IQ

The Institute of Quarrying

Good Practice Guide for Handling Soils in Mineral Workings

GOOD PRACTICE GUIDE FOR HANDLING SOILS

In Mineral Workings

Published in the UK by:

The Institute of Quarrying

McPherson House
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Chetwynd Business Park
Chilwell,
Nottingham
NG9 6RZ

www.quarrying.org

The information in this publication is general guidance on the best practices and approaches to soils guidance. Specialist advice should always be sought if you need more details about what action to take in your own circumstances.

First Edition published 2021.

For over 100 years the Institute of Quarrying has been supporting people working in the mineral extraction industry. It is the only international professional body for quarrying, construction materials and the related extractive and processing industries. IQ's focus is to be the global leader in standards for the sector, to push innovation and operational best practice, to support the industry in driving healthy, sustainable workplaces and to promote the positive impact of the industry and profession. Being a member of IQ means being part of a global community of industry professionals committed to sharing knowledge and improving industry standards.

GOOD PRACTICE GUIDE FOR HANDLING SOILS

In Mineral Workings

PART ONE: Introduction

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Introduction

Foreword

Over the past twenty years the MAFF guidance has been widely used by the mineral industry and planning authorities, and their advisors. With the recent changes in land use (natural capital) and environmental (climate and biodiversity) related policies it is appropriate that the guidance is updated and expanded to include these.

In recognition of this, the Institute of Quarrying undertook to update the guidance in consultation with Natural England and the Welsh Government. This was with the support and guidance of a Steering Group representing the minerals industry, mineral planning authorities, and professional bodies and specialist consultants.

Attention is rightly focused on soil natural capital to ensure that the natural resource is left in a measurably better state than beforehand. Environmentally positive policies are increasingly driving operational practices, and as the professional membership body for the quarrying and aggregates sector, the Institute believes it is critical to provide current guidance that supports better performance outcomes for the industry. The Institute of Quarrying is proud to have worked with all of the stakeholders on the project to revise and update this guidance and also thank you to all those who have contributed.

James Thorne
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July 2021

Acknowledgements

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S Elson	Surrey County Council
S Warren	British Aggregates Association
B Lascelles	British Soil Science Society
I Briggs	Landesign Planning and Landscape Ltd
I Meadows	Meadows Archaeology

Dr S G McRae (Consultant), Dr N A D Bending (Progressive Restoration), R Stock (Consultant), V Redfern (Consultant) and R J K Thompson (Celtic Energy Ltd) kindly provided further comments and insights.

The supporting art work was provided by R Shelton (H J Banks & Co) and D Fisher (Blue Room Graphics Ltd).

Preface

In 2000 MAFF published its Good Practice Guide for Handling Soils by a range of earth-moving machines. This was a comprehensive guide to soil handling practices to help achieve a high standard of reclamation for mineral extraction sites across all agricultural land qualities (DoE 1989; DETR 1999; Welsh Assembly Government 2004 & 2009; Welsh Government 2021). It also contributed to the drive to achieve a more sustainable use of soils (DEFRA 2009a & 2009b).

The focus of current UK Government policy in England, as set out in its 25 Year Environmental Plan (DEFRA, 2018), is to safeguard soil resources (as Natural Capital, DEFRA, 2021) and that by 2030 for all soils to be managed sustainably. The same objective of Sustainable Management of Natural Resources (SMNR) is encompassed in the Environment (Wales) Act (National Assembly of Wales, 2016). Good quality agricultural soils are to be protected and all soils are to be fully valued for their environmental and ecosystem services and are to be better managed to improve soil health. The purpose of this updated guidance is to assist the mineral industry in their contribution by achieving sustainable soil based after uses and that impacts on the soil resources and soil functions are minimised and enhanced wherever possible.

The purpose of **Part One** of the Institute of Quarrying's updated guidance on good soil handling practice by machines is to provide an overarching explanation of the context and aims of the model methods given in Part Two.

In addressing the new Natural Capital driven policies for protection of soil resources and their sustainable management, soil compaction and its associated limitations on soil functions has long been known to be the main adverse effect of handling and trafficking soils with earth-moving machines.

It remains the primary challenge for successfully achieving the intended after uses and the maintenance provision of defined environment and ecosystem services, and the associated soil functions associated with healthy soils. Whilst the occurrence and degree of compaction is related to the choice of machinery combination and handling practice, they are also a function of the type of soil and wetness of the soils at the time of handling.

The prime aim of the guidance is to minimise the compaction of soils as they are handled with the minimal reliance on the need for remedial treatment of compaction caused by the machinery and handling practices. Hence, in the updated guidance greater attention is given to the wetness of soils during handling operations.

It also introduces the key role of the Soil Resource & Management Plan. This should be the primary reference material for characterising the soil resources available, informing and successfully delivering the intended after use(s) whether it is agricultural, horticultural, forestry, semi-natural vegetation/ecosystems or other soil-based ones. It will underpin the operational design, land use and landscaping plan, and the practices needed to be deployed, and the means of communication to all those involved. The importance of competency in the technical understanding of soils and the implications of the operational practices is also emphasised.

The familiar MAFF presentation of the model methods as individual 'Sheets' has been retained in Part Two for everyday communication to all levels of users. Model methods are provided for the two widely used machinery combinations of excavators & dump trucks, and bulldozer & dump trucks. The MAFF model methods for the use of earth-scrapers are no longer included but can be found in the National Archive (DEFRA, 2009c, Sheets 5 to 8).

Model methods are provided for the three most commonly used soil handling practices (the 'bed/strip', the 'windrow/peninsular' and the layer by layer).

A method for an alternative 'loose-tipping' approach (using excavators for the subsoil and bulldozer for the topsoil) is a new addition.

The processes of decompaction and the removal of stones/non-soil debris in the soil replacement procedures are now integrated into the method sheets.

It is intended that this guidance remains as a 'live' document and is updated with site experiences and future developments in mineral extraction.

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Introduction

Minerals are recognised as essential Natural Capital, providing for our modern society and its wellbeing, as are the soil that covers the mineral resource (Wikipedia, 2020).

Soils provide essential environmental and ecosystem services, such as food, water regulation including water infiltration and flood avoidance, carbon storage, and biological functioning. Consequently, current planning and environmental policy not only protects good quality agricultural soils but also focuses on the sustainable management of all soil resources and to ensure their ecosystem services are fully valued and their use is sustainable. Hence, the machines and handling practices used in the recovery and conservation of soil resources (Humphries et al, 2018), and their reuse in the reclamation of mineral extraction sites will be material considerations in the granting of planning consent.

The updated guidance is intended for use by planning officials, statutory consultees, mineral operators and their supporting teams and specialist consultants, and earth-moving contractors, their site supervisors and machine operators. It has key roles to play from i) the inception of projects and their development through to the application and securing of planning consent, and to operational implementation, to ii) providing the basis for training modules. Its adoption throughout all these stages processes should ensure that the necessary actions are addressed and communicated to all those involved (**Figure 1**) and that they are fully informed as appropriate so that the best results possible are achieved.

In **Part One** the important aspects of soil handling are introduced under the headings of Key Issues and Choice of Machinery Combinations, Handling & Remedial Practices, and these are supported by Supplementary Notes.

KEY ISSUES

- Health & Safety
- Soil Natural Capital, Soil Function & Ecosystem Services
- Soil Resource & Management Plan
- Soil Compaction
- Soil Wetness
- Monitoring & Recording
- Planning Conditions & Control

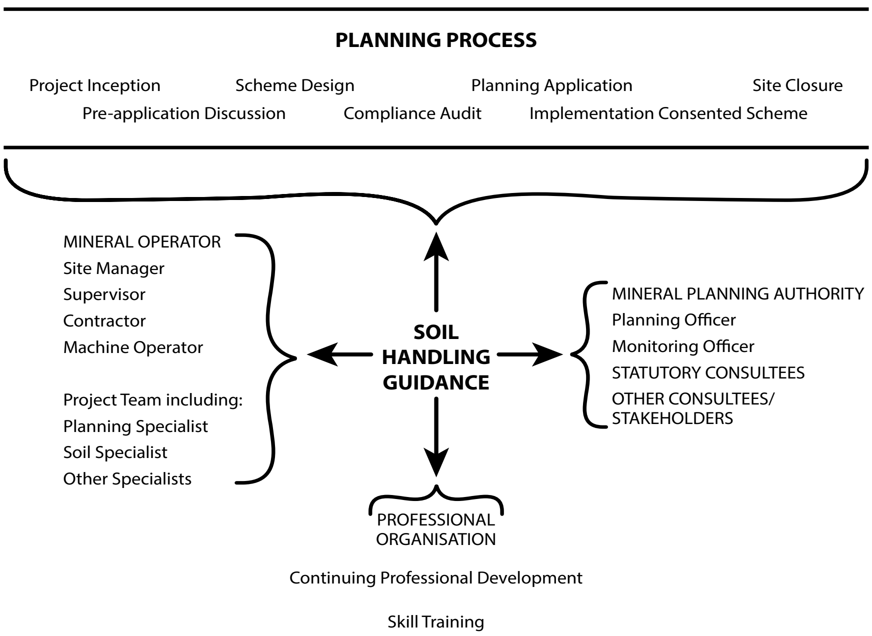

Figure 1: Key informative and training role of the soil handling guidance in the development and reclamation of mineral workings.

Choosing Machinery Combinations, Handling & Remedial Practices

- Health & Safety
- Available Machinery Combinations
- Commonly Deployed Soil Handling Practices
- Available Remedial Practices
- Relative Risk of Significant Compaction: Machinery combinations & Handling Practice / Soil Storage / Efficacy of Soil Recovery / Relative Susceptibility to Rainfall Delays
- The Deployment of Earth-moving Machinery & Handling Practices
- Remedial Treatment of Compaction
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Supplementary Notes

- 1. Soils
- 2. Soil Resource & Management Plan
- 3. Soil Compaction
- 4. Soil Wetness
- 5. Soil Mixing

Part Two provides detailed model methods of best practice for each machinery combination and soil handling practice. However, in doing so the guidance does not specify size, make or model of equipment as this is left to the mineral operator and/or contractor to specify, justify and provide.

KEY ISSUES

Health & Safety

Of overriding importance is the issue of safety. All persons involved in the handling of soils must comply with all relevant legislation with respect to Health and Safety, in particular the Health and Safety at work Act 1974 (UK Government, 2020a) and in the case of mineral extraction operations The Quarries Regulations 1999 (UK Government, 2020b) and its relevant statutory provisions, especially those aspects which relate to the construction and removal of tips, mounds and similar structures.

The users of this guidance are solely responsible for ensuring all activities comply with safety legislation and good practice, including the manufacturer's specifications for the safe operation of the specific machines being used, and that all machines are in a good condition and well maintained. The machines must be of a kind which are appropriate for the task and the outcomes required and can carry out the work safely and efficiently. These requirements take preference over any suggested practice in this guidance. For example, the position and orientation of an excavator on handling soils which could affect its stability, and the positioning and proximity of other machines as described in the text and shown in the illustrations.

It is important that those involved in the operation of earth moving machines are competent and have the necessary training and certification.

Soil Natural Capital, Soil Function & Ecosystem Services

The concept of Natural Capital, from which we as human society derive the benefits of supporting, provisioning, regulating and cultural environmental/ecosystem services, will become firmly established in future land use policy and decision making by central and local government (UK Government, 2020c).

Natural Capital includes soil, minerals, water, and other natural resources. Soil based ecosystem services provide food and fibre, regulate water quality and drainage, store carbon and help regulate greenhouse gases, support biodiversity and biological functioning of soil, and is the basis of our modern-day culture. Hence, the services they provide are an important consideration in the exploitation and reclamation of mineral sites.

Soils with different textures and structure differ in their land use capability and level of environmental and ecosystem services provided. The composition and condition (or health) of soils, and their functioning, can be significantly altered during soil handling. This can have consequences for the subsequent delivery of environmental/ecosystem services and the after use of land and can be costly to remedy. Losses and degradation of soil natural capital and its services can be a consequence of the soil machinery and handling practices used.

Hence, the characterisation of the affected soils (see Supplementary Note 1) will be an important factor in determining the choice of machinery combination and handling practice.

Soil Resource & Management Plan
A Soil Resource & Management Plan (SRMP) (see Supplementary Note 2) is an essential component and integral part of the updated guidance. It has a key role in achieving the successful delivery of the intended after use, and the conservation and functioning of soil resources in mineral extraction schemes. It should be the prime source of soil resource and handling information (British Society of Soil Science, 2021; Natural England, 2021), and used as the means of communication to all those involved in the design and specification, decision making, and oversight and audit of the scheme from a project inception and development through all the stages from the planning application to site closure (**Figure 2**). It is also a means whereby everyone involved can be updated and liaise regularly to ensure the best results possible are achieved.

The SRMP comprises essentially:

i) a field survey to characterise in detail the soil resources on the site and where agricultural land, the associated agricultural land classification grades,

ii) develops the baseline information into a soil handling and management plan describing in detail how the site is to be developed during mineral extraction, and

iii) its reclamation (restoration & aftercare).

It should contain location of the mineral, and any other relevant site, operational and infrastructure details (see Supplementary Note 2). Successful soil handling and restoration schemes are dependent on having a detailed soil resource survey (including an ALC where needed) to be undertaken by appropriately qualified and experienced soil specialists (British Society of Soil Science, Undated) which are then interpreted into practical soil advice on scheme design and phasing, identifying any particular constraints and opportunities for future after-uses, proposals for stripping and replacement soil units, along with any particular requirements.

The SRMP must show the soil resources to be recovered or substituted (as soil forming materials, Bending et al, 1999) and their use in the

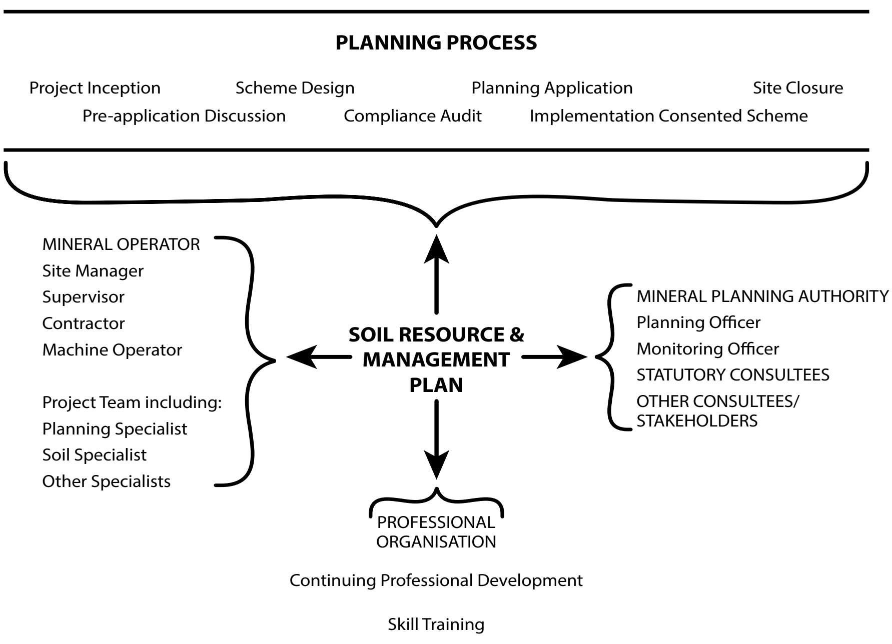

Figure 2: Key informative role of the soil resource & management plan in the development and reclamation of mineral workings

replacement scheme appropriate to the intended after uses and ecosystem services to be provided. In consultation with the mineral operator and planning authority, having taken the safety constraints (such as ground conditions, gradient) into account, the SRMP should state the type of earth-moving machinery, specify the handling, storage and remedial practices to be deployed to achieve the intended after use, and the provisioning of environmental and ecosystem services.

The SRMP should show where the access and haul routes and soil storage areas are to be located and their progressive development throughout the operations.

In most cases the areas for infrastructure, haul routes and those soil storage areas are to be stripped of soils before the rest of site is developed. The SRMP should identify any deviation from good soil handling practices, for example where haul routes may have to be upon the in-situ topsoil because of low load bearing capacity of the lower soil profile or underlying material. This may also be the case where there is known archaeological that need to be protected prior to ground investigations taking place.

The occurrence of other constraints/influences on the selection of machinery and/or handling practice, and the contingencies to be made should be included in the SRMP. For example, the occurrence of buried archaeological artefacts can determine the soil stripping practice (**Table 1**) or the occupation of the affected land by ground nesting birds (UK Government, 2021a) can delay or modify operations too late in the season.

The SRMP should include the rainfall and soil moisture limits the soil handling operations are work to and agreed with the Planning Authority before determination and included in the earth-moving contract.

Importantly, the SRMP should identify the roles and responsibilities of those involved, and the details of monitoring and reporting to take place. The soil handling provisions within the SRMP are to be communicated to all those carrying out the work and in particular the site supervisors and machine operators by appropriate means, including detailed plans, toolbox talks and site demonstrations.

Supervision by trained staff is essential, as is the monitoring and reporting by competent

Machinery Combination & Handling Practice (see Part Two)	Watching brief	Investigation & recording
Excavator – Dump Truck Using Bed/Strip Practice (Sheet A)	Suitable	Not suitable
Excavator – Dump Truck Using Windrow/Peninsular Practice (Sheet E)	Suitable	Suitable
Bulldozer – Dump Truck Using Windrow/Peninsular Practice[1] (Sheet F)	Not suitable	Not suitable
Bulldozer – Dump Truck Using Modified Layer by Layer Practice (Sheet I)	Not suitable	Not suitable

Table 1: Likely Suitability of Soil Handling Methods for Archaeological Investigations

soil specialists (British Society of Soil Science, Undated).

Soil Compaction

Compaction within the replaced profile is the most common problematic condition of replaced soils (Reeve et al, 2000). It is often overlooked as a factor inhibiting the successful delivery of the intended after uses, function and services, resulting in poorer growth of crops or other vegetation, reduced water infiltration and storage leading to enhanced risk of run-off, erosion and flooding, and reduced soil aeration and normal biological functioning with risk of increased emissions of nitrous oxides (potent greenhouse gases). Whilst the risk of compaction is exacerbated by handling soils when wet (Duncan & Bransden, 1986), it can occur in drier conditions through excessive machinery trafficking. The degree and significance of effect is likely to vary between the types and size of machinery used and the handling practice adopted, soil textural class and soil wetness condition (see Supplementary Note 3).

Whilst some degree of remedial effect can be achieved where appropriate equipment is used and the soil mass is sufficiently dry to enable shattering (Bacon & Humphries, 1987; Dunker et al, 1992; Spoor, 2006), experience has demonstrated that practices which minimise the trafficking of the soil by machinery is the more effective and reliable option (Bransden, 1991; Reeve et al, 2000). However, for some after uses, such as wetland ecosystems where the drainage is to be impeded, some compaction within or below the soil layer may be necessary to create the required wetness condition. For other habitats the deliberate degradation of soil functions (e.g., fertility and drainage) by soil mixing or other means may be necessary to achieve particular habitat creation schemes (see Supplementary Note 5).

Advice is given in **Part Two**, Sheets S & T, on the use of the two remediation options available, and when and how they should be integrated into the soil replacement process, and the monitoring of their efficacy.

Where relevant, these are likely to be specified in the planning consent and should be stated in the SRMP and agreed with the planning authority.

Soil Wetness

There are two causes of soil wetness;

i) the inherent water regime of the soil (wetness class) based on the average duration of waterlogging at different depths and determined by reference to soil characteristics and local climate (MAFF, 1988)

ii) the shorter-term effect of individual rainfall (precipitation) events.

Historically, soil water content and variations in climate across England and Wales has been a significant and sometimes an overlooked factor in determining the delivery of some intended after uses and services, such as productive agriculture and forestry. An increase in soil water content (soil wetness) increases a soil's susceptibility to compression and smearing (compaction) during all handling operations (Duncan & Bransden, 1986). The resulting compaction degrades the soil's ability to recover functionally and hence the delivery of the intended after uses and services (see Supplementary Note 4).

The degree of effect due to soil handling is likely to vary between the soil textural class, structural condition, and organic matter content, the local climate and daily weather conditions, but also between the types and size of machinery used and handling practice adopted. The primary cause of compaction arises from the compression caused by trafficking by the machinery and stockpiling of soil in storage.

Whilst some degree of remedial actions might be possible, experience has demonstrated that minimising compaction by handling soil in a dry condition is the more effective and reliable, and likely most cost-effective option.

Action can be taken to minimise the consequences of soil wetness through the timing of operations to coincide with the drier season (Reeve, 1994), the maintenance of a transpiring vegetation cover and site drainage and allowing exposed soils to dry out after significant rainfall events (see Supplementary Note 4). Although the practice of windrowing soils is suggested as a mitigation measure (DEFRA, 2009b), it is likely to cause additional damage by the handling and should not be relied upon in mineral extraction schemes.

It is likely that when soils are in a wet condition the issues of unsafe operation and inefficient working will arise. Here, it is a joint operational, environmental and soil protection decision by those responsible for whether handling should start, continue, cease, or restart.

Advice is given in Supplementary Note 4 on the general timing of operations and a field-based determination of when the actual operations should start, cease or restart based upon actual soil wetness. This process should be set out clearly in the SRMP and agreed with the planning authority, along with a mechanism whereby further consultation and amendments can take place as circumstances arise.

Monitoring & Reporting
The requirement for monitoring and reporting during the operational stages of a mineral extraction scheme is an integral part of the soil handling process (Natural England, 2021). The details of which would be agreed with the planning authority and set out in the Soil Resource & Management Plan or if not, it should be required as a planning condition. The monitoring would provide the basis for any actions needed in the subsequent aftercare period. Importantly, the SRMP provides a factual basis for compliance and completion audits by the planning authority Monitoring Officers in their oversight and regulation roles of mineral extraction schemes.

General compliance monitoring recording of the actual practices used is likely to be undertaken by the planning authority, but regular soil audits and assessments for specific soil conditions (soil wetness and compaction) should be by competent soil specialists (British Society of Soil Science, Undated).

Standard methods for soil physical conditions, soil structure and Soil Wetness Class are described in Hodgson (1997), MAFF (1982) and (MAFF, 1988) respectively. In addition, visual assessment methodologies (Ball & Munkholm, 2015; Ball et al, 2017, SRUC, 2021) for soil structure and function are now widely deployed and often in conjunction with other determinations such as organic matter content and micro-biological activity (Humphries et al, 2019). Without this basic information it will not be certain if the intended soil functioning and ecosystem services have been met by the choice of practice and machinery, and by subsequent aftercare actions.

Planning Conditions & Control
Soil resources and handling practice is likely to become more of a significant planning consideration for all future mineral developments given the recent focus on the sustainable management of soil natural capital (UK Government, 2014; UK Government, 2020c). This would require the provision of all relevant soil information about the development site and its after use before determination can be made by the planning authority, whether or not a scheme falls within the Environmental Impact Regulations.

In the past for those requiring an Environmental Assessment the information was usually provided in the submission even though the same and further information was often required to be resubmitted subsequently by means of a planning condition. The reliance on multiple submissions often resulted in discrepancies between the application and conditioned proposals. It should be made clear at the pre-application scoping/consultation and during the pre-determination stage that an integrated and comprehensive Soil Resource & Management Plan (SRMP) is required to enable planning determination and not a matter of subsequently requiring it as a planning condition, as often has been the case. In doing so, the SRMP should be required by a suitable planning condition to be updated prior to development and thereafter annually throughout site development, its reclamation (restoration and aftercare) (DEFRA, 2005).

If the methodology needs to be modified or changed, for example due to site conditions, this should be agreed in advance with the mineral planning authority and documented by updating the SRMP.

Given that planning consents are legally enforceable, it is essential that there is an appropriate level of flexibility provision in the SRMP to enable speedy resolution of unexpected and insignificant operational or soil resource issues that arise during active soil movement operations. It would be expected that the SRMP would set out a protocol for the scope and consequences for the planning authority and its advisors to deal with what might be such instances as needing a change in machinery and/or practice. Hence, it is essential that appropriately detailed site studies and assessments are undertaken in the first instance by appropriately qualified and experienced personnel. However, significant changes to a scheme and the SRMP, such as replacing soils that were not capable of supporting agriculture when that was the original scheme, would probably need to be dealt with through a Section 73 planning application (UK Government, 2020d).

CHOOSING MACHINERY COMBINATIONS, HANDLING & REMEDIAL PRACTICES

Health & Safety

The primary decision as to which machinery and practices to be used is a matter of operational safety and those who have this responsibility. Commonly occurring limiting safety factors are gradient, topographical complexity, and ground stability.

Those of the trafficability of haul routes on areas stripped of soil due to surface wetness can be managed by the stoppage of works to allow the drying or the deployment of bulldozers/graders to remove the slurry or the laying of a suitable surface etc.

Available Machinery Combinations

The most commonly used machine combinations for stripping, storage and replacement operations for mineral extraction schemes in the UK are either, excavators with dump trucks (**Part Two**, Sheets A – D, & E) or bulldozers (with an excavator to load the dump truck at soil stripping) and dump trucks (Sheets F – H). A hybrid combination of excavator replaced lower soil horizons with bulldozer spread topsoil tipped from dump trucks is sometimes deployed (Sheet K). Other machines such as graders and bulldozers are usually deployed in the maintenance of haul roads (Humphries et al, 2018).

Commonly Deployed Soil Handling Practices

Guidance is given in **Part Two** on the three commonly used handling practices deployed in mineral sites for soil stripping and replacement. These are:

i) the ‘bed/strip by strip’ (Sheets A & D),
ii) the ‘windrow/peninsular’ (Sheets E, F & H) and
iii) the modified ‘layer by layer’ methods (Sheets I, J & K).

The replacement using the bed/strip system with excavators and dump trucks is often referred to as ‘loose soil tipping’, but generally are also truck tipped soils graded using bulldozers.

Available Remedial Practices

During the course of soil replacement actions may be needed to treat significant compacted soil layers (**Part Two**, Sheets N & O) and/or to remove stones and debris such as concrete slabs and wire-rope (Sheets L & M).

The commonly used practices are to deploy bulldozer drawn tines or excavators with specialist stone-rake buckets. Their deployment of these is integrated into the updated model method Sheets for soil replacement.

Relative Risk of Significant Compaction

Machinery Combination & Handling Practice

The risks of soil compaction, efficacy of soil resource recovery and replacement, and susceptibility to rainfall interruptions differ between the machinery combinations and handling practices. This should be addressed in the Soil Resource & Management Plan.

The risk of significant compaction and susceptibility of different soil horizons should be a particular consideration when determining the likelihood of delivery of the intended after use.

The inherent risk is largely a function of the ground pressure of the machinery, amount of trafficking of the soil that takes place, and soil baring capacity (largely related to soil wetness). The size (ground pressure exerted and its operating footprint) of the machinery is the primary agent in soil compression, but also the mode of operation (number of passes, traction and turning manoeuvres) and the care taken.

Intuitively the smaller variants of the machines exert the less pressure and are usually the better option, but they may result in more trafficking and difficulties in operation than larger units because significantly more passes are needed to achieve the same output, as sometimes can also be the case with wide tracked (low ground pressure) bulldozers.

Soils and their horizons can differ in their susceptibility to compaction depending on their ‘textural class’ (largely a function of their clay and organic matter contents), degree of structural development, and water retention properties.

Coarse textured mineral soil, such as sands and loamy sands, are significantly less susceptible than the finer clayey and silty soils. Peaty (>20% organic matter) and organic (8-20% organic matter) soils generally have an inherent low resilience to compaction (Askew, 2020). However, risk levels are also significantly modified by the soil water regime (Soil Wetness Class) and the local climate.

Table 2 sets out the relative inherent risk of damage to soils (when in dry/non-plastic condition) during soil handling. However, the depth to a duration of saturated soil and climate (Soil Wetness Class & Field Capacity Days, MAFF, 1988) are confounding factors where, for example, sandy soils can be at high risk where soils remain saturated at a shallow profile depth (Askew, 2020).

Soils with weakly developed structure (aggregation of particles) may be more susceptible than those which have strong more stable aggregates, and mineral soils with a high organic matter or calcium carbonate content can be more resistant to compaction, with topsoil tending to be more resilient than subsoil.

Risk to Soil Structural Damage During Handling When in a Dry Condition	Soil Texture Class (top- & subsoil)
High Resilience - Low Risk	Sand, loamy sand, sandy loam, sandy silt loam
Medium Resilience Moderate Risk (<27% clay content)	Medium silty clay loam, medium clay loam, sandy clay loam
Low Resilience High Risk (>27% clay content)	Silt loam, heavy silty clay loam, heavy clay loam, sandy clay, silty clay, clay; organic mineral, peaty soils, peat

* Based on Askew, 2020

Table 2: Simplified Inherent Risk of Soil Structural Damage Occurring within the Soil Profile Based on Soil Texture*

However, clayey soils with an apedal structure and low porosity may be less significantly affected by further compression.

Soil wetness is a major determinant of the susceptibility to compaction when trafficked by machines (Duncan & Bransden, 1986) (also see Supplementary Note 3). The differential degree of compaction between machinery combinations and handling practices is less when the soils are in dry condition. Dry soil is more resistant to compression than wet soils which have a water content at or above their plastic limit when fine (clay and silt fraction) soil particles become 'mobile' within compression increasing their packing density and reducing pore size and porosity. Sandy soils with a small percentage of clay size fraction/mineralogy are inherently less prone to this form of deformation compared to loamy, clayey and silty soils.

Table 3 summarises the inherent risk of compacting soils with the choice of machinery and handling practice options owing to the degree of trafficking by the machines over the surface of the soil horizons.

Soil Storage
As indicated in **Table 4**, the practice of storing (stockpiling) stripped soils in mounds (often referred to as 'bunds') prior to their replacement has a high risk of causing additional compaction as well as the degradation of the soil's biological functions.

The degree of effect depends on the machinery and practice used, but also the height of the storage mound (i.e. depth of soil burial), the type (texture) and condition (wetness) of the soils, and the length of time in store (Abdul-Kareem & McRae, 1984; Johnson et al, 1988).

The best practice is to avoid soil storage by direct placing the newly stripped soils on the area to be restored. Where storage is unavoidable, it should be for the minimal time possible, unless longer term storage facilitates the direct placement of the majority of the soil.

Where possible, storage of the high-risk low resilient textural classes (see **Table 2**) should be avoided or at least minimised by limiting the height of mounds to less than 3m.

Machinery Combination & Handling Practice (see Part Two)	Dry Soil Condition	Wet Soil Condition
Excavator – Dump Truck Using Bed/Strip Practice[1 2] (Sheets A & D)	Low	High
Excavator – Dump Truck Using Windrow/Peninsular Practice[1] (Sheet E)	Low/moderate	High
Bulldozer – Dump Truck Using Windrow/Peninsular Practice[1 2] (Sheets F &H)	Moderate* - High	High
Hybrid Excavator - Bulldozer – Dump Truck Using Modified Layer by Layer [2] (Sheet K)	Moderate*	High
Bulldozer – Dump Truck Using Modified Layer by Layer Practice[1 2] (Sheets I & J)	Moderate* - High	High

* With Low Ground Pressure Bulldozers; [1] = soil stripping; [2] = soil replacement

Table 3: Relative Risk of Significant Compaction During Soil Stripping & Replacement

It has become standard practice for topsoil mounds to be restricted to a maximum height of 3m and 5m for subsoils (Natural England, 2021). Where single mounds have different soil types, they should be kept separated by geotextile or other suitable means. In the case of particularly large mounds with long storage durations, it may be acceptable for the subsoil to be covered with a layer of topsoil to its natural depth and utilised for landscape, agricultural or amenity purposes.

The above should be taken into account in the SRMP by the professional soil advisor.

Efficacy of Soil Recovery - Variable Soils and Mixing
Table 5 summarises the inherent efficacy of recovering the soil resources according to the choice of machinery and handling practice options. This is related to the ease of ability to see and react to changes in soil type and thickness of soil horizons (i.e., patterned ground), and the relative risk of soil horizon mixing due to trafficking (see Supplementary Note 5).

Relative Susceptibility to Rainfall Delays
The inherent susceptibility of the operations to significant programme delays following rainfall events due to extensive exposed soil surfaces during soil stripping and soil replacement in the absence of a vegetation cover is summarised in **Table 6**.

Smearing of the exposed surface of the soil (known as 'soil sealing') using a bulldozer blade or excavator bucket to reduce water infiltration is a temporary action widely practiced. It is deployed where soil surfaces are likely to be exposed to rainfall events and when soil handling has been suspended. However, this is likely to require remedial decompaction/cultivation measures on the resumption of operations.

The better practice, and that given in the guidance in **Part Two**, is to ensure bare soil surfaces are not exposed to rain events. However, in doing so it is imperative that the completed soil surfaces are cultivated, seeded or planted without delay and before the onset of prolonged wet conditions.

Machinery Combination & Handling Practice (see Part Two)	Direct Placement	Storage in Single Tier Low Mounds	Storage in Multi-Tier Mounds
Excavator – Dump Truck Using Bed/Strip Practice[1 2] (Sheets A & D)	Low	Moderate	High
Excavator – Dump Truck Using Windrow/Peninsular Practice[1] (Sheet E)	Low/moderate	Moderate	High
Bulldozer – Dump Truck Using Windrow/Peninsular Practice[1 2] (Sheets F &H)	Moderate* - High	Moderate* - High	High
Hybrid Excavator - Bulldozer – Dump Truck Using Modified Layer by Layer [2] (Sheet K)	Moderate*	Moderate*	High
Bulldozer – Dump Truck Using Modified Layer by Layer Practice[1 2] (Sheets I & J)	Moderate* - High	Moderate* - High	High

* With Low Ground Pressure Bulldozers; [1] = soil stripping; [2] = soil replacement

Table 4: Relative Risk of Significant Compaction of Stored Soils

Machinery Combination & Handling Practice (see Part Two)	Reactive to Changes in soil type, thickness, patterned ground	Risk of Soil Horizon Mixing
Excavator – Dump Truck Using Bed/Strip Practice[1 2] (Sheets A & D)	High	Low
Excavator – Dump Truck Using Windrow/Peninsular Practice[1] (Sheet E)	High	Low
Bulldozer – Dump Truck Using Windrow/Peninsular Practice[1 2] (Sheets F &H)	Low	High
Hybrid Excavator - Bulldozer – Dump Truck Using Modified Layer by Layer [2] (Sheet K)	High/Low	Low/High
Bulldozer – Dump Truck Using Modified Layer by Layer Practice[1 2] (Sheets I & J)	Low	High

[1] = soil stripping; [2] = soil replacement

Table 5: Reactiveness to Changes in Soil Characteristics & Risk Soil Horizon Mixing

Further information on the geographic based risk of seasonally wet soil conditions is given in the Supplementary Note 4, which also includes an established protocol for the stoppage and restart of operations due to rainfall events (according to the duration and intensity of rainfall events).

The Deployment of Earth-moving Machinery & Handling Practices

Whilst all combinations of earth-moving machinery and handling practices could be used to strip, store and replace soil material, as demonstrated above, there are inherent differences in the degree of risk for the delivery of the intended after uses, and soil functioning and ecosystem services according to the choice made. This is primarily due to the degree of significant compaction affecting the ability of the replaced soil profile to function in the required manner, but also ones of risk of programme delays due to weather and poorer efficacy in soil resource recovery.

In terms of soil textural class, the minimal information that should be available for all schemes, simplistic choices can be made according to the relative resilience to compaction of damaging soil structure (**Table 7**).

For the reasons set out above, the excavator-dump truck combination and bed/strip practice (**Part Two**, Sheets A & D) has the lowest risk of all the options and is the most suitable for all soil texture resilience categories. Because of higher intrinsic risk due to greater trafficking of machines on the soil surfaces the windrow handling practices, using either excavators (Sheet E), low ground pressure bulldozers (Sheets F & H) or the ‘hybrid’ excavator-bulldozer combination (Sheet K), restricts their suitability to soils of a moderate and high resilience. However, this level of risk in using the bulldozer combination is dependent on the soils being and remaining in a dry condition throughout the soil profile being handled and for the duration of the work.

In England and Wales where agricultural land is to be stripped of its soils and the after use is to be for agricultural production, it too is a factor in the choice of machinery and practices. To achieve sustainable agricultural production, maintain flexibility in the land use and resilience to climate change, the soil resources and their functional attributes on reclamation are to be conserved as much as possible. In the past a distinction was sometimes made between Agricultural Land Quality Grades

Machinery Combination & Handling Practice (see Part Two)	Ability to Maintain Transpiring Vegetation Cover for Soil Stripping	Ability to Progressively Establish Vegetation Cover on soil Replacement	Inherent Risk of Delay in Operations for Soil Stripping/Replacement
Excavator – Dump Truck Using Bed/Strip Practice[1,2] (Sheets A & D)	High	High	Low/Low
Excavator – Dump Truck Using Windrow/Peninsular Practice[1] (Sheet E)	High	NA	Low/NA
Bulldozer – Dump Truck Using Windrow/Peninsular Practice[1,2] (Sheets F &H)	High	Low	Low/High
Hybrid Excavator - Bulldozer – Dump Truck Using Modified Layer by Layer [2] (Sheet K)	High	High	Low/Low
Bulldozer – Dump Truck Using Modified Layer by Layer Practice[1,2] (Sheets I & J)	High	High	Low/Low

[1] = soil stripping; [2] = soil replacement

Table 6: Inherent Risk in Operational Delays Due to the Ability to Maintain and Quickly Establish a Vegetation Cover

Soil Texture Inherent resilience of Soil See Table 1	Machinery & Handling Practice (assuming soils are in dry/non-plastic condition and not stored)		
	Increasing Risk of Soil Compaction ->		
High Resilience - Low Risk	ExDt-Bed[1,2]	ExDt-Wind[1] / Hybrid-Wind[2]	BuDt-Wind[1,2]/ BuDt-Mod Layer[1,2]
Medium Resilience - Moderate Risk	ExDt-Bed[1,2]	ExDt-Wind[1] / Hybrid-Wind[2]	
Low Resilience – High Risk	ExDt-Bed[1,2]		

Key: Machinery Combinations & Soil Handling Practices (also see Part Two):

[1] = soil stripping; [2] = soil replacement
ExDt-Bed = Excavator – Dump Truck using Bed/Strip Practice (Sheets A & D)
ExDt-Wind = Excavator – Dump Truck using Windrow/Peninsular Practice (Sheet E)
BuDt-Wind = Low ground pressure Bulldozer – Dump Truck using Windrow/Peninsular Practice (Sheets F & H)
BuDt-Layer = Low ground pressure Bulldozer – Dump Truck using Modified Layer by Layer Practice (Sheets I & J)
Hybrid-Layer = Excavator for subsoil & Low ground pressure Bulldozer for topsoil – Dump Truck using Modified Layer by Layer Practice (Sheet K)

Table 7: Most likely suitable machinery & soil handling practice

1, 2 & 3a (i.e. Best & Most Versatile (BMV), MAFF, 1988) and 3b, 4 & 5 (i.e. non-BMV) as to which standard of restoration was applied (Paragraphs 3.1 & 3.2, Schedule 5, Town & Countryside Planning Act 1990, UK Government 2021b).

Current government policy is that all reclamation (restoration and aftercare) agricultural schemes should be to high standards. For agricultural after uses, the best available practice (i.e. least risk) is using the excavator-dump truck combination in conjunction with the bed system (Sheets A – D) which should be use wherever possible irrespective of land quality (Welsh Assembly Government, 2004). With the anticipated effects of climate change on soils (Keay et al, 2013; Welsh Government, 2020), it is important the soil resource per se is conserved whatever its quality grading because of the range of ecosystem services it might provide in addition to agricultural production, for example water storage, flood mitigation, carbon storage and greenhouse gas regulation etc. Where alternative options are proposed for agricultural land, the reasons need to be justified and agreed with the planning authority and the statutory advisors (Natural England & Welsh Government), along with any remedial measures to be in place, and set out in the Soil Resource & Management Plan.

Justifications might include constraints on the safe operation of machinery (eg gradient, complex topography), soil profile attributes (e.g. shallow profile, excessive stoniness, massive apedal soil structure).

For forestry and woodland, in the recent past there have been strong recommendations for the use of excavators and dump trucks in site reclamation (Moffat & Bending, 2006; Moffat, 2014). Hence, it is recommended that the general use of excavators and dump trucks deploying the bed system of soil stripping and replacing (Sheets A - D) woodland soils is adopted in preference to others. Where alternative options are proposed for forestry/ woodland, the reasons need to be justified and agreed with the planning authority with advice from the statutory advisors (Forestry Commission, Natural England & Welsh Government) as appropriate, along with any remedial measures to be in place, and set out in the Soil Resource & Management Plan.

Except for BMV land, there are no current policy expectations for reclamation to non-agricultural land, such as amenity, biodiversity and habitat recreation schemes (Bradley et al, 2006) and the machinery and handling practices to be deployed. For non-agricultural after-uses on lower quality land, it is recommended that the selection is based upon the soil texture/resilience model set out above in **Table 2**, and as appropriate, the more refined version of Askew (2020). The reasons for the selection along with any remedial measures to be in place should still be justified and need to be agreed with the planning authority and the statutory advisors (as appropriate). These should be set out in the Soil Resource & Management Plan. For BMV soils that are to be reclaimed for non-agricultural uses, the expectation is that the soils will be restored to their former capability (ALC Grade) (Paragraph 040, UK Government, 2014).

Remedial Treatment of Compaction
Where there is a risk of significant compaction occurring through the choice of machinery/handling option deployed and/or soils have been handled in sub-optimal wetness conditions there will be reliance on subsequent remedial treatment to achieve the intended after use and services.

Many former mineral workings have been backfilled with inert waste. Remedial treatments of the infill, by digging or ripping, may not be advisable where these are not to be part of the replaced soil profile, and this should be covered in the SRMP. There may also be ‘capping layers’, required by the Environment Agency and Natural Resources Wales, which must not be disturbed. The treatment of former silt-lagoons needs particular careful consideration and consultation with a geotechnical specialist where there is a possibility of breaking through a dewatered and stabilised upper material into the saturated underlying lower material.

Two commonly used methods for remedying compaction caused are the use of tines drawn through the soil layer (often referred to as ‘ripping’) or digging using an excavator bucket (Sheets N & O). Their effectiveness is dependent on the tools reaching the compacted layer within the process of the replacement of soils. Hence, the use of standard agricultural ploughing and subsoiling methods are largely limited to the topsoil layer in their application and efficacy during the soil replacement process. What is needed is specialist equipment of the SIMBA bespoke types (SIMBA, 1983).

The actions of ripping and digging serve to break down the compacted soil mass into smaller lumps creating air spaces between them and/or creating fissures (planes of weakness and cracks). They do not result in the enlargement of the compressed larger soil pores per se which is a matter of soil development processes, such as swelling and shrinkage in clayey soils with changes in water content, plant root penetration and microbial activity over a long period of time.

However, the physical cultivation of compacted layers can facilitate these, although its effectiveness may be short lived and less effective than minimising the degree of compaction in the first place through the choice of more appropriate machinery and handling practice.

The effectiveness of both methods (Sheets N & O) are dependent on the soil being in a dry condition in order to be able to ‘shatter’, thereby creating small lumps of soil and planes of weakness. Soils in a wet (plastic state), particularly those of a finer textured low and moderate resilience (see **Table 2** above), will simply deform and smear around the tines and compress further within the bucket exacerbating the compaction condition. Hence, where the choice of machinery and practice is to rely upon the effectiveness of decompaction to achieve the after use and ecosystem services, the re-laid soils need to be in a dry condition at the time of stripping and storage, and during relaying. Where this is not the case, progressive and costly remedial work over a number of years will have to be relied upon during the aftercare period and beyond when transpiring vegetation can be grown to assist with the drying of the soil profile to facilitate soil decompaction.

Model methods are provided in **Part Two**, Sheets N & O of the guidance for the use of tines and digging with buckets, and their integration into the process of soil replacement. This should be clearly set out in the SRMP as it is often overlooked and is essential if compaction is to be reduced during the reinstatement of the site, particularly when it is at depth and is the only opportunity to do so.

The following sets out the basic options where decompaction, involving a final profile comprising a basal layer, subsoil and topsoil layers, may be needed to achieve the intended after use and ecosystem services:

Option 1: is where the basal layer needs to be treated but is left until the subsoil is placed when both are decompacted together, followed by the decompaction of the topsoil and subsoil layers together (and basal layer) using tines that are long enough. This option is not suited to digging where the soil horizons would be mixed.

Option 2: is where each layer is treated separately by either tines or digging.

Option 3: is where the basal layer is treated or left untreated, followed by the placement of the subsoil and topsoil layers, which are to be decompacted by the use of tines. In the case of deep horizons this option can be limited by the capability of the machinery, the tines or bucket used. This option is not suited to digging where the soil horizons would be mixed.

Removal of Stones and Non-soil Debris

The need for the removal of stones of a particular size and non-soil debris (such as concrete slabs, tree stumps or wire rope) from the reinstated soil profile or from the interface with inert fill may be necessary to facilitate effective decompaction work and enable agricultural tillage operations to take place, as well as to achieve the required standard of reclamation, the intended after use, and provision of ecosystem services. For imported soils (where there is a shortfall), screening may an option and cost effective.

The options for removal within the placed soil are limited by where the stone and debris occur. Generally, each affected soil layer will need to be treated separately. This will also determine the options for the treatment of compaction, although the removal operation may also serve at the same time to reduce compaction. Guidance on the deployment of the available methods are given in **Part Two** Sheets L & M. The provisions for this should be set out in the SRMP along with the method to be used, the criteria to be used (eg stone size), along with its operational integration into the soil replacement process.

Cultivations Following Soil Replacement
Additional cultivations may be necessary (such as the creation of a seedbed and reduction in the surface stoniness) following the replacement of the soil profile and completion of remedial works for decompaction and stone/artefact removal. It is expected that these would be of a type relevant to the after use. The specification for these is outside of the scope of this guidance but should be covered in the SRMP. The timing of these finishing cultivations is critical as the replaced soils will be vulnerable to compaction by the trafficking of the machines used, particularly if rainfall events cause the soil to become wet. Importantly, these operations should be undertaken progressively as soon as the replaced topsoil is laid.

The finishing cultivations required following soil replacement are likely to differ between the earth-moving machinery combinations used. With the excavator option and friable soils (Sheet N), the bucket may be sufficient with or without the use of a stone-rake attachment (Sheet L). Where the soil clods to be broken down are too hard, the use of disc or ‘crumbler bar’ cultivation tools may be necessary. For the bulldozer combinations, secondary treatment by discing is the most likely.

Under-Drainage
Guidance on the installation of under-drainage is outside of the scope of **Part Two**. Where under-drainage needs to be installed, this usually takes place during years 1 or 2 during the aftercare period following any settlement of the replaced soil profile. There have been schemes that have installed under-drainage progressively using the ‘bed/strip’ system of soil replacement (Sheet D), however, this may be less satisfactory than the conventional approach. On the other hand, subsequent installation can result in the disruption and compaction of the reinstated soil profiles if undertaken without care and when the soil profile is wet, as often occurs.

Vegetation Cover
It is important for a vegetation cover to be established as soon as possible and in sufficient time before the growing season ends to protect the soil surface and minimise slaking of the loosened soil profile, attenuate surface runoff and to initiate soil recovery processes. The extent of soil replacement should not usually exceed the capability of establishing an effective vegetation cover. It should be undertaken progressively as soon as the replacement operations and final cultivations are completed to avoid the soil surface remaining bare and unprotected by vegetation over the winter with the high risk of loss of soil from wind and water erosion, and the infestation by weeds. Where the earlier than expected deterioration of weather conditions prevent proper preparation the sowing of a temporary (sacrificial) quickly establishing grass cover may be an option. In unavoidable circumstances alternative seeding methods can be deployed, including hydro-seeding and aerial seeding.

Other measures include the installation of cut-off grips and use of biodegradable geotextiles. Where these measures are deployed further remedial treatments may be necessary when operations are undertaken to establish the intended vegetation. Again, all these provisions should be covered in the SRMP.

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SUPPLEMENTARY NOTES

Supplementary Note 1
Soils

The starting point in determining the appropriate soil handling strategy and method for the reclamation of particular land uses and soil-based ecosystem services is the description of the original and proposed soil profiles. This information can help to identify the practicability of after uses at the outset when designing a reclamation scheme, whether it is a replication of the original or a novel profile for the intended after use, soil function and environmental and ecosystem service provisions. The same applies when assessing the restoration achievement against the original pre-working soil characteristics.

Soil is the surface covering layer which provides for the land use and ecosystem services such as vegetation cover, food production, and water run-off attenuation. The soil layer can be mineral and/or organic matter in its origin and nature. Soils vary spatially in their functional attributes and capacity depending on the parent material, geological and fluvial processes, time, climatic conditions, and land use history.

Simplistically, the idealised soil is differentiated vertically in profile (see **Figure 1.1**) into distinct or graduated layers (Hodgson, 1997). The upper vegetated 'A' horizon, in soil science terms referred to as the 'topsoil'[1], being the most biologically active with accumulated humified organic matter and is often structurally well developed. The underlying layer(s) 'E' and/or 'B' horizon 'subsoil' layer(s) are often chemically altered parent material. They are less biologically active and structurally developed. The underlying 'C' horizon, from which mineral topsoil and subsoil may have developed, is usually less altered, structured and biologically active, but may be an important part of the functioning soil profile. This layer and underlying unaltered drift/solid geology (if present) lying above the economic mineral layer is usually termed 'overburden' and handled differently from the soil resource as a bulk material to be removed/replaced according to civil engineering practice.

However, in some cases the overburden is of a character that it can be used as substitute soil material (soil forming material, Bending et al, 1999) particularly where there is a historic shortfall because previous land development. In some instances, particularly river terrace sand/gravel deposits, the B and/or C horizons may be considered to be part of the economic mineral deposit and if used a substitute for the lost soil horizons may need to be found. Wherever possible, the supplementary/substitute soil forming material should be treated during handling as if it were a subsoil material.

Beware the use of the terms Topsoil and Subsoil in civil engineering for the geotechnical description of soils is different from that used in soil science and are not inter-changeable.

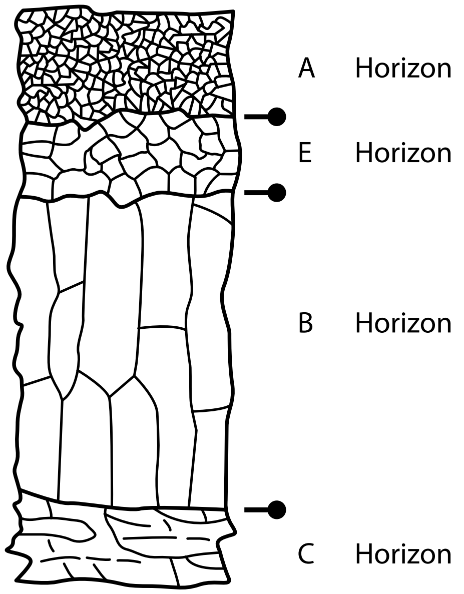

Figure 1.1: An idealised soil profile

Naturally occurring soil profiles in England and Wales have been described in detail and formally classified as to their origin, soil forming processes and functional characteristics (Soil Survey of England & Wales, 1984). Whilst the different soils of the UK have been mapped (some examples are illustrated in **Figure 1.2**), this is usually of not sufficient local detail for devising Soil Resource & Management Plans and operational purposes. Hence, site specific surveys are to be undertaken by qualified soil surveyors (British Society of Soil Science, Undated).

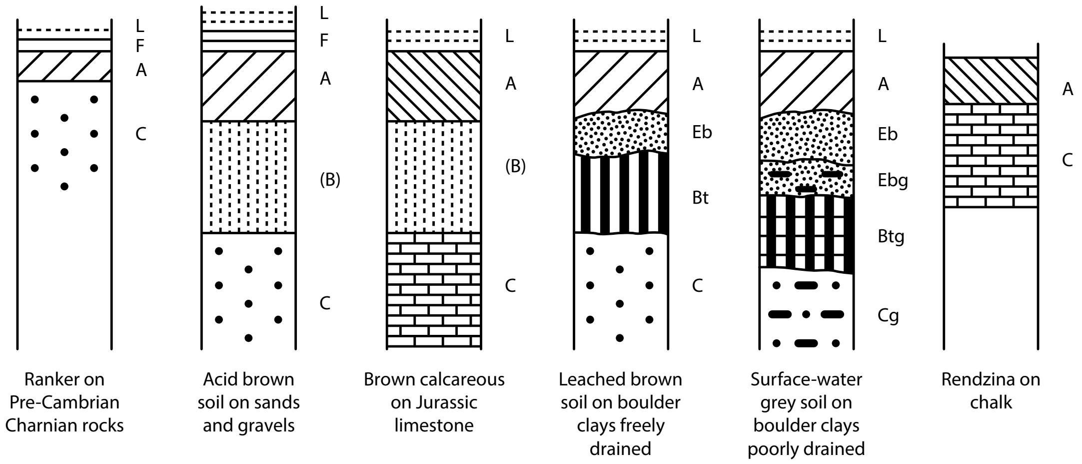

Figure 1.2: Some examples of the variation in soil profiles (L & F surface accumulated organic matter; A = topsoil B&E = subsoil horizons C = 'parent' material)

The soil information to be collected to help inform the landscape plan and reclamation strategy is usually from profiles of up to 1.2m deep (Natural England, 2021). It may include the upper part of the workable mineral or may even be deeper depending on circumstances such as where peat deposits occur. Importantly, the different soil characteristics and functions of the soil horizons within the profile and the underlying material need to be recorded.

Whilst most of the information may be collected during agricultural land quality assessments and can be used without the duplication of effort, more intensive sampling may be needed where there are substantial lateral and vertical variations in soil distribution and where boundaries between soil types need to be defined.

Additional data on soil pH, nutrient status, and organic matter content as both a record of baseline conditions, and for scheme design, such as the identification and management of soils for biodiversity-led after use where, for example lower nutrient topsoils or those soils with a particular pH range may require identification.

Standard field soil survey methods and descriptions should be used (Hodgson, 1997) to include thicknesses of recognisable soil development layers (soil horizons), for which texture and aggregate structure, porosity and size of pores, stoniness and stone sizes, the distribution and rootable depth of plant roots, colour and staining/deposits, and biological activity (**Figure 1.3**). From these the available water capacity can be estimated as well as the depth to slowly permeable layers can be identified and the Soil Wetness Class assigned (MAFF, 1988). Free- calcium carbonate and soil reaction (pH) and salinity can be determined in the field. Supplementary laboratory determinations may be required for soil organic matter, particle size determinations. Other factors such as gradient, patterned ground and climate will influence current and future potential land use and ecosystem services.

The collection and interpretation of the local circumstances and soil information requires skill and is to be done by experienced soil surveyors. They are able to define the topsoil, subsoil and drift/solid geology layers for the purpose of soil stripping, storage and replacement, and the inherent limitations or qualities for the intended land use and ecosystem services.

The most useful characterisation of soils for the practical purpose of determining their resilience and susceptibility to compaction and the resulting consequences are those of mineral particle size classification (textural) and organic matter content groupings (**Figure 1.4**). Soils with an organic matter content of over 20-25% (depending on clay content) are referred to as 'organic' or 'peaty' and are differentiated from 'organic mineral' soils with

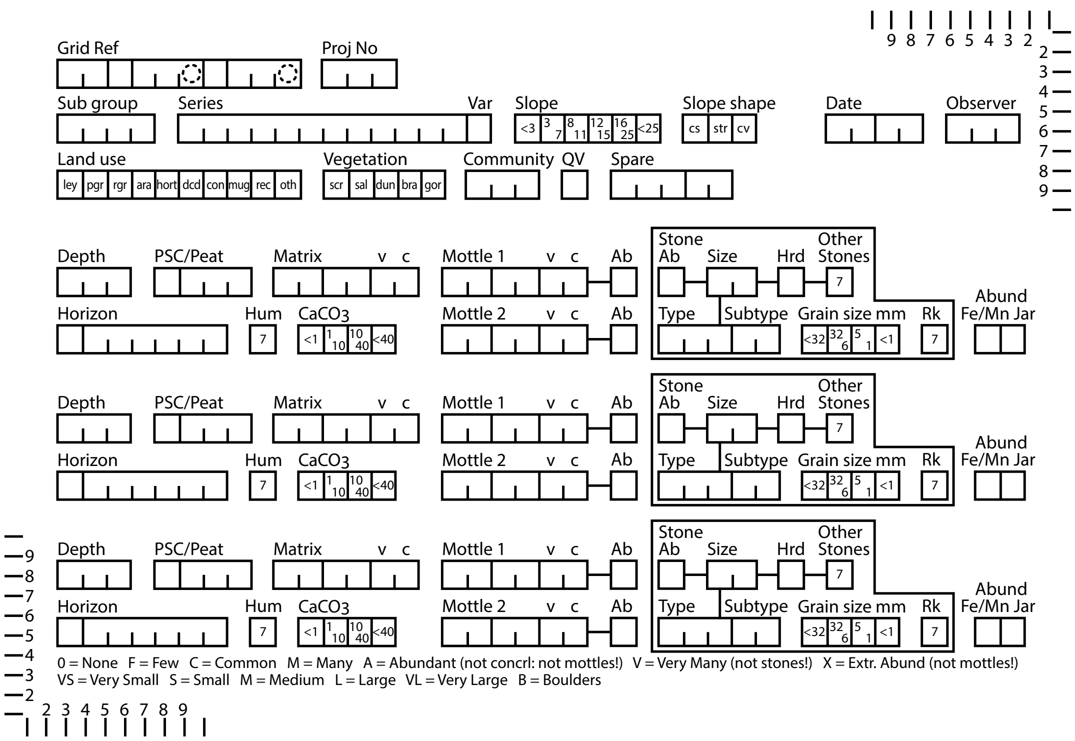

Figure 1.3: Example of soil profile recording card

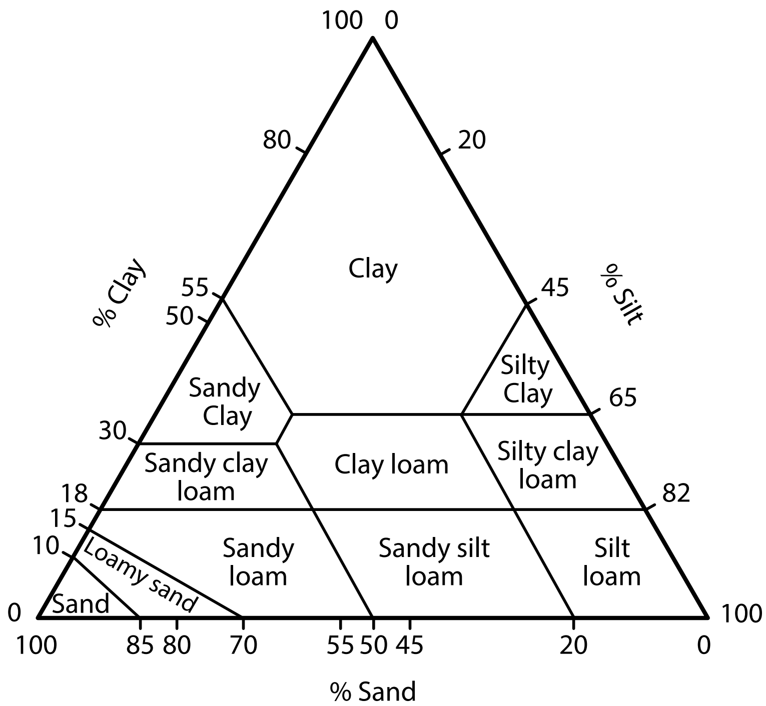

Figure 1.4: Soil mineral particle size (texture) classes

a content of between 6-20% or 10-25%, whereas 'Mineral' soils have a content lower than 6-10% (Natural England, 2008).

Mineral soils are categorised into 11 main particle-size classes according to the proportion of sand, silt and clay sized mineral particles. Sands are further divided into fine, medium, and coarse fractions.

In terms of resilience and susceptibility to compaction, the clay content of the soil largely determines the change from a solid to a plastic state (the water content at which this occurs is called the 'plastic limit' (MAFF, 1982)). This is the point at which increasing soil wetness has reduced the cohesion and shear strength of the soil.

Sands, gravel and peat do not exhibit plasticity and have no plastic limit, silts only occasionally, whereas clay materials possess a high degree of plasticity. Mineral soil textures can be grouped, according to clay content (Reeve, 1994), to represent a descending hierarchy of risk from most to least:

- Soils <10% clay particle size fraction – sand class (often referred to as 'very light soils') – most resilient & least susceptible
- Soils 10-18% clay particle size fraction – loamy sand, sandy loam, sandy silt loam, silt loam classes (often referred to as 'light soils')
- Soils 18-27% clay particle size fraction – sandy clay loam, clay loam, silty clay loam classes (often referred to as 'medium soils')
- Soils >27% clay particle size fraction – sandy clay, clay loam, silty clay, clay classes (often referred to as 'heavy soils') – least resilient and most susceptible.

Askew (2020) sets out a similar soil texture categorisation of risk (resilience), this is reproduced in a simplified form in **Part 1**, **Table 1**.

The relative potential of the soil groupings to be in a plastic state when sufficiently wet is a significant consideration in the timing of handling of soils and in the need for remedial treatment. Soil wetness is a function of climate (especially rainfall and evapo-transpiration), soil (texture, structure, porosity, organic matter content), and site conditions such as gradient and landform, flood risk and groundwater conditions. Indicative soil textures (top- and subsoil) and likely ranges in Soil Wetness Classes for England and Wales are shown on the National Soil Resource Institute's LandIS web pages (National Soil Resources Institute, 2020); also see Supplementary Note 4 for more about soil wetness.

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Supplementary Note 2
Soil Resource & Management Plan

As soils are important Natural Capital providing a range of essential environmental and ecosystem services (UK Government, 2020), a Soil Resource & Management Plan (SRMP) is likely to be required for most planning consents for mineral developments (DEFRA, 2005; UK Government, 2014; British Society of Soil Science, 2021c; Natural England, 2021).

The purpose of the SRMP is to ensure the soil capital is clearly identified as a pre-working baseline, not unduly degraded or lost and that the after uses are sustainable and sufficiently resilient. Without an appropriate SRMP there is a risk of losing, damaging or contaminating the soil resource, and failure to identify opportunities and constraints for site working and reclamation design at the outset.

The SRMP should normally be prepared to support a planning application for mineral extraction, for example as part of an environmental statement. The detail within the SRMP will vary between mineral sites and their context and is to be agreed prior to determination with the Mineral Planning Authority with advice from their statutory advisors Natural England, Welsh Government and the Forestry Commission. Early consultation as part of the pre-application process is advisable. The approved SRMP should be a condition of the planning consent and considered as a 'live' document that is reviewed and updated periodically as appropriate during the operational development and reclamation (restoration and aftercare) of the scheme.

The scope of the information to be needed is set by Natural England (2021) in their Planning and Aftercare Advice for Reclaiming Land to Agriculture. It can be used as a basis for other land uses and reclamation schemes. The now archived DEFRA (2004) Guidance for Successful Reclamation of Mineral and Waste Sites also provides useful checklists.

The British Society of Soil Science (2021a & 2021b) also provides guidance on the background and field collection of soil and related climatic data as does the National Soil Resources Institute's (2020) information system.

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Supplementary Note 3
Soil Compaction

Soil compaction is the term used to describe a condition where the soil particles have been compressed tightly together to give a higher packing density/bulk density (**Table 3.1**) than would be expected for the soil-type or particular horizon within the soil profile (Hodgson, 1997). Soil density has a profound effect on the drainage and aeration of soils, and hence on plant root growth and soil ecology, soil structural development, and overall functioning, including greenhouse gas emissions.

Soil types differ in their inherent packing density, but also within their profiles, with the upper horizons having lower densities than their lower horizons because of a greater porosity. Compression can reduce the porosity and pore size resulting in an increase in volumetric density and hence soil strength. The increase can significantly reduce plant root growth and/or soil infiltration/drainage and aeration, thereby reducing productivity and the recovery of soil function after soil handling, besides causing waterlogging and increasing runoff.

Compaction is typically caused when soils are traversed by heavy machinery or trampled by livestock, but also in the handling (stripping, stockpiling and transporting) of soils. Soils are generally most susceptible to compaction in a wet condition when soil strength and resistance to compression are at their lowest (see Supplementary Note 4).

The potential for compacted soils to occur in restored mineral workings is particularly high and can inhibit the achievement of the planned land use and provision of the intended ecosystem services. In some circumstances, like the modification of drainage characteristics for some wetland creation schemes, here compaction within the soil profile or underlying material for a higher density/lower porosity can be beneficial.

The packing density of soils is a useful indicator of soil strength and its relative compaction (Hodgson, 1997: Ball & Munkholm, 2015; Ball et al, 2017). Alternatively, penetrometers can be used to measure soil strength (MAFF, 1982), although their interpretation can be confounded by a number of soil factors such as its water content and stoniness.

Packing Density Category~	Indicative Bulk Density (g/cm3)~
Low* – single grain loose when moist / weak strength when moist	<1.40
Medium – moderately firm with many macropores	1.40 – 1.75
High – single grain compact / firm to strong strength with few macropores#	>1.75

~ see Hodgson (1997); *rare in clay & sandy clay mineral soils; # rare in mineral topsoils unless clay/clay loam mineral soils, also rare in organic minerals soils & peat

Table 3.1: Packing Density Categories and Corresponding Typical Bulk Densities in Mineral Soils

Bulk density measurements are more accurate, and whilst requiring laboratory determination (MAFF, 1982), they can be used to verify field visual assessments.

Soils with relatively high packing/bulk densities naturally occur where they are of a fine texture and/or have weak structural development. In the subsoil layers, a high density may not necessarily indicate compaction, but other structural characteristics of the soil. For the underlying C-horizon material, a high density would generally be expected. The occurrence of these profile characteristics should be taken into account in the SRMP. Professional soil surveyors can advise on the comparative packing densities of the in situ and reinstated soils, and on the potential for compaction and where compaction occurs (British Society of Soil Science, Undated).

Minimising Compaction

The complete avoidance of the compression of soils during soil handling (striping, storing and replacing soils) in mineral workings is unrealistic. However, measures to minimise significant increases in packing density (compaction) occurring can be deployed.

The main cause of compression is the traversing of soils with earth-moving machinery. The heavier the machines, the greater is the potential for compaction. Whilst machines differ in size and contact pressures (loaded and unloaded), it is usually the choice of machinery combination and handling practices that determine the degree and extent of compaction. The frequency of traversing the soils and soil condition, with the greater potential for significant compression occurring when wet (plastic), are likely to be contributing factors, but also can be the action in the loading of soils, loaded soils being carried, and the mounding of soils in stores. Consequently, in most circumstances, the best option available for soil handling is that based on excavator and dump truck and the bed/strip handling practice (Bransden, 1991; Moffat & Bending, 2006; Moffat, 2014).

Treating Compaction

Whilst natural physical and biological processes can over a very long period of time reduce induced higher soil packing density closer to their original state, remedial treatment is needed to accelerate the processes of soil recovery.

Compacted materials can be broken up by physically ‘digging’ or ‘ripping’ or cultivating by mechanical means (Spoor & Foot, 1998: Spoor, 2006). Whilst this is referred to as ‘de-compaction’, the actual result is the reduction of the soil mass into smaller masses (‘clods’ (>10 cm in size) or ‘fragments’ (<10 cm)) which themselves remain in the compressed state. The effect in the short term (as a surrogate for natural soil structure) can facilitate plant root penetration, drainage and aeration through the voids between the soil clods/fragments and any planes of weakness created.

The longevity of such a surrogate for natural soil processes is dependent on soil characteristics (texture, aggregate stability) and biological activity such as plant roots or the addition and incorporation of organic matter to maintain the voids and planes of weakness. Subsequent practices which re-compact the soil (which can easily reoccur in the short term through machinery trafficking and livestock) during the aftercare period need to be avoided.

Where compaction is identified or expected within the replaced soil profile and is of consequence for the intended land use and ecosystem services, treatment should be scheduled during or after the replacement process as it is completed; where this is omitted the only and often less satisfactory option (if agricultural equipment is relied upon) is for it to be undertaken from the soil surface during the aftercare period.

Treatment of compaction before soil replacement is unlikely to have any subsequent benefit as recompaction of the loosened clods/fragments is likely to take place in subsequent handling. For other reasons, such as the ease of recovery of the soil from storage mounds, some decompaction of the soil in situ may be achieved.

The effectiveness of loosening compacted soil layers is dependent on the tools and practices used, and on the soil type and its wetness condition. The two principal tools used are digging buckets operated by excavators or tines drawn by bulldozers. Both can be effective in promoting plant root penetration, drainage and aeration at least in the short term, but are dependent on the practice used, discipline in application, and soil condition for their effectiveness. Both options can result in uneven soil surfaces which for agricultural uses may need secondary cultivation treatment such as the use of discs and/or the use of crumbler-bars. The cultivated soil should be sown/planted as soon as possible as the decompacted profiles will have a low bearing capacity until natural settlement has taken place (usually over the first winter). The choice of the finishing of the completed soil surface can be a matter of operational preference and experience, the intended land use, time taken and cost, and gradient limitations.

Decompaction by digging subject to the capability of the excavator and size of bucket, can be used on completed soil profiles where the entire profile is to be dug or dug to a particular depth. The digging of the final profile might be an option (Options 1 & 3) where the mixing of surface and underling soil horizons is not of concern. It is to be carried out as sequential retreating strips across the land to minimise recompaction as shown in Part Two, Sheet N. The digging of the surface layer to a limited depth can be used in combination with stone removal from the upper soil layer when specialist stone-rake buckets with rows of stub-tines are used.

The same digging treatment can be deployed to individual soil horizons (Option 2), where digging of the final profile is not an option because of soil mixing (see Supplementary Note 5), as they are laid and where stones/non-soil debris are to be sequentially removed without the excavator working on the soil layers.

The ripping with tines can also be used on completed profiles (Option 3) and/or sequentially to treat individual horizons (Options 1 & 2) as the profile is built up as shown in **Part Two, Sheet O**. It is to be carried out as sequential retreating strips across the final profile or individual horizons depending on the potential effectiveness of the tine size and configuration and capability of the pulling power unit (Binns, 1983; Bacon & Humphries, 1987; Spoor & Foot, 1998). Importantly, the configuration of the tines must at least include tines that are centred on the bulldozer's caterpillar tracks to treat the recompaction caused.

Again, with the ripping of individual soil horizons as they are laid (Option 2), there is a risk of recompaction by where the bulldozer is working on overlying successive layer(s). To rectify this decompaction from the surface of the overlying layer or the final surface may be required (Bacon & Humphries, 1987; Spoor & Foot, 1998). The length of the tines determine the potential depth to which decompaction might take place, although the actual effective depth because of soil heave dragging on the tool bar, is less and needs to be taken into account when determining the option to rip from the final surface.

The lateral effectiveness of the tines is determined by their spacing and operating depth, the wider the spacing the less effective they are in breaking up compacted soil into clods/fragments and creating planes of weakness. As the number of tines affect the drag and the load being carried, and hence the power needed, the addition of wings enables a wider spacing and hence fewer tines (Binns, 1983; Spoor & Foot, 1998), provided that the tines are operating at optimal depth.

There is nothing wrong with using straight non-winged tines if they are close enough and can be pulled by the bulldozer or there is a sufficient number of over lapping of the passes. Experience has shown that to achieve consistent decompaction that is comparable with digging, overlapping parallel passes are required and this is more effective than other patterns such as 'cross-ripping' (Spoor & Foot, 1998).

The mode of action of the tines as they are drawn through the compacted layer is to create lateral forces that radiate in front of the tine that shatter the surface of the soil and deeper radiating forces that uplifting the soil mass and create fissures and planes of weakness (Spoor & Foot, 1998). The shallower the ripping process the less uplift and the closer the tines need to be to break up the soil. With deeper ripping, the wider spaced they can be and this may be necessary to reduce the drag on the bulldozer unit.

With the use of both methods, the depth to the uppermost compacted layer may be the determining factor in the realisation of particular land uses and ecosystem services. In some cases, this will be at depth in the profile, whereas in others it will be shallower. Hence, the digging/ripping, final or sequential treatment being adopted needs to be co-ordinated with the requirement and the capability of the equipment being used and the intended afteruse and soil functions and environmental/ ecosystem services to be provided.

Historically, there is a poor record in achieving the adequate treatment of soil compaction. This has been mainly because of :

i) the inadequacy and poor condition of ripping equipment
ii) lack of knowledge of how to use the equipment effectively and/or
iii) the lack of supervision, and
iv) its deployment when soils are too wet to be effective.

Given the importance of soil compaction in relation to soil handling, professional soil surveyors should be consulted on the potential for compaction and the significance (if any) for the intended land use and services to be provided, the effectiveness of decompaction options and practices, and to identify its occurrence and significance in the field (British Society of Soil Science, Undated).

The setting up and operation of the decompaction practice and equipment should be overseen by a competent person with advice from the professional soil surveyors. Where decompaction is important in achieving the intended land use and services, it should be monitored and as work proceeds and adjusting the practice/operation as necessary.

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Supplementary Note 4
Soil Wetness

Soil wetness is a major determinant of land use, and environmental and ecosystem services in the UK. It is also a factor in the occurrence of significant compaction arising from handling soils with earth-moving machines and the practices used (Duncan & Bransden, 1986).

Relative soil wetness can range from the waterlogged to moist (mesic) or dry (xeric) depending on rainfall distribution and depth to a water-table and duration of waterlogging. In the UK, soil wetness is largely seasonal with higher evapo-transpiration rates potentially exceeding rainfall in the summer resulting in the soil profile becoming drier where there is vegetation. Whilst soil wetness is largely weather system and equinox (climate) driven, it varies with geographical and altitudinal locations, and importantly the physical characteristics of the soil profile, such as texture structure, porosity, and depth to the water-table and topography including flood risk (MAFF, 1988). The Soil Wetness Class is based on the expected average duration of waterlogging at different depths in the soil throughout the year (days per year), and can be determined by reference to soil characteristics and local climate (MAFF, 1988). The likely inherent wetness and resilience status of a soil should be indicated in the SRMP (see **Part 1, Table 2 & Supplementary Note 1**), reflecting potential risks for soil handling such as low permeability, permanently high groundwater, or a wet upland climate.

Wet soils can also be a result of other circumstances. For example, the interception of water courses, drainage ditches and field land drains. Where these occur, the provisions are to be made in the SRMP to protect the soils being handled and the operational area.

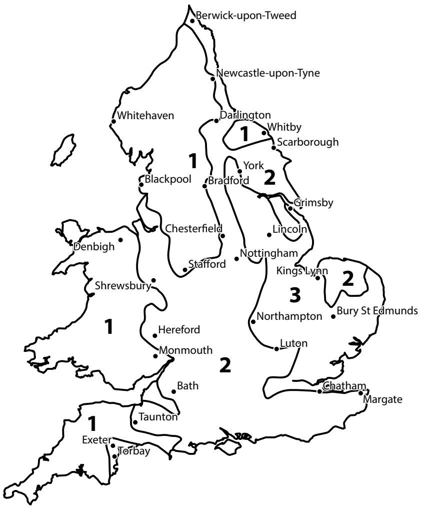
Soils, when in a wet condition generally have a lower strength and have less resistance to compression and smearing than when dry. Lower strength when soils are wet also affects the bearing capacity of soils and their ability to support the safe and efficient operation of machines than when in a dry state.

In terms of resilience and susceptibility to soil wetness, the clay content of the soil largely determines the change from a solid to a plastic state (the water content at which this occurs is called the ‘plastic limit’ (MAFF, 1982)). This is the point at which an increasing soil wetness has reduced the cohesion and strength of the soil and its resistance to compression and smearing.

Whilst coarse textured sandy soils are not inherently plastic when wet, they are still prone to compaction when in a wet condition. Hence, handling all soils when wet will have adverse effects on plant root growth and profile permeability, which may be of significance for the intended land use and the provision of services reliant on soil drainage and plant root growth. It may be less so in other circumstances where wet soil profiles, perched water tables and ponding are the reclamation objectives, though drainage control, for example to control flooding, may still be important in these contexts.

In cases of permanently wet soils, such as riverine sites, upland or deep organic soils where there is a persistent high water-table throughout the seasons within the depth of soil to be stripped and/or the soil profile remains too wet, a strategic decision has to be made to be able to proceed with the development of the mineral resource. This may mean alternative and less favourable soil handling practices have to be agreed with the planning authority.

Predicting & Determination of Soil Wetness
There are well established methods to predict and determine soil wetness of undisturbed and restored soil profiles (Reeve, 1994). The challenge has been the prediction of the best time for soil stripping. Models based on soil moisture deficits and field capacity dates for a range of soil textures can provide indicative regional summaries (**Table 4.1**) that can help with planning operations at broad scale but cannot be relied upon in practice for deciding operationally whether to proceed on the ground given the actual variation in weather events from year to year and within years.



	Climatic Zones		
Soil Clay Content	**1**	**2**	**3**
Soil Depth <30cm			
<10%	Mid Apr - Early Oct	Late Mar – Early Nov	Late Mar – Early Dec
10 -27%	Late May - Early Oct	Early May – Early Nov	Early Apr – Early Dec
Soil Depth 30-60cm			
<10%	Late Apr - Early Oct	Mid Apr – Early Nov	Early Apr – Early Dec
10-27%	Late May - Early Oct	Early May – Early Nov	Early Apr – Early Dec
>27%	Late June – Early Oct	Early June – Early Nov	Late May – Early Dec
Soil Depth >60cm			
<10%	Late Apr - Early Oct	Mid Apr – Early Nov	Early Apr – Early Dec
10-18%	Late May - Early Oct	Early May – Early Nov	Early Apr – Early Dec
18-27%	Late June – Early Oct	Early June – Early Nov	Late May – Early Dec
>27	Mid July – Mid Sept	Early July – Mid Oct	Late June – Mid Oct

Table 4.1: Indicative on-average months when vegetated mineral soils might be in a sufficiently dry condition according to geographic location, depth of soil and clay content

The timing of most soil handling operations takes place between April and September. Although in western (Zone 1) and central (Zone 2) areas it typically can be a later start in May with an earlier termination in August. Whilst the return to climatically 'excess rainfall' is later in the eastern counties (Zone 3) and can be as late as November/early December, there is a need to maintain transpiring vegetation to keep the soils being handled in a dry as possible condition and to establish new vegetation covers as soon as possible (on replaced soils and storage mounds). Hence, soil handling operations generally need to be completed no later than the end of September (Natural England, 2021), unless appropriate provisions can be assured.

Where data is available, more realistic local and real-time predictions can be made, however, because weather patterns and events differ between and within years, and soils can be vary locally in their condition. Experience has shown that the most practical approach for operations is to inspect the site and soils in question near to/ at the time when soil handling is to take place. Professional soil surveyors can advise on the best time for soil handling (stripping, storage & replacement) and carry out site assessments of soil wetness condition prior to the start of operations.

A Practical Method for Determining Soil Wetness Limitation

During the soil handling season (see Table 4.1 above), prior to the start or recommencement of soil handling soils should be tested to confirm they are in suitably dry condition (**Table 4.2**). The 'testing' during operations can be done by suitably trained site staff and reviewed periodically by the professional soil surveyors.

The method is simply the ability to roll intact threads (3mm diameter) of soil indicating the soils are in a plastic and wet condition (MAFF, 1982; Natural England, 2021). Representative samples are to be taken through the soil profile and across the area to be stripped. It is the best available indicator of soils being too wet to be handled and operations should be delayed until a thread cannot be formed. For coarse textured soils which do not roll into threads, a professional's view as to soil wetness and the risk of compaction may have to be taken.

Table 4.2: Field Tests for Suitably Dry Soils

Soil tests are to be undertaken in the field. Samples shall be taken from at least five locations in the soil handling area and at each soil horizon to the full depth of the profile to be recovered/replaced. The tests shall include visual examination of the soil and physical assessment of the soil consistency.

i) Examination

- If the soil is wet, films of water are visible on the surface of soil particles or aggregates (e.g. clods or peds) and/or when a clod or ped is squeezed in the hand it readily deforms into a cohesive 'ball' means **no soil handling to take place.**
- If the samples is moist (i.e. there is a sligh dampness when squeezed in the hand) but it does not significantly change colour (darken) on further wetting, and clods break up/crumble readily when squeezed in the hand rather than forming into a ball means **soil handling can take place.**
- If the sample is dry, it looks dry and changes colour (darkens) if water is added, and it is brittle means **soil handling can take place.**

ii) Consistency
First test
Attempt to mould soil sample into a ball by hand:

- Impossible because soil is too dry and hard or too loose and dry means **soil handling can take place.**
- Impossible becuase the soil is too loose and wet means no soil handling to take place.
- Possible - Go to second text.

Second test
Attempt to roll ball into a 3mm diameter thread by hand:

- Impossible because soil crumbles or collapses means soil handling can take place.
- Possible means no soil handling can take place.

N.B.: It is possible to roll most coarse loamy and sandy soils into a thread even when they are wet. For these soils, the Examination Test alone is to be used.

A Rainfall Protocol to Suspend & Restart Soil Handling Operations

Local weather forecasts of possible rainfall events during operations and the occurrence of surface lying water have been used to advise on a day-to-day basis if operations should stop (Natural England, 2021). Single events such as >5mm/day in spring and autumn months, and >10mm/day in the summer have been suggested as more precise triggers for determining soil handling operations (Reeve, 1994). However, in practice the following generic guidelines are often used:

- In light drizzle soil handling may continue for up to four hours unless the soils are already at/near to their moisture limit.
- In light rain soil handling must cease after 15 minutes.
- In heavy rain and intense showers, handling shall cease immediately.

In all of the above it is assumed that soils were in a dry condition. These are only general rules, and it is at the local level decisions to proceed or stop should be based on the actual wetness state of the soils being handled. After the above rain event has ceased, the soil tests in **Table 4.2** above should be applied to determine whether handling may re-start, provided that the ground is free from ponding and ground conditions are safe to do so.There can be extreme instances where soil horizons have become very dry and are difficult to handle resulting in dust and windblown losses. In these conditions the operation should be suspended. The artificial wetting of extremely dry soils is not usually a practice recommended but has been successful in some cases.

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Supplementary Note 5
Soil Mixing

The mixing of soil material can be both deleterious and beneficial, depending on circumstances, and if relied upon, needs special consideration of how it is to be achieved in the Soil Resource & Management Plan (SRMP).

Mixing of Soil Horizon Interfaces
The mixing of soil horizons at the interface can occur during soil stripping and replacement operations for several reasons such as, i) the lack of care taken in the operation, ii) failure to identify and communicate the distinction, iii) the physical impress of soil material during trafficking of machines traversing the soil, iv) spillage of soil when tipping and spreading during soil reinstatement, v) the result of decompaction by bucket or tines, but also vi) soil characteristics such as a gradation in change rather than distinct boundary, and vii) variation in horizon thickness and topography.

The significance of soil interface mixing depends on the extent as well as the intended land use and services. Mixing at the interface of soil layers is often beneficial for plant rooting and drainage, which can be impeded where there is an abrupt change in physical properties.

Wholesale Mixing of Soil Materials
Wholesale mixing of soil types and horizons can occur as a deliberate action or unintentionally. Its occurrence can be for various reasons, from being a consequence of poor record keeping of storage mounds, the absence of adequate soil resource plans to the consequence of soil importation schemes where there is a shortfall of soil material. The latter is often associated with long established inert fill and brown-field sites. Where importation of soils is to occur, it should meet prescribed standards (BSI, 2015) and be considered in detail in the SRMP. The former poor practices should be prevented by the adoption of the SRMP and good site oversight practices.

A common misunderstanding that results in soil mixing is the too literal interpretation of the Natural England (2021) guidance that all topsoil should be stripped to 300mm, and subsoil should be stripped as a single 700mm layer. Soil horizons should be stripped according to their natural occurrence and separately according to their main functional characteristics (see Supplementary Note 1).

The mixing of soil types and horizons is sometimes advocated to 'improve' soil quality, as is the deliberate mixing of top- and subsoil to reduce topsoil fertility and other soil functions to achieve habitat creation schemes. Where this results in the degradation of soil capital, it should be approached with caution and requires evidence of the benefit to be provided in the SRMP before being adopted.

Historically, more effective than soil mixing has been the substitution of intractable soil horizons with other material, particularly soil forming material from within a site's geological horizons (Bending et al, 1999).

There are instances where the mixing of soil types and horizons are largely unavoidable because of the machinery used and spatial characteristics of the soils. Examples include thin lithomorphic soils on rock deposits and small-scale mosaics in warp and periglacial soils. Because of the practical limitations in recovering the individual thin soil horizons, the surface and sub-surface materials are often stripped together as a single layer, as are the lateral components of mosaics.

In all of the above situations, the professional soil surveyor should have identified these and advised in the SRMP how they are to be treated for stripping, storage and replacement to achieve the intended land use, soil functioning and ecosystem services.

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GLOSSARY OF TERMS

Apedal
No observable soil particle aggregation and lines of weakness in soil mass.

Basal layer
Unweathered material or fill/capping layer below soil layer not considered to be part of the soil profile/ resource.

Clod
An artificial and less stable aggregation of soil particles ranging in sizes and shapes, can be a fragment of a ped.

Ecosystem services
The many benefits to humans provided by the natural environment and from healthy ecosystems, for example, extreme weather mitigation, flood control, clean drinking water, the decomposition of wastes, productivity of food and fibres, human mental and physical well-being.

Field Capacity
The maximum amount of soil water held in the soil after excess water has drained away.

Field Capacity Days
The number of days when the soil moisture deficit is zero.

Natural Capital
The world's stock of natural resources, which includes geology, soils, air, water, and all living organisms.

Ped
Natural stable aggregation of soil particles ranging in sizes and shapes (units of soil structure).

Reclamation
A term encompassing both restoration (the re-instatement of soils) and aftercare stages.

Soil consistency
The cohesion/adhesion of soil particles within the peds giving the characteristic of strength (resistance to crushing/deformation (ranging from loose, weak, firm, strong to rigid).

Soil forming material
Non soil materials usually derived from mineral wastes, such as overburden materials and uneconomic geological materials encountered during quarrying or mining, that have the potential to turn into soils over time.

Soil function
Includes the physical support for plants and soil organisms, attenuation and drainage, water supply and purification, nutrient accumulation and cycling.

Soil sealing
The temporary careful compaction/smearing of a soil surface by a bulldozer or excavator to reduce the infiltration of precipitation and the wetting of the soil profile.

Soil plastic limit
The water content at which soil material be-comes plastic (mouldable) and prone to compression and smearing. Although the plastic limit not is not manifest in sandy soils, they are prone to compression at high water contents.

Soil structure
The shape (granular to prismatic/platy), size (fine to very coarse) and degree of aggregation (weak, moderate, strong) of soil particles into structural units (peds) and voids, and their spatial arrangement.

Soil texture
The size distribution (sand, silt & clay sized particles) of less than 2mm fraction of soil material.

Soil Textural Class
Eleven main groupings of soil particle distributions according to the proportions of sand, silt and clay sizes.

Soil wetness
And 'wet soil', a generic term to denote water content at or above the soil's plastic limit.

Soil Wetness Class
Six groupings of the depth to (slowly permeable/ compacted layer) and duration of waterlogging in the soil profile.

Subsoil
The physio-chemically and biologically altered layers below the topsoil that are functioning parts of the soil profile, in some cases this includes part of the parent rock/drift mate-rials.

Topsoil
The uppermost and most physically and biologically altered horizon, excluding organic litter layer, of undisturbed soil profiles.