A GEOMORPHOLOGICAL FRAMEWORK & DECISION TOOL FOR HABITAT TRANSLOCATION PRACTICES IN THE UK[1]

R. N. Humphries[2]

Abstract: With the continuing increase in population and growth in per-capita wealth there is ever more land taken for development and use of natural resources. Over the past 30 years this has resulted in significant losses of biodiversity occupying land within developments or resource footprints. Habitat translocation has become a frequently advocated and used technique in the UK, USA, Australia, and elsewhere for mitigating the adverse effects of development, including mining.

Three mechanised translocation techniques are frequently used in the UK and the choice can have a bearing on the level of success achieved. Guidance for which to use for a particular site is notably absent leaving the practitioner to decide on commercial or other arbitrary grounds. The objective of this paper is to formulate a Framework and Decision Tool that can be used by planning authorities, regulators, scheme designers and developers to select and evaluate techniques specifically for herbaceous (e.g., grassland, swamp) and dwarf shrub (e.g., heathland) vegetation.

There is a long established scientific base on which a Geomorphological Framework and Decision Tool for translocation can be developed. There are comprehensive data sets for landform, soils and climate in published or accessible form for the UK, and guidance that integrates these in a meaningful manner for predicting the safe and efficient cultivation of soils and vegetation by agricultural machines in various landform and soil scenarios.

Eight case histories are used to provide evidence that Geo-morphology (landform (gradient) and soil characteristics (profile thickness, stoniness, strength)), with adjustment for climatic (wetness/dryness) is a common factor determining the success of translocation technique, and that established criteria for agricultural machinery can be used as a Framework for a Decision Tool. The tool devised is a simple decision-tree based on a hierarchy of the differentiating criteria of gradient, soil thickness, and soil stoniness and strength.

Additional Key Words: landscape, landform, vegetation, turf

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[1] Paper was presented at the 2010 National Meeting of the American Society of Mining and Reclamation, Pittsburgh, PA ***Bridging Reclamation, Science and the Community*** June 5 - 11, 2010. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Neil Humphries, Visiting Professor at National Soils Research Institute, University of Cranfield and Vice President, URS Corporation, Derwent Business Centre, Clarke Street, Derby DE1 2BU, United Kingdom.

Proceedings America Society of Mining and Reclamation, 2010 pp 449-467
DOI: 10.21000/JASMR10010449
http://dx.doi.org/10.21000JASMR10010449

Introduction

With the continuing increase in population and growth in per-capita wealth there is ever more land taken for development and use of natural resources. Over the past 30 years this has resulted in significant losses of biodiversity occupying land within developments or resource footprints. Habitat-vegetation translocation has been seen for some time as a means of mitigation and maintaining biodiversity under such pressures (Humphries, 1979). Habitat translocation has become a frequently advocated and used technique in the UK, USA, Australia and elsewhere for mitigating the adverse effects of development, including mining.

Habitat translocation in the UK has not been without controversy. It has been seen by the nature conservation regulators as developers justifying the loss of important, often legally protected sites and has been the topic of debate and disagreement at all levels in the UK planning process McLean (2003). Typically, the regulator's position being that the translocations, even if successful, are artificial and cannot reproduce the intrinsic scientific interest of the site and all of its interrelated components and historical contexts, besides which translocations usually fail with loss of species (Jefferson et al., 1999). Whilst, it is the case some elements cannot be replicated, the technique is better understood and practiced, and the main plant elements can be maintained provided the receiving site is not dissimilar to the donor and management continues (Horton & Benyon, 1994; Humphries, Horton and Benyon, 1995; Humphries, 2000a, Humphries, 2001).

Despite the hostility, translocation as practice is now generally an acceptable form of mitigation in terms of planning guidance in the UK (depending on the site's legal status and type of development) where the development is of overriding importance and where there are no alternatives (Anderson, 2003). The wider value of translocations are increasingly being appreciated in terms of contributing to community benefit and feeling of well-being with the enhanced landscape value they bring to schemes compared with planting approaches.

However, many factors may influence and determine the use of the technique in practice, of which cost and timing are usually in the forefront. It can be a costly operation because of the need to use machines and transport the material over substantial distances. Timing of the translocation can be an issue because of seasonal variation in condition of the site and soils affect the operational precision and ease of access and transport. Hence, it should not be a mitigation technique that is adopted without due consideration of its necessity and achievability.

The translocation technique used can have a bearing on the level of success achieved and operational efficacy according to the geomorphological setting and circumstances (i.e., landform, soil types and climate). Guidance for which translocation technique to use for particular site conditions is notably absent even in the current best practice guidance publications, such as Anderson (2003), leaving the practitioner to decide on commercial or other arbitrary grounds. The concept of providing reliable guidance has already been discussed (Humphries, 2008). The objective of this paper is to present the development of a scientific based Framework & Decision Tool for planning authorities, regulators, scheme designers and developers to select and evaluate proposed techniques for specifically herbaceous (e.g., grassland, swamp) and dwarf shrub (e.g., heathland) vegetation.

Methodology

Translocation as a Procedure

In summary, the translocation of herbaceous and dwarf shrub vegetation involves the sequential lifting of the target vegetation and supporting soil layers from their current location, and their transportation to and replacement in another. The translocation may involve the sequential movement of the complete soil profile or just the vegetation and topsoil. Two principal techniques are deployed, either the lifting of Intact Turf as blocks of vegetation and soil, and the relaying as a 'carpet' (i.e., continuous turf) or as turf 'patches', or as Turf Fragments which comprise mechanically shredded vegetation and topsoil (which can also be placed as a carpet or patches). Different machines are employed in each case, for the Intact Turf approach this is either using a front-loading flat blade-shovel powered by an excavator or loading-shovel (here the action is a slicing/under cutting the target vegetation/soil horizon) or by a back-acting bucket power by an excavator and using a digging motion. The Turf Fragment approach involves cultivators as fixed-tynes or powered rotorvators drawn by tractors with the cultivated vegetation and soils lifted by excavators or mechanised shovels in to dump trucks.

The Scientific Basis for a Geomorphological Framework & Decision Tool

There is an existing scientific base on which a Geomorphological Framework and Decision Tool for translocation can be developed. Firstly, there are comprehensive data sets for landform, soils and climate in published or accessible form for the UK. Secondly, there is long-standing science based guidance that integrates these in a meaningful manner for predicting the safe and efficient cultivation of soils and vegetation by agricultural machines in various scenarios (Bibby et al., 1982; Ministry of Agriculture, Fisheries and Food, 1988). They have been deployed on a wider landuse planning and evaluation basis (Humphries and McQuire, 1994; Humphries, 1995). Furthermore, they have been used in the development of the UK guidance for handling soils by earthmoving machines in mining and other large-scale developments (Humphries, 2000b). The same science and data-base has potential for the development of a Framework & Decision Tool for selecting translocation techniques for a given a set of landforms and soil circumstances.

<u>Landform (Slope & Micro-relief)</u>. Gradient (slope) is a significant attribute of landform and limits the safe operation of agricultural machines and their efficacy. Gradients of 7^{o} (moderately sloping), 11^{o} (strongly sloping) and 18^{o} (steeply sloping) are considered as threshold limits for wheeled machines and operations (Bibby et al., 1982; Ministry of Agriculture, Fisheries and Food, 1988). Other aspects of landform such as aspect and altitude are not strictly influencing the selection of machines for the purpose of translocation (although they may be of significance in terms such as suitability for the target vegetation type and weather conditions (wind, snow cover etc)).

Translocation operations are considered to be sufficiently similar to agricultural ones in terms of access, timeliness and precision required (even though tracked machines may be deployed). A gradient 11^{o} (1:5) is an appropriate threshold limit for operating front-loading machines for Intact Turf. This is because their mode of operation (whether wheeled or tracked) is to force the bladed bucket into the horizon with precision and consistency and then to lift the turf. In any case, the gradient will also be at the limit for safe operation of towed wheeled trailers or dump-trucks to carry the turf. The same applies to the replacement of the turf and other soil horizons; although the latter can be achieved using standard soil handling methods (see Humphries, 2000b).

Operationally, intact turfs could be recovered and laid using a tracked excavator and bucket on much steeper slopes ($>18^{o}$), but this ‘dig and carry’ approach by definition is a low precision technique and is not usually suitable where a high degree of consistent turf thickness and integrity is required.

The Turf Fragment technique by nature has a low degree of precision and there will be more scope to use tracked machines on steep slopes of up to 18^{o} (1:3) or greater using bulk handling routines (where soil can be mounded for loading by excavators and collection by dump-trucks running down slope).

Micro-relief is the local fine grain variation in topography typically taking the form of humps and hollows, rock outcrops, pools etc. This can, depending on scale, have a bearing on safety and efficiency of operations. There is no established guidance for agricultural operations other than to review on a case-by-case basis. However, for translocation of Intact Turf using front-loading flat buckets the technique could be restricted by 3 - 5 m lateral and 10 cm vertical variation in amplitude. The turf fragment and digging with excavator are techniques that are less likely to be restricted by micro-relief.

Flooding. Flooding of lowland valley and wetland sites is a consideration, but probably the same for all techniques. A consequence of flooding is soil wetness and the concomitant consequences for strength and plasticity (see below), and which will influence selection of technique.

Soil Profile Characteristics. The physical nature of the soil profile (i.e., soil texture, soil thickness (depth), stoniness, soil wetness and dryness and hence soil strength), would be expected to have bearing on operational efficiency and hence selection of technique.

Soil texture per se is not considered to be a determining factor for selection of translocation technique, but will have an influence in combination with wetness and dryness, and hence soil strength and plasticity, which are significant in the deployment of agricultural machines (Bibby et al., 1982; Ministry of Agriculture, Fisheries and Food, 1982; Ministry of Agriculture, Fisheries and Food, 1988).

Soil profile thickness of the upper surface vegetated horizon and underlying supporting soils is of significance for agricultural cultivation and will be for translocation techniques. Upper soils horizons of 60 cm (deep) or greater will not be a limiting factor. Profiles of less than 15 cm thick limit agricultural cultivation (Bibby et al., 1982; Ministry of Agriculture, Fisheries and Food, 1988), and will have bearing on lifting, transport and relaying of turf by machines. For this Intact Turf, each horizon lifted by the front-loading shovels should be at least 15 cm thick to maintain turf integrity and (depending on the capacity of the machines being used and soil conditions) probably not greater than 45 cm (in order to minimise variation in thickness between blocks which increases with soil thickness).

For Turf Fragments, the vegetated topsoil horizon will need to be greater 5 –10 cm thick to enable cultivation. Such subsoil thicknesses would not usually be a factor and could be recovered and spread using standard soil handling practices (Humphries, 2000). Excavators using buckets could potentially recover thinner soil layers as may be needed in the case of some communities.

Stoniness, both stone abundance and size are limiting factors for deployment of agricultural equipment, where, a smaller volume of larger stones is the more pernicious than the same of smaller size. It is suggested that thresholds of 35% volume of stones <2 cm size (20% for stones >6 cm) are adopted as these determine if the soils are suitable for cultivation (Ministry of Agriculture, Fisheries & Food, 1988). Front-loading buckets used for Intact Turf are likely to be restricted by very stony (35%) soils and adversely affect the integrity of the turf being lifted. Whilst extreme stony (75%) soils are likely to limit the deployment of the Turf Fragment technique, operationally, it could be more flexible and open to modification to overcome the limitation. Larger stones and boulders (>60 cm) will be more limiting for both approaches, here, the excavator with back acting bucket may be a possible solution.

Depending on location (climate), landform (drainage) and soil type and development (ie texture, structural development), soil wetness and dryness have a considerable bearing on operational efficiency of agricultural machinery and their cultivations (Bibby et al., 1982; Ministry of Agriculture, Fisheries and Food, 1988). This is largely manifest through the effects of wetness and dryness on soil strength and the consequences for cultivation and trafficking. The same is expected to apply to translocation using machines.

The relative strength of the soils varies with soil water content and plasticity from ‘rigid’ to ‘very weak’ (although this may vary with site location, season, weather pattern etc - see Ruddeforth et al., 1984, Jarvis et al., 1984 and Ragg et al., 1984 for examples). Intact Turf techniques such as the lifting by front-loading blade are likely to be suited to moderately firm to strong soils which enable undercutting whilst maintaining precision so that the integrity of the turf blocks on lifting is preserved. Soils such as heavy clays and silts usually increase in density and strength as they shrink on drying (Ministry of Agriculture, Fisheries and Food, 1982) and so become highly resistant to cultivation and tend to shatter in to large lumps. In a dry condition, there will be a high resistance of the soils to under-slicing using front loading shovels to a point that either the integrity of the turf blocks will be compromised through shattering or incompletely undercut. The integrity of blocks could also be at risk when using excavator buckets to dig the turf under these conditions.

In a plastic condition there is a risk that the undercut soil surface using the Intact Turf technique will be smeared or compacted and restrict subsequent root growth. The Turf Fragment technique, which relies on surface cultivation, is likely to be better suited for soils below their plastic limit, but has the potential to be used over a wider range of soil strength categories, but would not be expected to be suitable for very weak saturated soils where integrity may only be possible using excavators with buckets.

Case History Sites

For a translocation Framework and Decision Tool to be useful there needs to be evidence that the landform and soil profile criteria set out above actually differentiate between techniques in practice and produce the successful outcome required. This evidence is provided by reference to eight successful schemes carried out over the past 20 years (where the plant species components were maintained at the new locations) and spanning a range of landforms, soils and climatic conditions in the UK from Scotland in the north to South Wales in the south. In all cases, I have intimate knowledge of the sites and the translocation operations as both the Designer and Overseer of the translocations and their monitoring. The evidence is based on successful schemes, as opposed to a comparison of successful verses unsuccessful schemes. The latter would not be particularly yielding for several reasons including: reliance on incomplete information, unfamiliar sites and operational history. To counter, the question of "would the other translocation technique worked had we used it", alternatives were often tried during the course of our schemes. Over the past 20 years we have gained a comprehensive understanding of what works and what does not. Whilst this is a bias in our evidence base, the scientific evidence from agricultural operations on landforms and soils supports the validity of the approach taken.

The vegetation and species in all the translocations have been monitored for success (as part of the statutory aftercare provisions for restored mineral workings) using the criteria described by Humphries and Benyon (1999). In all cases the translocated vegetation has maintained its character and species, including national rarities. Importantly all the schemes (except Stony

Heap which still has three years of aftercare to complete) have been 'signed-off' by the mineral planning authorities as being successful and meeting in full the conditions attached to the mining consent. At Stony Heap the progress of the vegetation translocation is expected to be equally successful using the predictive methodology of Humphries and Benyon (1999).

Burrowine Quarry, Fife, Scotland. The granting of planning consent to the extension of this slica sand quarry involved the translocation of 5 ha of wet dwarf shrub heathland in 2000. The heathland was deemed by the nature conservation regulating authority to be of national quality (Joint Nature Conservation Committee, 1989), although it had not been notified for legal protection as a Special Site of Scientific Interest (SSSI). The landform was typically middle - upper slope of a valley side and moderately sloping (slope classification following that of Hodgson, 1974), with micro-relief of hollows and pools and wetter/drier types of dwarf shrub communities. The soils were typically a humus iron-podzol of the Rowanhill-Wilton Association (Brown and Shipley, 1982). Similar micro-relief landform and soil characteristics were created in the receiving area (a former silt operational silt lagoon). Intact Turf was excavated by bucket from and around the pools, and the Turf Fragment technique was used for the accessible and drier areas.

Keepershield Quarry, Northumberland, England. The consented extension of the basalt aggregate quarry involved the translocation in 1998 of 5 ha of short acidic and calcareous (with nationally rare plant species) grasslands, and ephemeral communities and using the Turf Fragment technique (although the rarest national rarity was rescued as individual plant species (Humphries, 2001; Richardson, 2009)). Most of the area had been designated as a SSSI, with the rest having a non-statutory nature conservation designation and of local importance. The landform was upper valley side and moderately sloping with a high degree of micro-relief and patterned ground owing to former quarrying activities of the shallow limestone layer over the basalt extrusion. Where present, the soils had an affinity with shallow variants of the Dunkerswick Association (Jarvis et al., 1982). The donor site landform and soil characteristics were recreated a worked-out part of the quarry.

Stoney Heap Coal Mine, Durham, England. The surface coal mine involved the translocation in 2007 of 10 ha of dry to humid grassland communities using the Turf Fragment technique. The grasslands were of local importance and had a non-statutory nature conservation designation.

The landform was mid slope of a valley side with moderately steep slopes with subdued micro-relief of local depressions. The loamy-clayey soils had affinity to the Brickfield 3 Association (Jarvis et al., 1984) and were variable, shallow and stony, and prone to drying and becoming extremely hard. The original landform and soil characteristics were recreated in restoration of the site.

Pithouse West Coal Mine, Derbyshire, England. The granting of planning consent for the Pithouse West surface coal mine involved the translocation in 1987 of 3 ha of swamp and emergent aquatic wetland vegetation by the Intact Turf approach using an excavator with bucket. The wetland was of local importance and had a non-statutory nature conservation designation. The landform was a valley floor basin partially filled with stone free saturated alluvial clay. The soils were derived from clays of either the Dale or Bardsey Associations (Ragg et al., 1984). A similar wetland landform and soil characteristics were created for the translocation on land not mined within the curtilage of the site.

Bleak House, Staffordshire, England. The consented surface coal mine was predominantly within an area designated as a SSSI and involved the translocation in 1994 of 5 ha of wet dwarf shrub heathland communities which were considered to be of high quality using both Intact Turf and Soil Fragment techniques. The overall mid slope landform was gently sloping comprising a shallow variant of the Clifton Association (Ragg et al., 1984). A similar landform and soil characteristics were created on the periphery of the surface mine (Humphries, Benyon and Leverton, 1995; Humphries, 2000a).

Nant Helen Coal Mine, Powys, Wales. The working of the consented surface coal mine involved the translocation of 4 ha of mire, wet and dry dwarf shrub heathland from a peat filled basin in 1997 using the Intact Turf (excavator bucket) technique. The heathland was deemed by the nature conservation regulating authority to be of national quality (Joint Nature Conservation Committee, 1989), although it had not been notified for legal protection as a Special Site of Scientific Interest (SSSI). The landform comprised a small basin on the shoulder of a valley side moderately sloping basin. The peatland had affinity with the Crowdy Soil Association (Ruddeforth et al., 1984). A similar landform and soil characteristics were created in the receiving area in a mined and backfilled part of the surface mine (Humphries, 2000).

Selar Farm Coal Mine, Neath Port Talbot, Wales. The area given planning consent for the surface mining of coal included the Selar Farm SSSI and during 1994 - 1995 involved the translocation of 10 ha of humid and wet grassland/wet using heath Intact Turf and Turf Fragments techniques. The landform was a mid valley side with steeply sloping ground. The soils were typically of the Wilcocks 1 Association (Ruddeforth et al., 1984). The receiving area comprised similar landform outside of the mine site.

Parc Slip Coal Mine, Neath Port Talbot, Wales. The consented surface coal mine included an area of wet grassland and tall herbaceous communities heathland which were potentially of national quality (JNCC, 1989), although it had not been notified for legal protection as a Special Site of Scientific Interest (SSSI) by the nature conservation regulating authority. The translocation in 1998 by the Turf Fragment technique involved 6 ha of stone free shallow wet/saturated soils of the Wilcocks 1 Association (Ruddeforth et al., 1984). The wet grasslands were located in a valley floor on gently sloping ground with a micro-relief of small wet areas with concomitant patterning in the vegetation communities. A similar landform and soil characteristics were recreated outside of the mine on previously mined and restored land.

The following information was collected during the feasibility assessment, operational planning and field implementation of the translocations using the standard soil survey recording classes (see Hodgson, 1974 and Ministry of Agriculture, Fisheries and Food, 1988):

- Landform
- Gradient
- Upper soil profile depth
- Upper soil profile texture
- Soil stoniness and stone size
- Soil wetness
- Soil strength

Table 1. Summary of site and soil characteristics at case history sites.

Sites	Gradient	Micro-relief	Profile Depth	Soil Texture	Stoniness	Plasticity	Strength
Burrowine	Moderately sloping	Simple	Shallow	Loamy sand	Very	Non-plastic	Moderately strong
Keepershield	Moderately sloping	Very complex	Thin - shallow	Sandy clay loam	Extremely	Non-plastic	Very strong
Stony Heap	Moderately steeply sloping	Simple	Shallow	Sandy clay loam	Moderately	Non-plastic	Rigid
Pithouse West	Level	Simple	Deep	Clay	Slightly stony	Very plastic (saturated)	Very Weak
Bleak House	Gently sloping	Simple	Intermediate	Sandy loam	Moderately	Non-plastic	Moderately Firm
Nant Helen	Level	Simple	Deep	Peat	Stone free	Slightly plastic (Saturated)	Very Weak
Selar Farm	Steeply sloping	Simple	Intermediate	Sandy clay loam	Moderately	Non-plastic	Very strong
Parc Slip	Gently sloping	Complex	Shallow	Sandy clay loam	Slightly	Slightly plastic	Moderately weak

Review of Evidence

Gradient and Micro-relief

Where the landform at Selar Farm was moderately steeply sloping to steeply sloping (Table 1), the effective and safe use of Intact Turf technique using front-loading shovels was not possible, whereas in these locations it was possible to use the Turf Fragment technique. With the exception of Stony Heap (where it was judged only the Turf Fragment technique could be used due to the moderately steeply sloping ground), less steep gradients were not a limiting factor at the other sites (Table 1).

Micro-relief, with the exception of Keepershield, was not an overriding determining factor in choice of technique at the sites despite some patterning/gradients in vegetation and soils. Elsewhere, local variation as pools and humps or hollows could be circumvented or another technique such as back-acting excavators with buckets (as at Burrowine and Parc Slip).

At Keepershield the Intact Turf approach could not be deployed on a systematic basis because there was intense and varied patterning of landform, soil thickness and stoniness (Table 1). Here, the Turf Fragments approach was adopted.

Soil Profile Thickness

The thickness and variation in thickness of the upper soil profile depth were also a major determinant of technique. Shallow soils (<15 cm thick) prevented the general use of the Intact Turf method at Burrowine, Keepershield, Stony Heap and Parc Slip (Table 1) because of the poor cohesion of the turf resulting in fragmentation during lifting, transport and relaying. Locally, extremely thin soils (<5 cm), such as at Keepershield, meant that translocation was only possible by scraping with back-acting buckets.

Stoniness

Stoniness was a factor in the selection of technique at Burrowine and Keepershield where the very-extremely stony soils (>35%) (Table 1) resulted in turf fragmentation due to the disruptive effect of displaced stones when using the Intact Turf approach with front loading shovels or back-acting buckets. Here, reliance was on the Turf Fragment technique (Humphries, 2001). In the case of Keepershield (Table 1), the extreme stoniness (>75%) meant that a ‘wind-rowing’ technique had to be devised to facilitate cultivation.

Soils Wetness & Dryness

Where soils were in a non-plastic condition (Table 1) they had a firm-strong strength and both Intact Turf and Turf Fragment techniques were deployed successfully at Bleak House, Selar Farm, Burrowine and Keepershield. Where soils were particularly dry and hard, as at Stony Heap (Table 1), the rigid soils were expected to shatter on lifting with front loading shovels or back-acting buckets, and the Turf Fragment approach was deployed.

Where soils were in a saturated condition, as was the case at Pithouse West and Nant Helen (Table 1), their concomitant low cohesion and very weak strength meant that neither the Intact Turf (front-loading) nor the Turf Fragment techniques could be deployed. Here, translocation was only possible using a bucket and back-acting excavators (Humphries, 2000a). Soils in a plastic condition (water content above lower plastic limit (following the definition of Ministry of Agriculture, Fisheries and Food, 1982)), as at Parc Slip (Table 1), were particularly prone to deformation when lifting as Intact Turf with front-acting shovels, whereas this was not limiting Turf Fragments (where the soil profiles had sufficient strength (i.e., not more than moderately plastic and less than moderately weak) to support the cultivation equipment).

Development of a Framework and Decision Tool

Framework

The above case histories are evidence that geomorphology (landform (gradient) and soil characteristics (profile thickness, stoniness, strength)), with adjustment for climatic (wetness/dryness) is a common factor determining the success of translocation technique, and that established criteria (Bibby et al., 1982; Ministry of Agriculture, Fisheries and Food, 1988) for agricultural machinery can be used as a Framework for a Decision Tool.

Decision Tool

The hierarchical decision-tree is based on differentiating criteria in the order of descending limitations of: gradient, soil thickness, soil stoniness and strength (Tables 2 & 3). At each Stage, threshold criteria differentiate between the appropriateness of the techniques as follows:

Table 2. Decision tree STAGES 1 – 2: Selection of technique by gradient and soil depth.

STAGE 1 - Gradient	<11^{o} (1:5)			>11^{o} - <18^{o}		>18^{o} (1:3)
	S F D**			F D**		D**
	Go to Stage 2			Go to Stage 2		
STAGE 2 - Soil Thickness	>15 cm	>5 cm - <15 cm	<5 cm	>5 cm	<5 cm	
	S F D	F D	D	F D	D	
	Go to Stage 3			Go to Stage 3		
STAGE 3 - Soil Stoniness & Strength	Go to Table 3	Go to Table 3		Go to Table 3		
** S = Intact Turf / F = Turf Fragments / D = Back-acting Excavator with Bucket						

For sites with less than a steeply sloping landform (gradients <18^{o}) and with shallow (>5 cm thickness) or deep soils (>15 cm) the selection of the translocation technique will be dependent on soil stoniness and strength, and selection will progress to STAGE 3. Where gradients are steeper and/or soils less than 50mm thick, the selection will be limited to the back-acting excavator with bucket.

STAGE 3 of the selection is subordinate to gradient and soil thickness (as set out above) and is a matrix of relative soil stoniness and soil strength (Hodgson, 1974). Selection of the translocation technique is dependent on which stoniness-strength field the site's soils are located in (Table 3).

Differentiation between Intact Turf and Turf Fragment techniques in STAGE 3 is dependent on soils being less than very stony (<35% volume or 20% if stones >6 cm size) and soils being of a moderately firm to strong consistency (Table 3). The evidence for the stoniness threshold is based on the experiences at the very/extremely stony sites of Burrowine and Keepershield and the moderately stony sites of Stony Heap, Selar Farm and Bleak House (Table 1).

For dry soils differentiation on strength is between the 'rigid' soil condition at Stony Heap compared with the 'strong' soils at Keepershield, Burrowine and Selar Farm, and for wetter soils, the 'moderately firm' soils at Bleak House compared to the 'moderately weak' soils at Parc Slip. Differentiation between the Turf Fragment and the excavator and bucket approach is proposed where the soils are of a 'very weak' strength and are saturated or at or near their upper plastic limit (Table 3). Here, Nant Helen and Pithouse West fall into this latter category compared to Parc Slip which had a 'moderately weak' soil strength and was able to support machinery.

Table 3 Decision tree STAGE 3: Selection of technique by soil stoniness and strength.

Extremely stony (>70% vol)	F	F KSh	F	F	F	F	D
Very stony (>35% vol)	F	F Bw	F	F	F	F	D
Moderately stony (>15% vol)	F SHp	F/S SFm	F/S	F/S BH	F	F	D
Slightly stony (>5% vol)	F	F/S	F/S	F/S	F PS	F	D PW
Very slightly stony / stone free	F	F/S	F/S	F/S	F	F	D NHn
Soil Strength	**Rigid**	**Strong**	**Very Firm**	**Moderately Firm**	**Moderately weak**	**Very Weak**	**** Very Weak**

**Saturated / Above Upper Plastic Limit

Selected Technique: S = Intact Turf, F = Turf Fragments, D = Back-acting Excavator with Bucket

Site Evidence: KSh = Keepershield, Bw = Burrowine, SHp = Stony Heap, SFm = Selar Farm, BH = Bleak House, PS = Parc Slip, PW = Pithouse West, NHn = Nant Helen

Conclusions

There is field evidence on which to select successful translocation techniques for grasslands and dwarf shrub vegetation for a given a set of landforms and soil characteristics. The evidence is supported by established science based criteria that can be rationalised into a practical and unambiguous Framework and Decision Tool which is simple to apply by planners and designers of translocation schemes.

The necessary soils and site information for developers, scheme planners and designers should be available from routine surveys, and information compiled during the description and assessment of mining projects. For the regulators, it is equally simple to check alignment of techniques being proposed with the site conditions reported and provides an objective basis for discussion where alternative methods are being proposed.

There maybe other non-geomorphological considerations that might influence the choice of technique and these could be built into a broader framework and decision tool if required. For example, there is scope for matching technique with the scale of spatial patterns of often associated with some types of vegetation, the resilience of the plant species and their recovery varies and so selection might also be influenced according to vegetation type (Table 4).

For grasslands, swamps and fens, and ephemeral vegetation selection would follow rigorously the Decision Tool, but in the case of heathland the spacing of the dwarf shrubs could lend to the use of the excavator bucket approach. The Decision Tool may well be intuitively applicable to other vegetation types, but as yet the evidence has not been examined.

Table 4 Potential deployment of translocation technique according to broad vegetation types.

	Intact Turf	**Turf Fragment**	**Excavator Bucket**
Grassland	Yes	Yes	No
Dwarf shrub heathland	Yes	Yes	(Yes)
Swamp & Fen	No	(Yes)	Yes
Ephemeral	No	(Yes)	Yes

Other considerations may be operational (costs and programme timing), but these are outside the scope of this paper.

Acknowledgements

I am grateful to the British Coal Corporation, Celtic Energy, Fife Silica Sand Ltd, Hanson Aggregates Ltd, and UK Coal Ltd for the opportunity to work on their habitat translocation schemes, and for the support of their staff and the co-operation of the contractor companies

undertaking the schemes. It has been great a pleasure to work with my colleague Paul Benyon in the pursuit of perfecting translocation techniques.

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