Overarching Topic

Physical Environment

Bruce Lascelles & Mark Nason

Rebuilding nature
Good practice guidance for ecological restoration

CIEEM

This document is part of a series written by experts in ecological restoration from the UK and Ireland, led by members of CIEEM's Ecological Restoration Special Interest Group. The series is prefaced by ten good practice principles for ecological restoration, set out in *Rebuilding nature: Good practice guidance for ecological restoration*, and includes five Overarching Topics that apply to any ecological restoration project in the terrestrial, freshwater and marine environments of the UK and Ireland:

- **Integrating Ecosystem Services into Ecological Restoration**
- **Project Planning and Implementation**
- **Physical Environment**
- **Large Scale Nature Recovery and Restoration**
- **Monitoring**

Accompanying the five Overarching Topics are the habitat specific documents applicable to ecological restoration projects in terrestrial, freshwater and marine environments.

"When we try to pick out anything by itself, we find it hitched to everything else in the universe."

John Muir

The Physical Environment

The physical environment can be considered to comprise the following components:

- Geology (both solid and drift geology)
- Landform (topography)
- Climate
- Hydrology and hydrogeology
- Geomorphology
- Soils

The ecological world does not exist in isolation from these aspects. It is formed on and within the physical environment and ecological characteristics are driven by the nature of the physical environment. In turn, the ecological world influences how the physical environment functions, for example how much carbon is stored in soils and how quickly rainfall can reach watercourses.

The physical environment is not static; there are processes operating across all the components of the physical environment, at all spatial and temporal scales, which result in change. These processes, and the changes they result in, also influence the ecological world and in some instances are critical to supporting its components. Take for example migratory fish such as salmon, eel and lamprey; these species rely on riverine processes to create and maintain the specific conditions needed for spawning and survival of the young.

Figure 1

Gravel bar deposits on the Afon Mawddach (downstream from the Old Llanelltyd Bridge)

Photo credit: Bruce Lascelles

Temporal change is a critical aspect to understand. Whilst some change is readily observable, occurring over very short to medium timescales (within a lifetime), such as sediment deposition in rivers or catastrophic cliff collapse, some changes are taking place over millennia, such as the weathering of rock and the formation of soils, and so whilst critical to biodiversity are imperceptible.

These changes over time mean that the current physical landscape is a function of processes operating now and also those that have operated in the past, often under different climatic conditions. Understanding why certain features exist (which may be important to the present-day biodiversity) requires therefore an understanding of time as part of the physical environment system. A good example of this are dry valleys in chalk downland, which are likely to be an outcome of historic water table fluctuations, climate variations and periglacial conditions (with downcutting occurring during the waning stage of each periglacial phase) – often described as a relic landscape (Whiteman and Haggart, 2018).

This Overarching Topic sets out the key components of the physical environment and explains why these aspects are critical to understanding the spatial distribution of habitats and species and how an understanding of this system must be central to the design and delivery of sustainable habitat creation, restoration and translocation.

The guidance relates to the above aspects of the physical environment, with a focus on soils as the medium which supports terrestrial ecosystems, and which is so critical to the quantity and quality of water reaching freshwater and marine ecosystems.

Sources of information are provided and a checklist set out to ensure all aspects have been understood and covered in the design and execution of habitat creation, restoration and translocation projects.

System Thinking

Whilst this guide will provide information specific to each element of the physical environment, there are multiple and complex interactions and interrelationships (Singh, 2024). Because of this, a systems thinking approach must be taken throughout the planning, implementation and monitoring of habitat creation.

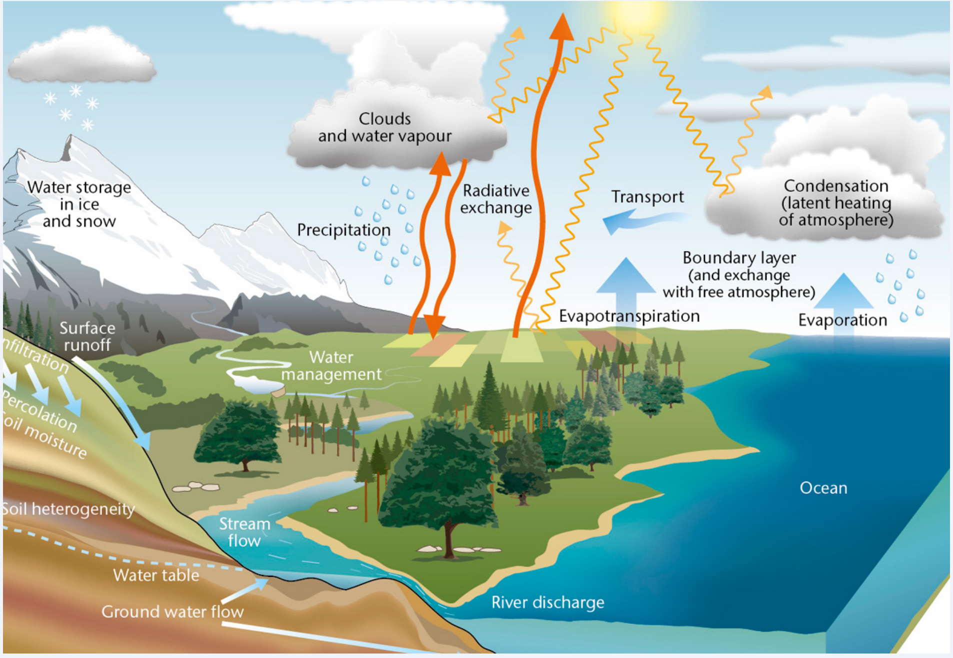
The Supplementary Evidence Report to the 25 Year Environment Plan (HM Government, 2023) states:

"A key concept underpinning a natural capital approach is system-based thinking which recognises the interdependencies between the different elements of the natural capital framework and any emergent properties which occur through these interactions."

As an example, through the lens of the water cycle, the infographic below from the Meteorological Office highlights some of the interrelationships within the natural system.

Figure 2

The water cycle (Met Office).



System thinking will also require a multidisciplinary approach. In a review of systems thinking (Voulvoulis *et al.,* 2022) various researchers have emphasised the need for improved inclusivity and multi-actor participation to provide a greater understanding of the plurality of perspectives. They also emphasise the need to include scientists together with industry, government, citizen groups and environmental organisations.

Given the multitude of interrelationships, stakeholder engagement is absolutely critical to bring the right technical and local knowledge to the table, and unpick potential conflicts which may arise, ensuring maximisation of the benefits delivered. For example, conversion of arable land to species-rich floodplain hay meadows to deliver multiple benefits will require water table levels to be raised, possibly through blocking ditches combined with some ground lowering to create scrapes. Successful creation of such habitats can have significant biodiversity benefits, but may also impose a limitation on agricultural productivity, create the potential for increased wetness of surrounding land (so important to consider if a buffer is required), limit the machinery which can be used (at least at certain times of the year), and potentially require restriction to access/footpath re-routing. Good stakeholder engagement is important to manage the interplay between different drivers for land use and optimise and equalise the final benefits which are delivered by a project.

Figure 3

Wet grassland creation in Somerset (combination of water level raising and the creation of scrapes and grips)

Photo credit:
Bruce Lascelles

Key aspects of the physical environment in relation to habitat creation, restoration and translocation

Geology

There are two key aspects of geology to assess: the solid geology and the drift geology .

- Solid geology – the underlying geology comprising igneous, sedimentary or metamorphic rocks. Sometimes referred to as bedrock geology, it is a term used for the main mass of rocks forming the Earth that are present everywhere, whether exposed at the surface in outcrops or concealed beneath superficial deposits or water.

- Drift geology – also referred to as superficial deposits, these are the youngest geological deposits formed during the most recent period of geological time, the Quaternary, which extends back about 2.6 million years from the present. They rest on older deposits or rocks referred to as bedrock and examples include glacial deposits such as till, materials moved by rivers (alluvium) and materials which have moved downslope (such as colluvium and head deposits).

Figure 4

Solid geology comprising fractured siltstone, Llyn Aled Isaf, Hiraethog Moors

Photo credit:
Bruce Lascelles

vDifferent geologies will have differing characteristics, such as hardness (resistance to erosion), particle size, drainage and chemistry. This will affect key aspects of the physical environment including topography, hydrogeology (groundwater), soil chemistry and soil moisture.

Geological information can be found via the Geology Viewer (British Geological Society), Geological Survey of Northern Ireland or the Geological Survey Ireland. The resolution is based on the available mapping, and so actual mapping scales may vary. This should be used as a guide to the likely solid and drift geology present at any given location; where required, further information from borehole data, for example as available from the British Geological Society or specialist advice should be sought.

Solid and drift geology are often used to refer to the natural ground conditions. It is important to assess whether any made ground is present (i.e. ground conditions resulting from activities, such as construction, landfill etc.). If made ground is likely to be present expert advice should be sought in relation to the nature of the made ground and any potential hazards.

Landform (topography)

Landform refers to the natural features of the Earth's surface that have distinct shapes and characteristics. There are two spatial scales at which landform should be assessed:

- The specific characteristics of the project site, such as altitude, aspect and gradient, and the scales at which these change (microtopography). These will influence climate (including microclimate), drainage, soil depth, accessibility (for works required to create and manage the habitat), effect of land use change on landscape views (from the area and into the area)
- The setting of the area within the wider landscape. It is important to understand how conditions at the project site may be affected by the landforms in the surrounding area, and in turn how any land use change may affect areas beyond the project site (taking a source – pathway – receptor approach).

Landform information should first be sought from available Ordnance Survey mapping and aerial photos which will provide a good overview of the likely landforms present.

Figure 5

Cwm Idwal, a result of the combination of geology, glacial activity and current hydrology

Photo credit:
Bruce Lascelles

Depending on the project there may be a requirement for additional topographical information to be collected, utilising technologies such as LiDAR or the creation of digital elevation models created from data captured by Unmanned Aerial Vehicles (UAVs). This can be particularly important when undertaking river and floodplain restoration, determining surface water flow routes, watercourse channel geometry or detailed ground elevation to assess water table levels in comparison with the ground surface.

Climate

Climate is the long-term pattern of weather in a particular area. Weather can change from hour-to-hour and a region's weather patterns, usually tracked for at least 30 years, are considered its climate (National Geographic).

The climate in any particular area will be a result of a number of factors:

- Latitude;
- Proximity to the oceans or large freshwater bodies;
- Altitude;
- Aspect;
- Range of factors influencing the micro-climate (such as canopy cover, buildings, sinking of cold air down slope along gullies).

Climate defines how much rain falls, when it rains, temperature ranges, snow and frost incidence, windiness etc. (and past climates may have imposed very different processes over time). It is therefore critical to understand the climate of the project area and how this may influence the habitats present/being created. This is particularly important for river and wetland habitats where rainfall, temperature and evapotranspiration rates may need to be monitored alongside surface and groundwater levels to understand the drivers for changes observed in the physical environment.

Whilst it is not possible to cover climate change in detail in this guidance, the effects of climate change, and the roles habitats can play in enabling mitigation, adaptation and resilience to change must be considered.

The Intergovernmental Panel on Climate Change (IPCC) states in their latest synthesis report that:

"Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals."

This will continue to affect habitats. More frequent and severe droughts, higher temperatures, greater rainfall intensity, glacial retreat, sea level rise, and changes to the ranges of pest species, should all be taken into account. The role of habitats in mitigating the impacts of these changes is an important consideration in project design and rationale, looking for nature based solutions such as:

- The role of street trees in reducing the urban heat island effect (*Ettinger et al.,* 2024);
- The structure of a habitat and the extent of rainfall interception and erosion protection this can provide;
- The capacity for plant roots to build and stabilise soil structure, increasing infiltration, moisture retention, water filtration and erosion protection;
- Soil health and its carbon content and ability to absorb and retain water and release it slowly back to watercourses or aquifers (Trumper *et al.* 2009);
- Wetlands, ponds and peatlands and their role in storing carbon and holding water to be slowly released back to watercourses or aquifers, especially important during drought (Trumper *et al.* 2009);
- The role of saltmarsh in storing carbon, providing natural coastal protection and significant biodiversity value (Marin-Diaz *et al.,* 2023);
- The importance of new areas of flowering and fruiting plants which provide valuable food sources (particularly in the context of changing ranges for species).

There are a range of online resources to check the current weather conditions. The Met Office provides access to monthly data for a selection of long-running historic stations. The series typically range from 50 to more than 100 years in length and provide:

- Mean daily maximum temperature
- Mean daily minimum temperature
- Days of air frost
- Total rainfall
- Total sunshine duration

Similar information for Ireland is available from The Irish Meteorological Service. There are also resources available to show how the climate is expected to change, including the Met Office's UK Climate Projections (UK Climate Projections (UKCP) - Met Office) and the Climate Risk Indicator Explorer (https://uk-cri.org/) provided by the UK Climate Resilience Programme.

Decision support tools that can be used to guide choice of species and provenance for climate resilience include the Forestry Commission's Climate Match (https://climatematch.org.uk/) and the Centre for Ecology and Hydrology (CEH) 'Find your niche: Plant species model assessment' app (https://landuse-fyniche.datalabs.ceh.ac.uk/), which allows users to visualise MultiMOVE fitted niche models for almost 1500 British vascular plants, common bryophytes and lichens. Niche models describe, based on occurrence data, where species are likely to occur in relation to environmental gradients. The CEH app allows users to explore plant niches by climate indicators (and also by substrate fertility and acidity), including maximum July temperature, minimum January temperature, annual precipitation, and substrate wetness. Restoration practitioners can use niche models in combination with climate models to guide planting choices, for example by assessing the likelihood that certain plant species are to find themselves outside of their preferred niche in the future, and building climate resilience by choosing or later adding species that are likely to be suited to future climatic conditions.

Hydrology / Hydrogeology

Freshwater ecosystems support high biodiversity and play a critical role in the carbon cycle. They can also be dynamic systems, changing over a range of timescales with the geodiversity created and reformed supporting biodiversity (Stafford *et al.*, 2021).

In the context of habitat creation, restoration and translocation, hydrology (surface water) and hydrogeology (groundwater) should be considered for all habitats. This should be in the context of the water cycle, as shown in **Figure 2**, to ensure the interrelationships are understood.

Things to consider include:

- Water requirements of the habitat(s) (rainfall quantity and seasonal distribution, groundwater levels, flood regime, flow characteristics);
- The presence of sensitive Groundwater Dependant Terrestrial Ecosystems[1] such as fens and turloughs[2] which could be affected upstream/downstream;
- Water chemistry – will be influenced by the geology and soil types present;
- Water quality – this may be affected by land management activities, pollution, silt and nutrient laden runoff etc.; does the habitat enhance water quality or remove nutrients?
- The role habitats can play in intercepting rainfall and enhancing infiltration (through root growth and soil health), slowing and cleansing the flow towards watercourses;
- Flood risk – does flood risk impose restrictions on the activities required to create the habitat; does the habitat help reduce downstream flood risk;
- Groundwater source protection zones – are there important groundwater reservoirs or private water supplies which need protecting (in terms of both quantity and quality of water);
- Potential conflicts, for example natural flood management (NFM) measures to hold and spread water as close to source as possible which could result in reduced water levels in downstream wetland habitats;
- Climate change – how will this affect availability of water resources? Has the design taken climate change into account, for example incorporating NFM measures to retain water and limit erosion risk? Does future increased flood risk or drought (in particular the frequency and duration of surface water inundation) place a limitation on the ability of the habitat (or individual plant communities) to persist? Is the existing condition sustainable in the long term? The questions to answer will depend on how far ahead it is feasible to look ahead (for example managed retreat decisions could be based on a 'hold the line' approach in the short-term or allowing change now to future proof a coastline).
- Future management – how does the hydrology and hydrogeology affect the ability for the habitat to be managed? For example, what restrictions does this place on access, grazing, and cutting.

There are good online resources available for information. For example, in relation to flooding flood maps are available as follows:

- England
- Wales

1 Groundwater Dependent Terrestrial Ecosystems (GWDTE) are wetlands such as springs, flushes and fens which are fed by groundwater rather than rainfall or surface runoff.

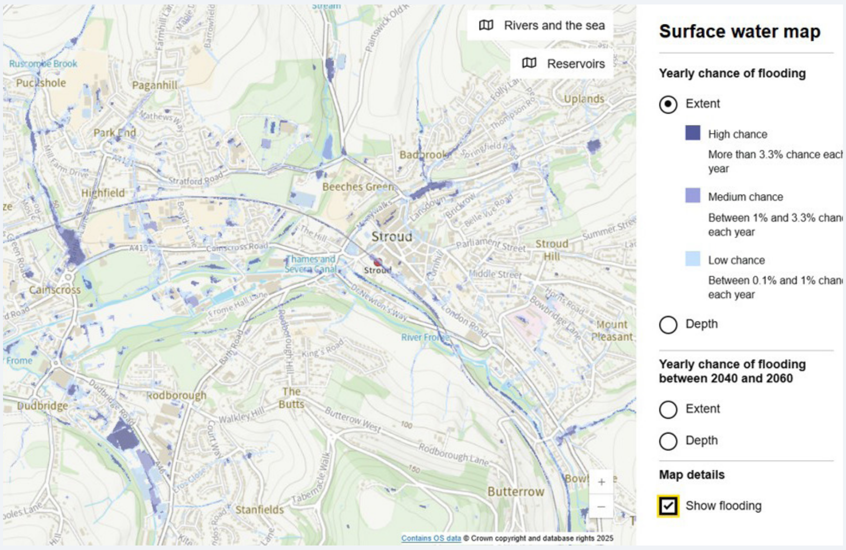
2 Seasonally-flooded lakes in karstic limestone areas, that are principally filled by subterranean waters and drain back into the groundwater table – they have no natural surface outlet.

- [Scotland]
- [Northern Ireland]
- [Republic of Ireland]

Figure 6

Example flood maps for Stroud in Gloucestershire

[Flood maps for England]



Groundwater level information is available for some boreholes, for example as made available by the [British Geological Survey]. Research reports are also available on the water requirements of individual habitats, such as Defra (2002).

Where water flow characteristics or groundwater levels are critical for the habitat, there may be a need for site-specific monitoring to be undertaken, for example through the use of surface water depth gauges or groundwater measuring wells (Rothero *et al.,* 2016). Expert advice should be sought on the design of monitoring programmes to ensure sufficient information is gathered. As water levels will be dependent on current and antecedent weather conditions, any monitoring will be required to be undertaken over periods of months or years (and as noted above undertaken in conjunction with weather monitoring).

For information on individual habitats refer to the respective habitat sections.

Geomorphology

Geomorphology is the study of landforms and the processes that have shaped and are currently shaping them ([British Society of Geomorphology]). It requires an understanding of geology, hydrology, hydrogeology, soils and topography, the interplay with the biological world in relation to effects such as biological weathering, slope processes or the role of large woody material in influencing riverine processes, and how these processes and resultant features have changed over time.

The concept of geomorphology links to the need to take a systems thinking and multidisciplinary approach. Geomorphology can help with understanding the relative impacts of slow, progressive climate change and rapid, individual hydroclimatic events on landscape and ecosystem processes, function and form, and in the development of nature-based solutions, including various adaptation and mitigation strategies to help manage climate change impacts and increase societal resilience ([British Society of Geomorphology]).

Whilst landform processes affect all of the physical environment, situations where it will be more imperative that an expert geomorphological opinion or assessment is included within a project include:

- River restoration – understanding the sources, transport and deposition of sediments, the natural form of watercourses in any given location and the potential lateral and vertical mobility of a channel;
- Hydrological changes (for example water taken from a river to supply a hydroelectric plant) – assessing the

potential for changes in river channel and floodplain form and function, and thus the biodiversity they support;

- Floodplain / coastal habitat creation – assessing and understanding flood and flow regimes and the lateral and vertical variability in sediments / soils (for example organic-rich infilled channels);
- Peat stability – assessing the potential risk of peat slide associated with changes to the moisture content/ water levels within a peat body;
- Slope stability – assessing the potential for erosion or soil creep as a result of land use change.

Soils

Soils form at the interface of all the above aspects of the physical environment. They are also the medium through which the above processes work and which support biodiversity .

The Natural Capital Committee (2019) published advice on soil management in 2019. This report highlights the critical importance of soils to our existence, with their role in food production clearly recognised but their wider role in supporting and delivering ecosystem services less well recognised. The report lists these as including climate regulation, flood risk reduction and water purification, support for buildings, landscape and heritage as well as the platform for biodiversity. Soils contain and allow to thrive an immense biodiversity and support the landscapes we see, giving us aesthetic, spiritual, cultural and educational benefits.

The report notes the pressures soils have and continue to be under, highlighting that soil degradation in England and Wales is estimated to cost between £0.9 and £1.4 billion per year. Soil is a non-renewable resource, forming at very slow rates of millimetres over hundreds of years. Rates of erosion and loss of soil are often much greater, with an estimated 2.2 million tonnes of soil eroded each year stated in the NCC report.

The report highlights some beneficial practices, noting that it is widely recognised that managing soil organic carbon is central to optimising soil health and therefore function because organic matter influences numerous soil properties supplying ecosystem services. The report notes some beneficial practices as:

- Conversion from arable to grassland or woodland;
- Retention of crop residues and applications of organic matter
- Minimum tillage
- Use of cover crops
- Restoration of peatlands

All of these, whilst they could be inferred to be associated with agricultural practices, are applicable to ecological restoration projects.

The benefits gained from soils in good condition all have value. It is easy to place a value on the crops or fuel grown. The benefits from clean water, reduced flood risk, stored carbon and our wellbeing are all equally important; but much of this is difficult to directly value. If we understand our soils then measures can be put in place to repair, protect and enhance them, increasing the services we get, not least biodiversity, and the resilience of the system to change.

As Franklin D Roosevelt said, “*a nation that destroys its soils destroys itself*”.

What is soil?

Soil is a combination of minerals from the rocks or sediment (which can include substrates such as crushed construction materials or chalk cake from tunnel borings) in which the soil has formed, organic material and living organisms (dead plants, fungi, microbes and animals), along with air and water. These components all occur in differing proportions depending on the soil type, the season, the weather conditions and how they are being managed.

When looking at more detailed definitions of soils, we need to consider the user. A farmer growing crops will want to maximise yields and minimise inputs. They will want a soil that is highly fertile, easily workable and good at retaining moisture, which might also be suitable for woodland creation. In contrast, an ecologist looking to create heathland will want a soil that is nutrient poor, possibly very freely draining, acidic and with lots of microtopographic variation.

How soils form

Soils develop in the rocks and sediments that make up the earth. With time, these materials are broken down by a mix of physical and chemical processes, both of which can include a biological element. Some examples of weathering include:

- Freeze – thaw processes, causing water to expand and force rocks and particles apart;
- Heating – cooling processes, causing expansion and cracking;
- The growth of plant roots through cracks and crevices;
- The action of acids, such as carbonic acid in rainfall or organic acids produced when vegetative material decomposes (important in the weathering of calcareous rocks such as chalk and limestone) .

Physical, chemical and biological weathering occur together, and can accentuate each other. As rocks are physically broken down into smaller and smaller fragments, their surface area increases, allowing chemical weathering processes to act on a larger proportion of the material. These processes combine to form the soils we see, and importantly cause the release of nutrients which sustain life.

These processes are not things that have happened in the past and the soils we see today are not the end result. These are on-going processes which continue to shape the soils and ensure the release and cycling of nutrients.

Many of the physical and chemical weathering processes can operate without the need for inputs from living, or dead, material. These processes will produce sediment; broken up rock material. However, as soil is defined as a mix of mineral and organic material, life is needed to create soil. Conversely, soils are needed to support and sustain life.

The Soil:Life Nexus – There can be no life without soil, and no soil without life.

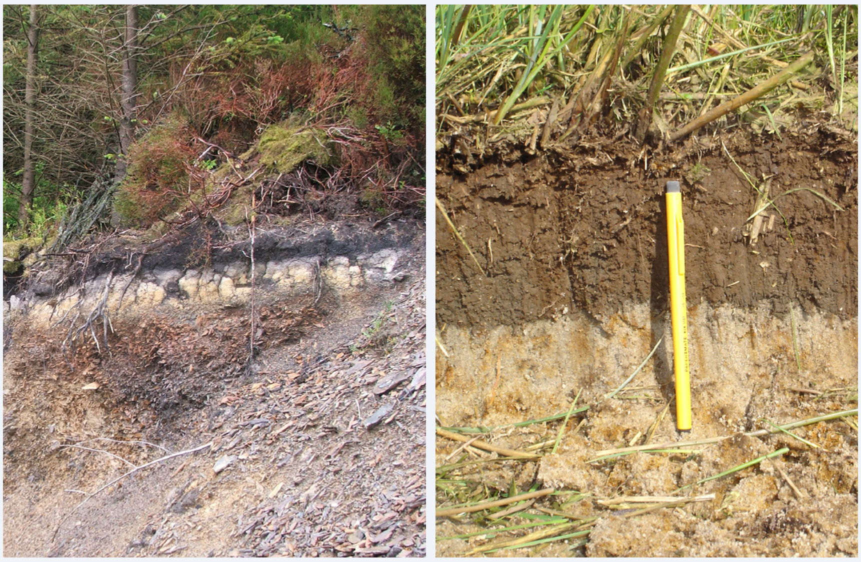
Professor Rattan Lal

The story of these processes can be read by digging down and exposing a section of soil; this is called the soil profile and a number of distinct layers, known as horizons, may be visible. Two very different soil profiles are visible in the images below and the different histories of these soils can be understood from this.

Figure 7

Upland soil (Podzol) in mid-Wales (left) with multiple horizons, and floodplain soil developed in sand (right), North Wales

Photo credit:
Bruce Lascelles



Key aspects of soils

Parent material

The material the soil is formed in is described as the parent material. This can be solid rock, as in the podzol profile on the left of **Figure 7**, or can be sediment (i.e. drift geology) as in the right-hand example where the soil has formed within old beach sands.

Soil horizons

The horizons above the parent material can be broadly defined as either subsoil or topsoil. Subsoil comprises mainly rock fragments that have been altered in some way, physically or chemically. It contains some plant material, often deeper plant roots, and some soil plant and animal life will be present. The processes which form soils will be active within this layer, reorganising material and releasing nutrients.

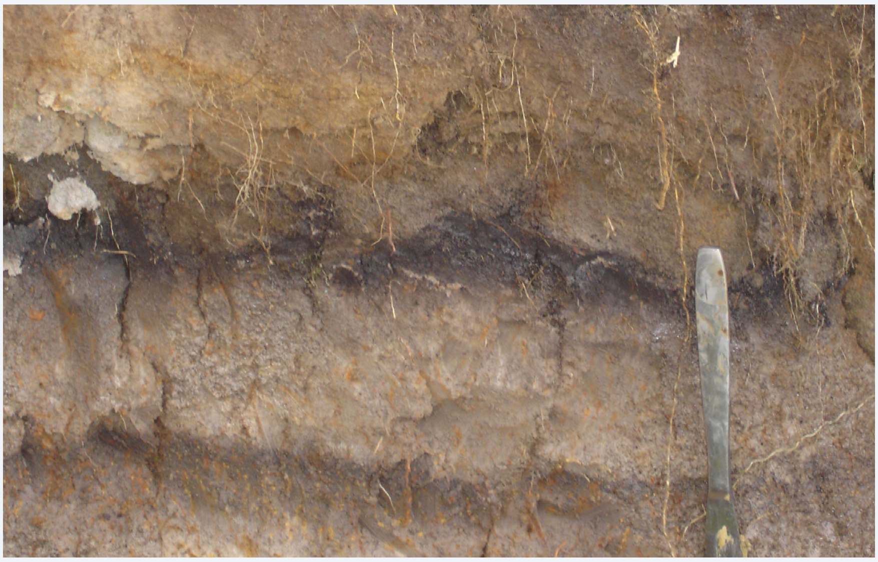
Topsoil, as the name suggests, lies at the top of the soil profile. It is usually darker in colour than the lower horizons as a result of the accumulation of decomposed plant remains mixed with the mineral material. The proportion of organic material will differ between soils, from low quantities in dry soils to soils which are nearly 100 % organic in nature, such as peat soils. It is this layer that contains most life, and which is also most affected by the activities of living things, including ourselves.

In places, the profile can tell very clearly the history of the landscape within which it sits, and may be historically important for scientific and nature conservation reasons. **Figure 8** below shows a series of dark layers in the profile; these are topsoil horizons which have been buried by soil erosion, each one depicting a period of stability and soil formation before being buried by a catastrophic erosion event.

Figure 8

Buried horizons depicting past phases of soil formation and erosion

Photo credit: Bruce Lascelles

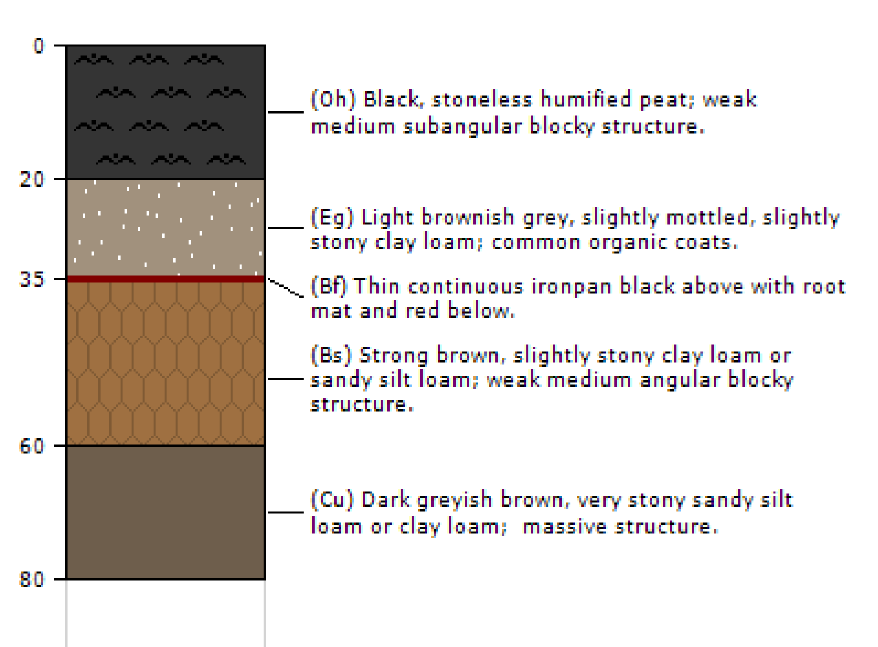


Whilst not covered further in this advice note, the role of soils (particularly wet soils) in holding and protecting archaeology (both known and yet to be discovered) should be assessed before soils are disturbed. Opportunities to further understand our cultural heritage should also be highlighted, for example using pollen preserved in peat or in pond and lake sediments to understand vegetation change over time or using buried topsoil (as in the above image) to understand historical levels of pollutants.

Figure 9

Soil profile description for the Hiraethog Series, a podzol found in upland environments

(**LandIS** Soils Guide)



Soil biology

Soil as a resource is so much more than the sum of its parts and how these are put together to produce different soil types. Soil is a habitat: an ecosystem in its own right. A teaspoon of soil supports more living organisms than there are people on this planet (British Society of Soil Science). Soils support life from large mammals, such as badgers and moles, down to earthworms, nematodes and microorganisms such as bacteria and fungi, including mycorrhizal fungi, critical for many ecosystems.

These organisms interact and are interdependent, just as life interacts and is interdependent above the surface. They enable nutrients to be cycled and made available for plant growth. They compete for resources (which includes each other) and, in healthy soils, balance each other just as, for example, pests are kept in check in a healthy above ground ecosystem.

Soil, alongside air and water, is one of our three critically important natural resources. The soil strategy for England (Defra, 2009), published by the government, states "*Along with air and water, soil is one of the building blocks of life*" in the opening paragraph. And whilst a huge amount of work is undertaken to study our soils, because of their complex and microscopic nature, there is a huge amount we don't know. For example a large number of the most commonly used antibiotics have originated from soils; Penicillin came from *Penicillium*, a fungus found in soil. And within the last decade new antibiotics have been found in soils (Ling *et al.,* 2015). Protecting and promoting soil health is therefore vital to ensure potential future discoveries are still possible.

Soil physical properties

The key soil physical properties have been set out in **Table 1** below, to provide a brief explanation of each and set out why each is important to be taken into consideration during project design and development.

Table 1

Key soil physical properties to consider during project design and development

Soil physical property	Description	Importance
Horizons	Distinct layers, often visible, in a soil profile. Different horizons can usually be distinguished by colour change, but in some soils may relate to changes in, for example, soil texture or chemistry (which might not be visible). Can broadly relate to topsoil and subsoil resources (noting there may be litter or organic matter layers associated with topsoil and potentially several subsoil layers as properties change with depth).	- Understanding topsoil and subsoil thickness is critical to approaches to soil sampling. - If soils are being translocated or inverted it is likely this will need to be undertaken based on recorded thicknesses and an understanding of spatial variation. - Soil stripping should always ensure that soil from different horizons is stripped and stockpiled separately (unless, for example, mixing layers is required to create materials suitable to the proposed end use).
Soil colour	The colour of the soil matrix for each horizon and the colour of mottles or other inclusions. Clay-rich waterlogged soil showing mottling (Photo credit: Bruce Lascelles) 	- Parent materials impart a certain colour to soils (for example reddish soils formed on Old Red Sandstone in Devon). - Higher levels of soil organic matter content will impart brown to dark brown to black colours. - The presence of mottles and / or a grey matrix will indicate evidence of waterlogging / the extent of waterlogging. Very grey colours may represent permanent or prolonged waterlogging.
Soil texture	The proportions of different-sized particles. These are split into sand, silt and clay. Soil texture is described according to the [soil texture triangle]().	- Influences infiltration and drainage rates and water-holding capacity. - Influences the shape and size of structural units which form, from single grain sandy soils to prismatic clay-rich soils (see below). - Can limit root growth (for example in sandy soils). - Determines potential erodibility of exposed soils (noting that good structural stability is also important) – generally fine sandy and silty soils are the most easily eroded.

Soil physical property	Description	Importance
Soil structure	The way individual soil particles (sand, silt and clay) are combined to form units (peds). Soil structure can be described as granular, blocky, prismatic or platy. It is important to understand both the structural units which are present and their stability. Soil structural stability will be enhanced by the presence of higher levels of soil organic carbon, extensive root network, as well the presence of crystalline materials such as iron oxides.	▢ Influences infiltration, drainage and root growth. ▢ Affects ease of cultivation and ability to create a good tilth prior to sowing seeds. ▢ The extent of soil structural development is a good indication of the presence of soil compaction. Soil compaction may be present throughout the soil or just as a single layer (for example a plough pan beneath arable land). Soil compaction is a significant issue in many soils, contributing to flooding and preventing aquifer recharge
Rooting depth	The depth to which roots occur in the soil.	▢ The rooting preferences of the species included within a habitat should inform the depth of rootable material required (for example >1m usually required for tree growth but 100-200mm may be sufficient for grassland communities as long as the subsoil/parent material does not impose other limitations, such as impeded drainage). ▢ If turfing is being proposed, the main rooting depth should be a key consideration in relation to the depth to which turves should be cut (to limit the loss of soil material from the base of the cut turf).

The effects of soil handling on the physical properties of soils are not covered by this overarching topic: refer to guidance such as Defra (2009) and the Institute of Quarrying (2021) for guidance on measures to minimise the risk of damage to soil properties during soil handling operations.

Soil chemistry

The key soil chemical properties have been set out in **Table 2** below, to provide a brief explanation of each and set out why each should be taken into consideration during project design and development. If there is the potential for contamination to be present expert advice should be sought before soils are surveyed or handled.

Table 2

Key soil chemical properties to consider during project design and development

Soil chemical property	Description	Importance
pH	A measure of the acidity or basicity of the soil. Recorded on a scale of 0 – 14. Soils will generally have a pH between 4 and 9. Ultra-acidic soils (pH <3.5) and very strongly alkaline soils (pH >9) are generally rare, although historical acid pollution has further lowered the pH of some soils.	Individual species and plant communities may have specific pH tolerances (see relevant habitat sections). If the pH is outside the range tolerated it is unlikely the habitat created will persist at that location in the long-term. Soil pH can be altered (for example with lime or sulphur additions); however if the underlying soil/parent material is of a contrasting pH nature applications may be needed in perpetuity. pH will influence the availability of some nutrients and so needs to be taken into account when assessing potential plant available nutrient levels Important to understand the pH of surface and groundwater flows into an area, as may be different if originating from a different geology. If watering is proposed, where practicable ensure the water source is local/from the same geology and thus the same pH.
Plant available nutrients	The levels of nutrients available to plants (usually tested by extracting from the soil using a weak reagent). ▢ Key nutrients are: ▢ Total Nitrogen (N) ▢ Phosphate (P) ▢ Potassium (K) ▢ Magnesium (Mg) Often reported against Defra Indices.	▢ Where high levels of plant available nutrients are present, a small number of vigorous species is likely to dominate. ▢ Generally, species-rich habitats will require low levels of plant available nutrients (in particular P). ▢ If P is very low, this can be a limiting factor (and so elevated levels of other nutrients may not be important). ▢ Nutrients are often concentrated in the topsoil; in coarse textured soils nutrients are less well held on soil particles and can be leached deeper into the soil (i.e. don't assume subsoil will always be low nutrient). Understanding topsoil and subsoil fertility will therefore be important in project design. ▢ Nutrient levels can be reduced through measures such as soil inversion, topsoil stripping or nutrient cropping.

Soil Organic Matter (SOM)/ Soil Organic Carbon (SOC)	The quantity of living or dead material in the soil (including materials such as manure added to soil). A proportion of SOM will comprise SOC. See additional resources: - British Society of Soil Science: Science Note – Soil Carbon (and Soil Carbon (Short Version)) - Anderson, P. (2024). Carbon in Ecosystems - management, restoration & creation for carbon capture - Integrating Ecosystem Services into Ecological Restoration (this series). https://cieem.net/resource/good-practice-guidance-for-ecological-restoration/	- Improves soil structural development and stability (thereby reducing erosion risk); - Improves infiltration and water holding capacity (thereby improving drought resilience); - Adds nutrients to the soil; - Supports the microbial soil community; - Increases in long-term storage of carbon, especially where soils are not disturbed / waterlogged.
Other	There may be project-specific requirements to take into account	- Assess potential for there to be contaminated materials present (e.g. heavy metals or asbestos). - There may be chemical properties which are natural which need to be understood – for example conductivity levels (related to salinity) may be naturally elevated in coastal areas affected by salt-laden winds. - In urban environments the soil parent material may comprise inert materials such as concrete, brick rubble etc. – understanding the chemical composition will be critical to determining the types of habitats these can support (for example concrete can result in elevated pH levels). - Where soil materials are being imported or exported refer to the relevant British Standards for information on the chemical test suite required: a. *BS3882:2015 Specification for topsoil (The British Standards Institution, 2015)** b. *BS8601:2013 Specification for subsoil and requirements for use (The British Standards Institution, 2013)**

* The relevant British Standards should be applied where soil materials are being imported or exported. They should not be used to determine the usability of site-won materials which may naturally have characteristics which fall outside the British Standard specification. Site won materials should always be assessed on a site-specific basis.

Soil types and classification

The processes described above, and the combination and character of the horizons which make up the soil profile, give rise to the wide range of soil types present. There are over 750 different soil types mapped in England and Wales, for example. There are resources available to find more information on the distribution and character of soil types for a particular area:

- England and Wales (this includes a Soils Guide providing more detailed information on the soil of England and Wales and also includes a growing suite of Soil Alerts, highlighting some of the key issues or concerns associated with particular soil types) along with Bulletins and regional maps.
- Scotland
- Northern Ireland
- Republic of Ireland

The British Society of Soil Science has published a number of guidance and science notes, including one focused on Soils and Land Quality: How to find online maps and data sets.

Soil across the UK can broadly be described as brown soils (brown earths), waterlogged soils (known as gley soils), podzolic soils (generally acidic and nutrient poor) and organic soils (which can be thin soils overlying the parent material or deeper peat soils) (Avery, 1980). The UK has a remarkable and renowned diversity of soils which can be seen on the soil maps, and this results in an equally diverse range of landscapes and native biodiversity.

Land is also classified in relation to its potential productivity under the Agricultural Land Classification (ALC) system for England and Wales and Northern Ireland and the Land Capability for Agriculture (LCA) System in Scotland. Where habitats are being created the balance with food production must be taken into account; it may be that habitat creation is more suited to land of lower quality (and thus likely providing a more stressed environment to favour species-richness).

Soil surveys (including monitoring)

The resources detailed above will provide background information on the likely spatial distribution of broad soil types across any given area. Some mapping is available at more detailed scales; but soils are naturally highly variable (both in terms of lateral distribution and vertically in terms of horizon thicknesses etc.). As such, it is likely that a soil survey will be required to understand the key characteristics (and the variation in these) of the soils across a site.

There are guides available which set out the approaches to surveying, as listed below. It is recommended that advice is sought from soil scientists in the planning, execution and interpretation of surveys.

- Soil survey terminology should follow the Soil Survey of England and Wales (1976) guide. Ensure the survey approach covers both the description of soil physical properties (this may require a grid pattern of survey points or be surveyor-led) and the collection of samples for analysis (which may require sampling along a 'W' transect as specified by Natural England).
- If Agricultural Land Classification (ALC) surveys are required, the ALC Guidelines (MAFF, 1988) must be followed.
- TIN035 Soil Sampling for habitat recreation and restoration - Natural England (2008).
- If peat is present (or likely to be present) this will require a specific approach to ensure peat depth data at the required spatial resolution is collected and the peat stratigraphy is recorded (for example see NatureScot (undated) and Natural England, 2023)).
- Specialist advice should be sought where soil biology surveys are required.

The requirement for a soil monitoring programme should also be established (using the survey techniques outlined above). There is a real lack of evidence regarding how soils perform following ecological restoration. Where soils are disturbed there will be physical, chemical and biological changes – understanding how soil characteristics respond over time may be critical to assessing the success of a project (importantly in relation to soil microbial communities in long-undisturbed systems). As such post-construction monitoring, including the adoption of emerging eDNA techniques, should be considered a priority (and the data shared) to support future decision making, policy advice and guidance development.

Summary of key considerations

1. Habitats do not exist in isolation from the physical environment ('the right trees in the right place').
2. The physical environment is an intricately interconnected system, in part influencing what biodiversity occurs where and being influenced by the biodiversity which is present. A systems thinking approach is therefore critical.
3. It may not be possible to maximise everything everywhere. Optimising the benefits of a project will therefore be critical and will need good stakeholder identification (to include citizen groups and local communities) and engagement.
4. Geology:
    a. *Solid or drift geology*
    b. *Chemistry (locally and imparted through water flowing from upstream areas)*
5. Landform:
    a. *Aspect, altitude and gradient*
    b. *Position in the landscape and potential interaction with upslope and downslope areas and how visible the area is from more distant viewpoints*
6. Climate
    a. *Influence of existing climate (and existing climatic variations)*
    b. *Potential effects from climate change and designing for long-term sustainability within the context of a changing climate*
7. Hydrology/Hydrogeology
    a. *Setting of the site within the water cycle*
    b. *Habitat requirements (rainfall, surface/flood and groundwater inputs); i.e. certain habitats such as fens, floodplain meadows, wet woodland and wet heathland can ONLY be created and sustained with very specific conditions*
    c. *Water chemistry (including chemistry of inflows which may originate from a different geology)*
    d. *Water quality and potential for pollutants to be present*
    e. *Flooding (both risk to the area and potential role in flood risk reduction)*
    f. *Presence of Groundwater source protection zones*
    g. *Potential conflicts in relation to water quantity*
    h. *Potential changes resulting from climate change*
8. Geomorphology
    a. *How does or could the physical environment change? Erosional or depositional changes within watercourse changes, slope failure risk, etc.*
9. Soils

a. *The soil profile*

b. *Soil physical, chemical and biological properties*

c. *Soil health and function*

d. *Potential presence of buried archaeological features or artefacts*

e. *Soil types (including pH)*

f. *Soil survey requirements*

10. Monitoring – which aspects are critical to the sustainable future of the project?

Lead author

Dr Bruce Lascelles

Bruce Lascelles CEnv MCIEEM F.I. Soil Sci has a research background in soil science and forestry, and completed his PhD on the development of soils in North Wales, before post-doctoral research into mechanisms of soil erosion and rill formation. He then moved into consultancy and has developed significant expertise in soil and Agricultural Land Classification survey, the design and supervision of appropriate soil handling methodologies and in habitat creation, restoration and translocation. Bruce is UK Director for Sustainable Land Management at Arcadis, is a Past President and a Fellow of the British Society of Soil Science, and President Elect of the International Union of Soil Sciences.

Contributing author

Dr Mark Nason

Mark Nason CERP MCIEEM M.I. Soil Sci has over 25 years of experience in ecological research and education. Following research in North Wales on soil formation and constructed soils for habitat restoration, he became a lecturer and leader in Further and Higher Education, developing new ecology and ecological restoration degrees and apprenticeships. He is currently Head of Professional Practice at CIEEM, a Certified Ecological Restoration Practitioner by the Society for Ecological Restoration, and a Member of the British Society of Soil Science.

Publication of this guidance is kindly supported by Arcadis

Arcadis are one of the world's leading companies, delivering sustainable design, engineering and consultancy solutions for natural and built assets. We have more than 36,000 people in over 30 countries dedicated to improving quality of life. Nature-based solutions, soil health, holistic water management, Net Zero and overall environmental health, for the benefit of communities, lies at the heart of our work. We are very proud to be sponsoring this guidance, promoting knowledge sharing and upskilling and are excited by the potential for inspiration, action and legacy that the ecology profession can deliver.

ARCADIS

References

Avery, B.W. (1980) Soil Classification for England and Wales (Higher Categories). Soil Survey Technical Monograph No. 14. Harpenden. https://doi.org/10.1002/jpln.19811440221

British Geological Society. Geology Viewer. https://geologyviewer.bgs.ac.uk/?_ga=2.141869810.1548964026.1728229950-2095559071.1728229950

Defra (2009).Construction Code of Practice for the Sustainable Use of Soils on Construction Sites. https://www.gov.uk/government/publications/code-of-practice-for-the-sustainable-use-of-soils-on-construction-sites

Defra (2002). The Water Regime Requirements and the Response to Hydrological Change of Grassland Plant Communities. Defra-commissioned project BD1310. https://floodplainmeadows.org.uk/sites/default/files/files/d96437.pdf

Defra (2009). Safeguarding our soils. A strategy for England. https://assets.publishing.service.gov.uk/media/65fd6fddf-1d3a0001132adb8/CD1.I_DEFRA__Safeguarding_our_Soils_A_Strategy_for_England.pdf

Ettinger, A.K., Bratman, G.N., Carey, M., Hebert, R., Hill, O., Kett, H., Levin, P., Murphy-Williams, M. and Wyse, L. (2024). Street trees provide an opportunity to mitigate urban heat and reduce risk of high heat exposure. *Nature Scientific Reports*, 14, 3266. https://doi.org/10.1038/s41598-024-51921-y

Geological Survey of Northern Ireland. https://www2.bgs.ac.uk/gsni/

Holmes, A. (1944). Principles of Physical Geology. Halsted Press.

HM Government (2023). A Green Future: Our 25 Year Plan to Improve the Environment. Annex 1: Supplementary evidence report. https://assets.publishing.service.gov.uk/media/65fd713d65ca2f00117da89e/CD1.H_HM_Government_A_Green_Future_Our_25_Year_Plan_to_Improve_the_Environment.pdf

Institute of Quarrying (2021). Good Practice Guide for Handling Soils in Mineral Workings. https://www.quarrying.org/soils-guidance

Ling, L.L., Schneider, T., Peoples, A.J., Spoering, A.L., Engels, I., Conlon, B.P., Mueller, A., Schäberle, T.F., Hughes, D.E., Epstein, S., Jones, M., Lazarides, L., Steadman, V.A., Cohen, D.R., Felix, C.R., Fetterman, K.A., Millet, W.P., Nitti, A.G., Zullo, A.M., Chen, C. and Lewis, K. (2015). A new antibiotic kills pathogens without detectable resistance. *Nature*, 517, 455-459. https://doi.org/10.1038/nature14098

MAFF (1988). Agricultural Land Classification of England and Wales. Revised guidelines and criteria for grading the quality of agricultural land. https://publications.naturalengland.org.uk/publication/6257050620264448

Marin-Diaz, B., van der Wal, D., Kaptein, L., Martinez-Garcia, P., Lashley, C.H., de Jong, K., Nieuwenhuis, J.W., Govers, L.L., Olff, H., Bouma, T.J. (2023). Using salt marshes for coastal protection: Effective but hard to get where needed most. Journal of Applied Ecology, 60(7), 1286-1301. http://dx.doi.org/10.1111/1365-2664.14413

Met Office. The Water Cycle. https://weather.metoffice.gov.uk/learn-about/met-office-for-schools/other-content/other-resources/water-cycle#:~:text=The%20water%20cycle,%20also%20known%20as%20the

Met Office. Historic Station Data. https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data

Natural England (2008). Technical Information Note TIN035. Soil Sampling for habitat recreation and restoration. https://publications.naturalengland.org.uk/publication/31015

Natural England (2023). https://www.iucn-uk-peatlandprogramme.org/sites/default/files/2023-06/Data%20Exchange%20Standard%20for%20Peat%20Surveys%20v1.0.pdf

NatureScot (undated). Peat depth and Peatland Condition Survey. https://www.nature.scot/doc/peatland-action-peat-depth-and-peat-condition-survey-guidance-and-recording-form-guidance

Rothero, E., Lake, S. and Gowing, D. (eds) (2016). Floodplain Meadows – Beauty and Utility. A Technical Handbook. Milton

Keynes, Floodplain Meadows Partnership. https://www.floodplainmeadows.org.uk/sites/default/files/Floodplain%20Meadows%20-%20Beauty%20and%20Utility%20A%20Technical%20Handbook.pdf

Soil Survey of England and Wales (1983). Soil Map of England and Wales. https://www.ukso.org/static-maps/published-soil-maps-great-britain.html

Soil Survey of England and Wales (1976). Soil Survey Field Handbook.

Singh, V. (2024). The Environment and Its Components. In: Textbook of Environment and Ecology. Springer, Singapore. https://link.springer.com/chapter/10.1007/978-981-99-8846-4_1#:~:text=The%20physical%20environment%20of%20planet%20Earth

Stafford, R., Chamberlain, B., Clavey, L., Gillingham, P.K., McKain, S., Morecroft, M.D., Morrison-Bell, C. and Watts, O. (Eds.) (2021). Nature-based Solutions for Climate Change in the UK: A Report by the British Ecological Society. London, UK. Available at: https://www.britishecologicalsociety.org/wp-content/uploads/2022/02/NbS-Report-Final-Updated-Feb-2022.pdf

The British Standards Institution (2015). BS3882:2015 Specification for topsoil. https://knowledge.bsigroup.com/products/specification-for-topsoil

The British Standards Institution (2013). BS8601:2013 Specification for subsoil and requirements for use. https://knowledge.bsigroup.com/products/specification-for-subsoil-and-requirements-for-use

The Geological Society. What is Geology? https://www.geolsoc.org.uk/Geology-Career-Pathways/What-is-Geology.html

Trumper, K., Bertzky, M., Dickson, B., van der Heijden, G., Jenkins, M., and Manning, P. (2009). The Natural Fix? The role of ecosystems in climate mitigation. A UNEP rapid response assessment. United Nations Environment Programme, UNEP-WCMC, Cambridge, UK. https://wedocs.unep.org/handle/20.500.11822/7852

Voulvoulis, N., Giakoumis, T., Hunt, C., Kioupi, V., Petrou, N., Souliotis, I., Vaghela, C., binti Wan Rosely, WIH (2022). Systems thinking as a paradigm shift for sustainability transformation. *Global Environmental Change,* 75, Article 102544. https://doi.org/10.1016/j.gloenvcha.2022.102544

Whiteman, C.A. and Haggart, B. A. (2018). Chalk landforms of Southern England and Quaternary landscape development. Proceedings of the Geologists' Association, 136 (1-2). http://dx.doi.org/10.1016/j.pgeola.2018.05.002

Raising the profile of professional ecological and environmental management and promoting the highest standards of practice for the benefit of nature and society.

CIEEM
Grosvenor Court
Ampfield Hill, Ampfield
Romsey, SO51 9BD

Design by Buckley Creative