>
<tr>
<td></td>
<td>Topography</td>
<td>x</td>
<td></td>
<td>Slope controls water flows and water content at the local and landscape scales through its orientation and inclination. May influence up to 65% of spatial water content variations.</td>
<td>High evapotranspiration on sun-exposed slopes. Little time for infiltration on steep slopes and increased risk of erosion. Formation of crust on gentle slopes.</td>
</tr>
</tbody>
</table>
# Chapter 2: Parameters determining soil water retention capacity

<table>
<thead>
<tr>
<th>Categories</th>
<th>Parameters</th>
<th>Role in SWR capacity</th>
<th>Threats to SWR capacity</th>
<th>Possibility to manage the parameter</th>
<th>Possibility to manage its impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Capture</td>
<td>Storage</td>
<td>Releases</td>
<td>SOM increases CEC, stabilise soil aggregates and improve soil structure and porosity through its support to biodiversity.</td>
</tr>
<tr>
<td>Chemical parameters</td>
<td>SOM content</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Mineralogical composition</td>
<td>Different compositions of clay influence the CEC and the capacity of soils to store water through swelling.</td>
<td>Non deformable minerals limit the capacity of soils to store water.</td>
<td>No</td>
<td>Idem as for texture</td>
<td></td>
</tr>
<tr>
<td>Composition of soil solution</td>
<td>Dissolved salts impact soil structure, and supporting processes delivered by biodiversity.</td>
<td>Excessive salt levels limit the ability of plants to extract water from the soil due to osmotic pressure. Excessive sodicity results in reduced infiltration, hydraulic conductivity and higher surface crusting, through the dispersion of soil particles.</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biological parameters</td>
<td>Soil cover</td>
<td>x</td>
<td>x</td>
<td></td>
<td>Soil cover plays a role on infiltration through water interception by leaves and physical action of roots. It also plays a role on evapotranspiration through water demand from plants.</td>
</tr>
<tr>
<td>Soil biodiversity</td>
<td>Biodiversity influences infiltration and storage conditions through chemical and physical actions in the soil.</td>
<td>Loss of biodiversity through pollution, erosion, depletion of organic matter, salinisation, soil compaction and soil sealing.</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Chapter 2: Parameters determining soil water retention capacity

<table>
<thead>
<tr>
<th>Categories</th>
<th>Parameters</th>
<th>Role in SWR capacity</th>
<th>Rationale</th>
<th>Threats to SWR capacity</th>
<th>Possibility to manage the parameter</th>
<th>Possibility to manage its impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water parameters</td>
<td>Water content</td>
<td>x</td>
<td>x x x</td>
<td>Water content influences the additional volume of water that can infiltrate the soil, the importance of adsorptive forces and soil structure.</td>
<td>Saturated soils, likely to result in runoff and water logging of soils Anomalous dryness, impeding infiltration</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>Periods of drought Extreme rainfall events Splashing effects of raindrops on vulnerable soils resulting in the formation of crust</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>Temperature influences releases through evapotranspiration.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate parameters</td>
<td>Precipitation</td>
<td>x</td>
<td></td>
<td>Evapotranspiration demand higher than water supply</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperatures</td>
<td>x</td>
<td></td>
<td>Wind influences releases through evapotranspiration.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind</td>
<td>x</td>
<td></td>
<td>Evapotranspiration demand higher than water supply</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
This chapter explores the influence on SWR capacity of climate change and land use trends, including land use changes and management practices.

3.1 Land use trends

Land uses affect SWR capacity through different types of soil cover and associated modifications of biophysical soil properties (e.g. permeability, degree of compaction). This section provides some insights about current land uses before discussing how land use changes may respectively degrade, maintain or enhance the associated SWR capacity. Management practices are discussed in the next chapter.

3.1.1 Context

The EU-27 covers a territory of 4.3 million km². It consists of a patchwork of different land uses, which include artificial surfaces, agricultural areas (including arable land, permanent crops and pastures), forests and semi-natural areas, wetlands and water bodies.

Agriculture and forestry are the dominant land uses in the EU and represent almost 80% of the EU-27 (respectively, circa 46% and 32%) (CLC, 2006). Within agricultural areas, pastures remain a minor land cover (16% of agricultural areas) compared to arable land and permanent crops. Because of their geographical coverage, agriculture and forestry have an important role to play in the maintenance or improvement of the overall SWR capacity in the catchments. Their potential contribution may however vary across the Member States. For instance, the share of Used Agricultural Area (UAA) is about 73% of the land in Ireland, and 66% in the UK, but was around 7.5% in Sweden and Finland (Eurostat, 2012b). Likewise, six MS have more than half of their area covered with forests (Finland, Sweden, Slovakia, Latvia, Spain and Estonia) while five countries have less than 15% of forested land (Malta, Netherlands, Ireland, United Kingdom, Denmark) (Eurostat, 2011b).

In Europe, the large majority of the population (about 75%), however, lives in urban areas and this trend is projected to increase to about 80 % by 2020 (EEA, 2010). Forty to forty five percent of the EU-27 population lives in areas considered predominantly urban; about 35% live in areas considered intermediate (Eurostat, 2011a). Artificial areas account for a bit more than 8.8% of the territory, but only half of this surface is actually sealed by buildings, roads and parking lots (LUCAS, 2009). The share of soil sealing in urban areas is subject to great variations among the

38 The share of Used Agricultural Area is also particularly high in Czech Republic, Denmark, Greece, Hungary, and Spain.
Member States\textsuperscript{39}, reaching up to 75\% e.g. in Paris, Thessaloniki, Bucharest and Barcelona (EEA, 2013). The most urbanised countries include the Netherlands, Belgium, Malta, Germany, Luxemburg and Cyprus\textsuperscript{40}. As they currently stand, the detrimental impacts of most urban areas on SWR capacity are manifold and much larger than the space they occupy.

The location (e.g. upstream/downstream) and organisation (continuous areas, patches) of different land use types within catchments also influence the overall water retention capacity of the area. The landscape within a catchment is a complex mosaic of forest areas, grasslands, agricultural areas and urban areas, which all present different assets and shortcomings in terms of SWR capacity. These are combined, in a non-linear manner, to generate a specific hydrological response in the overall catchment (O’Connell et al., 2007). Work in this area is still in progress. New multi-scale monitoring and modelling would be necessary to be able to assess how a local-scale effect due to a specific land use propagates downstream, and how it is combined with other local-scale effects in the catchment.

3.1.2 Land use changes between forests, grassland, arable land and urban areas

3.1.2.1 Past and future land use changes

As land is a finite and multifunctional resource, increasing tensions have arisen between society’s need for resources and space, and the capacity of land to support and absorb these needs (Antrop, 2005; Lowe et al., 2002; MacDonald et al., 2000; Terluin, 2003). This has led to substantial land use changes (see land use trends as detailed in Annex 3).

Past trends show increases in arable land (from 38\% cover in 1960 to 40\% in 1990) and forest cover (from 25\% to 33\%), along with substantial losses of grassland (from 19\% in 1960 to 7 \% in 1990) in particular in central Europe, parts of France, the UK and Portugal, and northern Spain (IEEP et Alterra, 2010). Meanwhile, built-up area had grown at a high speed. These trends are not homogeneous across Member States, as shown in Figure 16 and Figure 17 for the period 2000-2006.

The following trends can be observed:

- major conversions of grassland to crops across the EU, in particularly emphasised in central part of France, north part of Germany, Latvia, Estonia, and Romania. On the contrary, in central (Czech Republic, Slovakia, southern part of Poland) and eastern parts of Europe (Hungary, other parts of Romania), increasing conversions of crops to grassland could be observed;
- mild increasing conversions of grassland to forest in the UK, in particular in Scotland;

\begin{footnotesize}
\textsuperscript{39} ec.europa.eu/environment/soil/pdf/sealing/3.%20Introduction.pdf

\textsuperscript{40} www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing-100m-1
\end{footnotesize}
increasing conversions of forest to crops in Scandinavia in particular Finland, Central Europe (Czech Republic, Slovakia, southern part of Poland) and partly southern part of Portugal and Spain;

- major urbanisation due to changing crops land to urban land across the EU, in particular in industrialised parts of Europe such as Germany, northern Italy, Czech Republic, France and parts of Poland, Denmark and along the coastal eras of Spain and Portugal;

- urbanisation from changing grassland to urban environments, especially in the Netherlands, southern part of Germany, UK and central part of France.

The conversion of forests to urban environments only occurred to a limited extent, in Portugal, Sweden and Finland.

The latest trends show relatively small declines in arable land and grassland, and a steady increase of urban areas all over Europe. Future trends even project a switch towards increasing conversions to grasslands and forests, although conversions of grassland to crops are still projected in Central Europe (Hungary and Poland), Ireland and Baltics (in particular in Lithuania).

**Figure 16:** Land cover land use changes for the period 2000-2006

Source: CORINE dataset
Figure 17: Urbanisation trend for the period 2000-2006

Projections per country are available in Annex 3. Remarkable trends include:

- significant increasing conversions from grassland to forest in the Netherlands, France, Slovenia, Lithuania and Ireland, and moderate increases in Scandinavia (Denmark, Sweden), Portugal, Estonia, and parts of Central and Easter Europe.
- mild increasing conversions of crops to grassland only in Ireland and the Netherlands; and
- increasing conversions of crops to forest in Ireland, the Netherlands, Portugal and Slovenia.

Urbanisation at the expense of grasslands and croplands is also projected to slow down, as shown by:

- mild increasing trend of urbanisation due to changing grassland to urban environment in Benelux and France and partly in the Baltics countries (Estonia).
- mild increasing trend of urbanisation due to changing crops (arable land) to urban environment in Denmark, Hungary, Romania and France.
3.1.2.2 Expected impact on SWR capacity

Changes in land uses, and especially in land cover between predominantly vegetated areas into areas with abiotic dominance, result in important mutations of soil surface physic properties and changes in evapotranspiration demand. Besides the direct impact of soil cover on SWR capacity through water interception, changes in land use strongly influence, locally, the soil structure and soil organic carbon content, which are key parameters of SWR processes and determine the maximum water contents. By changing the responsiveness of soils to rainfall, land use changes influence the occurrence and frequency of floods. Based on changes in bulk density and organic content (see Annex 3\textsuperscript{41}), conversions from forest to crops, forest to grassland or grassland to crops negatively affect the maximum soil water content (-10% to -15%). On the other hand, conversions from crops to grassland to forest result in increased maximum soil water content (+5% to +10%) and hydraulic conductivity in saturated soils (+20 to +30%). Table 6 summarises the quantitative impacts of each type of land use change and highlights in a semi-quantitative manner their impact on maximum water contents.

Table 6: Impact of land use changes on bulk density (BD) and organic carbon (OC)

<table>
<thead>
<tr>
<th>Land use change</th>
<th>Estimated change in BD</th>
<th>Estimated change in OM</th>
<th>Impact on max soil water contents</th>
<th>Remarkable future trends in the EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest to grassland</td>
<td>+ 10%</td>
<td>- 15%</td>
<td>- 5%</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Forest to crops</td>
<td>+ 17%</td>
<td>- 35%</td>
<td>-10%</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Forest to Urban land</td>
<td>+ 40 to 50 %</td>
<td>- 40 to 45 %</td>
<td>-20 to 25%</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Grassland to forest</td>
<td>- 9%</td>
<td>+ 10%</td>
<td>+ 9%</td>
<td>+++ in NL, FR, SI, LT, IE ++ in Scandinavia (DK, SE), PT, EE and parts of Central and Eastern Europe (HU)</td>
</tr>
<tr>
<td>Grassland to crops</td>
<td>+ 7%</td>
<td>- 20%</td>
<td>- 4%</td>
<td>+ in HU, IE, LV, PL</td>
</tr>
<tr>
<td>Grassland to Urban land</td>
<td>+ 30 to 40 %</td>
<td>- 20 to 25 %</td>
<td>- 10 to 15%</td>
<td>+ in BE, NL, LU, FR, partly in the Baltics countries (EE), in Central and Northern DE (Hamburg). To a least extent, Northern and Southern IT</td>
</tr>
<tr>
<td>Crops to forest</td>
<td>- 15%</td>
<td>+ 15%</td>
<td>+ 5%</td>
<td>++ in IE, NL, PT and SI</td>
</tr>
<tr>
<td>Crops to grassland</td>
<td>- 6%</td>
<td>+ 5%</td>
<td>+4%</td>
<td>+ in IE and NL</td>
</tr>
<tr>
<td>Crops to Urban land</td>
<td>+ 20 to 25 %</td>
<td>- 15 to 20 %</td>
<td>- 1 to 3%</td>
<td>+ in DK, HU, RO, FR ++ DE and IT</td>
</tr>
<tr>
<td>Others to Urban land</td>
<td>&gt;50 %</td>
<td>&gt; - 45 %</td>
<td>&gt; -25%</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>

Note: +++ to + → significant increase to mild increase in associated land use change

\textsuperscript{41} Annex 3 aims at describing the methodology, used data sources and data analysis for quantitative estimation of the trends in soil water content; the Case studies n°24, 25 and 26 developed in Annex 1, combined with existing databases contributed to the estimation of expected impacts of land cover changes on SWR. They are not used in the main text to describe results as they mostly consist in methodological inputs.
Changes in land use may also disturb evapotranspiration, and thereby, locally, the storage of water within the soil. Land vulnerability to drought and desertification for instance is shown to be higher in areas experiencing land-use changes than in areas with stable patterns of land-use (Salvati et al., 2013).

Urban development is particularly associated with substantial increases of run-off and the reduction of evapotranspiration, because of soil sealing and compaction. In the city of Leipzig for instance, urban development from 1870 to 2003 significantly impacted water balance, resulting in increased direct runoff rates by 282% in the area and decreases in the evapotranspiration rates by an average of 25% (Haase, 2009) [see case study n° 10 in Annex 1]. Urban development therefore comes along with increased risks of floods and a lower contribution of soils to climate regulation. It also contributes, but to a lesser extent, to reducing the replenishment of groundwater bodies. These impacts and how they can be mitigated are further discussed in section 3.3.

Land use changes that significantly decrease evapotranspiration, such as deforestation, have also been shown to be able to modify the hydrological cycle beyond the local scale and to impact adjacent regions (Millan, 2007). This phenomenon has several consequences. Locally, the absence of precipitation inland results in increased inland drought, while moist air coming from the sea is eventually returned to the coast. There two situations are possible: either the greenhouse effect of the water vapour, photo-oxydants and aerosols accumulated over the sea finally create torrential rains in Mediterranean coastal areas, or the moist air is vented out to Central and Eastern Europe, where it contributes to intense summer precipitations.

Based on Table 6, most past trends in land use must have contributed to develop unfavourable conditions for soil water retention across the EU and to decrease the EU initial potential in terms of maximum soil water contents. Most recent trends and projected future trends in land use are less alarming, as the most critical conversions (deforestation and conversion of grassland to crops and crops to urban land), if they still happen, are more limited geographically. Note, however, that stable land use types may hide substantial changes in practices, such as the intensification of agriculture. This will be addressed in section 3.2.

Note that the impacts of land use changes on SWR capacity do not only depend on the type of land use change. They also greatly depend on the percentage of catchment area converted, which was shown to possibly have a greater contribution to flooding events than the type of land use change (Solin et al., 2011), and on the location of land use changes. The following sections highlight the cases of afforestation, sealing or compaction of areas of high infiltration, degradation of wetlands and urbanisation in floodplains.

**Magnitude and location of afforestation**

Although flash floods and small floods can be reduced, locally, through afforestation (Dijk and Keenan, 2007, Hamilton, 2008), the flood mitigation potential at the catchment level largely differs depending on the percentage of the catchment area covered, the location of the reversion/afforestation in the catchment, and the continuous vs. discontinuous nature of this development. Extended afforestation in small catchments was shown to be able to reduce flood peak by up to 50% (e.g. Fayey et al., 2004). Yet, unless most of the catchment is afforested, the impact of forests downstream a catchment can actually be quite low. This significantly reduces its impact in large catchments, although the critical size of afforestation development for flood
mitigation can be reduced if substantial afforestation is made upstream the catchment. However, extensive afforestation can offer limited comparative advantages in specific cases. For instance, its impact can be relatively low on peak flows in the case of afforestation of all unwooded floodplains compared to 5m riparian zones along river banks, as shown in the mountain catchment of the upper Flöha river on the Germany-Czech Republic border (Reinhardt and Bölscher, 2011). Annex 2 provides further analysis. Moreover, despite extensive afforestation, the reduction in runoff from several small blocks of afforested or reverting land can be easily overwhelmed by ‘normal’ runoff from much larger areas e.g. of surrounding farmland. Therefore, afforestation could be a key mitigation option in some areas whereas improved crop practices could be more relevant in others.

Sealing of areas of high infiltration

The location of urban developments in relation to soil permeability and the initial capacity of soils to store water also influences the impacts of soil sealing on the water balance. Once the soil is sealed, runoff will occur, independently of the initial capacity of soil to infiltrate water. However, runoff may be all the more significant where underlying soils used to have high infiltration and capacity to store water and therefore natural SWR capacity. Hence, urban development on less permeable soils (e.g. clay) will have relatively less impacts than on soils allowing infiltration (e.g. sand, sandy loam) (EC, 2012a). Yang and Li (2011) showed that, in the Woodlands (USA), urban development on clay soils had less marginal impact on run-off than similar development on sandy soils, as it resulted in a 8% lower additional run off. On the other hand, they also show that in the case of small rainfall events, the density of development may have more influence on long-term runoff than the underlying soil type (Yang and Li, 2011) [see case study n° 18 in Annex 1].

Degradation of natural buffers that are wetlands and floodplains

Wetlands strongly influence hydrology, as well as water quality and biodiversity, over the whole catchments area (Merot et al., 2005). Wetlands function like natural tubs or sponges, storing water and slowly releasing it. This process slows the water’s momentum and erosive potential, reduces or delays flooding, and allows for ground water recharge, which contributes to base flow of surface water systems during dry periods (Holcová, 2007, based on Novitzki et al., 1999; Merot et al., 2005). They may also play a role in the protection of riverbanks and the dilution of contaminants and purification of water (nitrates, phytopharmaceuticals, heavy metals). In the last decades, the EU witnessed the progressive loss and degradation of wetlands through drainage because of competing land uses, especially in agricultural areas. For instance, in France, 67% of wetlands have been lost in the period 1900 to 1993, while the Netherlands have lost 55% of wetlands in only 35 years between 1950 and 1985 (Schuyt and Brander, 2004). Multiple wetlands restoration initiatives are conducted in river catchments, taking into account their positive impacts on water management (Verhoeven, 2013). For example, following the 1993 and 1995 floods, which resulted in $300 million worth of damage and the evacuation of 250,000 people.
people, the Netherlands revised their flooding strategy. They adopted in 2007 the “Room for the River” Programme\(^{44}\) for about €2.3 billion, which aims to give the river more room to be able to manage higher water levels. Measures bringing back the ecological functions of the river surroundings are being taken to give the river space to flood safely.

Risk of floods are also increasing in many inland cities because of their expansion in areas little protected by natural flood-regulating services or flood protection measures. In Bulgaria for instance, a study about the Etropole municipality area highlighted how areas of high demand for flood regulation services, like agricultural areas or cities, were often located in places of very low supply, such as flat surfaces along the river streams (Figure 18) (Nedkov and Burkhard, 2012) [see case study n° 19 in Annex 1].

**Figure 18: Map of flood regulating ecosystem services supply-demand budget for the Etropole area in Bulgaria**

The case of the Elbe is a remarkable example of the consequences of such mismatch. The Elbe has lost 80% of its floodplains and forests, which were originally able to absorb some of the water pressure, for settlement purposes, and is now one of the EU areas where the most dramatic flooding events occur\(^{45}\).

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\(^{44}\) [www.ruimtevoororderivier.nl/meta-navigatie/english.aspx](http://www.ruimtevoororderivier.nl/meta-navigatie/english.aspx)

Impact of urban expansion in floodplains and flooding - Case of Dresden, Germany

In Dresden, the built-up area flooded had increased dramatically over time because settlement areas in flood plains had grown considerably over the past century. The most devastating flooding event occurred in 2002: although the overall flooded area was somewhat similar to the 1890 flood, the settlement area flooded tripled. This can be partly explained by an increased exposure of the city to floods (about 50 km$^2$ between 1990 and 2000), because of the many new residential areas built in flood-prone areas. Below, light blue areas represent flooded areas (Figure 19).

Figure 19: Flooded areas in Dresden in 2002

This could be witnessed very recently, in summer 2013, as Elbe level raised dramatically after a wet spring and intense rainfall events (getting as much rain in a few days as in a couple of months), reminding of the devastating floods from 2002. Last June, the media reported that the Elbe was running at about 8.5 meters (Figure 20), compared with a normal average of 2 meters, and was expected to reach about 9 meters near Dresden $^{46}$. This caused consequent material damages in Southern and Eastern German States as well as western regions of the Czech Republic, affecting buildings (homes and businesses) and transport infrastructures (roads, railway connections and river transport), along with the evacuations of population and fatalities [see Case studies n°13 and 14 in Annex 1].

$^{46}$ edition.cnn.com/2013/06/06/world/europe/europe-flood
Likewise, in the UK, in 2009, it was estimated that 3.8 million properties in England were located in areas at risk of surface flooding (pluvial and fluvial), i.e. more than one house every ten houses (UK Environment Agency, 2009) (and one in six houses considering the overall risk of flooding, i.e. surface and coastal). Unlike flash floods, floods occurring in floodplains can usually be predicted through the raise in the river’s level, with relatively good accuracy.

Similarly to the restoration of wetlands, there has been an increasing interest in floodplain restoration among policy and research circles, not only for flood management but for all their associated ecosystem services (nutrient retention, carbon stocks and carbon sinks, habitat function). Concrete initiatives are now being implemented in the EU, at the example of Germany, where the German Environment Minister called for rethink in flood protection, in order to “give rivers more room to buffer their floodwaters”\(^47\). Case studies were conducted in 2010 to better understand and value the functions of floodplains, including flood protection. Several strategies exist for optimising water retention in flood plains and mitigating flood damages. The large-scale assessment of flood risks along the Elbe river concluded for instance that the effects of controlled retention at the most upstream possible location and largest possible extent generated the most pronounced reduction of average annual damage (de Kok & Grossmann, 2010). Some authors also argue that agricultural floodplains could be seen as a good opportunity for flood storage and attenuation (Morris et al., 2005, in Wheater and Evans, 2009), all the more since farm land is considered more tolerant to floods than urban land, with lower economic impacts in general (Wheater and Evans, 2009). In this case, the question remains, however, of the fair allocation of the damage costs supported by farmers. More generally, increasing attention has been paid in the EU to the development of green infrastructures, which provide multiple ecosystem services through a reasoned spatial structure of natural and semi-natural areas and the preservation of other environmental features. Published in 2013, the Green infrastructure strategy\(^48\) aims to further help understand the value of the benefits that nature provides to human society and to mobilise investments to sustain and enhance them. It highlights, for instance, that restoring

\(^{47}\) www.dw.de/german-minister-calls-for-rethink-on-flood-protection/a-16873352

floodplain forests is often cheaper in terms of one-off and maintenance costs than purely technical solutions such as building dams and floodplain reservoirs to mitigate flooding events.

Because of the long timelags (decades to centuries) between land use changes and system response (e.g. recharge, stream flow, and water quality), the full impact of land use changes is still to come in many areas (Scanlon et al., 2007), hence the necessity to anticipate detrimental land use changes.

As current land uses respond to socio-economic demands and needs, opportunities for improving SWR capacity through land use changes remain limited in practice. It is therefore important to highlight what could be done within current land uses to improve or maintain SWR capacity, and the associated ecosystem services.

3.2 Management practices in agriculture, and opportunities for improving soil water retention capacity

Within each land use type, there can be large differences in management practices, with variable impacts on SWR capacity. In some cases, the impacts of these management practices may even be higher than the actual benefits of specific land uses. This is namely the case of agricultural areas, which contribution to SWR capacity mostly depend on practices in terms of soil management, water management and landscape management.

3.2.1 Farming systems in the EU

Farming systems result from a combination of soil, livestock, water, and landscape management practices. The predominant farming systems in EU-27 are field crops, mixed farms and pasture and grasslands, except in regions of Spain and Italy where permanent crops are predominant (e.g. grapes, olives). They are characterised by different levels of intensity, ranging from intensive systems, focused on maximising production, to more sustainable agriculture, focused on limiting inputs, field operations and/or ensuring the ecological sustainability of the productive system.

In the last decades, numerous technical improvements and agricultural services have facilitated the development of more intensive forms of agricultural production. Motivated by increased remunerations at least in the short run through higher yields and the reduction of environmental uncertainties, intensive agriculture generally includes a high use of inputs such as inorganic fertilisers, irrigation, and pesticides, as well as cultivation of monocultures, use of tillage practices, and large field size. This is a common type encountered across the EU, especially for the cultivation of cereals.

However, the European Union, through the several reforms of its Common Agricultural Policy, increasingly promotes the return to more sustainable production systems, with the principle of

cross-compliance and the funding of agro-environmental measures. Beyond specific agronomic practices, such as soil cover and crop residue management, it encourages on-site landscape management and multi-functionality of agricultural areas.

Organic farming and conservation agriculture are two examples of such sustainable production systems. Driven by the increased awareness of the impacts of agriculture on health and the environment, organic farming is characterised by the importation of organic inputs such as manures and composts, recycling of on-farm organic matter, and well-designed crop rotations (including cover crops and perennial forages). It is also heavily reliant on tillage for weed control, even more than conventional systems, as it does not allow the use of herbicides. Most of EU regions currently show very low percentages of organic farming. The EU average in 2011 was 5.4% of the Utilised Agricultural Area, although Austria stood at 18%, at Italy 8% and Spain at almost 7%.

Primarily motivated by reductions in the operating cost of machinery, fuel and labour, conservation agriculture consists in the reduction of field operations, mainly through the reduction or suppression of tillage operations, the development of crop rotations, and the maintenance of soil covers. Currently, there are some 1.3 million hectares of arable cropland under conservation agriculture in Europe, mainly in Spain, France, Finland, UK, Italy, Portugal and Switzerland. Perennial crops further contribute up to 1 million hectares consisting of olive and other fruit trees.

Agroforestry is an integrated system that positively affects SWR capacity. It consists in the production of livestock or food crops on land that also grows trees, inside parcels or on the boundaries, for timber, firewood or other tree products (CIRCLE-2, 2013) (IPCC, 2007). Agroforestry was previously not eligible for receiving CAP subsidies and was only recognised in the CAP through the introduction of the Rural Development Policy in 2006 (EURAF). Since then, this practice has been extended in Europe. During the CAP program 2007-2013, 19 out of 88 programs involve agroforestry measures, representing 60,000 ha in seven Member States (Szedlak, 2012). At European scale, the potential spread of agroforestry systems could reach up to 65 million of hectares, i.e. 40% of arable lands in Europe (Palma, 2006) (Hamon, Dupraz, & Liagre, 2009).

Figure 21 illustrates the implementation of predominant type of practices (tilling, amendment, residue management and grazing) across the EU. This map is used in Chapter 4 to estimate the combined impact of agricultural practices on maximum soil water contents in the EU, through the impact on the key soil parameters such as the BD and OM, summarised in Table 7. The map is based on a dataset which is derived using CORINE and LUCAS datasets and enriched by the type and intensity of agricultural practices, hence consistent with the previously elaborated land use changes and expanding more in details regarding the arable and grass land. Nitrogen application was selected as an appropriate indicator for the intensity of arable land.

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51 www.ecaf.org/index.php?option=com_content&task=view&id=53&Itemid=52
Table 7: Impact of agricultural practices on bulk density (BD) and organic matter (OM)

<table>
<thead>
<tr>
<th>Agricultural practice</th>
<th>Intensity</th>
<th>Changes in BD</th>
<th>Changes in OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composting ^52</td>
<td>Moderate arable</td>
<td>-10% (±2%)</td>
<td>+85% (±8%)</td>
</tr>
<tr>
<td>Grazing ^53</td>
<td>Extensive grassland</td>
<td>+8% (±2%)</td>
<td>+20% (±3%)</td>
</tr>
<tr>
<td>Grazing ^54</td>
<td>Intensive grassland</td>
<td>+17% (±3%)</td>
<td>+35% (±5%)</td>
</tr>
<tr>
<td>Tillage ^55</td>
<td>Intensive arable</td>
<td>-10% (±2%)</td>
<td>-12% (±2%)</td>
</tr>
<tr>
<td>Crop residue management ^56</td>
<td>Extensive arable</td>
<td>-15% (±3%)</td>
<td>+20% (±3%)</td>
</tr>
</tbody>
</table>

Figure 21: Reference map of the agricultural practices in 2000 derived from the agricultural land use intensity dataset (including arable land and grassland)

Because of their specific combination of practices, different farming systems and levels of intensity will have different impacts on the parameters of SWR capacity. The following sections highlight, where possible, the extent of the implementation of each of these practices in the EU and how they are likely to influence SWR capacity, in particular:

- what are the plants cultivated i.e. how much water they require and at which moment during the year and whether they cover the soil throughout the year;
- how the soil is managed, i.e. how many field operations are planned, whether the soil is tilled, residues are conserved, crop rotations are implemented, etc., as this influences soil structure and the content in organic matter, which binds water to the soil;
- how water is managed, i.e. whether or not the land is irrigated, and drained, and;
- how the landscape more broadly is managed, as features of the landscape may help retain water or provide barriers to runoff.

Note that beyond the expected impacts of different practices, the adequacy between the management techniques and the specific environment where they are applied is critical in the impact of agriculture on SWR capacity.

### 3.2.2 Choice of plant species

In Europe, the most cultivated crops are cereals (wheat, barley, grain maize and corn cob mix), root crops (sugar beets), vegetables (tomatoes) as well as oilseeds (rape and turnip rape, sunflowers), grapes and olives. Rye also occupies large areas in Eastern Europe (e.g. 16.3% of cropland in Poland in 2009), as well as in Germany and Spain.

Plant management and the choice of crops influence how much and when crops need water, i.e. how much they can take advantage of soil water. This depends inherently on crop needs and the timing of such needs, as well as on the associated soil management and irrigation practices. Choosing a crop species and a variety adapted to the climate is important to maximise the use of soil water and reduce abstractions from surface water bodies or from the aquifer. Indeed, crops differ both in term of water requirements and total growing period. Barley and wheat require for instance about 450-650 mm of water during the growing season. This is less than sunflowers (600-1000 mm) and maize (500-800), rather equivalent to potatoes (500-700 mm), but twice as much as ryegrass (about 220 mm) and more than most legumes (beans and peas between 300-500). The alfalfa legume is a very high water user, as it requires between 800 and 1600 mm of water per growing season (FAO, 1986). Yet, its predominant taproot system is very deep, which allows exploring zones that other plants could not reach, and this plant is also amongst the most productive legumes (it produces the greatest amount of forage protein per unit) (Huyghe, 2003), which makes its water use relatively efficient compared to other legumes (Putnam et al., 2001). A key step towards optimising the use of water is selecting those crop varieties that have a water demand consistent with local soil and climate conditions.

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Where the choice of plant species is limited, modifying the planting and harvesting dates to avoid periods in which water is scarce, or ensuring that the timing of fragile stages of the crop development does not coincide with drought periods is a sound strategy. This has been investigated for several crops such as sunflower (Barros et al., 2004, Anastasi et al., 2000, Gimeno et al., 1989) but the potential of such adjustments could not be quantified at the EU level. It is, however, expected to remain marginal, as sowing and planting times are usually in line with plant requirements.

Beyond the optimised use of soil water, the type of crops can also be important to increase infiltration and prevent run-off generation through its influence on soil cover and structural stability. The establishment of winter cereals in late autumn and the late-harvested crop enhance soil degradation and surface run off in the fields (Palmer and Smith, 2013). Maize for instance raises particular concerns, because the soil stays bare before and after the crop is harvested, in addition to leave strips of bare soil between cultivated rows in the growing season. Its cultivated areas significantly increased since the boom in the use of biomass for energy, as in the UK, where areas cultivated with maize have risen from 1,400 hectares to 160,000 since 1970 and where agriculture is now increasingly pointed at as the responsible of flooding events. Where possible, replacing row crops with perennial/permanent crops improves soil cover and structure, with a positive impact on infiltration (Poláková et al. 2013) and downstream flooding potential. Some forages also have a positive impact on soils, such as alfalfa for instance. Because of its dense canopy and taproot system, particularly helps stabilise the soil, reduce erosion, and improve soil structure, with subsequent impacts on maximum soil water content. It is already used for long and short term crop rotations as a leguminous head of rotation for 2 or 3 years in France, Poland and Italy (BIO, 2010b). Although it is a high water user, it could be further introduced as a cover crop in crop rotations to improve soil structure for the following crops.

In agroforestry systems, planting trees in arable plots increases soil organic matter, particularly carbon sequestration, and the root system prevent soil from erosion (INRA, 2013; Oelbermann & Voroney, 2004; Frelih-Larsen, Leipprand, Naumann, & Beucher, 2008). The impact of agroforestry on SWR capacity could, however, not be quantified. Agroforestry systems also optimize the use of soil water since standing trees draw deep water whereas crops hold superficial water (INRA, 2013), although there might be a tree-crop competition for water in dry areas leading to water stress and low crop yields (Schroeder, 1995). They can be implemented in all crop systems, provided that tree density is adjusted to crop shadow requirements.

58 www.theguardian.com/commentisfree/2014/feb/17/farmers-uk-flood-maize-soil-protection
59 In the large and intensely agricultural Raccoon River watershed in Iowa, Schilling et al. (2013) showed for instance that converting half of agricultural land to perennial vegetation or extended rotations (and leaving the remaining area in cropland) could have major effects on reducing downstream flooding potential.
3.2.3 Soil management

Soil management practices influence soils structure (including formation of aggregates and pores and compaction), and determine whether or not a crust is formed at the surface (that prevents infiltration), whether soil is left bare, and how the soil binds water through soil organic matter. They also greatly influence soil biodiversity.

3.2.3.1 Field operations and use of heavy machinery

The increasing use of heavy machinery and the multiplication of field operations in agriculture in response to increased mechanisation is recognised as the main cause of soil compaction, beyond the effect of agronomic practices. Structural damages may occur both in the topsoil and the subsoil, possibly down to 50 cm (The Research Council of Norway, 2011). This may disrupt the capacity of soil to infiltrate water, along with the increased risk of run off, and impedes the movement of water down to the water table, resulting in possible logging (see section 2.1.1). When the risk of compaction extends to the subsoil, down to 30 cm, soils are compacted to a depth that cannot be removed by conventional tillage. It is usually the case with heavy machines with axle loads exceeding 10 tons or with loaded combines and manure tankers which commonly weigh 20 to 30 tons (Wolkowski and Lowery). This requires subsoiling, which is an expansive practice and usually requires a substantial return in crop yields to be justified. This may lead to the permanent compaction of agricultural soils, in particular when driving on wet soils. Compaction may also occur from the substantial transformation of the physical characteristics of a plot, such as during the field preparation and levelling in the Pênedès vineyards [see case study n° 22 in Annex 1].

The issue of compaction is all the more problematic as the weight and size of the machinery have increased significantly during the past ten years. There is no sign that this trend will not continue. It is also expected to take an increasing importance in the near future, in the context of a changing climate, which is projected to cause more precipitations in spring and autumn, when most farming operations occur. As the use of machinery is necessary in most EU farming systems, mitigation options should be implemented in order to prevent or limit compaction as much as possible. Although it allows relieving some pressure from heavy loads, the option of using wider tires and the use of duals or flotation tires – often encouraging field operations on wetter soils - is not that efficient, as it will often fail at compensating the actual load and the compaction effect of deep layers will be further distributed over greater soil volumes. Tandem axles will help reduce soil surface compaction and compact less area than dual systems, but the issue of deep compaction remains. A more sustainable option rather consists in better taking into account environmental conditions before driving heavy machinery where possible. This means, concretely, avoiding whenever possible driving on wet soils or more generally on soils with water content above the field capacity, especially in clay soils and sandy soils which are prone to compaction. This is not easy to promote in practice, since farmers are particularly concerned by timely filed operations in order to avoid large yields reduction, for instance from delayed planting, or lower quality in case of late harvest. However, even delaying an operation from the morning to the afternoon for instance can make a difference in terms of drying of the soil. Other options include ensuring the tractor is properly balanced, avoiding oversized equipment, ensuring the maintenance of equipment and in particular ensuring that the soil-engaging tools
are sharp in the case of tillage. Limiting load when operating under wet conditions can also make a difference. It can consist for instance in partially filling the grain or manure tank. Similarly, mitigation can also include reducing the frequency of field operations.

In comparison, compaction pressure from overgrazing is negligible at the EU scale, although it could not be properly quantified. It can, however, be a worrying issue locally, as in the UK where it has been directly related to a number of floods that threatened British cities from York to Shrewsbury in 2000. Optimising grazing intensity, length and timing on grassland and/or applying the rotational grazing allow grassland species after being well-grazed to regrow, thus reducing soil erosion and maintaining soil C sequestration (Poláková et al., 2013). In Wales for instance, where soils can be shallow and little permeable, excluding sheep from vulnerable plots and planting trees instead drastically decreased run-off generation compared to the adjacent grazed sites (about -78%) (McIntyre, 2012).

### 3.2.3.2 Tillage

Many of the regions in EU–27 are implementing more than 60% of conventional tillage out of total arable land. The soil management practice of reduced tillage is not extensively undertaken although some regions like in Cyprus, Halle region in Germany and Severoiztochen region in Bulgaria are implementing more than 60% of reduced tillage out of total arable land. The EU-27 average of reduced tillage implementation out of total arable land is approximately 18% and for zero tillage is 3%. In the very short term, tillage may have positive effects on SWR capacity, by decreasing soil bulk density and increasing porosity. However, as it destroys the continuity of macropores and disturbs soil structure, natural processes (e.g. precipitation) rapidly reverse this phenomenon (Strudley et al., 2008). Rainfall on freshly tilled soils results in the formation of a thin but dense crust (Green et al., 2003), that reduces infiltration. This may lead to the need to till after every rain event because of the increased formation of a crust. Tillage is also known to disturb soil macrofauna, in particular earthworms’ populations through mechanical action or indirectly through the disturbance of the soil matrix (Binet et al., 1997; Paoletti et al., 1998; Chan, 2001 in Lamandé et al., 2003), and to accelerate the loss of organic matter, with knock-on effects on reducing SWR capacity (Zhou et al., 2008) (Annex 2).

In comparison, conservation tillage (including no-tillage or reduced tillage) usually preserves soil structure, which is less heterogeneous due to the absence of both incorporated residues and soil displacement and fragmentation during tillage. They increase the presence of crop residues on the soil surface (no incorporation or removal) and therefore tend to increase soil cover, C stocks and soil cohesion. As a result, conservation systems increase the amount of water stable aggregates (Keretsz et al., 2010) and increases macropores connectivity, namely through the action of earthworms, which increases in turn soil water infiltration (Soane et al., 2012; Green et al., 2003) [see also Case studies n°3, 4, 5 and 6 in Annex 1]. Reduced runoff after adoption of conservation-tillage are widely observed and are of particular importance in south-western
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Europe (Soane, 2012). For instance, for maize cropping, runoff may be reduced by between 30 and 100% in conservation-tilled plots compared to conventional management, where the plots are usually ploughed in the autumn and spring (reviewed in O’Connell et al., 2007). This was also observed in Hungary in experimental plots near the lake Balaton [see case study n°4 in Annex 1]. Run-off observed in conservation tillage plots corresponded to 32% of the runoff observed on conventional plots. Furthermore, the Hungarian case shows that conservation tillage also guarantees a higher water storage (+ 8.8%) in the upper 20 cm, which may however be progressively reduced and even reversed in the subsoil. Reduced tillage has been shown to present benefits over no tillage, although they are less substantial. In Spain, run off from reduced-tilled plots represented about 80% of run off from the non-tilled soil. It was also slightly more effective in rainfall capture and allowed a reduction in the annual irrigation water need of the tree plantations of about 6-9% (Abrisqueta et al., 2007). Despite the advantages of conservation tillage for soil water retention, environmental trade-offs lie in the increased use of herbicides, which is often associated with these practices for weed control. Technically, the use of pesticides could, however, be reduced through e.g. appropriate rotations and use of cover crops (Melander et al., 2013).

Experienced farmers know how to minimise the negative consequences of tillage through careful consideration of the timing of tillage, equipment operation, soil conditions, crop rotation and possible combination with catch crop [see case study n° 9 in Annex 1] in which tillage practices are applied. Furthermore, the importation of organic inputs such as manures and composts and the recycling of on-farm organic matter tend to offset the negative influences of tillage on soil structure and organic matter. As for the negative impact of tillage on slopes potentially leading to substantial water run-off, it can be mitigated to a certain extent with contour tillage, although from a certain rainfall intensity, depending on local conditions, it may become ineffective in reducing water erosion (De Alba and Barbero, 2007).

3.2.3.3 Monoculture vs. crop rotation

Crop rotations consist in growing different crop types, cultivated on the same field consecutively, and alternated with fallows period. It is widely undertaken in most of the EU-27 regions, as the EU-27 average of crop rotation implementation out of total arable land is approximately 86%. Hundreds of various crop rotations exist throughout the European Union today. They usually include successions of temporary grasslands (which clean the soil from the residues of preceding crops), legumes (which contribute to maintaining soil fertility and increase the amount of available nitrogen by fixing atmospheric nitrogen) and cash crops. Although the choice of crop rotation is driven by the intended outputs in terms of agricultural commodities, several factors will influence the choice of a given crop rotation such as climate conditions, soil properties and water availability. Under continental climate (Eastern Germany, Poland, Czech Republic, Hungary, Slovakia, Austria and Romania), crop rotations may include a sequence of potato and beets, as well as cereals. By contrast, under oceanic climate (Ireland, the UK, the Netherlands, Belgium, Denmark, most of France, western Germany and the oceanic coast of Spain) crop rotation include relatively weak but high yielding varieties, fruits and horticultural species. Finally

62 Corresponding to average runoff volumes of 172.6 m³/ha vs. 453.8 m³/ha in conventional plots.
in countries with a prevailing Mediterranean climate, (Spain, Italy, South of France, Greece and Cyprus), permanent cultures like olive and fruit trees, as well as legumes like soybean, faba bean or alfalfa and maize are common (BIO, 2010).

Crop rotations usually play a role in SWR capacity through maintaining soil cover, improving soil structure and by causing a possible increase in soil organic matter, which insures better water absorption and holding capacity (and less pesticide leaching) (Poláková et al. 2013). Crop alternation has physical impacts on pore morphology and connectivity, as well as on the aggregate stability. This is particularly visible when comparing maize monoculture with a maize/grass rotation (1yr/3yrs) (Lamandé et al., 2003) [see case study n°2 in Annex 1]. In the latter, the development of more abundant and diverse populations of earthworms in particular has a beneficial impact on the continuity of soil porosity. However, the effectiveness of crop rotation in SWR capacity depends on the choice of plants in the rotation (e.g. addition of legumes or N-fixing crops to cereal rotation can target an increase in soil organic matter and thus in SWR), its duration and the associated practices (e.g. tillage, fertilisation, irrigation). For instance, intensive wheat rotation would have negative impacts by consistently reducing the biomass of all components of the soil food web compared to extensive rotation (De Vries, 2013). The most important effect of appropriate crop rotations is yet to guarantee that soil is not left bare for a certain period of time, thus decreasing evaporation and runoff, for instance through the cultivation of cover crops (see section 3.2.3.4).

3.2.3.4 Soil coverage, including residue management

As seen in section 2.2, soil coverage can significantly modify the capacity of soils to infiltrate water, as well as the conditions of evapotranspiration. Methods currently used in agriculture in the EU include cover crops, residue management, mulching, or even application of artificial covers.

Winter cover and catch crops, which are grown between successive plantings of a main crop, maintain soil cover and add C to soils, contributing to improving soil structure (Poláková et al. 2013). Cereal rye is an excellent winter cover crop because it rapidly produces a ground cover that holds soil in place against the forces of wind and water while requiring a limited amount of water. Strip cropping alternating e.g. hay and grain strips where forages are part of the rotation, or cereal crops alternated with soybean or corns, contribute to slowing down water flows and therefore reducing water erosion. Across slopes, it helps intercept water run-off, reducing soil losses by 50% when compared to up-down slope cropping. Winter cover crops are reported to be able to reduce surface run-off to up to 80% (O’Connell et al., 2007). The use of cover crops, associated to reduced tillage, was also shown to lead to water savings between 12 and 46% (depending on technique and type of crop) thanks to increased water infiltration (Reeves et al., 2005). However, these practices are still very undeveloped across Member States and remain an untapped potential63.

Similarly, according to the SMARTSOIL project63, most of the regions are barely implementing residue management with percentages lower than 20% out of total arable land and there is no

region with percentages higher than 60%. Consistent crop residue removal, recently fostered by the development of advanced biofuels (Kretschmer et al., 2013), negatively affects the minimum soil water content by progressively decreasing the soil cover. Ward et al. (2013) showed for instance that after three years of residue removal in a sandy soil in a Mediterranean-type environment, average ground cover in the subsequent summers (2011 and 2012) decreased from 78% to 51% (i.e. about -35%), and surface soil water contents decreased from 5.1% to 3.1% (i.e. -40%). Yet, today, above ground plant residues are increasingly taken off the field following the trends in the use of biomass for energy.

Furthermore, artificial cover has also proven to be efficient to preserve SWR capacity, through reduced evapotranspiration. This was demonstrated in Estonia, in afforested land, where soil water is a determining parameter for trees’ growth, based on the annual height-growth of populations of silver birches with soil coverage with polyethylene. This is now considered a potential tool for the faster afforestation of abandoned agricultural soils (Vares et al., 2001) [see also case study n°8 in Annex 1].

3.2.3.5 Amendment

In Europe, trend is to the decrease of soil organic matter content in croplands, due to intensive agricultural practices. In Belgium for instance, arable soils have lost 25% of their SOC reserve during the past three decades (Gobin et al., 2011). Soil organic matter can, however, be increased by the incorporation of crop residues in soils, manure application or other amendments. For instance, leaving straw from cereals in the field as a residue can double the effective organic carbon input to the soil. Yet, this fraction is essentially unstable. More efficient is the application of manure and compost64, which contribute to the more stable fraction of soil carbon that is humus. In particular, compost application has been proved to increase soil C content, especially within aggregates, thus preserving porosity and increasing the aggregate stability. Results from several experiments demonstrated that an additional 0.15 to 0.33% SOC content can be expected after 10 years of compost application at a rate of 10-15 t/ha, on loamy soils with initial carbon content of 1% (Cognon and Reheul, 2008; Sleutel et al., 2008) [see case study n° 7 in Annex 1]. However, a significant increase can only be realised in soils with low initial carbon contents. Results show that yearly compost applications are much more efficient than applications every 3 years, and that the higher the dose applied the higher the increase in SOC. Yet, in practice, doses are regulated by the maximum amount of nitrogen the plants can absorb (30t/ha/yr would already be too much). Because of the increase in SOC, porosity increases and the infiltration rate may increase 5 to 10 times compared to infiltration rate obtained in mineral fertilisation conditions (Figure 22). Runoff rate also decreases under relatively small compost application rates.

Furthermore, the capacity of soils to absorb water can be significantly increased, as compost can retain between 80 to 115 litres of water per ton (Cognon et al., 2008; Sleutel et al., 2008).

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64 Compost, which results from the controlled biological decomposition of organic material, is an excellent source of organic matter and is commonly used as a soil amendment. It can be made out of vegetables, fruit and garden waste (VFG compost), kitchen and catering waste, made out of prunings, branches, grass and leaf litter (green compost) or obtained from aerobically composted digestion residuals.
Moreover, the soil water content improved by 10-40 litres of water per m³ soil (at respectively 15 t and 45 t VFG-compost/ha/yr) in a loamy soil after 9 year application, compared to the application of mineral fertilisers. Although this result is important in term of maximum infiltration capacity, it is not as interesting in terms of plant available water as the difference in water content is mostly observed at near-saturation conditions.

Figure 22: Effect of amount and frequency of compost application on infiltration compared to mineral fertiliser (on a loamy soil)

Source: reported in Gobin et al., 2011

3.2.4 Water management

Irrigation

Irrigation is a commonly used technology to supplement crops with water in periods where soil water is not available due to lower precipitations, and/or warmer temperatures that increase evapotranspiration. This is particularly developed in Mediterranean countries, where it is a limiting factor of production. In the EU, around 33 % of freshwater abstraction ('blue' water) is used for agriculture (EEA, 2012a). However, large differences exist among MS, as up to 80 % of abstracted water in Mediterranean countries is used in the agricultural sector for irrigation (EEA, 2012e), whereas irrigation only accounts for 10 % of freshwater abstraction in Northern European countries. In addition, it is commonly highlighted that agriculture has a high consumptive use (i.e. most of the water does not go back to a water body after abstraction, although it is "recycled" through evapotranspiration). Management of pressures on water resources therefore must engage with agricultural water use. The Blueprint to safeguard Europe’s water resources (EC, 2012b) highlights in particular that over-abstraction is the second most common pressure on EU ecological status, partly due to over-allocation, and partly to illegal abstraction. Both are issues in particular in agriculture. In addition, irrigation increases salinity and sodicity, with negative effects on the ability of soil to retain water.

The effects of SWR capacity as to the need for irrigation are little investigated, and do not seem to be quantified in the literature. Yet, all reports that investigate better water management and/or water savings in agriculture underline the benefits of techniques that retain water in soils to reduce the impacts of irrigation (e.g. Scanlon et al., 2007, Power 2010, BIOIS, 2012). This is a
key challenge since the seasonality of irrigation often coincides with the period when water levels are the lowest and where the water demand from other sectors is the greatest (Hart et al., 2013).

In addition and quite importantly, the maximisation of soil water use helps ensure that water is used efficiently at the landscape scale. Indeed, irrigation efficiency is often pointed out as being an important target to save water in agriculture, but depending on implementation it may also have negative effects on other areas of the landscape and/or result in more water being used (e.g. if irrigated surfaces increase). An assessment at landscape scale is needed to take account of all ecosystem services that may indirectly be provided by ‘inefficient’ irrigation systems (Molden et al., 2009, BIOIS, 2012). For example, increased efficiency can reduce drainage outflows with negative impacts to connected water bodies (Molden et al., 2009).

Another aspect of irrigation is its influence, in turn, on SWR mechanisms, as irrigation often results in drastic and long-term changes in local hydrology. On the one hand, the presence of a regular supply of water can be seen as an opportunity since it supports biological processes (growth and decay of roots as well as soil biodiversity) (Murray and Grant, 2007), likely to enhance in turn mechanisms related to SWR capacity (see section 2.1.4 on soil biodiversity). On the other hand, when irrigation water is of poor quality, it may largely influence infiltration and the capacity of soils to hold water through the mobilisation of salts, which affects soil structure (see section 2.1.1). For instance, a soil of stable structure may originally have low sodicity and salinity. Irrigation with a saline water source (or saline groundwater accession), increases both salinity and sodicity. Winter rainfall or a change to high quality irrigation water leaches the salinity but a good deal of the sodicity remains. This soil now has a more unstable structure (Murray and Grant, 2007) [see also case study n°1 in Annex 1].

Drainage

Where too much water is present in soils, drainage is implemented to avoid soil water logging. It is especially implemented in Northern Europe, where lie the most poorly drained soils. Drainage helps manage artificially the level of the water table and therefore the degree of water saturation, by removing surface and sub-surface water from the fields. However, linear drainage structures, such as ditches at the border of fields, can also significantly increase peak flows by 30%, and accelerating runoff to streams. In winter, open ditches can also favour ground water exfiltration and increase outflows from rivers (Fiener et al., 2011).

3.2.5 Landscape management

At local scale, landscape features – such as hedgerows and buffer strips impact SWR capacity through the possibility to intercept and slow down water flows and/or to protect soils from wind erosion and high evaporation. At the catchment scale, reducing the size of natural land use patches could increase the amount of water that is retained and is made available for plants.

As shown in section 2.2, trees and woody vegetation can reduce run-off locally and contribute to more gradual water flows. In Wales for instance, a simulation suggested that the introduction of tree shelter belts optimally placed to the current land use could reduce peak flow by 29%

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65 http://eusoils.jrc.ec.europa.eu/projects/sinfo/7_4_5_en.htm
Buffer strips and grassed waterways also contribute to slowing down water, increasing infiltration or limiting peak flows. Note that even if these structures are more or less stable in space, their impact on SWR capacity may change in time, as the dormant vegetation is not as efficient on water flows in winter (Fiener and Auerswald, 2006). These structures are increasingly implemented in the EU, in response to water and biodiversity policies.

Reducing the size of natural land use patches could increase the amount of water that is retained and is made available for plants possibly by 25% over a catchment (Ludwig et al., 2005). An increased patchiness and an optimised patch arrangement indeed maximise the number of water transfers between patches of different hydrological behaviour, thereby reducing run-off generation at an agricultural catchment level. The effect of patchiness is particularly significant during summer, as the hydraulic properties of agricultural fields tend to be quite similar during winter. However, in arable landscapes where fields are shifted annually in a rotation, such optimisations might only be possible if arable fields are combined with permanently buffering land uses, like forest or grass buffers.

### 3.2.6 Discussion

The present analysis shows that the majority of practices associated with intensive farming have negative impacts on the key parameters of SWR capacity, such as soil structure, soil organic matter, soil cover, water content and soil biodiversity.

As demonstrated in the previous sections, they promote soil compaction and crusting, higher susceptibility to erosion, increased mineralisation of SOM, and loss of biodiversity. They are even shown to trigger substantial degradation of high quality soil structures, such as on well-drained high quality sand and coarse loamy soils (Palmer and Smith, 2013). These lead to decreased infiltration, with a degradation of maximum soil water contents and reduced winter recharge rates to aquifers. Because of the associated increase in run off, several authors raised concerns that intensification has led to increased flooding (Wheater, 2006; Evrard et al., 2007; Pinter et al., 2006; Bronstert et al., 2002; Pfister et al., 2004; Savenije HHG, 1995; Holman et al., 2003, Stevens et al., 2002, Boardman et al., 1994, Burt, 2001 in Wheater and Evans, 2009). The effects on runoff generation and local flooding of the intensification of agricultural practices have been demonstrated at the local scale. These effects are however less predictable over the course of the year than less intensive practices (Fiener and Auerswald, 2011). Surprisingly, no conclusive evidence on the impacts of intensive practices on floods at the catchment scale could be found (O’Connell et al. 2007; McIntyre et al., 2012; Schilling et al., 2013).

At the opposite of such systems, organic farming benefits from its practices in terms of soil cover, rotations, and management of organic matter, but is penalised by its heavy reliance on tillage. The impact of tillage is however mitigated compared to intensive systems as the other practices tend to increase the soil structural stability and to confine the possible impacts to parcels of smaller sizes. Conservation farming, which includes reduced tillage, represents the more balanced asset with regards to SWR capacity. Associated practices maximise the SWR functions of soil biodiversity, in particular through earthworms management which represent an excellent potential partner for humans in managing ecosystem services. Agroforestry is also expected to
benefits SWR capacity through better infiltration and higher maximum soil water contents by increasing soil organic matter while preventing erosion.

Yet, most farming systems across the EU are still oriented towards intensive practices. Conversion to more sustainable and integrated systems, although increasingly promoted, is still at its infancy. However, most recent trends, although timid, show a step to the right direction to be able to better preserve and maintain SWR capacity. In particular, the Common Agricultural Policy (CAP) participates to this improvement by affecting the location and type of crops grown, production intensity and addressing soil protection. While the CAP has been a powerful driver of intensification in the past, in particular, the GAEC specifically address soil protection, including soil erosion, soil organic matter, soil structure and protection of landscape features. Depending on how Member States decide to make use of the choices provided, the CAP reform 2014-2020 may enhance this trend since the share of direct payments subject to conditionality will increase, with a focus on crop diversification, the devotion of 5% of land to an ecological focus area, and the maintenance of permanent pasture. Moreover, up to 15% of the funds can be transferred between the 1st and the 2nd Pillar, which will potentially permit Member States to increase the support regarding agri-environmental measures, should they choose to do so.

3.3 Urbanisation patterns and opportunities for better SWR capacity

Several factors in the urban design can influence the impact of urban development on the natural water balance. Key factors of influence include the density of development (compactness, fragmentation), and the capacity of cities to infiltrate water (presence of green areas, permeable surfaces, capacity of urban drainage systems).

3.3.1 Density of development

Urban dwellers on average consume less land for living per capita than rural residents (EEA, 2010). In line with the European Spatial Development Perspective, which advocated the development of compact cities, researchers suggest compact cities are the best choice from an environmental point-of-view, as a greater area of surrounding natural landscape can be safeguarded (EC, 2012a). It is interesting to note that in residential areas, compact multi-storey stocks can present the same degree of sealing than single and semi-detached housing estate, although they host many more inhabitants (Figure 23). Much small-scale sealing may take place undetected by authorities, for instance through the gradual pavement of gardens as in Flanders (Belgium) and in Leeds (UK) but the accumulated impacts can be significant (Verbeek et al., 2011; Goddard et al., 2009; Perry and Nawaz, 2008; EC, 2012a) (see also section 3.3.2). Furthermore, with the development of commercial sites, transport infrastructure (roads) which are further developed in case of urban sprawl represent the greatest degree of soil sealing (Nuissl et al., 2009).
Because less land is taken in compact cities and is used more “efficiently”, large scale impacts of urban development on infiltration and runoff, and hence on water balance, are expected to be reduced. In this context, it has been shown that the density of development have more influence on long-term runoff than the underlying soil type. In the Woodlands, in the US, Yang and Li (2011) showed that, compared with original forest conditions, urbanisation of watershed would result in a greater runoff of 40 to 50% in case of high-density development compared to 90 to 100% in the scenario of low-density development. Likewise, aquifer recharge almost halved in the low-density scenario compared to high-density scenario [see case study n°18 in Annex 1]. Similarly, in the Mexico gulf, Brody et al. (2013) showed that more connected and concentrated urban development patterns lead to a reduction in observed flood damages compared to fragmented and low-density development patterns. Locally, the problems compact cities face from the reduced amount of green space can be minimised by removing unnecessary soil sealing and boosting and diversifying green infrastructure within cities (BfN, 2008).
However, the current trends are towards the development of low-density structures, which require more built-up areas per person. Over the past 20 years, the extent of built-up areas has indeed increased faster than population (EEA, 2010). The increasing living space per capita tends to counteract possible reductions in land consumption (Haase et al., 2013). It is therefore expected that by 2035 and in the context of European population decline, many more cities will have to cope with the problems of low-density settlements (EEA, 2010) and derelict land within their cities (Haase et al. 2012). The restoration of brownfields (land previously used for industrial purposes or some commercial uses) into green areas represents a key opportunity to improve SWR capacity within cities.

Despite higher land take, lower densities may relieve some environmental pressures by creating more opportunities for green space (EEA, 2010) than compact cities by e.g. regenerating brownfields (land previously used for industrial purposes or some commercial uses) (Lorance Rall & Haase, 2011).
3.3.2 Capacity of infiltration within the cities: green infrastructures, permeable materials and urban drainage capacity

Overall, in compact cities, water-related ecosystem services can be safeguarded through the concept of low impact development (LID), which consists in restoring the initial ability of urban sites to absorb storm water. For instance, this involves removing all unnecessary soil sealing, replacing complete pavement into permeable surfaces in yards, parks, along streets etc., and restoring urban green spaces which may provide areas within the built environment where infiltration and evapotranspiration can take place (Gill et al., 2007; Gill et al., 2008; Armson et al., 2013). This can be considered to mitigate the impact of ‘necessary’ urban development but also to prevent extensive small-scale sealing (e.g. progressive development of paved garden, individual car parks), which may take place undetected by authorities but which accumulated impacts can be significant. The example of Leeds, in the UK, shows that between 1971 and 2004, the small-scale but cumulative paving of residential gardens accounted for 3/4 of the 13% increase in impervious surfaces observed (although these residential garden only represent 9.5% of the area studied). This resulted in a 12% increase in annual average run-off over the period of the study [see case study n° 11 in Annex 1].

The use of permeable materials for pavements is increasingly used to mimic natural hydrology and cope with the shortcomings of traditional storm water management. Their hydrological benefits have been well documented for runoff volume and peak flow reduction. They highly contribute to reducing flood risk by postponing the occurrence of surface runoff peak generated, through continuous infiltration (Lin et al., 2013), even when they are developed at relatively small scale. For instance, the development of permeable car parks can significantly reduce the volume of storm water discharged during rainfall period. Experiences on permeable block-surfaced car parks and grass-concrete car parks show that run-off could be reduced by respectively 40% and 0-35%, compared with the performance of traditional impermeable surfaces, which discharge close to 100% runoff within the storm duration (Pratt et al., 1995; Smith, 1984) [see case study n° 12 in Annex 1]. Other initiatives show successful results, such as the experimental site of Rézé in France where porous pavements where developed on a 700m street section and where storm water volumes were reduced by 97% compared to a reference catchment with housing estate drained by conventional sewer systems (Legret and Colandini, 1999). The reduction in storm water volumes through better infiltration depends, however, on the underlying soil type and its drainage characteristics (Abbott and Comino-Mateos, 2003). The installation of permeable pavements is not suitable to soils with low drainage, unless they include an overflow system or under-drains. They are not suitable either to areas where large amounts of sand or sediments may block the pores of the material. In any case, the long term behaviour of the infiltration

66 Smith (1984) carried out a comparison of water runoff occurring in two different surfaces on two similar car-parking areas in the City of Dayton, Ohio. One car park was surfaced with grass-concrete and equipped with only one gully to receive surface runoff; and the second was surfaced with impermeable asphalt and drained via a number of gullies. The observations showed that runoff volume from the grass-concrete car park into the drain ranged from 0-35% of the runoff from the asphalt surface (mean value 10% for eleven storms; no runoff at all from four of the eleven).
capacity of such systems depends largely on street maintenance, in order to counteract clogging (Stenmark, 1995).

Locally, the impact of grass and trees on run off reduction can be substantial, both in winter and in summer (e.g. about – 60% according to Armson et al. (2013)⁶⁷). At the scale of a residential area, Gill et al. (2008) showed that increasing green cover by 10% could reduce runoff by about 5%, in the case of an extreme rainfall event, and that adding green roofs to all the buildings in town centres, retail and high-density residential areas also significantly reduces runoff from these areas.

The percentage of impervious surfaces is only one factor amongst others that modify natural water balance in urban areas, including increasing flood risk. For instance, although about 60% only of the area of Copenhagen is sealed (which is less than in many other cities), extremely heavy rainfall in Copenhagen (more than 150 mm rain within 2 hour) in 2011 caused widespread flooding and damage when the sewers could not cope with the huge volume of water. Insurance damages alone were estimated at €650–700 million (EEA, 2013). Surface urban drainage systems play a major role in flood control, by allowing storm water to be collected, infiltrated and/or redirected to river streams or infiltration areas. In Copenhagen, a long-term plan⁶⁸ has been suggested to process the majority of the surface rainwater via a system of small canals that can divert the water, either into streams or areas where it can be stored until being processed into the sewage system (EEA, 2012d). The Copenhagen Climate Adaptation Plan shows that the implementation of a Sustainable Urban Drainage System (SUDS) combined to backwater valves and surface adaptation (redirecting of water) could provide a net saving of 7 499 million DDK (i.e. 1 005 million EUR) out of the 15 552 million DDK (i.e. 2 084 million EUR) of total costs of damages for society estimated without taking any actions.

However, drainage systems may have various impacts on runoff volumes, depending on whether they exploit the natural ability of open ground to infiltrate water. For instance, in the Woodlands (USA), open grassy swales (ditches) allow a greater volume of water to infiltrate and evaporate before out-flowing to streams than conventional piping drainage (Yang and Li, 2011). They also slow down the response to heavy rainfall events. Conventional drainage may indeed be more vulnerable to rainfall exceeding the capacity of drainage systems and therefore to flash flood (EC, 2012a), in particular in the context of a changing climate.

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⁶⁷ Armson et al. (2013) investigated the role of trees and grass in reducing surface water runoff in urban areas by measuring and comparing the amount of rainwater entering a drainage system in three adjacent 3x3 metre plots covered by asphalt, trees and grass respectively. They showed that the highest surface runoff was from the asphalt plots, where an average of 62% of total winter rainfall and 53% of total summer rainfall was collected in the drains (the rest of the water falling on the asphalt would have evaporated or remained in small puddles). Rainwater collected from the tree plots suggested that these plots reduced surface runoff by 58% and 62% respectively during winter and summer periods when compared with the plots completely sealed with asphalt. Lastly, the grass plots absorbed most of the rainfall, with the average runoff measuring less than 1% of the total rainfall. Grass cover therefore helps reduce the risk of flooding in urban areas.

⁶⁸ Copenhagen Climate Adaptation Plan.
3.4 Climate change

As seen in section 2.4, climate influences the recharge of the soil water content and replenishment of groundwater bodies, through changes in precipitation and temperature.

Past, current and future trends highlighted below are based on the compilation and processing of the results of largely acknowledged EU-tailored models (see Annex 3 for further details). Past and current climate trends for the period 2000-2010 demonstrate evidence of increased precipitation in most of the EU countries (10 to 20 mm/year), with decreased precipitation trends (-10 to -20 mm/year) in Scandinavia (Sweden and Finland), Iberian Peninsula (Portugal and Spain) and Cyprus. Future precipitation are projected to keep increasing in most of the EU and more extreme intensities are expected in Italy, Malta, France and Portugal. Decreasing precipitation are however expected in Greece, Cyprus and Bulgaria. Where increases in precipitations will occur, they will contribute to increasing soil water content and groundwater replenishment as long as soils can absorb the increased supply of water, i.e. in soils with high maximum water content and/or a high cumulative infiltration capacity. Yet, as precipitation are also likely to occur more randomly and with a higher intensity, large amounts of the water supplied may, in practice, end up running-off and be lost for the soil.

Climate change will also have a key effect on evapotranspiration, and therefore on soil water content, through increased temperatures. Between 2000 and 2010, increases in temperatures could be observed in Southern countries, up to 0.13°C in Cyprus, Greece, Italy, Malta, Spain. On the basis of the ECHAM5 13 datasets (see Annex 3 for details) and the analysis of past trends, a mild increasing trend of +0.12 °C between 2010-2020 can be observed. Further increases will be observed in the next decades in all EU countries (e.g. + 0.1 to 0.2°C between 2020 and 2030). Some comprehensive models exist and show regional or national variability of climatic conditions for different climate change scenarios [see case study n° 21 in Annex 1]. These trends will result in higher water-demand from water, causing expected increases in crop irrigation requirements globally by between 5 and 20 per cent, or possibly more, by the 2070’s or 2080’s (Döll, 2002 and Fischer et al., 2007, in Gornall et al., 2010; Climator project70). The impact of increasing water requirements is expected to be particularly acute in southern Europe, where projections indicate a decreasing suitability for rain-fed agriculture71. Plant water stress will be particularly occurring in areas with superficial soils and unfavourable soil water conditions before the flowering stage. However, in some cases, a shortening of the vegetative cycle for some crops may decrease the duration of water demand in the long term: for instance, a cycle shortening of traditional varieties, provided constant sowing dates, could decrease water needs of summer crops (e.g. maize) in Spain by 20% (Rey et al., 2011).

69 Note: The drought trends are based not only on the precipitation trends: it includes the projected changes in the SWR combined with the precipitation and temperature trends. This is nonlinear combination of factors affecting the drought projections. Therefore, Mediterranean regions show drier projections. Simple increase of precipitation is projected, and especially precipitation intensities (more extreme climate events). However this does not mean that by increased precipitation (and intensities) the projected drier conditions will be affected, due to the role of the other factors, SWR and increased temperature in Mediterranean countries.

70 Climator Project: w3.avignon.inra.fr/projet_climator/

Furthermore, climate change may indirectly affect the maximum soil water content and percolation of water down to the water table, through its impacts on soil structure (e.g. wetting/drying cycles) and the degradation of organic matter. In the longer term, and even more indirectly, climate change is expected to modify land uses and vegetation patterns through changes in the suitability of locations.

In the long-run, these dynamics are projected to result in significant, although non-homogeneous and non-linear, changes in soil water content across the EU, associated to increases in the intensity and frequency of floods and drought events [see case study n°23 in Annex 1]. These trends are estimated in Chapter 4. Note, however, that although climate change is expected to have substantial impact on low stream flows (Hamdi et al., 2010), the impact of increased impervious cover in urban areas may be more substantial on flooding than the higher rainfall projected under climate change scenarios (impact on summer flooding can be four times greater) (EC, 2012a).

### 3.5 Synthesis and discussion

Climate change, land use changes and management practices impact positively or negatively SWR capacity, by modifying some of the key parameters described in Chapter 2. The main drivers of SWR capacity identified are listed in Table 8.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Sub category</th>
<th>Key drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use trends</td>
<td>Land use change</td>
<td>Conversions to cropland Conversions to urban areas Natural revegetation and afforestation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farming practices</td>
<td>Landscape management</td>
<td>Preservation or restoration of hedgerows, wetlands, etc.</td>
</tr>
<tr>
<td></td>
<td>Plant management</td>
<td>Plant species</td>
</tr>
<tr>
<td></td>
<td>Soil management</td>
<td>Fields operations requiring the use of heavy machinery Tillage; Crop rotation Soil cover and residue management Amendment (organic and mineral)</td>
</tr>
<tr>
<td></td>
<td>Water management</td>
<td>Irrigation; Drainage</td>
</tr>
<tr>
<td>Urban development</td>
<td>Soil sealing</td>
<td>Location</td>
</tr>
<tr>
<td></td>
<td>Urban sprawl</td>
<td>Density of development Capacity of infiltration (incl. drainage)</td>
</tr>
<tr>
<td>Climate change</td>
<td>Occurrence of extreme events</td>
<td>Increases in temperature Uneven and intense precipitation</td>
</tr>
</tbody>
</table>

The effect of global warming on SOC stocks is still debated, because of the complex interactions between multiple factors (environmental conditions, microbial communities, physical state of SOC within the soil) (e.g. Schmidt et al., 2012). Climate change was however shown to have an impact primarily on surface carbon stocks, compared to deeper soil layers (Albaladejo et al., 2013).
Land use changes

Land use influences the capacity of soils to capture, store and release water, through the type of associated soil cover but also through the modification of biophysical parameters within the soil profile (soil organic matter content, soil structure, biodiversity, etc.). Forest and agricultural areas, through their large geographical coverage, are instrumental to influence overall trends in SWR capacity in the EU. While forests and grasslands play a crucial role for SWR capacity, urban areas have demonstrated prominent impacts on water runoff and therefore on damages related to flooding events or low groundwater replenishment. Similarly, with the current cultivation patterns, soils in cultivated areas generally have lower SWR capacity than semi-natural areas. The pattern and geographical coverage of cities, infrastructures, agricultural land, and natural areas within a watershed further influence infiltration properties, evapotranspiration rates, and runoff patterns.

Changes in land use, in particular the transition to agricultural and urban land, result in important mutations of soil surface physio properties and evapotranspiration demand. Although past trends were particularly detrimental to the SWR capacity through the decline of forests and grasslands and the increase in crop and urban areas, most recent trends and projected future trends are less alarming. They indeed tend towards afforestation and a slower pace of urbanisation.

The full impact of land use changes has not been witnessed in many areas yet, and the effects of remediation to reverse impacts will be observed mostly in the long-run. Because land use changes are long-term modifications that are difficult to reverse, it is all the more important to understand their impacts on the different dimensions of SWR capacity, and in particular on the risks of floods, to consider them early in planning processes.

Besides the afforestation of abandoned agricultural land, which significant benefits remain mostly local, there are limited opportunities to proactively change land uses to preserve or improve SWR capacity. Great potential lies, however, in preserving valuable areas, such as forests, grasslands and (semi-) natural areas as part of a wider landscape mosaic to deliver regulating ecosystem services alongside other land uses. This is the concept of Green infrastructures, recently promoted through the EU 2013 Green Infrastructure Strategy. Today, spatial planning in urban areas still fail, usually, at actively considering the connections and interactions with adjacent landscapes, which is often rather considered as a potential area for future expansion. At the planning stage, better consideration could be made of the vulnerability of different locations intended for urban development to the risks related to decreased SWR capacity. Action could be taken to prevent building development in flood basins and discourage any construction or works likely to form an obstacle to the natural flow of waterways that cannot be justified by the protection of densely populated areas. Wetlands could also be better safeguarded, in particular in agricultural areas, where they slow down run-off and therefore phenomenon of erosion.

Within each land use type, there can be large differences in management practices, with variable impacts on SWR capacity.
Agricultural practices

Farming practices, through different levels of intensity in plant, soil and water management can significantly influence SWR capacity by modifying the soil parameters and subsurface conditions. The choice of crops and rotations is likely to impact SWR capacity through their water requirements but also through their impacts on soil structure and soil organic matter. Some crops are particularly detrimental to the infiltration and storage of water, such as maize, which is a high water user in summer when water resources are the scarcest, and which leaves the soil bare before planting and after harvest. In general, the establishment of winter cereals in late autumn and the late-harvested crop such as maize enhance soil degradation and surface run off in the fields. Grassland and most legumes play a beneficial role in SWR capacity. Rye grass and peas or beans are interesting for their low water demand and their soil cover, which allows limiting impacts of precipitations at the soil surface while preserving the soil water content. Other plants, like alfalfa (which is a high quality forage), and agroforestry system are interesting for their additional structuring effects on the soils. These may namely represent good opportunities to increase SWR capacity through their integration into extensive crop rotations.

Within soil management practices, the use of heavy machinery, which many farming systems rely on for the field operations, is responsible for extensive damages to soil structure across the EU, with increasing risks of permanent compaction. Unless substantial (and rather unlikely) conversions towards the principles of conservation agriculture occur in the short run, actions to mitigate the impact of machinery are to be taken for preserving the capacity of soils to infiltrate water. This includes avoiding driving on wet soils whenever possible or more generally on soils with water content above the field capacity, ensuring the tractor is properly balanced, avoiding oversized equipment, ensuring the maintenance of equipment or limiting the load. In comparison, grazing intensity has more marginal impacts on compaction and associated run off, although hotspots exist, as observed in the UK. Although tillage tends to increase infiltration and water storage in the short run by reducing the bulk density in the top soil, it may also favor chronic crusting, especially in clay soils, along with a decrease in soil biodiversity and the faster mineralisation of SOM. Conservation tillage is a sustainable response to preserve soil structure while increasing water infiltration and storage in the long run, although it is often associated with increased use of pesticides to compensate lower weed control. To a lesser extent, the better knowledge of appropriate conditions for tillage is another alternative which allows reducing its negative impact on soil structure and therefore on run-off. Contour tillage for instance allows mitigating the detrimental effect of the combination of tillage and slope. Regular organic amendment is beneficial to the infiltration of water and groundwater recharge compared to mineral fertilisers. However, its impact on soil water content is relatively negligible. The effect will be all the more significant that the soil initially contains low amount of carbon. Cover/catch crops and residue management which protect soil surfaces, increase SOM and biodiversity represent a still relatively untapped potential in the EU. The development of residue management however is competing with the use of residues for food production and increasingly for advanced production of bioenergies. Furthermore, maintaining landscape natural features like hedges, is a promising approach to slow down water flows and optimise the delivery of associated ecosystem services (e.g. flood regulation, erosion). Irrigation and drainage can artificially modify the soil water content to regulate water stress and the saturation of soils
respectively, however, with associated environmental impacts (e.g. on soil quality after irrigation with water of poor quality).

The majority of practices associated with intensive farming have negative impacts on the key parameters of SWR capacity, such as soil structure, soil organic matter, soil cover, water content and soil biodiversity, by favouring soil compaction and crusting, higher susceptibility to erosion, and increased mineralisation of SOM. They lead to higher run off, with debated risks of floods, and to reduced infiltration, with a decrease in maximum soil water contents in the long run and a likely increase in irrigation (which could not be quantified). At the opposite of such systems, organic farming benefits from its practices in terms of soil cover, rotations, and management of organic matter. Its heavy reliance on tillage is relatively mitigated as the other practices tend to increase the soil structural stability and to confine the possible impacts to parcels of smaller sizes. Conservation farming represents the more balanced asset with regards to SWR capacity. Most farming systems across the EU are still oriented towards intensive practices and the conversion to more sustainable and integrated systems, although increasingly promoted, is still at its infancy. However, most recent trends, although timid, show a step to the right direction to be able to better preserve and maintain SWR capacity.

It is to be seen how the Common Agricultural Policy (CAP) is contributing to this improvement of SWR, by affecting farming intensity and enhancing the implementation of practices that positively affects SWR, as its implementation depends on options selected by Member States and the actual behaviour of individual agents. In particular, the GAEC specifically address soil protection, including soil erosion, soil organic matter, soil structure and protection of landscape features. Under the new CAP for 2014-2020 the share of direct payments subject to conditionality has increased, with a focus on crop diversification, the devotion of land to an ecological focus and the maintenance of permanent pastures.

Management of urban areas

Although they represent less than 10% of EU territory, urban areas have strong impacts on SWR capacity. Urban development and building activities in general decreases infiltration locally and increases total runoff volume through land take and soil sealing, increasing the risks of floods and to a lesser extent, the low replenishment of groundwater bodies. Although the location of urbanisation is essential, several other factors may contribute to the importance of impacts of urban areas. The most important include the density of urbanisation, and the capacity of infiltration within cities. Several good practices can be implemented to mitigate the negative impacts of urban development on SWR capacity. Although efforts should tend towards compact cities, in order to limit land take and its impacts on SWR capacity, it is important to maintain and manage green areas within cities, as they can increase the temporary water storage during heavy precipitation and provide flood retention rooms (e.g. sport fields, parks). Besides the introduction of green roofs in new buildings, it is generally unlikely to be able to create green areas after urban development occurred. However, the restoration of brownfields or other derelict land into green areas offers promising opportunities. If derelict land is rather reused for building purposes, it allows at least reducing further conversion of grassland and arable land at the fringe of cities. Where hard surfaces are necessary (e.g. car parks, roads), another interesting opportunity is offered by the increasing development of permeable pavements. The development of Sustainable Drainage systems allow further mitigating the impact of sealing by slowing down the
response to heavy rainfall events, which allows dealing with the issue of overflow of conventional drainage systems with insufficient capacity.

These opportunities to maintain or enhance SWR capacity are all the more important in the context of climate change. Reduced infiltration due to uneven and intense precipitations are expected to occur along with higher risks of floods, despite the increase in precipitation in some regions. Furthermore, changes in temperatures are likely to increase the need for irrigation in rural areas, and the demand for water in urbanised areas, with subsequent impacts on water shortages.
Chapter 4  Trends in soil water retention capacity

This chapter aims to present the trends in SWR capacity in the EU for the period 2000-2030. It explores the effects of each key driver on SWR capacity, such as land cover land use changes, urbanisation, agricultural practices and climate trends. The “maximum soil water content”, i.e. the inherent capacity of soil to contain water, is used here as a proxy for the SWR capacity. Although these trends provide interesting information to assess changes in SWR capacity, note that they do not reflect real soil water content, which vary, as explained in the previous chapters, depending on evapotranspiration, infiltration at the soil surface and percolation down to the water table. Here, maximum soil water contents are estimated based on a set of key soil parameters that can explain related trends by themselves. These include:

- soil texture, represented by percentages of clay and silt;
- soil compactness and structure, represented by the soil bulk density;
- soil cation exchange capacity, represented by the soil organic matter content; and
- hydraulic conductivity, expressed by saturated hydraulic conductivity.

The impacts of land use changes on these maximum soil water contents are estimated in the context of a changing climate, with specific insights on the respective impacts of rural land uses (cropland, grasslands and forests and related agricultural practices) and urban development. This chapter also presents the evolution of the risks of floods and droughts in the EU, respectively through the run-off associated with the trends in maximum soil water content, and through the difference between precipitation and evapotranspiration following land use trends, as proxy indicators. The full description of the methodology, used data sources and data analysis for quantitative estimation of the trends in soil water content is detailed in Annex 3.

Presented results on past and current trends in soil water content (between 2000-2010) are considered representative. They are more reliable and certain when compared to the projected future trends to the 2030 horizon, which are more indicative due both to the uncertainties of the scenario used\(^73\) and the higher level of aggregation of data used to project LCLU changes\(^74\) (see Annex 3). Therefore, conclusions should be considered with care. The Reference scenario considered includes the following policies related to land use changes:

- set of policy alternatives deals with different implementation options of the proposed Renewable Energy Directive (Directive 2009/28/EC) and considers potential changes in the demand of land (through biofuel production) that can be associated with this policy;

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\(^73\) Reference scenario used for the work of the Land Use Modelling Platform. See Lavalle et al., 2013.

\(^74\) Future trends are based on regional and national data available from the Land Use Modelling Platform (LUMP), whether past and current trends are based on datasets with spatial resolution of 10x10 km grid and the recently created European HYdropedological Data Inventory (EU-HYDI).
the set of biodiversity policies to increase the protection of specific ecological and landscape related values, including policy options for fragmentation control and promotion of clustering of nature, controlling urban growth, natural corridors, Natura 2000, high nature value protection, Less Favoured Areas and protection of peat land;

- the set of Soil and Climate Change policies that focus on adaptation and mitigation measures related to water management and soil protection, including flood damage reduction (Flood Directive 2007/60/EC), restoring water balance, protection of permanent pastures, protection of peat land, soil protection and erosion prevention (Water Framework Directive, 2000/60/EC).

4.1 Trends in the capacity of soil to hold water

4.1.1 Trends due to land use changes and agricultural practices

4.1.1.1 Impacts of land use changes (excluding urbanisation)

- Past and current trends in SWR capacity

Changes in land uses (see section 3.1 and Annex 3) are quantitatively translated into associated changes in the soil water content, computed spatially on the 10x10 [km] raster grid for the period between 2000-2010. The difference in relative soil water content due to the LCLU changes for the period 2000-2010 in the EU-27 is mapped. The map accounts for the conversions between cropland, grasslands and forests, but excludes urbanisation, tackled in section 4.1.3.

The left part of Figure 24 maps the current capacity of soils to store water in the EU. It is expressed as a relative volumetric content\textsuperscript{76}, which means that “1” represents the regions with the highest soil water content, and “0” the regions with the lowest soil water content. The right part of Figure 24 maps changes in soil water contents between 2000 and 2010 as a result of land-use changes. It shows decreasing trends (marked in yellow) in SWR capacity in parts of Iberia (Spain and Portugal: -10 to -15%), Finland, Baltics and northern Germany (up to -10%). Some regions in Northern Germany, such as the Schleswig-Holstein and Mecklenburg-Vorpommern show larger SWR capacity decreasing trends (between -20% to -30%, marked in red), especially around Hamburg, Luebeck, Schwerin and Rostock. The possible reasons for such impact are the large LCLU changes that were observed locally and significantly disturbed the SWR. Further small decreasing evidence is seen locally in northern parts of Czech Republic and western parts of Hungary (-2% to -5%). Increasing trends depicted in green colour (between +5 to +10%) can, however, be observed in the east part of Germany, western Poland, large parts of Hungary and Czech Republic, Scotland and east part of Sweden.

\textsuperscript{75} Using raster grids of 10x10 [km] for the EU 27 countries.

\textsuperscript{76} Normalised between values of 0-1, which corresponds to values between 0-100%.

\textsuperscript{77} Grey areas represent areas where no land use change was observed using the CORINE dataset. The impact on soil water retention capacity is therefore not represented.
The main reason for the **decreasing trends in SWR capacity** in the specified regions is the conversion of land uses from forest to grassland, forest to crops and grassland to crops. Decreases that could be observed in France, Northern Germany, and Baltic countries for instance, can be partly attributed to the conversion of substantial grasslands areas into crops. Such land use changes contribute to decreasing SOM content and increasing bulk density, which negatively affect the capacity of the soil to withhold water, as summarised in Table 6 on p. 67. On the other hand, the **increasing trends in SWR capacity** are attributed to land use conversions from crops to forest (as in parts of Spain and Portugal), crops to grassland (as in large parts of Czech Republic and Hungary) and grassland to forests (as in North UK).

**Future trends in SWR capacity**

The projected future trends for 2020 and 2030\(^{78}\) were extracted based on a reference scenario using the key findings from the Land Use Modelling Platform provided by JRC. The expected % changes were aggregated per countries [in ha]. These projected (modelled) changes for the EU 27 countries are presented in Annex 3.

The left part of Figure 25 shows the current capacity of soils to store water in the EU, expressed as a relative volumetric content (like for past and current trends). The right part of Figure 25

\(^{78}\)Explanatory note: For consistency of the presented results and their rates of changes through time, the past trends analysis was based on the period between 2000-2010. For the projections and the future (projected) trends the period between 2020-2030 was used in order to have the same period of time and rate of changes (intensities). In addition, the available data from the LUMP platform was utilised for the same period of time. The same data periods of 10 years provide more consistent results for comparison.
depicts the different regions in the EU where soil water retention will most likely be an issue in the future due to the changes in the land use patterns.

On the one hand, increasing trends in SWR capacity due to land use conversions from crops to grassland and crops to forests are projected in most of Portugal, France, Lithuania, Slovenia and parts of Ireland (between +1 to +2 %). SWR capacity in the provinces of Utrecht, Friesland and Groningen in the Netherlands is even projected to increase up to 6%. Slight increased trends in SWR capacity are projected in Scandinavia (Sweden and part of Denmark), Estonia, Bulgaria, part of northern Italy and Czech Republic (between +0.5 to +1%). On the other hand, decreasing trends due to land use conversions from forests to grassland and grassland to crops are projected in Scotland, part of Wells and northern and southern parts in Germany. Neutral trends are projected for the rest of the EU 27 countries. These trends reflect the nature of projected land use changes, as highlighted for past and current trends.

It is important to stress that the difference in magnitude of changes between 2000 -2010 and 2020-2030 is only due to the level of spatial aggregation of the data available\(^79\). Therefore, attention should be paid to the dynamics of future trends in SWR (increase / decrease) and their relative intensity (significant / mild), rather than to the absolute values, which are not meaningful when compared with past and current trends.

Figure 25: Relative soil water content difference map (between 2020 and 2030) based on the projected land use changes and their impact on the key soil parameters.

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\(^79\) This is due to the fact that the projected values of the LCLU % changes are aggregated on a country level (due to the available data), which balances out the effects of changes in SWR, while the LCLU % changes for the period between 2000-2010 are based on 10x10 km grid cells for the EU 27 countries.
4.1.1.2 Impact of farming (agricultural) practices

Past and current trends

The previous section addressed the possible impacts of land use changes on SWR capacity. In this section, we focus on management practices implemented in arable land and grassland (out of the land use trends described above) in order to quantify the impacts of agricultural practices. The maximum water retention is estimated through variations in bulk density and organic matter brought about by different land management practices, which have been highlighted and discussed in Chapter 3. Increasing soil bulk density leads to decreasing SWR capacity. On the other hand, an increase of organic matter positively correlates with an increase of the SWR capacity. These changes are quantitatively estimated and computed spatially on the 10x10 [km] raster grid for the period between 2000-2010, using our raster-based model (see Annex 3 for more details). Agricultural practices considered in the modelling include tillage, composting, crop residue management, and intensive/extensive grazing.

The left part of Figure 26 shows the current capacity of soils to store water in the EU, expressed as a relative volumetric content (similarly to the previous sections). The right part of Figure 26 maps the difference in relative soil water content due selected agricultural practices for the period 2000-2010. Trends result from the nonlinear combination effects of the agricultural practices and the land use intensity (including arable land and grassland) on the SWR capacity, expressed through their impact on the soil bulk density and the changes in organic matter.

Figure 26: Relative soil water content difference map (between 2000 and 2010) based on the different agricultural practices and their impact on the key soil parameters.

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80 For this analysis, a new high-resolution map of land use intensity for the EU27 MS was used, developed by the Vrije University (VU) of Amsterdam, whereby as an appropriate indicator for the intensity of arable land management nitrogen application was selected (see Annex 3).
The map shows decreasing trends in SWR capacity in the Netherlands, central and northern part of France, west part of UK, north Portugal, central and southern part of Germany (-15% to -20%). These trends match the areas where tilling and intensive grazing are representative (see Figure 21 p.78). It also shows moderate decreasing trends in central Romania, eastern Poland and west parts of Greece and Latvia (-10% to -15%).

Increasing trends in SWR capacity can be observed (between +15 to +20%) in the north-east part of France, central Germany, northern and southern Italy, central and south part of Spain, most of Poland, eastern UK, most parts of Bulgaria, Lithuania and northern Denmark. These trends correspond relatively well to the areas where organic amendment is applied to the soils, where crops residues are left as a soil cover or where extensive grazing is implemented (see Figure 21 p.78).

Finally, neutral (stable ±2%) trends in SWR capacity can be observed in most of Ireland (except the wider Dublin area), western France and central-east parts of the UK.

The main reasons behind these trends are the nonlinear combination effects of the agricultural practices and the land use intensity (including arable land and grassland) on the SWR capacity, expressed through their impact on the soil bulk density and the changes in organic matter. Increasing soil bulk density leads to decreasing SWR capacity. On the other hand, an increase of organic matter positively correlates with an increase of the SWR capacity. Although the combination of impacts from different practices makes it difficult to isolate individual impacts and to draw firm conclusions, the general trends based on the land use change patterns combined with the agricultural practices show decreasing SWR capacity in Benelux, northern and central parts of France, parts of Iberia (Portugal and Spain) and Central Europe. Neutral and increasing trends of SWR are visible in the east part of Germany, western Poland, parts of Hungary, most of Ireland, central-east parts of UK and east part of Sweden. The relative comparison of the impact of the land use changes and the agricultural practices indicate that the agricultural practices, in particular composting and crop residue management that impact highly on organic matter, show possibility to increase soil water maximum contents on average between 20% to 25% while same land use is assumed.

Future trends in SWR capacity

Unlike projections of SWR capacity based on land use changes datasets presented in section 4.1.1.1., past and current trends are here comparable with the projected future trends in terms of spatial resolution and magnitude, as the dataset used matched here those used for past and current trends. The projected future trends for 2030 were analysed based on a reference scenario using the aggregated land use changes focused on arable land and grassland and assuming the same agricultural practices trends as for the 2000-2010 period. The water content maps were computed for the scenario 2020 and 2030, and were then subtracted to emphasise the trends.

Explanatory note: For consistency of the presented results and their rates of changes through time, the past trends analysis was based on the period between 2000-2010. For the projections and the future (projected) trends the period between 2020-2030 was used in order to have the same period of time and rate of changes (intensities). In addition,
The right part of Figure 27 maps the different regions in Europe where soil water retention will most likely be an issue in the future due to the effect of the analysed agricultural practices. The left part of Figure 27 maps soil water content in 2030 due to changes in agricultural practices.

Decreasing trends in SWR capacity are projected in the Netherlands (especially around the Randstad area), central and northern part of France, west part of UK, north Portugal, north and south Spain, central and southern part of Germany (-20% to -25%), and moderate decreasing trends in central Romania, central Italy, west parts of Greece, Latvia and west Lithuania (-12% to -18%). These relatively match areas with prominent tilling and intensive grazing (see Figure 21 p.75).

Increasing trends in SWR capacity can be observed (between +20 to +25%) in Scotland, central parts of Spain, and the north part of Germany, and moderate increasing trends (between +10 to +15%) for Czech Republic, northern Bulgaria, largely Poland, western Romania, central and northern Greece, south-west of Spain and northern Italy. These areas tend to match the areas implementing composting (amendment), crop residue management and extensive grazing (see Figure 21 p.75).

Finally, neutral (stable ±2%) trends in SWR capacity can be observed for the rest of the EU-27 countries with emphasis on most of Ireland (except the wider Dublin area), western France, central Spain, central-east parts of the UK, central Germany, Hungary, central Bulgaria and parts of Scandinavia.

Figure 27: Relative soil water content difference map (between 2020 and 2030) based on the projected different agricultural practices and their impact on the key soil parameters.

the available data from the LUMP platform was utilised for the same period of time. The same data periods of 10 years provide more consistent results for comparison.
4.1.1.3 Conclusions on the impacts of land use change and agricultural practices

The combination of the impacts on SWR capacity of LCLU changes and changes in agricultural practices for arable and grasslands leads to the following conclusions:

- alarming decreasing trends in SWR capacity have been occurring in the past decades and are likely to continue in the future, especially in central Europe, Benelux, northern and central parts of France, Spain and Portugal. Stable and slightly increasing trends in SWR capacity are projected for the rest of the Member States. In particular, increasing trends of SWR capacity are visible in the east part of Germany, western Poland, parts of Hungary, most of Ireland, central-east part of UK and east part of Sweden;

- promoting and implementing appropriate agricultural practices would contribute to significantly increasing SWR capacity. The combination of impacts from different practices makes it difficult to isolate individual impacts and to draw firm conclusions. However, the analysis shows that composting and crop residue management, which highly impact on SOM, would be particularly relevant to increase SWR, as the potential for increase was estimated to range from 20 to 25% within the same land use type;

- overall, in terms of magnitude the past trends of decreasing SWR capacity due to land use changes are more prominent when compared to the projected future trends, which can be explained by the slowing down of detrimental land use conversions at the EU scale. Yet, cumulative degradation raises concerns for the future.

4.1.2 Impact of urbanisation

- Past and current trends

Figure 28 presents the difference in relative soil water content for the period 2000-2010 due to the urbanisation change\textsuperscript{82}. Note that the key detrimental effects of urbanisation is the immediate effect on runoff, but the water running on the soil surface can infiltrate later on, where surfaces become porous again.

\textsuperscript{82} The percentage changes in the key soil parameters due to the urbanisation changes have been quantitatively translated into associated changes in the soil water content computed spatially using Mualem - van Genuchten equation on the 10x10 km raster grid for the EU 27 countries.

The background map presents the administrative borders and the larger urbanised areas in EU27 as polygons.
Chapter 4: Trends in soil water retention capacity

Figure 28: Relative soil water content difference map (between 2000 and 2010) based on the urbanisation changes and their impact on the key soil parameters

The grey areas depicted on the map indicate that there are no significant urbanisation changes observed for the analysed period.

Past trends show decreasing SWR capacity in the most densely populated parts of EU 27 countries with:

- an evident decrease (-20% to -25%) in Germany, Netherlands, the industrial regions of Northern Italy, Poland, Czech Republic, along the coastal areas (-15% to -20%) of Spain, Portugal, France, Denmark, Cyprus, southern part of Sweden and eastern Ireland. These areas are mapped with orange towards red colour.
- a moderate decrease (-10% to -15%) in Portugal, which are mapped with yellow towards orange colour; and
- a mild decrease (-5%) in Ireland with the exception of the wider Dublin area, which are depicted with green colour indicating less worsening conditions.

Figure 29\(^3\) shows the current capacity of soils to store water in the EU, expressed as a relative volumetric content. It shows that overall, soils from Ireland and Scotland as well as some areas in western Romania, northern Germany and Baltic countries present the highest SWR capacity. Very low SWR capacity can be observed in big metropolis, like Paris (France) and London (UK). Although the spatial extent of land take is quite small in relation to the other LULC classes for the EU27 MS, its impact on the SWR capacity is quite significant at the local scale, and can be

\(^3\) including a background map of the catchment areas
substantially higher than the average of 25% estimated. This is due to the fact that land use changes excluding urbanisation are widespread, whether the urbanisation changes are more intense and more local, resulting in significant decrease of the SWR capacity.

Figure 29: Relative soil water content for year 2010 based on the urbanisation changes and their impact on the key soil parameters

Note: Areas tagged as “High:1”, in dark blue, are the areas with the highest SWR capacity in the EU. The lighter the blue, the lower the SWR capacity.

Future trends

Future trends for 2030 were projected using the aggregated urbanisation changes per countries (based on the JRC reference scenario) summarised in section 3.1 and described in the Annex 3.

Figure 30 depicts the different regions in the EU where soil water retention will most likely be an issue in the future due to the changes in the urbanisation patterns.

Decreasing SWR capacity trends (depicted in yellow, orange towards red colours) because of urbanisation are projected in most of the Western European countries, such as France, the Netherlands, Belgium, Luxemburg, Denmark, northern part of UK, in Eastern European countries such as Romania, Hungary, parts of Czech Republic and Slovakia and in Estonia and Sweden. Mild decreases (depicted in light green colour) are projected in Italy, rest of UK, Germany and Czech Republic and Slovakia; stable projected SWR capacity (depicted in green colour, indicating less worsening conditions) in Iberia (Portugal and Spain), Greece, Bulgaria, Austria, Poland, most of Ireland, Finland. As explained before, it is important to note that the projected urbanisation changes aggregated per countries in the SWR calculation resulted in the lower percentage changes of SWR capacity as quantitative amounts, but provide indicative future trends in SWR based on the Reference scenario used.
Figure 30: Relative soil water content difference map (between 2020 and 2030) based on the urbanisation changes and their impact on the key soil parameters.
4.2 Trends in the risk of SWR related flooding and droughts in a changing climate

Various studies and projections up to 2100 show a general reduction in summer soil water content over most of Europe, significant reductions in the Mediterranean region, and increases in the North-Eastern part of Europe (EEA, 2012c). SWR capacity plays an important role for flood and drought risk management, in the context of changing climate, with increasing evidence of more extreme and frequent weather-related hazards.

Increasing flood damages are expected in large parts of western and central Europe as well as in the UK, in particular in urbanised regions. The Pan-European flood studies and regional studies show that we can expect a moderate increase of risk of flood damages for most other regions in Europe when taking into account climate change. To counteract the impacts of climate change, the role of soil water retention as a provider of flood regulation services will therefore become increasingly important in these regions.

Within the scope of this study we have carried out an additional quantitative analysis of the combination of the impact of past and future climate trends (precipitation and temperature) and SWR capacity trends on increased flood and drought risks. These are expressed through plausible increase of surface runoff and increase of precipitation deficiencies respectively.

4.2.1 Risk of flooding (increased runoff)

- **Past and current trends**

  Urbanisation changes between 2000-2010 (see section 4.1.3), which clearly showed a degradation in SWR capacity due to soil sealing effects, were overlaid with precipitation trends to estimate their impacts on run-off generation. The main assumption made was that the decrease of the SWR during rainfall events will generate significant higher volume of surface runoff that can potentially cause flooding (as demonstrated in section 3.3, e.g. 10% decrease of SWR can lead to 40% increase of surface runoff volume). The results from the GIS analysis were further classified in 3 classes that indicate plausible increase of surface runoff:

  (i) significant increase of surface runoff (>20%) – red colour;

  (ii) mild increase of surface runoff (1-10%) – yellow colour; and

  (iii) neutral (<1%), no increase of surface runoff – green colour.

  As a result, Figure 31 shows the plausible increase of surface runoff volume resulting from past and current trends in urban development.

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84 Ntegeka et al, 2013; Rojas et al, 2013; Min et al., 2011; Lung et al., 2011; Dankers and Feyen, 2009; Dankers and Feyen, 2008

85 Bastola et al., 2011; Pall et al., 2011

86 The background map is also showing the identified catchment basins based on the EU Water Framework Directive guidelines.
It clearly indicates plausible significant increase of surface runoff in the densely populated and urbanised (industrial) regions in Europe with the emphasis on Germany, Czech Republic, Hungary, Romanian, Italy, France, Ireland, UK, with increased surface runoff in Belgium, Luxemburg and Lithuania, and neutral risk in Spain, Portugal and Scandinavian countries. It is important to mention, however, that although in same countries and regions significant urbanisation changes have been observed with decreasing trends of SWR capacity, these changes do not automatically lead to plausible increase of surface runoff because of changing climate patterns where reduced precipitation trends are observed, such as the coastal areas of Spain and Portugal.

**Figure 31:** Quantitative assessment of the plausible increase of surface runoff due to urbanisation changes and precipitation trends from 2000-2010 in the EU 27 MS

The derived results from Figure 31 do not necessarily correspond with the flood occurrence mapped in the EU (Figure 32)\(^7\), as shown in the cases of the Ebro river basin in Spain, the

\(^7\) Various sources (Allianz, UNISDR, GAALFE, Eurostat) were used to create a thematic map of the large flood occurrence events (that can be categorised as natural disaster) between the period 2000-2010. The aggregated large flood occurrence per river basin areas for the EU27 is thematically presented in Figure 32, overplayed on a background Open Street map. Large flood events are categorised as events that fulfil at least one of the following criteria: (i) killed
southern part of Italy or the western part of France and Denmark. This evidence map indeed shows *high flood occurrence* trends in the following river basins: Garonne, Rhone, Ebro, Po, Rhine, Danube, Weser, Elbe, Oder, Wisla, Thames and most of the other rivers in UK, with *very high flood occurrence* of the Danube river basin in Romania.

It is important to note that flood events are of generally of local impact and occur in certain parts of the water basins only, mainly along the river courses. Hence, Figure 32 is showing the affected basins but not the regions actually affected. It is evident that there is a need for detailed and localised flood hazard and flood risk analysis based on full deterministic and economic models.

**Figure 32: Number of large flood occurrences (2000-2010) in the EU 27 MS**

The differences observed between the map of run-off generation and the map of floods is explained by the fact that only urbanisation changes and its effect on the SWR were taken into account in the former. The impacts of other land uses, such as agriculture, are not taken into account. Furthermore, the increased surface runoff does not necessarily leads to increased flood risks in all regions. Hence, it is important to mention that this derived map of plausible increase of the surface runoff is an indicative map with the following limitations:

- the impact of the urbanisation and soil sealing on the SWR, hence implicitly linked to the risk of floods, is not straightforward and detailed analysis will
require setting up rainfall-runoff hydrological models on a river basin scale (or gridded scale), which is outside of the scope of this study;

- similarly, the impact of interception by vegetation on run-off and infiltration cannot be fully taken into account in the modelling of the SWR, only through the key soil explanatory parameters.

Future trends

Future trends in flood risks caused by the combination of urbanisation patterns and increased precipitation are difficult to estimate due to the shortcomings of data and tools that could be used in the present study. There is an essential need for more detailed grid-to-grid regional or catchment based hydrological rainfall-runoff-routing models (such as LisFlood model, van der Knijf et al. 2008 and de Root et al. 2000).

However, using a similar approach, the urbanisation changes for the period 2020-2030 were overlaid with the future trends in precipitation using the main assumption made that the decrease of the SWR due to urbanisation changes during rainfall events will generate significant higher volume of surface runoff that can potentially cause flooding. The results from the GIS analysis were further classified in the three classes indicating plausible increase of surface runoff for the period 2020-2030, as depicted in Figure 33. The results show that for some countries, such as Germany, the steady urbanisation uptake does not directly lead to projected plausible increased runoff, due to projected decreases in precipitation. On the other hand, significant plausible increase of surface runoff is projected for Portugal and Italy due to the combination of increased urbanisation and steady projected precipitation climate trend.

It is important to note that these are rough results based on the available projected (modelled) aggregated LCLU and urbanisation changes using administrative borders. These indicative trends were further compared to the outcome of several Pan-European flood studies (e.g. Ntegeka et al, 2013; Rojas et al, 2013; Min et al., 2011; Lung et al., 2011; Dankers and Feyen, 2009; Dankers and Feyen, 2008). They indicated that projected increasing flood damages are expected in large parts of western and central Europe as well as in the UK, in particular in urbanised regions, which correlate with the projected plausible increase of surface runoff presented in Figure 33. Although significant urbanisation changes have been observed in same countries and regions, along with decreasing trends of SWR capacity (such as Germany) these changes do not automatically lead to plausible increase of surface runoff because of changing climate patterns where reduced precipitation trends are observed, such as significant increase of precipitation deficiency (see Figure 35) and increase of temperature (evaporation), see Annex 3. Hence, plausible increase of surface runoff for Germany is projected as neutral. On the other hand, projections for some countries such as Sweden, Finland, Italy and Portugal in particular, show significant plausible increase of surface runoff. These trends are based on the effect of changing climate patterns. Although neutral precipitation trends are observed, the decreasing trends in SWR capacity due to urbanisation combined with the increased precipitation intensities (more extreme events) lead to plausible surface runoff increase projections. In the case of Portugal storm surges due to depressions moving from the Atlantic oscillator are projected to generate more extreme precipitation intensities leading to plausible increase in surface runoff. Firm conclusions on flood risks in EU 27, caused by the combined effects of SWR capacity trends and projected increases in the intensity and frequency of precipitation events, are difficult to
draw without detailed physically-based hydrologic and hydrodynamic modelling as stressed above.

Figure 33: Quantitative assessment of the plausible increase of surface runoff due to urbanisation changes and precipitation trends between 2020 and 2030 in the EU 27 MS

4.2.2 Risk of droughts

Past and current trends

The precipitation deficiency (difference between the precipitation and the evapotranspiration) was used as an indicator to estimate past and current drought risk trends. It has a direct link to the SWR capacity as it provides an indication of general reduction in soil water content. Annex 3 includes the quantitative analysis of the climate parameters such as precipitation and temperature trends based on the European-wide ECHAM5 r3 ensemble datasets produced within the ENSEMBLES FP7 project. Overall land use changes for the period 2000-2010 (see section 3.1, and Annex 3 for more details) with the corresponding SWR capacity difference were
overlaid with the trends in precipitation and temperature (see Annex 3 for more details) and then classified in 3 classes that indicate:

(i) significant increased risk of drought – red colour;
(ii) mild increased risk of drought – yellow colour; and
(iii) neutral risk of drought for the analysed period 2000-2010.

As a result, Figure 34 shows the plausible increase of drought risk deficiency (expressed as precipitation deficiency) resulting from the impact of past and current land use changes on SWR capacity. There is no significant difference in the risk of drought in most of the EU, but mild and significant increased risk may occur in Spain, and in Cyprus and part of Greece, respectively. This increased risk of drought is based on classification of the magnitudes of shortage of precipitation due to the combined effects of precipitation decreases and temperature increases and does include any occurrences of the drought events. These trends are not incompatible with projected increasing run-off in Spain, which can result from the steady urbanisation increase coupled with land use changes and agricultural practices and intense, although scattered, precipitation events (Figure 33).

Note that the presented precipitation deficiency map as a drought risk indicator is an indicative map based on average yearly aggregates of the temperatures and precipitation for the EU27 countries. Detailed crop-growth models coupled with the SWR and the hydrometeorology on a regional or gridded scale would be required for better representation of these trends.

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Note that the background map of the catchment basins areas as identified with the EU WFD is provided as a background reference only.
Figure 34: Quantitative assessment of the increase of drought (based on precipitation deficiency) in the EU 27 MS (2000-2010)

Plausible increase of precipitation deficiency 2010
- Significant increase
- Increase
- Neutral

Note: The neutral class is +2%, increase class is +5% and significant increase class is > +10%.

Future trends

Similarly to the projections of the risk of floods, projections of increased drought risks due to the combination of the urbanisation patterns, precipitation pattern and the increased temperature are difficult to estimate.\textsuperscript{89}

\textsuperscript{89} Due to the available projected aggregated data per countries and the essential need for detailed regional and downsampled (horizontal resolutions <= 2.5 km) ensemble meteorological models (such as Hirlam and its forerunner Harmonie: Seity et al., 2011, Brousseau et al., 2011).
An indicative estimation using the same methodology as for the past trends was conducted, through the plausible precipitation deficiency. Overall land use changes for the period 2020-2030 (see section 3.1, and Annex 3 for more details) with the corresponding SWR capacity difference were overlaid with the trend in precipitation and temperature (see Annex 3 for more details) and then classified in 3 classes. The results are depicted in Figure 35.

Figure 35: Quantitative assessment of the plausible increase of drought (based on precipitation deficiency) in the EU 27 MS (2020-2030)

Note: The neutral class is +2%, increase class is +5% and significant increase class is > +10%.

It is important to note that these are rough results based on the available projected (modelled) aggregated LCLU and urbanisation changes using administrative borders.

The effect of SWR capacity on the mitigation of risks of floods and droughts is being further investigated through various projects and initiatives. Recently established initiative in the Netherlands by the association of all Water Boards called SATWAT aims at quantifying the soil capacity to hold water through water accounting principles, which enables clear breakdown of key components of the hydrologic cycle. This is achieved through a combination of high-resolution microwave satellite images acquired by the recently launched Copernicus-based Sentinel mission, in-situ sensors and integrated hydrologic models. Initial results based on in-situ
measurements and modelling approach demonstrated significant seasonal effects of the SWR capacity, namely almost double capacity of the soils to store and retain water during the summer months when compared to the winter months, which can be used as an additional storage as part of the operational water management.

4.3 Effects of SWR capacity's evolution on water use

The previous analysis raises important concerns in terms of long-term availability of water resources in the context of a changing climate, and hence in terms of environmental impacts and sustainability of the associated socio-economic activities.

The availability of water in the EU is theoretically largely sufficient to meet the overall demand from society, as the annual water abstraction for socio-economic activities accounts for only 13% of the available water resources. However, water shortages occur, because of the insufficient availability of water, at the local scale and at a certain period, to match both demands from the society and from the natural environment.

According to the European Commission, at least 11% of the EU-25 population and 17% of its territory have been affected by water scarcity in 2007 (European Commission, 2012). Moreover, over-abstraction is currently considered the second most common pressure on ecological status of water bodies in the EU (EC, 2012b). In this context, safeguarding or improving SWR capacity is a promising “green” response to promote, with multiple co-benefits, water quality, biomass and biodiversity support, reduction of soil erosion, contribution to nutrient cycles, etc.

Substantial progress has been made in the EU in the last decades in the field of water efficiency, since water abstraction per year was around 290 km\(^3\)/year in 2009 compared to 476 km\(^3\) in 1995 (Heinrichs and Acalmo, n.d.). The 2009 figure corresponds to 500 m\(^3\) per capita/year or a daily consumption of 150 litres/person\(^{90}\) and 24% of abstracted water is dedicated to agriculture, including irrigation and cattle watering (EEA, 2009). Further progress is anticipated, for instance in the field of irrigation, where the potential water savings in the irrigation sector would amount to 43% of the current agricultural volume abstracted.

Decreasing trends in SWR capacity may however eventually counterbalance the benefits of the substantial progress in water efficiency achieved in the EU in the last two decades. Water shortages are likely to occur more frequently or to be exacerbated as the capacity of soils to store water as a reservoir decreases and as water demands subsequently increase, in particular in the context of changing climate.

The agricultural sector, which heavily relies on green water, already faces particular challenges, and will even more in the context of changing climate and competing demands. Several studies that investigate water issues and water scarcity concentrate about the availability of ‘blue’ water, i.e. water from streams and lakes, used for irrigation. When there is a risk of water stress, irrigation is extensively used to meet the crops water requirements. In Mediterranean EU countries, 80% of abstracted water is used in the agricultural sector for irrigation whereas 20%  

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\(^{90}\) ec.europa.eu/environment/water/quantity/pdf/exec_summary.pdf [Accessed online 09/13]
are used for this purpose in northern EU countries. Approximately 70% of water abstracted does not return to a water body but is consumed by evapotranspiration (EEA, 2009).

Surface-water based irrigation can result in disruption of stream flows, as well as in increased groundwater levels in seepages, secondary salinisation of soil and water logging in certain areas of the world (Scanlon et al., 2007); while groundwater based irrigation may lead to depletion of groundwater levels, disruptions in linked stream flows, and increased pumping costs (Scanlon et al., 2007). Both abstraction sources may result in negative impacts to linked ecosystems.

Increasing trends in the amount of water required by cultivated areas raises concerns, since the analysis of SWR shows that conversions to arable land tended to decrease the overall SWR capacity, and even more in the case of intensive practices. It can therefore be assumed that the Member States with high abstraction for irrigation (i.e. Cyprus, Spain, Italy and Malta) will continue to experience severe water stress in the future (BIOIS, 2012). While agricultural land is expected to decrease in the EU-27 by 2030 (European Commission, 2012), large increase in irrigated areas can be expected from agricultural regions, which for most cases, would not match regions where increases in SWR is expected. The regions will experience new water stress due to decreased SWR capacity, in particular in case of no strengthening of current soil and water policies. The regions with an intensification of farming systems, potential rainfall deficiency linked to climate change and high SOM decrease, such as in Mediterranean regions, will be particularly affected. For instance, the Jucar River Basin in Spain faced significant decline of water resources due to the expansion of irrigated agriculture between 1985 and 2001 (EEA, 2009), enhanced by non-authorised abstractions. The application at Member States level of the Communication addressing the challenge of water scarcity and droughts (2007) and the Blueprint to safeguard Europe’s water (2012) should take into account the specific risk of decreasing SWR at regional level if necessary. The new CAP reform 2014-2020 that has increased the importance of GAECs and agri-environmental measures also specifically aims at protecting parameters such as soil organic matter or soil structure affecting SWR.

In urban areas, substantial water shortages can also occur, in particular during the touristic season where water abstractions drastically increase whereas the overall replenishment of groundwater bodies remains low throughout the year due to the reduced permeability of soil surfaces.
4.4 Discussion and Conclusions

The impacts of EU land use changes, urbanisation and agricultural practices on maximum soil water contents were estimated and mapped based on the currently available datasets, the relationships established through the case studies, and relatively simple modelling exercises using geospatial analysis. The impacts for past and current trends were quantified and estimated to be representative. However, impacts describes for future trends remain semi-quantitative and mostly indicative. This exercise informs on the magnitude of changes in maximum soil water contents for key categories of drivers, but it is very difficult to attribute such increases or decreases to specific factors (e.g. large forest areas, specific contribution of isolated agricultural practices) as the combination of their effects is not linear.

Overall, historical trends show significant decreases in maximum soil water content in large parts of the EU because of land use changes. Current and future trends show, however, that marginal negative impacts on maximum soil water contents are projected to be less critical in the next decades, in particular if sustainable land management practices are implemented which lead to fewer detrimental land use conversions (urbanisation or conversions between forests/grasslands and arable land). Yet, cumulative impacts still raise significant concerns for the future.

Historical trends based on the land use change patterns (excluding urbanisation) combined with prominent agricultural practices show significant decreases, up to 20%, in maximum soil water contents in Benelux, northern and central parts of France, parts of Iberia (Portugal and Spain) and Central Europe. Neutral to increasing trends are expected elsewhere (in particular, in the east part of Germany, western Poland, parts of Hungary, most of Ireland, central-east parts of UK and Scandinavia). In the next decades, under the strong assumption that prominent practices remain the same, further significant decreases are expected in France, Portugal and Spain as well as central and southern part of Germany (-20% to -25%) and to a lesser extent in central Member States. Stable and slightly increasing future trends in SWR capacity for the rest of the EU27 MS can be anticipated.

Without considering the impact of various agricultural practices, unsurprisingly, historic increases in maximum soil water contents match quite well areas where conversions from cropland to forest, crops to grasslands, and grasslands to forests occurred. Similarly, significant decreases could be observed in countries where substantial grasslands areas were converted into crops. Substantial decreases in maximum soil water contents match the areas where tilling and intensive grazing are representative. On the contrary, significant increases in maximum soil

91 The currently available soil datasets for the EU 27 countries are not fully consistent in terms of the key explanatory soil parameters needed to carry out different regional water and environmental studies, and hence require significant amount of processing. Significant improvement was made, however, through the publication of hydropedological information in Europe (EU-HYDI database and report) by JRC (2013), which was used as a basis for the geospatial analysis in this work. This database holds data from 18 countries with contributions from 29 institutions on soil physical, chemical and hydrological properties. It also contains information on geographical location, soil classification and land use/cover at the time of sampling, combining the ESDB, LUCAS and partially the HWSD (Harmonized World Soil Database). It was assembled with the aim of encompassing the soil variability in Europe.

The projected future trends were extracted based on a reference scenario using the key findings from the Land Use Modelling Platform provided by JRC.
water contents correspond relatively well to the areas where organic amendment is applied to the soils, where crops residues are left as a soil cover or where extensive grazing is implemented (central parts of Spain, north part of Germany, Czech Republic, northern Bulgaria, largely Poland, western Romania, central and northern Greece, south-west of Spain and northern Italy). In particular, practices that highly impact SOM, such as organic amendment and crop residue management, have a great potential to increase maximum soil water content (20 to 25%).

Combined with increased temperature trends, which are particularly noticeable in Greece, Cyprus, Bulgaria, Romania, Italy, Spain, Portugal and Malta, conversions from land uses with high SWR capacity (e.g. forests, grasslands) to land uses with a lower SWR capacity (e.g. croplands, urban areas) raise significant increase of precipitation deficiency (as an important drought risk indicator) in these regions.

Increasing trends in urbanisation resulted in significant decreases in SWR capacity (up to 25%) in the most densely populated areas in the EU, in particular in Germany, northern Italy, Czech Republic, Denmark, France, parts of Poland, Portugal, and along the coastal areas of Spain. Very low SWR capacity can be observed in big metropolis, like Paris (France) and London (UK). Although the spatial extent of the changes in land use related to the urbanisation are quite small in relation to the other LULC classes for the EU27 MS, their impact on the SWR capacity is quite significant at the local scale, and can be substantially higher than the average of 25% estimated through the model, which dilutes the reduction in maximum soil water content to larger areas than cities. Combined with increased precipitation patterns, past and current urbanisation trends also resulted in significant plausible increase of the surface runoff in the densely populated and industrial regions in Europe mentioned above (Germany, Czech Republic, Italy, France) which presented significant reductions in maximum soil water contents, as well as in Hungary, Romania, the Netherlands, Ireland and the UK. The flood occurrence evidence shows significant correlation with the risk of increased surface runoff due the urbanisation trends and disruption of SWR capacity. In the next decades, these trends are expecting to slow down because of the decreased pace in urbanisation, but will still raise concerns, in particular in the most densely populated areas, where damages from floods may increase due to the increasing vulnerability and economic value of these areas.

The analysis of SWR capacity trends raises important concerns in terms of long-term availability of water resources in the context of a changing climate, and hence in terms of environmental impacts and sustainability of the associated socio-economic activities. In the most concerned countries (mostly Spain, parts of Portugal, southern Italy, Greece and Cyprus), decreasing trends in SWR capacity may eventually counterbalance the benefits of the substantial progress in water efficiency achieved in the EU in the last two decades, as the capacity of soils to store water as a reservoir decreases and as water demands subsequently increase. The agricultural sector, which heavily relies on soil water, will face particular challenges. Hence, limiting where possible the conversion towards land uses penalising SWR capacity, implementing appropriate agricultural practices and sustainable and climate-resilient urban planning, will further stimulate safeguarding the soils of Europe and contribute towards increasing SWR capacity in the context of the changing climate.

It is important to highlight that quantitative results that establish direct links between the changes in SWR capacity on the one hand and on floods and droughts on the other hand in the
EU27 countries are difficult and not straightforward to establish. This is due to the following assumptions and limitations:

- the plausible increase of the surface runoff, leading potentially to a higher flood risks, was computed based on the changes in the SWR capacity taking into account the urbanisation and climatic changes (trends) only. The complete land use changes and other aspects of river basin management plans (structural and non-structural measures) in the rural areas are not taken into account;

- the projected future trends for 2030 in terms of increased surface runoff (leading to increased flood risks) and increased precipitation deficiency (as indicator for drought risk) due to the combination of the urbanisation patterns and precipitation and temperature trends are difficult to estimate due to the available projected land use aggregated data per countries, when compared to the SWR capacity computed at 10x0 [km] grid scale.

What is missing in establishing these direct links is essentially using SWR capacity as an important variable in physically based rainfall-runoff hydrological models on a river basin scale (or gridded scale) in order to explicitly model and simulate the effect of the SWR on the flood hazards and translate these results in accurate flood risk maps based on the exposure and vulnerability of flooding. It also applies for the drought risk assessment, which requires setting-up detailed regional and downscaled meteorological models coupled with crop-growth (yield) models. Although these modelling approaches are outside of the scope of this particular study, it is highly recommended that those are considered as follow-up study activities, in order to establish the direct links between the disruption of the SWR and the economic implications as further discussed in Chapter 5. Some of these activities are already ongoing as part of the EU Flood Directive (2007/60/EC), where each of the member states are producing detailed flood risk management plans on catchment management scales.
Chapter 5  Economic implications of the disruption of soil water retention capacity

As demonstrated in the previous chapters, the capacity of soils to capture, store and release water influences the supply of a range of ecosystem services, including the production of biomass and the regulation of extreme events such as floods and droughts. In particular, Chapter 3 and Chapter 4 showed the strong correlation between flood occurrence and water availability with the decrease in maximum soil water contents. Although flood occurrence usually results from exceptional rainfalls, such as the 2007 summer floods in England, it is fostered by changes in the capacity of landscape to retain and slow down water and therefore a disruption of its capacity to prevent fluvial and pluvial floodings. This was namely shown in central and eastern Europe, through 2002 and 2013 extreme flooding events in the Elbe river basin, where 80% of floodplains and forests have been lost to urbanisation, and in the Vlatva river basin near Prague where agricultural and urban areas were extended over natural retention areas. More locally, it was shown in the UK through the correlation of intensive grazing, along with the reduced capacity of vegetated soils to retain water, with the 2000 large summer flooding events in England. It was also shown in Italy, in Malborghetto-Valbruna in 2003, where reduced soil water retention capacity due to anomalous dryness conditions combined with intense rainfalls led to flash floods in 2003. Furthermore, flood associated damages are also strengthened by the inability of current land uses to natural buffer water levels and mitigate the impacts of flooding when it occurs.

Yet, data that establish a direct link between the changes in SWR and its impact on water-related services in different sectors (e.g. agriculture, water distribution, industries using water in their production process, and tourism) are scarce, scattered and site-specific, which makes the estimation of economic impacts very challenging (see Annex 4). Abundant data is available on the impacts of extreme events, such as droughts and floods, although datasets are mostly scattered and local, and subject to high discrepancies. These factors do not allow quantifying the link between the trends in SWR capacity and floods and drought damages at the EU level in the context of the present study.

Against this background, this chapter will not attempt to quantify a direct link between the changes in SWR and the economic impacts in association with these changes. It rather tackles it more indirectly through the evaluation of the social economic impacts of flood and drought events that are partly attributed to the changes in SWR capacity. The obtained economic estimates therefore can reflect the potential of SWR in reducing the dramatic economic impacts caused drought and flood events. Estimations are made where possible for the four different types of land uses addressed in the study, namely cropland, grassland, forest and urban land. They must be considered in light of the risks of floods and drought caused by changes in SWR capacity in the context of a changing climate, mapped in Chapter 4.
5.1 Impacts of floods

Most of the economic damages caused by flood events are tangible and thus relatively easy to estimate. A recent study conducted by the EC Institute for Environment and Sustainability (2010) shows that many European cities, such as those in the Veneto region in the North-East of Italy, mid-west of the Netherlands, and London area in the UK are under high damage potential due to extreme flood events with significant economic losses (Figure 36) [see Case studies n° 15, 16 and 17 in Annex 1]. We have selected ten EU countries, including Belgium, Czech Republic, Germany, France, Italy, Poland, Romania, Spain, the Netherlands and the United Kingdom, where the frequency and magnitudes of the damages are more significant with respect to many other countries.

Figure 36: Flood damage potential (in million Euros) in purchasing power parities for 100-year return period floods

Due to the extremely limited data at the EU level and modelling capacity when this project has been conducted, the project team decided to investigate in-depth the 2007 summer floods in the UK, in order to demonstrate to what extent the decreased SWR could contribute to aggravating the damage of very intense and unprecedented rainfalls in that area. This case study focuses on the impacts of floods in agricultural areas based on a real-time economic impacts assessment study commissioned by Defra after the flooding season, together with the climatic ECHAM5-r3 data we used for the climatic trends in Chapter 3.
5.1.1 Arable land

**Approach**

To map the impact of rainfall and SWR capacity on flood, we first estimated average amount of rainfall for different regions of the UK in July 2007. The average amount of rainfall for July 2007 in SW England based on the climatic ECHAM5-r3 data, amounts to 177.3 [mm] (= 1 773 m³/ha). According to the UK Met Office, the average rainfall across the UK was 135.7 [mm] (= 1 357 m³/ha), with wettest July record in Whales with 208.4 [mm] (= 2 084 m³/ha).

Based on the quantitative analysis conducted in the present study, the average maximum soil water content per ha of healthy agricultural soils for SW England area is estimated at an order of magnitude of 223 [mm]/1000 x 10 000 m² = 2 230 m³. The hydrological model developed for this project has shown that SWR capacity has been reduced for about 13% between 2000 and 2007 due to the intensive agricultural practices in the area. At the time of the extreme precipitation events in 2007, the average soil water maximum content per hectare for SW England could be estimated at about 1940 m³/ha. Although this capacity is still higher than the cumulative rainfall events observed over the period (1 773 m³/ha), soils are more likely to reach saturation, especially in case of heavy rainfall events such as storms and river overflows (see Figure 37), because of the reduction of the infiltration capacity due to the aggregates instability. This is shown by modelled increased in run-off of more than 10% between 2000 and 2007 (based on simulations performed in the present study).

![Figure 37: Monthly average rainfall in the UK between 2004 and 2007](image)

In terms of economic valuation of these damages on arable land, recent studies have pointed out that there is a clear need to ensure that the characteristics of agricultural activities that make them particularly vulnerable are accurately considered in the methods concerned (Brémont, et al., 2013). In particular, for a precise assessment of the damages caused by flood, it is required to identify the extent of the farming area affected by the floods, estimate the area and type of

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92 This number is then transformed to the average amount of rainfall received by per hectare of land, using 1 [ha] = 10 000 m².
crop affected, and estimate crop losses and value as a direct impact of the flood. This is, however, far beyond the scope of the present project. Therefore, in this study, we derived our damage assessment based on an ex-post damage assessment study (ADAS, 2007) done for the 2007 summer floods in the UK to show the possible magnitude of the flood damages to arable land. ADAS (2007) study was selected because it presented a detailed classification of different types of croplands affected by several flood events across the UK between June and July in 2007. The crops studied include wheat, barley, cereals, potatoes, fodder crops, other crops and oilseed rape. Moreover, the study also reported the information concerning the total land area, average yield and prices of the studied crops. The market prices of crops were originally reported in 2007 GBP and converted to 2007 Euro in the present study. Note that only the short-term economic impacts, i.e. the economic losses immediately after the flood event, are considered here.

Results

During the 2007 summer floods in the UK, the unprecedented flooding events in that area resulted in total economic damages estimated to be around €2.7 million over an area of 23,500 hectares of cropland that have been under water. The final estimated economic losses due to flood events in the UK are presented in Table 9. It is clear that economic losses during the flood events may differ depending on the crop type, which is interrelated with the SWR capacity of the cropland. Amongst others, wheat, barley and oilseed rape are the most valuable crops, therefore the associated value losses are also huge. However, total value losses during the flood events depend largely on the size of the affect area and the market value of the damaged cash crops. The per hectare damage value estimates can be extrapolated to other EU countries once precise information on crop price and productivity will be available at country level.

<table>
<thead>
<tr>
<th>Type of crops</th>
<th>Total area under flood (ha)</th>
<th>Average yield (t/ha)</th>
<th>Crop Price (€/100kg, 2007)</th>
<th>Average crop value (€/ha, 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>11 800</td>
<td>7.3</td>
<td>19</td>
<td>139</td>
</tr>
<tr>
<td>Barley</td>
<td>3 000</td>
<td>5.7</td>
<td>18</td>
<td>100</td>
</tr>
<tr>
<td>Other Cereal</td>
<td>400</td>
<td>5.5</td>
<td>16</td>
<td>88</td>
</tr>
<tr>
<td>Potatoes</td>
<td>1000</td>
<td>3.0</td>
<td>1</td>
<td>44</td>
</tr>
<tr>
<td>Fodder Crop</td>
<td>1 200</td>
<td>3.0</td>
<td>3</td>
<td>88</td>
</tr>
<tr>
<td>Other Crops</td>
<td>3 000</td>
<td>3.0</td>
<td>26</td>
<td>79</td>
</tr>
<tr>
<td>Oilseed rape</td>
<td>3 100</td>
<td>3.0</td>
<td>35</td>
<td>105</td>
</tr>
</tbody>
</table>

Note: 1. Approximate areas of agricultural land under flood in June/July 2007 by crop type. Data derived from the ADAS (2007); 2. value reported in ADAS (2007) was converted to Euro at rate: £1 = €0.46

As highlighted earlier, the (mis)management of the soil and/or agricultural practices in the area has decreased SWR, with subsequent increases in run-off, thus contributing to aggravating the damage of very intense and unprecedented rain in that area. If the SWR had not been decreased to the extent that it was decreased in that area over the past year, one could reasonably have expected that the damage costs could have been lower. This implies
that although it is not possible to quantify such cost reduction in this report and although in this specific case, one may assume that even the best SWR capacity may not have prevented that disaster, but it can effectively mitigate the damages to certain extent, even in the case of extreme weather conditions. In other words, if actions have been taken to improve the SWR capacity on arable lands, then the total area that could have been affected by flood can be reduced and the consequent economic losses can be minimised.

Nevertheless, the project team is aware that the consequences of a flood event depend on multiple factors that are not included in the present estimation, such as frequency of flooding, duration of event, level of water and seasonal distribution of flooding. For example, a flood event of relative short duration may have a limited impact on cereals in winter, but in summer, it may totally destroy a crop ready for harvest (Morris et al., 2010). Furthermore, in addition to the direct instantaneous damage (e.g. crop loss and yield reduction just after flooding) and direct induced damage (e.g. loss of added value due to the loss of yield in the first years after replanting perennial plant material orchard, vineyard later after flooding), there is also the indirect damage that is larger than the farm scale (i.e. at regional or national scale). Therefore, to obtain a precise estimation of the magnitude of the actual damages of a flood event, it is important to conduct a site-specific valuation to factor in all damages types.

5.1.2 Grassland

**Approach**

In order to obtain an estimate of the economic impact of flood events on grassland, the marginal damage costs of flood on grassland derived from in a previous study on the 2007 flood in the UK is used (Penning-Roswell et al., 2005). This cost has been computed to include only the value of replacement feed for the grazing animals due to damages of flood on the grass production. Therefore, the total economic damages on grassland affected by flood event can be estimated by multiplying the marginal replacement cost by the total affected grassland area. For simplicity reasons, it is assumed that the value of this indicator calculated for the UK is valid for all EU countries, but separate calculations should be made for each country to obtain more precise estimates.

**Results**

Using the approach described above, Morris et al. (2010) estimated marginal economic losses due to grassland damages caused by a flood event at €292/ha in the UK. It is important to note that this value estimate of damage cost does not include costs due to replacement of animals for example, and thus represents an underestimation of the economic impacts. Same as in the case of arable land, the per hectare damage value estimates can be extrapolated to other EU countries once precise information on crop price and productivity will be available at country level.
5.1.3 Forest land

**Approach**

Considering that a flood is unlikely to damage the wood supply of a forest in its totality, the project team has decided to restrain the economic impact evaluation to the cost of a flood on the recreational services of a forest. To estimate the economic damages due to the loss of recreational value of forest in a flood event, it is assumed that the forgone non-market recreational benefits provided by forests at country level equal to the potential economic damages due to the loss of this service that is provided disrupted forest during the flood event. In the scope of this study, the project team has employed the use of marginal value of forest recreational services provided by EU country to assess the magnitude of the total economic impacts at large. The value estimates of forest recreational services are obtained from a previous EU FP7 project - EXIOPOL (Giergiczny et al., 2008), which estimated the average amount of money that a EU citizen is willing to pay for preserving the recreational function of forest in Europe using a value transfer method.

**Results**

The final value estimates of marginal willingness to pay (WTP), which is measured in terms of €/ha/year for the selected 10 EU countries under high flooding risk are presented in Table 10. The highest marginal WTP for recreational services are found in the Netherlands, UK, and Belgium. The magnitude of total economic loss depends largely on the actual area of recreational forests being disrupted during the flood events and therefore should be estimated in a specific context. If

<table>
<thead>
<tr>
<th>EU Country</th>
<th>WTP (size, density, income, altitude) €/ha/year (1) (£2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>1.25</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>0.44</td>
</tr>
<tr>
<td>France</td>
<td>0.49</td>
</tr>
<tr>
<td>Germany</td>
<td>0.82</td>
</tr>
<tr>
<td>Italy</td>
<td>0.68</td>
</tr>
<tr>
<td>Poland</td>
<td>0.32</td>
</tr>
<tr>
<td>Romania</td>
<td>0.24</td>
</tr>
<tr>
<td>Spain</td>
<td>0.35</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1.40</td>
</tr>
<tr>
<td>UK</td>
<td>1.34</td>
</tr>
</tbody>
</table>

(1) Source: EXIOPOL project, 2008 (2) Source: data derived from FAO/FRA 2010 report. The forest area reported here concern only the forest’s designated function is under conservation category. For three countries, France, Germany and Poland, the forest areas under conservation category are not reported in ‘ha’, but in percentage in FRA 2010, we therefore made the estimates on our own.
It is however important to note that the present economic impact assessment caused by flooding in forests do not take into account the direct monetary losses such as the foregone revenues that could have been generated from tourism activities in association with the forests without disruption by the flood event. Moreover, other possible economic impacts are excluded from the present study, including direct monetary loss due to damages on public or private properties on the forestland and other intangible damages of human health to the population in the affected areas. Therefore, the actual economic impacts of flood in forest are most likely to be higher than the estimates made in this study.

5.1.4 Urban land

Approach

The flooding of urban areas can be caused not only by flash floods, river and coastal floods, but also by reduction of infiltration and drainage through urbanisation (e.g. buildings, pavement of roads, etc.). The economic impact associated with urban flood has risen substantially over the past 20 years (Genovese, 2006). The magnitude of the damage and thus its associated economic impact of floods in urban areas depend on a set of factors, such as the total affected population and their income, as well as the prominent functionality of the urban area, i.e. whether it is major touristic city, industrial city, or residential city.

To estimate the economic aspects of flood damages in urban areas, the present study considers only the direct costs due to the physical damages to capital assets and inventories, valued at same-standard replacement costs. These include damages to residential uses (residential properties), commercial and industrial facilities (warehouses, industrial buildings, etc.), transport network (flooding of roads, railways, structural damages to bridges), which then allow us to obtain an aggregated value for different cities. Due to the complexity of the economic assessment, intangible losses such as loss of human life are not taken into consideration in this study. Car damages, which can represent a non-negligible part of the damage costs, will not be considered in this study either, due to the lack of data.

In order to provide a realistic and plausible estimation of economic impacts of floods on urban land, the project team has decided to focus on several past flood events occurred in four European regions for which adequate data have been found in previous studies. These include: the Prague region in Czech Republic, the Po river basin region in Italy, the Itteren and Borghaven region in the southern part of The Netherlands, and England in the UK [see case studies n°14 – 17 in Annex 1]. These areas all have different characteristics concerning their urban land use, representing one or more functionalities, including touristic, industrial and residential functions of an urban land, which therefore could show that the magnitudes of economic impacts of floods in urban area depending very much on the city functions.

Results

Final estimates of the economic impacts on the selected four regions are presented in Table 11 below. The reported damages show that the total area affected by flood and the prominent functionality of the city has a significant impact on the magnitude of the economic damages. In comparison, the highest economic losses, estimated at over 9 billion €, are registered for the 2000 flood in Po river basin region of Italy, which is an essential economic hotspot with higher value for
commercial land. However, the estimates may be higher if counting for many other intangible damages, such as the lost human life and physiological damages.

Table 11: Economic damages due to floods in urban areas

<table>
<thead>
<tr>
<th>EU region</th>
<th>Flood event</th>
<th>Flooded floor surface (m²)</th>
<th>Type of city / region</th>
<th>Residential damage costs (€/m²)</th>
<th>Commercial/industrial damage costs (€/m²)</th>
<th>Transport damage cost (€/m²)</th>
<th>Total estimated damage value (€/m²)</th>
<th>Total loss (Bn€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech Republic (1)</td>
<td>2002</td>
<td>&gt;1000</td>
<td>touristic and residential</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>Italy (2)</td>
<td>2000</td>
<td>86 850</td>
<td>industrial and residential</td>
<td>618*</td>
<td>475*</td>
<td>20*</td>
<td>1,113*</td>
<td>9.44</td>
</tr>
<tr>
<td>The Netherlands (3)</td>
<td>1995</td>
<td>1 600</td>
<td>residential</td>
<td>1 861.9</td>
<td>15.74</td>
<td>68.07</td>
<td>1 945.71</td>
<td>0.71</td>
</tr>
<tr>
<td>UK</td>
<td>2007</td>
<td>n/a</td>
<td>Residential and commercial</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>4,62-5.92</td>
</tr>
</tbody>
</table>

* The values are calculated for a hypothetical flood event causing maximal damage.
(2) In the Po region. Amadio (2012).
(3) In the Itteren and Borghaven region. Vrisou van Eck and Kok (2001)
(4) In England. UK Environmental Agency (2005)

5.2 Impacts of droughts

Compared to the impacts of floods, droughts are more progressive, spatially extended, cover a longer time span, and often do not result in as many structural losses as floods, thus assessing their economic consequence is more complex and less straightforward. The economic impacts of droughts for arable land and forests are estimated below. Economic impacts for grasslands and urban areas could not be estimated in this study.

93 To assess the economic impacts of drought on grassland, it is assumed that during a drought year, the natural regeneration of grass for animal feeding may be disrupted, therefore the farmers will have to increase the use of concentrates to maintain the level of animal production, which may result in higher operational costs than a normal year. This additional costs could be used as an indicator to assess the economic impacts of the drought on grassland. Although extensive data sources, including the Eurostat, were reviewed by the project team, the quality and quantity of the data were not good enough for conducting the expected economic assessment. Further data will be needed for investigating the associated economic impacts on grassland.

As regards drought in urban land, it is excluded from the current study because of the complexity to link increased water consumption or water scarcity in urban area with drought caused by a disruption in SWR capacity. Water supply in urban area, in particular big capital cities in Europe usually relies on more than one sources of water reservoir and is planned with back-up solutions to deal with emergency situations, such as drought alarms. Depending on the capacity of a municipality to handle its water supplies, the incurred economic impacts may vary. Moreover, increased water consumption is caused by many other factors, including the standard of living, the expansion of the urban population,
5.2.1 Arable land

In order to estimate the economic impacts of drought events in Europe on the production of arable land, the project team has looked into the total yields of a variety of climate sensitive crops for a period of 9 years between 2001 and 2009. In particular, the data sources with respect to the yields of selected crops used in this study were taken from various sources such as Eurostat and FAOSTAT, including common wheat, durum wheat, rye, barley, maize, and dried pulses. Furthermore, to investigate on the correlation between the droughts and yields of the crops, the data on production were mapped with the climate data regarding the annual average temperature and precipitation observed in Europe for the same period of time. The results regarding the correlation between yields of the selected crops and the two climate parameters, temperature and precipitation are presented in Figure 38 (left and right).

Despite data scarcity, the mapping in this figure could show some interesting insights. For instance, it shows consistently that low precipitation rate and high temperature (both of which are typical indicators for a drought year) could pose negative impacts on the overall productivity of the lands. This is particularly clear for the year 2003, when a large scale of European continent has suffered severely from drought impact, in terms of a sharp decline in the productivity of many temperature sensitive crops per hectare of land. This thus results in an economic loss with respect to the previous year. To estimate these economic impacts in monetary terms, we have calculated the reduced yield after the drought, by comparing the average productivities of climate sensitive crops for 27 EU MS reported in both 2002 and 2003. Furthermore, the marginal economic loss of each crop (measured in €/ha) can therefore be estimated by multiplying the reduced productivity by the price of the crop.
Chapter 5: Economic implications of SWR capacity disruption

Results

The estimated results are presented in Table 12. Among others, the highest economic losses are observed for maize, estimated at 138.2 €/ha, which were directly lost after the 2003 drought event. Other essential climate sensitive crops include common wheat, durum wheat and rye, whose marginal economics losses were estimated at 56.7, 41.9, and 51.7 €/ha, respectively; followed by Barley and dried pulses, which account for 21.1 and 15.1 €/ha economic damage at the margin. The total economic damages depend on the total area of land occupation for each of the specific crops. Nevertheless, it shall be noted that the impact of droughts goes beyond the loss of a cash crop. Broader socio-economic impacts may include farmers giving up their business and affect the farming industry losing their customers.

Table 12: Estimated economic impacts of drought on arable lands

<table>
<thead>
<tr>
<th>Type of crops</th>
<th>Reduced productivity in 2003 (%)</th>
<th>Reduced productivity in 2003 (100kg/ha)</th>
<th>Average price * (€/100kg, 2007)</th>
<th>Estimated economic loss (€/ha, 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common wheat</td>
<td>-9.2%</td>
<td>-4.7</td>
<td>13.1</td>
<td>61.8</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>-11.7%</td>
<td>-3.0</td>
<td>15.2</td>
<td>45.6</td>
</tr>
<tr>
<td>Rye</td>
<td>-15.5%</td>
<td>-4.9</td>
<td>11.5</td>
<td>56.3</td>
</tr>
<tr>
<td>Barley</td>
<td>-4.5%</td>
<td>-1.9</td>
<td>12.1</td>
<td>23.0</td>
</tr>
<tr>
<td>Maize</td>
<td>-17.1%</td>
<td>-10.9</td>
<td>13.8</td>
<td>150.5</td>
</tr>
<tr>
<td>Dried pulses</td>
<td>-7.2%</td>
<td>-1.3</td>
<td>33.5</td>
<td>16.4</td>
</tr>
</tbody>
</table>

NB: *The estimation was made based on 2003 market prices of crops, and then adjusted to 2007 value using Consumer Price Index (CPI).

To sum up, our results show that drought can have prominent impacts on the yields of many climate sensitive crops in Europe. However, the magnitudes of these impacts may vary depending on the type of crops and their respective commercial values. Moreover, it is also important to note that in the correlation between yields and drought is not clear for year between 2005 and 2009 mainly due to the poor data quality reported in Eurostat, as large number of countries show missing data for this period of time. Therefore, project team suggests that better data need to be gathered from reliable data sources to further improve the preciseness of the estimates and draw concrete conclusions regarding the potential drought impact on arable land in Europe. Finally, the project team is aware that other indirect economics costs, such as additional costs of increased demand for irrigation water in the drought period and costs of drought impacts on human health are excluded from the reported values, as their complexity is going beyond the scope of the present study. For this reason, the reported economic impacts shall be perceived as a lower-bound estimate of the total economic damage.
5.2.2 Forest land

In order to estimate the economic impacts of drought events in Europe on the production of forest land, it is assumed that higher temperature and lower precipitation of a drought year may lead to higher probability of forest fire risk. Figure 39 illustrates this correlation for 2011 in Poland (JRC, 2011). This is a very simplified assumption, as forest fires are not necessarily a consequence of droughts, but rather due to arson.

Figure 39: Number of forest fires according to air temperature, precipitation and relative air humidity for 2011 in Poland

Therefore, the economic impacts associated with drought may be assessed by assuming that if the forests are burnt down, the tangible economic damages will be the lost timber production that could have been harvested on the forestland. To estimate this damage, the project team has looked into various data sources regarding the total forest area used for timber production, the
average percentage of the forest burnt annually in 7 selected countries, and the average productivity of roundwood (m$^3$/ha) on forestland in those countries. By combining these data together, it is possible to approximate the total loss of timber production on the burnt down forestland and thus their associated economic values. In the present study, various data sources have been exploited. The data with respect to total forest land areas dedicated for timber production were derived from FAOSTAT; the data regarding timber production and prices of roundwood were derived from Eurostat; and the data regarding the percentage of burnt down forest land area were taken from CORINE Land Cover (CLC) database.

**Results**

Table 13 presents the estimated economic impacts due to the loss of timber production on burnt down forests caused by forest fires in 10 selected countries. As expected, the three countries in the Mediterranean Europe suffer the most from forest fire, and total estimated economic losses due to the loss of roundwood production only range from 1,628 to 4,877 and 4,333 Million€ for France, Italy and Spain, respectively. Drought due to SWR may lead to higher probably of having forest fires in these countries, which thus implies subsequent economic impacts. However, it is important to note that the actual economic impacts are likely higher if taking into account the lost properties, other assets and human life during the forest fire.

<table>
<thead>
<tr>
<th>Countries</th>
<th>Burnt down forest* (ha, 2011)</th>
<th>Average price of roundwood** (€/ha, 2007)</th>
<th>Estimated economic loss (Mn€, 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>340</td>
<td>480 089</td>
<td>163</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>403</td>
<td>306 626</td>
<td>123</td>
</tr>
<tr>
<td>France</td>
<td>4 114</td>
<td>412 971</td>
<td>1 699</td>
</tr>
<tr>
<td>Germany</td>
<td>214</td>
<td>386 921</td>
<td>82</td>
</tr>
<tr>
<td>Italy</td>
<td>12 938</td>
<td>39 336</td>
<td>5 090</td>
</tr>
<tr>
<td>Poland</td>
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<td>1 482</td>
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** source: self-estimation based on the data of roundwood production and value derived from Eurostat and total forest area designated for timber production derived from FAOSTAT. The value was originally reported for year 2005, and then adjusted for 2007 using CPI.

*** Eurostat 2010
5.3 Synthesis and discussion

SWR related phenomena (droughts and floods) can cause significant socio-economic impacts. In order to provide a comprehensive and plausible estimation of such damages, the project has reviewed extensively the existing literature and collected a large amount of data from various data sources for the selected indicators at either MS level or specific case study level.

The magnitudes of the flood impacts depend on a wide range of factors: the location of the flood, the size and duration of the flood, the economic activities disrupted during the flood, the income of affected population, etc. Due to the extremely limited data at the EU level and modelling capacity by the time when this project has been conducted, the project team decided to investigate in-depth the 2007 summer floods in the UK, in order to demonstrate to what extent the decreased SWR can contribute to aggravating the damage of very intense and unprecedented rainfalls in that area. This case study focused on the impacts of floods in the agriculture based on a real-time economic impacts assessment study after the flooding season, together with the climatic ECHAM5-r3 data we used for the climatic trends in Chapter 3. During the 2007 summer floods in the UK, the unprecedented flooding events in that area resulted in total cost damages estimated to be around €2.7 million over an area of 23,500 hectares of cropland that have been under water. The (mis)management of the soil and/or agricultural practices in the area has been shown in Chapter 4 to decrease SWR, thus contributing to aggravating the damage of very intense and unprecedented rain in that area. If the SWR had not been decreased to the extent that it was decreased in that area over the past year, one could reasonably have expected that the damage costs could have been lower. Although it is not possible to quantify such cost reduction in this report and although in this specific case, one may assume that even the best SWR capacity may not have prevented that disaster, but it can effectively mitigate the damages to certain extent, even in the case of extreme weather conditions.

In terms of flooding impacts on the urban land area, we have selected four post-flooding studies in different urban areas. For instance, damages for the 2000 flood in Po river basin region (Italy), which is an essential economic hotspot with higher value for commercial land, were estimated at over 9 billion€ for a total affect area of 86,850 m²; whereas the damages to the 1995 flood in the Itteren and Borghaven region of the Netherlands were much smaller, estimated at 0.71 billion€ only, due both to its relatively lower commercial value of the land and the much smaller area affected by the flood (1,600 m² only). To gain precise estimation of the flood damages, it is important to focus on specific areas or cities. It is important to note that flood damage is incalculable and the results presented in this study represent the lower-bound of the possible economic impacts, as many intangible damages, such as the lost human life and physiological damages are excluded from the study. Finally, in addition to the directly determinable losses, the indirect potential losses from unproductivity in many areas - in agricultural, in business, in trade, and in commerce, may be added to the total damage. All these losses can wipe out whatever gains that may have been achieved in economic development. In other words, precise quantifiable damage is always difficult to estimate. This result implies that although it is not possible to quantify such cost reduction in this report and although in this specific case, one may assume that even the best SWR capacity may not have prevented that disaster, but it can
effectively mitigate the damages to certain extent, even in the case of extreme weather conditions. In other words, if actions have been taken to improve the SWR capacity on arable lands, then the total area that could have been affected by flood can be reduced and the consequential economic losses can be minimised.

As regards droughts, they have noticeable economic effects on a range of important economic sectors in Europe. However, the economic assessment of this impact is less straightforward compared to flood, as droughts are more progressive, spatially extended, cover a longer time span, and often do not result in as many structural losses as floods. Some sectors are affected for some time (years) after the drought has passed, which however could not be tackled in the present study due to the lack of data and model scenarios. In this study, only part of the economic impact of drought is captured, in particular, only the potential impacts on crop productivity and timber production are estimated. For instance, our results show that drought already have prominent impacts on the yields of many climate sensitive crops in Europe. The magnitudes of these impacts may however vary depending on the type of crops and their respective commercial values. Among others, the lost highest marginal land values during the 2003 drought event in Europe are observed for maize production, estimated at 138.2€/ha. Thus, the total direct losses shall be estimated for the total area of arable land affected by the drought event. Nevertheless, many other impacts, such as for grassland and urban land, are excluded from the present economic assessment due to a lack of data. It is therefore recommended that additional efforts therefore should be made to improve the data availability at the Member States level, in order to allow for producing more complete estimates and aggregations as a basis for EU policy decisions. Finally, the value estimates made here are lower-bound estimates, as many other indirect economics costs, such as additional costs of increased demand for irrigation water in the drought period and costs of drought impacts on human health are excluded from the reported values, as their complexity is going beyond the scope of the present study.

We acknowledge the limitations of the estimated economic impacts and recommend that the readers interpret results with caution. In particular, the reported figures by no means shall be understood as the solo economic impacts caused by SWR, neither should it be interpreted that the economic damages of flood and drought are mainly caused by changes in SWR. The efforts in estimating the economic implications of SWR should rather be viewed as an indication of the economic potential of the improvement of SWR. That is if the overall capacity of SWR in Europe is improved, then this may decrease the frequency or the scales of damages caused by flood and drought events, and therefore reduce the economy-wide economic losses.
Today, most of the EU has to cope with the degradation of SWR capacity that occurred in the last decades following land use trends and agricultural practices (leading to soil sealing, compaction, erosion and loss of organic matter). This degradation affects the provision of the multiple services dependent upon the soil and water, such as flood and drought mitigation. Despite overall increases in water efficiency, the substantial environmental and socio-economic impacts related to dramatic flooding events – such as those that recently occurred in Central and Eastern Europe - and to water shortages give reason to consider more closely the impacts of our current development on SWR capacity and on the related resilience of natural ecosystems in rural and urban areas. This is all the more important as the full effects of recent trends are still to come and as future trends project further degradation of SWR capacity in some EU regions, in particular in Mediterranean countries.

As detrimental land use changes are difficult to reverse, there is an urgent need to integrate issues related to SWR capacity into land use planning. Furthermore, because different management practices within the same land use type can have substantial impacts on SWR capacity, it is essential to promote the implementation of more sustainable alternatives. Agriculture, which relies heavily on soil water, has a key role to play in the maintenance or enhancement of the overall SWR capacity at the EU level through the promotion of alternative soil management and cultivation practices compared to those generally implemented in intensive systems. Urban areas also present opportunities to mitigate the impacts on SWR capacity associated with soil sealing and compaction, although they might require more substantial economic investments.

Possible future steps

Improvement of the knowledge base

Current hydrological tools have a limited ability to assess non-linear effects of multiple factors (e.g. climate, geologic, anthropogenic) at the catchment scale, including the spatial organisation of different land uses and the roles of linear features. There is a need to further improve modelling capacity in order to be able to quantify the specific contribution of SWR capacity on floods and drought, and on other ecosystem services.

Additional efforts should also be made in order to improve the availability of economic data at the Member State level, in order to be able to produce more complete estimates of impacts of different land uses and management practices, as a basis for EU policy decisions.

Promotion of good practices

An "optimal" SWR capacity - as the capacity to retain water within the soil yet in a form allowing water and air exchanges and to deal with large water quantities during wet periods - can be

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95 The economic analysis in this study is limited to the damages caused by floods and droughts in different types of catchments. In the scientific literature, there is a lack of economic data and analysis which relate directly to the soil water retention capacity and this preliminary assessment is based on broad assumptions.
Concluding remarks

achieved through ensuring a balanced pore-size distribution, good soil stability (to prevent compaction) and soil surface permeability (to ensure infiltration). There is no one-size-fits-all approach for maintaining or improving SWR capacity, but rather a range of possible options, which can be implemented based on the catchments specificities, in particular in the countries identified as representing a concern through the modelling. Key following principles for improving or maintaining SWR capacity can, however, be shared, based on the results of the study.

At the landscape level:

- limiting the conversion of land uses with high SWR capacity (forests, grasslands, wetlands) to land uses with lower SWR capacity (agricultural land, urban areas), and in particular avoiding urban sprawl;
- preventing building development in flood basins and discouraging any construction or works likely to form an obstacle to the natural flow of waterways that cannot be justified by the protection of densely populated areas;
- maintaining semi-natural areas and grasslands within agricultural areas as part of a wider landscape mosaic and as green infrastructures, and promoting re-vegetation where relevant to deliver regulating ecosystem services alongside other land uses;
- restoring floodplains and wetlands to benefit from their flood regulation functions.

In agriculture:

- mitigating the impacts of the use of heavy machinery, which is a key driver of soil compaction, e.g. through sound consideration of environmental conditions (avoid driving on soil with a water content above the field capacity), avoiding any unnecessary field operation, ensuring the tractor is properly balanced, avoiding oversized equipment, or ensuring the maintenance of equipment or limiting the load;
- mitigating the impact of tillage, through reduced tillage or tillage adapted to environmental conditions, such as contour tillage on slopes, while keeping in mind the possible rebound effects on the increased use of pesticide for weed control;
- promoting the return of organic matter to the soil, through organic amendment and crop residue management;
- better integrating the issue of SWR when designing crop rotations, which remains relatively untapped in the EU and represents a great opportunity for integrating alternative crops and soil management practices, in order to:
  - protect soil surfaces through soil cover throughout the year (e.g. winter rye; legumes such as peas and beans) and enhance soil structure through specific root systems, which increase the capacity and duration of infiltration (e.g. alfalfa), and
Concluding remarks

- Limit evapotranspiration, through the choice of species with limited water demand during periods of limited availability, whenever possible (e.g. winter vs. spring varieties);
- Optimise the use of soil water, through the choice of species with different rooting depths.

- Maintaining landscape features such as hedges and buffer strips along rivers, which help slow down water flows, and reducing the size of patches to optimise the hydrological functioning of the catchment.

In urban areas, in addition to better selecting development sites, impacts on SWR capacity could be mitigated by:

- Promoting integrated and compact cities, in particular in areas facing fast urban sprawl, such as in the suburbs of a big metropolis or in coastal areas. There, green areas should be maintained and managed to increase the temporary water storage during heavy precipitation and provide flood retention rooms. In old industrial cities and cities experiencing population shrinkage (such as in Central and Eastern Europe), the restoration of brownfields or other derelict land into green areas represents a promising opportunity;

- Promoting the development of permeable pavements and sustainable drainage systems, which slow down the response to heavy rainfall events, in already highly urbanised areas.

Better integration into policies

Soil and water are often tackled by separate environmental policies. Although an integrated approach of soil and water management is emerging in the EU, as illustrated in the Floods Directive 2007/60/EC\(^96\), the Communication "Addressing the challenge of water scarcity and droughts"\(^97\) or within the Thematic Strategy for Soil Protection\(^98\), the concept of SWR capacity could better promoted in the EU. It could benefit from being dealt with in a more integrated manner in agriculture and forestry management, as well as in urban development, and more generally in land use planning.

The EU has a direct role to play through the Common Agricultural Policy (CAP), as it can promote and financially support the implementation of practices that positively affect SWR. These include for example the implementation of good agricultural and environmental conditions (GAEC), which specifically address soil protection, including soil erosion, soil organic matter, soil structure and

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and protection of landscape features. The CAP reform 2014-2020 may contribute to maintaining SWR capacity, namely through crop diversification and the maintenance of permanent pasture.

In both rural and urban areas, the recent Green Infrastructure Strategy appears to be a promising instrument for valuing the ecological function of green areas, amongst which soil water retention capacity, and promoting it within and in the vicinity of cities.

Furthermore, the land communication to be published by the European Commission in 2015, which is thought to tackle both the issues of land take and soil degradation, would be a great opportunity to better highlight the services dependent on soil water retention.
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Soil and water in a changing environment

ANNEXES TO THE FINAL REPORT

DG ENV
27 June 2014
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DISCLAIMER

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Annex 1: Overview of the case studies investigated

A number of case studies were investigated to illustrate parameters, drivers and impacts of SWR capacity. They were selected in a manner so as to be representative of four land use types (urban areas, agricultural areas, forests and grasslands) and linked to extreme events related to SWR capacity (floods and droughts). They allowed complementing the findings from the literature review, through illustrative boxes. They also allowed collecting both scientific information on SWR mechanisms and economic data, which were further used in estimating SWR capacity trends and economic impacts.

Table 1 presents the list of case studies investigated along with their key characteristics.

<table>
<thead>
<tr>
<th>Theme</th>
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**Context**

- Some irrigation methods combined with tillage techniques can cause water quantity and quality changes that may favor soil compaction. This case study aims at presenting the impacts of subsoil compaction on soil water balance.
- Maize crops cultivated were irrigated three consecutive years (1991-1993) on a loamy sand soil by furrow with some sprinkler irrigations applied between planting and the establishment of the furrows.
- Tillage operations that were used include mouldboard ploughing to 20.5-30 cm depth after harvesting of maize crop, harrowing 15 cm deep (twice crossing the field) before sowing and application of the cultivator (15-20 cm depth) between crop row as secondary tillage.
- SWR, evapotranspiration and drainage below the root zone were determined experimentally or with the SIMWASER model.

**Conclusions**

Irrigation of crops combined with tillage practices may alter soil structure making it more fragile and more prone to...
In the case of a sandy soil, the development of a heavily compacted plough layer at 35–45 cm depth will cause only minor differences in soil water balance (ETP and drainage) as well as in yields of irrigated maize crops. However, compaction causes a noticeable reduction of total maize root depth (from 30 to 40%).

Even for the compacted case, the air filled pore volume generally does not reach values under 10%, which guarantees a sufficient aeration for roots.

### Case study

#### Impact of crop rotation on soil water balance in experimental plots in Brittany, France

**Context**

- This case study aims at determining the impacts of different agriculture practices and natural earthworm populations on the physical properties of soil.
- The results obtained for maize/grassland (1yr/3yr respectively) crop rotation were compared to those obtained for maize monoculture and old pasture with white clover and rye grass.
- In temperate regions, earthworms constitute the principal component in term of biomass: they have a large influence on soil physical properties (through their burrowing and casting activities) and their presence can be affected by agricultural management.

#### Identified effects of the tested agricultural practices on soil water balance

- Influence on earthworm community

  *Abundances of earthworms vary from one treatment to another: the highest abundance is found in old pasture and lowest in maize monoculture.*

  *In old pasture, earthworms are 5 time more abundant in comparison with maize fields. The community is dominated by endogeic (surface) earthworms (48%). The low abundance of epigeic (mid deep) species in the old pasture (10%) compared to the pasture phase of rotation (52%) may be explained by cattle trampling.*

  *The old pasture presents the highest diversity of earthworms. There are more individuals of the three ecological earthworm groups in the old pasture than under the rotation system.*

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<td>compaction.</td>
<td></td>
<td>Lamandé et al. (2003)</td>
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[2] Impact of crop rotation on soil water balance in experimental plots in Brittany, France

Lamandé et al. (2003)
### Case study

- **Influence on bulk density**

  *For the experimental plot where crop rotation was tested, measured bulk density: \(1.21 \text{ g cm}^{-3}\) for maize phase, \(1.26 \text{ g cm}^{-3}\) for pasture phase*

  *Bulk density in the old pasture: \(1.43 \text{ g cm}^{-3}\)*

### Conclusions

Both agricultural practices and earthworm communities have consequences and induce changes in soil properties. Pores and packing voids are important in controlling water flow and retention.

Earthworms, depending on species, enhance water infiltration in top or deep soil layers and stimulate root growth through their burrowing activities. Tillage practices may have for consequence the disconnection of water preferential flow paths such as earthworm burrows or cracks. The frequency of tillage operation is also an important factor to consider. For instance, continuous soil tillage causes or soil tillage every four years will not have the same impacts.
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<tr>
<td><strong>[3] Comparison of conventional or no tillage techniques on soil water balance in experimental plots, France</strong></td>
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<td>Gobin et al. (2011)</td>
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<tr>
<td><strong>Context</strong></td>
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<tr>
<td>• This case study aims at characterising the long term effects of two tillage systems on soil organic matter. The focus, here, will be made on the impacts of these agricultural practices on soil water balance</td>
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<td>• Reduction of tillage intensity has become increasingly popular over the last decade</td>
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<td>• Experimental plots were cultivated with a maize/wheat rotation testing conventional tillage (CT) (mouldboard ploughing at 20cm depth) or no tillage (NT) systems from 1970 to 2004</td>
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<td>• The same quantity of crop residues were integrated in the two systems, but crop residues were incorporated into the soil during tillage whereas those in NT always remained in the soil surface and has neither be burned nor removed from the plots</td>
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<tr>
<td><strong>Identified effects of no tillage systems on soil water balance</strong></td>
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<tr>
<td>• Decreased run-off water and soil evaporation and reduced field erosion</td>
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<td><em>NT systems imply letting crop residues on soil surface. Those residues form a protective layer that limit evapotranspiration and that makes soil surface less impervious, decreasing water run-off.</em></td>
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<tr>
<td>• Easier infiltration</td>
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<tr>
<td><em>Less impervious soil surface facilitates infiltration</em></td>
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<tr>
<td>• Bigger SWR</td>
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<td><em>In CT systems, stable aggregates and less sealed surface result in a bigger SWR (crop residues are incorporated mechanically into soil which makes the presence of mulch impossible)</em></td>
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<tr>
<td><em>In NT systems, less stable aggregates and more sealed surfaces result in a smaller SWR. However, the protective layer, makes soil surface less impervious. Thus more water enters into soil, less water evaporates and a better porosity granted by stable aggregates allows to stock this water. Eventually, SWR is bigger.</em></td>
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<tr>
<td>• Larger C-stock</td>
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<td><em>After 32 years, NT plots presented 5-15% larger C stocks in superficial soil layers compared to CT: mainly attributed to an improved macroaggregate formation in the 0-5cm layer due to higher SOM content and better protection of SOM (5-20 cm layer) due to a better proportion of small pores and lack of soil disruption by tillage.</em></td>
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Soil and water in a changing environment

Theme

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<td>or climate. This difference in C stocks decreases with depth.</td>
<td>Kertész et al. (2010)</td>
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Conclusions

In no-tillage systems, the soil is not entirely turned-over and is always entirely or partially covered by crop residues. The absence of both incorporated residues and soil displacement and fragmentation that occur during tillage provides a less heterogeneous soil structure and increases the amount of water stable aggregates, which results in less impact of intense rainfall events on soil structure. Besides, no-tillage increases runoff infiltration by slowing the flow of rainwater.

However, no-tillage systems may also entail several disadvantages compared to conventional tillage: it may increase the use of herbicides for weed control, surface mulch of residues may promotes the presence of parasites, soil compaction associated with no-tillage may cause problems for the establishment or emergence of some crops and increase runoff.

Other benefits of no-tillage are reduced field erosion, cleaner runoff water and decreased soil evaporation due to the protective crop residues layer.

[4] Impact of conservative tillage techniques on soil water balance in Dióskál, Hungary

Context

- This case study aims at studying the impact of conservative tillage methods
- Maize and wheat experimental crops were cultivated (maize and wheat are amongst the most representative culture in the EU-27)
- Conservation tillage consisted in direct drilling and if conditions were not appropriate, drilling was preceded by a shallow disking

Identified effects of conservative tillage on soil water balance

- Reduced soil loss
  
  *Average soil loss per year represent 2.44t.ha⁻¹ for conventional tillage and 0.08t.ha⁻¹ for conservative tillage*

- Reduced average run-off
### Theme

**Average run-off volume per year represent 453.8 m$^3$.ha$^{-1}$ for conventional tillage and 172.6 m$^3$.ha$^{-1}$ for conservative tillage (32% decrease)**

- More favorable conditions for earthworm populations which tend to improve soil porosity
- Larger C stocks and improved soil cohesion
  
  **Conservative tillage increases the presence of crop residues on the soil surface**

- Better soil moisture conditions
  
  **The difference between conservative and conventional plots diminishes below 20cm under the soil surface**

- Higher water storage
  
  +8.8% water content in the upper 20cm; +1.7% below 20cm

### Conclusions

By contrast with conventional tillage, conservative tillage preserves soil structure which is less heterogeneous due to the absence of incorporated crop residues and soil displacement and fragmentation that occur during tillage. It prevents the soil surface from forming a crusting layer that would be impermeable to water in case of extreme rainfalls. The conservative method increases the amount of water stable aggregates, which reduce the impacts of rainfall events on the soil structure.

The increase presence of crop residues on the soil surface tends also to increase C-stocks, which has for consequence a better soil cohesion. Concerning biodiversity aspects, conservation agriculture provides excellent food and habitat for micro-organisms, earthworms and insects offering better nesting sites and better food supplies for birds, small mammal and game populations.

**[5] Comparison of conventional and conservative tillage techniques impacts on soil water balance, Hungary**

**Context**

- This case study aims at studying the effects of different agricultural practices on soil water balance
- Tillage variants included: direct drilling, mouldboard ploughing, disking and loosening combined with disking
- Climate scenarios were represented through the cumulative probability function of the annual

**Main references**

Farkas et al. (2009)
Soil and water in a changing environment

**Theme**

- **Case study**
  - precipitation sum
  - crop sequence: winter wheat - maize during years 2001–2003; improved by catch crops (mustard, rye and pea). In 2003 maize, sown in winter wheat mulch was the main crop grown, after which rye was sown as a catch crop in half of the territory of each tillage treatment
  - Prevailing soil type is calcic chernozem, developed on loam, moderately sensitive to soil compaction
  - In 2003, disturbed samples and undisturbed soil cores of 100 cm³ were collected from each tillage in 3 replicates; from layers soil surface (0-5 cm), the cultivated layer (5-10cm), the pan (15-20cm) and the non-tilled layer (45-50cm), capacitive probes were also installed up to 80cm depth in each plot for continuous measurement of soil temperature and soil water content (4 times a day)

**Main references**

Identified effect of tillage systems and catch crop application on soil water balance

- Influence on soil bulk density and soil penetration resistances
  - *For all treatments except disking: lower bulk density, no differences between soil penetration resistances in the treatment without catch crop compared to the treatment with catch crop*
  - Influence on total soil water stored in the deeper layers (under 20cm)
    - *Ploughing had the lowest total soil content, then came loosening and disking, direct drilling and eventually, disking had the highest total soil content*

**Conclusions**

A statistical evaluation of main soil hydraulic properties was performed. Results showed that both tillage systems used in the experiment and the application of absence of catch crops had strong influence on soil structure and on the water and heat regimes of soil.

It was observed that catch crop application had valuable effect on topsoil properties and consequently on evaporation and infiltration characteristics of soil. The presence of catch crops in winter had favourable effects on soil structure, increasing the water holding capacity of the soil.

Concerning lower soil layers, the catch crop treatments were generally dryer in all tillage varieties except disking treatment due to rye water consumption. The total biomass of rye was significantly higher in the ploughing treat-
### Theme | Case study | Main references
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Soil and water in a changing environment

Case study

- **Main conclusion**
  - The direct drilling treatment provided more equilibrated soil water distribution within the profile due to more uniform root distribution enabled by the absence of tillage induced subsoil compaction (e.g. plough or disk pan).

- **One conclusion of this case study is that catch crop application can be an efficient measure for environment protection. However, further quantification of the soil water balance elements (including plant water uptake and transpiration) and water use efficiency would be needed to range the studied soil management systems to moisture conservation.**

**[6] Comparison of conventional and conservative tillage impacts on soil water balance, Poland**

**Context**

- This case study aims at assessing the effect of long term use of various tillage systems on pore size distribution, areal porosity, stained porosity and infiltration of silt loam eutric fluvisol and their effects on flow characteristics of water and solutes in soil.

- Four tillage methods have been compared: conventional tillage and three semi-conventional tillage methods (ploughing to 20 cm every 6 years and to 5 cm in the remaining years, harrowing to 5 cm each year and sowing to the uncultivated soil (no tillage)).

**Identified effects of conservative tillage on soil water balance**

- Lower cumulative infiltration
  
  *After 3 hours of water application, cumulative infiltration was the highest under conventional tillage (94.5 cm or infiltration rate of 17.0 cm h⁻¹) and it was reduced by 62%, 36% and 61% in semi-conventional tillage; corresponding reductions were similar compared with those after 10 min.*

**Conclusions**

Understanding the relations between pore structure induced by tillage and infiltration is of crucial importance in predicting flow characteristics of water and solutes in the soil profile. Important parameters that will affect infiltration rate are pore size distribution and continuity of pores or pathways.

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<th>Lipiec et al. (2005)</th>
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<td>The results on infiltration rates contrasts with the results of the previous case studies that tend to show that pores in conservative soils can be more effective in transmitting water than in conventional tillage thanks mainly to the protective effect of crop residues against crusting and increased pore continuity. Greater infiltration of soil under conventional tillage than semi-conservative or non tillage techniques in this study can be due to relatively high soil organic matter and associated low susceptibility to sealing that could stop the entry of water to the high interaggregate flow-active porosity in conventional tillage. The sampling of treatments may induce some uncertainties.</td>
<td>Gobin et al. (2011)</td>
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<td><strong>[7] Impacts of the frequency and dose of compost application on infiltration and soil water content in experimental plots in Belgium</strong></td>
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| Context | - In Belgium, arable soils have lost 25% of their SOM reserve during the past three decades  
- Compost is an excellent source of organic matter and can be used as soil amendment.  
- The study aims at quantifying the effects of compost, applied as a fertilizer, on soil quality in terms of chemical, physical and biological soil properties, and the consequences on soil water retention.  
- 3 types of compost are compared: VFG-compost, green compost and Humotex  
- Compost trials were made on arable crop rotations, fodder crops, maize crops, vegetables, organic farming at different places in Belgium. |                  |
| Identified effects of compost on soil water balance | - Larger C stocks  
a yearly application of 45t/ha of compost for 12 years may double C content in a loamy soil  
- Bigger support of earthworm population than mineral fertilized soils and thus increased porosity and reduced bulk density  
aggregates porosity is multiplied by 2  
- Increased infiltration rates and reduced run-off  
infiltration rate increases 5 to 10 times, and run off rate decreases under relatively small compost application |                  |
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<td>Increased SWR: compost can retain between 80 to 115 litres of water per ton, and that compared to the application of mineral fertilisers, the SWR capacity improved by 10-40 litres of water per m³ soil (at respectively 15 t and 45 t VFG-compost/ha/yr) in a loamy soil after 9 year application</td>
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<td></td>
<td>Reduced field erosion for a wide range of precipitation intensity compared to mineral fertilisation 20-30% lower erosion or 1 – 1.2 t/ha lower even for small compost quantities. For instance, an application of 25 t green compost /ha resulted in 20 to 25% less wash erosion and 50 % less splash erosion</td>
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**Conclusions**

Compost application increases soil C content, especially in aggregates, thus preserving porosity and increasing the aggregate stability. The effect of soil cover due to compost application can also play a valuable role in limiting field erosion for a wide range of precipitation intensity compared to mineral rainfall. Moreover, composting boosts earthworms’ density and biomass, which also contributes to improving soil porosity.

The results showed an improved SWR capacity. Compost application has thus an important impact in terms of maximum infiltration capacity. However, this result is not as interesting in terms of plants available water as the difference in water content is mostly observed at near-saturation conditions.

[8] Impacts of afforestation practices on soil water balance in Finland

**Context**

- Afforestation of agricultural land has been an important land use change in Finland in recent decades
- This study aimed at assessing potential of former agricultural soil for the production of tree crops; the focus here, will be made on the soil characteristics of the afforested sites
- SWR characteristics, bulk density, organic matter, and particle-size distribution were studied in soil on afforested agricultural soils (mainly mineral soils) in western Finland
- The study sites were chosen randomly from among fields afforested with Scot pine; at the time the sample plots were established, the ages of the plantations were 11-12 years or 19-20 years

Wall et al. (2003)
### Theme

- Undistributed core samples were taken from different soil depths (5-10, 15-20, 25-30 and 35-40cm) at 38 profiles on 23 sites.
- The results of this study were obtained several years after afforestation, thus the soil properties may have evolved and changed since afforestation. Caution is thus needed when applying the results to agricultural land still under cultivation but subject to afforestation in the future. However, the effects of trees on soil properties were considered minor due to the young age of the sampled plantations.

### Conclusions

Cultivation of agricultural land alters physical properties of the soil. According to this case study, former agricultural soils are characterised by high organic matter content, fine texture, gleyic properties and low air filled porosity. These properties are partly inherent to soils chosen for agriculture and to agricultural practices.

Forest sites that are more fertile are more common on fine-textured soils. Thus, the fine-textured soils in former agricultural land would have a high yield potential for growth of forest trees. However, the gleyic properties of these lands suggest prolonged period of saturation during the year. In this case, a high water table by filling the pore space will have consequences low soil aeration and reduced tree growth. Effective drainage or soil mounding are thus required prior to afforestation in order to maintain favourable conditions for trees growth (larger pores and increased distance to groundwater level).

### Case study

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<tr>
<td>[9] Impacts of soil tillage in soil water balance in case of extreme weather and hydrological situations in Hungary</td>
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<tr>
<td>Farkas et al. (2009)</td>
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</table>

### Main references

- Farkas et al. (2009)
conserving soil management systems.

**Conclusions**

Uniform, overstandardized adaptation of tillage methods for soil moisture conservation is rather risky. Their application needs special care and the future is for site-specific precision technologies. Combination with catch crop application can change the soil water regime and the water could penetrate below the plough pan layer, due to improved soil structure and root channels. The catch crops also result in higher and lower soil water contents in the topsoil and subsoil, respectively.

The results of this study may be much relevant to the Chernozem soil which is dominantly found in Eastern Europe.

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<tr>
<td><strong>Context</strong></td>
<td>This case study aims at understanding the consequences of urban sprawl on water balance. The focus, here, is made on the effects on soil water balance.</td>
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<td>• Several large-scale changes in land use in Leipzig since 1870</td>
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<td>• Evolution of soil imperviousness in Leipzig: in 1870 land surface was mainly covered by arable land and forest (89% of the city area), the city has rapidly undergone a huge development, after WWII, the city has experienced a little urban sprawl and impervious cover increased by 19% between 1945 and 2003.</td>
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<td><strong>Identified effects of soil sealing on soil water balance in Leipzig</strong></td>
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<td>• reduced evapotranspiration and contribution to the heat island effect</td>
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<td>average evapotranspiration has decreased of 25% from 1870 to 200</td>
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<td>evapotranspiration decreases with an increase in impervious surface: in areas with a share of impervious land of 0-20%, evapotranspiration rates range from 351-550mm.yr^-1, in areas where the share of impervious land is very high, from 80-100%, evapotranspiration range from 151-200mm.yr^-1 (or a decrease of approximately 40% between poorly and highly covered surfaces)</td>
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<td>reduced evapotranspiration will participate to the heat island effect by disrupting the cooling regulation effect of evapotranspiration, resulting in and increased soil surface temperature</td>
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<td>reduced seepage rate and groundwater storage</td>
<td>Perry and Nawas (2008)</td>
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<td>from 1870 to 2003, infiltration rate has decreased of 4%</td>
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<td>increased peak discharge rate, total runoff volume and stream flashiness (flood recurrence)</td>
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<td>reduction in groundwater recharge and decline in effective evapotranspiration will participate in increasing water runoff</td>
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<td>in Leipzig, total runoff volume have increased of 282% from 1870 to 2003</td>
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**Conclusions**

Soil sealing modifies natural water cycle by reducing soil surface permeability. It greatly increases water run-off (+282% increase in the case of Leipzig), increasing also the risks of urban flooding in the event of heavy precipitation. In contrast, groundwater recharge rate is only slightly affected (about -4% decrease). If water infiltration is limited under sealed surface, neighbouring areas of good infiltration capacity will, however, be affected by the increased surface run-off and may experience higher groundwater recharge.

**[11] Impacts of cumulative soil sealing on soil water balance in Leeds, UK**

**Context**

- This case study aims at studying the impacts of cumulative soil sealing on soil water balance
- Aerial photographs were taken from 1971 to 2004 and were used to map changes in impervious cover of a 1.16km² suburban area of Leeds; a 13% increase in impervious surfaces was observed of which 75% was due to paving of residential gardens (accounting for 9.5% of the total land in the study area); the L-THIA was used to estimate annual runoff variations over the study period and for 4 soil types groups with different infiltration rates

**Identified effects of soil sealing on soil water balance in Leeds**

- increase in run-off volumes per year
  - an increase 13% in the impervious surface area over 33 years led to 12% increase in annual average run-off over the period of the study: in 1971, the impervious area accounted for 56% of the total runoff, in 2004 it...
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<td></td>
<td>accounted for 66%</td>
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**Conclusions**

The increase in runoff is explained not only by the lower levels of infiltration into the soil but also by the reduced evapotranspiration and storage from vegetation. The runoff change is dependent on the soil type of the area to be paved and its infiltration rate. Soil types with low infiltration rates, will have lower increase in runoff levels due to increased imperviousness whereas for soil types with relatively high infiltration rates, any paving will result in larger runoff increase.

In Leeds suburban, although impervious gardens represent an area of 0.11km², the increase in soil imperviousness has progressively led to an increase of 12% in runoff. Cumulative small scale soil sealing has the potential to cause serious urban flooding issues. The main difficulty for the authorities involved in flooding and drainage management relies on the fact that the paved area is not paved as a single plot and is thus more difficult to detect.

**[12] Impact of soil imperviousness on soil water balance in the UK and US**

**Context**
- In the city of Dayton, US, Smith (1984) carried out a comparison of water runoff occurring for two different surfaces on similar car-parking areas (one grass-concrete car-park with one gully to receive water runoff and impermeable asphalt car-park with several gullies to ensure drainage).
- In Nottingham, UK, Pratt et al. (1995) compared storwater discharges of a small elemental permeable block-surfaced car-park that was completely enclosed within an impermeable membrane with traditional impermeable surface. The outflow was limited to flows from sub-bas drains and to evaporation from the surface.

**Identified effects of soil sealing:**
- In Dayton, run-off volumes from grass-concrete car park ranged from 0-35% of the runoff from the asphalt surface (mean value 10% for eleven storms; no runoff at all from four of the eleven).
- In Nottingham, the small elemental permeable car-park showed a reduction of the volume of stormwater discharged during a period of rainfall of 40% of total discharge as compared with the performance of tradi-
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<td>tional impermeable surfaces (which discharge close to 100% runoff within the storm duration)</td>
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<td><strong>Conclusions</strong>&lt;br&gt;Soil sealing impact on water runoff depends on soil type. More permeable soils will make water infiltration easier, thus decreasing water runoff.</td>
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<tr>
<td><strong>[13]</strong> Impact of urban expansion into floodplain on soil water balance in Dresden, Germany</td>
<td><strong>Context</strong>&lt;br&gt;- Expansion of settlement areas and growth of impervious cover in floodplains over the past century&lt;br&gt;- Flash flood episode in 2002 that caused several casualties and large damages (buildings, bridges, railway tracks, streets, etc.): flood episode similar to the 1890 flood event although the settlement area flooded tripled.</td>
<td>Hutter et al. (2007)</td>
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<td></td>
<td><strong>Conclusions</strong>&lt;br&gt;Urban development in floodplains creates favourable conditions for frequent and damaging floods. Former land covers, which were able to absorb some of the water pressure, are now replaced by residential areas and impervious surface.</td>
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<td>Economic impacts of floods in urban areas</td>
<td><strong>[14]</strong> Economic impacts of the 2002 flood in Prague, in Czech Republic&lt;br&gt;The flood that is considered for this study is the dramatic flood event in central Europe in August 2002. In Prague, the historical districts of Lesser Town, Old Town, the Jewish Quarter (Josefov), and Karlin were heavily touched. Extensive losses have occurred related to residential districts in floodplain areas and especially to modern properties, which have a higher tendency to be located in a floodplain (Kupkova, n.d.). Commercial properties and warehouses were also seriously affected. Large industrial facilities, which tend to have a better protection against floods and are less represented in our studied area, were less badly affected. The total costs estimated for this flood event is 1 billion Euros.</td>
<td>Toothil (2002)</td>
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### Main references

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<td><strong>[15]</strong> Economic impacts of 1995 floods in Itteren and Borghaven region, in the Netherlands</td>
<td>The area around the villages of Itteren and Borghaven has been flooded in 1995. The area measures approximately 16 km² and comprises agricultural land, residential areas and a few industrial sites. The urban area is considered as mainly residential. The residential damages have been responsible for the major part of the costs heading up to 1861,9 €/m², which represents costs superior by a factor 20 at least for the transport costs, and by a factor 100 for the commercial and industrial damage costs. The estimates have been calculated based on a depth-damage function, which depends on the depth of the flood, the land use class and its area, the economic value of the land use. This value is normally based on the principle of replacement value (costs of replacing a similar asset.)</td>
<td>Amadio (2012).</td>
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<tr>
<td><strong>[16]</strong> Economic impacts of a scenario of floods in the Po River Basin</td>
<td>The Po River Basin in Italy covering an area of 71,000 km² is the economically most important area in Italy. It is home to 16.5 million inhabitants or about 28% of the national population. More than one third of the Italian industries are located in this basin area and up to 40% of the national GDP. The industrial sector, ranging from big industries to small and medium enterprises, represents an important part of the income. The data used as an estimate of the flood damages are the maximum damage values estimated in a previous study (Amadio, 2012) imagining a scenario case of a flood event with the highest magnitude/depth factor (6m), as this factor has been seen to be correlated with the depth of water. The simulations in this study have been computed based on a depth-damage function, depending on the depth, category of land use, economic value of this land use. In this region, the residential costs per square meter predominate, followed by the industrial and commercial costs. We note that the value of the latter is much higher than for the region in The Netherlands. This is probably due to the economic importance of the territory due to its high industrial activity.</td>
<td>Vrisou van Eck and Kok (2001)</td>
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<td><strong>[17]</strong> Economic impacts of 2007 floods in the UK</td>
<td>Exceptional rainfall in the summer of 2007 caused extensive flooding in parts of England, especially in South and East Yorkshire, Worcestershire, Gloucestershire and Oxfordshire. Following a sustained period of wet weather starting in early May, extreme storms in late June and mid-July resulted in flooding from heavy surface flows, overloading and surcharging of surface and subsurface drainage systems, and overtopping of river flood defences. As</td>
<td>UK Environmental Agency (2005)</td>
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<td>Theme</td>
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<td>consequence there was unprecedented flooding of properties and infrastructure in some areas, including about 46 000 to 48 000 flooded homes (65 000 £ claims on average). The events were associated with 13 fatalities. Thousands of people were evacuated from properties, and many more were in fear of evacuation. Public water and power utilities were disrupted, with threat of power blackouts at the regional scale. The resultant disruption, economic loss and social distress turned the summer 2007 floods into a national catastrophe. The total economic damage reported in Table 12 are mainly derived from insurance claims.</td>
<td></td>
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</table>

**Impacts of other land covers on soil water balance**

[18] Impact of soil planning approaches on soil water balance in the Woodlands, US

**Context**
- This case study aims at assessing the impacts of planning approaches on a watershed streamflow using watershed streamflow modelling in the Woodlands, Texas. The focus, here, will be made on the impact on water runoff and aquifer recharge.
- Five development scenarios reflecting different planning approaches were created for watershed simulation
- Two planning variables were examined in the scenarios: development density (in terms of soil impervious percent range: a low-density scenario corresponds to a range of 20-49%, 80-100% for high density) and development location (soil type: clay or sandy soil)
- The five development scenarios include: a forest baseline condition scenario, 2 low-density scenarios (with the same total developed area and total impervious cover but developed on different type of soil) and two high-density scenarios (with the same total developed area and total impervious cover but developed on different type of soil)

**Identified effects of planning approaches on soil water balance in the Woodlands**
- Influence on stormwater runoff depending on soil texture and urban development strategy
  
  Watershed runoff increases around 35% for high-density scenarios and around 85% for low-density scenarios compared with the forest baseline condition
  
  Average simulated surface runoff outputs for the years 2001-2005 (unit: 10^6 m^3): 25.1 for the forest baseline scenario; 33.8 high-density on clay soil; 36.1 for high-density on sandy soil; 45.0 for low density on clay soil and

| [Yang and Li (2011)] |

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### Conclusions

Surface runoff increases as development density decreases and spreads in the watershed. When total imperviousness is held constant, high-density compact development generates 40% less runoff than low-density development.

Concerning the development area location and its type of soil, the simulation showed that the long-term watershed outflows differ slightly (7–8%) between the two options in each density group. In other words, development on clay or sandy soils does not yield much difference in the long-term watershed outflow. However, the consequences can become more important in extreme storm events (e.g. 50 or 100-year storms).

For long-term watershed runoff and during small rainfall events, development density is a more prominent factor than development location. Developments that preserve highly permeable soils are less prone to flooding.

A common practice in the region was to place building foundations on sandy soils and to avoid clay soils, because sandy soils provide better drainage and have a higher bearing capacity than clay soils. To build foundations on clay soils may require special treatment, which adds to the construction cost. The study suggests building on clay soils in order to preserve sandy soils (which have better infiltration capacities) to respond to increased flood-risk.

[19] **Impact of Ecosystems’ water retention function on soil water balance in Etropole, Bulgaria**

**Context**

- The Etropole municipality’s area is characterised by very high flood regulation capacities: mixed and coniferous forests; only 2.5% share of floodplain and wetlands
- Although the share of areas with high and very high demands in flood regulation capacities is has limited extent, their share in the urban territories is about 35%

<table>
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<th>Theme</th>
<th>Case study</th>
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<tr>
<td>48.4 for low-denisty on sandy soil scenario.</td>
<td>Influence on <em>aquifer recharge</em> and <em>sediment loading</em>. Aquifer recharge almost halved in the low urban density scenario compared to high urban density scenario. Sediment yields increase around 30% and 80% for high- and low-density scenarios, respectively</td>
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Increasing frequency of flood events causes significant damages in the region

2 main processes are at stake in flood natural limitation: interception (depends on land cover) and infiltration (strongly determined by the soil properties and to a lesser extent by factors such as rock abundance and topography)

### Identified effects of ecosystems on soil water balance

#### Interception

*Forests (in particular coniferous and mixed) present the highest interception rates and flood regulating capacity, before natural grasslands and agriculture areas and pastures.*

Interception varies according to the disposable surface (leaves as a rule) able to catch the rain drops and prevent them from falling on the soil surface

*Cultivated lands presents a weak interception, that can be neglected compared to natural grasslands and forest*

#### Infiltration

*Soil texture, mainly determined by geological conditions, controls its capacity to absorb extra water. The coarser the elements (sandy soils e.g), the greater the absorption capacity. For example, clays have a weak absorption capacity. When a given quantity of water falls on soil surface, it can be either absorbed (enhances by coarse textures) or runs off (enhances by thin textures)*

### Conclusions

The choice of spatial location for urban development is decisive and not wisely selected, can create favourable conditions for frequent and damaging flood events.

[20] Impact of land abandonment and revegetation in experimental plots in Zaragosa and Aisa valley, Spain

### Context

*Increase land abandonment in the rainfed agriculture sector in some region in Spain; Abandoned land in areas previously cultivated but where farming has ceased and the natural vegetation has been allowed to grow under various intensities of grazing*
### Theme

**Case study**

- This case study aims at determining the effects of cropland abandonment and revegetation on soil water balance in two different environments.
- 2 sites with 2 land use transitions with contrasting environments: in Zaragoza, climate is semi-arid with short intense storm events distributed throughout the year (300-350 mm per year), slopes are covered by sparse shrubs; in the Aisa valley the site is characterised by sparse shrubs, 74% of the cultivated surface is abandoned, temperate middle mountain zone with slopes of between 20 and 40% and with an average annual rainfall around 800 mm.
- For both sites, runoff and soil loss data were collected in experimental plots in abandoned land and in cereal crops located near the abandoned land.

#### Identified effects of land abandonment on soil water balance

- **Results in the Zaragoza site**
  - Runoff coefficient in the Zaragoza site: 45% for cereal plots and 75% for the abandoned land.
  - Soil loss (g.m$^{-2}$): 109 for cereal plots and 40 for the abandoned land.
- **Results in the Aisa valley site**
  - Runoff increases exponentially with precipitation in both cases but the shrub plot has a greater inertia and a more moderate hydrological behaviour, hence, higher intensity rains are needed to trigger runoff.

#### Conclusions

Land abandonment will have diverse consequences on soil water balance depending on the environment and the potential for plant colonisation.

Under good climatic and soil conditions, like in the Aisa valley, land abandonment may lead to revegetation. A spontaneous plant colonisation occurs, improving soil characteristics (enhanced organic matter content, aggregation and structural stability) and reducing soil erosion and sediment exportation by providing a better natural regulation runoff and infiltration. As the vegetation cover increases both runoff and sediment loss decrease. Bigger density and leaf area of shrubs and trees growing on the land after abandonment allow a better interception of precipitation and their stronger root system allow better infiltration of water and evapotranspiration. Shrubs also have a protective effect on the soil surface.
However, in some cases, vegetation cover remains poor after land abandonment, like in Zaragoza, increasing the erosional process and making the regeneration of the abandoned land more difficult. Runoff increases slightly through time due to the saturation of the soil and the sealing of the soil surface, while sediment yield decreases because the loose particles are removed by the initial runoff.

[21] Impacts of climate change and soil moisture on soil water balance in the Bodrog-Tisza interfluve floodplain area, Hungary

**Context**
- The study aims at evaluating the possible effects of two climate change scenarios on soil water regime of a sensitive floodplain area
- 2 climate change scenarios A2 and B2 for the period 2070-2100 were used to evaluate their effect on soil water regime as compared a baseline (period from 1960-1990): both scenarios present respectively an increase and a decrease in average growing season temperature and yearly precipitation, with some specificity for each scenario such as higher average temperature for scenario A2 and more varying precipitation distribution in case of scenario B2 with more frequent occurrence of extreme situations.

**Conclusions**
Compared to the current climatic conditions, more uneven and extreme surface and subsurface hydrological situations under changing climatic conditions are expected. Drier conditions are expected on average.

[22] Impacts of soil levelling, topography and precipitation intensity on soil water balance in Penedès, Spain

**Context**
- This case study aims at highlighting differences in soil moisture, runoff and sediment concentration resulting from land levelling works carried out before new vineyard establishment
- The study was carried out on two plots of a commercial vineyard, which suffered two types of disturbance during the land levelling work: high disturbance (HD) (3m of soil was cut from the upper part of the plot and filled at the bottom) and low disturbance (LD) (soil surface was modified to adapt the field to the new

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<th>Theme</th>
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<td>Soil and water in a changing environment</td>
<td>However, in some cases, vegetation cover remains poor after land abandonment, like in Zaragoza, increasing the erosional process and making the regeneration of the abandoned land more difficult. Runoff increases slightly through time due to the saturation of the soil and the sealing of the soil surface, while sediment yield decreases because the loose particles are removed by the initial runoff.</td>
<td>Farkas (2009)</td>
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<td>[21] Impacts of climate change and soil moisture on soil water balance in the Bodrog-Tisza interfluve floodplain area, Hungary</td>
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<td>Ramos and Martinz Casanovas (2007)</td>
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</table>
Identified effects of soil levelling on soil water balance

- **Varying soil moisture** conditions
  After rainfall period, soil water content was higher in the HD plot than in the LD plot
  Higher differences of soil moisture along the slope were observed in the HD plot: soil moisture was on average 20% lower at the upper part than downslope
  Soil moisture is more variable in shallow soils
  In the LD plot differences between positions within the plot were not significant: the average differences between top and bottom were about 8%

- **Varying infiltration rate**
  In the HD plot, steady-state infiltration rates ranged between 15 mm h\(^{-1}\) in the upper part and 45 mm h\(^{-1}\) downslope
  In the LD plot it was up to 45 mm h\(^{-1}\), and was higher in the upper part than downslope, but without significant differences.

- **Varying water availability**
  Water availability for crops is more reduced in levelled plots in relation to the non-disturbed soils, particularly in soils with low water storage capacity

- **Inegal yield**
  As a consequence, levelled plots showed a yield reduction in comparison with those undergoing less perturbation. Grape production was up to 50% lower in areas with high land perturbation

- **Soil water content** profiles depends on the intensity of rainfall more than total rainfall
  When rainfall is scarce or prolonged dry periods occur, soil water content may reach very low values (<3% v/v).
  At high intensities, soil moisture increases only occur in the surface layer, but no significant increases are observed in deeper layers, where vines have most of their roots. On the other hand, under low intensity rainfalls the soil water content increases in the whole profile.
Conclusions
The alteration of the soil profiles caused by land levelling in vineyards has consequences on soil moisture at different depths and on runoff rates at different slope positions.

Two main differences between the two plots were their susceptibility to sealing and their water retention capacity. In the HD plot, soil tended to seal very quickly, particularly after heavy intensity rainfall events, infiltration rates and soil moisture were always lower than in LD soils.

In the upper part of the HD plots, soil moisture increased more by the rainfall than in the lower parts. This difference was restricted to the surface layers (unless conditions are very wet). After long dry periods, HD soils dry faster, favoured by their low water retention capacity and soil moisture can reach very low values (about 5% vol./vol.).

Runoff and sediment concentrations differed according to the degree of disturbance. Higher sediment concentrations were produced by HD soils, which together with the higher runoff volumes resulted in higher soil losses. The heterogeneities created by land levelling increased the variability of runoff and erosion within the plots. These heterogeneities are more affective in high intensity rainfall events leading to significant differences between top and bottom positions within the HD plot, while no trends were observed within the LD plot.

[23] Impacts of soil water content on the occurrence of floods in Malborghetto-Valbruna, Northern Italy River Basin

Context
- 2003 flash flood occurred at the end of a climatic anomaly of prolonged drought and warm conditions in Europe and over the Mediterranean
- Anomalous soil moisture conditions have participated to trigger the flood
- Unique occasion to evaluate the impact of a brutal perturbation of soil moisture pattern in space in flood events triggering

Identified influence of soil moisture in soil response to flood events
Soil moisture and soil water storage capacity influence soil response to flood events. In the case of the Malborghet-
<table>
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<th>Main references</th>
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<tr>
<td><strong>Soil and water in a changing environment</strong></td>
<td>to-Valbruna flood, measured peak discharges were large but not as exceptional as implied by the measured rainfall. The exceptionally dry summer of 2003 The combination of high soil moisture storage capacity and low antecedent soil moisture conditions resulted in low runoff ratios and emphasized the nonlinearity of the flood response.</td>
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<td><strong>Contribution to the extrapolation and the modelling exercise</strong></td>
<td>[24] Impacts of tillage methods on soil porosity and infiltration in Poland</td>
<td>Lipiec et al. (2005)</td>
</tr>
<tr>
<td><strong>Context</strong></td>
<td>Arable soils in Poland  (Silt loam Eutric Fluvisol soils with maize, spring barley, winter rape, winter wheat and faba bean crops)</td>
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<tr>
<td><strong>Key findings</strong></td>
<td>There is a relation between pore structure induced by tillage and infiltration for predicting flow characteristics of water and solutes in the soil profile.</td>
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<tr>
<td><strong>Conclusions</strong></td>
<td>Cumulative infiltration was the highest under conventional tillage (94.5 cm) and it was reduced by 62%, 36% and 61% in semi-conventional tillage (ploughing to 20 cm every 6 years and to 5 cm in the remaining years, harrowing to 5 cm each year and sowing to the uncultivated soil (no tillage), respectively. The sampling of treatments may induce some uncertainties.</td>
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<tr>
<td><strong>Context</strong></td>
<td>Various types of soils in Sweden</td>
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<tr>
<td><strong>Key findings</strong></td>
<td>Reliable pedotransfer functions can be developed for estimating available water content, soil texture and soil organic carbon concentration, porosity and bulk density; where the latter two may not be available in Swedish soil surveys.</td>
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</table>
Swedish pedotransfer functions can be developed using limited porosity and bulk density data based on the available data from surveys (soil texture and soil organic carbon concentration). The pedotransfer functions for North America was satisfactorily applicable for Sweden. Some performance measures of the resulting pedotransfers:

- Root mean squared (RMS) error = 0.03 water/m³ soil
- Bulk density and porosity prediction RMS errors: 0.14 g/cm³ and 5.3% by volume

The results of this case study can be used for the areas where the data is rather limited.

[26] Pedotransfer functions for predicting SWR properties, France

**Context**
Various types of soils in France

**Key findings**
The soil water retention can be predicted by generalized and stratified pedotransfer functions.

**Conclusions**
Stratification on texture and bulk density gave a 20% improvement on prediction accuracy.
Type of horizon had no improvement contribution.
The areas where the soil types are different with the ones in France may be not reliably predicted by these generalized pedotransfer functions.
Annex 2: Further analysis of some parameters and drivers of soil water retention capacity

2.1 Physical parameters

2.1.1 Soil structure

Role in soil water retention

The way solid soil particles are aggregated and built together is referred to as soil structure, resulting in an arrangement of macropores and fissures. There are six main categories of soil structure: single grain, granular, blocky, prismatic, platy and massive. Two extremes correspond to a massive structure, where the entire soil horizon appears cemented in one great mass and to single-grain structure (non-coherent), where the individual soil particles show no tendency to cling together, such as pure sand (Figure 1).

Figure 1: Influence of soil structure on infiltration

Source: http://aces.nmsu.edu/pubs/_circulars/CR667/welcome.html

Role of soil structure in SWR capacity

Soil structure is a key parameter to determine the capacity of soil to infiltrate and store water. However, there is no “ideal” soil structure associated to SWR capacity. Each structure presents different characteristics in terms of overall porosity, permeability, stability of aggregates, soil strength (toughness and resilience of structures) and behaviour when dealing with mechanical disturbances. Soil structure therefore represents different assets and shortcomings depending on whether focus is made e.g. on flood prevention, on agricultural productivity or on water quality.
For instance, an ideal soil structure for agricultural activities would consist of a granular structure with stable aggregates allowing the circulation of air and water while retaining water within the soil. However, this type of structure may not allow very high infiltration rates and would generate run-off in case of long lasting or short but torrential rainfall. Similarly, a soil structure that increases infiltration and therefore reduces runoff (e.g. single grain structure, such as sandy soils) could be suitable for flood mitigation, but percolating water may not be retained within the soil and may favour the deep leaching of contaminants with percolating water, resulting in risk of groundwater contamination. This is the case when fractures or fissures allow preferential flows down to the water table (Figure 2) (Gerke, 2006).

![Figure 2: Illustration of fractures with preferential flows](pnwmg.org/mgsoils.html)

The degradation of soil structure generally goes along with a reduction in soil water retention capacity. Compaction, for instance, increases soil bulk density and decreases its porosity, forcing a smaller distribution of pore sizes within the soil. These changes affect the way in which air and water move through the soil (USDA-NRCS, 2000; Richard et al., 2001; Mueller and Thompson, 2009), with negative impacts on infiltration and rainfall runoff behaviour as well as unsaturated and saturated hydraulic conductivity. A low level of compaction already results in a significantly lower infiltration rates. Figure 3 depicts schematically the detrimental influence of compaction on the SWR capacity. The abscissa represents the suction imposed on water. The ordinates represent the soil water content. At low water tension (or suction), a compacted soil retains less water than an aggregated soil. Conversely, at higher water tension, and until a certain threshold, it contains a higher share of non-available water to plants (residual water). Soil structure degradation can also be reflected by facilitated dispersal of soil particles, making the soil erosion-prone.
Figure 3: Influence of compaction on the soil water content

Source: pnwmg.org/mgsoils.html

Links with other parameters

Unlike soil texture, which is inherent to the soil, soil structure can be enhanced or degraded in the short run by natural factors and land use practices.

Plant roots and macroorganisms play a beneficial role in water infiltration (Coleman & Crossley, 1996), by increasing porosity (roots penetration and burrowing activity of earthworms) and stabilising aggregates (activity of microorganisms). The presence of organic matter also increases aggregates stability. Furthermore, climate may impact soil structure through wetting-drying and freezing-thawing episodes, causing frequent changes in soil water content, along with soil volumetric changes (wetting soils tend to swell whereas drying soils shrink (te Brake et al., 2013) and mechanical disturbance of aggregates (soil freezing tend to increase the stability of aggregate, whether thawing favours the dispersal of soil particles (Dagesse, 2012)). This has two important consequences. First, these alternating episodes alter the structure of aggregates and produce cracks, especially in clay soils, forming preferential paths down to the water table (Al Zubaydi, 2011), with consequences for water storage within the soil and the contamination of groundwater. Second, fields can be impracticable for farmers in wet seasons if they want to limit the risks for compaction.

Soil structure is particularly determining for the capacity of soils to hold water in conditions near saturation. During desaturation, the less water there is in the soil, the more its distribution within the soil profile is conditioned by soil texture and the presence of organic matter (Malaya and Sreedeep, 2012).

Management

A number of practices can improve or degrade soil structure. In agriculture for instance, tillage aims at reducing the bulk density in the top soil to favour root penetration, although it may also favour crusting in clay soils; amendment allows enriching the soil in organic matter to stabilise the soil aggregates. On the other hand, compaction may occur with the use of heavy machinery. Similar threat occurs in the building sector through repeated passages of heavy machines.
2.1.2 Soil texture

Soil texture indicates the relative content of particles smaller than 2mm, such as sand (<2 mm), silt (<0.075 mm) and clay (<0.02 mm) in the soil (Figure 4 left). Gravels and stones are therefore excluded. In the field soil texture can be determined by moisturising the soil and rolling it in the hands. The stickier the soil is, the more clay there is. The soaper the soil feels the higher the silt content. The crispier it is, the higher the sand content. Twelve major soil texture classes are defined depending on the preponderance of silt, clay or sand (Figure 4 right).

![Comparison of the size of soil particles (left) and soil textural classes (right)](Source: pnwmg.org/mgsoils.html)

Coarse soils, like sandy soils, consisting of large particles, leave ample space between particles (macro pores), whereas fine soils, like clay soils, consisting of smaller particles, mostly form micropores.

**Role in soil water retention**

Because of their influence on pore-size distribution and the overall porosity, each soil texture class has specific consequences on infiltration, storage, and percolation.

The coarser the texture, the better the infiltration and the lesser runoff in unsaturated conditions. In fine-textured soils, high particle cohesion may create impermeable layers within the soil (e.g. clay layer, see Figure 5 and Figure 6) and crust at the surface of soils exposed to the splashing effect of raindrops.
The coarser the texture is, the lower the capacity of soils to hold water but also the lower the residual water. A coarse soil presents less cumulated pore space than a finer soil (Figure 7). This means that even if attraction to soil particles were similar, the overall porosity obtained with a coarse texture would not allow storing a great volume of water compared to a fine texture.

Furthermore, whereas much water drains down to the water table out of gravity in coarse soils (leaving little time for soil filtration), in fine soils the high adsorptive and capillary forces resulting from high specific surface area¹ and smaller intraparticle pore space allows holding and storing water within the soil (Fredlund 2000; Aubertin et al. 2003 in Malaya and Sreedeep, 2012) (Figure 8). In this respect, clay is an important soil fraction because it has the most important influence on such soil behaviour as water holding capacity (Table 2).

¹ Surface area of particles per unit mass or unit volume of particles. Sand has a small specific surface area (e.g. 0.1 m²/g) compared to clay (e.g. 10-1000 m²/g). Source: www.landfood.ubc.ca/soil200/components/mineral.htm#13
Figure 7: Pore space in Sandy soil vs. Clay soil

![Diagram showing pore space in Sandy soil vs. Clay soil](image)

Less total pore volume = Less porosity
Greater total pore volume = Greater porosity

Source: COMET Program, 2010

Table 2: Typical water retention capacities for soils of different textures

<table>
<thead>
<tr>
<th>Textural class</th>
<th>Water held at Field Capacity (cm/100cm soil)</th>
<th>Water held at Permanent Wilting Point (cm/100cm soil)</th>
<th>Available Water Capacity (cm/100cm soil)</th>
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<tr>
<td>sand</td>
<td>10</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>sandy loam</td>
<td>20</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>loam</td>
<td>29</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>silt loam</td>
<td>35</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>clay loam</td>
<td>38</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>clay</td>
<td>38</td>
<td>21</td>
<td>17</td>
</tr>
</tbody>
</table>

Source: Brady and Weil, 2002

However, this also leads to a higher amount of water hold by finer soils at wilting point.

Figure 8: Influence of soil texture on soil water retention curve

![Diagram showing influence of soil texture on soil water retention curve](image)

Source: age-web.age.uiuc.edu/classes/age357/html/Soil%20Water%20Retention.pdf
Beyond the soil texture, the degree of stoniness (presence of rock fragments) may also influence SWR capacity. Rock fragments reduce the available water capacity in direct proportion to their volume unless the rocks are porous (NRCS, 1998). For instance, it was noted that neglecting the presence of rock fragments in calcareous soil may overestimate the available water content by 39%, because of the induced lower specific surface area and lower cumulated pore volume (Cousin et al., 2003).

### Links to other parameters

Soil texture is an inherent soil property, resulting from a combination between:

- type and mineral composition of parent material: finely textured parent materials (e.g. basalt) tend to weather into finely textured soils, and similarly for coarse parent materials (e.g. granite);
- soil position in the landscape: residual (texture depends on the nature of parent material), colluvial (soils tend to be coarse and stony), alluvial (finer texture downstream since finer particles are carried out with water), loess deposits (fine particles transported by wind); and
- physical and chemical weathering processes involved in soil formation.

Once saturation is reached, surface runoff will occur regardless of the soil texture (Loague et al., 2010; Church & Woo, 1999).

### Management

These factors cannot be influenced by management practices. Soil texture cannot be modified to improve SWR capacity in a given area. However, related impacts can be mitigated through appropriate practices. In agriculture for instance, winter crops or mulching prevent the formation of crust in clayey soils due to the impacts of raindrops, and runoff can be mitigated.

### 2.1.3 Soil organic matter

Soil organic matter (SOM) is “the organic fraction of the soil, excluding undecayed plant and animal residues, their partial decomposition products, and the soil biomass”. The amount of organic material stored in the soil can be expressed in two ways, as organic matter or organic carbon. Soil organic matter is a key indicator of soil quality and productivity. Soil organic carbon (SOC) is the main constituent of soil organic matter by weight. It refers to the amount of carbon stored in soils and expressed in g C/kg soil. About 45% of soils in Europe are thought to have a

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3 Residual: pertaining to unconsolidated, weathered, or partly weathered mineral material that accumulates by disintegration of bedrock in place.

4 Colluvial: pertaining to material or processes associated with transportation and/or deposition by mass movement (direct gravitational action) and local, unconcentrated runoff (overland flow) on side slopes and/or at the base of slopes. Often different from the bedrock below it. [Colluvium debris]

5 Alluvial: pertaining to material or processes associated with transportation and/or subaerial deposition by concentrated running water. Nearly always different from the bedrock below it

6 Material transported and deposited by wind and consisting predominantly of silt-size particles. [Aeolian sand/loess]]

low or very low organic content matter (0-2% organic carbon) (JRC, 2012). Estimations reveal that the issue of low and medium carbon content soils particularly concern Southern countries, where 74% of the soil had less than 3.4% organic matter, as well as parts of France, the United Kingdom, Germany and Sweden (EC, 2006). Moreover, as illustrated in Figure 9 the LUCAS Topsoil Survey shows that SOC levels in the EU increase according to a South-East to North-West trend.

**Figure 9: Predicted organic carbon content in the topsoil for the EU based on the LUCAS Topsoil Database 2013**

Source: Source: Toth, 2013

**Role in SWR capacity**

Organic matter plays a key direct role in the capacity of soil to hold water, and indirectly contributes to favouring infiltration and circulation of water within the soil, through increasing the soil cation exchange capacity and stabilising the aggregates. It is one of the key parameter of the overall SWR capacity, with soil texture, soil structure, soil cover and water content.

Soil organic matter plays a role in water infiltration and percolation through its impact on the formation and stabilisation of aggregates and therefore on the pore-size distribution (Blanco-Canqui et al., 2013; Chesworth, 2008; Hudson, 1994; Eswaran et al., 1993). The biodegradation of soil organic matter by microorganisms releases polysaccharides which act like glue, and contribute to the physical and chemical binding of soil particles and microorganisms together into aggregates. It helps form and maintain the air passages and channels, protecting the soil from compaction. Lastly, soil organic matter indirectly influences SWR capacity through the support of biodiversity, for which it is a source of alimentation and/or a habitat.

Several studies reported the importance of soil organic matter in SWR capacity, and showed that increasing soil organic matter contents were positively correlated with an improvement in the capacity of soils to store water (Ohu et al., 1987; Hudson, 1994; Wall et al., 2003; Saxton and
Rawls, 2006; Singer et al., 2006; Margulies, 2012). In particular, as SOM content increases, the plant available water content increases. The volume of water held at field capacity indeed increases at a greater rate than that held at the permanent wilting point, irrespective of the texture considered (sand, silt loam, or silty clay loam) (Hudson, 1994). It is considered that for each 1% of OM increase, the available water increases by more than 1.5 - 2%, these increases being the most remarkable in silt loams (e.g. up to 4%) (Hudson, 1994; NRCS, 1998). However, quantitative information concerning the water content of soil organic matter and its impact on SWR capacity remains very scarce.

The contribution of soil organic matter to SWR capacity may vary depending on the soil texture, the initial organic carbon content of soil and the initial water content. For instance, the effect of soil organic matter will be relatively more significant on a coarse-textured soil, such as a sandy soil, than on a fine-textured soil with mainly fine pores, where clay already plays a key role in binding aggregates and adsorptive forces. Likewise, the marginal effects of increased soil organic matter will be all the more remarkable at low initial carbon content, where the structuring effect will be significant (Rawls et al., 2003). Furthermore, the structure-forming effect of soil organic matter will be all the more prominent at water content close to field capacity than water content close to the wilting point (Rawls et al., 2003; Wall et al., 2003).

The main threat to SWR capacity would be a decrease in soil organic matter, which would degrade the SWR capacity. This can be naturally caused by a higher mineralisation rate than assimilation and/or through erosion, as most organic matter is found in the topsoil. Significant removal can also be caused by fire events, through volatilisation or alteration within the soil, leading to water repellence.

**Link with other parameters**

The amount of organic matter in a soil results from the balance between accumulation and breakdown (Yang & Janssen, 2000) and depends on a range of factors. These include:

- climate: for similar soils under similar management, organic matter is greater in areas of higher rainfall, and lower in areas of higher temperature, the rate of decomposition doubling for every 8 or 9°C increase in mean annual temperature\(^7\). For instance, in the EU, the SOC pool to 1 meter depth ranges from 30 t/ha in arid climates to 800 t/ha in cold regions (Lal, 2004). The effect of the climate on soil organic carbon (SOC) can also be shown by the organic carbon stock of different climate zones. The total EU topsoil\(^8\) organic carbon stock in 2009 has been estimated to 50-60 gigatonnes, whereof about 70% in the Boreal and Atlantic regions (Toth et al., 2013).

- soil type: clay soils in the same area under similar management will tend to retain more carbon than sandy soils. In coarse-textured soils, organic matter is more quickly decomposed, due to greater soil pores and higher decay rates. In fine-textured soils, clay helps protect organic matter from breakdown, either by bind-

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\(^8\) Top-soil depth in LUCAS Topsoil Survey is considered to be 20 cm.
ing organic matter strongly or by forming a physical barrier which limits microbial access\(^7\) (reported in Gobin et al., 2010);

- topography: soils at the bottom of slopes generally have higher carbon because these areas are generally wetter and have higher clay contents\(^7\);

- fire events.

**Management**

Plant species and soil management practices (e.g. tillage) may significantly impact the amount of organic matter contained in soils. Agricultural and forestry practices (e.g. plant selection, crop rotation, crop and forestry residues management, amendment) as well as changes in land use (e.g. conversion of grasslands, forests and natural vegetation into cropland) are therefore key leverages to influence the amount of soil organic matter and enhance related SWR capacity (reported in Gobin et al., 2010).

### 2.1.4 Soil stocks

**Role in SWR capacity**

Soil depth contributes to SWR capacity as it determines the maximum volume of water the soil can infiltrate before water from precipitation accumulates at the soil surface or runs off and the volume it can store (Vervoort & Van Der Zee, 2009) (Figure 10). Soil depth is more important for infiltration and percolation processes than the slope or length of infiltration surface.

**Figure 10: Influence of soil depth on soil water retention capacity**

The loss of soil through wind and water erosion reduces the maximum amount of water that can be stored by the soils. In case of gully erosion, gullies concentrate water into narrow channels and accelerate water flows, depriving surrounding areas of water supplies and leading to severe off-site impacts (Valentin et al., 2005). It therefore decreases the buffer capacity of soils in case of
heavy rainfall events as well as the potential for water storage. JRC has estimated the surface area affected by erosion in the EU-27 at 1.3 million km$^2$. Out of this area, almost 20% is subject to soil loss in excess of 10 tonnes/ha/yr. Losses of 20 to 40 t/ha in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t/ha in extreme events (JRC, 2012). Three erosion zones can be distinguished in the EU: a southern zone characterised by severe water erosion risk; a northern loess zone with moderate rates of water erosion risk; and an eastern zone where the two zones overlap and where former intensive agricultural practices caused significant erosion problems. Mean annual soil erosion risk rates at country level clearly identify Greece, Portugal, Italy and Spain as the most affected (Kirkby et al., 2004).

**Management**

Soil depth is inherent to a specific location, with its topography and climate conditions. It can be preserved from erosion namely through specific actions in terms of landscape management and farming practices.

### 2.1.5 Topography

**Role in SWR capacity**

Topography influences water flows and soil water content at the local and landscape scales. Some studies even show that, combined with solar radiations, it could influence up to 65% of the spatial soil water content variations (Western et al., 1999; Western et al., 2004; Wilson et al., 2004).

First, the direction of the slope influences evapotranspiration through the amount and intensity of solar radiation which a location is exposed to and subsequently the temperature regime (Seibert, 2007). It also influences the amount of precipitation received and therefore water inflows. Furthermore, the slope angle impacts water flows both at the surface (e.g. proportion of precipitation that is converted to runoff: steep slopes increased the surface exposed to the rain and accelerate runoff, leaving less time for water to infiltrate the soil) and within the soil (e.g. prominence of lateral flows). It has however to be noted that appreciable surface runoff may also occur in relatively flat areas (Appels et al. 2011; Appels, 2013). Below 5° inclination, a slope can be considered gently inclined (2°-5°) or gently sloping (<2°). A slope can be considered steep between 15° and 25°inclination, and very steep beyond 10°. The slope angle has important consequences in terms of water erosion and crusting in clayey soils. On the one hand, when the slope is gentle, runoff energy is too weak to carry relatively coarse sandy particles very far. These particles can, however, be detached during a rain event. On a steep slope, all particles detached by the rain's force are carried off the plot. On the other hand, formation of crust occurs much faster on gentle slopes, through splashing effect. Lastly, the position with regard to the slope influences water content, which results from a balance between upslope accumulation of water,

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9 [www.fao.org/docrep/t1765e/t1765e09.htm](http://www.fao.org/docrep/t1765e/t1765e09.htm)
10 [w3.salemstate.edu/~lhanson/gls210/gls210_slopes.htm](http://w3.salemstate.edu/~lhanson/gls210/gls210_slopes.htm)
11 [www.fao.org/docrep/t1765e/t1765e09.htm](http://www.fao.org/docrep/t1765e/t1765e09.htm)
down-slope drainage efficiency and vertical recharge from the unsaturated area (Lanni et al., 2011).

- **Threats to SWR capacity**

  Key threats include:
  
  - high releases through evapotranspiration on sun-exposed slopes;
  - little time for infiltration and acceleration of runoff on steep slopes, resulting in water erosion;
  - release of coarse particles through the action of rain, which will move slowly down the slope and may block pores in the meantime, resulting in the formation of crust on gentle slopes.

- **Drivers and management**

  The slope is naturally designed by geology, climate and hydraulic flows. It can be substantially modified through human activities such levelling and terracing. An alternative to the construction of terraces and altering the slope structure is to use vegetation barriers. The negative impact of slopes on SWR capacity can be e.g. mitigated through permanent vegetation or appropriate cropping patterns, such as contour farming, which consist of planting and tilling the crops across, rather than with the slope.

### 2.2 Water-related parameter: soil water content

- **Role in SWR capacity and related threats**

  Soil water content counts amongst the key parameters of SWR capacity, along with soil structure, soil texture, soil organic matter, and soil cover. Soil water content is both a consequence and an influencing parameter of SWR capacity. The degree of saturation of soils influence the additional volume of water that can be absorbed by the soil, and subsequently the infiltration process. Marchi et al. (2010) showed that antecedent saturation conditions have a significant impact on event runoff coefficients. Runoff is indeed more likely to occur when soils are saturated with water. The initial soil water content may even influence the occurrence of extreme flash flood events. However, low water contents do not always guarantee high level of water infiltration and or retention within the soil, as the drying of soil after a long period of drought may alter soil physical and chemical properties and impede its water retention abilities, e.g. through the formation of crust in clayey soils. For example, the flash flood that occurred in Malborghetto-Valbruna (Northern Italy) was explained by the combination of an extreme precipitation event (355mm within 3 to 6 hours) with an anomalous dryness of the soil. Despite a high capacity to hold water, the dryness of the soil impeded infiltration, preventing it to play its flood mitigation role (Borga, 2007; Scolobig, 2008; Norbiato, 2008) (Figure 11). This was demonstrated in a more theoretical way by Jeyakumar et al. (2012), which show that after air-drying of soil fractions, 16 to 96% of precipitation could be lost for the soil through run-off (increasing losses from Fluvisol to Histosols). Repellence due to drying can therefore delay wetting of soil for periods ranging from as little as a few seconds to several weeks.
The degree of saturation of soils also conditions the ability of soil to hold water, since the importance of adsorptive forces increases with soil desaturation. Therefore, at high suction ranges, when macropores are empty, the capacity of soils to store water is mostly governed by water content and soil texture becomes negligible (Vanapalli et al. 1999; Baker and Frydman, 2009; Malaya and Sree deep, 2010). In some cases, however, the formation of fractures due e.g. to wetting-drying cycles of clay soils may lead to rainwater draining directly into the deepest layers of the soil, without being stored and made available for plants.

Figure 11: Flash flooding in Malborghetto-Valbruna (Northern Italy) in August 2003

In addition, and as mentioned earlier, soil water content dynamics, through wetting-drying cycles, may also impact SWR capacity through modifications of the soil structure and surface permeability. Soil water content may also impact SWR capacity indirectly through its role on chemical and biological processes, and in particular on soil biodiversity.

Lastly, soil water content is closely related to the regulation of evapotranspiration processes.

Links with other parameters

Soil water content is strongly dependent upon climate conditions (temperature and precipitations, both in terms of intensity and duration) as well as upon the soil infiltration and holding capacity.

Management

Soil water can be actively managed, either directly through water supply via irrigation or water removal via drainage, or indirectly through soil management practices and land cover influencing the natural processes of rainwater infiltration, evapotranspiration and percolation.
2.3 Biological parameters: abiotic surfaces and soil biodiversity

2.3.1 Land cover: sealed areas

Soil sealing, which consists in the covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.), is the most intense form of land take and is essentially an irreversible process. By preventing or drastically decreasing the capacity of soils to infiltrate water, and reducing the overall evapotranspiration, soil sealing modifies the natural water balance. When the soil is sealed, water cannot infiltrate the soil locally (infiltration rate equals 0% on site), unless drainage systems are in place. Run off from sites with high proportions of sealed surfaces could be two to three times that from predominantly vegetated surfaces (Dunnett and Clayden, 2007). They increase significantly with the degree of imperviousness, as depicted in Figure 12 and illustrated by historical trends in Leipzig, Halle and Brussels. In Brussels, for every 10% increase in impervious surface area, annual cumulated runoff was estimated to increase by 40%, high stream flow by 32% and flood frequency by 2.25 flood events (Hamdi et al., 2010). Similarly, in Leipzig and Halle, Germany, with between 40 and 60% impervious cover (e.g. in pre-fabricated housing estates), the increase in runoff was up to 200mm a year higher than the average precipitation amount (see Table 3). In areas with the highest impervious cover (80-100% sealing), direct runoff increased by 450mm a year, which is more than 75% of the average annual precipitation (Nuissl et al., 2009).

Figure 12: Water balance components in built-up areas as a function of sealed surfaces

Table 3: Water balance of new sealed areas in Leipzig since 1940 in function of the percentage of imperviousness

<table>
<thead>
<tr>
<th>Proportion of impervious land (%)</th>
<th>Area (ha)</th>
<th>Evapotranspiration (mm/a)</th>
<th>Surface run-off (mm/a)</th>
<th>Seepage water rate (mm/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;0-20</td>
<td>1111</td>
<td>351-550</td>
<td>1-150</td>
<td>51-500</td>
</tr>
<tr>
<td>&gt;20-40</td>
<td>626</td>
<td>251-450</td>
<td>51-250</td>
<td>51-250</td>
</tr>
<tr>
<td>&gt;40-60</td>
<td>2547</td>
<td>201-350</td>
<td>151-300</td>
<td>101-200</td>
</tr>
<tr>
<td>&gt;60-80</td>
<td>146</td>
<td>151-300</td>
<td>251-350</td>
<td>51-125</td>
</tr>
<tr>
<td>&gt;80-100</td>
<td>1842</td>
<td>151-200</td>
<td>351-450</td>
<td>1-75</td>
</tr>
</tbody>
</table>

Note: mm/a corresponds to mm/ly


Source: Nuissl et al., 2009
Depending on the characteristics of the watersheds, the groundwater recharge can also be impeded, although to a relatively small extent. Taking again the well-studied case of Leipzig, the groundwater recharge rate had only decreased slightly between 1870 and 2007 (about – 4%), despite substantial urbanisation. This is explained by the fact that water running off will generally end up infiltrating areas of good infiltration capacity within cities or in their close vicinity (Nuissl et al., 2009).

Furthermore, the combined effects of the cut down of soil evaporation through sealing and the absence of vegetation impede soil water and atmosphere exchanges and cause a drop in evapotranspiration, with subsequent impacts on SWR capacity in the vicinity. Significant rise in temperatures can be therefore be observed in urban areas with a high degree of soil sealing. There, the drop in evapotranspiration limits exchange between the soil water and the atmosphere, and sealed surfaces increase the absorption of sun radiations (see Figure 13). For instance, in Leipzig, with less than 20% and up to 40% impervious cover, evapotranspiration rates decrease by 100-150mm a year, whereas they decrease by 450mm a year where impervious surfaces cover 80 to 100% of the land surface (Haase et al., 2007). In cities, heat waves thus created can cause dwellers’ discomfort and even the death of vulnerable people. This occurred for instance during the summer of 2003 in Central and Western Europe where the heat wave was estimated to have caused 40 000 to 70 000 excess deaths over a four-month period (Brücker, 2005; Robine et al., 2008; Sardon, 2007; García-Herrera et al., 2010). Although correlations between the degree of soil sealing and the rise in temperatures could be established, it is difficult to quantify this impact in practice, as it depends on many factors in addition to urban design (e.g. pollution, etc.).

Figure 13: Schematic diagram of urban heat and green areas cooling effect

Like in agricultural areas, management practices (e.g. use of permeable materials) can mitigate to a certain extent the impact of soil sealing.

2.3.2 Soil biodiversity

Role in SWR capacity

Soil biodiversity is very rich; as such, it has diverse and complex impacts on SWR capacity through the modification of infiltration and water storage conditions, through changes in soil structure, chemical composition and degradation processes. Biodiversity impacts on soil can be divided into three categories, depending on type of process, its scale and the organisms implied:
physical engineers, chemical engineers and biological regulators. Figure 14 provides some examples of key soil dwellers. Soil biodiversity is an important supporting factor in enhancing key parameters of SWR capacity that are soil structure and soil organic matter.

Soil macrofauna influences the partitioning of water between surface runoff and infiltration as well as modifies water movement within soils (Swift et al., 2004). Earthworms, ants and termites but also mammals, have physical impacts on the soil. These organisms are called physical engineers. Their burrowing activity may modify soil structural features at three different scales of soil porosity (Lamandé et al., 2003). At a macroscale, the burrowing activity creates preferential path flows for water, thus increasing the hydraulic conductivity (Chan, 2001). Earthworms, ants and termites, but also little mammals like moles for instance, contribute to improve soil structure through burrow networks (Green et al., 2003). At a smaller scale, earthworms may change the pore space between mineral and organic particles and the accumulation of casts below the soil surface modifies the soil matrix, contributing to the formation of granular aggregates and hence to meso-porosity and micro-porosity (Jongmans et al., 2001 in Bottinelli et al., 2010; Pérès et al., 1998). Earthworms casts also enhance the nutritional supply, supporting other organisms such as the chemical engineers (see the box below). Similarly, plants roots can increase infiltration significantly by increasing macroporosity, through pushing their way through the soil.

Figure 14: Key soil dwellers, intervening on SWR capacity as physical and chemical engineers or biological regulators

Source: eusoils.jrc.ec.europa.eu/library/themes/biodiversity
Earthworms are divided into three primary ecological categories that contribute differently to the modification of soil structure and related hydrological processes (Figure 15). Epigeic species live in the litter and produce casts at the soil surface that affects its roughness and the distribution of macro-pores. Anecic species live in vertical burrows, used as shelters, and connected with the soil surface. Endogeic species make horizontal or randomly oriented burrows in the mineral soil (Blouin, 2013).

In temperate climates, the abundance of earthworms is generally beneficial to SWR capacity, through the reduction of runoff and the increase in water storage. For example, surface runoff during rain was negatively correlated with Lumbricus terrestris L. dry weight in observations made in the field in Finland (Pitkanen & Nuutinen, 1998 in Blouin, 2013). This increase in infiltration rate related to earthworm burrows was shown to possibly decrease soil erosion by 50% (Sharpley et al., 1979; Shuster et al., 2002 in Blouin, 2013). Ehlers (1975) also reported an increase of water storage of 25% in a field, ten years after the introduction of earthworms.

All three categories of species play a synergetic role in SWR capacity. The role of anecic species in SWR capacity is particularly remarkable, since they were was identified as an important independent variable in runoff models, after plot slope, soil water content and rainfall intensity (Valckx et al., 2010 in Blouin, 2013). For instance, Bouché and Al-Addan (1997) measured an average infiltration rate of 282 mm/h per 100 g/m² for anecic species and 150 mm/h per 100 g/m² of all the other earthworms.

Soil biodiversity also have chemical impacts on soil. Some microorganisms (e.g. bacteria and fungi), called chemical engineers decompose the soil organic matter, which influence on aggregates stability has been explained (see section 2.1.3). It is interesting to note, however, that their survival within the soil depends on several conditions, e.g. in terms of soil water content and pore space. Fungi, bacteria, leaves and plant roots are secreting sticky proteins or substances that allow reinforcing soil structure through binding soil particles into aggregates (Rillig, 2004; Purin, 2007). However, these secretions can also have a water-repellent behaviour by creating coating hydrophobic surfaces, which reduces the affinity of soils for water. The isolated impact of these secretions on SWR capacity, through water repellence, is not quantified in the literature.
**Biological regulators** control the interaction of populations of micro and macroorganisms within the soil, therefore acting indirectly on soil structure. Furthermore, their movement within the soil directly helps fragmenting organic material, creating more surface area and therefore increasing the capacity of soils to hold water. Like chemical engineers, their presence depends on soil type, water availability and cultivation practices. These organisms represent very diverse taxa and can take many different forms (Ingham, Coleman, et al. 1989). They namely include protists, nematodes and microarthropodes.

Figure 16 summarises the role of biodiversity on water-related soil properties (left), with the details of mechanisms leading to soil water repellence (right).

**Figure 16: Impacts of soil biodiversity on soil water redistribution (left) and water repellence (right)**

![Diagram showing water redistribution and water repellence](image)

**Threats**

A brochure from the European Commission and a report on soil biodiversity highlights the main threats likely to impair the SWR capacity provided by the soil biodiversity (EC, 2010; BIOIS, 2010a). These include erosion, depletion of organic matter, salinisation, soil compaction and soil sealing, in addition to pollution. In addition to be lethal to soil biodiversity, fire events also impact soil water retention through the phenomenon of water repellence. Hydrophobic substances accumulated in the litter layer and mineral soil immediately beneath move downward along temperature gradients, forming a water-repellent layer (DeBano, 1981).

Gardi et al. (2013) recently demonstrated that the intensity of land exploitation is the main factor applying pressure on soil biodiversity, both in terms land-use dynamics and farming practices. Climate change is considered to be another important driver of soil biodiversity losses, which will be detrimental for the soil infiltration and storage capacity. It is expected to impact on soil organisms directly, by altering their habitat and food web, or indirectly, through increased erosion, droughts, wildfires, etc. (EC, 2010).
Management

Certain land uses support more soil biodiversity than others: for instance, grasslands support more biodiversity than forests, croplands and urban land (EC, 2010). Moreover, land use strongly affects the resistance and resilience of soil food webs to climate change. Extensively managed grassland promotes more resistant, and adaptable, fungal-based soil food webs (de Vries et al., 2012).

Furthermore, sustainable practices can maximise the SWR functions of soil biodiversity. In particular, earthworms management through appropriate land uses and farming practices represent an excellent potential partner for humans in managing ecosystem services (Byers et al., 2006 in Blouin et al., 2013). Conversely, intensive farming practices (short rotations of annual crops, tillage, high rates of fertiliser and chemical application, and absence of organic amendments such as manure, grass break crops, straw, etc.) result in degradation of soil biodiversity. De Vries (2013) namely showed that intensive wheat rotation consistently reduced the biomass of all components of the soil food web across all countries compared to extensive rotation. Conventional tillage is also pointed out as detrimental for earthworms activity. In this context, earthworm abundance and biomass (in particular for anecic species) tend to increase with reduced or no-tillage practices (Chan, 2001; Peigné et al., 2009).

2.4 Chemical parameters

2.4.1 Composition of soil solution

In the soil, water is present in a solution with a complex chemistry. This solution contains nutrients under a dissolved form, called ions (e.g. H+, Na+, K+, Ca2+, Mg2+ and Cl−). Their nature and concentration influence SWR capacity, namely through their influence on salinity, and to a least extent on soil pH.

2.4.1.1 Soil pH

Soil pH indicates the concentration of hydrogen ions in soil solution and describes the relative acidity or alkalinity of a soil. The larger the concentration of hydrogen ions (H+) in the soil water solution, the lower the pH. The total range of the pH scale is from 0 to 14. Values below the mid-point (pH 7.0) are acidic and those above pH 7.0 are alkaline.

Role in SWR capacity and corresponding threats

Soil pH affects SWR capacity namely by impacting the biological and physical processes of the soil. A too high or too low pH can disrupt indirectly the soil structure as well as modify the degradation processes of organic matter - which both play a key role in SWR capacity - through the regulation of the abundance of soil microorganisms. However, no quantitative evidence of a clear

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12 www4.lu.se/soil-ecology-group/research/soilservice/reports-and-publications
13 www.ctahr.hawaii.edu/mauisoil/c_acidity.aspx
link with SWR could be found in the literature. The effects of pH are mostly indirect and can be considered negligible.

- **Management**

Soil acidity can be corrected where relevant through agricultural practices.

### 2.4.1.2 Salinity and sodicity

- **Role in SWR capacity and corresponding threats**

Salinity, which refers to the content of dissolved salts in soil solution, can have a positive effect on soil aggregation and stabilisation by causing fine particles to bind together into aggregates\(^{14}\). This process is known as flocculation and is beneficial in terms of soil aeration, root penetration, and root growth\(^{15}\). However, excessive salt levels can indirectly impact soil structure through the loss of soil organisms (death), thereby reducing their engineering role on the soil. It can also affect the ability of plants to extract water from the soil (osmotic potential) in addition of having potentially toxic effects for plants (Moreno et al., 2003; Murray and Grant, 2007).

Sodicity results from high concentrations in sodium compared to calcium and magnesium. When irrigating with saline water that contains relatively much sodium ions, these may displace other (multivalent) ions such as calcium and magnesium. Sodium has the opposite effect of salinity on soils, because monovalent sodium (Na\(^+\)) is less effective in neutralizing negatively charged clay minerals than divalent calcium and magnesium (Ca\(^{2+}\), Mg\(^{2+}\)). It affects soil structure by preventing soil particles from sticking together (and hence to form both aggregates and macropores), the forces binding clay particles together become disrupted when too many sodium ions replace Ca and Mg. Then, the clay particles expand, causing swelling and soil dispersion, plugging and collapsing soil pores and resulting in reduced soil permeability. The three main problems caused by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting\(^{16}\). In addition, soil organic matter may likewise become less effective as ‘glue’ and be lost from the soil by leaching. Key effects of salinity and sodicity are summarised Figure 17.

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\(^{14}\) Flocculation occurs, because high salt concentrations lead to an effective neutralization of the negatively charged clay minerals, allowing those to approach to each other and bind chemically.

\(^{15}\) waterquality.montana.edu/docs/methane/basics_highlight.shtml#EffectsofSalinityonSoilPhysicalProperties

\(^{16}\) waterquality.montana.edu/docs/methane/basics_highlight.shtml#EffectsofSalinityonSoilPhysicalProperties
Drivers and management

Salinity and sodicity of soils mostly result from irrigation and contamination through transfers with saline groundwater. Irrigation water can indeed be contaminated following fertilisation or during its previous transport through geological strata, which explains why irrigated soil are more prone to salinisation than rainfed soils. Salt accumulation occurs, as the soil water evaporates. Salinity and sodicity can be managed through more appropriate agricultural practices. For instance, this includes mixing of groundwater and surface water supply through the whole irrigation season creates a balance between leaching salts from the soil profile and maintaining the right soil salinity to stabilise sodic soils. Furthermore, applying gypsum and increasing soil organic matter are additional methods used to stabilise fragile sodic soils.  

2.4.2 Mineralogical composition

The impact of clay, silt and sand composition on the SWR capacity was described in section 2.1, in particular through the role of specific surface areas. The mineralogical composition of clays may further influence the capacity of soil to hold water, depending on their capacity to swell with water. Deformable minerals such as smectites and vermiculite have stronger capacity to hold water than other clay minerals. More generally, amorphous materials such as allophanes (hydrated aluminosilicate minerals) are characterised with high capacity to hold water (Mile & Mitkova, 2012).

Note:

Point A represents a soil of stable structure, with low sodicity and salinity.

Point B represents a soil with increased sodicity and salinity due to irrigation with poor water quality.

Point C represents a soil after salinity was leached by winter rainfall or a change to high quality irrigation.

Source: adapted from Quirk and Schofield (1955) in Murray and Grant (2007)
2.5 Driver: Natural perennial revegetation and afforestation

Driven by demographic and socio-economic dynamics, changes in land use patterns may encompass the marginalisation of some rural areas, which lost their socio-economic attractiveness. Land abandonment in rural areas generally leads, in the long-run, to an increase in perennial vegetation such as scrub and forest in the landscape. Through water interception, this re-vegetation plays an important role in regulating water flows and prevents flooding, where water would run off otherwise on “bare” soils that were once cultivated (Arbelo et al., 2006; Navarro and Pereira, 2012; Kuemmerle et al., 2008; Pointereau et al., 2008; Stoate et al., 2009 in Hart et al., 2013). This is also associated with enhanced organic matter content, aggregation and structural stability (Martinez-Fernandez et al., 1995; Lopez-Bermudez et al., 1996), which contribute to higher infiltration.

Although the impacts of natural reversion or afforestation on interception and infiltration are widely acknowledged, their flood mitigation potential is debated. It depends both on environmental conditions and characteristics of reversion and afforestation. For instance, the efficiency of afforestation in reducing flood peaks is remarkable for small storm events, but tends to decrease with their intensity. Although it is commonly agreed that, locally, flash floods and small floods can be reduced through afforestation (Dijk and Keenan, 2007, Hamilton, 2008), the flood mitigation potential at the catchment level largely differs depending on the percentage of the catchment area covered, the location of the reversion/afforestation in the catchment, and the continuous vs. discontinuous nature of this development.

For instance, it is commonly agreed that, locally, flash floods and small floods can be reduced (Dijk and Keenan, 2007, Hamilton, 2008). However, the impact of forests downstream a catchment is not as clear and can actually be quite low, unless most of the catchment is afforested (Dijk and Keenan, 2007). The impacts of natural reversion or afforestation on floods have been well studied in small catchments (less than 1 km$^2$ to about 10 km$^2$), where they represent almost all the catchment area. There, they were shown to be able to reduce flood peak by up to 50% (e.g. Fayey et al., 2004). Much fewer results are available for large catchments and the extrapolation of results from small catchments would not be correct, as the proportion of afforested areas is generally much lower. The few published studies of partial afforestation in large catchments from New Zealand report much smaller changes in water flows in the catchment (e.g. - 5%). The critical size of afforestation development for flood mitigation can however be reduced provided substantial afforestation is made upstream the catchment. For instance, in the Mella River basin (311 km$^2$) in the Italian Alps, natural afforestation between 1954 and 1994 upstream the catchment (+ 15.1 km$^2$, i.e. +9% compared to previous forested areas) was even shown to be able to “compensate” at the catchment scale, through water interception and infiltration, the impact of urban development (+ 12.1 km$^2$, i.e. + 252%) (Ranzi et al., 2002). Furthermore, the type of afforestation (by small blocks or in a continuous area) may influence the impact of such an initiative on run-off within a catchment. The reduction in runoff from small blocks of afforested or reverting land can be easily overwhelmed by ‘normal’ runoff from much larger areas e.g. of surrounding
Therefore, afforestation could be a key mitigation option in some areas whereas improved crop practices could be more relevant in others (which is in line with the results from Burek et al. (2012) based on different scenarios of land uses and hydrological and climatic modelling). Conversely, the afforestation of all unwooded land in floodplains would have limited impact on peak flows compared to 5m riparian zones along river banks, as shown in the mountain catchment of the upper Flöha river on the Germany-Czech Republic border. There, afforestation of floodplains reduced peak flows by up to 4% when applied to all unwooded floodplains rather than restricted to 5m riparian zones along river banks (Reinhardt and Bölscher, 2011).

Regarding the soil water content and the replenishment of groundwater bodies, reversion and afforestation may reduce the overall water availability in the catchments because of their high evapotranspiration (Brauman et al., 2007 and Navarro and Pereira, 2012 in Hart et al., 2013). This is a downside effect of afforestation initiatives, which can significantly decrease low flows and create water conflicts where most surface water is allocated to private users to sustain their economic activities (e.g. irrigation). The increased evapotranspiration from afforestation has however been shown to increase precipitation at the regional level and therefore contribute to the recycling of water (Ellison et al., 2012).

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Annex 3: Detailed methodology for the estimation of past, current and future trends in SWR

This Annex aims to describe the methodology, used data sources and data analysis for quantitative estimation of the trends in soil water content.

Measurement of soil hydraulic properties is costly and time-consuming. Therefore, in order to estimate past and current trends on SWR, the project team used a methodology that combines both qualitative and quantitative data, where available.

The quantitative estimation of the SWR was carried out using developed ArcGIS routines and using key explanatory soil parameters highlighted in Table 5 as inputs to the MV model. This analysis resulted in average SWR capacity maps for the EU 27 countries. The actual SWR and its relation to the key drivers such as the land use and land cover (Corine dataset), agricultural practices, urbanisation and soil sealing, and relationships with the climatic data trends (change in precipitation, temperature and implicitly evaporation) were quantitatively estimated using the case studies and GIS analysis (see further text for example results). Maps regarding associated risks of floods, drought and soil erosion are also provided.

3.1 Identification of key explanatory soil parameters and collection of information

The sources of information used to identify key explanatory parameters and their indicators were based on the collected European soil databases (summarised in Table 4) and the relevant case studies on the soil parameters as summarised in Annex 1.

<table>
<thead>
<tr>
<th>Databases</th>
<th>Websites</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGDBE – Soil Geographical Database of Eurasia</td>
<td>eu-soils.jrc.ec.europa.eu/ESDB_Archive/raster_archive/ESD_Bv2_ETRS_LAEA_raster_archive.html</td>
</tr>
<tr>
<td>PTRDB – Pedotransfer Rules Database</td>
<td>eu-soils.jrc.ec.europa.eu/ESDB_Archive/raster_archive/ptrdb_rasters.html</td>
</tr>
<tr>
<td>HYPRES – Database of Hydraulic Properties of European Soils</td>
<td><a href="http://www.macaulay.ac.uk/hypres/hypresdescr.html">www.macaulay.ac.uk/hypres/hypresdescr.html</a></td>
</tr>
<tr>
<td>LUCAS – Land Use/Cover Area frame statistics</td>
<td><a href="http://www.lucas-europa.info">www.lucas-europa.info</a></td>
</tr>
</tbody>
</table>
The analysis of these sources has enabled the project team to identify (see Table 5) the common important parameters in SWR, the *key explanatory soil parameters* and corresponding indicators, including parameters involved in a relevant pedotransfer functions (PTF) in case key explanatory parameters cannot be determined on their own.

**Table 5:** List of soil parameters, key explanatory parameters (in bold text) and their indicators (proxies) essential for quantitative analysis of the SWR

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Key explanatory parameter used in the SWRC</th>
<th>Indicator (estimated using PTFs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil texture</td>
<td>Percentage of silt (%)</td>
<td>Granulometric distribution</td>
</tr>
<tr>
<td>Soil texture</td>
<td>Percentage of clay (%)</td>
<td>Granulometric distribution</td>
</tr>
<tr>
<td>Soil texture</td>
<td>Percentage of sand (%)</td>
<td>Granulometric distribution</td>
</tr>
<tr>
<td>Soils compactness and structure</td>
<td>Soil bulk density (BD)</td>
<td>%OM, %Clay, % Silt, topsoil, subsoil</td>
</tr>
<tr>
<td>Soil cation exchange capacity</td>
<td>Organic matter (% OM)</td>
<td>Organic Carbon content, total N</td>
</tr>
<tr>
<td>Soil cation exchange capacity</td>
<td>Hydraulic conductivity (K)</td>
<td>Saturated hydraulic conductivity</td>
</tr>
</tbody>
</table>

An example result of the impact of the soil texture (and its key explanatory parameters % Silt and % Clay) on the soil water content (expressed through the SWRC) is provided in Figure 18.

**Figure 18:** Impact of the soil texture on the volumetric SWR capacity for the different soil texture parameters based on the European Soil Database

The initial geographical coverage of soil data based on the combination of the case studies and the used data sources is shown in Figure 19.
The following steps were performed in order to fill-in the missing data and create a unified 10x10km raster dataset in order to estimate past and current trends in soil water content:

- The reference raster is created from the Inspire ETRS89 Lambert Azimuthal Equal Area 10x10km reference grid obtained from the European Soil Portal. This polygonal grid is then rasterized and clipped to the EU27 countries based on the Eurasia countries dataset from the European Soil Portal. The result of this GIS analysis is a 10x10km raster dataset covering all EU27 countries, according to the INSPIRE directive guidelines (Directive 2007/2/EC).

- The following 4 key explanatory soil parameters for the 10x10km raster dataset were collected, namely: Clay percentage [%], Silt percentage [%], Organic Matter percentage [%], Bulk Density [g/kg]. The first step was to create a spatial dataset from the Spade2 v11 database which consists of soil measurements throughout the EU. The Spade2 dataset is combined with the European Soil Database (SGDBE4) based on the Soil Mapping Units (SMU). The vector dataset is then rasterized based on the reference grid created from the Inspire raster described above. The Spade2 database does not cover the complete EU27.

- For the countries that the soil data was missing some of parameters were extracted using the documented case studies and extended literature review. The case studies which contain data of the Clay, Silt, Organic Carbon and the Bulk Density are used to fill the complete country with these single values. After filling the Case Study parameters some countries were still not fully available.

- The Lucas database contains soil samples based on multispectral reflectance. The topsoil parameters are available from the European Soil Portal for research usage. For the missing countries, this dataset was added to the datasets for the parameters except the Bulk Density parameter. The Bulk Density values were populated from the European Soil Database for the countries which are covered by the Lucas database. For the two countries which were not covered, namely Cyprus and Malta, the Harmonized World Soil Database was utilised for the missing Bulk Density parameters. The available measurements did not cover the full countries extend, hence a nearest neighbour calculation was carried out to fill the gaps between the interpolated measurements.

- The Organic Matter soil parameter is based upon the Organic Carbon values from the various data sources. Based on the literature review (Bormann, 2007; Laganiere et al., 2009), the most common proxy used to estimate the Organic Matter is expressed as Organic Carbon $\times 1.724$, which resembles the value of 58% Organic Carbon the in total Organic Matter percentage.

- For the assessment of the agricultural practices on the SWR Capacity a high-resolution 10x10 km spatial database was used developed by Vrije Universiteit in Amsterdam, based on the Corine LCLU dataset as reference data which is reclassified in respectively 3 classes of intensity of agricultural management for arable land and 2 classes of intensity for grassland. As an appropriate indicator for the intensity of arable land management nitrogen application was selected.
Finally, the resulting 10x10km raster dataset with the averaged soil parameters for the Soil Water Retention calculation using the Mualem - van Genuchten equation spatially.

Figure 19: Geographical coverage of the EU27 using different data sources as listed in Table 4

Modelling explicitly the hydraulic conductivity as one of the key explanatory parameters was not part of this study, since this requires knowledge (direct measurements) of its proxy, which is the saturated soil conductivity. This is related to the hydraulic potential for movement of the groundwater in the saturated soil zone.

3.2 Estimation of the past, current and future trends in SWR

3.2.1 Overall approach

Based on the data collected from the literature and the relevant cases studies supported by review of the available soil datasets, we established casual links between the plausible impact of the main drivers on the key soil explanatory parameters affecting the SWR.

Specifically the following quantitative estimations of the past and current trends of SWR, taking into account the project objectives and feedback from the Commission, were carried out:

- Quantitative estimation and impact of the Land Cover Land Use changes using the Corine dataset on the key soil parameters (OM and BD in particular) and the effect on the SWR for the EU27 countries.
Quantitative estimation and impact of the change of arable land (crops) and agricultural practices on the key soil parameters (OM and BD in particular) and the effect on the SWR for the EU27 countries.

Change in urbanization and its impact such as the increase of impermeable land cover and decrease of infiltration on the on the key soil parameters and the effect on the SWR for the EU27 countries.

Other combinatory trends such as the combination of urbanization and soil sealing effect coupled with the climatic data trends (change in precipitation, temperature, evaporation) and correlate those with increased flood and drought risks for the EU27 countries.

The results of this quantitative analysis provides further inputs for to the estimation of the possible economic impacts of changes in SWR (Annex 4) and the identification of general trends in water consumption patterns and regional climate conditions (Annex 5).

3.2.2 Scenarios selection and modelling of future trends

The estimation of future trends allows shedding light on some of the impacts of current land uses and practices on SWR capacity, but will need to be considered with caution, acknowledging underlying assumptions. These land use changes were then related to changes of the explanatory parameters of SWR to estimate future trends in maximum stored water content.

3.2.3 Selection of an established land-use model: the IES JRC Land Use Modelling Platform

Projected trends in land use were obtained through the Land Use Modelling Platform (LUMP), which provides projected land use maps at a detailed geographical scale (100m², regional or country level), translating policy scenarios into land-use related impacts (e.g. shifts in agricultural production, changes in water use and demand, afforestation/deforestation, pressure on natural areas, urbanisation, etc.). This operational platform has been developed and continuously improved by the Institute for Environment and Sustainability (IES) of the European Commission Joint Research Centre (JRC)\(^\text{19}\), and has been used in several EU projects\(^\text{20}\). LUMP takes full and detailed account of competing land use demands between different sectors (e.g. for households, industry and agriculture) and of spatial policy restrictions (e.g. Nationally Designated Areas); as well as planned transport infrastructures (JRC, 2013). The main output of LUMP is simulated maps of the land use/cover for given years and policy scenarios in the future, notably at Nuts3.


\(^{20}\) To date, LUMP has been applied in the following ex-ante impact assessments: Integrated Coastal Zone Management; Green measures of the Common Agricultural Policy post-2013; 2012 Blueprint to Safeguard Europe’s Waters. It is also mentioned as an option in the Commission staff working document on Assessing territorial impacts: Operational guidance on how to assess regional and local impacts within the Commission Impact Assessment System. Brussels, 17.1.2013 SWD(2013) 3 final. Further applications are being prepared in the field of resource efficiency, bioeconomy and the adaptation strategy to climate change.
Nuts2 and national levels. The model runs from 2006, producing yearly results up to 2050, with intermediary milestones at 2020 and 2030.

This model is appropriate for the aim of estimating trends in the capacity of soil to hold water since it can provide future trends in land use changes for urban, agricultural (including pastures) and forest areas up to 2030, per country, while taking into account socio-economic and policy perspectives.

3.2.4 Selection of a scenario of reference

The present study aimed to assess future trends in the capacity of soil to store water based on business-as-usual land use trends, i.e. the “what if no further action for preserving services offered by soils to retain water is taken” situation. The projection of future trends was based on the 2010 Reference scenario defined in the Energy Trends to 2030 publication by DG ENER and DG CLIMA (EC, 2009) and the Impact Assessment, annex to the Energy Roadmap 2050 (EC, 2011a), as well as the Roadmap itself (EC, 2011b).

This Reference scenario has already been confirmed as a benchmark for assessing impacts of different elements of the Resource Efficiency Roadmap, the Energy Roadmap and an assessment of the Cohesion Policy period 2014-2020 (JRC, 2013). It reflects the full implementation of the Climate and Energy package, including the targets for 2020: 20% reduction in EU greenhouse gas emissions from 1990 levels; raising the share of EU energy consumption produced from renewable resources to 20%; and a 20% improvement in the EU’s energy efficiency. It also assumes that national targets under the Renewable directive (EP, 2009a) and the GHG Effort-sharing decision (EP, 2009b) are achieved (JRC, 2013).

This scenario has the advantage to provide socio-economic and current policy storylines. It also focuses on all land uses (urban, industrial and commercial; agriculture; grasslands; forests) and addresses key sectors (household, energy, transport, agriculture and forestry). Please note, however, that climate change is assumed to be constant within LUMP for the Reference scenario.

3.2.5 Quantitative estimation and impact of the Land Cover Land Use changes

Past and current trends

The Corine dataset (2000-2006) was used to study and thematically map the changes in the LCLU. Figure 20 depicts the LCLU changes within this period for the EU27 countries.

21 The main policies included in the Reference scenario at the spatial level of the land use model are the Renewable Energy Directive, the Common Agricultural Policy (including support schemes and certain elements of cross-compliance), TEN-T transport network, and the 2020 biodiversity strategy.
This map is created by grouping the Corine land use classes into new categories. These categories are then extracted from the Corine 2000 and Corine 2006 datasets and gridded to the previously referenced grid of 10x10 km for the EU27 countries. The Corine classes and the newly used classed in this report are summarised in Table 6.

**Table 6: Used classes from the Corine data set to compute the impact on the SWR**

<table>
<thead>
<tr>
<th>Class name</th>
<th>New class No</th>
<th>Corine class No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crops (arable land)</td>
<td>1</td>
<td>2.1.1, 2.1.2, 2.1.3, 2.2.1, 2.2.2, 2.2.3, 2.4.1, 2.4.2, 2.4.3, 2.4.4</td>
</tr>
<tr>
<td>Grassland</td>
<td>2</td>
<td>2.3.1, 3.2.1</td>
</tr>
<tr>
<td>Forest</td>
<td>3</td>
<td>3.1.1, 3.1.2, 3.1.3</td>
</tr>
<tr>
<td>Urban land</td>
<td>6</td>
<td>All 1.x.x classes</td>
</tr>
</tbody>
</table>

Based on the case studies and the literature review synthesis that links the land cover land use change (spatial planning driver) to the key explanatory soil parameters is provided below. The land cover transitions related to the volumetric soil water content directly affect the soil key explanatory parameters (such as the bulk density, organic matter and the hydraulic conductivity). Based on the collected cases studies and the international literature review (Bormann, 2007; Laganier et al., 2009) a link between the land cover land use changes and the relative change of organic carbon content (OM = 58% OC) and soil bulk density is qualitatively and quantitatively established, as schematically depicted in Figure 21 and Table 7.
Figure 21: Mechanisms of impacts of land cover land use change on SWR based on the case studies and literature review (past and current trends).

Table 7: Estimated LCLU quantitative changes in bulk density (BD) and organic carbon (OC) based on case studies and literature review

<table>
<thead>
<tr>
<th>Land cover land use change</th>
<th>Estimated change in BD</th>
<th>Estimated change in OC -&gt; OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crops to grassland</td>
<td>6% decrease</td>
<td>5% increase</td>
</tr>
<tr>
<td>Crops to forest</td>
<td>15% decrease</td>
<td>15% increase</td>
</tr>
<tr>
<td>Grassland to crops</td>
<td>7% increase</td>
<td>20% decrease</td>
</tr>
<tr>
<td>Grassland to forest</td>
<td>9% decrease</td>
<td>10% increase</td>
</tr>
<tr>
<td>Forest to crops</td>
<td>17% increase</td>
<td>35% decrease</td>
</tr>
<tr>
<td>Forest to grassland</td>
<td>10% increase</td>
<td>15% decrease</td>
</tr>
</tbody>
</table>
The percentage changes in these key soil explanatory parameters can be quantitatively translated into associated changes in the soil water content computed spatially using Mualem - van Genuchten equation on the 10x10 km raster grid. Figure 22 depicts the average soil water content computed for year 2000.

Figure 22: Computed relative soil water content for year 2000 based on the initial set of the key soil parameters

The map depicts the current capacity of soils to store water in the EU. It is expressed as a relative volumetric content, which means that “1” represents the regions with the highest soil water content (100%), and “0” the regions with the lowest soil water content (0%).
The soil water content map for year 2000 is the one based on the initial four parameter raster grid dataset without any changes. The equation is run for the soil depths between 120 [cm] (apx 120 [hPa] suction pressure) and 1 [cm] depth (apx 1 [hPa] suction pressure) for different depth steps. The integral results is the soil water content in [cm³/cm³] or relative soil water content on 10x10 km grid distributed spatially for the EU27 countries. The LCLU quantitative changes based on the past and current same trends and their impact on the BD and OM parameters as summarised in Table 7 were further used to compute the soil water content map for year 2010. The resulting map is shown in Figure 23.

Figure 23: Computed relative soil water content for year 2010 based on the LCLU changes and their impact on the key soil parameters

The difference map depicting the trend of the soil water content for the period 2000-2010 due to the LCLU changes is presented in Figure 24.
The resulting SWR difference maps due to the LCLU changes analysed period 2000-2010 is showing general trend of SWR decreasing. It shows decreasing trends (marked in yellow) in SWR capacity in parts of Iberia (Spain and Portugal: -10 to -15%), Finland, Baltics and northern Germany (up to -10%). Some regions in Northern Germany, such as the Schleswig-Holstein and Mecklenburg-Vorpommern show larger SWR capacity decreasing trends (between -20% to -30%, marked in red), especially around Hamburg, Luebeck, Schwerin and Rostock. The possible reasons for such impact are the large LCLU changes that were observed locally and significantly disturbed the SWR. Further decreasing evidence are seen in Czech Republic and western Hungary (-5% to -10%). Increasing trends depicted in green colour (between +5 to +10%) can, however, be observed in the east part of Germany, western Poland, parts of Hungary, Scotland and east part of Sweden.

The main reason for the decreasing trends in SWR capacity in the specified regions is the conversion of land uses from forest to grassland, forest to crops and grassland to crops. Decreases that could be observed in France, Northern Germany, and Baltic countries for instance, can be partly attributed to the conversion of substantial grasslands areas into crops. Such land use changes contribute to decreasing SOM content and increasing bulk density, which negatively affect the capacity of the soil to withhold water, as summarised in Table 6. On the other hand, the increasing trends in SWR capacity are attributed to land use conversions from crops to forest (as in parts
of Spain and Portugal), crops to grassland (as in Czech Republic and Hungary) and grassland to forests (as in North UK).

The summary resulting values of the soil water content ($\theta_s$) and the saturated hydraulic conductivity ($K_s$) using the previously described PTF (Burek et al., 2012) are shown in Figure 25. The results show that the LCLU sequence forest to crops, forest to grassland or grassland to crops negatively affects the soil water content. On the contrary LCLU changes with a sequence of crops to grassland to forest results in increased soil water content and saturated hydraulic conductivity.

Figure 25: Quantitative estimation of land cover land use changes into change of soil water content and hydraulic conductivity based on the Mualem-van Genuchten equations

Future trends in SWR capacity

The projected future trends for 2020 and 2030$^{22}$ were extracted based on a reference scenario using the key findings from the Land Use Modelling Platform provided by JRC. The expected % changes were aggregated per countries [in ha]. The left part of Figure 25 shows the current capacity of soils to store water in the EU, expressed as a relative volumetric content (like for past and current trends). The right part of Figure 26 depicts the different regions in the EU where soil water retention will most likely be an issue in the future due to the changes in the land use patterns.

On the one hand, increasing trends in SWR capacity are projected in most of Portugal, France, Lithuania, Slovenia and parts of Ireland (between $+1$ to $+2$ %). SWR capacity in the provinces of Utrecht, Friesland and Groningen in the Netherlands is even projected to increase up to 6%.

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$^{22}$ Explanatory note: For consistency of the presented results and their rates of changes through time, the past trends analysis was based on the period between 2000-2010. For the projections and the future (projected) trends the period between 2020-2030 was used in order to have the same period of time and rate of changes (intensities). In addition, the available data from the LUMP platform was utilised for the same period of time. The same data periods of 10 years provide more consistent results for comparison.
Slight increased trends in SWR capacity are projected in Scandinavia (Sweden and part of Denmark), Estonia, Bulgaria, part of northern Italy and Czech Republic (between +0.5 to +1%). On the other hand, decreasing trends are projected in Scotland, part of Wells and northern and southern parts in Germany. Neutral trends are projected for the rest of the EU 27 countries. These trends reflect the nature of projected land use changes, as highlighted for past and current trends.

It is important to stress that the difference in magnitude of changes between 2000-2010 and 2020-2030 is only due to the level of spatial aggregation of the data available. Therefore, attention should be paid to the dynamics of future trends in SWR (increase / decrease) and their relative intensity (significant / mild), rather than to the absolute values, which are not meaningful when compared with past and current trends.

Figure 26: Relative soil water content difference map (between 2020 and 2030) based on the projected land use changes and their impact on the key soil parameters

3.2.6 Quantitative estimation and impact of farming (agricultural) practices

- Past and current trends

The previous section addressed the possible impacts of land use changes on SWR capacity. In this section, we focus on management practices implemented in arable land and grassland (out of the
land use trends described above) in order to quantify the impacts of agricultural practices. The maximum water retention is estimated through variations in bulk density and organic matter brought about by different land management practices. Increasing soil bulk density leads to decreasing SWR capacity. On the other hand, an increase of organic matter positively correlates with an increase of the SWR capacity. These changes are quantitatively estimated and computed spatially on the 10x10 [km] raster grid for the period between 2000-2010, using our raster-based MV model. Agricultural practices considered in the modelling include tillage, composting, crop residue management, and intensive/extensive grazing.

The left part of Figure 27 shows the current capacity of soils to store water in the EU, expressed as a relative volumetric content (similarly to the previous sections). The right part of Figure 26 maps the difference in relative soil water content due selected agricultural practices for the period 2000-2010. Trends result from the nonlinear combination effects of the agricultural practices and the land use intensity (including arable land and grassland) on the SWR capacity, expressed through their impact on the soil bulk density and the changes in organic matter.

Figure 27: Relative soil water content difference map (between 2000 and 2010) based on the different agricultural practices and their impact on the key soil parameters

The map shows decreasing trends in SWR capacity in the Netherlands, central and northern part of France, west part of UK, north Portugal, central and southern part of Germany (-15% to -20%). These trends match the areas where tilling and intensive grazing are representative (see Figure 21 p.78). It also shows moderate decreasing trends in central Romania, eastern Poland and west parts of Greece and Latvia (-10% to -15%).

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23 For this analysis, a new high-resolution map of land use intensity for the EU27 MS was used, developed by the Vrije University (VU) of Amsterdam, whereby as an appropriate indicator for the intensity of arable land management nitrogen application was selected (see Annex 3).
Increasing trends in SWR capacity can be observed (between +15 to +20%) in the north-east part of France, central Germany, northern and southern Italy, central and south part of Spain, most of Poland, eastern UK, most parts of Bulgaria, Lithuania and northern Denmark. These trends correspond relatively well to the areas where organic amendment is applied to the soils, where crops residues are left as a soil cover or where extensive grazing is implemented (see Figure 21 p. 78). Finally, neutral (stable ±2%) trends in SWR capacity can be observed in most of Ireland (except the wider Dublin area), western France and central-east parts of the UK.

Future trends in SWR capacity

Unlike projections of SWR capacity based on land use changes datasets presented in section 4.1.1.1. of the Report, past and current trends are here comparable with the projected future trends in terms of spatial resolution and magnitude, as the dataset used matched here those used for past and current trends. The projected future trends for 2030 were analysed based on a reference scenario using the aggregated land use changes focused on arable land and grassland and assuming the same agricultural practices trends as for the 2000-2010 period as summarised in Table 8. The water content maps were computed for the scenario 2020 and 2030, and were then subtracted to emphasise the trends.

Table 8: Estimated quantitative impact of agricultural practices on bulk density (BD) and soil organic matter (OM) for different intensities

<table>
<thead>
<tr>
<th>Agricultural practice</th>
<th>Intensity</th>
<th>Estimated increase / decrease in BD</th>
<th>Estimated increase / decrease in OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composting</td>
<td>Moderate arable</td>
<td>-10% (±2%)</td>
<td>+85% (±8%)</td>
</tr>
<tr>
<td>Grazing</td>
<td>Extensive grassland</td>
<td>+8% (±2%)</td>
<td>+20% (±3%)</td>
</tr>
<tr>
<td>Grazing</td>
<td>Intensive grassland</td>
<td>+17% (±3%)</td>
<td>+35% (±5%)</td>
</tr>
<tr>
<td>Tillage</td>
<td>Intensive arable</td>
<td>-10% (±2%)</td>
<td>-12% (±2%)</td>
</tr>
<tr>
<td>Crop residue management</td>
<td>Extensive arable</td>
<td>-15% (±3%)</td>
<td>+20% (±3%)</td>
</tr>
</tbody>
</table>

The water content maps were computed for the scenario 2030 and 2020 which were then subtracted to emphasise the trends. The right part of Figure 28 maps the different regions in Europe where soil water retention will most likely be an issue in the future due to the effect of the ana-

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24 Explanatory note: For consistency of the presented results and their rates of changes through time, the past trends analysis was based on the period between 2000-2010. For the projections and the future (projected) trends the period between 2020-2030 was used in order to have the same period of time and rate of changes (intensities). In addition, the available data from the LUMP platform was utilised for the same period of time. The same data periods of 10 years provide more consistent results for comparison.

lysed agricultural practices. The left part of Figure 28 maps soil water content in 2030 due to changes in agricultural practices.

Decreasing trends in SWR capacity are projected in the Netherlands (especially around the Randstad area), central and northern part of France, west part of UK, north Portugal, north and south Spain, central and southern part of Germany (-20% to -25%), and moderate decreasing trends in central Romania, central Italy, west parts of Greece, Latvia and west Lithuania (-12% to -18%). These relatively match areas with prominent tilling and intensive grazing (see Figure 21 p.76 of the main report).

Increasing trends in SWR capacity can be observed (between +20 to +25%) in Scotland, central parts of Spain, and the north part of Germany, and moderate increasing trends (between +10 to +15%) for Czech Republic, northern Bulgaria, largely Poland, western Romania, central and northern Greece, south-west of Spain and northern Italy. These areas tend to match the areas implementing composting (amendment), crop residue management and extensive grazing (see Figure 21 p.76 of the main Report).

Finally, neutral (stable ±2%) trends in SWR capacity can be observed for the rest of the EU-27 countries with emphasis on most of Ireland (except the wider Dublin area), western France, central Spain, central-east parts of the UK, central Germany, Hungary, central Bulgaria and parts of Scandinavia.

Figure 28: Relative soil water content difference map (between 2020 and 2030) based on the projected different agricultural practices and their impact on the key soil parameters

3.2.7 Conclusions on the impacts of land use change and agricultural practices

The combination of the impacts on SWR capacity of LCLU changes and changes in agricultural practices for arable and grasslands leads to the following conclusions:
- alarming decreasing trends in SWR capacity have been occurring in the past decades and are likely to continue in the future, especially in central Europe, Benelux, northern and central parts of France, Spain and Portugal. Stable and slightly increasing trends in SWR capacity are projected for the rest of the Member States. In particular, increasing trends of SWR capacity are visible in the east part of Germany, western Poland, parts of Hungary, most of Ireland, central-east parts of UK and east part of Sweden;

- promoting and implementing appropriate agricultural practices would contribute to significantly increasing SWR capacity. The combination of impacts from different practices makes it difficult to isolate individual impacts and to draw firm conclusions. However, the analysis shows that composting and crop residue management, which highly impact on SOM, would be particularly relevant to increase SWR, as the potential for increase was estimated to range from 20 to 25% within the same land use type;

- overall, in terms of magnitude the past trends of decreasing SWR capacity due to land use changes are more prominent when compared to the projected future trends, which can be explained by the slowing down of detrimental land use conversions at the EU scale. Yet, cumulative degradation raises concerns for the future.

### 3.2.8 Quantitative estimation and impact of change in urbanisation and soil sealing

#### Past and current trends

The process of rapid urbanization directly coupled with soil sealing represents one of the main treads to which soils are subjected in the past decennia and at the present time, especially in industrialised EU countries. Soil sealing is extremely detrimental to the ability of the soil to exercise its natural function as soil-water regulatory medium. As built-up areas consume large proportion of the available land, the consequential sealing of the soil surface is one of the main impacts soils are subjected to. Figure 9 schematically depicts the effects of the soil sealing on the urban water cycle. Due to the increased urbanisation, the surface - land cover is changed to more impermeable area. The increased impermeable surfaces lead to reduced infiltration and hence more surface runoff will be generated for the same precipitation event. The percolation rate for groundwater is reduced, whilst the surface runoff of precipitation is accelerated, which leads to increased flooding. The loss of filter capacity (due to increased BD and reduced OM) in the sealed soil increases the threat of higher contaminant input into neighbouring soils or waterways. The consequences for the microclimate are significant. The temperature above sealed surfaces tends to be higher, because there is less evaporation and artificial surfaces absorb more heat than ones with natural vegetation. The relative humidity is reduced, resulting in poorer air quality. The map of the urbanisation changes from 2000 to 2006 was created in the same way as the land use changes map but now only using the changes into different types of urban development land. Figure 30 depicts the urbanization changes trend within this period for the EU 27 countries. Based on literature review (A. Imeson, et.al., 2005), the analysed case studies in Germany and Hungary
and the available data sets, the quantifiable impact of the urbanisation and soil sealing on the key soil explanatory parameters (BD and OM) and the increased impermeability are summarised in Table 9 and Table 10 respectively.

Table 9: Estimated quantitative impact of urbanization change on bulk density (BD) and organic carbon (OC) based on case studies and literature review\(^3\)

<table>
<thead>
<tr>
<th>Land cover urbanisation change</th>
<th>Estimated increase in BD</th>
<th>Estimated decrease in OC</th>
<th>Estimated decrease of SWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crops to Urban land</td>
<td>20-25 %</td>
<td>15-20 %</td>
<td>1-5%</td>
</tr>
<tr>
<td>Grassland to Urban land</td>
<td>30-40 %</td>
<td>20-25 %</td>
<td>10-15%</td>
</tr>
<tr>
<td>Forest to Urban land</td>
<td>40-50 %</td>
<td>40-45 %</td>
<td>20-25%</td>
</tr>
<tr>
<td>Others to Urban land</td>
<td>&gt;50 %</td>
<td>&gt;45 %</td>
<td>&gt;25%</td>
</tr>
</tbody>
</table>

Table 10: Estimated impact of the urban land (soil sealing) on the surface impermeability

<table>
<thead>
<tr>
<th>Type of land cover urbanisation</th>
<th>Mean degree of sealing and increase of impermeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact multi-story housing</td>
<td>60-80 %</td>
</tr>
<tr>
<td>Single and semi-detached housing</td>
<td>60-80 %</td>
</tr>
<tr>
<td>Large-scale housing (pre-fab)</td>
<td>40-60 %</td>
</tr>
<tr>
<td>Transportation routes (roads and parking lots), Commercial sites</td>
<td>80-100 %</td>
</tr>
</tbody>
</table>

\(^3\) The estimated impact is based on the pedotransfer functions from literature studies, e.g. Al Majou et al. (2008), Kätterer and Andrén (2006). The impact on the SWR is computed using the van Genuchten–Mualem model.
The percentage changes in these key soil explanatory parameters due to the urbanisation changes can be quantitatively translated into associated changes in the soil water content computed spatially using Mualem - van Genuchten equation on the 10x10 km raster grid.

Figure 30: Urbanisation land use changes trend for the period 2000-2006 based on the Corine dataset
The urbanisation quantitative changes based on the past and current same trends and their impact on the BD and OM parameters as summarised in Table 9 were further used to compute the soil water content map for year 2010. The resulting map is shown in Figure 31.

**Figure 31: Computed relative soil water content for year 2010 based on the urbanisation changes and their impact on the key soil parameters**

Note: Areas tagged as “High:1”, in dark blue, are the areas with the highest SWR capacity in the EU. The lighter the blue, the lower the SWR capacity.
The difference map depicting the trend of the soil water content for the period 2000-2010 due to the urbanisation changes is presented in Figure 32.

Figure 32: Relative soil water content difference map (between 2000 and 2010) based on the urbanisation changes and their impact on the key soil parameters

Past trends shows decreasing SWR capacity in the most densely populated parts of EU 27 countries with:

- an evident decrease (-20% to -25%) in Germany, Netherlands, the industrial regions of Northern Italy, Poland, Czech Republic, along the coastal areas (-15% to -20%) of Spain, Portugal, France, Denmark, Cyprus, southern part of Sweden and eastern Ireland. These areas are mapped with orange towards red colour.
- a moderate decrease (-10% to -15%) in Portugal, which are mapped with yellow towards orange colour; and
- a mild decrease (-5%) in Ireland with the exception of the wider Dublin area, which are depicted with green colour indicating less worsening conditions.
Future trends

Future trends for 2030 were projected using the aggregated urbanisation changes per countries (based on the JRC reference scenario).

Figure 33 depicts the different regions in the EU where soil water retention will most likely be an issue in the future due to the changes in the urbanisation patterns. Decreasing SWR capacity trends (depicted in yellow, orange towards red colours) because of urbanisation are projected in most of the Western European countries, such as France, the Netherlands, Belgium, Luxembourg, Denmark, northern part of UK, in Eastern European countries such as Romania, Hungary, parts of Czech Republic and Slovakia and in Estonia and Sweden. Mild decreases are projected in Italy, rest of UK, Germany and Czech Republic and Slovakia (depicted in light green colour); stable projected SWR capacity in Iberia (Portugal and Spain), Greece, Bulgaria, Austria, Poland, most of Ireland, Finland (depicted in green colour, indicating less worsening conditions). As explained before, it is important to note that the projected urbanisation changes aggregated per countries in the SWR calculation resulted in the lower percentage changes of SWR capacity as quantitative amounts, but provide indicative future trends in SWR based on the Reference scenario used.

Figure 33: Relative soil water content difference map (between 2020 and 2030) based on the urbanisation changes and their impact on the key soil parameters
3.3 Trends in the risk of SWR related flooding and droughts in a changing climate

Various studies and projections up to 2100 show a general reduction in summer soil water content over most of Europe, significant reductions in the Mediterranean region, and increases in the North-Eastern part of Europe (EEA, 2012c). SWR capacity plays an important role for flood and drought risk management, in the context of changing climate, with increasing evidence of more extreme and frequent weather-related hazards.

Increasing flood damages are expected in large parts of western and central Europe as well as in the UK, in particular in urbanised regions. The Pan-European flood studies and regional studies show that we can expect a moderate increase of risk of flood damages for most other regions in Europe when taking into account climate change. To counteract the impacts of climate change, the role of soil water retention as a provider of flood regulation services will therefore become increasingly important in these regions.

Within the scope of this study we have carried out an additional quantitative analysis of the combination of the impact of past and future climate trends (precipitation and temperature) and SWR capacity trends on increased flood and drought risks. These are expressed through plausible increase of surface runoff and increase of precipitation deficiencies respectively.

3.3.1 Risk of flooding (increased runoff)

- Past and current trends

For the purposes of this study several climatic data sets were explored such as the EUMETSAT (MSG) data, MARS meteorological database generated by JR, available climate change studies and several EU-funded research project. The Royal Dutch Meteorological Organization (KNMI) together with several EU meteorological institutes and research organisations have finalised an EU-funded FP6 research project ENSEMBLES. We have used the ECHAMPS r3 datasets ran by the KNMI and available for research purposes from the KNMI datacentre. The dataset contains past assimilated regional climate models runs and includes future climate change scenarios using ensembles forecasts in order to deals with uncertainty and sensitivity of model parameters and initial and boundary conditions. The data consists of daily averages of precipitation and surface temperatures as key meteorological parameters in a grid 25x25 [km] covering the whole EU. For the objectives of this project the available data was processed into yearly averages for the time periods of 2000-2010 and 2020-2030 used in Task 4. From the yearly averages the precipitation and temperature trends maps were created (see Figure 34 and Figure 35).
The precipitation changes 2000-2010 consist of the yearly precipitation averages in [mm] recalculated with a linear trend. This trend is additionally visualised in a form of ‘traffic light’ style classification. The Neutral class (yellow colour) is based on a small variance of 2 [mm] change per year (interval between -2 [mm] and +2 [mm]).

The temperature changes for the period 2000-2010 consist of yearly temperature averages in [C°] recalculated with a linear trend in a same manner. Similarly the temperature map is also visualised using traffic light style to clearly demonstrate countries with increased, decreased and neutral trends in the temperature changes. The Neutral class (yellow colour) is based on a small variance of 0.5 [C°] change per year (interval between 0.0 [C°] and +0.125 [C°]).
As part of the analysis of the past and current trends we have also made an effort to produce as much as possible quantitative data using the combination between the drivers such as the urbanisation and soil sealing together with the increased precipitation trends in order to compute increased surface runoff (leading to potentially higher risk of floodings) due to the combined effects. The urbanization changes trends for the period between 2000-2010 was overlaid with the precipitation increase trend map and then classified in 3 classes that indicate plausible increase of surface runoff:

(i) significant increase of surface runoff (>20%) – red colour;
(ii) mild increase of surface runoff (1-10%) – yellow colour; and
(iii) neutral (<1%), no increase of surface runoff – green colour.

As a result, Figure 37 shows the plausible increase of surface runoff volume resulting from past and current trends in urban development. It clearly indicates significant increase of surface runoff in the densely populated and urbanised (industrial) regions in Europe with the emphasis on Germany, Czech Republic, Hungary, Romanian, Italy, France, Ireland, UK, with increased surface runoff in Belgium, Luxemburg and Lithuania, and neutral risk in Spain, Portugal and Scandinavian countries. It is important to mention, however, that although in same countries and regions significant urbanisation changes have been observed with decreasing trends of SWR capacity, these changes do not automatically lead to plausible increase of surface runoff because of changing climate patterns where reduced precipitation trends are observed, such as the coastal areas of Spain and Portugal.
Figure 36: Quantitative assessment of the plausible increase of surface runoff due to urbanisation changes and precipitation trends from 2000-2010 in the EU 27 MS

It clearly indicates significant increase of surface runoff in the densely populated and urbanised (industrial) regions in Europe with the emphasis on Germany, Czech Republic, Hungary, Romanian, Italy, France, Ireland, UK, with increased surface runoff in Belgium, Luxemburg and Lithuania, and neutral risk in Spain, Portugal and Scandinavian countries.

The derived results from Figure 36 do not necessarily correspond with the flood occurrence mapped in the EU (Figure 39), as expressed for examples like the Ebro river basin in Spain, the southern part of Italy or the western part of France and Denmark. This evidence map indeed shows high flood occurrence trends in the following river basins: Garonne, Rhone, Ebro, Po, Rhine, Danube, Weser, Elbe, Oder, Wisla, Thames and most of the other rivers in UK, with very high flood occurrence of the Danube river basin in Romania.

It is important to note that the flood events are of local impact occurring in certain parts of the water basins only, mainly along the river courses. Hence, Figure 37 is showing the affected basins but not the regions actually affected. It is evident that there is a need for detailed and localised flood hazard and flood risk analysis based on full deterministic and economic models.
Figure 37: Number of large flood occurrences (2000-2010) in the EU 27 MS

The differences observed between the map of run-off generation and the map of floods is explained by the fact that only urbanisation changes and its effect on the SWR were taken into account in the former. The impacts of other land uses, such as agriculture, are not taken into account. Furthermore, the increased surface runoff does not necessarily lead to increased flood risks in all regions. Hence, it is important to mention that this derived map of plausible increase of the surface runoff is an indicative map with the following limitations:

- the impact of the urbanisation and soil sealing on the SWR, hence implicitly linked to the risk of floods, is not straightforward and detailed analysis will require setting up rainfall-runoff hydrological models on a river basin scale (or gridded scale), which is outside of the scope of this study;
- similarly, the impact of interception by vegetation on run-off and infiltration cannot be fully taken into account in the modelling of the SWR, only through the key soil explanatory parameters.
Note: Impacts of drivers of SWR that cannot be directly linked to explanatory parameters:
cases of soil imperviousness (soil sealing or formation of crust) and interception of water by vegetation?

The impact of soil sealing on the SWR is not straightforward and detailed analysis will require setting up rainfall-runoff hydrological models on a river basin scale (or gridded scale), which is outside of the scope of this study. The link between the LCLU and the soil imperviousness is also affecting indirectly the soil hydraulic conductivity $K$, which is a key explanatory parameter describing the hydraulic potential of the movement of the ground water. The direct quantitative link between the soil imperviousness and the hydraulic conductivity is hard to establish without proper physical measurements of the indirect proxy (e.g. saturated hydraulic conductivity for different soil probes). The results from the EU case studies as summarised in Table 6 are used to complement the characterisation of the impact of soil imperviousness on infiltration.

Similarly, the impact of interception by vegetation cannot be fully taken into account in the modelling of the SWR only through the explanatory parameters. Its impact on soil compaction and formation of crust (due to the protection of bare soil for example) may be considered through indirect changes in hydraulic conductivity, but changes in hydraulic conductivity are not explicitly used in the modelling of SWR trends, as explained above. Furthermore, the fact that some rainfall never reaches the soil because of interception by the leaves and evaporation cannot be taken into account through any of the selected explanatory parameters. The impact of interception on run-off and infiltration is discussed in a qualitative way, following the different land covers. Using GIS analysis and the LCLU datasets, we provided indications where possibly we can expect high risk of floods due to soil sealing and reduced infiltration.

Future trends

Future trends in flood risks caused by the combination of urbanisation patterns and increased precipitation are difficult to estimate due to the shortcomings of data and tools that could be used in the present study. There is an essential need for more detailed grid-to-grid regional or catchment based hydrological rainfall-runoff-routing models (such as LisFlood model, van der Knijf et al. 2008 and de Root et al. 2000).

However, using a similar approach, the urbanisation changes for the period 2020-2030 were overlaid with the future trends in precipitation using the main assumption made that the decrease of the SWR due to urbanisation changes during rainfall events will generate significant higher volume of surface runoff that can potentially cause flooding. The results from the GIS analysis were further classified in the three classes indicating plausible increase of surface runoff for the period 2020-2030, as depicted in Figure 38. The results show that for some countries, such as Germany, the steady urbanisation uptake does not directly lead to projected plausible increased runoff, due to projected decreases in precipitation. On the other hand, significant plausible increase of surface runoff is projected for Portugal and Italy due to the combination of increased urbanisation and steady projected precipitation climate trend.

It is important to note that these are rough results based on the available projected (modelled) aggregated LCLU and urbanisation changes using administrative borders. These indicative trends were further compared to the outcome of several Pan-European flood studies (e.g. Nte-
They indicated that projected increasing flood damages are expected in large parts of western and central Europe as well as in the UK, in particular in urbanised regions, which correlate with the projected plausible increase of surface runoff presented in Figure 38. However, firm conclusions on flood risks in EU 27, caused by the combined effects of SWR capacity trends and projected increases in the intensity and frequency of precipitation events, are difficult to draw without detailed physically-based hydrologic and hydrodynamic modelling as stressed above.

Figure 38: Quantitative assessment of the plausible increase of surface runoff due to urbanisation changes and precipitation trends between 2020 and 2030 in the EU 27 MS

### 3.3.2 Risk of droughts (precipitation deficiency)

**Past and current trends**

The precipitation deficiency (difference between the precipitation and the evapotranspiration) was used as an indicator for the past and current drought risk trends. The precipitation deficiency includes the climatic sessional past and projected trends in terms of projected increases in the intensity and frequency of extreme events such as droughts. As such, it has a direct link to the
SWR capacity as indication of general reduction in soil water content. The quantitative analysis of the climate parameters such as precipitation and temperature trends is based on the European-wide ECHAMP5 r3 ensemble datasets produced within the within the ENSEMBLES FP7 project. Overall land use changes for the period 2000-2010 with the corresponding SWR capacity difference were overlaid with the trends in precipitation (and temperature and then classified in 3 classes that indicate:

- significant increased risk of drought – red colour;
- mild increased risk of drought – yellow colour; and
- neutral risk of drought for the analysed period 2000-2010.

As a result, Figure 39 shows the plausible increase of drought risk, based on precipitation deficiency resulting from the impact of past and current land use changes on SWR capacity\(^3\). The map shows that there is no significant difference in the risk of drought in most of the EU, but shows mild and significant increased risk in Spain and in Cyprus and part of Greece, respectively. This increased risk of drought is based on classification of the magnitudes of shortage of precipitation due to the combined effects of precipitation decreases and temperature increases and does include any occurrences of the drought events. These trends are not incompatible with projected increasing run-off in Spain, which can result from the steady urbanisation increase coupled with land use changes and agricultural practices and intense, although scattered, precipitation events (Figure 38).

Note that the presented precipitation deficiency map as a drought risk indicator is an indicative map based on average yearly aggregates of the temperatures and precipitation for the EU27 countries. Detailed crop-growth models coupled with the SWR and the hydrometeorology on a regional or gridded scale would be required for better representation of these trends.

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\(^3\) Note that the background map of the catchment basins areas as identified with the EU WFD is provided as a background reference only.
Figure 39: Quantitative assessment of the increase of drought (based on precipitation deficiency) in the EU 27 MS (2000-2010)

Note: The neutral class is +2%, increase class is +5% and significant increase class is > +10%.

Future trends

Similarly to the projections of the risk of floods, projections of increased drought risks due to the combination of the urbanisation patterns, precipitation pattern and the increased temperature are difficult to estimate\(^{32}\).

An indicative estimation using the same methodology as for the past trends was conducted, through the plausible precipitation deficiency. Overall land use changes for the period 2020-2030 with the corresponding SWR capacity difference were overlaid with the trend in precipitation and temperature and then classified in 3 classes. The results are depicted in Figure 40.

\(^{32}\) Due to the available projected aggregated data per countries and the essential need for detailed regional and downscaled (horizontal resolutions <= 2.5 km) ensembles meteorological models (such as Hirlam and its forerunner Harmonie: Seity et al., 2011, Brousseau et al., 2011).
3.3.3 Quantitative assessment of potential soil erosion coupled with LCLU and the climatic trends

Using the available LUCAS dataset combined the LCLU Corine dataset, coarse digital terrain model (DTM) of EU 27 countries and the meteorological precipitation changes in the last decade, it is also possible to carry out a soil erosion risk assessment in order to support sustainable land use management practices in Europe. The Universal Soil Loss Equation (Norman, 1993) can be used for quantitative assessment of the long term average annual rate of (sheet or rill) erosion on a field slope:

\[ A = R \times K \times L \times C \times P \]

where: A is the potential long term average annual soil loss (tons/acre/year), R is the rainfall pattern [mm/year], K is a soil erodibility factor (tons/acre/unit area), L is the slope length gradient factor calculated from DTM, C is a crop/vegetation and management factor, based on LCLU Corine dataset and P is a support practice factor. Within the scope of this project, the project team used already available research results from several EU-funded projects, in particular the Pan-European Soil Erosion Risk Assessment (PESERA) and the RUSLE (Revised Soil Revised Universal Soil Loss Equation) model. For details refer to the report on the project 'Sustainable Agriculture and Soil Conservation' Chapter 2: Soil degradation processes across Europe, Pages 29-66. The resulting soil erosion risk map is depicted in Figure 41.
Figure 41: Soil erosion risk map derived from Pan European Soil Erosion Risk Assessment (PESERA) and the RUSLE (Revised Universal Soil Loss Equation) model.
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Annex 4: Estimating economic impacts of changes in SWR

**Introduction**

For estimating economic impacts, there are not sufficient data to establish a direct link between the changes in SWR and its impact on water-related activities in different sectors (e.g. agriculture, water distribution, industries using water in their production process, and tourism). However, a significant amount of data is available on the economic impacts of extreme events, such as droughts and floods, which in part are due to the soil and water retention. To overcome the problem associated with data scarcity, our methodology will focus on assessing the economic impacts caused by extreme events, such as floods and droughts, rather than the direct causal relationship between changes in SWR and the consequent social impacts. The linkage between SWR and the economic impacts caused by extreme events will be made by estimating the contribution of the different drivers that influence SWR and that also drive or contribute to such extreme events.

**Methodology**

From a pure methodological perspective, the valuation methods used for assessing the economic impacts of changes in the SWR is mixed, depending on the type of damages under consideration, and subject to the data availability. Following the general framework of environmental economics, the economic damages caused by natural disasters, such as flood and drought due to Soil and Water Retention (SWR), can be classified in three categories: the **clean up and restoration costs (CRC)**, the **use value damages (UVD)** and the **passive-use value/non-use value damages (PUVD)**, which imply that different valuation techniques shall be used to assess different types of costs involved.

First of all, the CRC represent the human efforts that are installed to deal with the physical damages caused by the flood or drought events, including the installation of cleaning techniques and hiring human resources to clean up the affected areas, as well as the reconstruction of the damaged facilitates such as road, buildings, and so on. The magnitude of this sector can be easily estimated in virtue of the market prices of equipment and the financial costs of physical operations including hiring human resources. Secondly, the UVD consist of two components: (i) the financial losses due to the reduced production, lost assets, and/or disrupted business directly resulted from the flood or drought events. These losses are direct **market damages (MD)**; (ii) the economic losses from declined recreational demand in the affected area after the extreme events have occurred. These losses refer to the **non-market damages (NMD)**. The estimated magnitudes of CRC and UVD are served as the base to assess the quasi-tangible economic impacts of any significant drought and flood events in Europe, which can be integrated into the conventional cost-benefit analysis for appraising projects concerning soil erosion prevention and natural resource defences. Finally, the PUVD caused by flood and drought events refer to the losses of non-use values caused by the event. These may include the direct physical impacts on interrupted/damaged ecosystems such as the negative effects on ecological functioning, the lost amenity...
value of affected areas, the risks of existence benefits loss (e.g. local species extinction) and legacy benefits loss.

Table 11 provides a summary of the standard classification of the economic damages and the most suitable economic valuation techniques for each type of economic damages.

### Table 11: Classification of economic damages caused by SWR

<table>
<thead>
<tr>
<th>Category of economic damages</th>
<th>Definitions</th>
<th>Most suitable valuation techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean up and Restoration Costs (CRC)</td>
<td>Costs of installing cleaning technique and hiring people to clean up the affected areas and costs of rebuilding the facilities such as road, buildings, etc.</td>
<td>Aggregate price analysis, Clean up and restoration expenditure</td>
</tr>
<tr>
<td><strong>Use Value Damages (UVD)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market damages (MD)</td>
<td>- Destruction of natural resources with commercial value, e.g. reduced productivities for timber and agricultural products</td>
<td>Aggregate price analysis, Replacement costs</td>
</tr>
<tr>
<td>Non-market damages (NMD)</td>
<td>- Losses of tourism benefits due to the destruction of extreme events, e.g. flood</td>
<td>Tourism expenditures *, Aggregate price analysis</td>
</tr>
<tr>
<td></td>
<td>- Declined recreational activities of visiting historical urban sites or forests designated for recreational use</td>
<td>Travel cost method, Contingent valuation method</td>
</tr>
<tr>
<td>Non-use Value/Passive-Use Value Damages (PUVD)</td>
<td>- Negative effects on biomass and ecosystems,</td>
<td>Production function method, Contingent valuation method</td>
</tr>
<tr>
<td></td>
<td>- Amenity losses of the affected natural habitat and urban area</td>
<td>Travel cost method, Contingent valuation method</td>
</tr>
<tr>
<td></td>
<td>- Risk of loss of existence benefits, e.g. no knowledge guarantee that some ecosystem, natural habitat and respective species are locally extinct</td>
<td>Contingent valuation method</td>
</tr>
<tr>
<td></td>
<td>- Risk of loss of legacy benefits, e.g. no legacy of biodiversity for future generations</td>
<td>Contingent valuation method</td>
</tr>
</tbody>
</table>

*Note: * Also known as market price valuation technique
Ideally, all three categories of economic damages shall be integrated into damage assessment study in order to better understand the overall and long-term social economic losses after a specific flood event or an incident caused by extreme drought (e.g. forest fire). Nevertheless, constrained by the existing data and studies in the literature, we will tackle neither the CRC nor the PUVD value damages caused by flood and drought events for mainly two reasons. Firstly, the expenditures spent on cleaning and restoration activities associated with certain extreme events, such as flooding and accidental forest fire can be assessed especially after the events, which are hard to anticipate as the magnitude of the total costs depends largely on the social, economic and demographic characteristics of the area and population disrupted by the events. Secondly, precise valuation of such non-use values is always difficult in practice as the absence of market prices. It is therefore important for the readers of this report to realise that the reported economic impacts of these damages are most likely to be underestimated here. This point will be further elaborated through the detailed estimations of flood-and drought-caused economic damages for each of the four different types of land uses, namely cropland, grassland, forest and urban land under consideration. Finally, other intangible damages directly resulted from the extreme events, such as physiological damages to the affected population in the flooded area could be also counted for to cover the full range of the damage costs, which however go far beyond the focus of the present study.

Data description

The project has surveyed extensively the existing literature, including both peer-reviewed and gray publications and published technical reports, concerning the valuation of the economic damages caused by extreme flood and drought events appeared in the European history. In addition, a large amount of data has been collected from various data sources (including EUROSTAT, FAOSTAT, EM-DAT, the CORINE landcover database, EEA climatic data and EXIO-
POL database\(^{35}\) for the selected indicators at either MS level or specific case study level. Table 12 below presents a summary of the indicators selected for assessing the economic damages caused by floods or droughts under each type of land uses, and indicate the relevant data sources used for conducting the assessment. It shall be noted that the guiding principle for indicator selection in the present study is based on the availability of accessible data and therefore it is most likely that the estimated economic impacts here will not cover the full range of the damages tangibly and/or intangibly caused by the extreme drought and flood events.

\(^{35}\) faostat.fao.org/site/339/default.aspx


\(^{38}\) Exiopol project, Report documenting the results of the meta-data analysis linking the monetary values with the physical characteristics of forests, 2008.
Table 12: Data collected for selected indicators for specific economic damages by damage and land use types

<table>
<thead>
<tr>
<th>Type of land use assessed</th>
<th>Causes of damages</th>
<th>Selected impacts to be assessed</th>
<th>Indicators (unit of measurement)</th>
<th>Valuation method</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>direct losses of farm property</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Droughts</td>
<td></td>
<td>- increases in irrigation needs</td>
<td>- increased water demand for irrigation (m³/ha)</td>
<td>aggregate price analysis (i.e. additional costs of increased irrigation demand, and loss of crop value)</td>
<td>- Eurostat <a href="http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Agricultural_census">http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Agricultural_census</a></td>
</tr>
<tr>
<td>Grassland (permanent pasture)</td>
<td>floods</td>
<td>- direct loss of animals</td>
<td>- costs of died animals (kg/ha)</td>
<td>aggregate price analysis (i.e. replacement cost)</td>
<td>- Eurostat <a href="http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Agricultural_census">http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Agricultural_census</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- losses of animal feeds</td>
<td>- costs of replacing the grass with external cereals or hay (kg/ha)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Droughts</td>
<td></td>
<td>increased used of concentrates and imported feeds to replace grass</td>
<td>additional cost due to increased consumption for concentrates and imported feeds (kg/ha)</td>
<td>aggregate price analysis (i.e. replacement cost)</td>
<td>N/A</td>
</tr>
<tr>
<td>Forest</td>
<td>floods</td>
<td>destruction of forests for leisure and tourism uses</td>
<td>losses of recreational value and amenity beauty (Euro/ha)</td>
<td>contingent valuation methods</td>
<td>Giergiczny et al. 2008</td>
</tr>
<tr>
<td>Type of land use assessed</td>
<td>Causes of damages</td>
<td>Selected impacts to be assessed</td>
<td>Indicators (unit of measurement)</td>
<td>Valuation method</td>
<td>Source of data</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------------</td>
<td>-------------------------------</td>
<td>---------------------------------</td>
<td>------------------</td>
<td>---------------</td>
</tr>
</tbody>
</table>
| Drought                  | Loss of trees/timber due to accident forest fires | Losses of timber products (tons/ha) | Aggregate price analysis | - CLC 2000 database [source link]  
- EFFIS MODIS satellite imagery from JRC, (2012)  
- Eurostat [source link]  
- Amadio et al., 2012  
- Genovese E., 2006  
- EM-DAT International Disasters Database (2009) [source link] |
| Urban                    | Floods            | Destruction of urban functioning | Damages to houses, infrastructure, and companies (Euro/ha) | Aggregate price analysis (i.e. replacement cost) | - Eurostat [source link]  
- Amadio et al., 2012  
- Genovese E., 2006  
- EM-DAT International Disasters Database (2009) [source link] |
| Drought                  |                   |                               | Not considered |                  |               |
Annex 5: Experts’ consultation

Several experts were consulted at an early stage of the study to identify major references and at a later stage to review the key findings of the study. They commented on and provided inputs on sections relevant to their specific expertise (see Table 13 below).

Table 13: Experts involved in the study

<table>
<thead>
<tr>
<th>Expert</th>
<th>Expertise</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof. Sjoerd van der Zee, from Wageningen University (NL)</td>
<td>Agrohydrology; Groundwater hydrology</td>
<td>Review of previous versions of Chapters 1 and 2</td>
</tr>
<tr>
<td>Dr. Dagmar Haase, from the Helmholtz Centre for Environmental Research (DE)</td>
<td>Urban areas, Landscape Ecology and Land Use Modelling</td>
<td>Review of previous versions of Chapter 3 urban development</td>
</tr>
<tr>
<td>Dr. Csilla Farkas, from the Research Institute for Soil Science and Agricultural Chemistry (HU)</td>
<td>Soil hydraulic properties / water regime in rural areas, under various land use, soil management &amp; climate</td>
<td>Review of previous versions of Chapter 3 farming and forestry practices</td>
</tr>
<tr>
<td>Prof. dr. Wim Bastiaansen, from Wageningen University / Water Watch (NL)</td>
<td>Soil hydrology modelling</td>
<td>Methodological inputs for Chapter 4 definition of the key explanatory soil parameters, available datasets, soil measurements and the used methodology</td>
</tr>
<tr>
<td>Dr. Rolf A. de By, from University of Twente / ITC (NL)</td>
<td>Additional soil datasets review</td>
<td></td>
</tr>
<tr>
<td>Ir. Remco Dost, from eLeaf</td>
<td>Soil hydrology modelling</td>
<td></td>
</tr>
<tr>
<td>Dr. Janneke Hadders, from Dacom (NL)</td>
<td>Soil hydrology modelling</td>
<td></td>
</tr>
<tr>
<td>Carlo Lavalle, Claudia Baranzelli and Ana Luisa Barbosa, from JRC (EU)</td>
<td>Land use modelling</td>
<td>Data production and insights related to the land use scenario of reference for Chapter 4</td>
</tr>
</tbody>
</table>
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