Landscape Institute Technical Information Note

Soils and Soil-forming Material

Technical Information Note 04 /2017

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Contents

> ***"Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel, and our shelter and surround us with beauty. Abuse it and the soil will collapse and die, taking humanity with it."***
>
> **From Vedas Sanskrit Scripture – circa 1500 BC**

The aim of this Technical Information Note is to assist Landscape Professionals (primarily landscape architects) when considering matters in relation to soils and soil-forming material.

Soil is an essential requirement for providing sufficient food and other primary resources for the world's population, primarily via agriculture and silviculture. It provides countless influences on the natural and man-made world, facilitating important natural systems and providing numerous ecosystems services. Understanding the complexities of soil and how to manage, protect and utilise it is vitally important to a wide range of professions including Landscape Professionals.

It is hoped that the Note will help to improve Landscape Professionals' knowledge and understanding of soil to facilitate their work and help to conserve a natural asset.

1. Introduction to Soils

What Is Soil?

1.1 The term **Soil** does not have a universal definition and can be described in a number of ways in relation to its **chemical, physical** and **biological** components, processes and characteristics that, when soil is present, differentiate it from (and creates a transition zone between) the air (or atmosphere) above and the geology (**lithosphere**) below, and forms the **pedosphere**.

1.2 Soil is predominantly a 'terrestrial' component of the earth's surface but may also be present permanently below water, generally only where water is no deeper than circa 2.5m, such that it can support rooted emergent aquatic plants. The surface of soil may also be predominantly covered by vegetation (e.g. turf grass) or may be exposed at the surface, which may also vary over very short and very long (geological) periods of time.

1.3 Soil can be natural (having formed and developed over many years (termed **pedogenesis**)) or be 'manufactured' by humans, but, due to the complex systems and interactions that develop over many (often hundreds of) years within soils, manufacturing of soils does not instantly create soils that fully replicate natural soils. Such manufactured soil is often referred to as **soil-forming material** (or, less commonly, soil-making material) such that the intention is to provide the precursor conditions required to facilitate the soil-forming material's accelerated development, to achieve target characteristics and uses of the soil.

1.4 Soil is one of the world's most important natural resources providing many important **ecosystems services**, via its functions as a:

- Medium for plant growth;
- Habitat for other organisms;
- Structural support medium;
- Recycling system for nutrients and organic matter;
- Regulator of water quality and movement; and
- Modifier of atmospheric composition.

1.5 Soil consists of a mixture of a number of components:

- **Mineral** grains and rock or stone fragments, from the rock deposits and sediments beneath them;
- **Organic matter**, from rotting and decomposed vegetation;
- **Water**, from the atmosphere, the surface and from below (ground water), which may interact with other chemical components within the soil to create **aqueous solutions**;
- **Gases**, which are largely related to the atmosphere and biological processes occurring in the soil, but may also be related to adjacent or underlying land-use (e.g. methane from landfilling) or from geology (e.g. radon); and

- **Living organisms**, which, at the microscopic level, are usually exceptionally numerous and diverse, forming a complex soil ecosystem and a large proportion of the world's biodiversity, and otherwise include an array of life at different scales, ranging from animals as large as badgers, to organisms as small as bacteria.

Key Terms and Other Fundamentals

1.6 The following terms and outline information are provided to the reader to enable those unfamiliar with them to more readily understand the subsequent information provided. The distinction between geology and soils has historically been a blurred one, but as knowledge and specific areas of expertise have developed over time, the distinction has become clearer. As a number of areas of earth science are heavily interlinked it is useful to have a basic understanding of these when considering soils.

Geological Terms

1.7 Earth's outer solid layer of rock (Earth's Crust and Upper Mantle) which form the tectonic plates is referred to as the **lithosphere**. It comprises **bedrock** geology (or 'solid' geology) and is present everywhere, whether exposed at the surface (**outcrops**) or concealed beneath superficial deposits, soil, water or man-made features.

1.8 **Superficial deposits** (**regolith** or 'drift') are the youngest geological deposits (geological sediments) and generally lie above bedrock, where present, and are usually derived from bedrock, either at that location or deposited from a more distant location. Most superficial deposits are unconsolidated sediments such as gravel, sand, silt and clay, and form relatively thin discontinuous patches or larger spreads. Almost all of these deposits were formerly classified on the basis of mode of origin with names such as, 'glacial deposits', 'river terrace deposits' or 'blown sand'.

1.9 In quarrying (i.e. where extraction of useful raw materials from sub-surface take place), material which lies above the target rock or target geological deposits (the 'mineral') but below the subsoil (see 1.28) is often called **overburden**.

1.10 **Geology**, broadly, means the study of solid Earth, the rocks of which it is composed and the processes by which they change, but is also generally the term used when making reference to rock or superficial deposits (e.g. "*the geology underlying the soil in this part of the UK is granite*").

1.11 **Petrology** is a subdivision of geology that focusses on the study of the origin, composition, distribution and structure of different rocks, usually based on the microscopic characteristics.

1.12 **Lithology** is the description of a rock's physical characteristics visible at an outcrop, in hand or core samples, or with low magnification microscopy, and include aspects such as colour, texture, grain size, or composition and forms the basis of classifying areas of different geology.

1.13 At a granular level, rocks are composed of grains of **minerals** and **mineraloids**. Minerals are naturally occurring solid (at room temperature) crystalline chemical compounds that are represented by chemical formulae, that haven't been created by living organisms. There are over 5,000 known minerals distinguished by various chemical and physical properties. A mineraloid is a mineral-like substance that does not demonstrate crystallinity (being '**amorphous**'). The minerals and mineraloids (referred to collectively in the rest of this document as 'Minerals') forming rock are held together by chemical bonds.

> ***Note*****:** The word "mineral" is used to mean a number of different aspects in soil science and geology, depending on the context, and can refer to:
>
> - The chemical compounds that form rocks, at a granular level; and
> - Geology present that forms an asset of value as a raw material to man, and which may be targeted for removal and use as a resource (via quarrying or 'mineral extraction').

1.14 **Weathering** of the geology (i.e. the breaking down of rocks and minerals through contact with the atmosphere, water and biological organisms) releases rock fragments, of varying sizes, including grains of Minerals, initiating the formation of superficial deposits and soils. Rocks and geological sediments form the main **parent material** of soils (i.e. the primary materials from which soils have formed) and their characteristics contribute a direct effect on the characteristics of the soils that they help to create. Transfer (translocation) of this material (e.g. via surface water flows or wind) from that location (i.e. from the **eluviation zone** via **erosion**) and dropping the material elsewhere (i.e. in the **illuviation zone** via **deposition**) may occur (see 1.20).

1.15 **Hydrogeology** is the area of geology that deals with the distribution and movement of groundwater in the soil, superficial despots and rocks. Although essentially solid in nature, rocks may be described as **porous** (containing many pores) and where these pores are interlinked, such that they allow flow of liquid (and movement of gases) between the pores, the rock can be described as being **permeable**. Heavily fissured rocks and loose superficial deposits may also be permeable.

1.16 Different rocks and superficial deposits exhibit different degrees of permeability: pervious, semi-pervious and impervious (impermeable). Rocks which contain fissures are said to be pervious. See Figure 1.

<table>
<tr><th>Permeability ➢
Geology ⮛</th><th colspan="2">Pervious</th><th colspan="4">Semi-Pervious</th><th colspan="3">Impervious</th></tr>
<tr><td>Unconsolidated Sand & Gravel</td><td>Well Sorted Gravel</td><td colspan="2">Well Sorted Sand or Sand & Gravel</td><td colspan="4">Very Fine Sand, Silt, Loess, Loam</td><td colspan="2">-</td></tr>
<tr><td>Unconsolidated Clay & Organic</td><td colspan="2">-</td><td colspan="2">Peat</td><td colspan="3">Layered Clay</td><td colspan="2">Non-weathered Clay</td></tr>
<tr><td>Consolidated Rocks</td><td colspan="2">Highly Fractured Rocks</td><td colspan="3">Oil Reservoir Rocks</td><td colspan="2">Fresh Sandstone</td><td>Fresh Limestone, Dolomite</td><td>Fresh Granite</td></tr>
</table>

Figure 1 Intrinsic Permeability of Different Geology (Bear, 1972) - adapted

1.17 Geology that is permeable may contain an **aquifer** (a continuous widespread layer or band of underground water, i.e. it is saturated). This groundwater can flow laterally as well as vertically through the permeable geology. Semi-pervious geology that *restricts* movement of groundwater beyond the aquifer is called an **aquitard**. Where rock completely prevents further movement, it is called an **aquiclude** (or aquifuge).

1.18 Aquifers can be confined by an impervious layer of geology above the aquifer (**confined aquifer**) but the uppermost aquifer is generally **unconfined** and, where it is close to the surface, may restrict drainage of soils or result in saturated soils, or result in standing (or flowing) surface water. Where unconfined, the groundwater settles at a level below the surface which is called the **water table**. Groundwater near the sea may be saline.

1.19 **Geomorphology** is the study of landforms, their processes, form and sediments at the surface of the Earth. It overlaps geology, biology and soil science, each aspect influencing the others.

1.20 Such processes vary across the world, such that soil characteristics and processes can vary on a global scale, depending on climate variations. Landform (relief) at a location can influence the soil characteristics, affecting more localised weather conditions (e.g. via differing elevations and aspects) and slope angle can also affect drainage rates and rates of erosion and deposition. A series of soils can develop along a slope, as the form changes along its drop, and the description of this 'chain' of soils is called the **soil catena**.

Soil Terms

1.21 **Soil Science** is the study of soil as a natural resource including soil formation, classification and mapping; physical, its properties of soils; and management in relation land-use. **Pedology** is a branch of soil science which focusses on the formation, chemistry, morphology and classification of soil (in its natural setting). **Edaphology** focusses on the influence of soil on organisms, especially plants, including man's use of land for plant growth. Primary influences from, or characteristics pertaining to, soils are referred to as '**edaphic**'.

1.22 **Soil Biology** is the study of the organisms present within soil and forms a specialist area of both soil science and biology. **Soil organisms**, soil life, soil biota, soil biomass, or **edaphon** are collective terms that encompasses all the organisms that spend a significant portion of their life cycle within soil. The overlap and interaction with organisms that rely on the soil in other ways (e.g. natural vegetation, crops, or fauna) intrinsically links the work of ecologists, landscape scientists, agronomists, silviculturalists etc., with that of soil biologists.

1.23 The **Soil Profile** is a description of a particular soil as it changes vertically (i.e. from the surface to the underlying geology) and is usually represented by a vertical cross-section diagram and an associated description. As soils develop, different **horizons** (describable layers) may form. These horizons are largely a result of the pedogenic processes occurring in the **soil system**.

1.24 The different horizons are referred to by specific letters to indicate their origin. Generally, six or seven base, or 'master', horizons are recognised by the capital letters **H** and **O** (organic horizons), and **A, E, B, C** and **R** (mineral horizons), with the H and O horizons sometimes being grouped together (also see Figure 2):

- **H Horizon**: Humic (organic) layer of soil, made up mostly of leaf litter ('**L**') partly decomposed fragmented (fermenting see 2.11) leaves etc. ('**F**') and humus (decomposed), with a very small or absent Mineral component;
- **O Horizon**: Organic layer of soil normally categorised as being saturated with water for prolonged periods, although 'O' can often refer to organic layers generally (e.g. peat);
- **A Horizon**: Topsoil, generally found below the O horizon and above the E horizon, comprised of humus (decomposed organic matter) mixed with Mineral particles;

- **E Horizon**: Eluviation layer (from where soluble elements may have been leached ('washed') out), lighter in colour, found beneath the A Horizon and above the B Horizon, although not always present;

- **B Horizon**: Subsoil, found beneath the E Horizon and above the C Horizon, which may contain clay and Mineral deposits from layers above as well as below (forming an illuviation ('**I**') layer (where leached elements from above may have been re-deposited);

- **C Horizon**: Regolith, found beneath the B Horizon and above the R Horizon, containing little biota or organic matter; and

- **R Horizon**: R for Rock (i.e. non-weathered bedrock) layer that is beneath all the other horizons (but may be exposed at the surface as an outcrop).

1.25 An additional letter can be added to the master horizon to describe the sub-horizons or processes evident within, including: W (water), p (ploughed) etc. A list can be found here.

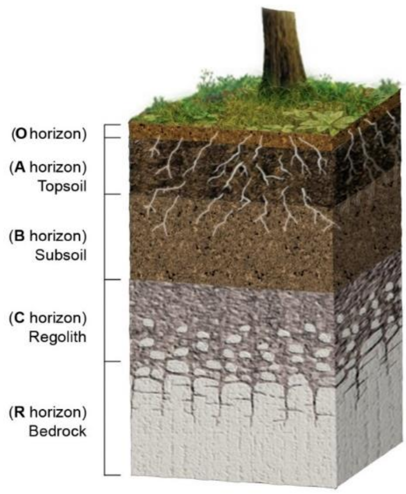


Figure 2 Generalised Schematic Representation of a Soil Profile (© Biora)

1.26 The soil horizons that are related through, and linked by, the same *pedogenic* processes are collectively referred to as the **solum** (i.e. the A, E and B horizons), below which is **substratum**. All horizons need not be present and the junctions of between horizons may not always be immediately clear, due to the processes that take place within the **soil system**.

1.27 **Topsoil** is the top [mineral] layer of soil (typically 5-20cm deep in the UK), darker in colour and with more organic matter than the layer below (subsoil) (BSi, 2015). It may be natural in origin or manufactured and forms the A horizon in the soil profile.

1.28 **Subsoil** is the soil layer extending between the topsoil and the little-weathered parent material below, or material that functions in the same way in a constructed soil profile and on to which topsoil can be spread (BSi, 2013). It may be natural in origin or manufactured and forms the B horizon in the soil profile. It may be sub-divided, in general terms, into lower subsoil and upper subsoil, where differences are present.

1.29 In areas (geographical zones) where a relatively even balance of soil processes has been taking place without extremes of climate and where a stable soil system has been present for a sufficient period of time, a well-developed soil profile with clear horizons are more likely to be present (classed as '**Zonal soils**'). Soil horizons are less distinct when there is much soil organism activity. **Intrazonal soils** may occur where localised factors (e.g. geology or poor drainage) predominate. **Azonal soils** have not had sufficient stability or time to develop into zonal or intrazonal soils and generally do not have horizons. See Figure 20.

2. Components and Properties of Soil

2.1 Five major factors control how a soil can form and change:

1. Climate
2. Organisms
3. Parent material
4. Relief (landform)
5. Time.

2.2 The 'organisms' category also contains **human** influences (directly and indirectly) on soils. Together, the five major factors they influence the characteristics, components and properties of soils, through natural and human processes. The properties can be grouped into physical, chemical and biological components as described below.

Physical Components and Properties

2.3 The main properties relating to the physical components of soils, which affect one another, are:

- Mineral (Inorganic) Matter Content
- Organic Matter Content
- Texture (and Stoniness)
- Structure
- Drainage / Permeability
- Temperature
- Colour

Mineral (Inorganic) Matter Content

2.4 Minerals weather from parent material, contributing to the physical mineral composition in the mineral horizons, including 'stones', and contributing to other components and properties of soil (e.g. nutrients, drainage and cohesiveness).

2.5 **Primary Minerals** are resistant to chemical weathering processes but break down more easily from physical weathering and remain unchanged in composition from that present in the parent material (i.e. they are 'inherited'). These primarily form the larger particles in soil (**sand** and **silt** - see 'Texture' below), usually either as quartz, calcite or dolomite in the UK, but can form **clay**-sized particles if the parent material is sedimentary material, rich in clay minerals. Due to the lack of water in arid regions primary minerals dominate in the natural soil.

2.6 **Secondary Minerals** are more easily broken down by chemical weathering processes, forming a variety of clay minerals, amorphous minerals (mineraloids) and sesquioxides (see 2.8). In regions where more intense weathering occurs (e.g. wet tropical areas) secondary minerals may predominate. Secondary minerals generally form the *clay-sized particles* present (see 'Texture' below).

> ***Note*:** The word "clay" is used to mean a number of different aspects in soil science, depending on the context, and can refer to:
>
> - The classification of *mineral types* present (i.e. based on what they are comprised of, chemically);
> - A *size classification* of soil particles present; and
> - The *textural classification* of a soil, as a whole.

2.7 Due to their small size (clay-sized particles) and due to them having very high surface area for their size these minerals exhibit **colloidal** properties (being microscopically dispersed insoluble particles suspended throughout another substance). They are electrically charged at their surface, and thus attract and absorb ions (e.g. nutrient elements) that have an opposite charge (see 2.71)

2.8 **Sesquioxides** are so called because they comprise of oxygen in the ratio of three atoms to two of another element – primarily iron and aluminium). They act as binding agents between clay mineral particles, and as a source of electrical charge, the nature of which is **pH-dependent** (i.e. it can be positive or negative depending on the pH). The iron-based sesquioxides have a red-brown colour.

2.9 Clay mineral particles vary greatly in their shape, surface area and swelling characteristics, but generally have a negative charge that is <u>not</u> pH-dependent.

Soil Organic Matter

2.10 **Soil organic matter** (SOM) can refer to all organic material in the soil, in varying stages of life (**biomass**, see 1.22) and decomposition, but dead, decaying and decayed matter form the primary reference for this material. It includes **humus**, the residual material after decomposition has completed, which gives soil its dark brown colour. The primary source of SOM (where present) is plant material and provides the main source of energy for organisms using soil as their habitat.

2.11 **Leaf litter** forms the material that has not decomposed to any great degree such that the material is clearly recognisable. A layer of **fermentation** may be visible in the soil, where decomposition is most rapid and where only fragments of plant material are readily recognisable, followed by humus which is comprised of highly complex and very large organic molecules.

2.12 SOM coats the minerals (even the smallest of particles) in the soil, forming an **organomineral complex**, facilitating the formation of **peds** (see 2.24). A **clay-humus complex** provides a soil with significant water and nutrient-holding capacity (see 2.77).

2.13 SOM is drawn downwards through the soil by the action of soil organisms and drainage, but cultivations will rapidly transfer SOM from the near the surface into deeper parts of the profile. The typical values of SOM under different vegetation covers can vary from 1-5% for arable land, 5-15% for woodland with grassland varying from circa 9%.

Texture

2.14 Soil texture is a commonly used term used to describe the 'coarseness' or 'fineness' of a soil and in mineral soils (i.e. those with over 6% organic matter) is directly related to the *proportion* of **sand**, **silt** and **clay** sized particles present (collectively termed 'fine earth'). In the UK, the following diameter sizes are generally used to classify the particle sizes, although particles are not always spherical:

- Sand (Coarse): 0.6 to 2mm (600 to 2,000µm)
- Sand (Medium): 0.2 to 0.6mm (200 to 600µm)
- Sand (Fine): 0.06 to 0.2mm (60 to 200µm)
- Silt: 0.002 to 0.06mm (2 to 60µm)
- Clay: Less than 0.002mm (less than 2µm)

See Figure 3 for a visual size comparison.

2.15 'Particles' larger than 2mm are grouped together and described as 'stones' (and are often categorised further into grit, gravel, and boulders). Stones play a role in the physical properties and processes of soil but they are not considered in the determination of soil texture, this being referred to as '**stone content**', as a % of volume.

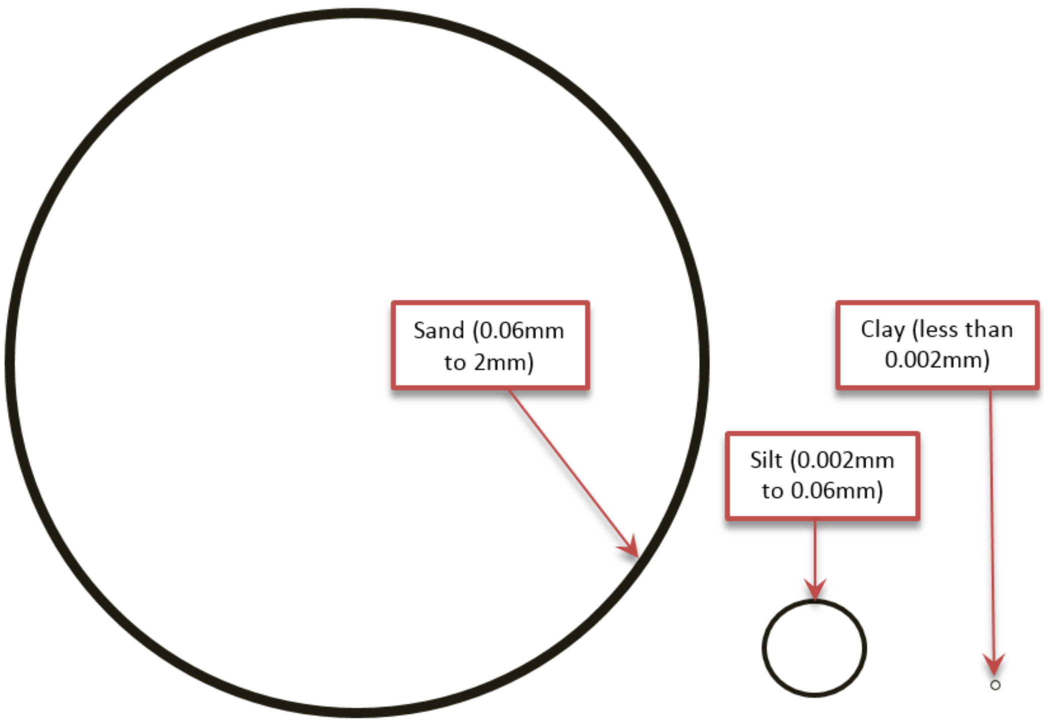


Figure 3 Relative size of soil particles

2.16 **Texture** is usually determined in the field and otherwise analysed in the laboratory via sieving, sedimentation (see BS ISO 11277:2009 Soil quality - Determination of particle size distribution in mineral soil material - Method by sieving and sedimentation) or laser methods to provide the **particle size distribution (PSD)**. The relative proportions of each particle size in the soil is represented either on a pie chat or on the soil texture triangle (see Figure 4) to provide a **textural classification** of the soil.

2.17 Soils high in calcium carbonate (more than circa 10%), which can be present in all particle sizes, are treated differently when determining textural classes, as soils containing this are usually better structured and more workable. In such cases the clay fraction is classed as silt to provide a more appropriate textural classification.

2.18 Due to their colloidal properties, the clay-sized fraction of the soil is also referred to as the **colloidal fraction**. The colloidal fraction can absorb (and repel) water (resulting in shrinking and swelling of soils, an important consideration, for example, when specifying 'thirsty' trees close to building foundations). Due to the colloidal fraction's electrical charge, texture also directly relates to the 'availability' and retention of nutrients within the soil, these being readily attached to (adsorbed) clay-sized particles compared to larger particles (see 2.78).

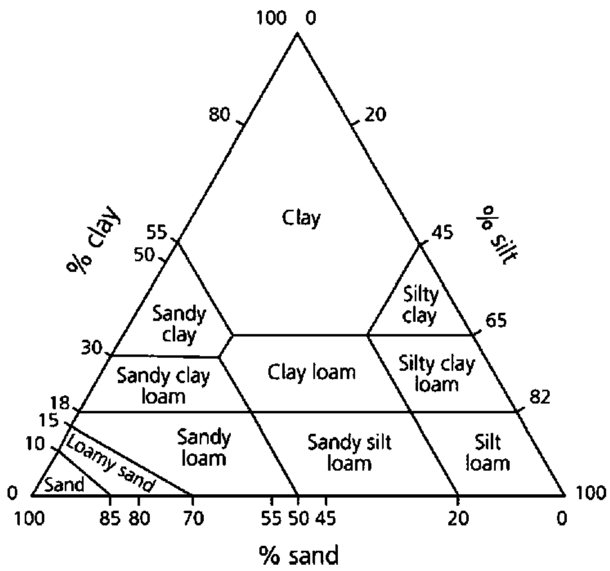


Figure 4 Soil Texture Triangle (BSi, 2015) - adapted

2.19 Texture controls key characteristics such as the workability of the soil, susceptibility to erosion, size and spacing of soil pores present, thus affecting the water content, water flow and aeration of the soil, and also plays a major part in defining soil 'structure' (see 2.24). It is therefore a useful tool for 'managed' soils, e.g. with agricultural uses.

2.20 Sandier ('lighter') soils are more easily cultivated (more workable) than clayey ('heavier') soils and are more easily penetrated by plant roots. See Figure 5.

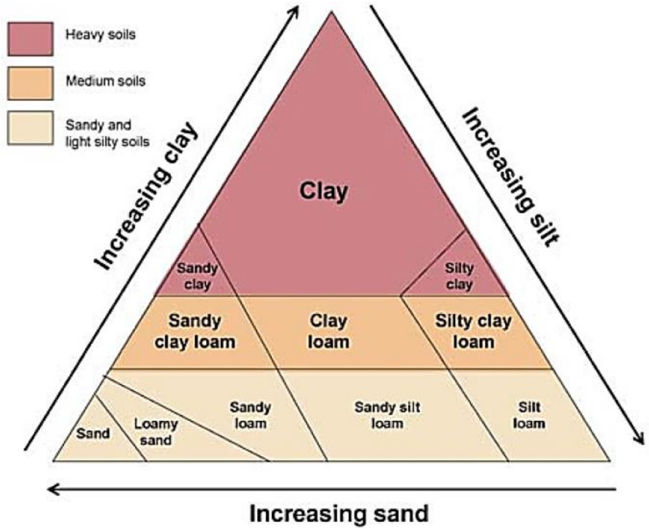


Figure 5 Relationship between workability and texture (Natural England, 2008)

2.21 '**Loams**' have a fairly even distribution of particle sizes such that there is sufficient clay to hold moisture and retain nutrients, sufficient sand to facilitate drainage and cultivations, sufficient silt to help bind the sand and clay together and reduce erosion rates. This makes them particularly useful for sowing and planting (e.g. ornamental plants, lawns, agricultural crops), however different plants grow can often more successfully in soils of different texture, depending on the species and their 'niche'. The characteristics of soils in relation to texture are summarised in Figure 6.

Soil Aspect ⮚ Soil Type ⮛	Drainage	Water Retention for Plant use	Cultivation	Nutrients	Other
Loams	Good	Good	Easy	Good retention and source.	-
Coarse Sands	Good	Poor	Easy	Poor retention and source.	Warms quickly. Low cohesive strength.
Fine Sands & Silts	Medium - Poor	Medium	Easy	Medium	Prone to erosion, compaction and 'capping'. Low cohesive strength.
Clays	Poor	Good	Hard	Good retention and source.	Easily damaged depending on moisture level. Becomes hard (high cohesive strength) when dry. Warms slowly. Expands/contracts readily.
Stony Soils	-	Negatively affected.	Negatively affected.	May be a source, but negatively affects retention.	Stones take up space within soil, limiting effect of other properties of remaining soil. Helps soils warm up. Can damage root crops during harvest.
Organic Soils	Poor	Good	Easy	Good retention, lower source.	Some expansion/contraction. Lower strength.

Figure 6 Characteristics of Soils in Relation to Texture

2.22 The British Standards for the Specification of Topsoil (BSi, 2015) and for the Specification for Subsoil (BSi, 2013) is more specific than 'loams' in its criteria in relation to textural requirements – see Figure 7 and Figure 8.

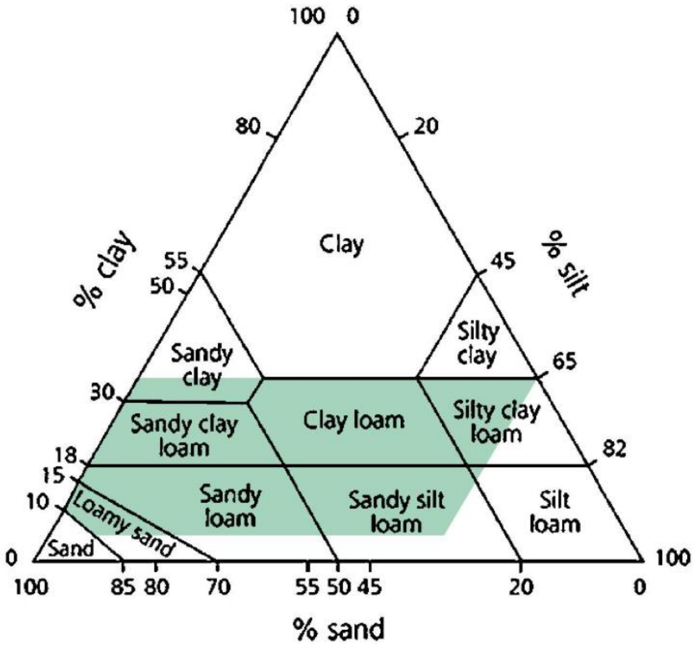


Figure 7 BS 3882 Textural Requirements for Topsoil (BSi, 2015) - adapted

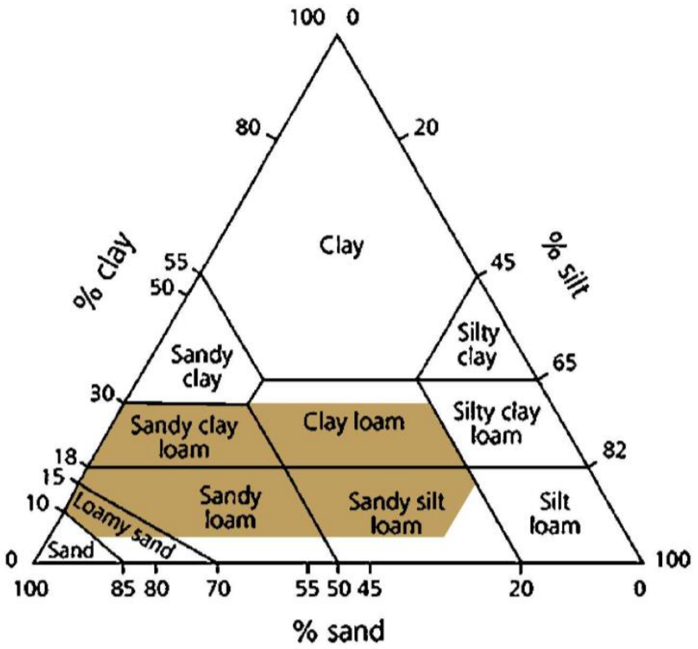


Figure 8 BS 8601 Textural Requirements for Subsoil (BSi, 2013) - adapted

2.23 Organic matter is removed from the soil before laboratory testing of PSD, therefore soils high in organic matter (over 6%) are categorised separately for texture and '**Peaty**' is used to describe the textural classes of such soils, as shown in Figure 9.

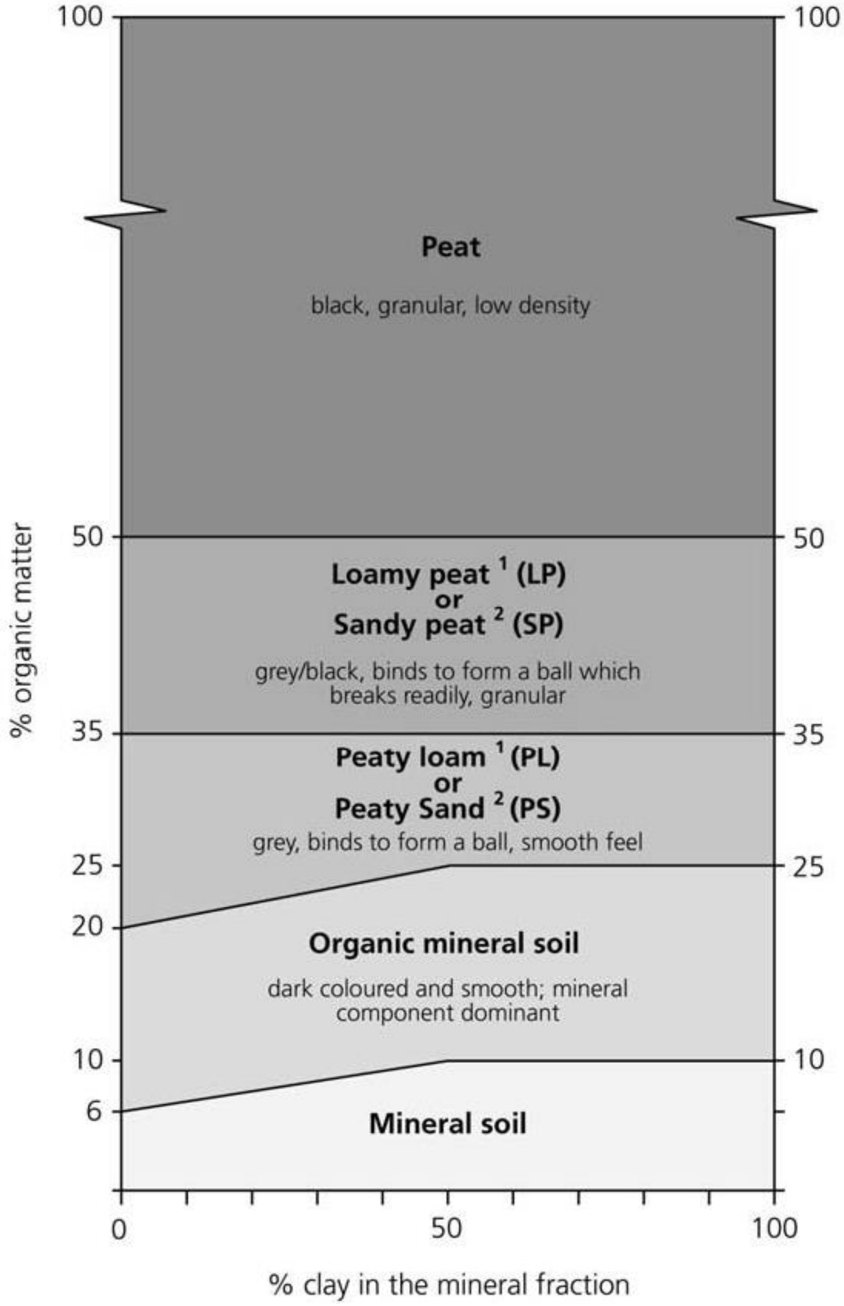


Figure 9 Textural Classes of Soils with High Organic Matter (Natural England, 2008)

***Note*:** The word "peat" is used to mean a number of different aspects in soil science, depending on the context, and can refer to:

- *The textural classification* of a soil, as a whole; and
- A name given to a *soil type*, where both of the following occur:

A) More than 40cm depth of peaty textured material is present within the upper 80 cm of the soil profile; and

B) Organic mineral or peaty textures are present within 30 cm depth.

Structure

2.24 Soil structure refers to the aggregation of individual particles. These aggregations in a soil are called **peds** or **aggregates** and the natural processes that aid in forming peds are:

- Wetting and drying;
- Freezing and thawing;
- Microbial activity that aids in the decay of organic matter;
- Activity of roots and soil animals; and
- Adsorption of ions.

> ***Note***: The word "aggregate" is used to mean a different aspect in soil science to that in geology, where aggregates are crystalline or granular rocks that are extracted and processed for use in the construction industry (e.g. gravels or crushed hard rock).

2.25 The aggregation occurs due to the:

- Cohesive properties of the colloidal fraction in the soil;
- Chemical compounds (such as iron oxides and soil carbonates) acting as a cement;
- Organic compounds (from the decomposition of organic matter and secretions from organisms) acting as a cement; and
- The binding action of plant roots and soil fungi.

2.26 Soils with a higher proportion of smaller particles otherwise usually have a stronger, more defined structure than coarser soils (with a higher proportion of larger particles) due to shrink-swell processes from wetting and drying predominating in clay-rich soils and the higher cohesive strength between clay particles.

2.27 Clay particles tend to stay together even when wet, so tend to give the most strength to a soil, rather than silt or sand, such that, without clay, the soil may have no structure when dry and be classed as or '**Single grain**' (e.g. in coarse sands). Soils may also be '**Structureless**' or have a '**Massive**' structure such that there is no visible structure due to tightly arranged and densely packed clay particles dominating (e.g. in raw wet clays).

2.28 Different types of intermediate soil structure classes are shown in Figure 10 although other classifications for specific situations also (e.g. Visual Evaluation of Soil Structure Score Chart (Scotland's Rural College, n.d.)).

2.29 Each soil horizon is likely to have its own distinctive ped (and may be used to define a horizon), but there may be more than 1 ped type present in each.

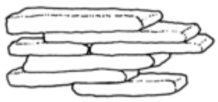
Type of Structure (ped)	Size of Structure (mm)	Description of peds	Shape of peds	Location (horizon-texture)	Planting value
Crumb	1 to 5	Small individual particles similar to breadcrumbs. Porous.		A horizon Loam soil	The most productive. Well aerated and drained. Good for roots.
Granular	1 to 5	Small individual particles. Usually non-porous.		A horizon Loam soil	Fairly productive. Problems with drainage and aeration.
Platy	1 to 10	Vertical axis much shorter than horizontal, like overlapping plates preventing flow of water		B horizon Silts and clays, or when compacted by trafficking	The least productive. Hinders water and air movement. Restricts roots.
Blocky	10 to 75	Irregular shape. Horizontal and vertical axes about equal. May be rounded or angular but closely fitting.		B horizon Clay-loam soils	Productive. Usually well drained and aerated.
Prismatic	20 to 100	Vertical axis much larger than horizontal. Angular caps and sides to columns.		B **and** C horizons Often limestones or clays	Usually quite productive. Formed by wetting and draining. Adequate water movement and root development.
Columnar	20 to 100	Vertical axis much larger than horizontal. Rounded caps and sides to column.		B **and** C horizons Alkaline and desert soils	Quite productive (if water available).

Figure 10 Structural Classes of Soils (Waugh, 1990)

2.30 Structure influences bulk density, porosity and pore size in a soil. Pores within a ped (**micropores**) are relatively small in comparison to those between peds, and between soil particles (**macropores**). This balance of micropores and macropores provides for good soil aeration, permeability and water-holding capacity.

2.31 For most managed soils and land-uses, a crumb structure is generally accepted to be best for the promotion of sufficient movement of water and organisms (including roots) through the soil, and develop best under grasses. Addition of organic matter is also important for the promotion of a good crumb structure, and, as organic material is incorporated through cultivations, soil animals and microorganisms, it also aids in subsoil structure development.

2.32 Handling soils in inappropriate conditions, compaction of soils (e.g. through vehicles and animals accessing areas when wet, causing poaching of the soil), ongoing cultivations to the same depth over time, and even the action of rain on a bare earth surface can all result in the deterioration (or even destruction) of a soil's structure, through the physical breaking up of peds and formation of hard or dense 'crusts', 'caps' or 'pans'.

> ***Note***: The word "capping" is used to mean different things in soil and geo science or engineering, depending on the context, and can refer to the:
>
> - Formation of a compact surface layer on bare earth by rain, hindering germination and emergence of seedlings and cause water to run off the soil surface); and
> - The 'engineered' impermeable separation layer (e.g. clay or geomembrane) above potentially damaging materials (e.g. waste, or contaminated ground) and below the soil profile.

2.33 Additional useful information on understanding and managing soil structure can be found in the *Healthy Grasslands Soils Pocketbook* (Agriculture and Horticulture Development Board, 2015) and *A Guide to Better Soil Structure* (National Soil Resources Institute, Cranfield University, 2001).

Soil Water and Air

2.34 Pores within the soil are occupied either by air or water. The changes of this balance have significant effects on the processes that can take place in the soil (e.g. erosion and **gleying** (see 2.41) thus affecting other physical characteristics of the soil and vice versa. It will also affect organisms that it can support, the soil temperature, decomposition rates and availability of plant nutrients and thus the suitability for different plant communities. A soil that is very dry or very wet will be unsuitable for earthworms, for example, thus having another indirect on the nutrient cycling processes that will take place in the soil.

2.35 Water inputs may be from above (e.g. precipitation, irrigation and surface water infiltration) and from below (e.g. rising groundwater – see 1.17). Drainage depends upon the balance between the soil's **water retention capacity** and the **infiltration rate**, affected by texture, structure, density and organic matter present. **Gravitational water** (or free water) is the excess water that readily drains away from a saturated soil until the excess water is no longer present (i.e. when **field capacity** has been reached), and is unavailable for take-up by plants.

2.36 When soil is at or drier than its field capacity, it contains both **hygroscopic water** and **capillary water**. Hygroscopic water is bound strongly, through surface tension, to soil particles and is always present but cannot be extracted by plants – it is unavailable. When only hygroscopic water is present (when the soil is 'dry') the soil will reach its **permanent wilting point** (**PWP**). Capillary water forms a layer around the hygroscopic water, and with lower cohesive strength, is available to plants and can also be lost via evaporation. The moisture available to plants between the field capacity and the PWP is referred to as **Readily Available Water** (**RAW**).

Soil Type	% Moisture at Field Capacity	% Moisture at PWP	% RAW
Coarse Sand	8	4	4
Sandy Clay	29	19	10
Clay	42	25	17
Clay Loam	34	28	6

Figure 11 Typical Soil Moisture Values – Adapted from: (Prinn, 2005)

2.37 Gaps in the pores between the layers of capillary water in the soil are filled with gases from organisms and via **mass flow** and **diffusion** (see 'My Agriculture Information Bank' website) from the atmosphere (with slightly higher carbon dioxide and lower oxygen being present than in free air). This is essential for organisms: Soil micro-organisms and plant roots need oxygen to respire, releasing carbon dioxide, with there being different rates of respiration at different times of year. Cultivation and aeration can help facilitate the diffusion of oxygen into the soil and carbon dioxide out.

2.38 Low oxygen concentrations in the soil can lead to anaerobic conditions (see 2.41), usually due to the presence of a high water table, a largely impermeable subsoil (e.g. clay) or heavily textured soils with poor infiltration rates.

Soil Colour

2.39 Soil colour in itself has little effect on the use of the soil, but does give clues as to the conditions, constituents and nature of the soil and varies considerably across an area and through the soil profile. It can be described using standard colour charts (e.g. following the Munsell Colour System) and can be used as a form of soil classification.

2.40 The Minerals present (from the parent material) give the primary colour (usually yellows, reds, browns (from various forms of iron and manganese oxides), and off-white colours from carbonates). Coatings of organic matter can mask the Minerals' colours and give it a darker appearance, and in organic mineral soils, where wet, can be almost black in colour, but otherwise, colour is not an indicator of particle size distribution.

2.41 Colour can also provide clues as to the hydrology at a soil's location. Dry soils generally have a lighter colour, and when soils are brighter throughout the profile can indicate good drainage and good aeration. Anaerobic conditions can change the chemistry of the iron oxide minerals present (causing chemical **reduction** – an increase in negative ions) with a resultant change in colour to dull blue-grey colours associated with **gleying** (i.e. when soils are waterlogged and become anaerobic, resultant in chemically 'reduced' forms of elements, especially iron). The horizon where gleying is evident can indicate the predominant water level within a soil. The colour can therefore provide an indication of the natural drainage conditions present.

Temperature

2.42 A reducing temperature gradient can be found downwards through the soil profile, with the presence of water reducing the temperature and buffering changes in temperature from heating and cooling associated with diurnal patterns. Dry soils will heat up more rapidly, especially if plants are not present at the surface (bare earth), as they readily absorb incoming radiation from the sun and radiate heat out at night, more rapidly than moist or wet soils and those with vegetation at the surface. Increases in temperature will increase growth, reproduction, germination and biota activity generally, with resultant increased rates of decomposition and nutrient cycling.

2.43 Soils contain about twice as much carbon as Earth's atmosphere, so their response to warming is crucial to understanding carbon fluxes in a changing climate. Recent studies have revealed that 4°C of warming increases annual soil respiration by up to 37%, increasing respiration rates and thus emitting more carbon dioxide (Smith, 2017).

Density

2.44 **Soil particle density** refers to the mass per unit volume of dry soil solids and therefore does not relate to pore size or soil structure. **Bulk density** is the mass of a unit of dry soil, and therefore includes both solids and pores and is affected by soil structure and texture.

2.45 Soils that are more compact and have less pore space will have a higher bulk density. It provides a figure, calculated as the dry weight of soil divided by its volume expressed in g/cm^3 or kg/m^3.

2.46 Bulk density provides the averaged density of the volume of soil tested, but variances within can occur (e.g. with a crust on the soil surface, or a 'hardpan' within the soil profile which otherwise has a low bulk density). The bulk density of a soil generally increases with depth (likely due to reduced organic matter and root growth, less aggregation and the weight from above). Some subsoils (e.g. those formed over (heavily compacted) glacial till, and subsurface hardpans, may have bulk densities as high as 2; concrete has a bulk density of circa 2.4 for comparison). Typical bulk densities of different soils would be 0.1-0.7 for peats, and between 0.9 and 1.75 for cultivated loam types and sands.

2.47 This is significant, as plant roots will grow into soils to a maximum level of 'compaction' present (varying between plants) such that if the soil or parts of the soil profile exceed this level, it will restrict the outward growth of roots and potentially affect the ability of the aerial parts of the plant to grow (see Figure 12). A high bulk density may also cause poor movement of air and water through the soil. Soils with too low a bulk density (e.g. peat) may not be able to structurally support the size of the plant (e.g. trees) such that wind throw may become a future hazard.

Soil Texture	Preferred bulk densities for plant growth (g/cm^3)	Bulk densities that restrict root growth (g/cm^3)
Sandy	< 1.60	> 1.80
Silty	< 1.40	> 1.65
Clayey	< 1.10	> 1.47

Figure 12 Soil texture and bulk density relationship to root growth (Soil Quality for Environmental Health, n.d.)

2.48 The following practices can lead to increased bulk density:

- Consistently cultivating to the same depth (denser at the base of cultivations);
- Vehicles (e.g. unsuitable earth moving plant or farm machinery) trafficking, rolling the ground etc. especially on wet soil;
- Using a limited crop rotation without variability in root structure or rooting depth; and
- Over-stocking fields with livestock, especially during wet seasons, increasing pressure on heavy-use areas (e.g. around watering points).

2.49 To reduce the likelihood of high bulk density and compaction:

- Minimise soil handling and trafficking when soils are wet;

- Use pre-designated routes for access;
- Reduce the number of trafficked trips across the area;
- Subsoil and cultivate to different depths to disrupt compacted layers; and
- Use practices that maintain or increase soil organic matter.

2.50 Compaction will generally increase bulk density and **soil strength**, and both will have an effect on resistance to root penetration, with roots potentially being able to grow through the same soil when wet, but not when dry (see below).

Soil Consistence and Strength

2.51 Soil **consistence** refers to how a soil reacts to applied physical exertions, of different levels of effort, at different moisture levels, such that the rupture or deformation effects of handling, cultivating, trafficking over and building on soils etc. can be predicted and mitigated. A soil's **strength** generally refers to the capacity of a soil mass to withstand stresses without giving way (via rupture ('**rupture resistance**') or **deformation**). Soils that crumble under light force are said to be **friable**, and are easy to cultivate. See this table produced by the Soil Science Society of America for categories and criteria for measures of consistence and consistency.

2.52 Soils can attain strength through cohesion, adhesion and friction. **Cohesion** occurs when bonding occurs between soils molecules of the same substance and **adhesion** occurs between molecules of different molecules. Water has both cohesive and adhesive properties. Soil **stickiness** is the capacity of soil to adhere other objects (estimated at a level of moisture content that displays maximum adherence between the thumb and forefinger). **Plasticity** is the degree that a soil can be moulded or reworked to cause permanent deformation without rupturing, and is calculated in terms of its moisture content.

2.53 The plasticity of a soil is measured in terms of its **Plasticity Index**; the size of the range of water contents where the soil exhibits plastic properties, which is the difference between the Liquid Limit and the Plastic Limit, which are defined as:

- **Liquid Limit:** The water (moisture) content (i.e. the ratio of water to solids/gases in the soil, measured as a mass or volume) at which a clayey soil loses its plasticity and changes its behaviour to liquid; and
- **Plastic Limit:** The water content at which a clayey soil is malleable, attaining plasticity (where the soil thread breaks apart beyond a narrowed diameter of 3.2mm). A soil is considered non-plastic if a thread cannot be rolled out down to 3.2 mm at any moisture level.

Plastic and Liquid Limits can be determined by simple laboratory tests.

> ***Note***: The recognised methods of laboratory testing of soils for engineering purposes is described British Standards Institution's *BS 1377: Methods of test for soils for civil engineering purposes* (Parts 1-8).

2.54 The following plasticity index ranges can be used to describe a soil as:

- 0-3: Non-plastic
- 3-15: Slightly plastic

- 15-30: Medium plastic
- 31+: Highly plastic

2.55 **Cohesive soils** (i.e. those with a clay content of more than 15%) gain strength from both friction (between particles) and inherent electrostatic attraction between clay particle surfaces and water in the very fine pores. The strength of these soils is significantly reduced when saturated, as the water forces the particles apart. When dry or compacted, the strength of cohesive soils increases, as the particles are much closer together (higher density).

2.56 The strength of dry **non-cohesive soils** (low clay content, generally sands) is provided by friction between particles only (with smooth grains providing less friction that 'rough-surfaced' grains and materials with higher density having higher friction between particles). A small amount of water can increase the strength by bridging the gap and providing tension between particles (think sand castles!). Saturated non-cohesive soils have lower strengths than the same material when dry.

2.57 This strength, particularly in relation to friction, is reflected in the different natural **angles of repose** (i.e. the steepest angle relative to the horizontal plane onto which a material can be piled without slumping or the surface material sliding) that different materials have. Figure 13 gives approximate angles for a variety of soils, but <u>always</u> seek advice from a qualified geotechnical specialist where stability poses a potential health and safety or environmental protection risk or where adjacent land could be affected.

Soil State ➢ Soil Type ⮛	Dry	Very Wet
Loams	40-45°	20-25°
Coarse Sands	30-45°	20-25°
Fine Sands & Silts	15-20°	15-25°
Clays	15-20°	15-20°
Loose Gravel (shingle)	35-45°	c. 40°
Medium Coarseness Gravel	30-45°	25-30°
Boulders	c. 20°	c. 20°
Peat	c. 15°	c. 45°

Figure 13 Indicative Angles of Repose for Different Materials (Cobb, 2008) - adapted

2.58 Compaction is to be avoided wherever plants are to be established, but may be undertaken for engineering purposes (e.g. to prepare an area prior to creating a hard surface). The achievable compaction (bulk density) of a soil will vary depending on the moisture content at the time of compacting them, such that, to maximise compaction, the optimum moisture level conditions is created (e.g. via sprinkler) prior to compaction (e.g. by a roller).

2.59 Soils can exhibit different levels of **compressibility** (how much they reduce in volume for a given force) and can take different lengths of time to compress (even after the force has been removed), depending on how readily liquids and gases can leave the pores, and can lead to differential settlement (unevenness) taking place after compaction works have finished. Peaty soils have very high compressibility and make unsuitable foundations.

2.60 Clays (particularly smectites) in cohesive soils can have high plasticity indices and swell when wet and shrink when dry, having a high **shrink-swell capacity**. When very dry, these **expansive soils** (or **shrink-swell soils**) can become highly fissured, with a regular pattern of cracks appearing at the surface.

2.61 In the movement associated with shrinking and swelling (subsidence and heave) extend below structure foundations, and if the movements are in excess of those that can be tolerated by the buildings, surfaces, shallow pipes etc., damage is likely to occur. Non-cohesive soils are not subject to significant swelling or shrinkage.

2.62 The shrink-swell process is heavily dependent on the UK's weather events and the measure of the magnitude and frequency of seasonal moisture changes, or the Potential Soil Moisture Deficit (PSMD) is used to help understand hazards posed by expansive soils. United Kingdom Climate Projections ($UKCP_{09}$) suggest that regions of Great Britain will experience hotter, drier summers and warmer, wetter winters through to 2050 (Pritchard, 2015). As a result, PSMD fluctuations are expected to increase, exacerbating the shrinkage and swelling of clay soils and broadening the areas exposed to this hazard (see Figure 15).

2.63 Over the last 25 years, a range of spatial soil-related geohazard models have been developed for Great Britain. The British Geological Survey (BGS) provides information on the potential for shrink–swell to be a hazard (see Figure 14 with interpretative information and advice for preventative or remedial action available on the BGS's "shrink-swell property hazard information" webpage) and detailed information relating to a particular location can be purchased (see BGS's Geosure™ product), however, this data does rely on modelled predictions for variation of the UK's weather/climate.

2.64 Another geohazard model is the Natural Perils Directory™ (NPD) held by Cranfield University. Soils are allocated six volumetric shrink/swell ('SSWELL') classes, ranging from 'Very Low' (0) (<3 % shrinkage) to 'Very High' (6) (>15 % shrinkage). A 'High*' SSWELL class represents soils with alluvial clay or peat at 1m depth, but which are only prone to shrinkage when effectively drained to at least 2m depth (Pritchard, 2015). See Figure 16.

2.65 Shrinking and swelling can be exacerbated by vegetation, through changes in take up of water by plants, especially trees with a high water demand. If trees are specified to be retained or planted too close to structures, on expansive soils, in association with inadequate foundation design damage may result indirectly though shrink-swell of the soil. Root barriers are not considered to be an acceptable solution. Similar damage may result from a tree being removed, dying or reaching over-maturity (reducing transpiration rates), such that rehydration of the soil takes place, causing heave.

2.66 The extent of effects on soil drying and rehydration from plants can be variable and unpredictable. Removing all risk may not be appropriate (e.g. due to suitability of existing foundations, excessive cost of new foundations, or other unacceptable planning or design outcomes) so a 'balance of risks' assessment, and decision process (between the relevant professionals and stakeholders, which may include insurers) may need to be required.

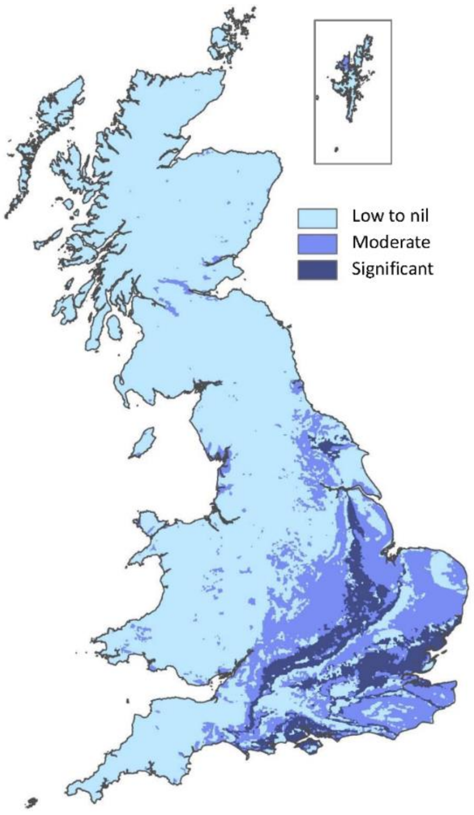


Figure 14 'Shrink-Swell Potential' in Great Britain (British Geological Survey, n.d.) - reproduced with the permission of the British Geological Survey ©NERC. All rights Reserved.

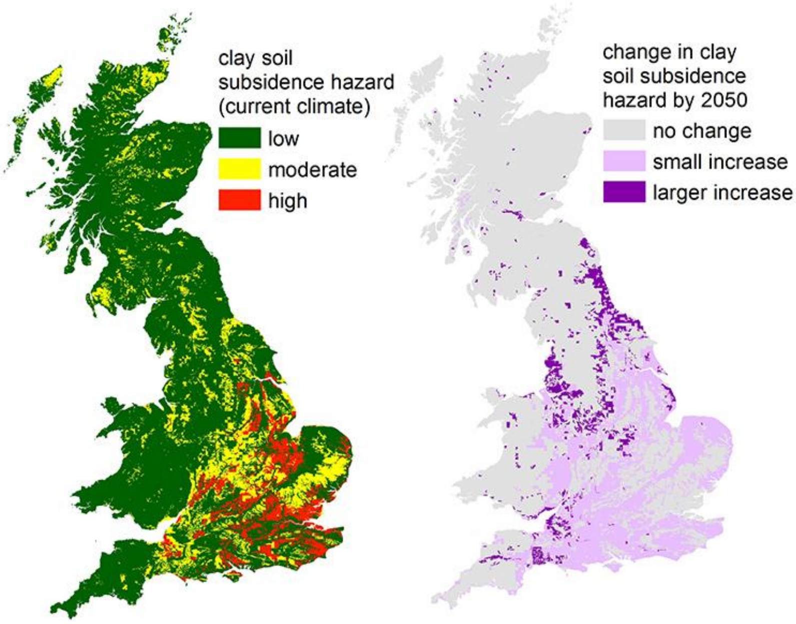


Figure 15 Predicted changes in Clay Soil Subsidence Hazard due to Climate Change (source: Natural Perils Directory™ © Dr. Timothy Farewell, Cranfield University, 2017 - Contains soils data ©Cranfield University and for the Controller of HMSO, 2017. Used with permission)

Figure 16 'Clay Subsidence Potential' in Great Britain (Pritchard, 2015) - © Dr. Timothy Farewell, Cranfield University, 2017 - Contains soils data ©Cranfield University and for the Controller of HMSO, 2017. Used with permission.

2.67 Damage is best avoided by increasing foundation depth to below the level where significant changes in moisture content are likely to occur. A foundation design calculator can be found here: http://www.labcnhw.co.uk/foundationcalculator and requires information on trees present as well as the ground conditions present (see note below).

Note: Herbaceous plants and grass can cause soil drying down to 1.5m as well as trees. Guidance on water demands of trees, and trees in relation to expansive soils and the built environment can be found in:

- Planting Trees Near Your Home (NHBC, n.d.) (Link here)
- Chapter 5.2 in LABC Technical Manual v8 (LABC, n.d.) (Link here)
- Water Use by Trees (Forestry Commission, 2005) (Link here)
- Chapter C5 (Expansive Soils) in the ICE Manual of Geotechnical Engineering (Institution of Civil Engineers, 2012) (link here)
- BS 5837:2012 - Trees in relation to design, demolition and construction - Recommendations (BSi, 2012)

Chemical Components and Processes

2.68 The ability of a soil to support plant life depends upon a wide-range of chemical properties. An important property is the soil's pH (level of acidity/alkalinity, relating to the concentration of free hydrogen ions (H+) that is present) which is measured on a scale of 1 (acid) through to 7 (neutral) to 14 (alkaline). The scale is logarithmic, meaning that a pH of 4 is ten times more acid than a pH of 5.

2.69 In soils of a low pH (acid) nutrients are more available, so much so that they become susceptible to being washed away, reducing the availability of these nutrients to plants. At high pH's (alkaline) nutrients are often insoluble and unavailable to plants. A soil with a high concentration of acid cations held by soil particles will have a low pH. In contrast, a highly alkaline soil predominately consists of base cations (see 2.76).

2.70 The amount of calcium (calcium carbonate (lime or calcite)) in a soil strongly controls a soil's pH. When a soil's **base exchange capacity** is saturated mainly with calcium the soil will have a pH of 7; if there is an excess of calcium present the pH will be greater than 7 and vice versa when there is a 'shortage' of calcium. Calcium carbonate freely disassociates to form carbonate ions, which combine with H+ ions, forming hydrogen carbonate ions and calcium ions, which can be easily washed away, resulting in an increase in acidity. However, the dominant effect on plants of a shortage of calcium carbonate in soil is manganese and aluminium toxicity rather than a deficiency of calcium (see below).

Nutrients

2.71 **Fertility** refers to the ability of the soil to supply essential plant nutrients and soil water in adequate amounts and proportions for plant growth and reproduction in the absence of toxic substances which may inhibit plant growth. Chemical elements in the soil that are essential for plant growth and survival are termed **nutrients**. When the concentration of elements in the soil rise to high levels, they may become toxic to plants, fauna (and humans) or may be accumulated in plant tissue to levels that may be toxic to humans or grazing animals when ingested (see 3.9). The amount of different chemical elements required to support plant growth varies and can be differentiated into **major elements** (which are needed in large quantities) and **minor (or trace) elements**, which are needed in much smaller amounts.

2.72 The 6 **major elements** are:

- Nitrogen
- Potassium
- Calcium
- Phosphorus
- Magnesium
- Sulphur

2.73 The 6 **minor elements** essential to plants are:

- Manganese
- Iron
- Copper
- Zinc
- Molybdenum
- Boron

2.74 The 'soil **cations**' (positive charged ions) essential for plant growth include ammonium (containing nitrogen), calcium, magnesium, and potassium. There are three additional 'soil cations,' which are not essential plant elements but affect soil pH. The additional 'soil cations' include sodium, aluminium and hydrogen.

2.75 Sodium, a constituent of sodium chloride (table salt) is an essential nutrient to a few species of plants that have evolved in saline conditions, and their agricultural counterparts (e.g. sugar beet) but can otherwise be toxic in sufficient quantities for most plants, making it difficult for the plants to absorb water. **Salinisation** (accumulating salts in a soil) and high salinity is generally a problem of arid and semiarid regions (where mineral salts can be brought to the surface through capillary action and washed down (and added to) by irrigation) and also from road salting. **Electrical conductivity** (EC) is the most common measure of soil salinity and is indicative of the ability of an aqueous solution to carry an electric current.

2.76 The 'soil cations' are further divided into two categories. Ammonium, calcium, magnesium, potassium, and sodium are known as the '**base cations**' (alkaline) while aluminium and hydrogen are known '**acid cations**.' The availability of different elements at different pH's is shown in Figure 17.

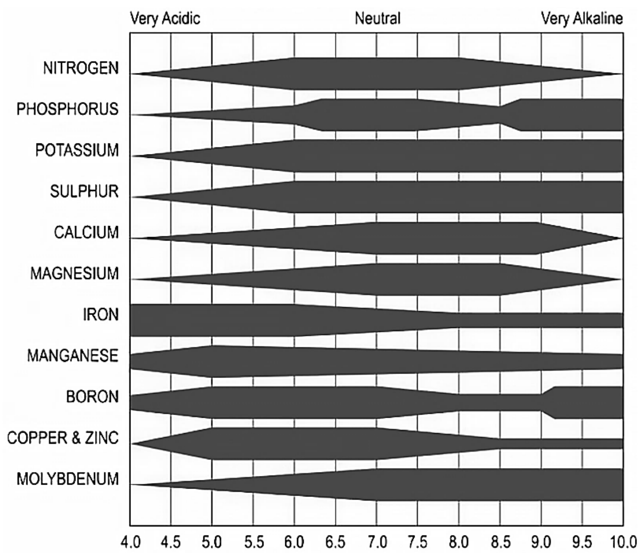


Figure 17 Nutrient availability at different pH's

Cation (Base) Exchange Capacity

2.77 The process by which nutrients absorbed to particles of clay and humus become detached (and taken up by plant roots etc.) is called **cation exchange**. Cations in the soil compete with one another for a spot on exchangeable site locations (on roots, clay particles, humus etc.). However, some cations are attracted and held more strongly than other cations. In decreasing holding strength, the order with which cations are held by the soil particles follows: aluminium, hydrogen, calcium, potassium and nitrate, and sodium.

2.78 H+ ions on roots of plants exchange with cations in the soil, releasing them into the soil, which in turn exchange with cations held by the **clay-humus complex** (see 2.12). Different soils have different **cation exchange capacities (CEC)** (i.e. different abilities to retain cations for plant use). Sandy soils have a very low CEC, clays higher and humus much higher. Soils with a high CEC are said to have a high **buffering capacity** – i.e. the soil can absorb more acid and/or base without a significant change in pH.

2.79 In the tropics, many highly weathered soils can have an **anion exchange capacity**, attracting and retaining **anions** (negatively charged ions), rather than cations. The anions held and retained by soil particles include phosphate, sulphate, nitrate and chlorine (in order of decreasing strength). Anion exchange capacity is dependent upon the pH of the soil and increases as the pH of the soil decreases.

Fertility Indices

2.80 ADAS developed 'fertility indices' for available levels (not total levels) of different nutrients, on a scale of 0 (low) to 9 (high) with soils usually being in the range of 0 to 4 (see Figure 18). Detailed information on nutrient management area available on the Agriculture and Horticulture Development Board website and on the interpretation of soil analyses in Natural England's TIN036 document.

ADAS Soil Index	ADAS Interpretation	Equivalent Macaulay Interpretation	Phosphorus ppm in soil	Potassium ppm in soil	Magnesium ppm in soil	Nitrate Nitrogen ppm in soil	Electrical conductivity mmhos/cm
0	VERY LOW	VERY LOW	0 - 9	0 - 60	0 - 25	0 - 25	1.90 - 2.20
1	LOW	LOW	10 - 15	61 - 120	26 - 50	26 - 50	2.21 - 2.40
2	SLIGHTLY LOW TO MEDIUM	MODERATE	16 - 25	121 - 240	51 - 100	51 - 100	2.41 - 2.60
3	MEDIUM TO HIGH	HIGH	26 - 45	245 - 400	101 - 175	101 - 150	2.61 - 2.70
4	HIGH	HIGH	46 - 70	405 - 600	176 - 250	151 - 200	2.71 - 2.80
5	VERY HIGH	HIGH	71 - 100	604 - 900	255 - 350	over 200	2.81 - 3.00
6	VERY HIGH	HIGH	101 - 140	905 - 1500	355 - 600		3.01 - 3.30
7	VERY HIGH	HIGH	141 - 200	1510 - 2400	610 - 1000		3.31 - 3.70
8	VERY HIGH	EXCESSIVELY HIGH	201 - 280	2410 - 3600	1010 - 1500		3.71 - 4.00
9	VERY HIGH	EXCESSIVELY HIGH	Greater than 280	Greater than 3600	Greater than 1500		Over 4.00

Figure 18 Fertility index scales

Biological Components and Processes

2.81 Soil organisms (soil biota) are essential for the conversion of leaf litter and other dead organic matter into humus and nutrients and help to distribute organic matter downwards into the soil profile. Importantly for plants, the transformation of inorganic compounds into plant-available forms (e.g. nitrates, sulphates and phosphates), as well as facilitating the availability of other essential elements (e.g. iron and manganese) is due to the processes undertaken by soil microorganisms. Fungi can remain active in soils across a wide-range of pH's although bacterial and actinomycete activity decreases in acid soils.

2.82 The soil fauna, when categorised by size, includes:

- **Megafauna**: (20mm upward in size);
- **Macrofauna**: (2 to 20mm in size);
- **Mesofauna**: (100 micrometres to 2mm in size); and
- **Microfauna:** (1 to 100 micrometres in size).

2.83 The main groups of important soil biota are further described in Figure 19.

Megafauna	Macrofauna	Mesofauna	Microfauna
Vertebrata:	**Arthropoda:**	**Arthropoda:**	**Nematoda:**
Reptiles	Ants	Mites	Nematodes
Badgers	Beetles	Springtails	**Roterifera:**
Mice	Maggots	Annelida	Rotifers
Squirrels	Spiders	Pot Worms	Water Bears
Badgers	Millipedes	**Arthropoda:**	**Protozoa:**
	Centipedes	Mites	Amoebae
	Woodlice	Protura	Ciliata
	Annelida:		
	Earthworms		
	Mollusca		
	Snails		
	Slugs		
Plants (Flora)			
Vascular Plants:	**Algae:**	**Bacteria:**	**Fungi:**
Feeder Roots	Greens	Aerobes	Yeasts
Root Hairs	Yellow-Greens	Anaerobes	Mildews
Bryophyta:	Diatoms	**Cyanobacteria:**	Moulds
Mosses	**Actinomycetes**	Bluegreen Algae	Mushrooms

Figure 19 General classification of various groups of soil organisms

2.84 Megafauna and macrofauna aerate, mix organic material into the soil, reduce compaction and provide channels for root growth. Earthworms are vital to the turnover of organic matter in the soil and the mixing of organic and mineral components of the soil as they feed on SOM and leaf litter. Earthworms are generally most active during spring and autumn but if living in burrows can be found within the soil at any time of the year. The best time to observe or count earthworm populations is early to mid-spring or after the soil has wetted up in autumn.

2.85 There are three main earthworm lifestyles in the soil (a guide to identification to worms is available at Open Air Laboratories (OPAL) network's 'Guide to British earthworms' webpage):

- Surface dwelling (**Epigeic**) worms that feed on leaf litter and other organic material on the surface - common in woodlands but rarely found in agricultural soils;
- Shallow (**Endogeic**) burrowers live in the soil and feed on organic matter there, making horizontal burrows in the topsoil; and
- Deep (**Anecic**) burrowers that come to the soil surface in the evening (leaving casts on the soil surface) and gather organic material into permanent burrows deeper down the soil profile.

2.86 Microfauna perform a variety of functions, including:

- Improving soil structure through aggregate formation;
- Decomposition of organic matter and nutrient cycling (importantly the release or plant-available nitrogen);
- Enhancing nutrient uptake by plants and growth; and
- Soil toxin breakdown (e.g. pesticides).

2.87 Although abundant in the atmosphere, nitrogen is not available to plants in this form. **Nitrogen-fixing rhizobia** are bacteria that associate with the roots of leguminous plants (forming nodules on the roots) fix atmospheric nitrogen into a form that is useable by the plant. Plants' defence responses to foliar pathogens can also be triggered by root-associated microorganisms.

2.88 **Plant growth-promoting rhizobacteria** (PGPR) are bacteria that colonise plant roots and benefit plants through mechanisms such as suppression of plant disease, production of antibiotics, improved nutrient acquisition, or plant hormone production.

2.89 **Mycorrhizal fungi** provide nutrients and water to their host plants in exchange for carbohydrates and sugars. There are two main types of this fungi:

- **Arbuscular Mycorrhizal** (also known as **endomycorrhizal**) fungi, being the most common, penetrate through the root systems of plants, effectively extending their root system; and
- **Ectomycorrhizal** fungi, which do not penetrate the cell walls of plants, and are often associated with more woody species such as Birch, Beech, Willow and Pine trees.

More information is available on the Landscape Institute's 'Mycorrhizal fungi – heroes of the landscape' webpage.

2.90 However, microorganisms that interact directly with roots can also affect plant health and/or productivity in negative ways (e.g. viruses can be transmitted by plant-feeding nematodes or certain groups of fungi that infect plant roots).

3. Describing and Categorising soils

Natural Soils

3.1 Even without a knowledge of soils, the relationship between vegetation and the underlying geology would be clear from examination of a geological map of the UK. Soils derived from limestone or chalk (‘**rendzinas’**, for instance) tend to be very thin, humus-rich, often alkaline and low in potassium, difficult to cultivate, and most likely to be used for light grazing, whereas soils derived from sandstone (typically, ‘**brownsoils**’) are usually characterised by much greater depth, acidity, low fertility and good drainage and, therefore, commonly found in agricultural use. In the absence of human intervention, these characteristics influence the vegetation, which in turn influences the soil.

3.2 The interaction of geology, drainage, aspect, altitude and vegetation is responsible for the wide range of native soils (over a 1,000 different types are recognised in Great Britain alone), identified in the national soil map (see Land Information Systems’ Soil Classification System for England and Wales webpage), which illustrates the distribution of the various soil ‘series’ or soil ‘types’). In developing ‘indigenous’ landscapes and habitats or simply to maximise the success of establishment of a planting scheme and minimise management input it would be important to refer to these basic environmental factors.

3.3 A description of the main soil types are provided on Land Information Systems’ Soil Classification downloadable document, and the more widely recognised soil types around the world can be broadly recognised as shown in Figure 20 (see 1.29).

Zonal (Climate / good Drainage)	Intrazonal (Parent rock, extremes of drainage, relief)	Azonal (Immature)
Tundra Podsol Brown earths Chenozems Chestnut and prairie Mediterranean Ferrallitic Ferruginous Desert soils	Rendzina, Terra rossa – calcimorphic Gleyed, Peat (or bog) – hydromorphic Saline - halomorphic	Alluvium Scree Till Sand dunes Salt marsh Volcanic

Figure 20 Example Zonal Soil Types (Waugh, 1990)

Modified Soils

3.4 It can be argued that little to no soils are exempt from human influence, and therefore any once ‘natural’ soils will have been modified, albeit, indirectly. However, the extent to which a soil is ‘natural’ is more generally reflected in the land use—both current and historic.

3.5 Soil formation results from the interaction of physical and biological process on exposed rocks. Humans have been influencing and managing land for thousands of years, initially by woodland clearance and latterly by agricultural and built development. There has been an 'evolution' of the way soils have been modified by human use over time, as agricultural practices have changed with new technologies and methods, such as the use of pesticides, irrigation and drainage systems, and a general shift to more monocultural land use and synthetic fertilisers. For these reasons, human impacts usually reverse the trend of soil formation – destroying the complex structures that arises from the interaction of stable organic compounds and the mineral fraction, making soils simpler, less organized, more homogeneous and containing less carbon. This has also, however, made soils more liable to erosion, with the Commission on Climate Change reporting in 2015 that the UK had lost 84 per cent of its fertile topsoil since 1850, with the erosion continuing at a rate of 1cm to 3cm a year (JW Knox, 2015).

Manufactured Soils

3.6 Manufactured soils are blends of soil, soil components and soil-like material often used in horticulture/landscape applications and site restoration. Using manufactured soils allows for 'tailoring' of soil properties to specific needs and provides a legitimate end use for materials that might otherwise reside in landfill sites. A knowledge or soils and the vegetation they will support can also be used to guide reuse – often with modification - of site-won materials.

3.7 While it would be generally permissible to manufacture soils on site for site use by the recycling of site-won granular material with, for instance, an imported PAS100 (Publicly Available Standard 100) compost, importation of quarried materials, use of other, imported recycled granular or organic materials is likely to fall under the Waste (England and Wales) Regulations 2011 and The Waste Management Licensing (Scotland) Regulations 2011.

3.8 Both the BS3882:2015 - Specification for Topsoil (BSi, 2015) and BS8601:2013 - Specification for Subsoil and Requirements for Use (BSi, 2013) were written to allow for equal qualification of 'as-dug' and manufactured soils, where they fulfil the specified criteria for topsoil. Unfortunately, there are no criteria for assessing life in the soils or, more generally, soil 'health', and no commercially-consistent methods for measuring soil structure, so a soil devoid of life and lacking structure could still be recognised as a soil according to these specifications.

3.9 It is recommended that soil specialists are consulted when attempting to construct soils from the base ingredients, especially where these materials are recycled and not 'pure' and that structural engineers be consulted when considering expansive soils and foundations etc. (see 2.61). Additional aspects of soil creation that need to be considered when formulating manufactured soils are

- **Nutrient antagonisms** – the excess of one nutrient can interfere with or block the uptake of another; in extreme cases, an excess might lead to **phytotoxicity** (see 2.71).
- **Nutrient deficiencies** – which can also affect the health and wellbeing of grazing cattle etc. but this is unlikely where nutrients are supplied through organic fertilisers.

3.10 Where there is time, the influence of the soil on plant growth could be accurately assessed by either field or laboratory-based trials. There are a number of agricultural plants with well-document responses that can be used to measure soil properties in their growth, which could be used in conjunction with the suite of tests recommended in the British Standards (BSi, 2015) and (BSi, 2013).

Contaminated Soils

3.11 Human land use and activities have detrimentally affected the soil which supports them. Soil contamination is a form of land degradation, usually caused by the introduction of human-made chemicals and pollutants. Industrial activity, agricultural chemicals such as certain pesticides, and any improper disposal of waste material such as solvents, lead, other heavy metals, and petroleum have had a long history of causing pollution and degradation in soils and groundwater.

3.12 Soil contamination is a concern primarily due to the health risks that come with it – but not all 'contamination' is deleterious or 'unnatural': 'night soil' (untreated human faeces), was used historically in the UK to fertilise soils, and it now generally acknowledge that the appropriate destination for the organic matter and fertility in treated sewage is back into soil (European Union Project Horizontal – see http://horizontal.ecn.nl/); much of the soils in the Lake District have 'elevated' arsenic, reflecting the composition of the rocks from which they were derived.

3.13 Anthropogenic sources of contamination range from direct contact with and presence of the contaminating material, vapours from the contaminants, and from secondary contamination of water supplies within and underlying the soil. Contamination in soils can also have harmful consequences on ecosystems in which it is contained, as well as other aquatic habitats that the pollutants may leech into. Given that soil forms the basis of food chains, this pollution can often accumulate higher up in trophic levels, having disastrous consequences for apex predators which disrupt and alter ecosystems further. There is now a greater realisation of the need for risk prevention and sustainable practices in agriculture and industry, with policies setting higher standards and increasingly regulating these practices. There is, unfortunately, an extensive legacy of contamination in ex-industrial sites across the UK, reflecting past industrial practices.

3.14 The presence of deleterious materials in soil is often apparent in the response of vegetation, typically through stunting, discoloration, disease, failure and, in extreme cases, the complete absence of higher plants. In some instances, 'contamination' is responsible for vegetation non-typical of the area, with, for example, acid-loving plants (**acidophiles**) on mine spoil in areas of limestone and alkaline-loving plants (**calciphiles**) in pulverised fuel ash (PFA) over acid sandstone, or the predominance of certain 'rare' species, such as *Minuartia verna* (Spring Sandwort), a lead-tolerant plant, over mine spoil containing elevated levels of lead.

Soil-Forming Material

3.15 The term 'soil-forming material' (see 1.4) has been used to describe non-natural soil-derived materials used in land reclamation, often to support vegetation growth. These are usually mineral wastes, such as:

- Overburden materials (see 1.9);
- Uneconomic geological materials encountered during quarrying or mining (spoils); and
- From the treatment or refinement of the mineral ores or raw products.

3.16 Consideration of soil formation is particularly important in urban areas or ex-industrial sites where greenspace is to be established, especially if the natural soil is inadequate or contaminated and soil-forming materials – the basic building blocks of a soil – must be used for vegetation growth. Artificial soil formation involves an understanding of soil development to accelerate soil-formation processes. Effective soil-forming materials must blend in and turn into 'natural' soils over time. Treatment can encourage this process to relieve compaction; the incorporation of organic matter such as green-waste compost; and the choice of appropriate vegetation types that will endure and improve the quality of the substrate.

3.17 Soil blends can be modified to ameliorate or modify the balance of nutrients and texture, for example:

- Where manufactured soils are low in nitrogen and/or organic material, the growth of a leguminous crop, such as clover or a vetch, and subsequent turning-in as a green compost will add both organic material and nitrogen to the soil.

- The addition of un-composted wood-chip will remove nitrogen from the surrounding soil as the wood decomposes. Consideration would have to be given in this instance, however, to the possibility of introducing plant pathogens from the source material, such as Honey Fungus.

- The growth and removal by cropping of non-aggressive plant species would be one means of reducing soil fertility.

- Addition of gypsum (calcium sulphate) has been traditionally used to help dis-aggregate heavy clay soils.

3.18 Detailed advice is available in the publication '*Soil-forming Materials: Their Use in Land Reclamation*' (Bedning, 1999).

3.19 Appropriate consideration will also need to be given to the development of life in the soils as much as the vegetation supported. 'Made soils' are typically rapidly colonised, but where the area of made soil is isolated or extensive, 'inoculation' (see 5.9) may be appropriate to accelerate the development of a 'healthy soil'.

3.20 Guidance on the soil manufacture its uses has been provided by the government funded Waste and Resources Action Plan (WRAP), including:

- Soil Manufacture and Habitat creation;

- Guidance in the use of PAS 100 Compost in Topsoil Manufacture;

- Guidance in the use of PAS 100 Compost in Soil Amendment and Surface Treatment; and

- Guidance in the use of PAS 100 Compost in Soil Improvement.

Functions and Ecosystem Services

3.21 Soil is the foundation of all terrestrial ecosystems and the primary agricultural and forestry provisioning services (food, fresh water, wood and fibre, fuel). It also supports the entire terrestrial biosphere, including human-made infrastructure. The ecosystem 'services' provided by soil are arise out of its key 'functions', including:

- Production of biomass;

- Storage, filtration and transformation of nutrients, substances, and water;

- Provision of habitat, species and genetic biodiversity;

- Provision of the physical and cultural environment for humans and their activities;
- Provision of raw materials;
- Carbon storage and cycling; and
- Protection of archaeological heritage.

3.22 Soil 'health' or 'quality' generally refers to a measure of the capacity of soil to function as an ecosystem, sustaining plants and animals alike. Soil 'health', texture and type determine its ability to function and to provide ecosystem services. For instance, the water purification or decontamination service that soil provides is most effective in clayey soils, whereby contaminants can be more easily bind to the smaller, complex clay particles. Conversely, a heavy clay will be ineffective as flood defence as this will encourage water run off compared to less tightly packed sand or silt soils.

3.23 The functional biodiversity of soil microorganisms can also affect a soil's ability to break down unwanted chemicals such as petroleum, as some microbes are more efficient than others at this process, and the recycling organic material in general requires a host of organisms, from wood-grazers to cellulolytic fungi.

3.24 The ability to compact and remain stable is also essential for the reliable and safe functioning of built developments (see 2.61). Knowing the key requirements for microbe diversity, stability, sequestration of carbon etc. can allow for optimum ecosystem service functionality for a required task, potentially safeguarding humans from hazardous events such as flooding, or maximising crop yields – all of which contribute towards economic as well as environmental sustainability.

3.25 A '*The State of Soils in England and Wales'* report (Environment Agency, 2004) concluded that there was insufficient good quality information to design effective policies to protect and improve soil quality. Subsequently, soil quality indicators guidance was produced (Environment Agency, 2006) to promote the measure of 'health' of soils. The House of Commons Environmental Audit Committee Soil Health First Report of Session 2016, concluded that there was need for:

- Better funding to remediate contaminated land;
- Better data-gathering and reporting on contaminated land;
- Action to improve soil organic levels;
- Reversal of peatland degradation;
- Better cross-compliance to mitigate the impact of certain agricultural practices on soil health and incentivising provision of wider ecosystems services;
- Restructuring renewable energy subsidies to avoid harmful, unintended consequences, such as the growth of maize damaging soils in high-risk locations; and
- National, on-going soil monitoring.

Mapping

3.26 Mapping soils can help to improve strategic decision making in fields from habitat conservation and large infrastructure developments to sustainable farming and flood management. Given the multitude of factors influencing soil formation and type, such as climate, geology, landscape, vegetation, time and human activity, several thousand types of soil have been identified throughout the world. There is, unfortunately, no truly standardised approach which all countries and systems can follow. However, mapping of parts of the UK has been undertaken by bodies, for example, such as Cranfield University (see Land Information Systems' Soilscape webpages) for England and Wales, and which is also available as a **Soilscapes** smartphone app and as a GIS layer at www.MAGIC.gov.uk. British Geological Survey has a similar **MySoil** smartphone app. A similar map has been produced for Scotland, on Scotland's Soils webpages.

3.27 Cranfield University's Soil Site Reporter provides a more accurate picture of the likely soils at a soil association level (including the ground movement potential), but even this is taken from the 1:250,000 scale National Soil Map and might not match the actual soil type at a site.

3.28 To gain more detail understanding of the soils at any particular location, a soil survey would be recommended, which may be accompanied with an assessment of the agricultural land classification (see 5.2). For a list of professional soil surveyors, see the British Society of Soil Science 'Find and Expert' webpages.

3.29 Soils data for England and Wales can also be browsed at the UK Soils Observatory, which brings soil data together from multiple agencies such as the British Geological Survey, Centre for Ecology and Hydrology and the James Hutton Institute.

3.30 Printed soil maps, which have historically been focused on agricultural and not urban areas can be purchased (e.g. from Land Information Systems' website).

3.31 For mapped soil descriptions in Europe, there is a freely-available 2005 Soil Atlas of Europe that has been produced by the European Commission.

4. Policy, Regulation and Roles

Policy and Regulation

4.1 The Government had ambitious policy goals for soil management. In its 2011 'Natural Environment' White Paper, it announced an aspiration that soil should be managed sustainably by 2030. The major issue affecting the UK's soil is contamination, primarily due to the history of extensive industrial and agricultural use.

4.2 Part 2A of the Environmental Protection Act 1990, enacted in 2000, provides a mechanism for cleaning up contaminated land which cannot or will not be dealt with through the planning system or other voluntary measures. Part 2A sets out how local authorities should identify and remediate contaminated land, and the legislation requires local authorities to produce written strategies setting out how they will carry out their duties. The principles around this is that the 'polluter pays'. If the original polluters cannot be tracked down, then often the charge will fall on local authorities of that area.

4.3 The COP21 Paris Climate Change Agreement also brought about a soil-related target for the UK, with an initiative to increase carbon levels in UK soil by 0.4% per year, as a method contributing towards global temperature mitigation (see. There have as yet been no specific policies established which allow this target to be realised in practical terms.

4.4 Defra's key lever for ensuring protection of agricultural soil health is the cross-compliance rules for Rural Payments Agency payments. These rules, revised in 2015, require that those in receipt of payments keep their land in **Good Agricultural and Environmental Condition** (GAEC). The rules require a basic level of protection for soils through management techniques that: maintain minimum soil cover, particularly in the wetter winter months; prevent and ameliorate erosion; and retain levels of organic matter, through a ban on burning arable stubble, management of heather and grass burning and not carrying out improvements on uncultivated land. Where breaches are found, farmers can receive a monetary penalty.

Risks to Soils

4.5 Soil degradation involves both the physical loss (erosion) and the reduction in quality of topsoil associated with nutrient decline and contamination. These actions pose significant risks to the state of soils around the UK, and can seriously effect agriculture and the urban environment, exacerbating pollution and flooding and reducing fertility.

4.6 The UK has lost 84% of its fertile topsoil since 1850, with erosion continuing at a rate of 1cm to 3cm a year, the majority of which is caused by increasingly intense and unsustainable farming practices, including the exclusive use of chemical fertilisers. Deep-ploughing, rapid crop rotation and bigger fields with no trees all create the conditions for erosion, and as climate change becomes more pronounced, it is possible that some farmland could become unprofitable within decades if no action is taken.

4.7 In a more urban context, the loss of vegetation and soil organic matter is a key cause of increased erosion risk. As grasses and trees help keep soils in place, the lack of incorporating these into construction can lead to soils becoming less compact and therefore much more susceptible to erosion, which is made worse by impervious surfaces such as pavements channelling water run-off over soils already at risk. Increased erosion can lead to water pollution issues in urban areas, as deposition of sediment can carry other pollutants with it that can create the need for enhanced storm-water management programs and can put more strain on purification operations.

4.8 Conversely, if soil is too compacted, perhaps through vehicular trafficking, it will hold less water and become impermeable, much like the hardstanding ground around it, putting entire urban areas at risk of flooding. In general, more sandy soils are less at risk of flooding, but more at risk of erosion, whereas clayey soils are more at risk of flooding, but are often cohesive enough to prevent issues around erosion. Therefore, striking the right balance between the different textures in soil, ensuring steady input of organic material and maintaining or cultivating good soil structure can not only provide optimal plant growth conditions, but also minimise risk.

4.9 Defra has produced a guidance document on protecting soil water and air for farmers, growers and land managers.

Role of Government and Government Departments

4.10 Governance in terms of specific policies and regulations have largely been limited around the agricultural sector and the control of pollution and contamination from industry. In the European Union's environmental policies, soil is seen as a non-renewable resource, but its governance is maintained at a national level rather than a standardised regulatory system among all member states. The UK government is responsible for enforcing sanctions on businesses or individuals who break rules regarding the release of effluents onto land, and to ensure UK practice related to soils comply with necessary management practices that ensure the sustainability of soil into the future. This can be seen in particular in agricultural practice, whereby fertiliser use, crop rotation and tillage use are often controlled. The effect of climate change and associated increased soil erosion and degradation are not addressed in any specific policies, but the need for this is certainly apparent.

4.11 Following the EU referendum vote in 2016, the Government has reiterated its commitment to the aim of managing soils sustainably by 2030. The government has also revealed that soils will receive the required attention in the DEFRA '25-year plan for the environment' report, which is expected in the summer of 2017.

Role of the EA, SEPA, NRW, NIEA

4.12 The Environment Agency (EA) is the leading public body protecting and improving the environment in England, Natural Resources Wales (NRW) for Wales, Northern Ireland Environment Agency (NIEA) for Northern Ireland, and Scottish Environment Protection Agency (SEPA) for Scotland, via policy and regulation.

4.13 The EA's policy towards soils as a natural resource was set out in the Environment Agency's 'The State of Soils in England and Wales' document (2004). Acknowledging the need to develop a range of tools to accurately measure 'soil quality', to better inform their analysis, this document was subsequently supplemented by soil quality indicators guidance (Environment Agency, 2006).

4.14 SEPA provided an assessment of the state of soils in Scotland (2011) and guidance on the Assessment of Soil in Strategic Environmental Assessments (2017).

4.15 NRW recently set out their approach to soils as a natural resource in A Summary of the State of Natural Resources Report: An assessment of the sustainable management of natural resources (2016).

4.16 These agencies have key roles in monitoring and regulating 'waste', which includes soils, and prosecuting polluters under UK legislation. Unfortunately, there is not always a clear line between what is a recycled material and what is waste, and regulated guidance, such as the Publicly Available Standards (PAS) have helped bring potentially beneficial materials out of the heavily regulated 'waste' stream.

Environmental Permits

4.17 The EA in England and Wales, SEPA in Scotland and the NIEA in Northern Ireland oversee the permitted activities which may cause harm to land, water and air, in accordance with legislative requirements. For example, waste transfer stations are permitted under the Environmental Protection Regulations (2010) in England and Wales, The Pollution Prevention and Control (Scotland) Regulations (2012) in Scotland, and wastewater discharges to rivers are controlled by discharge permits, or what used to be called 'discharge consents'.

4.18 The potential contamination of soil by human activities is controlled by permits which restrict the magnitude of contaminants being disposed of in soil. This can include human sewage via soakaway septic tanks which is governed by General Binding Rules (for activities that are generally considered of low risk to the environment).

4.19 In England and Wales, permitting is regulated under the Environmental Permitting (England and Wales) Regulations 2016 and are applied for using forms and guidance via the National Permitting Team. In Scotland there is a planned replacement of the current four environmental permitting regimes with a single, consolidated framework; this has been published for consultation by the Scottish Government and SEPA. There are fees for a permit application, annual subsistence, permit variations and permit surrender. Enforcement action is set against the limits of permits and overall compliance of the permit holder.

4.20 Some activities can be exempt from permitting because of the nature of the activity being less of a risk to human health and the environment. These are called **Exemptions** and the EA's and SEPA's websites provides a list which applicants can review. With regards to soils, exemptions such as a 'Exemption U1' is for the use of up to 5,000 tonnes of inert mineral waste (i.e. rock, aggregates, soil and sands) for land development within a three-year period.

4.21 Planning and permitting decisions are separate but closely linked. Planning permission determines if a development is an acceptable use of the land. Permitting determines if an operation can be managed on an ongoing basis to prevent or minimise pollution. Local planning authorities must consult the Agencies before they grant planning permission for certain types of development. Further information is available from the Government's 'Check if you need an environmental permit' webpages and the Environment Agency's 'Guidance for developments requiring planning permission and environmental permits' document.

Contaminated Land

4.22 As the conflict for space to develop housing, business and infrastructure gets more and more intensive then brownfield sites, land which has had some degree of human impact, are becoming increasingly attractive options for development.

4.23 Such sites can include contamination to soil from farming (e.g. sheep dip and fertiliser storage); industry (e.g. petro-chemicals, ash deposits); military; landfill and mineral extraction. For such sites the source, pathway and receptor linkages for contaminants are determined to provide a risk assessment.

4.24 Ideally the land should present no risk to human or environmental health but this is often not possible given the costs to remediate large areas of land. Published recommended levels of contaminants such as metals, hydrocarbons, volatiles gases and asbestos are used to provide a quantitative risk for a site development and the level of remediation required.

4.25 Limits of contamination guidance such as the **Soil Guideline Values** (see the Environment Agency's guide to Using Soil Guideline Values (2009) document, and the 2015 'Suitable 4 Use Levels for Human Health Risk Assessment' guidance, for substances present in soil, produced by Land Quality Management (LQM) and the Chartered Institute for Environmental Health (CIEH), provide detailed risk factors from common contaminants with respect to human health (e.g. inhalation and ingestion of soil). The particular planned land use is also a factor, with commercial use having generally more relaxed limits compared to residential plots with gardens.

Material Management Plans

4.26 Where a site is being developed, the excavations may not be considered as waste and can be re-used, without the need for an Environmental Permit or Waste Exemption. To achieve this a Material Management Plan (MMP) must be registered and approved by a qualified person within CL:AIRE, the governing organisation of MMPs. CL:AIRE is an independent body (registered charity) that promotes sustainable remediation of contaminated land and groundwater. As part of its work, it has developed a Definition of Waste Code of Practice (CoP) to provide a clear, consistent and efficient process to enable the reuse of excavated material without it being classified as a waste.

4.27 The CoP enables the:

- Direct transfer and reuse of clean naturally occurring soil materials between sites;
- Conditions to support the establishment/operation of fixed soil treatment facilities; and
- Reuse of both contaminated/uncontaminated materials on their site of origin and between sites within defined 'cluster' projects.

4.28 To qualify, the MMP must provide the following:

- Protection of human health and the environment;
- Suitability for use without treatment - If the material requires treatment (e.g. crushing) material is treated as a waste but may be able to demonstrate it has ceased to be waste after treatment in the plan;
- Certainty of use; and
- Quantity of material.

Role of Planning Authorities

4.29 A Good Practice Guide (Scotland and Northern Ireland Forum for Environmental Research (SNIFFER), 2004) highlights the need and potential for the consideration of soils within Forward Planning, including Strategic, Local and Unitary Development Plans. The key recommendations of this document included:

- Development Plan Policies to highlight the importance of soils and provide criteria against which development proposals could be considered;
- Provision of Development Briefs and Guidance for soils;
- EIA screening and scoping to include soils;
- Soils to be considered in the after-use of previously developed sites;
- Use of development control and planning conditions to reflect the potential range of effects on soils; and
- Explicit recognition of soils in National and Regional Planning Policy.

Soil Scientists

4.30 Soil scientists study the fundamental properties and processes of soil, and how to apply this knowledge to provide solutions. Common problems that soil scientists investigate are crop production, pollution control and the reduction of soil degradation. The development of the profession of Soil Science over the years has led to several specialisms:

- **Pedology** and **Edaphology** – see 1.21.

- **Soil Physics** - soil water relations, soil as an environment for plant growth, soil as a filter for applied materials such as pesticide, sewage sludge and animal slurries, and soil structure and strength in relation to cultivations, susceptibility to erosion and its use in special situations (e.g. for establishing sports turf or embankments).

- **Soil Chemistry** - the understanding of the nature of soil constituents and their interactions based upon organic, inorganic and physical chemistry, soil fertility, crop nutrition, soil organic matter and the behaviour and retention of added materials such as pesticides and radio-nucleotides.

- **Soil Biology** - an understanding of the biology of soil systems, the microbial ecology of soils and soil-plant relationships, microbial processes in soils in relation to the provision of the needs of plants and the management of applied pollutants, especially pesticides. An understanding of the soil biology is important not only in the maintenance of a satisfactory environment for plant growth but also in the restoration of soils following activities such as mining or contamination from other sources and in the provision of ecosystem services.

- **Soil Mineralogy** - the identification and analysis of minerals, and their significance in soil structure plant nutrition and the soils resilience to pollution effects and other perturbations, such as compaction or inundation.

- **Soil Management** - an increasingly important component of both teaching and employment in soil science is the understanding of how best to manage soil. This may involve the identification of the range of alternatives and the selection of appropriate management strategies for different land use options. These options can include cultivations, drainage, irrigation, input of organic material, assessment of potential soil structure degradation, land reclamation, land restoration and the prevention of soil erosion and damage.

- **Soil Survey and Land Evaluation** - mapping the distribution of soils, recording soil properties and using this and allied information to evaluate the land's suitability for a range of uses. This information may be used in the development of land management strategies or in the resolution of planning conflicts.

Multidisciplinary Working

4.31 The increasing recognition of the fundamental importance of soils, together with the restriction on movement off site and cost of disposal are increasingly bringing professionals together to better manage and gainfully exploit this limited resource.

4.32 The Flood and Water Management Act 2010 encouraged the provision of Sustainable Drainage Systems (SuDS) in England and Wales by requiring drainage systems to be approved against a set of National Standards and made Local Authorities responsible for adopting and maintaining SuDS. The role of soils and subsoils and the vegetation they support in the storage and slowing down of the passage of water is being increasingly recognised within development.

4.33 Carbon sequestration and biodiversity are additional features of soils that are increasingly gaining recognition within the development process, bringing together a range of professionals and providing a potential additional funding stream through, for instance, carbon offsetting.

5. Soil Surveys, Handling and Management

Soil Surveys

5.1 Sampling of in situ soils on site can either be undertaken via **random sampling**, **systematic sampling** or a combination of both. X-shape, W-shape, grids (of squares, rectangles or diamonds) or a number of straight line transects can be used systematically, splitting the site up as may be appropriate where obvious differences may be visible (e.g. different vegetation or colouring) to keep sub-samples collated to apparently similar areas. Random sampling will actually require some logic to the locations to ensure that a representative set of samples is recovered. The number of samples and the size of the samples will relate to the size of the area, the apparent variance across the site and the volume required to undertake any laboratory analyses required.

5.2 To assist in assessing land quality usually for development and planning purposes, the former Ministry of Agriculture, Fisheries and Food (MAFF) developed a method for classifying agricultural land by grade according to the extent to which its physical or chemical characteristics impose long-term limitations on agricultural use for food production. **Agricultural Land Classification** ('ALC') surveys (in England and Wales) are undertaken to meet the requirements of the ALC Guidelines (MAFF, 1988).

5.3 They are undertaken by soil scientist field surveyors using handheld augers to examine soils to a depth of 1.2 metres, at a frequency of one boring per hectare for a detailed assessment. This is usually supplemented by digging occasional small pits (usually by hand) to inspect the soil profile. Information obtained by these methods is combined with climatic and other data to produce an ALC map and report. The report may identify areas of Best and Most Versatile ('BMV') land, the effects on which are a material consideration during land-use planning decision-making (e.g. Paragraph 112 of the NPPF (Department for Communities and Local Government, 2012)). More information is available in Natural England's Technical Information Note TIN049.

5.4 The equivalent land classification for Scotland is the **Land Capability Classification for Agriculture** (or 'LCCA'). The general survey and methodology is similar to the ALC, however the classification is derived from the United Sates Department of Agriculture system and has a higher number of land grades associated with it.

5.5 **Land Capability Classification for Forestry** ('LCCF') surveys are an aid to decision-making in Scotland at broad planning levels, as a guide for land managers and as a statement of the natural resources of land in terms of forestry. Due to the prevalence of planting in the hill areas of Britain where high wind speeds and soils producing shallow rooting are most likely to occur in combination, windthrow hazard is recognised as an additional limitation in this land classification.

5.6 Advice on soil sampling is available for habitat creation and restoration in Natural England's Technical Information Note TIN035 and in Appendices 2 and 3 of Defra's Fertiliser Manual (RB209), for agricultural and horticultural situations.

Soil Handling and Cultivations

5.7 Working, trafficking over, cultivating, moving and storing soils in the wrong conditions and using poor methods can be result in severe, largely irreversible damage to the structure of soils and its subsequent usability moving forward. Mixing soils of different types (e.g. during excavations) prior to replacement and placing soils back in a different (horizon) order to that prior to removal can also result in a poor residual soil profile and loss of an important resource. Poor soil management can also result in accelerated soil erosion, with further loss of an important resource.

5.8 Good practice guidance on the handling of soils is available in MAFF Good practice guide for handling soils (2000) and Best Practice Guidance for Land Regeneration Note 4 (Loose Tipping). Information on the management of soils and soil forming materials, including primary cultivations, secondary cultivations, stone removal and the use of various ameliorants are available in Soil-forming Materials – Their Use in Land Reclamation (N. A. D. Bending, S. G. McRae, A. J. Moffat - Department of the Environment, Transport and the Regions, 1999) and Soil Management (B. Davies, 1997). Following this advice will conserve soils, particularly their structure, drainage and ability to support soil organisms and plant growth. Where additional drainage is required for soils in certain land-uses (e.g. high quality agriculture, amenity areas) field drainage may be required - Detailed is available in the Agriculture and Horticulture Development Board's Field Drainage Guide and The Land Drainage Contractors Association's 1998 Technical Specification for Field Drainage Schemes document.

Inoculation

5.9 Microbes in soil often form symbiotic relationships with plant root systems, leading to more resilient establishment and greater growth on infertile soils (see 2.81). Soil inoculants are, therefore, typically, microbes added to soils to promote soil health and function. This technique is often used where manufactured or heavily modified soils lack the living element associated with undisturbed soils in native habitats, such as mature, broadleaf woodland.

5.10 Soils that might represent an optimal balance in texture may still be lacking in the appropriate microflora and fauna through, for example, disturbance: soil that has been tilled, compacted, water logged, treated with chemicals, or left without plant cover, may be lacking **mycorrhizal fungi** (*a fungus which grows in association with the roots of a plant in a symbiotic or mildly pathogenic relationship – see 2.89*); introducing the desired inoculants is therefore a potential solution to this problem.

5.11 Inoculants come in many forms, from fungi to bacteria. **Rhizobacterial inoculants** are often nitrogen fixers which enhance the availability of this nutrient to the host plant (see 2.87). Many crops around the world benefit from the increased nitrogen that this brings.

5.12 Phosphate solubilisers (i.e. organisms that makes phosphate soluble in water) are also bacteria which live freely in the soil, but break down phosphate nutrients into simpler forms for easier uptake by plants. It is thought that these symbiotic bacteria can help prevent various pathogenic diseases, and mitigate negative effects of agricultural chemicals which otherwise destabilise soil ecosystems.

5.13 Mycorrhizal fungi are perhaps the most common form of inoculant, with over 95% of plant species forming associations with these. Application of these fungi usually involve dipping plant roots in a water-based mix containing the spores, rather than direct application to the soil, as the fungi rely on the plants to survive, and may therefore die in soil before associating themselves with root structures. However, powdered forms can also be used, which when mixed with water can be incorporated into existing landscapes, and this works best with well aerated and un-compacted soils which allow more spores to reach the plant roots.

5.14 Degraded, newly-restored and 'made soils' often lack or may support in low numbers the organisms normally present in 'healthy' soils. The lack of earthworms may be apparent in poor drainage and soil structure. To correct this imbalance, it may be appropriate to introduce earthworms (Butt KR, 1995). However, the appropriate species need to be selected according to their natural habitat and function, and the ground needs to be prepared to receive the inoculation, with the provision of adequate organic matter for instance. There are now several commercial companies that can provide suitable earthworm inoculants. A specification for inoculation with earthworms is provided in the NBS **Q28 Topsoil and Growing Media**.

Monitoring

5.15 Given the importance of soils and their historic and current degradation, it is vital to maintain up-to-date records throughout the UK. Soil monitoring allows changes in soil structure to be mapped over time, giving a better understanding of how processes have, and will, shape the landscape.

5.16 Today's technology makes it possible to remotely monitor soil and track parameters without 'hand recording' in the field. Soil probes (also called soil sensors) are now extremely accurate and offer an unparalleled look at what is going on below the surface, providing information such as soil moisture content, salinity, and temperature. Soil probes are useful for farmers and soil scientists alike, and can be employed layered over one another in the soil to gain maximum insight.

5.17 Soil monitoring can be particularly useful around areas at particular risk to contamination, as any harmful chemicals can be instantly flagged up and dealt with. Therefore, soil monitoring detects and evaluates possible substance release from industrial and municipal facilities to soils and related environments as well as monitoring of historical spills and leaks at plant sites.

5.18 In Scotland, there is a specific citizen science scheme, whereby anybody from dog walkers to farmers can sign up to report observed incidences of soil erosion, which is added to a monitoring database. Involving the public in the collection of data for monitoring is useful as it reduces the cost of sending dedicated surveyors out to constantly update data.

6. Recommended Soil Specifications

Topsoil

6.1 Topsoil is defined by BS 3882:2015 (BSi, 2015) for trading; the 2015 (latest) version harmonised with the **Subsoil** (2013) BS; the 2007 version, which replaced the 1994 revision, provided for the specification of a range of soils, from acid to alkaline, low to high fertility, in recognition of the landscape industry's increasing need to create or restore habitats within development sites.

Subsoil

6.2 BS 8601:2013 (BSi, 2013)defines subsoil for trading, and this standard was created partly in recognition of the landscape industry's need to create entire soil profiles within reclamation sites.

Heathlands and Grasslands

6.3 British Plant Communities, Volume 3: Grasslands and montane communities (Rodwell, J. S. ed., 1998) describes the relationship between these vegetation types and their habitats. As these are 'managed' communities, i.e. reliant on a particular management regime for their continued existence, the provision of an appropriate maintenance has to be an additional consideration in their creation.

6.4 Generally, these plant communities are a result of the clearance of woodland and the subsequent degradation of the soils that supported the woodland, often, therefore, with lower fertility and higher or lower pH, in the absence of the buffering effects of woodland-derived organic matter (leaf-litter etc.). Where the existing soil is, for instance, too fertile, the growth and cropping of herbaceous plants (not including leguminous plants) will reduce fertility.

6.5 For heathland habitats, in general terms. it has been established that the most suitable situations for the creation or reconstruction of heathlands are those where the:

- Soil pH lies between 3.0 and 4.5 (no higher than 5.5);
- Exchangeable calcium lies between 50 and 180 mg/l;
- Extractable ammonium nitrogen lies between 1 and 3 mg/l;
- Extractable nitrate/nitrite nitrogen is generally less than 1 mg/l;
- Potassium is less than 120 mg/l;
- Magnesium is less than 50mg/l; and
- Extractable phosphorus lies between 1 and 8 mg/l (no higher than 15 mg/l).

6.6 Soil texture, soil permeability and the local hydrology are all important factors in influencing whether heathlands are dry, humid or wet, but ideally soils for creation of heathland should be free-draining and non-compacted. There is a fine distinction between acid grasslands and heathland and they often occur together naturally in a mosaic, but heathland soils are generally more fertile than acid grassland soils.

6.7 Soil parameters generally considered suitable for acid, neutral and calcareous grasslands are given in Figure 21 and some key soil characteristics for UK NVC grassland habitats are provided in Figure 22.

Grassland Type ➢ Soil Aspect ⮟	Acid Grasslands	Neutral Grassland	Calcareous Grasslands
Topsoil Depth (mm)	150 to 250	200 to 300	100 to 200
Drainage rate	Medium to Fast	Slow	Medium to Fast
pH	4.0 to 5.5	5.5 to 6.5	7.8 to 8.5
Available phosphorus (mg/l)	Ideally 7 to 11 Max. 25 (lower spp. diversity)	Ideally 4 to 10 Max. 25 (lower spp. diversity)	Ideally 5 to 10 Max. 25 (lower spp. diversity)
Organic matter (%)	3 to c. 9	4 to c. 15	4 to c. 19
Total Nitrogen (%)	0.12 to c. 0.4	0.2 to c. 0.7	0.2 to c. 1.16

Figure 21 Typical soil requirements of main UK grassland types, adapted from BPG Notes 16, 17 and 18 (Forestry Research, 2014)

NVC Community	pH	Fertility Olsen P (mg/kg)	Wetness class
Tall herb grassland – False oat-grass grassland (MG1)	5.5 - 8	8 - 20	1-4
Flood meadow – Meadow foxtail and great burnet - grassland (MG4)	6 - 8	6 - 10	4-6
Ridge and furrow old meadow – Crested dog's tail and common knapweed grassland (MG5)	4.5 - 8	1 - 9	1-3
Rye grass pasture – Rye grass and crested dog's tail grassland (MG6)	5 - 8	5 - 22	1-3
Water Meadow – Crested dog's tail and marsh marigold grassland(MG8)	5.5 - 7.5	3 - 9	5-6
Tussocky neutral grassland – Yorkshire fog and tufted hair-grass grassland (MG9)	5.5 - 7.5	9 - 19	3-6
Rush pasture – Yorkshire fog and soft rush grassland (MG10)	4 - 7.5	5 - 15	3-6
Wet alluvial meadow – Creeping bent and marsh foxtail grassland (MG13)	5.5 - 7.5	9 - 29	4-6
Species-rich chalk grassland – Sheep's fescue and meadow oat-grass grassland (CG2)	6.5 - 8	0 - 25	1-2
Brome chalk grassland – Erect brome grassland (CG3)	7 - 8	6 - 25	1-2
Chalk grassland – Tor grass grassland(CG4)	6.5 - 8	0 - 25	1-2
Limestone grassland – Erect brome and tor grass grassland(CG5)	6.5 - 8	0 - 15	1-2
Chalk grassland – Hairy oat-grass grassland (CG6)	6.5 - 9	6 - 25	1-2
Grass heath – Sheep's fescue, common bent and sheep's sorrel grassland (U1)	3.5 - 6	0 - 15	1-2
Grass heath – Wavy hair-grass grassland (U2)	3.5 - 6	6 - 15	1-3
Bracken community – Bracken and heath bedstraw (U20)	4 - 6	6 - 25	1-2

Figure 22 Typical soil requirements of various UK NVC grassland types (Gilbert, 1996) and (Gilbert, 2000) - adapted

Note: See Appendix 3 of the Agricultural Land Classification of England and Wales for wetness classes, which range from Class 1 (soils are not wet within 0.7m depth for more than 30 days per year) to Class 6 (soils are wet within 0.4m depth for more than 335 days per year).

Woodlands (and Forestry)

6.8 *British Plan Communities Volume 1: Woodlands and Scrub* (Rodwell, J. S. ed., 1991) provides guidance on the range of native woodland and scrub types throughout Britain. It relates each category to the soil type, location, aspect etc., or, more generally, the nature of the habitat.

6.9 Because of the close relationship between the soil and the vegetation it supports in native woodland, and because the development may take hundreds of years, including a series of colonisations and subsequent exclusions, provision of the approximate soils and planting lists is unlikely to achieve the full complexities of the woodland structure in the short term, if at all. However, an approximation may be achieved, made easier where the woodland is an extension of an existing feature (facilitating colonisation) or in conditions that supported such woodland previously.

6.10 When trying to establish broadleaved woodland, including as a commercial crop, there are several soil characteristics that are likely to determine successful establishment and growth, including:

- pH – avoiding extremes of pH is likely to be most beneficial, with the choice of tree species reflecting the particular pH range chosen.
- Soil texture – avoiding the extremes of soil texture is likely to provide good conditions for root establishment and tree growth. Sudden changes in texture will influence the distribution of root systems.
- Soil fertility - generally, the more fertile the faster the growth. This will also influence the growth of invasive weed species, which would compete for growth. Where the mobile nutrients are not being taken up as quickly as they are released into the soil from, say, degrading organic matter, there is likely to be an excess in the drainage, which might lead to eutrophication of adjacent water bodies or even pollution of aquifers.
- Drainage (which, in turn, relates to soil texture, structure, topography etc.).
- Depth of soils, both topsoil and subsoil – general, the deeper, the better (noting that 90-99% of tree roots are within the top 1m, and that organic material is likely to degrade anaerobically below approximately 300 mm).
- Slope and aspect – Steeper slopes hasten drainage, potentially increasing erosion, and aspect can affect temperature and moisture content.

6.11 Generally, extremes, such as water-logging or desiccation should be avoided, and a substantial depth of topsoil and subsoil are likely to assist in this situation. Other factors to be considered are the inoculation of soils with mycorrhizae (see 5.13) and other soil organisms which would otherwise play a part in the woodland soil ecosystem.

6.12 Advice on creating different native woodland communities on different soil types and in different situations is available from the Forestry Commission (Patterson, 1995).

6.13 Figure 23 provides information on the minimum standards of soil and soil-forming material for woodland.

Parameter		Standard
Texture		No limitations; however, the placement location of materials of different texture on site should be related to site factors, e.g. topography
Bulk density (after placement)		<1.5 g cm^{-3} to at least 50 cm depth <1.7 g cm^{-3} to below 1 m depth
Stoniness	Clay or loam	<40 % by volume of material greater than 2 mm in diameter and <10 % by volume of material greater than 100 mm in diameter
	Sand	<25 % by volume of material greater than 2 mm in diameter and <10 % by volume of material greater than 100 mm in diameter
pH		Must be within the range 4.0 to 8.0
Electrical conductivity		<0.2 S m^{-1}
Iron pyrite content		<0.05 %
Topsoil nutrient and organic content		N: 1000 kg N ha^{-1} (see note a) P: 16 mg l^{-1} (ADAS Index 2) K: 121 mg l^{-1} (ADAS Index 2) Mg: 51 mg l^{-1} (ADAS Index 1) Organic matter content: 10%
Specific metal and organic contaminants		These should, in the first instance, be assessed using appropriate generic assessment criteria (GAC), such as Soil Guideline Values (SGVs). Where no GAC are available, acceptable limits should be derived using a risk-based approach for human health

Figure 23 Minimum standards for soil-forming materials acceptable for woodland establishment as restoration (Forestry Research, 2014)

Agricultural, Horticultural and Equine Land Uses

6.14 Agricultural land use dominates the UK, and as such plays possibly the most vital role in maintaining soil structure and function. The agricultural industry faces a considerable challenge in meeting increasing demand for food and alternative fuels, particularly because of the combined pressure to reduce environmental impact and adapt to climatic change. Maintenance of soils is the foundation of any solution to these challenges. This is reflected in our National soil policies, which pay particular attention to the agricultural sector, due to a history of soil degradation.

6.15 Poor soil structure (see 2.24) leads to poor crop growth and soil loss through erosion and run-off that can get into rivers and streams and increases the peak flood flows. Previously, farmers learnt which crops were success at a particular location in a particular soil, and could husband crops by rotation to maintain good soils structure and fertility. The latter was usually supplemented with animal manures derived from on the farm. More recent farming practice applied means to boost production and lengthen growing season by the application of chemical fertilisers. The degradation in soil quality and volumes have seen policy (UK Government, Updated 2015) promoting return to less-intensive practices, to apply organic fertilisers, employ combinable crops to find alternatives to burning crop residues and to minimise compaction, organic matter loss and soil erosion.

6.16 Horticultural practices also require soils of a certain type in order to achieve optimal function. All types of soils need management for optimum plant growth. Usually, the preferable horticultural soil is much like that of agricultural soils – loamy, meaning it consists of a balanced mixture of clay, sand, and organic matter. This 'middle ground' is identified in the BS3882: Topsoil standard as a 'general purpose' soil.

6.17 Figure 24 provides information on the minimum standards of soil and soil-forming material for agriculture (1999). See 5.8 also.

Property	Cultivation layer	Rest of profile
Texture	Loamy (preferable); sandy, clayey or silty (just acceptable)	Loamy (preferable); sandy, clayey acceptable
Structure	Not massive (after cultivation)	Not massive
Bulk density	<1.3 g cm^{-3}	<1.5 g cm^{-3}
Stoniness	$<15\%$ by volume greater than 20 mm; $<10\%$ by volume greater than 60 mm	$<40\%$ by volume total stones
Organic matter (after amendment if necessary)	$>0.5\%$	nil
pH (after amendment if necessary)	6.0 to 8.5 (grass); 6.5 to 8.5 (arable)	3.5 to 8.5
Nutrients (after amendment if necessary)		
P index	2 or more	any
K index	2 or more	any
Mg index	1 or more	any
Electrical conductivity (1:1 soil/water suspension)	<2000 µS cm^{-1}	<2000 µS cm^{-1}
Iron pyrite content	$<0.5\%$	$<0.5\%$
Heavy metal content	at or below ICRCL threshold (ICRCL, 1993)	at or below ICRCL threshold
Organic contaminants	at or below ICRCL threshold (ICRCL, 1993)	at or below ICRCL threshold

Figure 24 Minimum standards for soil used in restoration to agriculture (N. A. D. Bending, S. G. McRae, A. J. Moffat - Department of the Environment, Transport and the Regions, 1999)

Ornamental Planting Beds

6.18 Ornamental planting beds are locations dedicated to the growth of ornamental species, typically, spring or summer-flowering annuals. As such, the beds must cater for the needs of the ornamental species, which might take in a ranges of soils qualities and cater for rapid growth in spring and summer. Typically, soils should be well drained, without need of a deep subsoil or topsoil, and fall within the range of 'multipurpose soils' in the BS3882:2015 Topsoil British Standard (BSi, 2015).

Green Roofs and Planters

6.19 Green roofs are a type of green infrastructure that provide a vegetative layer on top of buildings or other built structures, often with the aim of increasing habitat for biodiversity, reducing the urban heat island effect and flooding from storm water run-off; whilst making buildings more energy efficient, cutting down costs for air conditioning. As with any plant life, however, substrate in which it grows is vital to the continued functioning of green roofs. This has led to research into optimal soils for such structures, which are required to be secure but light-weight, so they can be easily accommodated on top of a normal building.

6.20 There are several types of green roof, which can generally be recognised as either **Extensive** or **Intensive**.

6.21 Extensive green roofs, which generally require 5-15 cm depth of growing medium that should consist mainly of lightweight inorganic materials such as perlite, sand, and crushed tiles and concrete. This growing medium will often sit on top of a water and root proof barrier layer such as pond lining, and will often provide the right conditions to be almost entirely self-sustaining when planted with appropriate species.

6.22 Intensive green roofs require at least 30 cm depth of growing medium, much more of which must be organic matter – often multipurpose compost with some perlite mixed in to reduce weight. These will often come in the form of container or raised bed gardens, which may require planning procedures and professional construction to incorporate into developments. Plants on these roofs will invariably require more attention, primarily because of the greater sizes achievable than under Extensive cultivation, ensuring drainage is adequate in winter and watering is managed in summer and that excessive growth is checked.

6.23 Planters have many of the same properties as roofs, in the predisposition to drying out or water-logging and exposure to extremes of temperature and winds. Getting the right balance of clay, silt and sand and organic matter and layering of the soils, including provision of a drainage layer, are key in minimising the impacts from the environmental extremes. An understanding of which plants can tolerate this range of conditions will help determine whether the planting is successful or not.

Amenity, Sports and Leisure Land Uses

6.24 Soils can play a crucial role in the functioning of sports fields, which must provide a playing surface which is resilient from heavy use, safe, and attractive. Creating large amenity, sports or leisure areas cannot be done without moving and/or depositing large amounts of earth, and this invariably must be done using heavy machinery. Consequently, topsoil is often removed from the surface to prevent damage to it. Topsoil that is kept in heaps, must be kept in a non-compacted state during this process. Leaving heaps of soil over 5 feet in height will often lead to it compressing, which can often be an almost irreversible effect.

6.25 Moisture content is also important, as wetter soils will compact more quickly. These sorts of land-uses often want one or very few grass species as vegetative cover, and so to reduce the need for maintenance, the correct soil to promote conditions favourable to the target species can be used. Whilst it is not normally possible to create a soil that restricts vegetative growth diversity completely, it can be a good method of reducing some need for the use of herbicides and other maintenance methods.

Arid Locations

6.26 Arid or desert soils have by definition very little or no water available to plants for long periods. This reduces plant growth and the subsequent input of organic matter from plant material into the soil – reducing the soils capacity to retain water. Soils formed in these circumstances generally have very poor structure and are more prone to physical weathering processes such as wind. This can cause substantial erosion on the often-sandy topsoil, depositing large amounts of this layer away from its source. Other features often observed in these conditions is the upward migration and concentration in the upper layers of salts following evaporation.

6.27 It is possible to irrigate arid soils effectively to sustain plants with higher water demands, but this is increasingly seen as a waste of an increasingly valuable resource. This acceptance of dry conditions has encouraged designers to use drought-tolerant species, such as cacti and succulents, in keeping with the geographical location. Urban environments in temperate locations can reproduce similar conditions, and it might, therefore, be more appropriate to refer to the vegetation of drier areas in designing planting schemes. Today, arid soils cover at least one third of the World's surface, and with global warming, desertification shows signs of spreading in regions around Africa and China, so it is increasingly necessary to retain as much soil quality as possible.

Street Trees

6.28 Soils in urban locations are often lacking in an organic layer and even topsoil (reducing water-holding capacity) and often have compacted subsoil (strongly impeding drainage and root growth), interspersed with underground utilities and debris from excavations, and potential contaminants from vehicles (e.g. heavy metals and hydrocarbons) and other spillages may also be present. Soils may also have an elevated pH (potentially restricting the availability of nutrients for uptake by street trees) due to the calcareous constituents of concrete construction materials, and elevated salinity from winter salt spreading.

6.29 Street trees can act as air cleansers, heat reducers, shade givers habitat and green corridors, and so are desirable, but, due to the difficulties with urban soils, require complex considerations when planting, and typically in areas paved over by concrete or other impervious hardstanding surfaces, the main issue is soil compaction, as this can limit or even halt tree growth by removing oxygen and water that is found in the voids of less compact soil, and irrigation. Pavement damage can arise as trees grown in compact soil will often seek out the space between the soil and paved surface above. To combat this problem, soils in urban areas are now often 'skeletal' in structure, whereby aggregate (circa 1-2cm in size grade, or more) or other solid structures create interconnected spaces—known as modular 'support cells' or 'grids'—that provide voids that are filled by soil to allow root growth whilst maintaining the integrity and safety of the pavement. The aggregate used is likely to form a large proportion of the soil (circa 80%) and the choice of material may have a strong influence on the pH of the growing medium, so the specification, in relation to the tree species tolerances, requires careful consideration.

6.30 The amount of space that tree roots will need to be able to grow into depends on the species in question, and there are several methods for estimating how much space to provide (see *BS 5837:2012 Trees in Relation to Design, Demolition and Construction* (BSi, 2012)), often using ratios of trunk or canopy diameters as proxies for root spread. Generally, the soils or other growing media that street trees grow in have to assist in retaining soil moisture at the same time as providing adequate drainage during periods of inundation. They also have to be structurally stable and have limited organic matter, to ensure that there is no subsidence with constant compaction and depletion of the organic content.

SuDS and Wetland Features

6.31 There are more 'structural' uses for soils, in, for example, the application of a deep subsoil layer within redevelopment sites to provide not only good rooting depth, but to store and transport water across a site or slowly releasing water into the bedrock as part of a Sustainable

Drainage Scheme (SuDS) design. Underlying soils and geology has to be suitable for infiltration purposes, but otherwise relatively shallow soils, with the appropriate properties can be used to hold water, slowly releasing it into outfalls, mimicking natural processes such that they reduce the potential of flooding and filter pollutants and sediment from the water before leaving the site. The same principles can be applied to rain gardens and street tree planting pits.

6.32 The Suds Manual (2015) provides very detailed advice on the use and protection of soils in SuDS features and street tree pits.

Waste Disposal Sites

6.33 Waste disposal sites ('landfills'), are operated to fill engineered 'cells' in accordance with the requirements of their Environmental Permit. Once the pre-agreed levels of waste have been achieved ('pre-settlement levels', called so because the waste will reduce in volume as it decomposes and generally consolidate under its own weight (to different degrees depending on the composition of the backfilled material)) the site will be restored to a residual land-use.

6.34 To separate the waste from the restoration land-use (for pollution and environmental management control purposes), an engineered cap is created above the waste. The engineered cap will primarily be an impermeable layer to prevent egress of gases etc. and ingress of water. The impermeable cap will likely be synthetic geomembrane, or clay, layered to a required engineered specification. A free-draining mineral layer (to remove water that may lie on the surface of the cap) may also be placed directly above the cap (e.g. to 300mm depth) and which may be treated as the equivalent of regolith in a natural soil. This layer may also contain horizontally laid pipework (of varying sizes) to facilitate gas and liquid removal from the waste.

6.35 To facilitate the sustainable residual land-use, soils of sufficient characteristics and of sufficient depth to support the land-use or habitats sought is required to provide for the:

- Minimum requirements for the quality of agricultural land sought;
- Presence of landfill gas and liquid removal pipework;
- Potential requirements for piped underdrainage;
- Provision of soil structural requirements (e.g. for trees); and
- Protection of the integrity of the landfill cap from cultivations or root penetration.

6.36 Previously, minimum recommended depths for different land-uses/habitats and landfills were devised (but not published, or replaced with more recent guidance), as provided in Figure 25.

After-Use	Landfill type	Subsoil (and/or soil-forming material)	Topsoil
Productive agricultural land (arable crops and productive grassland)	Hazardous/non hazardous	1000 mm subsoil over any gas control pipework	200mm
	Inert waste	800 mm	200mm
Low productivity grazing land in moist western and upland parts of England and Wales	Hazardous/non hazardous	850 mm over any gas control pipework	150mm
	Inert waste	350 – 500 mm	150mm
Intensively used amenity or open space	Hazardous/non hazardous	850 mm subsoil over any gas control pipework.	150mm
	Inert waste	500 mm	150mm
Amenity/open space (low intensity use/no drainage)	Hazardous/non hazardous	500 mm over any gas control pipework	Not required but total soil cover over cap must be at least 1m
	Inert waste	500 mm	Not required but total soil cover over cap must be at least 1m
Nature conservation	Hazardous/non hazardous	500 mm subsoil	May not be required but total soil cover over cap must be at least 1m
	Inert waste	500 mm subsoil	May not be required but total soil cover over cap must be at least 1m
Woodland/tree planted areas	Hazardous / non-hazardous, *Clay cap with gas control, Synthetic cap with gas control*	1.5 m subsoil 1 m subsoil	Not required Not required
	Inert waste	500 mm subsoil	Not required but total soil cover over cap must be at least 1m

Figure 25 Previously recommended minimum settled soil depths for different land-uses and habitats on landfills (Environment Agency, 2004) – not published

Other

6.37 Soils associates with highways (road verges, roundabouts) etc., generally have to be relatively infertile to minimise maintenance of the vegetation, to minimise the significant cost of maintenance due to the logistic complexities and safety issues with access. These soils must also have good water-holding capacity, and be resilient to air pollutants from traffic and gritting of road. For the latter reason, salt-tolerant plants (halophytes) can often be observed in central reservations on dual carriageways. No one soil can do all of this, but soils with a higher clay and organic-matter content are likely to be more resilient to pollutants encountered in this environment.

6.38 The broad range of UK vegetation types and their habitats has been defined and classified within the National Vegetation Classification series British Plant Communities (Volumes 1-5). Most of these are not 'climax communities', i.e. a relatively stable end to succession, and are reliant to a greater or lesser extent on a maintenance regime and the arresting of succession.

6.39 Where the goal is to recreate specialist habitats, it would be sensible to seek advice from an ecologist with specialist knowledge of that habitat and to establish a mechanism and the funds required to maintain the specialist habitat. The latter is made easier where the maintenance is potentially self-funding, such as through cropping or grazing.

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