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EU Soil Health Law: Soil as a key element in groundwater protection

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Report

EU Soil Health Law: Soil as a key element in groundwater protection

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Authors
Dr. Inge van Driezum & Dr. ir. Arnaut van Loon

Quality Assurance
Dr. ir. Gijsbert Cirkel

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More information
Dr. Inge van Driezum
T +31 30 606 9735
E inge.van.driezum@kwrwater.nl

PO Box 1072
3430 BB Nieuwegein
The Netherlands

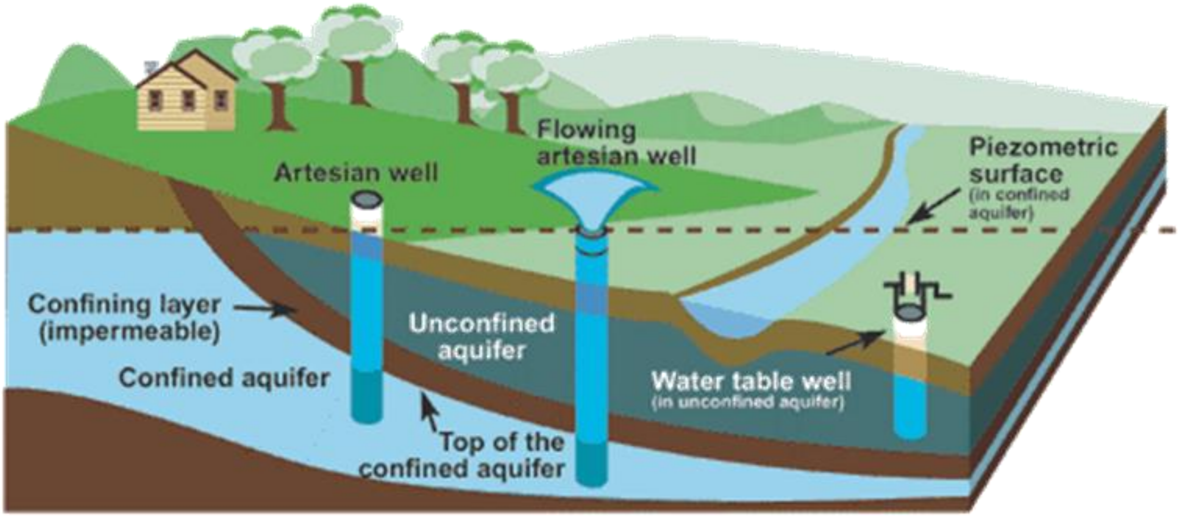
T +31 (0)30 60 69 511
E info@kwrwater.nl
I www.kwrwater.nl

Management summary

8 key actions in the EU Soil Health Law require incorporation of groundwater protection

Authors: Inge van Driezum & Arnaut van Loon.

With the newly published EU Soil Health Law (SHL), the European Union grants soil the same level of protection as air and water. This protection is needed since 60-70% of soil ecosystems in the EU are unhealthy and suffering from continuing degradation. The goal of the SHL is to achieve healthy soils by 2050. Soil quality is a significant factor in achieving good groundwater quality and enough groundwater replenishment. Groundwater is an essential source of drinking water in Europe: 75% of European drinking water is produced from this valuable resource. Therefore, a clear link between soil and groundwater should be present in the SHL. This report shows several European examples of the importance of healthy soils for sufficient groundwater quality and quantity. Several vital processes taking place in the soil are described, and their influence on groundwater quality and quantity is illustrated. All legislation in which groundwater plays an important role is described and links the actions from the SHL to groundwater. The link with groundwater should be defined more clearly in 8 key actions in the SHL.



Soil quality is interconnected with groundwater in aquifers, Europe's main source of drinking water

Interest: as a source of drinking water, groundwater should be part of the upcoming Soil Health Law

The European Union wants to achieve healthy soils by 2050, using the upcoming Soil Health Law (SHL). Since 75% of European drinking water comes from groundwater, the SHL should consider groundwater. Soil needs protection since 60-70% of soil ecosystems in the EU are unhealthy and suffering from continuing degradation. To stress the importance of including groundwater in the SHL, we present an overview of the existing scientific and legal connections between soil and groundwater. We also show examples of the impact of soil activities on groundwater (quality).

Method: combining information from scientific literature, legal texts, and environmental reports

This report is based on reviewing several sources of information. A study of the European Soil Strategy (as a background document for the EU SHL) and existing legislation on groundwater was done to show the link between the legal frameworks on groundwater and soil. The study included, in addition to the Soil Health Law, the Water Framework Directive, the Nitrates Directive, the Drinking Water Directive, the Groundwater Directive, the Sustainable Use of Pesticides Directive, the Proposal for Regulation on nature conservation and environmental quality standards & watchlists. Important passages from existing legislation on groundwater were linked to key actions in the SHL. (Chapter 2). State-of-the-art scientific knowledge on the linkages between soil and groundwater was summarized, and examples of soil activities' impact on groundwater quality were compiled (Chapter 3).

Results: soils not always protecting groundwater – 8 essential key actions identified
Our research shows groundwater is not always well protected from pollution caused by activities on or with the soil. Fortunately, several soil processes can contribute to improved groundwater quality (for example, through degradation or chemical transformation of pollutants). In order to ensure healthy soils and healthy groundwater, soils must keep their capacity to infiltrate clean (rain)water in sufficient amounts and for sustainable replenishment of groundwater bodies. To create a better link with groundwater, eight key actions from the Soil Strategy are essential:

1) Circular economy
2) Limiting land take and soil sealing
3) Clean water
4) Sustainable Soil Management
5) Preventing soil pollution
6) Restoration and remediation of degraded and contaminated soil
7) Soil and the digital agenda and
8) Soil data and monitoring

Implementation: incorporate direct links with groundwater and other legislative instruments on groundwater in SHL
The Soil Health Law should not only ensure healthy soils by 2050, but should also make sure that sufficient amounts of clean water replenishes the groundwater to maintain enough drinking water sources of good quality. Therefore, a direct link with groundwater and directives concerning groundwater should be incorporated into the different key actions in the EU SHL.

Report
This research is reported in *EU Soil Health Law: Soil as a key element in groundwater protection* (BTO-2023.043).

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More information
Dr. Inge van Driezum
T +31 30 606 9735
E inge.van.driezum@kwrwater.nl

PO Box 1072
3430 BB Nieuwegein
The Netherlands

T +31 (0)30 60 69 511
E info@kwrwater.nl
I www.kwrwater.nl

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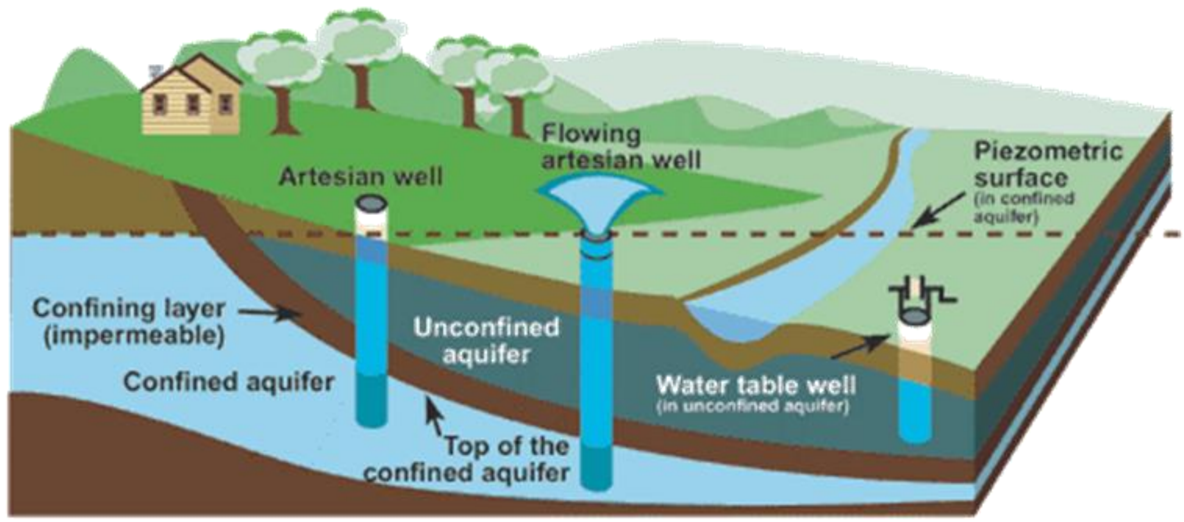
Managementsamenvatting

8 kernacties in de EU-bodemgezondheidswet vereisen opname van grondwaterbescherming

Auteurs: Inge van Driezum & Arnaut van Loon

Met de nieuw gepubliceerde EU Soil Health Law (SHL) verleent de Europese Unie de bodem hetzelfde beschermingsniveau als lucht en water. Deze bescherming is nodig aangezien 60-70% van de bodemecosystemen in de EU ongezond zijn en verder worden aangetast. Het doel van de SHL is om in 2050 te komen tot een gezonde bodem. De bodemkwaliteit is een belangrijke factor voor een goede grondwaterkwaliteit en voldoende grondwateraanvulling. Grondwater is een essentiële bron van drinkwater in Europa: 75% van het Europese drinkwater wordt geproduceerd uit deze waardevolle bron. In de SHL moet daarom een duidelijke koppeling tussen bodem en grondwater aanwezig zijn. Dit rapport laat enkele Europese voorbeelden zien van het belang van een gezonde bodem voor voldoende grondwaterkwaliteit en -kwantiteit. Enkele vitale processen die in de bodem plaatsvinden worden beschreven en hun invloed op de kwaliteit en kwantiteit van het grondwater wordt geïllustreerd. Alle wetgeving waarin grondwater een belangrijke rol speelt wordt beschreven en de acties vanuit de SHL worden geëvalueerd op bijdrage aan grondwaterbescherming. De link met het grondwater moet duidelijker gedefinieerd worden in 8 kernacties in de SHL.



Bodemkwaliteit is verbonden met grondwater in aquifers, de belangrijkste bron voor de drinkwatervoorziening in Europa.

Belang: als bron van drinkwater zou grondwater onderdeel moeten zijn van de aanstaande Wet Bodemgezondheid

Met de aanstaande Bodemgezondheidswet (SHL) wil de Europese Unie in 2050 een gezonde bodem bereiken. Aangezien 75% van het Europese drinkwater uit grondwater komt, zou de SHL rekening moeten houden met grondwater. De bodem moet worden beschermd, omdat 60-70% van de bodemecosystemen in de EU ongezond zijn en verder worden aangetast. Om het belang van het opnemen van grondwater in de SHL te onderstrepen, presenteren we een overzicht van de bestaande wetenschappelijke en juridische verbanden tussen bodem en grondwater. Ook laten we voorbeelden zien van de impact van bodemactiviteiten op grondwater(kwaliteit).

Methode: het combineren van informatie uit wetenschappelijke literatuur, wetteksten en milieurapporten
Dit rapport is gebaseerd op verschillende informatiebronnen. Er is een studie gedaan naar de Europese Bodemstrategie (als achtergronddocument voor de EU SHL) en bestaande wetgeving over grondwater om de samenhang tussen de wettelijke kaders over grondwater en bodem aan te tonen. De studie betrof naast de Bodemgezondheidswet ook de Kaderrichtlijn Water, de Nitraatrichtlijn, de Drinkwaterrichtlijn, de Grondwaterrichtlijn, de Richtlijn Duurzaam Bestrijdingsmiddelengebruik, het voorstel voor een verordening natuurbehoud en milieukwaliteitsnormen en watch lists. Belangrijke passages uit bestaande wetgeving over grondwater werden gekoppeld aan kernacties in de SHL. (Hoofdstuk 2). State-of-the-art wetenschappelijke kennis over de verbanden tussen bodem en grondwater werd samengevat en er werden voorbeelden verzameld van de invloed van bodemactiviteiten op de grondwaterkwaliteit (hoofdstuk 3).

Resultaten: bodems niet altijd beschermend voor grondwater – 8 essentiële kernacties geïdentificeerd
Uit ons onderzoek blijkt dat het grondwater niet altijd goed beschermd is tegen vervuiling door activiteiten op of met de bodem. Gelukkig kunnen verschillende bodemprocessen bijdragen aan een verbeterde grondwaterkwaliteit (bijvoorbeeld door afbraak of chemische omzetting van verontreinigende stoffen). Om gezonde bodems én gezond grondwater te waarborgen is het nodig dat voldoende schoon (regen)water in bodems kan infiltreren en dat een deel van dat water het grondwater duurzaam aanvult. Voor een betere aansluiting met grondwaterbescherming zijn acht kernacties uit de Bodemstrategie essentieel:
1) Circulaire economie
2) Beperking van ruimtebeslag en bodemafdekking
3) Schoon water
4) Duurzaam Bodembeheer
5) Voorkomen van bodemverontreiniging
6) Herstel en sanering van aangetaste en verontreinigde grond
7) Bodem en de digitale agenda, en
8) Bodemgegevens en monitoring

Implementatie: directe koppelingen met grondwater en andere wetgevende instrumenten over grondwater opnemen in SHL
De Bodemgezondheidswet moet niet alleen zorgen voor gezonde bodems in 2050, maar moet er ook voor zorgen dat voldoende schoon water het grondwater aanvult om voldoende drinkwaterbronnen van goede kwaliteit te behouden. Daarom moeten een directe link met grondwater en richtlijnen met betrekking tot grondwater worden opgenomen in de verschillende kernacties in de EU SHL.

Rapport
Dit onderzoek is gerapporteerd in *EU Soil Health Law: Soil as a key element in groundwater protection* (BTO-2023.043).

Contents

1 Introduction

The European Union recently introduced the EU Soil Strategy and the EU Soil Health Law (SHL). In the first half of 2023, the proposal for the SHL is set to be released after both public consultation and meetings with EU experts on soil protection in 2022. The SHL aims to protect and restore all European soils and strives to achieve healthy soil ecosystems by 2050. At the same time, soil pollution should be reduced to levels that are not harmful to human health and natural ecosystems. The SHL proposal describes a set of key actions which are used to achieve their goals.

Pollution of the soil not only has an impact on the quality of the soil itself, but also on the quality of the underlying groundwater. Groundwater is a very important source of drinking water worldwide. In Europe, 75% of the drinking water is produced from groundwater. Next to this very important ecosystem service, groundwater delivers services like active water purification (e.g. biodegradation of contaminants and inactivation or elimination of pathogens), nutrient recycling, biodiversity and mitigation of floods and droughts (Griebler et al. 2014). Several ecosystems are also dependent on groundwater, such as wetlands and rivers.

It is therefore of paramount importance that the key actions described in the European SHL will be linked to groundwater. Anthropogenic substances that might have an influence on the soil quality (whether it be positive or negative) should not be able to leach from the soil into groundwater bodies and cause a decrease in groundwater quality. Furthermore, soils should be able to maintain or increase groundwater recharge.

To demonstrate the importance of the link between the soil and groundwater and why groundwater should have a prominent entry in the European SHL, this report will elaborate on various subjects. The report first examines the link between the EU Soil Strategy & the EU Soil Health Law and other European Legal frameworks which affect groundwater. Secondly, various types of groundwater bodies are introduced. The processes taking place in the soil that have an impact on groundwater quality are described (chapter 3.2), just like the effects of the soil on water quantity (chapter 3.3). A way to monitor the impact of soil properties on groundwater quality could be by using soil indicators, of which the usability is described in chapter 3.4. Chapter 3.5 further stresses the importance of a good soil quality by giving multiple European examples in which land- and soil management impacted the groundwater quality and case studies that managed to achieve a better soil and groundwater quality by mitigation measures. In the last chapter, the importance of groundwater is added to the different key actions as described in the SHL. Propositions are made on how to include groundwater (both quality and quantity) in the key actions and achieve both healthy soils and healthy groundwater with the upcoming implementation of the European Soil Health Law.

2 European legal frameworks on soil & EU Soil Health Law & Strategy

The newly proposed Soil Health Law is part of the EU soil strategy for 2030 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0699). This strategy aims to protect and restore soils through a framework and concrete measures and wants to ensure soils are used sustainably. Concrete actions should be taken by 2030 and soils should be healthy in 2050. By being part of the EU biodiversity strategy, it will also contribute to protecting nature and reversing the degradation of ecosystems. The Soil Strategy will be closely linked with other EU policies stemming from the European Green Deal. It will build on and significantly contribute to several of the objectives of the Green Deal and objectives prior to that.

The targets of the EU Soil Strategy include a good chemical, biological and physical condition of the soil by 2050. Furthermore, soils should be healthy and resilient and should serve as many ecosystem services as possible. With the ambition to serve as many ecosystem services as possible, the ecosystem service protecting groundwater bodies comes to mind. This service entails the ability of soils to 'absorb, store and filter water and transform nutrients and substances to harmless end members'.

The EU Soil Strategy is not the only policy framework that entails groundwater. Groundwater is part of several other Directives, such as the Water Framework Directive, the Drinking Water Directive, and the Groundwater Directive. To create a more direct link between soil and groundwater, the most important Directives will be discussed in this chapter and the possible link with the upcoming Soil Health Law will be given.

2.1 The Soil Health Law

With the adoption of the Soil Strategy in 2021, the European Commission is set to present a new legislative proposal on soil health by 2023. This proposal should enhance a comprehensive EU legal framework for soil protection (the Soil Health Law), granting soil the same level of protection as air and water.
This protection is needed since 60-70% of soil ecosystems in the EU are unhealthy and suffering from continuing degradation. Land and soil degradation are addressed very unevenly in national policies and legislation, even though degradation of soil and its drivers and impacts know no borders.

The Soil Strategy describes a total of +/- 80 actions to ensure healthy soils by 2050. These key actions form the basis of the policy options that will be presented in the Soil Health Law. Most of these actions focus specifically on soil (such as guidance to reduce sealing, actions to prevent desertification and assessment of soil biodiversity). Only a few, however, mention clean water as an overall action. These clean water actions focus for example on the soil-sediment-water nexus and guidance on sustainable management of sediment. The abovementioned action is focused on the sediment load to streams caused by soil degradation. It is very important to understand that there are more interactions between soil, surface water and groundwater such as leaching of nitrate and pesticides, groundwater recharge etc. Including actions related to these interactions under the Soil Health Law ensures not only the protection of the soil, but also the protection of ground- and surface water bodies.

2.2 Water Framework Directive

The quality of soils and its influence on groundwater bodies and sources of drinking water production, plays a role in several different EU Directives. One of them is the Water Framework Directive (WFD).
The main objective of the WFD is to achieve a good status of surface waters and groundwater. A good status can be achieved by defining and implementing necessary measures. For waters which already have a good status, its status should be maintained, and deterioration should be prevented. For groundwater, any significant and sustained upward trend in the concentration of any pollutant should be identified and reversed. Since groundwater flow is slow, protective measures to ensure a good status of groundwater should be taken at an early stage. Pollution stemming from soils can affect the groundwater quality to a great extent. Furthermore, the ability of soils to absorb water can also affect the good quantitative status of groundwater. A link between the SHL and the WFD is therefore of paramount importance.

2.3 Nitrates Directive

Another Council Directive which is related to soil quality is the Directive concerning the protection of waters against pollution caused by nitrates from agricultural sources. Nitrate enters the soil mainly from agricultural practices and can easily leach into the ground- or surface water. When agricultural fields are present in the recharge area of a drinking water pumping station this can have an effect on the nitrate concentrations of the raw water which can sometimes even exceed the water quality standards which are set in the Drinking Water Directive (DWD), another important European Legislative instrument which is linked to soil quality.

2.4 Drinking Water Directive

In the DWD, the quality of water bodies used for abstraction of water intended for human consumption needs to be safeguarded and all hazards and risks should be considered. These hazards might very well arise from contaminated soils or soils which have a bad quality. One of the objectives of the DWD is to reduce the level of treatment required to produce water intended for human consumption. When soils are of good quality and are not polluted with anthropogenic contaminants, the groundwater abstracted from the underlying aquifer (water body) is much easier to treat and can easily serve as a source for drinking water.

2.5 Groundwater Directive

Another Directive which is directly linked to soil quality is the Groundwater Directive. Based on this Directive, groundwater is a valuable natural resource, and it should be protected from deterioration and chemical pollution. This Directive has also set quality standards for nitrates, pesticides and other substances and ensures inputs of hazardous substances are prevented and those of other pollutants are limited.

2.6 Sustainable Use of Pesticides Directive

The use of pesticides is also regulated through another Directive. Recently, a proposal has been made to replace the existing Sustainable Use of Pesticides (SUP) Directive with a Regulation on the sustainable use of plant-protection products. By replacing the SUP with a Regulation, it will be better aligned with the objectives of the European Green Deal and other legislative instruments. The proposal aims to reduce the risks from (and impacts of) pesticide use on the environment by achieving pesticide-reduction targets and promoting the use of less hazardous and non-chemical alternatives to chemical pesticides. The aims described in this proposal are also present in the Soil Strategy and will therefore be directly linked to the Soil Health Law.

2.7 Proposal for Regulation on nature conservation

Another link to the Soil strategy, and most likely the Soil Health Law, is the proposal for a Regulation on nature restoration. In the proposed nature restoration Regulation, some specific targets will be set to enhance biodiversity. Since many terrestrial ecosystems depend on and interact with the underlying soils, soil-related targets also need to be considered. These targets will however be integrated into future legislation governing soils. One of the targets in restoring agricultural ecosystems is to achieve an increasing trend of the stock of organic carbon in cropland mineral soils until satisfactory levels are reached.

2.8 Environmental quality standards & watchlists

Many of the aforementioned legislative instruments deal with (chemical) pollutants that have a negative impact on soil or water quality. For monitoring purposes, some of these legislations use watchlists of lists with priority substances that should be monitored. The WFD for example has established a list of priority substances which have to be monitored as quality elements. Member States should adopt measures to progressively reduce pollution of surface water by these substances and Environmental Quality Standard values are set. In order to monitor substances that may pose a significant risk to the environment, a WFD watch list has been established. All compounds on this list should be monitored, but they do not yet have to meet Environmental Quality Standards. Not only the WFD uses a watchlist, the Groundwater Directive and the DWD are also going to adopt watchlists consisting of chemicals of concern for either groundwater or water intended for human consumption. The compounds on these watchlists are not similar since different processes affect the behavior of chemicals in surface water or groundwater. Some compounds may easily leach from soils into groundwater, whereas other compounds are degraded easily in the soil.

It is scheduled to develop an EU priority list for contaminants of major and/or emerging concern that pose a significant risk for European soil quality under the Soil Health Law by 2024. The substances on this list should also link with the existing watchlists of the WFD, the Groundwater Directive and the DWD.

2.9 Wrap-up

The Soil Health Law will be designed to grant soil the same level of protection as air and water and stems from the EU Soil Strategy. A total of +/- 80 actions to ensure healthy soils by 2050 are described. These actions mainly focus on the soil, but a link to (ground)water is also very important. Groundwater is part of several Directives, which should be addressed by the Soil Health Law.
It has been shown that the WFD, the Groundwater Directive and the DWD should be directly linked to the Soil Health Law. The main objectives of these Directives correspond to the main goal of the Soil Health Law. To monitor contamination of the soil, and groundwater, the EU Soil Health Law could utilize the lists with priority substances and the watchlists that have been or are currently being developed.
Other Directives that link directly to the Soil Health Law are the Nitrates Directive, the SUP Directive, and the Proposal for Regulation on Nature Conservation. The Nitrates and SUP Directive prevent pollutants coming into the soil, whereas the Regulation on Nature Conservation is set to enhance biodiversity. The targets set in these Directives not only help soils getting healthier but can also help in protecting groundwater.

3 Linkages between soil and groundwater

To understand the link between soil and groundwater, this chapter first introduces the different types of groundwater bodies. A description of the level of protection from processes and activities on the soil, which plays an important role in preventing pollution entering groundwater bodies, is given. Secondly, the subsurface processes that influence groundwater quality are described next to the conditions that are provided by soils and sediments to reduce pollution. The role of soils in water quantity (another important feature in maintaining healthy groundwaters) is described in the next part of this chapter. Adjacent, a description is given on the development of new soil indicators, which is a way to link soil properties to groundwater.

After this theoretical part, multiple examples are given in which human activities on or with the soil impacted the groundwater quality in various parts of the EU. Next to examples with a negative impact on the groundwater quality, an example is given in which an intervention from a waterboard led to an increase in groundwater quality and extreme measures taken by the Swiss authorities to protect groundwater from substances leaching from a landfill led to a better soil and groundwater quality.

3.1 Types of groundwater bodies

Rainwater infiltrates in soils and travels through the soil towards the groundwater. Several different types of groundwater bodies (aquifers) can be described. Unconfined aquifers have no confining layer (impermeable layer). These aquifers are close to the surface and infiltrating rainwater does not need so much time to reach the groundwater table. In sandy Pleistocene uplands, like the Veluwe in the Netherlands, the unsaturated zone can be tens of meters thick and infiltrating rainwater takes longer to reach the saturated zone. Unconfined aquifers offer limited protection against pollution from the top layers of the soil and can easily be (negatively) influenced by anthropogenic activities on the surface. Confined aquifers, however, have low permeability layers below and on top of the aquifer (see Figure 1). These layers are making them fairly protected from pollution from above since water is not able to flow through the impermeable layers. The water quality in these aquifers is in general more pristine than in unconfined (phreatic) aquifers. Both types of aquifers are used for the abstraction of drinking water and their quality needs to be as high as possible.

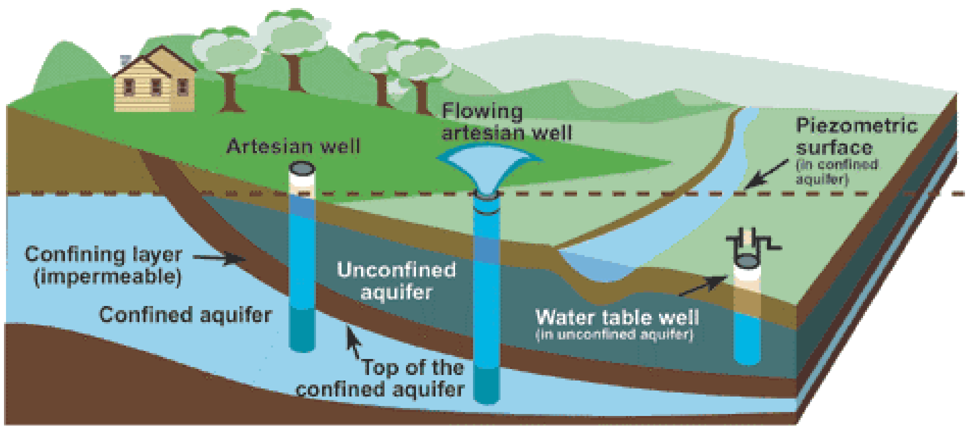


Figure 1 A graphical representation of confined and unconfined aquifers. Source: USGS https://www.usgs.gov/media/images/aquifers-and-wells

Another type of system which is becoming more and more popular for drinking water abstraction are riverbank filtration (RBF) sites (see Figure 2, Ray et al. 2002). These aquifers are adjacent to a stream, lake or river and are fed by infiltrating surface water. The quality of the groundwater is to a large extend influenced by the quality of the infiltrating surface water. It has been shown that surface waters are increasingly contaminated with chemical contaminants (Schwarzenbach et al. 2006). This could have a negative impact on the quality of groundwater bodies adjacent to surface waters. RBF systems, however, have the capacity to reduce or eliminate contaminants. Several processes in the sediment and the first part of the saturated soil influence the removal of these (chemical and microbial) contaminants.

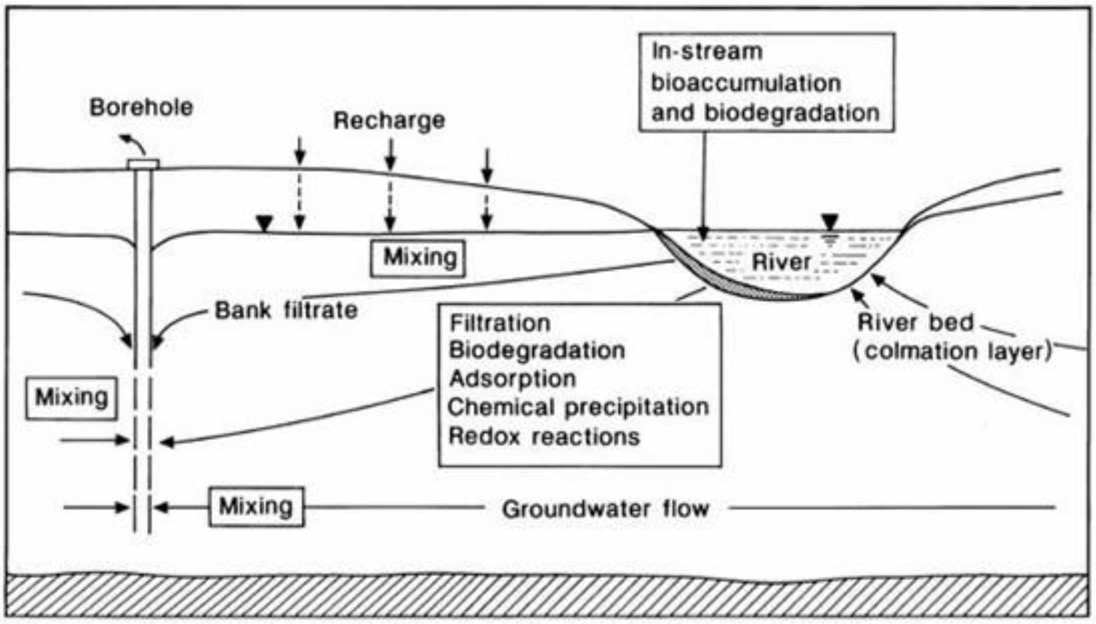


Figure 2 Schematic overview of riverbank filtration processes (Ray et al. 2002)

3.2 Groundwater quality

Groundwater quality can be impacted by a multitude of activities and current inputs. Land use activities can result in mobilization of substances that are naturally present in soils or that have accumulated as a result of past inputs. These mobilized substances and current inputs can leach through soils by infiltrating rainwater towards the groundwater. Infiltrating surface water can be another source of contamination for groundwater. The quality of surface water is under pressure by anthropogenic activities and by infiltrating into the groundwater, these contaminants can alter the groundwater quality.
Soils and sediments provide conditions for numerous attenuation processes that reduce impacts on groundwater quality. These conditions include a variety of matrices that allow for specific attenuating processes in space and time (see Figure 3). How these processes contribute to groundwater quality is described below.

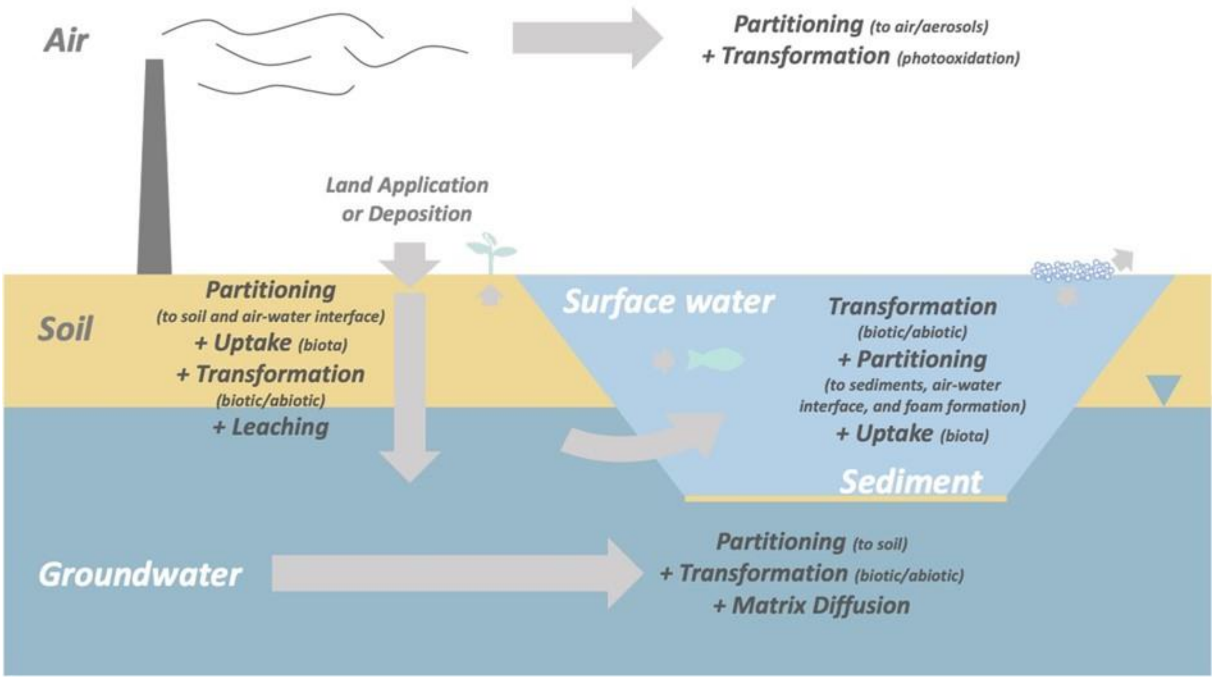


Figure 3 Soil processes impacting groundwater quality (Source: D. Adamson, GSI. Used with permission)

3.2.1 Space and time

Groundwater aquifers contain a very large volume of water. Contaminants that reach the aquifer can be spread out in the aquifer. Once the plume with contaminants reaches the drinking water abstraction well, the concentration of the contaminant can decrease by mixing with other, more pristine, groundwater.
Over time, chemicals are transformed in the presence of (ground)water. It depends on the characteristics of the compound how long it will take to degrade to another compound. The amount of time a compound needs to decrease to half of its original value, is called half-life. The older the groundwater gets; the more reaction time is available to decrease the concentration of the original compound. Water in confined aquifers can have ages up to hundreds or even thousands of years and the drinking water abstraction wells are usually located at a significant deeper depth than in RBF systems and unconfined aquifers. The age of water from unconfined aquifers or RBF systems can be much shorter, sometimes not even 60 days.

3.2.2 (Semi) Confining layers

Confining layers consist of materials (e.g., clay, solid rock) with a very low permeability. This prevents water from flowing through the layer. Water in a confined aquifer is therefore often still of pristine quality and can be very old. When these layers are perforated however, a short-circuit can be created between the confined aquifer and the phreatic aquifer on top. This can cause a decrease in groundwater quality of the confined aquifer due to the presence of contaminants in the phreatic aquifer.

3.2.3 Biogeochemical processes

Biogeochemical processes that play a role in retaining the pollutants are for example redox reactions, ion exchange and adsorption processes.
Reactive minerals and organic material naturally present in the soil can be seen as natural barriers, but these barriers are not infinite. Depending on the type of interaction between the soil and the pollutant, the soil components can be consumed during the process. This can eventually lead to more pollutants leaching towards the groundwater and a deterioration of the groundwater quality. The geochemical processes themselves can

sometimes also lead to a decrease in water quality, for example the release of heavy metals and sulphate as a result of pyrite oxidation by nitrate.

Soil organisms also form an important biological barrier for the protection of groundwater quality. The top part of the soil (0-25cm) receives the highest load of pollutants but also has a greater diversity and activity of microorganisms which are able to degrade pollutants than the deeper layers (Gibert et al. 1990). A distinction can be made between organisms that need oxygen to degrade contaminants, and organisms that do not need oxygen. In the top part of the soil and in the entire unsaturated zone (the portion of subsurface above the groundwater table), oxygen is present in higher levels and helps with the degradation of the pollutants and prevents them from leaching to the aquifer. Soil organisms are not only responsible for most of the degradation of pollutants in the top part of the soil, but also in river sediment and the first few meters of the aquifer in RBF systems.

3.2.4 Physical processes

Physical characteristics and processes that play a role in the movement of (rain)water through the soil are for example soil structure and soil moisture retention capacity. Soils consisting of clay can absorb less 'new' water than sandy soils. Saturated soils can also hold less 'new' water, resulting in more runoff during heavy rainfall events. This can cause a higher contaminant load to surface waters and less infiltration.

3.3 Water quantity

During droughts, crops and vegetations in many rural and urban areas rely on soil moisture, groundwater or irrigation for their water supply. Soil moisture is water stored in soil pores throughout unsaturated soils, that usually originates from infiltrated precipitation. Plant roots can abstract this water from soils, making it available for transpiration. Soils thus provide a crucial regulating service in the water supply of crops and vegetations. This limits the competition on scarcely available groundwater that is crucial for groundwater dependent natural vegetations and is also widely used for drinking water production.

Healthy soils provide the following regulating services on water availability for crops and vegetations:

1 Limiting rainwater losses through runoff

Runoff can limit the replenishment of soil water by precipitation when precipitation rates exceed soil infiltration capacity. This also causes loss of nutrients, pesticides, and other substances to surface waters, which may lead to deterioration of surface water quality.

Paving and unsustainable land use practices using heavy farming equipment cause completely or partly blocking of soil pores. This limits infiltration capacity, thus increasing water losses through run off.

Sustainable management of healthy soils provides sufficient plant rooting and macro-invertebrates activity to maintain natural infiltration capacity of soils. This limits water losses through run off and enhances the replenishment of soil water with rainwater.

2 Allowing sufficiently deep rooting depths for soil water uptake
Rooting depths largely determine the soil pore volume that is available for water uptake by plants.
Unsustainable and intense management of soils may lead to soil compaction, due to limited bioturbation or compaction by heavy farming equipment. This limits the growth of plant roots and thus the availability of soil water for plant uptake, which can be compensated by additional irrigation from groundwater.
Sustainable management of healthy soils provides loose soils with good rooting possibilities of crops and vegetations.

3 Maintaining soil water retention capacity
Soil water retention capacity is the amount of water that can be stored in unsaturated soils during a longer period of time. The soil water retention capacity is largely determined by the natural properties of the soil type. However, an increase of organic matter content with 1% is estimated to provide 20 mm additional soil water for Dutch sandy soils. Increasing organic matter content of soils requires decades of dedicated carbon management.

3.4 Soil indicators

Existing soil indicators are largely used for monitoring sustainable agricultural production. Some of these indicators have indirect relations with water functions. For example, soil organic matter content in general correlates with microbiological conversion of pollutants and provides conditions that enhances soil water availability for crops and vegetations (Van Loon, 2018). These relations cannot be generalized however, because of the wide range of pollutants sensitivity for conversion and more determining factors for water availability. Besides, a diverse microbiological population and the quality of organic matter seems more determining in water functions than their quantities alone.
Soil indicators need to be developed, linking soil properties with nutrient retention, ad- and absorption and conversion of pollutants. Indicators describing microbiological diversity and quality of soil organic matter probably provide the best perspectives.

3.5 Examples where groundwater quality is impacted by soil activities

The above-described processes taking place in the top and deeper parts of the soil are essential for groundwater quality, quantity, and the suitability of these aquifers as sources for drinking water. Several examples are known in which human soil activities caused contamination of the groundwater.

3.5.1 Example 1: Agriculture

Agriculture can be one of the sources of groundwater contamination. In the Netherlands, 25% of the groundwater used for drinking water originates from unconfined aquifers. Soil quality is very important for the water quality in these aquifers. In drinking water abstraction areas where agriculture is one of the main land uses, the aquifers can for example be polluted with nitrate which has leached from the topsoil layers after application of fertilizers.
In the Netherlands, nitrate concentrations exceeded the quality standards in 21% of all groundwater bodies used for drinking water abstraction. This is not only a problem in the Netherlands but stretches much further. In Austria for example, nitrate concentrations in groundwater from the Marchfeld area also exceed the quality standards from the Groundwater Directive in several cases (Cepuder, 1999). Furthermore, 22% of all groundwater bodies in Germany has a bad chemical status due to too high nitrate concentrations (Umweltbundesamt, 2023). Also in France, a significant proportion of groundwater bodies exceeds the quality standard of 50 mg/L for nitrate in groundwater. In 2016-2017, for example, 12.3% of all groundwater bodies had nitrate concentrations above the quality standard (OIEAU, 2023).

3.5.2 Example 2: Landfills

One of the most evident soil contaminations which have a direct effect on the groundwater quality are historical contaminations like landfills. In several countries, landfills played an important role in increasing the awareness of soil pollution and the link with groundwater. Between 1978 and 1985, 350,000 tonnes of hazardous waste was deposited in a disused clay-pit near the town of Kölliken in Switzerland (Bafu, 2023). The hazardous waste was deposited without an artificial lining which eventually caused the leaching of dangerously high amounts of contaminants into the surrounding groundwater. In total, 664,400 tonnes of contaminated soil, chemical waste and contaminated rock was excavated and thermally treated. Several similar cases are known from other European countries, like the Laarder Wasmeren in the Netherlands (Sevink, 2010), the Fischer Deponie in Austria (Altlasten Atlas, Umweltbundesamt, 2023) and the Brofiscin Quarry in Wales. Almost all of these cases were discovered due to the major contamination of the surrounding surface- or groundwater.
Contaminants from landfills that are currently receiving a lot of attention are per- and polyfluoralkyl substances (PFAS). They have been detected at numerous landfill sites, like in the central part of the Netherlands (Eschauzier et al. 2013), in Sweden (Gobelius et al. 2018), in Spain (Fuertes et al. 2017) or in Malta (Sammut et al. 2019). They can also be released by activities on the surface, like firefighting practices using aqueous firefighting foams (Eschauzier et al. 2013).

3.5.3 Example 3: Thermally cleaned soils

Other human activities on the soil which can have an impact on groundwater quality are the application of residuals from treatment processes like thermally cleaned soils. These soils are sometimes used as an alternative for sand in the construction of embankments like dikes. By thermally heating the soil, the (organic) contaminants present are removed from the soil. All other constituents however, like humus and plant residues, are also removed from the soil. This means that conditions for soil organisms and plant growth are very poor. In theory, all contaminants are removed from the soil by thermal treatment. It has however been shown that thermally heated soil can still contain harmful substances and have too high concentrations of salts and heavy metals, which can have a negative impact on groundwater quality (Brand et al., 2018).

3.5.4 Example 4: Application of sewage sludge

Application of sewage sludge on agricultural land can also be an important source for groundwater or surface water contamination. Sewage sludge can contain several pollutants, depending on the source of the wastewater and the treatment of the sludge before application on the soil (Seleiman et al., 2006). Pollutants like heavy metals, organic contaminants and pharmaceuticals can leach into the groundwater. In Germany, sewage sludge was used in an agricultural area near Brilon-Scharfenberg (Skutlarek et al., 2006). Due to improper treatment, PFAS was present in the sludge. This leached from the soil, causing contamination of the nearby lake and river and eventually the drinking water abstraction points downstream from to the agricultural lands.

3.5.5 Example 5: Polluted river sediments

Another source of pollutants in groundwater can be river sediments. In areas where river water is infiltrating in groundwater bodies (for example in Austria, Poland, or Spain), pollutants present in the river sediment can leach to the adjacent groundwater (van Driezum et al., 2019, Kruc et al. 2019, da Silva et al., 2011).

3.6 Management options

The abovementioned examples show that the groundwater quality can be impacted by activities taking place in the top layers of the soil or in sediment layers. To decrease the impact of these activities, several measures can be taken.
An example where an intervention on nitrate leaching to groundwater had a positive effect is in the Dutch province of Limburg (van Loon et al., 2019; Kusters et al., 2013). One of the drinking water abstraction wells of the drinking water company WML had problems with high nitrate concentrations in the raw groundwater. To decrease nitrate

concentrations in the groundwater, WML worked together with farmers in the region since most of the recharge area of the groundwater wells consisted of agricultural fields. Together with agricultural advisers (partly financed by WML), the farmers updated their management plans and reached a substantial decrease in nitrate leaching to the groundwater and therefore concentrations in the raw water of the drinking water abstraction wells decreased. Therefore, the removal of nitrate from the groundwater was no longer necessary.

Another example where an intervention increased the groundwater quality is the excavation of the Kölliken landfill in Switzerland. After the excavation, no more pollutants leached into the groundwater. Groundwater abstraction wells were built and the abstracted groundwater is treated by a separate wastewater treatment plant.

3.7 Wrap-up

A distinction can be made between unconfined (phreatic) and confined aquifers. The most important difference between these two types of aquifers is the presence or absence of an (semi) impermeable layer on top and underneath an aquifer. This (semi) impermeable layer protects the groundwater from pollution. Both aquifers are used for the abstraction of drinking water. Another type of system which is becoming more and more popular for drinking water abstraction are RBF sites as alternative to direct intake of surface water. The aquifer passage has the capacity to reduce or eliminate certain contaminants. The age of the groundwater varies from a couple of months in phreatic aquifers and RBF sites to thousands of years in confined aquifers.

Pollution coming from soil activities soils can have a large impact on groundwater quality. Several processes, however, can increase groundwater quality and alter the impact of the pollution. Pollution can be decreased by factors like time, space, the presence of confining layers, and biogeochemical and physical processes.

Soils also play an important role in water availability for crops and vegetations. Healthy soils limit rainwater losses through runoff, allow for a sufficiently deep rooting depth of vegetation and maintain the soil water retention capacity.

Soil indicators can be used in order to link soil properties to groundwater quality and quantity. Existing indicators are largely used for monitoring sustainable agricultural yields but have only indirect relations with water functions. Indicators describing microbiological diversity and quality of soil organic matter probably provide the best perspective.

Several examples have shown the impact of different soil activities on groundwater quality. Leaching of nitrate and pesticides to the groundwater in agricultural areas is a widespread problem in the EU, just as the leaching of pollutants from landfills. The use of thermally cleaned soils can also affect the groundwater quality and should be closely monitored, just as the application of sewage sludge on agricultural lands. Polluted river sediments can also be a source for several pollutants.
The impact of these activities is not irreversible. Interventions can help to prevent or decrease pollution of the groundwater and increase the groundwater quality over time.

4 Importance of linking groundwater to the Soil Health Law

The European Commission defined a total of around 80 key actions in order to achieve all the objectives of the EU Soil Health Law. Some of these key actions are indirectly related to groundwater and a direct link between the action and groundwater should be considered. In this chapter, the importance of linking groundwater to the SHL will be shown based for some of the key actions.

4.1 Key actions on circular economy

The Circular Economy key action on *closing nutrient and carbon circles by safely recycling excavated soil and biowaste* is important to groundwater since the usage of excavated soils or recycled biowaste could introduce contaminants to the soil (see chapter 3.5.4 for an example). If the recycling process for biowaste is not done properly, contaminants can leach into the groundwater and/or eventually end up in the surface water. It is important to regulate the quality of for example sewage sludge and restrict its usage in areas where groundwater is abstracted and where the groundwater is vulnerable to contamination. The amount and nature of contaminants is dependent on the wastewater treatment plant and the number of households or type of industry connected to it. Care should be taken to remove all contaminants from biowaste which are relevant for the protection of both ground- and surface water. Excavated soils should not be used if they are polluted with chemicals which are poorly degradable and can cause problems for the groundwater quality.

4.2 Key actions on limiting land take and soil sealing

The key action on *limiting land take and soil sealing* describes the key ecosystem services which are lost when soils are sealed. A key process to restock the groundwater is the ability of the soil to infiltrate rainwater. When more and more soils become sealed due to for example buildings or infrastructure, it is harder for rainwater to infiltrate and the groundwater levels won't be able to restore to sustainable levels. Less sealing can not only lead to better infiltration into the groundwater but can also lower the occurrence and impact of floods in urban areas caused by climate change. The actions described in the Soil Strategy and in the SHL should also encompass actions that can be taken by civilians. They can for example be urged to make gardens greener and make it easier for rainwater to infiltrate into the soil. This action, which is now referred to as point 4. in the land take hierarchy (see Figure 4), should get a more prominent role in this key action.

Figure 4 Key actions on limiting land take and soil sealing: land take hierarchy

4.3 Key actions on Clean Water

For Clean water, several key actions have been identified which need to be linked to the protection and conservation of groundwater. As one of the key actions, *a guidance on sustainable management of sediment* is proposed. This action relates to the re-use of highly fertile and carbon-rich soils which are eroded and deposited downstream in river basins, behind dams or in the sea as sediments. Re-use should only be an option when these sediments are clean. The role of sediments in cleaning pollutants present in surface waters is not well described in the Soil Strategy, neither is the impact of the sediment on groundwater quality. Heavily polluted sediments can emit many pollutants into the groundwater and care should therefore be taken when reusing these sediments. The ability of sediments to degrade pollutants and act as a first barrier in RBF systems is a very important aspect of many drinking water abstraction sites in Europe that use riverbank filtration.
Another action which is described is on *a better integration of soil and land use management in river basin management plans*. The nature of the integration is heavily on protection of the environment and surroundings to climate change (for example by extreme flooding or by droughts). The connection with groundwater is made by the restoration of the water retention capacity of the soil, but the impact of infiltration of polluted water to the underlying groundwater has not been described in the Soil Strategy. When groundwater bodies are used for drinking water abstraction, inundation with polluted water might very well be a problem. Moreover, the role of soil moisture should be described in cases of droughts. After an extensive drought, rainfall needs to be able to infiltrate into the soil and leach to the groundwater to restore the original groundwater table.

4.4 Key action on Sustainable Soil Management (SSM)

The key actions on *making the sustainable soil management the new normal* do mention a link with water and describe multiple benefits. The application of sustainable soil management (SSM) should increase soil biodiversity, fertility, and resilience. This action is set to link with the farm to fork and biodiversity strategies and should increase soil organic matter. Although this is a positive action for agricultural land, this might negatively influence groundwater bodies used for the abstraction of drinking water. In the requirements that are proposed for the sustainable use of soil, a distinction should be made in land uses. If agricultural lands for example are situated in a groundwater abstraction area, restrictions could be more stringent and should be focused on the impact of the soil on the groundwater, and not only on the impact on other ecosystem services.
The *'Test your soil for FREE' initiative* makes it possible for land users to know more about the soil characteristics. Care should be taken that environmental standards do not only meet the criteria for fertile lands, but also consider the standards for groundwater (used for drinking water).

4.5 Key actions on Preventing soil pollution

As key actions on preventing soil pollution, the EU will include *the impact of chemicals on soil quality and soil biodiversity in the risk assessments for chemicals, food and feed additives, pesticides, fertilizers etc.* This should not only encompass the impact on soil quality and biodiversity but should also take groundwater into consideration. As has been described in chapter 3.5, soil pollution can easily contaminate the groundwater. Therefore, this should by all means be prevented. More stringent measures can be taken in areas where the groundwater is used as a source for drinking water. The Water Framework Directive could be linked to these actions, next to priority lists from the DWD and the Groundwater Directive. Furthermore, actions taken under REACH could also call for information on the ability of the chemicals to be degraded in the soil.

4.6 Key actions on Restoration and remediation of degraded and contaminated soil

One of the key actions on remediation of contaminated soils is *making reporting of managing soil pollution mandatory and uniform across the EU* in the context of the EU Soil Health Law. It is very important to have a mutual definition of contaminated sites and an overview of these sites in the entire EU. Contaminated sites can pollute the environment and pollutants can reach the groundwater. When these sites are not registered, some sources of the pollution might be overlooked and remediation measures that could have been taken at the contaminated site are not considered. The reporting of contaminated sites should also include the impact of the pollution on groundwater and the risk it poses to the ground- and surface water quality, especially if the site is close to a drinking water abstraction area. This is also very important in contaminated sites where runoff can cause an increase of pollutants in surface waters, especially if they are used as a source for drinking water downstream of the polluted site. Monitoring of pollutants on the WFD and groundwater watch list can be an instrument for determining the risk these sites pose to the aquatic environment.

4.7 Key actions on Soil and the digital agenda

With the increasing knowledge and possibilities from Earth Observation and new techniques like DNA analysis for soil organisms, new opportunities are present for monitoring the pressures and conditions of soils. The *enhancement of the use of digital tools and Copernicus* (the Earth observation program of the EU) is defined as one of the key actions in this field. With these tools, it should be possible to address soil pollution and give insights into bio-geophysical variables, land cover and land use. One of the main interests when considering the link with groundwater is the amount of soil moisture. When using this data, the focus should not only be on agricultural practices, but also on the water retention capacity of the soil and the ability to restore groundwater levels. Farming should not only be done in a sustainable way for growing crops, but also for a better water balance.

4.8 Key actions on Soil data and monitoring

As key actions on soil data and monitoring, the *development of a soil dashboard with a set of reliable soil indicators integrating trends and foresight* is mentioned. As indicated in chapter 3.4, the existing Dutch soil indicators are largely used for monitoring sustainable agricultural yields. These indicators, however, should also link soil properties with nutrient retention, adsorption, and conversion of pollutants to protect the groundwater. This could be done with indicators which describe the microbiological diversity of the soil and the quality of soil organic matter. The action on *providing harmonized monitoring of the evolution in soil organic carbon content and carbon stocks through the LUCAS soil surveys* is a good step moving forward. Furthermore, the work that is going to be done on *integrating a pollution module in the future LUCAS soil survey* connected with other monitoring initiatives such as the EU groundwater watchlist is a very positive trend.

5 Conclusions

As has been shown, the European Soil Strategy and the EU SHL aims to protect and restore all European soils and thrives to achieve healthy conditions of soil ecosystems by 2050. With the protection of soil, groundwater automatically comes to mind. Groundwater is part of several European Directives, which should be addressed by the new SHL. Not only the WFD, the Groundwater Directive and the DWD should be considered; passages from the Nitrates Directive, the SUP Directive and the Regulation on Nature Conservation should also be integrated into the SHL. The lists of priority substances and watchlists from some of these Directives could help in protecting and restoring European soils and groundwater.

Groundwater is a very important source of drinking water in Europe: 75% of European drinking water is produced from this valuable resource. The groundwater aquifers are not always very well protected. Confined aquifers are protected by low permeability layers, whereas unconfined aquifers and RBF systems are not protected by these layers. Pollutants coming from activities on or with the soil can therefore be introduced into the aquifer. Several examples have shown that groundwater quality deteriorated as a result of agricultural activities, landfills or the reuse of soil or sewage sludge. Fortunately, several soil processes can contribute to the increase of the groundwater quality (for example by the degradation or chemical transformation of pollutants). It is however of key importance that soils keep their capacity to infiltrate clean (rain) water in sufficient amounts in order to contribute to sustainable replenishment of groundwater bodies. This not only ensures healthy soils, but also healthy (amounts of) groundwater for nature and drinking water production.

Many of the key actions described in the Soil Strategy can be linked to groundwater. For some key actions this link is described, albeit sometimes not to its fullest extent. The actions on clean water should for example describe the role of sediments in cleaning pollutants in surface water and also include the impact of sediment on groundwater quality. Important key actions linked to groundwater are: 1) circular economy, 2) limiting land take and soil sealing, 3) clean water, 4) Sustainable Soil Management, 5) preventing soil pollution, 6) restoration and remediation of degrades and contaminated soil, 7) soil and the digital agenda and on 8) soil data and monitoring.

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