MANAGING LANDSCAPE CHANGE WITH RESPECT TO FUTURE MINERAL EXTRACTION IN NORTH YORKSHIRE

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Abstract

North Yorkshire has a considerable wealth of mineral resources that are needed to support economic growth. It also has a very rich diversity of high quality landscapes; significant heritage assets relating to millennia of human occupation; fragmentary remains of diverse and formerly more extensive natural habitats; and considerable opportunities for enhancement in all of these areas. It is therefore of paramount importance that the ongoing need for mineral extraction is properly balanced against the need for environmental protection and that all opportunities for enhancement associated with mineral sites are harnessed to optimum effect.

The work outlined in this paper has brought together evidence relating to landscape, the historic environment and the natural environment and has demonstrated how all of these are inextricably linked together. This, in turn, has influenced the identification of key principles relating to the way in which a more sustainable approach to future mineral extraction might be developed, and has highlighted the over-arching need for an integrated, multi-disciplinary approach, rather than dealing with individual issues in isolation.

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Introduction

This paper summarises the findings of a major investigation, commissioned by North Yorkshire County Council (NYCC) and English Heritage, to inform their strategy for future mineral extraction across the whole of North Yorkshire, excluding the two National Parks.

The paper describes the key characteristics of the various mineral deposits found within North Yorkshire and uses the example of major river valley systems to illustrate how different factors have interacted to create the modern landscape in areas underlain by important mineral resources. Understanding these interactions provides a key to managing landscape change associated with future mineral extraction. Figure 1 shows some of the main geographical features and places referred to in the text.

Identification And Characteristics Of The Mineral Resources

The various mineral resources potentially available for future extraction by surface quarrying within North Yorkshire have been identified as 'Areas of Surface Mineral Resource Potential' (referred to throughout the study as 'ASMRPs'). Separate ASMRPs were defined for 14 types of mineral resource, using selected categories identified in the 1:50,000 scale mineral resource mapping produced by the British Geological Survey (BGS). Listed here in sequential order of the age of the deposits (most recent first), these comprise:

- Quaternary Sand & Gravel Resources - subdivided into
    - sub-alluvial gravels (ASMRP 1)
    - river terrace deposits (ASMRP 2)
    - glacio-fluvial deposits (ASMRP 3)
    - glacial deposits (ASMRP 4) and
    - undifferentiated sand & gravel (ASMRP 5)
- Quaternary Brick Clay Resources (ASMRP 6), comprising glacio-lacustrine clays and silts
- Cretaceous Chalk Resources (ASMRP 7)
- Jurassic Limestone (ASMRP 8)
- Permian 'Magnesian' Limestone (ASMRP 9)
- Carboniferous Shallow Coal Resources (ASMRP 10)
- Carboniferous Brick Clay Resources (ASMRP 11), comprising mudstones and 'fireclay' seams associated with shallow coal
- Carboniferous Sandstone Resources (ASMRP 12)

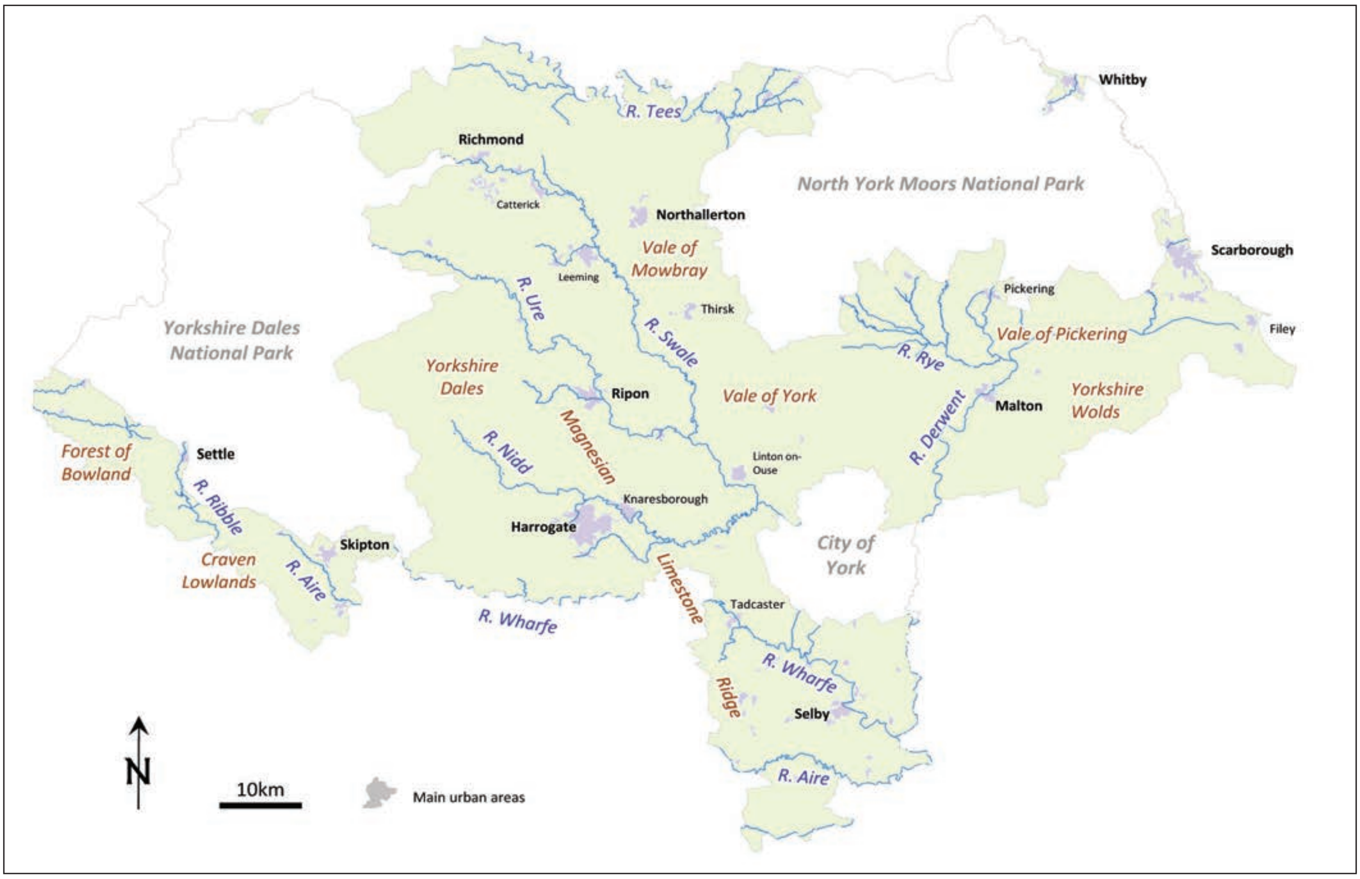

Figure 1. *The study area (green shaded area, within North Yorkshire), with principal towns, rivers and other features referred to in the text.*

- Carboniferous and Jurassic Silica Sand Resources (ASMRP 13) and
- Carboniferous Limestone Resources (ASMRP 14)

The extent and distribution of the ASMRPs, utilising the BGS resource mapping, are shown in Figure 2, below.

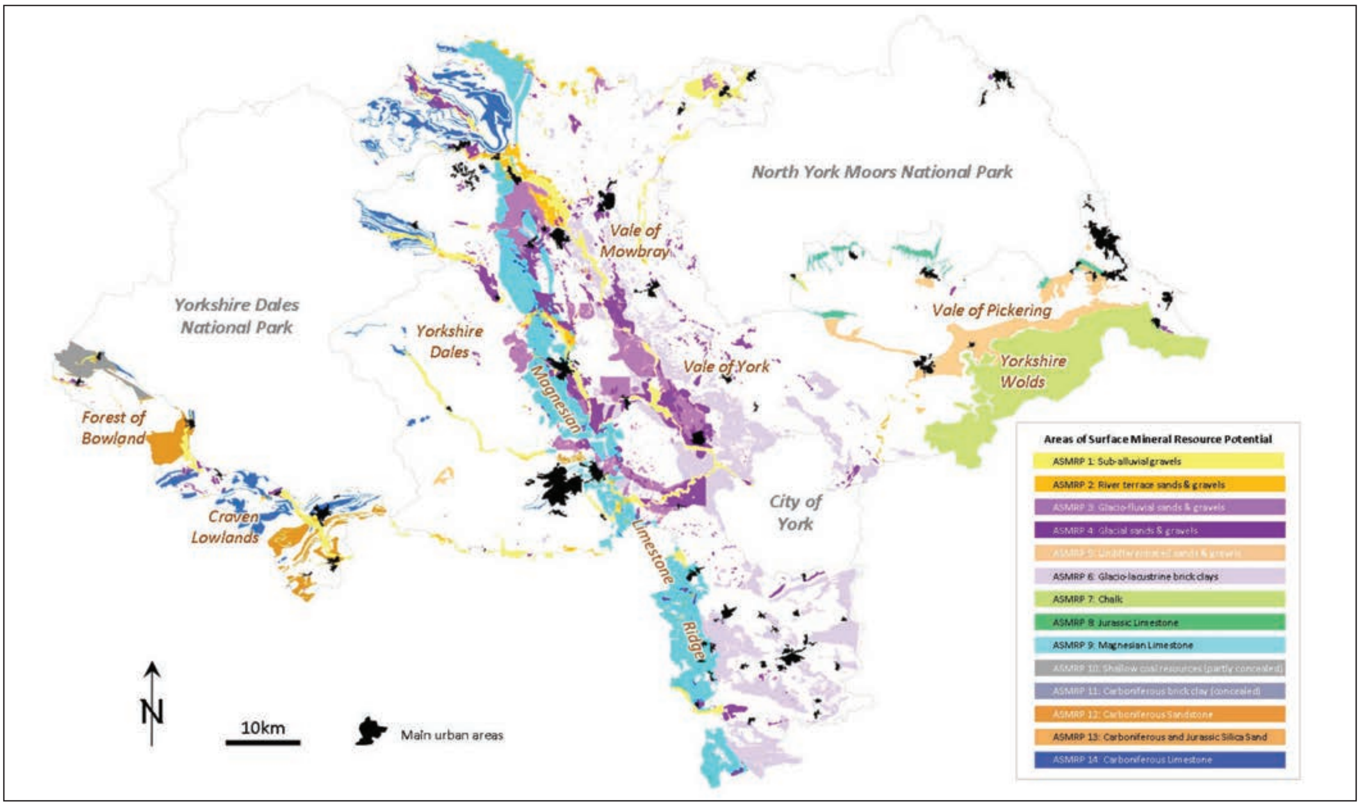

Figure 2. *The distribution of Areas of Surface Mineral Resource Potential within the study area. (Note: black areas are the main urban areas, from Figure 1, which were excluded from the analysis of potential resources).*

ASMRP 1: Sub-alluvial gravels

Sub-alluvial gravels occur beneath the floodplains of present day rivers. In many areas, the deposits are likely to be of limited commercial value because they are too thin; too limited in surface extent, or because the ratio of mineral to overburden and 'waste' (e.g. very silty or clayey layers) is too low. The upper sections of the valleys also tend to be more distant from potential markets, accessible only by relatively minor roads through numerous towns and villages and, in many cases, more sensitive in terms of landscape and environmental impacts. This combination of factors has influenced the current distribution of commercial extraction within these deposits, which occurs only to the East of Catterick, and around Ripon.

ASMRP 2: River terrace sands & gravels

River terraces are the remnants of older floodplains into which the present-day rivers have incised. They are therefore found, sporadically, along parts of the same major valleys, between the modern alluvium and the valley sides. In some cases they are also mapped along valleys where there are no significant alluvial deposits. Existing gravel pits within these deposits occur only between Brompton on Swale and Catterick.

ASMRP 3: Glacio-fluvial sands & gravels

Glacio-fluvial sands & gravels are the deposits of meltwater streams and rivers which issued from former glaciers and ice sheets. In the last (Devensian) glaciation, valley glaciers occupied most of the major river valleys draining from the high ground of the Pennines and coalesced into a much broader ice sheet which extended across the Vale of York and into South Yorkshire. A combined Scottish and Scandinavian ice sheet which flowed across the North Sea also impinged onto the coast of the North York Moors and East Yorkshire, extending inland across part of the Vale of Pickering. Meltwater from these various ice fronts generally followed the topography of the present-day valleys, often at a higher level, at the margins of the glaciers, and also extended across some of the 'interfluve' areas of higher ground between the valleys. The resulting deposits have been reworked in many places by post-glacial river activity, leaving behind a more sporadic pattern of glacio-fluvial sediments. The deposits are only worked, at present, at three quarries within the Ure Valley.

ASMRP 4: Glacial sands & gravels

Glacial sands & gravels are those which were deposited directly at the margins of the former glaciers, following transportation by ice. Unlike glacial till deposits, which comprise a mixture of all grain sizes, including large quantities of silt and clay, the glacial sands & gravels have been at least partially sorted by the action of meltwater within, beneath or on the surface of the glaciers. The resources, as mapped by the BGS, are located primarily within and at the margins of the Vale of York, indicating successive positions of the former Vale of York glacier, as it retreated back towards the higher ground of the Yorkshire Dales at the end of the last glaciation. Within this area the deposits are preserved as residual patches (following post-glacial erosion) both within the major valleys and across many of the intervening areas.

ASMRP 5: Undifferentiated sands & gravels

Undifferentiated sand & gravel resources are mapped by the BGS within the Vale of Pickering and correspond to (or at least to include) beach deposits formed at the margins of the former ice-dammed glacial lake which occupied the whole of this area during the Devensian glaciation. The deposits extend continuously along the foot of the Chalk escarpment of the Yorkshire Wolds, and along parts of the northern margin of the former lake. A further outcrop extends along the western margin of the former lake to the north west of Malton. The deposits are currently worked in the first two of these areas.

ASMRP 6: Quaternary brick clay resources

Fine-grained glacio-lacustrine sediments (clays and silts) accumulated on the beds of both large and small glacial lakes at the margins of the Vale of York glacier. Remnants of these deposits are widely preserved throughout this area, as indicated in Figure 2. A succession of different lakes would have developed at different stages during the advance and subsequent retreat of the glacier, being trapped between the ice-front and adjoining higher ground. The suitability of individual deposits for brick-making depends once again on a wide range of factors including grain size distribution (uniform clays being preferred), organic content, colour, and proximity to markets. The deposits are currently worked for brick-making at just one site within North Yorkshire, to the south of Easingwold.

ASMRP 7: Cretaceous chalk resources

The Chalk deposits of the Yorkshire Wolds represent an extensive resource that has been used in the past as a source of both agricultural lime and (in neighbouring East Yorkshire and Humberside) for cement manufacture. Within North Yorkshire the Chalk has most recently been worked to the east of Norton and to the north west of Hunmanby. Future workings are likely to be inhibited by the distance of these resources from principal construction markets, by comparison with the resources available at South Ferriby on the Humber Estuary, which are still used extensively for the production of cement.

ASMRP 8: Jurassic limestone resources

Jurassic Limestones occur within the southern part of the North York Moors, partly within the National Park and partly within North Yorkshire. The quarry at Newbridge, to the north of Pickering, produces crushed rock aggregates from the Upper Calcareous Grit formation which directly overlies the limestone, but the limestone itself, formerly used as a local building stone, is no longer worked in this area, except on a very local scale from intermittently active quarries.

ASMRP 9: Permian 'Magnesian' limestone resources

The Magnesian Limestone is primarily a dolomite rather than a true limestone, and is therefore used for a variety of industrial applications, notably in steel and glass-making, and as a source of agricultural lime. The rock has also been used extensively in the past as a source of building stone for many prestigious architectural projects, within Yorkshire and elsewhere, and is still used for this purpose to some degree, but the primary use today is as a construction aggregate. The resource comprises two geological formations: the Cadeby Formation, which tends to be massively bedded, and the most suitable for building stone production (as well as aggregates) and the thinner and more thinly-bedded Brotherton Formation, which occurs higher in the Permian sequence, cropping out further east.

ASMRP 10: Carboniferous shallow coal resources

Shallow coal resources, potentially suitable for opencast extraction or shallow mining, occur within the Carboniferous coal measure sandstone outcrops within Craven District. Whilst these resources have been worked in the past they are no longer viable. Shallow coal, concealed by up to 50m of overburden (including Magnesian Limestone resources) also occurs to the south of Tadcaster. These resources represent an easterly continuation of the exposed outcrops (including primary opencast resources) which occur within neighbouring West Yorkshire and South Yorkshire, and the same resources also continue further east at greater depth, within the Selby Coalfield, where coal was extensively worked by deep mining until 2004. Given their proximity to more accessible resources, it is unlikely that the shallow coal in this area will be exploited in the foreseeable future.

ASMRP 11: Carboniferous brick clay resources

Seams of mudstone and 'fireclay' within the Carboniferous coal measures have been extensively worked, as raw materials for brick and tile making, in most coalfield areas of the UK. The fireclays, which occur in thin beds directly beneath individual coal seams, have always been extracted as a by-product of coal production, and their future extraction is therefore intimately dependent on that of the coal. Resources occur along the western edge of Selby District but are concealed beneath a significant thickness of overburden, including Permian Limestone resources and the likelihood of future extraction would seem to be very limited.

ASMRP 12: Carboniferous sandstone resources

Sandstones occur throughout the Carboniferous coal measure series and have been utilised in the past for walling stone but are no longer commercially exploited. Better quality building stone is obtained from some of the sandstones towards the top of the underlying Carboniferous Millstone Grit series, and it is these which are picked out on the BGS resources map and represented by ASMRP 12. The identified resources crop out within parts of Craven District and further east, directly to the north of Harrogate and Knaresborough. None of these outcrops is currently worked however, either for aggregates or building stone, although there may be intermittently worked quarries in some areas that are used as sources of stone for the repair of local historic buildings. There are however, a number of sandstone quarries in other parts of the county, which are worked primarily for use as local building stone.

ASMRP 13: Carboniferous and Jurassic silica sand resources

Two separate, small areas of silica sand resources are identified on the BGS maps. The first of these, around the village of Blubberhouses, to the west of Harrogate, forms part of the Carboniferous sandstone sequence. The deposit has been worked in the past but is no longer active. The second area is located to the south of Malton in Ryedale District, and forms part of the Jurassic Scalby Formation.

ASMRP 14: Carboniferous limestone resources

Carboniferous Limestone occurs within the central part of Craven District, and more extensively within Richmondshire District. Smaller outcrops occur to the south west and north-west of Pateley Bridge in Harrogate District. Given the importance of hard Carboniferous Limestone as a major source of construction aggregate, the deposits are quarried in both of these areas. All of the resources provide both existing and potential future sources of high quality construction aggregate, with the possible exception of some of the thinner limestones within the Yoredale Series, which may not be economically viable.

Landscape Evolution Within The Resource Areas

The progressive evolution of the landscape in North Yorkshire, particularly since the end of the last glaciation, is of major importance in understanding both the distribution of mineral resources and the creation of other natural and man-made assets, all of which need to be managed successfully in the context of long-term sustainable development. Throughout this period, substantial variations in climatic conditions and a progressively growing impact of human activity have interacted to produce a complex sequence of changes in natural vegetation, active geomorphological processes, land use, settlement and land management practices. As a consequence, the modern landscape represents a 'palimpsest' (cumulative record) of past events, activities and interactions.

Building on this, the notion of 'predictive landscape modelling' allows for expectations regarding likely archaeological potential or environmental sensitivities (for example) to be developed for areas where substantive evidence is currently lacking. This, in turn, allows more informed decisions to be made regarding the planning and control of future development, including mineral extraction, particularly in terms of the focus required in pre-application studies, and regarding the design concepts to be used in future restoration schemes. Predictive landscape modelling and (more generally) an understanding of landscape evolution are therefore important starting points for the effective management of future landscape change.

In areas where there is scope to examine available evidence in great detail (for example in the case of individual planning applications), and in areas which have been subject to more comprehensive research programmes, such as the recent ALSF (Aggregates Levy Sustainability Fund) funded studies of the Swale-Ure Washlands (Bridgland et al., 2011), the predictive element of this can be done with a reasonably high degree of confidence. More generally, however, it is still possible to identify some of the major influences on landscape evolution across broader areas by piecing together the evidence from previous studies within comparable locations and environmental settings. The following account, greatly distilled from that produced for the NYCC research project, provides a starting point for understanding landscape evolution in different parts of North Yorkshire.

The best example of this, because of its close association with sand & gravel resources, and because of its importance to the overall story of landscape evolution in the area, is the relationship between Man and his changing environment within the major river valleys (including ASMRPs 1 and 2), throughout the post-glacial period. Here, in particular, there have been demonstrable cause and effect relationships between climate change, landform development, vegetation succession and human activity. The latter has both responded to, and increasingly influenced, the other factors. Whilst similar, but different relationships are found in most other ASMRP groups, and are fully detailed within the main research report (Thompson et al., 2012), for the sake of brevity this paper focuses purely on the example of the major valley systems.

Figure 3, below, illustrates the relationship of river valley deposits (ASMRP 1, river floodplains and ASMRP 2, river terraces) to other ASMRPs within the surrounding landscape. Although precise details vary from one location to another, the section illustrates how these fluvial sediments form flat, low-lying areas which are often incised into older Quaternary glacial (ASMRP 4) and glacio-fluvial (ASMRP 3) sediments. This particular example extends from south west to north east just to the north of Ripon. Although the surface profile and the surface positions of the ASMRP outcrops are accurate, the sub-surface detail and the distribution of glacial till (pale blue) are schematic (though informed by previous research carried out in this area; Thompson et al., 1996).

River deposits within the region accumulated at various stages during the post-glacial Holocene period, through the reworking of older glacial and glacio-fluvial sediments within high energy braided river environments. In some areas (Powell et al., 1992; Cooper & Burgess, 1993; Thompson et al, 1996; Frost, 1998) these deposits form part of a complex sequence of sedimentary infills within over-deepened palaeo-valleys. Such valleys were carved initially by Quaternary glaciers and sub-glacial rivers and the oldest sediments within them are overlain by Late Devensian glacial tills, as illustrated in Figure 4. This cross section is entirely schematic, but is comparable to the eastern part of the profile shown in Figure 3.

It seems likely, however, that the valleys were partially re-excavated by the river systems of the early Holocene period. At that time, the supply of sediment from upland areas was reduced by the retreat of the ice sheets and by the subsequent rapid growth of stabilising vegetation as climatic conditions improved. Woodland covered almost all the land surface of the Swale-Ure Washlands during the early and mid-Holocene (Innes, 2002). Being relatively 'starved' of new sediment, the rivers were able to cut down into the older deposits and associated landforms – a process that is likely to have been enhanced by isostatic uplift of the land surface following the retreat of the ice sheets (Bridgland et al., 2011;

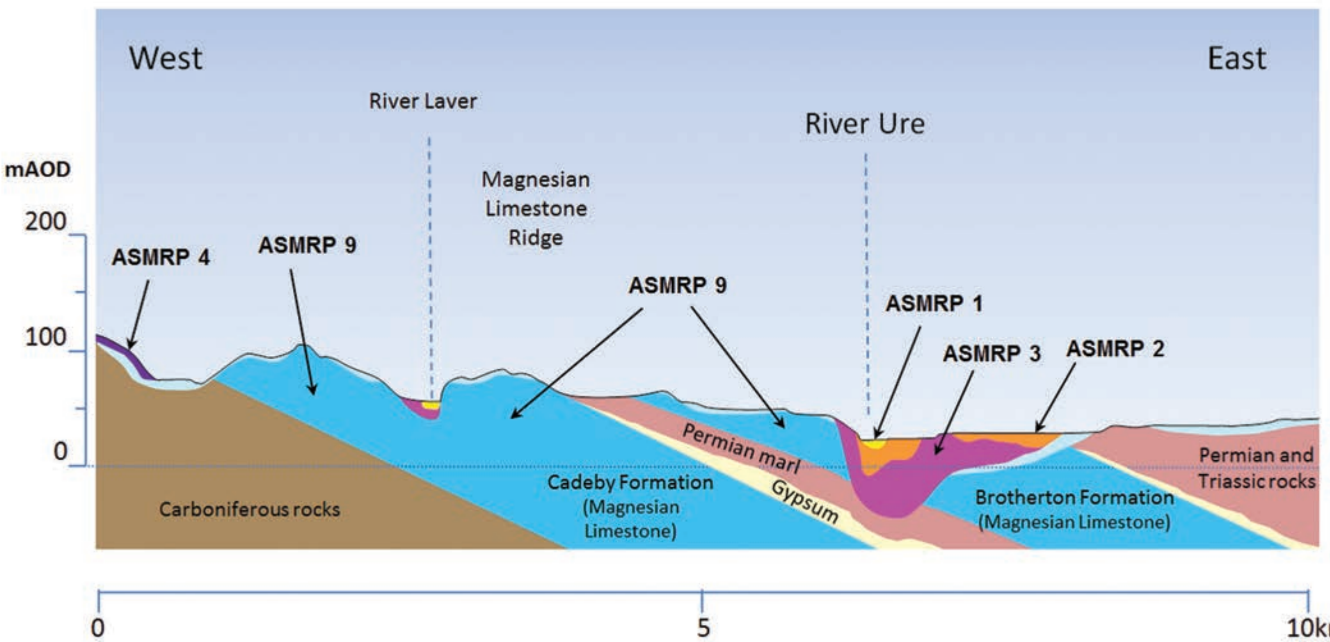

Figure 3. *West to east topographic profile and schematic geological cross section to illustrate the relationship of ASMRPs 1 and 2 to the surrounding landscape.*

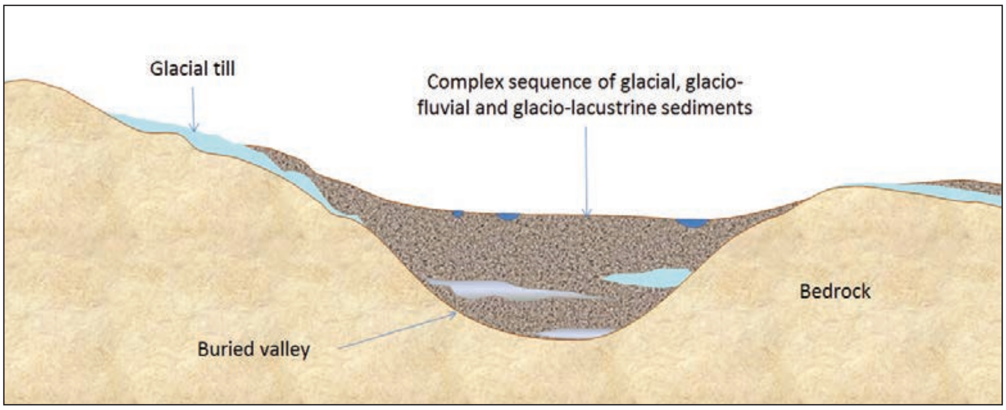

Figure 4. *Schematic cross section through a Pennine valley at the end of the Devensian glaciation.*

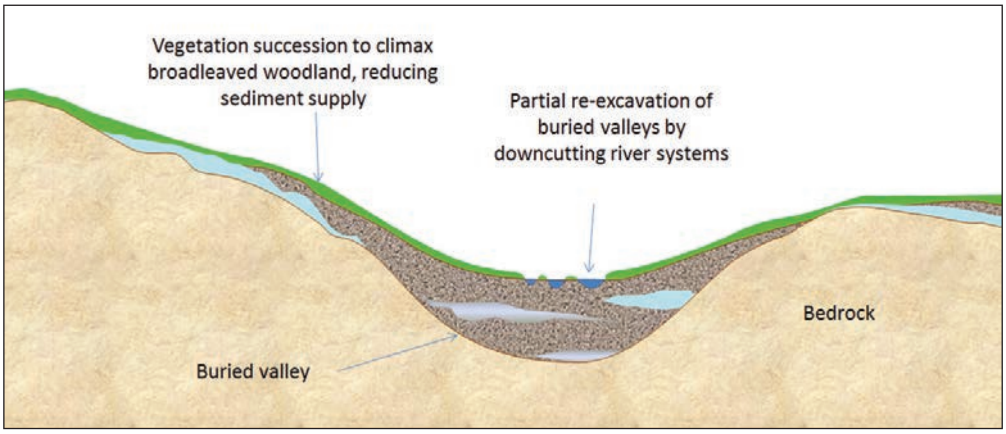

Figure 5. *Schematic cross section through a Pennine valley during the early Holocene.*

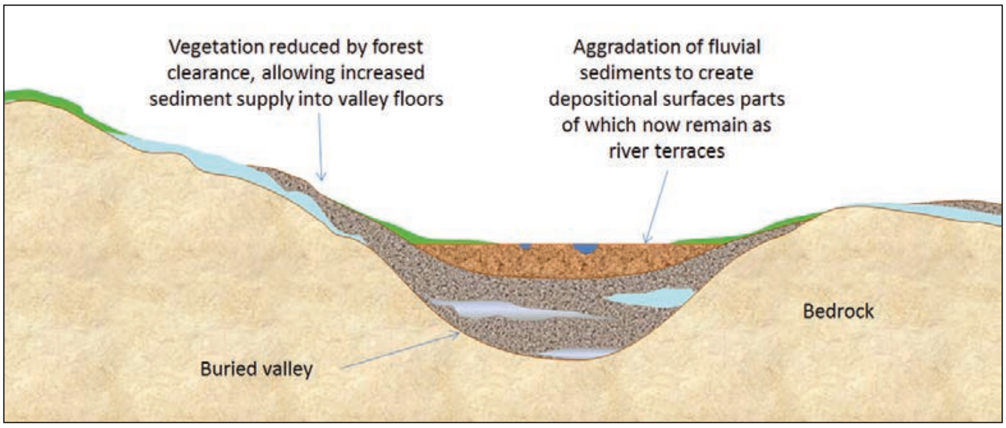

Figure 6. *Schematic cross section through a Pennine valley during the mid-Holocene.*

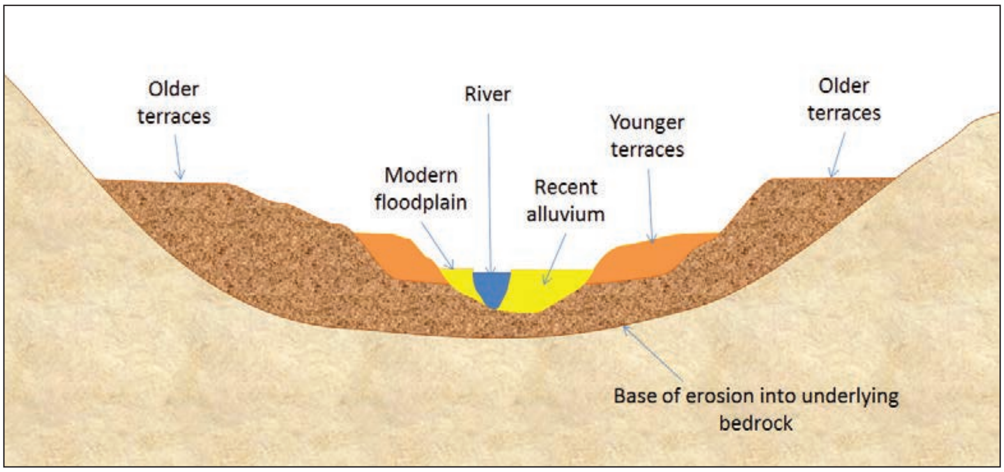

Figure 7. *Schematic illustration of the detail of Holocene cut and fill sequences within a river valley.*

Shennan et al., 2006; Howard et al., 2000). Figure 5 provides a schematic illustration of this stage of landscape evolution during the early to mid-Holocene.

From the Mesolithic period there is pollen evidence of a decline in upland tree species associated with the use of fire by hunter-gatherers, leading to the establishment of heath, bog and grassland over wide areas (Simmons and Innes, 1985). More widespread disturbance, through the permanent clearance of trees for animal husbandry and crop cultivation, occurred from the early Neolithic period onwards, around 5,000 years BP (Before Present). Evidence for this is seen in the 'Elm Decline' - a marked and widespread reduction in Elm pollen (*Ulmus sp.*) from around this time, accompanied by a rise in cereal pollen from arable farming. The process accelerated considerably, both in spatial extent and intensity, during the latter part of the Neolithic and into the mid Bronze Age (Bridgland et al. 2011). This was a time when the level of human settlement and activity in the area greatly increased – not least in response to a period of warmer and drier climate which allowed expansion of farming into previously unfavourable areas.

Throughout this period, from before 5,000 BP to around 3,000 BP, it is likely that river valleys would have experienced considerable net aggradation, i.e. the accumulation of sediment to higher levels than those of both pre-existing and present-day rivers (Figure 6). The sediments, being contemporaneous with Mesolithic to Bronze Age human activity, both incorporated and buried older archaeological evidence, whilst the depositional surfaces (remnants of which now form the highest river terraces), retain evidence of land use and settlement from these and subsequent periods.

Within this period, as Neolithic settlers began to make their mark on the landscape, some of Yorkshire's most important prehistoric features were created. These included the three henges at Thornborough, which are almost perfectly aligned with the one at Nunwick, north of Ripon and also linked with the largely destroyed henge at Catterick, further north. The henges at Thornborough were constructed on ASMRP 3 sand & gravel deposits, slightly above the aggrading deposits of the Ure valley, whilst those at Nunwick and Catterick were built on slightly lower ASMRP 2 terrace surfaces.

Interestingly, all five of these henges, as well as being located close to major rivers, were also constructed very close to the narrow outcrops of Permian gypsum deposits and two more henges to the east of Ripon (Hutton Moor and Cana Barn) are not far from the same outcrops. Gypsum (alabaster) is known to have been used in covering the earthworks of at least the central henge at Thornborough (Burl, 1976), giving it a brilliant white sheen visible for miles around within the landscape.

The conversion of the former depositional surfaces into the terrace features seen today resulted from subsequent downcutting by the rivers, interrupted by periods of renewed aggradation to produce complex 'cut and fill' sequences in many of the valleys, as illustrated schematically in Figure 7. The incision was driven partly by continued isostatic rebound of the uplands, but the process was also strongly influenced by the effects of ongoing climate change – both directly, in relation to the hydrology and delivery of sediment from upland catchments, and indirectly through its effects on farming practices and tree clearances.

Evidence from peat stratigraphy and other sources, summarised by Bridgland et al. 2011, shows that there was a marked climatic deterioration towards the end of the Bronze Age, from about 3100 to 2500 ^{14}C BP, with a particularly wet and cold phase near the end of that period, at around 2650 ^{14}C BP. This is likely to have had a strong influence on the distribution and types of land use conducted by late Bronze Age and early Iron Age communities. Palaeo-environmental and archaeological evidence from the region (Bridgland et al. 2011) suggests that this led to the regeneration of woodland, the spread of wetland ecosystems within the valley floors (with associated deposition of fine-grained overbank flood deposits) and the near absence of forest clearance and agriculture within upland areas.

During the late Iron Age and Roman periods which followed, environmental and cultural conditions were profoundly different to the preceding wet phase of the early Iron Age. Climate studies suggest that a dry and warm phase began about 2400 ^{14}C BP and lasted for several centuries. This greatly reduced the incidence of overbank flooding and alluviation (Macklin et al., 2000), so that much of the lowland in the Ouse system became drier and more stable and thus available for intensive agricultural exploitation. Environmental evidence also suggests that most areas experienced a high level of renewed forest clearance in the late Iron Age, and that this continued into and through the period of Roman control.

Thereafter, during the medieval period, there appears to have been a relaxation of human pressure on the landscape and a widespread regeneration of woodland. Throughout this time, from the late Iron Age to the early to mid-medieval period, human activity took place on what were then the valley floors, but which have since become low river terraces, following subsequent further incision to form the modern floodplains. These terraces would originally have been characterised by extensive wetland environments and dense vegetation. Habitats such as this would have been extensively engineered by European Beaver (*Castor fiber*) until it was finally hunted to extinction in Britain in the sixteenth century. This would have resulted in a dynamic environment consisting of a mosaic of woodland, woodland edge and open water which would have been of high ecological value. The re-creation of such environments, through the innovative design, reclamation and long term management of sand & gravel workings within river valleys, represents an important ecological objective to be considered alongside other factors, relating to landscape character and the historic environment.

Subsequently, during the much drier and warmer climate which characterised the late Iron Age to the Roman era (around 2,400 to 1,500 BP), many of these areas would have been progressively reclaimed for agriculture, a process assisted by the gradual further incision of the rivers down to their present levels, which left the terraces as higher surfaces of well-drained land, less frequently inundated by flooding.

Human occupation has progressively transformed the natural habitats through altering the fauna, felling forests, drainage, agriculture and built development. In places a good diversity of species still remains, but the residual habitats are much denuded, resulting in fragmented (and consequentially fragile) populations. Whilst this underpins the importance of protecting such habitats from further degradation, it also highlights the importance of using imaginative quarry reclamation schemes to create new habitats and to re-establish the wildlife corridors and other linkages that have been lost.

Dating evidence from various sources suggests that most of the present-day floodplains are features of the last millennium and that, in many cases, they are of much more recent origin, having been reworked by the active migration of meandering rivers and/or progressively covered by overbank flood deposits within the last few hundred years. For this reason, the antiquity of archaeological evidence preserved on modern floodplain surfaces is typically limited to the last 200 to 1,000 years.

More generally, the most important distinguishing feature of all surviving fluvial deposits is that they post-date all other mineral deposits in the region, including glacial, glacio-fluvial and glacio-lacustrine sediments, and that they have developed in parallel with human occupation. Crucially, this means that each successive phase of fluvial deposition has buried and/or reworked and redistributed any evidence of earlier occupation or land use; and that any evidence preserved at the surface can only be expected to date from the time of the last reworking of the sediments by the shifting course of the river. In the case of the oldest post-glacial terraces this may be up to around 3,000 to 5,000 years ago (Neolithic to Bronze age), although the deposits beneath those surfaces may well contain or overlie evidence dating from much earlier periods, as far back as the early Holocene (Mesolithic), up to around 11,000 years ago. This contrasts with all other ASMRPs, where the deposits existed prior to any known human activity in the area, and where archaeological evidence can therefore only be expected to be found at or very near the surface.

Linking Landscape And Environmental Characteristics To Future Planning Policy

The sequence of landscape evolution, as exemplified by the foregoing account of the major valley systems, formed only one of several elements of analysis carried out in the NYCC research project. Other aspects included a strategic review of the present day landscape and environmental characteristics; consideration of the potential impacts associated with different types of surface mineral extraction; and broad assessments of the sensitivity of different areas to such impacts, and of the capacity of these areas to accommodate landscape change. Full details of the findings of those elements of the study can be found in the various reports available on the NYCC website (North Yorkshire County Council, 2013), but a very brief overview is given below.

Environmental Characteristics

In terms of properly understanding the environmental 'baseline' characteristics of the various ASMRPs, the research highlighted the importance of adopting an integrated, holistic approach, taking account of the landscape and historic environment as well as natural environmental features, and developing an appreciation of the various inter-relationships involved. This is important, not only in terms of landscape evolution to date, but also in terms of managing future landscape change. Although the observations compiled in this strategic assessment were necessarily very generalised, they gave quite different impressions to those which would be gained from an assessment of formal designations alone (such as SSSIs, nature reserves and Scheduled Ancient Monuments). Whilst designations are, by definition, very important, and whilst they carry with them policy and/or statutory requirements in terms of their protection, they cover only a small proportion of the landscape and only provide a partial image of the environmental features and sensitivities involved. They cannot therefore be used to characterise the overall environmental qualities of any given area. Moreover, the absence of formal designations cannot be taken to imply an absence of historical significance or scientific interest as there may well be sites that have not been previously recognised or recorded. In addition, protecting isolated designated sites has only limited benefit in terms of wider conservation and sustainability objectives. There is a profound need to take account of the bigger picture so that optimum benefits can be gained by joining up ideas and restoring lost connections.

Potential Impacts Associated with Mineral Extraction

Mineral extraction inevitably gives rise to localised environmental impacts and often to other impacts over the wider landscape, particularly where the impacts are cumulative and/or on a large scale. Whilst many impacts can be mitigated, to varying degrees, the excavation and removal of mineral unavoidably changes the shape of the land and removes existing landscape features, habitats and archaeological material. In doing so, it also creates noise, dust, traffic and carbon emissions which otherwise would not exist. Quarrying may also disrupt the natural flows of groundwater and surface water, both physically and in terms of water quality, and this, unless properly mitigated, may have impacts on habitats and ecosystems in the areas which surround the quarry.

All types of impact are a function of both the intrinsic features of the operation (e.g. the level of noise, the amount of traffic, the depth of the void etc., and the effectiveness of the mitigation measures) and the nature and sensitivity of the receptors within and around the location involved. 'Receptors' in this sense range from people, fauna and flora to habitats, water resources, landscapes and various facets of the historic environment. For certain types of impact, which are directly related to the intrinsic type and amount of activity within the quarry (e.g. dust, noise, vibration, traffic), it is easier to identify generic distinctions between different types of working. For other types of impact, however, (e.g. on landscape, archaeology, habitats and species), it is the receptors which actually define the impact, and which are therefore far more important in determining the likely scale of potential adverse effects.

Consideration must also be given to cumulative effects, which can be a major issue where two or more quarries are located in close proximity to each other, either simultaneously, during the operational phase, or sequentially. In the first case, problems may arise from the compound effects of such things as noise, dust, traffic and the drawdown of water tables associated with dewatering from multiple locations. Whilst the effects from any one of the sites may be considered acceptable (subject to mitigation and/or compensatory measures) the cumulative effects of two or more sites within the same area might not. In the second case, where adjoining sites are developed sequentially, as is often the case with sand & gravel extraction within wide floodplains or river terraces, the operational impacts may be capable of adequate mitigation and management, but the consequences of working in terms of reclamation schemes and their relationship to the surrounding landscape might not be. This is especially likely where reclamation is partly or wholly to open water: the original landscape can become transformed into a pattern of isolated lakes, resulting in a complete change of character. Whether or not this is acceptable will depend on the sensitivity of the original landscape, including its historic and natural environment characteristics. In some cases, the progressive creation of a new, water and wetland-dominated landscape may have biodiversity, amenity and visual benefits which, if developed sensitively and as an integral part of appropriate landscape measures and vision, might outweigh any adverse impacts. But in other cases the changes will be more finely balanced or, in some cases, completely unacceptable.

It is increasingly being demonstrated that some impacts can be managed in such a way as to create positive environmental benefits in the longer term. This includes certain impacts on biodiversity and geodiversity, where quarrying often provides opportunities for substantial enhancement, compared with existing, baseline conditions, including the reconnection rather than fragmentation of existing habitats. Quarrying frequently provides opportunities for large scale changes to the physical form of the landscape. Whilst this can be damaging where the existing landscape is highly valued, in other cases, through sympathetic landform design, high quality implementation and effective long-term management of agreed reclamation schemes, it can also lead to the creation of harmonious and imaginative new landscape features and habitats which, in turn, may become highly valued in their own right. The potential for long term improvement differs markedly between the natural and historic environments. In the former case, although biodiversity can be harmed in various ways by mineral extraction, in the longer term it can also be markedly enhanced through high quality restoration and aftercare. By comparison, damage to the historic environment is permanent (though it can be compensated to some degree by investigation, recording, analysis and dissemination/outreach activities).

Assessment of Environmental Sensitivity and Capacity

The consideration of environmental sensitivity, as used in this study, attempted to deal with the intrinsic vulnerability of the natural and historic environments to potential impacts, irrespective of any mitigation measures that may be put in place. This was not to deny the importance of mitigation, merely to focus (initially) on vulnerability.

The starting point was to recognise that most forms of potential impact associated with surface mineral working will apply to all geographical areas and environmental settings, and that policies relating to the control of these impacts will therefore largely be generic across all areas. The analysis therefore attempted to identify the 'special' sensitivities (whether higher or lower than 'normal') that may be associated with particular areas, either because of the intrinsic characteristics of the landscape, historic environment or natural environment in those areas, and/or because of the type of mineral extraction likely to be involved, and its associated potential impacts.

In order to do this, some initial concept was needed of what is 'normal' and how this can be differentiated from what is 'special'. This would be extremely difficult and controversial to establish in any quantitative way, even for individual issues, but an attempt was made to provide more general, qualitative definitions that could be used to guide professional judgement. Across all three of the topic areas under consideration (i.e. landscape, historic environment and natural environment), the assessment sought to encompass the concepts of quality, uniqueness, significance and vulnerability. Further details are given in the main report (Thompson et al., 2012).

Environmental capacity is generally regarded as the inverse of sensitivity: the greater the sensitivity of a particular area to a specific type of development then, other things being equal, the lower the capacity of that area to accommodate further impacts from such development. However, capacity is also affected by a number of other factors: the specific nature of the sensitivities compared with the likely impacts of the proposed development; the size of the area compared with the scale of potential impacts; the extent to which the area has already been affected by previous extraction and associated reclamation schemes; and the potential to mitigate the likely effects of future mineral extraction, including cumulative effects within a given area. A key tenet of the planning system is that conditions can be imposed on a planning permission which will control development in such a way that it can be allowed to proceed in situations where this might not otherwise be acceptable. For the purposes of this study, therefore, the assessment of capacity was based on a consideration of both the intrinsic sensitivities and the potential for mitigation and enhancement. Again, further details are given in the main research report (Thompson et al., 2012).

Key Principles For Future Mineral Extraction In North Yorkshire

The research outlined above has provided a broad appreciation of the complex inter-relationships that exist between all aspects of the landscape, the natural environment and the historic environment. It also provided an understanding of the varying degree and nature of the environmental sensitivities involved, and of the wide range of potential impacts and corresponding mitigation and monitoring techniques which may need to be applied. On the basis of this understanding, and on the basis of existing good practice demonstrated by mineral operators, a number of key principles were identified as being important components of a successful strategy for managing future landscape change associated with mineral development in North Yorkshire. These relate, in part, to the development of an overall strategy, by North Yorkshire County Council, but also to the work which would need to be carried out by individual mineral operators as they prepare future planning applications. They may be summarised as follows:

- **Integrated understanding**: the development of a comprehensive awareness of the wider landscape surrounding the site of a development proposal or in the general area of potential future site allocations, including the historic environment and natural environment components, and their interactions over time. At the detailed level of specific proposals this can be expressed in the form of a conceptual 'predictive landscape model' which is then used to focus pre-application research to inform the location and design of the proposal;
- **Spatial planning**: the need to integrate the spatial requirements for current and future minerals development with those of other relevant factors, including the distribution of mineral resources, the occurrence and significance of environmental and other planning constraints (including existing and planned development); the geographical distribution of likely future demand; and alternative sources of supply. These are issues which need to be examined in considering alternatives for individual proposals, as well as in the formulation of policies, strategies and plans;
- **Long-term vision**: in relation to the development proposal, the landscape and environment involved and to the successive involvement of relevant personnel. This includes the need to consider mineral development as part of a continuum of landscape change, not only within the timescale of an individual Development Plan or planning application, but over a much longer period of time, in order to recognise and fit in with other environmental, climatic and land use changes that are likely to occur. To include the concept of 'dynamic baseline monitoring'[1];
- **Environmental Impact Assessment**: a normal requirement of most minerals planning applications, this should form an integral part of the design process, informed by a sound, integrated understanding of the environment and of the 'ecosystem services' provided by the various components of the landscape - both now and on completion of quarrying and reclamation;
- **Imaginative design** and the **creation of environmental benefits**: designing to ensure that adverse impacts are avoided or mitigated, that the proposal fits in with and (where possible) enhances the surrounding landscape, and that opportunities for creating environmental benefits during final reclamation are optimised through the imaginative design of the excavation itself. Again, this process can benefit from the balanced consideration of individual ecosystem services;
- **Monitoring**: planned strategies to ensure that progress and potential impacts are adequately and efficiently monitored, and that monitoring results are properly assessed so that, where necessary, they can trigger mitigation measures or changes in implementation, aftercare and management, and also the design of further extraction;
- **Mitigation Measures**: designed on the basis of a good, integrated understanding of the wider landscape (see above) and using demonstrably effective mitigation methods. Where uncertainty exists, staged or tiered mitigation strategies, linked to ongoing monitoring which provides early warning of impending impacts, allow the 'precautionary principle'[2] to be used; and
- **Compensatory Measures**: used as a last resort where there is an over-riding need for mineral extraction but where certain impacts cannot be avoided and adequate mitigation cannot be achieved.

It is important to emphasise that these general principles, and the more detailed recommendations which derive from them (as detailed in the main research report; Thompson et al., 2012), are suggestions rather than prescriptive requirements. The recommendations are deliberately front-loaded, in line with the requirements of the planning system itself. Particular emphasis is placed on the importance of pre-application research and investigation to ensure that development proposals are brought forward in the most suitable locations, and to facilitate the creation of sympathetic designs which are compatible with the surrounding landscape and environment.

Conclusions

North Yorkshire has a considerable wealth of mineral resources, the exploitation of which can help to support economic growth. It also has a very rich diversity of high quality landscapes; significant heritage assets relating to millennia of human occupation; fragmentary remains of very diverse and formerly more extensive natural and semi-natural habitats; and considerable opportunities for enhancement in all of these areas. It is therefore of paramount importance that the ongoing need for mineral extraction is properly balanced against the need for environmental protection and that all opportunities for enhancement associated with the reclamation of mineral sites are harnessed to optimum effect.

With this in mind, the Managing Landscape Change research project has brought together evidence relating

[1] The concept of 'dynamic baseline monitoring', in which the long-term impacts of mineral development are monitored against the observed, changing background of other, ongoing and independent aspects of environmental change, rather than just in relation to pre-operational baseline data, has been proposed within guidance relating to the control of impacts of surface mineral workings on the water environment (Thompson et al., 2008). In principle, it also has much wider applicability to other aspects of the natural environment and land use change, and allows for sensible adaptation of long-term reclamation plans.

[2] The 'Precautionary Principle' is a basis for adopting a cautious approach to regulating development which may otherwise cause damage to the natural environment. The concept was first defined as Principle 15 of the Rio Declaration, 1992 (United Nations, 1992) which states: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". This can be reflected in a number of different approaches. Planning permissions may be subject to incremental stages (e.g. one bench at a time for deep hard rock quarries), whereby each stage is subject to the satisfactory performance of mitigation measures in the previous stage and to the review of operational monitoring data. Alternatively, or in addition, where the likelihood of the risk is low but cannot be ruled out, this could be reflected in a staged mitigation strategy which requires certain measures to become mandatory in the event that the assessed likelihood of serious impact is increased through the results of routine operational monitoring.

to landscape, the historic environment and the natural environment and has demonstrated how all of these are inextricably linked together. This, in particular, has strongly influenced the identification of key principles relating to the way in which a more sustainable approach to future mineral extraction might be developed, and the over-arching need for an integrated, multi-disciplinary approach, rather than dealing with individual issues in isolation. It has also highlighted the importance of adopting a long-term vision which allows the design of mineral extraction sites and their eventual reclamation to be integrated as fully as possible with existing landscape character and environmental assets, allowing for the likely influence of future climatic and environmental change.

All of this can help to optimise the generation of long-term benefits associated with the reclamation of mineral sites (incorporating cultural, aesthetic and economic benefits as well as those associated with the natural environment). This is a vital component of minerals planning, but of greater importance still is the need for the avoidance and/or adequate mitigation of impacts associated with mineral extraction itself. Whilst many impacts can be minimised through the adoption of best practice mitigation and monitoring techniques, it should not be assumed that this will always be possible. For this reason, seeking to avoid adverse impacts through well-informed spatial planning is of paramount importance.

As a starting point, this project has attempted to provide a broad, strategic assessment of sensitivities relating to the historic and natural environments and to the wider landscape, and the resulting capacity for further mineral extraction. Whilst this provides some degree of guidance, focusing on the 'special sensitivities' of different areas as indicated by known aspects of their landscape character and environmental features, it also recognises that most sensitivities will require site-specific detail in order to be properly assessed. This is reflected in recommendations for detailed pre-application research by mineral operators, for areas surrounding their proposed extraction sites, so that conflicts with highly sensitive features can be avoided.

Emphasis throughout the recommendations is placed on the integration of knowledge relating to all different aspects of the landscape and the environment. This is needed in order to build understanding and to engender high quality, imaginative designs and mitigation measures which enable potential adverse impacts to be avoided or adequately controlled, and which allow for optimum enhancement of existing features. In this way, future mineral extraction will be able to contribute as fully as possible to the delivery of ecosystem services and to the goal of sustainable development.

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