Introduction to Soil-Water Interactions Guidance Note

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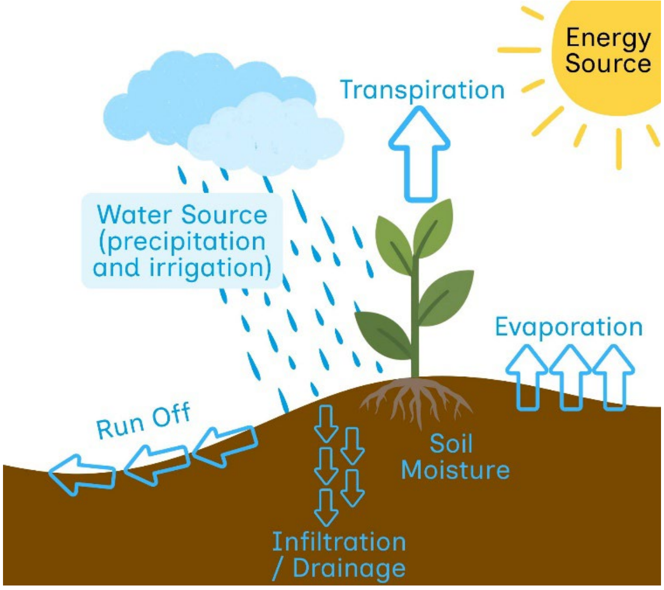
Soil–water interactions determine how water enters the soil (infiltration), how it is stored in soils (retention), how it moves through soil layers (percolation), and how it leaves soils (via evaporation, plant uptake, or runoff). Understanding these processes is crucial for farming, water resource management and environmental protection – since soils act as natural reservoirs and filters for water, influencing both surface and groundwater systems. Ultimately, the behaviour of water in the landscape – from sustaining crops to contributing to floods or droughts – is linked to soil conditions. This brief guidance note introduces key mechanisms of soil–water interaction and examines their implications for water quality and quantity.



(Based on AHDB's "Water and Soils" figure, with permission)

Key points

- **Soil structure critically governs water behaviour.** Soils with good structure (well-aggregated, porous) have high infiltration rates and water storage capacity, which reduces runoff and erosion risks. By contrast, compacted or structureless soils shed water quickly, increasing flood risk. Improving soil structure (whether through organic matter additions, reduced tillage, cover cropping, controlled traffic farming or other methods intended to avoid or ameliorate compaction) can dramatically alter a soil's hydrological response to rain.
- **Texture and organic matter drive water retention.** Clay soils hold more total water than sandy soils due to their small pores, but a smaller proportion of that water is available to plants. Plant-available water is maximised in organic, loamy soils. Increasing soil organic carbon content by 1% can boost water holding capacity by

thousands of litres per hectare. While this represents a fraction of typical crop demand over a whole growing season, it may prove critical to crop survival under drought conditions.

- **Surface water impacts are soil dependent.** Poor soil management can contribute to many surface water issues, whether sediment pollution, nutrient enrichment, or flash floods. Each 1 mm of runoff from a hectare equates to 10 cubic meters of water and keeping that water in soils can make the difference between normal stream flow and a flood, or between clear water and muddy water in a given catchment. Strategies like no / minimum tillage and cover cropping have been shown to reduce soil losses by between 40 and 80% and nutrient losses by between 30 and 50%. Managing soil is managing water at the catchment scale.
- **Groundwater recharge and quality rely on soil processes.** The quantity of water that reaches aquifers and the quality of that water are both mediated by the soil. Soil hydraulic properties are fundamental to groundwater modelling, while soils with high denitrification potential (such as organic-rich riparian soils) can attenuate nitrates and improve groundwater quality.
- **Climate resilience through soil resilience.** Soil's water buffering properties will become even more critical in a climate future where rainfall patterns have become more erratic, potentially with more frequent short bursts of high intensity precipitation. Research into regenerative agricultural practices is providing evidence that higher soil organic matter, continuous plant cover, and diverse rotations can improve water infiltration and retention – helping to mitigate negative climate impacts such as runoff and drought stress. Climate adaptation for water management and agriculture must include measures focussed on soils.

Soil-Water Interactions

Soil water dynamics are governed by the soil's mineralogy, structure, texture and organic matter content. These factors control several key mechanisms by which soil and water interact:

- **Water Retention.** Fine-textured soils high in clay or silt have many small pores and a high water-holding capacity. By contrast, sandy soils have large pores and a lower water-holding capacity. For example, clay-rich soils can retain between 35 and 50% of their volume in water at field capacity, whereas sands might hold between 10 and 20%. Organic matter also contributes to soil's water retention properties. Healthy, organic-rich soils can buffer against drought by holding more water and slowly releasing it for plant uptake.

- **Infiltration and Hydraulic Conductivity.** In well-structured soils with many large pores or cracks (macropores), infiltration can be rapid – for instance, in a friable sandy loam, water might infiltrate at 10–20 mm/hour or more, whereas this might drop to less than 5mm/hour in a compacted clay soil. Good soil structure (e.g. granular aggregates in topsoil, with continuous pores created by roots and soil fauna) enhances conductivity.

Conversely, when soil structure is compacted or crusted, pores collapse or seal, reducing infiltration. Surface capping is a common issue, resulting from the clogging of surface pores due to the breakdown of soil aggregates under heavy rainfall conditions, reducing infiltration rates significantly *(AHDB, 2020)*.

- **Adsorption and Desorption**. Fine soils with high clay content have a greater water adsorption capacity – contributing to high total water retention – but much of that water is tightly held due to capillary forces. This is why medium-textured loam soils can provide more plant-available water than fine clays *(British Geological Survey, 2020)*.

Implications for Surface Water

Soil compaction has a direct negative effect on soil–water interactions: pore space is reduced, so infiltration capacity drops, and more water runs off the surface. Studies in the UK have found that strongly compacted agricultural soils can have infiltration rates less than half those of well-structured soils in the same area *(DEFRA, 2018)*.

One outcome of reduced infiltration is increased runoff, which often leads to soil erosion. This not only strips fertile topsoil from fields but also drops it as sediment in surface water bodies, impacting aquatic ecology. The UK faces significant challenges with soil compaction and erosion: government assessments indicate that in England and Wales almost 4 million hectares of topsoil are at risk of compaction, with about 2 million hectares at risk of erosion *(Environment Agency, 2019)*. These at-risk areas largely coincide with regions of intensive agriculture. The loss of soil structure in such regions leads to reduced water infiltration, greater flood peaks, and sediment-laden runoff during storms.

When eroded soil enters rivers and lakes, it raises turbidity and can smother aquatic habitats. Fine sediment deposition degrades spawning grounds for fish and can harm aquatic plants by blocking sunlight. Sediment can also carry attached pollutants such as nutrients (phosphorus) and pesticides into water bodies. Thus, compaction and erosion set off a chain reaction: more runoff → more erosion → poorer surface water quality. In the UK, the combined effects of soil erosion and compaction have been estimated to cost around £1.2 billion per year in lost productivity and environmental damages *(Environment Agency, 2019)*.

Maintaining or improving soil structure can significantly mitigate these problems. Incorporating organic matter (like compost or manure) encourages soil biological activity and aggregate formation, while mechanical measures such as subsoiling can temporarily relieve compaction. Controlled traffic farming — confining heavy machinery to specific lanes — prevents widespread compaction. Additionally, keeping soil covered with vegetation (whether as cover crops, grass leys, or crop residues) protects the soil surface from the physical impact of raindrops and reduces capping.

When soils cannot absorb rainfall effectively, surface runoff increases. Rapid runoff contributes to flash flooding in both urban and rural contexts, even in small catchments. Climate change projections suggest that high-intensity rainfall events will become more frequent in the UK, with extreme downpours up to four times more frequent by 2080 under high-emission scenarios (*Kendon et al., 2023)*. This makes it increasingly important to manage soils as a form of natural flood defence: a well-structured soil can absorb and hold more rain, delaying and reducing the peak flow that reaches surface water bodies.

There is growing recognition that natural flood management and water quality improvement can go hand in hand through better soil management. Initiatives are emerging where farmers are supported to adopt measures like cover cropping (to increase infiltration and uptake excess nutrients), contour ploughing or terracing (to slow runoff), and wetland creation in low fields (to capture runoff and filter pollutants). These practices help keep water and topsoil on the land, thereby reducing downstream flood risk and improving the quality of water that does eventually leave the fields.

Implications for Groundwater

Groundwater is primarily recharged by water infiltrating and percolating down through soils. Not all rainfall contributes to groundwater recharge: much is taken up by plants or evaporates, and some runs off. The portion that does seep down beyond the root zone to the water table is influenced by soil type and condition.

- Coarse-textured soils tend to allow water to percolate quickly. For example, the chalk downlands of southern England are covered by thin, free-draining soils with a high hydraulic conductivity, meaning that rainfall rapidly moves downward rather than generating surface runoff. This is useful for aquifer recharge, but because water infiltrates so fast, these soils hold less water in the root zone, which can increase drought stress for crops.
- Fine-textured or compacted soils have slow infiltration and percolation characteristics, leading to slow groundwater recharge rates. Most intercepted rainfall is either used by plants, evaporates, or becomes runoff. Heavy soils often saturate in winter, after which additional rainfall will inevitably runoff.

Soil depth and subsoil layers also matter. A deep soil overlying permeable rock gives water more opportunity to be retained and percolate, whereas a shallow soil over bedrock can lead to rapid transmission of water through rock fractures (if present) or simply more runoff if the bedrock is impermeable. If an impermeable layer exists under the soil (for example, a compacted plough pan), water may perch above that layer, preventing deeper recharge. In general, maintaining good soil structure enhances groundwater recharge rates.

As water percolates through soil to reach groundwater, the soil acts as a natural filter that can attenuate water quality through a combination of physical filtration, chemical adsorption and biodegradation.

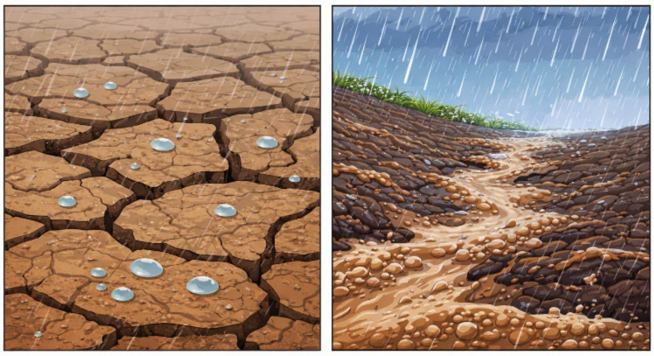
The soil matrix can strain out particles carried by water, including bacteria from manure or a septic infiltration system – provided that flow is slow enough for them to contact soil surfaces. Very rapid infiltration (e.g. through large cracks or gravel soils during a storm) reduces contact time, allowing pollutants to bypass these natural filters and contaminate groundwater.

Soil minerals and organic matter can adsorb and retain dissolved pollutants (and potential pollutants such as ammonium and phosphate). Many pesticides and other chemicals also sorb to soil particles – although the diverse biological communities in a healthy soil break down some organic pollutants, including pharmaceutical residues.

Overall, a well-managed soil significantly protects groundwater from contamination.

Climate change impacts

Climate change is altering precipitation patterns and extremes, which in turn affects soil–water interactions, including surface runoff and groundwater recharge. The general expectation for the UK's climate is wetter winters and drier summers, with more frequent heavy rainfall events and more frequent summer droughts. These changes have several implications:



Dry, Cracked Hydrophobic Soil Resisting Infiltration

Intense Rainfall Leading to Saturated Runoff

- Intense rainfall events: Heavier downpours can lead to more runoff and less infiltration, especially if soils are not in good condition. When a large volume of rain falls in a short time, even a well-structured soil might not absorb it all quickly, leading to surface runoff. If soil is dry and hard or capped, intense rain can initially run off, meaning that a greater proportion of annual rainfall may end up as runoff. This would not only increase flood risks but also reduce groundwater recharge despite high rainfall totals. The timing of events is also important, as a series of winter storms can keep soils near saturation, favouring runoff.

- Prolonged dry spells: Longer, hotter dry periods in summer can cause soils to become extremely dry and sometimes hydrophobic (water-repellent). Certain soils, particularly those rich in organic matter (peaty soils) or those that have experienced repeated wet-dry cycles, can develop hydrophobic coatings when dry. This means that when rain finally arrives, it takes time for the soil to start absorbing water again, often resulting in initial runoff or very slow infiltration. The impacts of combined dry and wet periods on water quality and quantity will be particularly high in poorly managed soils.

Overall, climate change is likely to make soil–water management more challenging by introducing greater variability. To maintain groundwater recharge and limit flooding and erosion, soils will need to be more resilient. This will mean enhancing soil organic matter (to improve structure, water holding, and resilience to wet-dry fluctuations), using cover crops and crop rotations that include deep-rooting species (to improve soil porosity and reduce compaction) and (potentially) changing land use (for example, converting some flood-prone arable land to permanent grassland or wetland to serve as buffers during periods of extreme weather).

Many of these strategies align with climate adaptation and mitigation goals (since increasing soil organic carbon also helps sequester carbon, and reducing flood risk protects communities), highlighting the importance of soil management in climate resilience planning.

References

- **AHDB (2020).** *Soil pore network and infiltration*. Agriculture and Horticulture Development Board Knowledge Library. (Accessed 10 Sep 2025).
- **BGS (2019).** *Groundwater resources in the UK*. British Geological Survey. (Accessed 10 Sep 2025).
- **BGS (2020).** *State of the Environment: Soil – Main findings (England and Wales).* Summary published on GOV.UK, 26 Jan 2023. (Accessed 10 Sep 2025).
- **DEFRA (2018).** *Rules for farmers and land managers to prevent water pollution*. UK Department for Environment, Food & Rural Affairs, guidance document. (Accessed 10 Sep 2025).
- **Environment Agency (2019).** *State of the Environment: Soil*. UK Environment Agency Report (June 2019). (Accessed 09 Sep 2025).
- **European Commission (2021).** “Nitrates Directive – Report on implementation.” *EU Commission Staff Working Document*. (Accessed 09 Sep 2025).
- **European Commission (2023).** *EU Soil Health: Proposal for Soil Monitoring Law and 2030 Strategy.* Brussels, European Commission Communication COM(2023) and COM(2021) 699 final. (Accessed 09 Sep 2025).

- **Farmers Weekly (Case, P., 2019).** "Compaction and erosion 'a serious threat' to UK farm soils." *Farmers Weekly*, 8 April 2019. (Accessed 08 Sep 2025).
- **Kendon, M., et al. (2023).** "State of the UK Climate 2022." *International Journal of Climatology*, **43** (S1): 1–35. (Summary accessed via Met Office, 07 Mar 2023).
- **Klopp, H. (2024).** *How Soil Holds Water.* South Dakota State University (SDSU) Extension, updated May 2024. (Accessed 09 Sep 2025).
- **Scottish Environment Protection Agency (SEPA) (2025).** *Diffuse Pollution General Binding Rules: Explained*. SEPA Guidance Document. (Accessed 09 Sep 2025).
- **Scottish Government & SEPA (2008).** *The Water Environment (Diffuse Pollution) Regulations 2008 – Guidance on General Binding Rules.* Edinburgh. (Accessed 09 Sep 2025).
- **Taylor & Francis Group (2020).** *Soil–Water Interactions* (Iwata, Shingo, et al., eds). CRC Press, Boca Raton. (Accessed 09 Sep 2025).
- **UK Groundwater Forum (2019).** "FAQ: Is the water in my tap groundwater?" UK Groundwater Forum educational material. (Accessed 10 Sep 2025).