DESIGN AND REPORTING CRITERIA FOR REED BED AND FEN RESTORATION IN MINERAL WORKINGS [1]

R Neil Humphries and Roger Meade [2]

Abstract. Hanson Quarry Products Europe and the statutory nature conservation body for England, English Nature (now Natural England), have a Partnership Agreement whereby Hanson in 2002 became the UK Habitats Champion for reed bed and fen recovery. Both reed bed and fen habitats are identified as a priority to halt their recent decline and to be enhanced and expanded in the UK Biodiversity Action Plan (BAP). The mineral extraction industry can significantly contribute to the 2010 national recovery targets. In 2003 English Nature commissioned, and subsequently published in 2007, 'Design & Reporting Criteria' to guide and facilitate the successful creation of reed bed, other swamp and fen vegetation as an after use of mineral extraction sites, and their subsequent reporting for inclusion in the national UK and local Habitat BAP inventories and audits. Reed bed is a specific type of open-water transition fen dominated by the common reed *Phragmites australis* and fen a generic term for this and other wetland types influenced by water that has been in contact with rock or soil. The term 'fen' embraces a very wide range of vegetation composition from low sedge and moss dominated to tall reed and tall-herb swamp types, and grading into the 'wet' end of meadows and woodland types. The scope for the creation of the various types of fen is dependent on a number of key physical factors (climate, hydrology, substrate (soils and geology) and fertility), but also in practice, land management and the availability of plant material. The physical factors were broadly considered for reed bed and 65 other published types of fen occurring in the UK from which the scope and opportunity for restoration in mineral workings, and generic design guidelines for their creation, are set out for use by planners and other practitioners alike. In concert, 'Reporting Criteria' were devised to enable the consistent and objective reporting of reed bed swamp and fen habitats created as a result of mineral site restoration. The reporting criteria are in line with the UK National Biodiversity Network definitions enabling incorporation of the data into UKBAP & Local BAP inventories.

Additional Key Words: biodiversity, action plans, climate, landform, hydrology, substrate

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Introduction

A previous paper explored some of the implications the national Biodiversity Action Plans (BAPs) might have for the minerals extraction industry in the United Kingdom (Humphries et al., 2000). In this paper, it was concluded that mineral extraction provided an opportunity to contribute to the plans on a national scale, but there was merit in focusing on a short targeted habitat list. In doing so, it was also considered that monitoring and reporting the achievements was an essential part of the process. This subsequent paper is such a focus on fen wetland habitats, providing guidance as to their creation and reporting.

The background contextual (legal, conservation and geographic) framework for the reed bed and fen BAPs is set out in detail on the UK Government web site http://www.ukbap.org.uk/ukplans/habitats . There are now well established local wetland visions and an overarching vision for wetlands in England (English Nature, 2005). As part of this, it is now widely recognised the minerals extraction industry has a second-to-none opportunity to create large-scale wetlands.

In 2002, Hanson Europe and English Nature signed a Partnership Agreement whereby the aggregate producer became the Habitats Champion for reed bed and fen habitat. Both are identified as priority habitats in the UK BAP. The Champion-ship was launched alongside the large collaborative project to create a 700ha reed bed complex in a rolling 33M tonne gravel extraction programme at Needingworth, Cambridgeshire, UK (Roberts and Elliot, 2007). This alone will satisfy 50% of the UK reed bed BAP 2010 target, but will contribute little towards other fen types. Indeed, it is notable that most wetland creation schemes are of a similar type, that is open water or open transitional reed bed, and there is need for a much wider vision and commitment given the opportunities.

The purpose of these Design Criteria is to facilitate the successful creation of reed bed and a wider range of fen vegetation types within mineral extraction sites, and their reporting for inclusion in national UK and local Habitat BAP inventories or audits. It does not set out to provide 'off the shelf' designs as each site and each will differ in potential, opportunity and local context, for which individual and detailed designs will be required. Rather, it is a set of principles that can be incorporated into the detail for particular situations.

A functional classification of reed bed and fen wetlands

It must be emphasised that reed bed and fen often occur naturally as part of a mosaic involving other habitats (not described in these Criteria), such as wet grassland, wet woodland, wet heathland, coastal wetlands and drier habitats as well. True 'biodiversity' is often dependent on developing such mosaics, even though it does create problems for habitat audit when measuring progress towards BAP targets, and there are often successional relationships between what we choose to see as discrete habitats.

There are many ways of classifying wetlands; a recent ecological review was undertaken by Wheeler and Proctor (2000). Depending on the recognition and weighting of the component characteristics the communities are rarely faithful to a particular type, and judgements have to be made. The relationships between these are not straightforward, and become even more complex when trying to identify them through the presence of particular National Vegetation Classification (NVC) plant communities (Rodwell, 1991, 1992 and 1995).

An alternative functional approach to wetland classification (WETMECs) has been developed and is based on an analysis of the water supply mechanisms to provide a functional and predictive template around which the NVC plant communities can be arranged (Wheeler and Shaw, 2000). It also has value in reconstructing wetlands, such as in mineral extraction site restoration. However, at the present time this is incomplete as to its coverage of fen types.

Given the complexity of characterising fens, a simpler version of fen classification has had to be developed as a basis for setting out generic criteria. This distinguishes tall fen from shorter fen, and this roughly corresponds to an un-quantified nutrient threshold. The nutrient-rich eutrophic situations produce the tall fen, while mesotrophic and oligotrophic circumstances produce shorter fen (Annex 1). The potential division of short fen into predominantly sedge- or moss-dominated fen has not been developed, though this would have produced a further rough division between mesotrophic and oligotrophic types. An attempt to achieve this has since been undertaken in conjunction with data contained in WETMECs for the replacement of fen habitats along the Suffolk Coast in advance of sea level rises (Howden et al., 2006).

While all fen types are valuable to the conservation of our natural heritage, it is the nutrient-poor end of the range that is particularly vulnerable to modern day land uses through, for example, diffuse agricultural pollution or point-source emissions. Where there is a choice, particular thought should be given to the creation of the mesotrophic and oligotrophic fens.

Reed Bed Fen

Reed bed is recognised as a specific type of open-water transition fen dominated by the common reed *Phragmites australis* (NVC S4). It is an important type of wetland habitat that warrants its own HAP (Habitat Action Plan) on account of the associated bird and invertebrate fauna.

Reed bed fen occurs naturally as open-water transition vegetation in floodplains, shallow lakes (meres), river deltas, estuaries and coasts, and is noted for its extensiveness on a landscape scale (Haslam, 1972; Ward, 1992; Hawkes and Jose', 1996). The NVC S4 reed bed fen is normally associated with slowly flowing/non-stagnant standing water which is present throughout the year, typically on flat land where drainage is impeded or within shallow sloping basins/troughs. Whilst widespread throughout England, it is mostly lowland in its distribution, though some stunted examples occur around northern lochs (drowned river valleys) and tarns (small glacial lakes).

Other Fens

Fen is a generic term for more 'terrestrialised' (wet soils and periodic inundated) wetlands. It embraces a wide range of composition from low sedge and moss dominated fens to tall reed and tall-herb swamps, and grading into the ‘wet’ end of meadows and woodland types (Treweek et al., 1997). The term 'swamp' in this paper refers to herbaceous dominated inundated wetland types and not wet woodlands which are discrete NVC types. Reed bed is included in the broad HAP category of fen when, broadly speaking, it is anything other than a mono-culture reed bed (pure) type S4. Other types of fen are particularly diverse and their flora and invertebrate fauna are adapted to the specific wetland conditions. They are aggregated within a single Fen HAP, and there has been no distinction between types when reporting progress. It is hoped that future revisions of the HAP may lead to more discrimination in the reporting of losses and gains for fens.

Fens occur extensively in floodplains and river valleys, shallow lakes and sediment/peat filled basins, and also on a smaller scale as springs, flushes (seepages) and runnels (small surface erosion channels). They are typically associated with saturated soil conditions throughout the year, with the swamp types having 'standing water' during the winter-spring period.

Tall reed swamps and tall herb vegetation are particularly characteristic of open-water transitions, floodplains, valleys and basins in the lowlands. They occur throughout lowland England, although some of the component NVC plant communities may be more frequent in certain regions of the UK than in others. Their distribution follows trends in temperature and rainfall. Springs, flushes and runnels are particularly characteristic of the uplands.

While NVC plant communities are abstract concepts derived from the analysis of field plant lists, it provides the best benchmark we have for describing the diversity of the plant cover as it is, and what we should aim for in creating new fen wetlands. There is no guarantee that the analysis of a new sample in, say, 100 years time, would yield the same suite of communities, and the existing species complement cited within the NVC volumes is unlikely to be complete until the fen has matured.

Understanding the distribution of reed bed and fen types

The distribution of fens is dependent on a number of factors, described and prioritised in many texts, such as Wheeler and Proctor (2000) and Wheeler and Shaw (1995 and 2000):

- Climate (mainly altitude, but with a north-west – south east axis as well)
- Hydrology (surface wetness regimes, aeration/stagnation).
- Substrate (geology, soils and their chemistry)
- Fertility (nitrogen, phosphorus, cations)
- Land management (cutting, mowing, grazing)

Climate

Altitude and position on the NW-SE axis (due to temperature and rainfall) is a major consideration when creating reed bed and fen types in England, for example see Table 1:

Table 1. Climatic effects on the distribution of fens according to NVC types.

Habitat Type	Widespread	Northern - Montane	Lowland
Reed bed fen			S4
Tall reed/herb fens	S9, S27	(S11)	S1-S3, S5-S8, S10, S12-S26, S28
Short fen (sedge & grass)*	M9, M23, M25	M7, M8, M10, M11, M12, M26, M28	M13-14, M21, M22, M23, M27
Short fen (moss carpet)*	M1, M2, M3, M9	M10	
Springs, Flushes, Runnels*	M29, M37	M31-35, M38	M36

* Mires sensu Rodwell, 1991: (S11) distribution less clear

Wetness (hydrology)

In broad terms and making many generalisations, the factors determining wetness requirements can be summarised as follows:

- Absolute level relative to the ground surface.
- Fluctuation (annual and sub-seasonal).
- Throughput (rate of supply, as in springs).
- Degree of oxygenation or stagnation.

Table 2. Broad water regimes for fen types.

Habitat Type	**Permanent standing water**		**Periodic inundation**		**Depth to saturated soil profiles**		**Comments**
	depth m +/-gl						
	Winter	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	
Reed bed fen	+1.0	+0.1			0	0	Quality reed bed only.
Tall reed/herb fens	+0 - +0.5	<+0.05	+0.1 - +1.0	<+0.2	0	0 - -0.05	Includes single species and mixed stands, very variable, some survive substantial summer dryness.
Short fen (sedge/grass & bryophytes)*	<+0.01	<+0.01			0	0 - -0.2	Includes communities forming rafts that buffer the effects of water table fluctuation.
Springs*					0	0	Dependent on groundwater pressure and supply rate. Slope means rapid run-off.
Flushes*	<+0.01	<+0.01			0	-0.02	
Runnels*	<+0.02	<+0.01	+0.2	+0.1	0	0 - -0.2	Dependent on water flux.

* Mires sensu Rodwell, 1991

The ability to provide the above required wetness conditions is dependent on the water balance between the inputs and the outputs. It is determined by a number of factors such as landform (extent and shape), hydro-geology and groundwater levels, drainage and rainfall. It is fundamentally important to appraise the ability of the material available for restoration to act as porous strata (aquifer), or to impede/prevent the flow of water, as aquitards or aquicludes (Brassington, 1988; Humphries et al., 1995; Miyazaki, 1993). WETMECs (Wheeler and Shaw, 2000) contains a series of conceptual models that can provide basic design principles for constructed wetlands, and is based on the functioning of aquifers, aquitards and aquicludes.

The sources of water and flow characteristics can be summarised as follows:

Table 3. Sources and flow of water for fen types.

Habitat Type	Source			Flow		Comment
	Groun d-water	**Surfac e water**	**Periodic flooding**	**Stagnan t water**	**Flowin g water**	
Reed bed fen	+	+			+	Very tolerant
Tall reed/herb fens	+	+	+	+	+	Contains communities with very different requirements.
Short fen (sedge/gra ss & bryophyte s)*	+	+		+	+	Contains communities with very different requirements.
Springs*	+				+	Dependent on aquifer for water supply.
Flushes*	+				+	
Runnels*		+			+	Dependent on adequate catchment

* Mires sensu Rodwell, 1991

Geology, soils, water chemistry and nutrients

Geology and soils also determine reed bed or other types of fen as they influence the hydrological conditions. For example, aquicludes and aquifers require very different types of material in their construction. Under natural conditions, solid and drift geology provides aquifers (e.g. sandstones and permeable deposits) or aquicludes (clays or impermeable rocks). As the WETMEC conceptual models show, groundwater supports many types of fen, and it is the position of an aquiclude in relation to the aquifer that determines where water becomes available at the ground surface.

The geo-chemistry of the mineral deposit and surrounding/underlying geology influences the base-richness of the soil via the water supply (e.g. calcium carbonate content, other alkaline minerals), ranging from low to high cation exchange capacity/base content. Whilst geochemistry is not usually a factor determining the scope for establishment of reed bed (which overall is largely tolerant of a wide range of water and soil chemistry), it has a strong influence on the botanical composition and character of other types of fen. For example, communities M10 and M13 only occur where the groundwater is from a calcareous (calcium rich) source; conversely, M21 occurs on rocks and deposits such as some sandstones from which the water is base (calcium) poor and acidic. Quarry restorations involving the use of calcareous spoil, or water sources from nearby calcareous rocks, offer particularly interesting and important opportunities for the creation of what is known as rich fen, or that which is dependent on base-rich water. It is potentially very species-rich as well.

Some communities associated with base-richness have a high nutrient supply but do not produce concomitant biomass. This is because phosphate may become insoluble in calcareous soils and waters (Mengel and Kirkby, 1978) and thus unavailable to the plant. Base-poor communities show the same effect where metal toxicity (Fe^{2+}, Mn and Al) is often a factor under acidic or waterlogged (anaerobic) conditions.

The availability of the macro-nutrients nitrogen (N) and phosphorus (P) usually determines plant growth rate, competitive advantage, and hence the structure of the plant community. Phosphorus, as phosphate, is probably the more limiting in semi-natural oligotrophic systems, but it may be nitrogen in meso- and eutrophic systems where phosphates are more available. The form of inorganic nitrogen (NH_4 or NO_3) can be of particular importance in the competitive ability of some species (Humphries and Guarino, 1987).

Table 4. NVC plant communities, base richness and nutrients (summarised from the table provided in Annex 1).

Habitat Type	**Base rich requirement****	**Oligotrophic**	**Mesotrophic**	**Eutrophic**	**Comment**
Reed Bed Fen			S4	S4	Good quality reed bed.
Tall Reed/Herb Fens	S2, S5, S24-S26	S2, S8, S13.	S2- S3, S12-S15, S24-S26	S3, S5, S12, S14, S20, S21, S24-S26, S28.	
Short fen (sedge/grass & bryophytes)*	M8-M14, M22, M24, M26,	M1-M3, M8-M22, M24, M26, M29, S9, S10, S19, S27.	M4-M10, M13, M14, M22-M30, S1, S6-S11, S17, S19, S22, S27.	M27, M28, S1, S6-S8, S10, S11, S16-S18.	If separated, bryophyte fens would be mostly in the oligotrophic column.
Springs, Flushes, Runnels*	M32, M37, M38.	M31-M35, M37, M38.	M35,		Mostly oligotrophic

* Mires sensu Rodwell, 1991

** These include obligate and less obligate communities. Some are associated with high mineral content rather than bases specifically.

Landscape & Landform

In nature, there is a strong relationship between NVC plant communities and landform Table 5. This is widely recognised and is used as a tool for selecting European and UK statutory protected sites as Special Areas of Conservation and Special Sites of Special Interest (Joint Nature Conservation Committee, 1995). They are not always mutually exclusive, as basins occur in floodplains and in valleys, and open water transitions occur in basins. However, it provides a practical framework for conceptualising the relationship between landform and fen plant community types.

Table 5. Distribution of fen types and NVC plant communities amongst landform classes.

Habitat Type	**Open-water transitions**	**Basin fens**	**Valley fens**	**Flood-plain fens**	**Springs and flushes**	**Runnels**
Reed bed fen	S4	S4	S4	S4		
Tall reed/ Herb fens	S2, S3, S5, S12-S14, S20, S24-S26, S28	S2,	S2, S3, S13, S24, S25	S2, S3, S5, S8, S12-S14, S24, S25, S28		
Short fen (sedge/grass & bryophytes)*	S1, S6, S7, S9, S11, S19, S27, S16,-S18, S21	M1-M4, M5, M6, M9, M10, M13, M14, M18, M21, M29, M36, S1, S27,	M1-M6, M9, M10, M13, M14, M18, M21, M22, M23, M25, M29, S1,S6, S9, S10, S27,	M1-M3, M5, M9, M10, M13, M14, M27, M29, S1, S6, S9, S10, S27	M4, M6, M10, M13, M14, M32, M35-M37	M29

* Mires sensu Rodwell, 1991

Design Criteria

The above analysis was used to derive generic Design Criteria for the establishment of reed bed and fen vegetation. To assist planners and practitioners alike the criteria were developed and presented as schematic topographic forms. In addition to the above physical factors determining reed bed and fen types, the following are also important selection criteria that need to be taken into account:

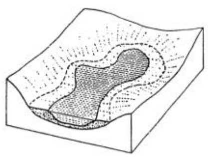
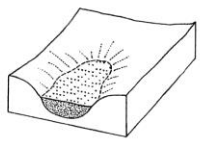
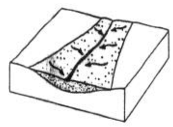
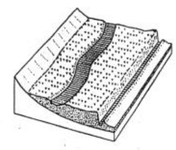
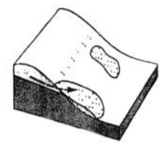
- Already identified in the Local BAP;
- Present in English Nature's Natural Area profiles;
- Present in old maps and recent records (post-glacial);
- Close to other reed bed, swamp & fens;

- Locally Scarce;
- Experiencing local loss/ degradation (e.g. agricultural drainage, water abstraction).

Vegetation Types

After climate, landform is the overriding factor in determining and selecting reed bed and fen type, as it fundamentally determines water supply and quality characteristics Table 6. Landform requirements can be directly related to the opportunities created by mineral extraction within their local geological and landscape settings as represented by the following five generic forms.

Table 6. Fen types and landform: a) types of NVC vegetation and reintroduction strategies.

Shallow Water Transition Fen	**Basin Fen**	**Valley Fen**	**Floodplain Fen**	**Springs, Flushes, & Runnels**
				
▪ *Phragmites australis*. (NVC S4) or other tall fen plant such as reedmaces *Tyha latifolia, T. angustifolia* or burr-reeds *Sparganium erectum*. ▪ For oligotrophic conditions, consider sedges such as bottle sedge *Carex rostrata*. ▪ Re-vegetation strategy strongly reliant on natural colonisation/ local introduction of turf/ soils to 'seed' process.	▪ Moss-sedge-ericoid mosaics (*Sphagnum* mosses, *Carex rostrata, Erica tetralix*). OR ▪ Tall reed (*Phragmites australis, Scirpus lacustris, Typha* spp. *Cladium mariscus*). ▪ Re-vegetation strategy strongly reliant on natural colonisation/ local introduction of turf/ soils to 'seed' process.	▪ Moss-sedge-ericoid mosaics or stands of sedges-rushes (*Schoenus nigricans, Juncus subnodulosus*). E.g. NVC Fen vegetation types. ▪ Re-vegetation strategy strongly reliant on natural colonisation/ local introduction of turf/ soils to 'seed' process.	▪ Wetter end suitable for reed bed, and other tall herb fen in which reed is a significant component. ▪ Stands dominated by sedges-rushes (e.g. *Schoenus nigricans, Juncus subnodulosus*). ▪ Re-vegetation strategy strongly reliant on natural colonisation/ local introduction of turf/ soils to 'seed' process.	▪ *Springs*- Mire vegetation types- *Carex dioica; Schoenus nigricans;* lowland springs and stream banks of shaded situations; *Cratoneuron commutatum- Festuca rubra* and *Carex nigra*. ▪ *Flushes*- Mire vegetation types—*Carex curta, C. dioica, C. demissa, C. saxatilis* & *C. demissa- Koenigia islandica* flush. ▪ *Runnels*- mire vegetation types- *Hypericum elodes* and *Ranunculus omiophyllus.* ▪ Re-vegetation strategy strongly reliant on natural colonisation/ local introduction of turf/ soils to 'seed' process.

The scope for creating the above landscapes and landforms is related to type of mineral being extracted and the operations used. The following table provides an outline of what sort of landform might be created in the restoration of different types of mineral extraction site. In summary:

Table 7. Landform and type of mineral working.

Habitat Type	Open-water transitions	Basins	Valley	Flood plain	Springs and flushes	Runnels
Hard rock quarries	+	+	+		+	+
Soft rock quarries	+	+	+		+	+
Sand & gravel -(river terrace) pits	+	+		+		
Sand & gravel pits (other)	+	+	+		+	
Opencast coal mines	+	+	+	+	+	+

It may be possible to plan and possibly engineer the opportunity and scope within mineral workings to enhance or to create appropriate hydrological conditions as the quarry is worked. This includes the mineral excavation itself and infrastructure facilities such as tailing lagoons and water treatment areas. The final location and landform of overburden (as tips or backfill) may also extend the scope. It means that it is advantageous to plan from the beginning the type of wetland required at the end, so that working practices and sequences can be organised accordingly. The opportunity for creating reed bed and fen types can be summarised in Table 8.

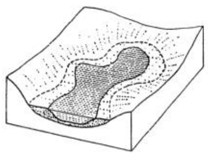
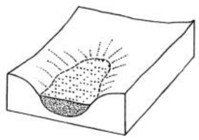
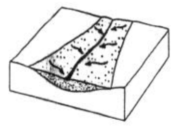
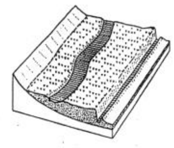
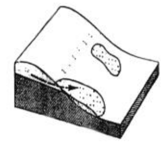
Table 8. Opportunities for creating swamp and fens in mineral workings.

Habitat Type	**Non-back filled excavations (floors/faces etc)**	**Back filled excavations**	**Water treatment areas / sediment lagoons**	**Waste / overburden tips**
Reed bed fen	Shallow lakes / impounded gently sloping / level ground	Shallow lakes / impounded gently sloping / level ground	Shallow lakes	Shallow lakes / impounded gently sloping / level ground
Tall reed/ herb fens	Shallow lakes / impounded gently sloping / level ground	Shallow lakes / impounded gently sloping / level ground	Shallow lakes	Shallow lakes / impounded gently sloping / level ground
Short fen (sedge/grass & bryophytes)*	Basins/ flood plain	Flood plain / basins / valley sides	Basins	Valley sides, basins / hollows
Springs & flushes*	Floors, faces and impoundment	Floors, faces and impoundment		Lower & change in slopes
Runnels		Crowns/upper slack slopes		Crowns & upper slack slopes

* Mires sensu Rodwell, 1991

Using the five generic landforms introduced in Table 6, the Design Criteria for restoring mineral workings to reed bed and fen were developed and given in Table 9.

Table 9. Fen types and landform: b) types of opportunities in mineral workings.

Shallow Water Transition Fen	**Basin Fen**	**Valley Fen**	**Floodplain Fen**	**Springs, Flushes, & Runnels**
Reed bed & tall fen	Mires & tall reed & herb fen	Mires & tall reed & herb fen	Tall reed & herb fen & mires	Mires
				
▪Excavation (floors) or backfilled excavations. ▪Impounded areas on floors or raised areas. ▪Waste overburden / waste tips. ▪Water treatment/ silt deposit structures.	▪Excavation (floors) or backfilled excavations. ▪Impounded areas on floors or raised areas. ▪Waste overburden / tips. ▪Water treatment/ silt deposit structures.	▪Backfilled excavations (may incorporate water treatment/ silt deposal structures). ▪Shaped overburden/ waste tips resulting in valley form.	▪Backfilled excavations.	▪*Springs*- faces and floors of hard rock quarries, where water does not pond or tipped/ raised materials on floors. ▪Damp north facing quarry surfaces can be valuable; their contribution to bryophyte conservation should not be under-estimated. ▪*Flushes*- sides/ bases of excavations, lower slopes of overburden and waste tips. ▪*Runnels*- surfaces of crown/ upper slopes of overburden and waste tips, quarry floors.

Detailing the landforms.

There are further details relevant to the characteristics of the landform, and water supply and quality which determine the type of vegetation possible Table 10.

Designing for the water supply

The ability of mineral extraction sites to provide the required wetness regimes throughout the year (following cessation of working/completion of restoration) is a key factor the success of creating reed bed and other fens. Where the source is rainfall or runoff, the annual rainfall figure and catchment size both need to be considered. In any case, impoundment and controlled release can help to smooth out the sporadic pattern of the water supply, though thought needs to be given to what vegetation would be appropriate in or around the reservoir, and how it would be affected by water table fluctuation. It may work best in association with a vegetation raft, which can rise and fall with the water level in the reservoir.

The landform, within the geological setting, determines the water supply characteristics and quality, and hence type of reed bed and fen possible Table 11.

Table 10. Fen types and landform: c) types of micro-topography.

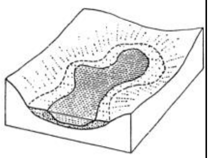
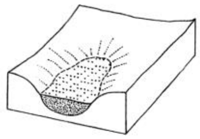
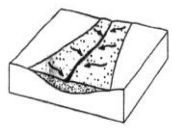
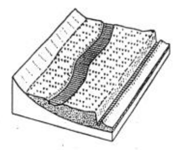
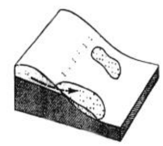
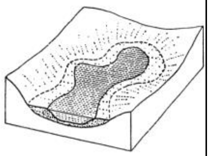
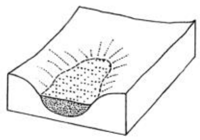
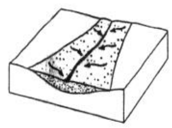
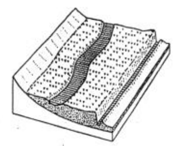
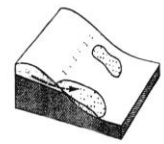
Shallow Water Transition Fen	**Basin Fen**	**Valley Fen**	**Floodplain Fen**	**Springs, Flushes, & Runnels**
Reed bed & tall fen	Mires & tall reed & herb fen	Mires & tall reed & herb fen	Tall reed & herb fen & mires	Mires
				
▪S4 (*Phragmites australis*) dominant. ▪Will develop & remain as such for longer on the edge of larger water bodies (>0.5ha). ▪Protect with partially submerged berms if risk of wave action. ▪Requires gently sloping edge, with the water level close to a significant proportion of it for much of the year.	▪Should be created in a series of basins (shallow hollows), less than 0.5ha in area. ▪Water depth should be designed not to fall by more than 0.5m. ▪Ideal - series of basins of differing wetness within a hummock-hollow landscape. ▪Silt ponds can develop naturally into wet woodland or fen carr as they dry out – can be incorporated into an overall restoration scheme to provide a mosaic of fen habitats.	▪Requires a valley – a variable patterned surface (humps & hollows)-landform. ▪Should be created in a single or a series of valleys no less than 0.5ha in area. ▪Unlikely to be creatable within aggregate restoration schemes due to the scale of the topography required.	▪Flatland divided by watercourse(s), possibly with a mosaic of hollows/ basins/ depressions/ impoundments. ▪Benefit in the inclusion of low berms to entrap floodwater and increase the water residence time. ▪Particularly successful on flattened clay spoil, provided the top layer is sufficiently friable for plants to establish.	▪*Springs*- associated with exposed geological strata, lower slopes of valley sides, or at the base as occasionally associated with floodplains, or an artesian discharge zone. ▪*Flushes*- associated with lower valley sides where there's a change in slope. ▪*Runnels*- associated with gently sloping ground, especially with crowns and upper slopes, trackway sides etc.

Table 11. Fen type and landform: d) types of water supply.

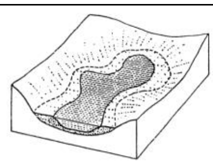
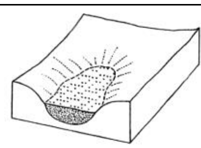
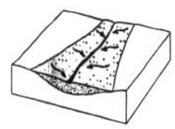
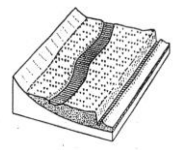
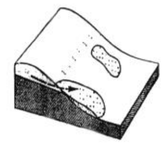
Shallow Water Transition Fen	**Basin Fen**	**Valley Fen**	**Floodplain Fen**	**Springs, Flushes, & Runnels**
Reed bed & tall fen	Mires & tall reed & herb fen	Mires & tall reed & herb fen	Tall reed & herb fen & mires	Mires
				
▪Requires standing / slow flowing water throughout year. ▪Effective aquicludes needed unless reliable source of groundwater to maintain reed bed. ▪High permeability spoil required to enable water body to equilibrate with groundwater. ▪Stagnation should be avoided.	▪Saturated soil throughout year for tall reed fen; most of year for other types. ▪Spoil stratified to construct effective aquicludes beneath basins & larger water bodies unless reliable source of groundwater to maintain the fen. ▪Open water bodies & basins for terrestrialisation should rely on groundwater, rainfall, & surface run-off from the immediate catchment, provided the last is not likely to add unwanted nutrients. ▪Stagnation should be encouraged by minimising the throughput of water and wave action.	▪Saturated soil throughout year for tall reed fen; most of year for other types. ▪Receives water from valley sides as run-off & seepage, & from higher up the catchment by streams.	▪Dependent on periodic flooding from a source such as a watercourse. ▪Should not be inundated all year round; summer groundwater level may fall several tens of centimetres below the surface. ▪Saturated soil throughout year for tall reed fen; most of year for other types. ▪If groundwater supply is available as well as floodwater, may be possible to design a mosaic of sumps and basins with a higher, less fluctuating water table .	▪*Springs*- local small pools with flowing water, and surrounding saturated soils, maintained by groundwater/ aquicludes. ▪*Flushes*- saturated soil layer throughout the year, maintained by groundwater/ aquicludes. ▪*Runnels*- seasonally flowing water, saturated soil layer throughout the year with a maximum summer draw down of less than 20cm.

Choosing the substrates

The substrate, soils and geological strata, also affect the hydrology and water quality (base richness, fertility, texture) and hence type of reed bed and fen possible.

In the constructed wetland, granular porous material such as sand or gravel is required to act as the aquifer to hold and slowly release water, while something as fine as clay is needed to construct an aquitard in the appropriate position to contain the water in the aquifer and cause it to emerge at the right point and at the right time in the wetland.

Table 12. Fen type and landform: e) types of substrate.

Shallow Water Transition Fen	**Basin Fen**	**Valley Fen**	**Floodplain Fen**	**Springs, Flushes, & Runnels**
Reed bed & tall fen	Mires & tall reed & herb fen	Mires & tall reed & herb fen	Tall reed & herb fen & mires	Mires
				
▪Organic debris accumulates on raw sand & gravel, this improves the shoreline as a growing medium & buffers plants against drought. ▪Clay aquiclude where the reed bed is surface water dependent.	▪Organic debris accumulates on raw sand & gravel, this improves the shoreline as a growing medium & buffers plants against drought. ▪Clay aquiclude where the fen is surface water dependent. ▪Low macro-nutrient levels.	▪Sands, silt and /or organic soils/ peat. ▪Clay aquiclude where surface water dependent. ▪Low macro-nutrient levels.	▪Sands, silt and /or organic soils/ peat. ▪Clay aquiclude where surface water dependent. ▪Low macro-nutrient levels. ▪If totally irrigated by seasonal floodwater (and rainfall) it does not require the redistributed quarry waste to be carefully segregated into permeable and impermeable.	▪Sands, silt and /or organic soils/ peat. ▪Clay aquiclude where surface water dependent. ▪Low macro-nutrient levels.

Studies of the colonisation of recently exposed glacial deposits and mineral wastes have shown that it can take decades for the nutrients accumulate through the growth of undemanding pioneer species such as lichens and bryophytes (Humphries and Rowell, 1994). Complete absence of macronutrients may need to be addressed by kick-starting the wetland with some artificial inputs from the outset (Humphries, 1980 and 1982), or by taking advantage of high background levels of diffuse pollution in runoff and ground waters within the feeding catchment. Where imported soils are used the levels of the macro-nutrients need to be checked because they may be too high and promote aggressive non-fen species. Some raw waste materials used in the restoration of mineral workings are unlikely to be rich in N or P, but there are some exceptions. For example, if peat or peaty soil have been stripped and stored for the restoration it is likely to release N and P due to oxidation during storage and in the early stages of the restoration.

Hence, the initial nutrient supply and its eventual sink must be carefully planned and managed in the restoration of most types of fen, although reed bed generally survives well in high nutrient regimes.

Soil and 'substrate' textural types can influence the success of planting and re-colonisation. Sands, loams, silts and sandy-clays are generally more favourable for the establishment of wetland and fen vegetation.

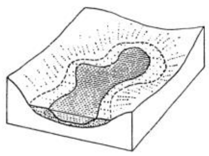
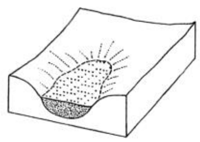
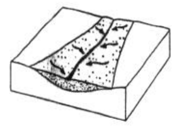
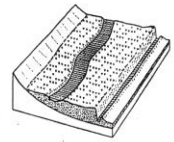
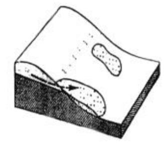
Generally speaking, it is probably better to adopt a horticultural approach to soil preparation and planting, as the objective is to establish a range of plant species to eventually form a stable and sustainable community under appropriate management (Street, undated; Giles, 1992; Humphries, 1980, 1982 and 2000). If nutrients are deemed necessary in these early stages it is important to think through to later stages and ensure they are leached out, cropped, or inactivated in peat deposits or by geochemical processes if the community ultimately required is associated with low nutrients.

Stockpiled peat may be available for the restoration, and can increase germination success. However, care should be taken in its use, as decomposition during storage and use, or from being part of the more nutrient-rich lower peat strata, may provide excessive nutrients leading to strong growth of unwanted species such as *Juncus effusus*.

Planning and operational considerations

In achieving the reed bed and fen types in practice, there are a number of planning and operational considerations which are common to all landform types Table 13.

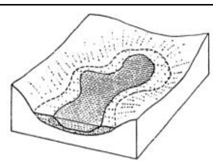
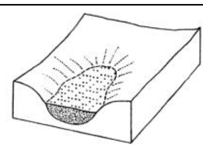
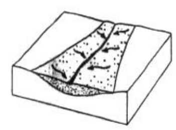
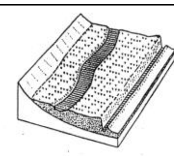
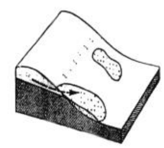
Table 13. Fen types and landform: f) planning and operational considerations.

Shallow Water Transition Fen	**Basin Fen**	**Valley Fen**	**Floodplain Fen**	**Springs, Flushes, & Runnels**
Reed bed & tall fen	Mires & tall reed & herb fen	Mires & tall reed & herb fen	Tall reed & herb fen & mires	Mires
				
▪Retain existing habitat/ swamp-fen vegetation if possible to integrate into scheme or use as source of biological material. ▪Retain swamp fen soils/ peat for reuse. ▪Source aquiclude (clay) material. ▪Design layout prior to site working to achieve required water supply & landform. ▪Identify & quantify sources of water prior, during & post extraction. ▪'Buffer Areas' required if adjacent to agricultural land.	▪Retain existing habitat/ swamp fen vegetation if possible to integrate into scheme or use as source of biological material. ▪Retain swamp fen soils/ peat for reuse. ▪Source aquiclude (clay) material. ▪Design layout prior to site working to achieve required water supply & landform. ▪Identify & quantify sources of water prior, during & post extraction. ▪'Buffer Areas' required if adjacent to agricultural land.	▪Retain existing swamp fen vegetation if possible to integrate into scheme or use as source of biological material. ▪Retain swamp fen soils/ peat for reuse. ▪Source aquiclude (clay) material. ▪Design layout prior to site working to achieve required water supply & landform. ▪Identify & quantify sources of water prior, during & post extraction. ▪'Buffer Areas' required if adjacent to agricultural land.	▪Retain existing swamp fen vegetation if possible to integrate into scheme or use as source of biological material. ▪Retain swamp fen soils/ peat for reuse. ▪Source aquiclude (clay) material. ▪Design layout prior to site working to achieve required water supply & landform. ▪Identify & quantify sources of water prior, during & post extraction. ▪'Buffer Areas' required if adjacent to agricultural land. ▪However, being a relatively nutrient-enriched fen type, it is less vulnerable to the quality of imported topsoil, & may require it to develop originally.	▪May be possible to engineer such fens around the base of sizable spoil heaps that weep slowly. This means integrating the flush with drier habitats on the spoil, and if woodland, this may lose much of the potential seepage water to the atmosphere. ▪Retain existing swamp fen vegetation if possible to integrate into scheme or use as source of biological material. ▪Retain swamp fen soils/ peat for reuse. ▪Source aquiclude (clay) material. ▪Design layout prior to site working to achieve required water supply & landform. ▪Identify & quantify sources of water prior, during & post extraction.

Management and sustainability issues

In achieving the reed bed and fen types in practice, there are a number of management and sustainability considerations which are common to all landform types.

Table 14. Fen types and landform: g) access and aftercare.

Shallow Water Transition Fen	**Basin Fen**	**Valley Fen**	**Floodplain Fen**	**Springs, Flushes, & Runnels**
Reed bed & tall fen	Mires & tall reed & herb fen	Mires & tall reed & herb fen	Tall reed & herb fen & mires	Mires
				
▪Access for management. ▪Public access / viewing. ▪Aftercare period 5-10 years – a shorter after care period is needed where plant material is introduced, longer where there is reliance on colonisation.	▪Access for management. ▪Public access / viewing. ▪Aftercare period 5-20 years – a shorter after care period is needed where plant material is introduced, longer where there is reliance on colonisation.	▪Access for management. ▪Public access / viewing. ▪Aftercare period 5-20 years – a shorter after care period is needed where plant material is introduced, longer where there is reliance on colonisation.	▪Access for management. ▪Public access / viewing. ▪Aftercare period 5-20 years – a shorter after care period is needed where plant material is introduced, longer where there is reliance on colonisation.	▪Access for management. ▪Public access /viewing. ▪Aftercare period 5-20.

Reporting Criteria

The following Reporting Criteria were developed so that common reporting standards could be applied to reed bed, swamp and fen habitats created as a result of mineral extraction. They are based on the National Biodiversity Network definitions so that the data can be incorporated into UKBAP and Local BAP inventories. They do not attempt to assess quality of habitat or the contribution to species BAP, although 'extent' is an index of quality. These guidelines do not address wet woodland, an important BAP habitat in its own right, and one that reed bed and other fens ultimately develop into if management is not applied to keep them open.

Sites in reality may contain several wetland types, and those that are not strictly wetland. While such mosaics may be excellent news for nature conservation, and totally natural, it makes it more difficult to know where to draw the line, literally, between them. The advice on common standards for monitoring of designated sites is helpful (Joint Nature Conservation Committee, 2004), though the degree of detail may be more than you require. The distinction between reed bed, other fen, and the 'wet' end of other habitats is sometimes not easy to determine. Where it is not, a judgement and record of the reason is needed.

The following is a schematic presentation of the formulated Reporting Criteria.

Table 15. Fen Type Definitions.

Reed Bed Fen	Other Fens
Reed bed fen habitat dominated by *Phragmites australis*, and is recognised as a specific and key type of wetland habitat that warrants its own HAP on account of the rich associated bird and invertebrate fauna.	Fen is a generic term for marginal and transitional wetland habitats and embraces a range of landscape and vegetation types; open-water transitions, basin fens, valley and floodplain fens, and springs, seepages and runnels. They are particularly noteworthy for the diversity and adaptation of their flora and invertebrate fauna. They are typically associated with saturated soil conditions throughout the year often with standing water during the winter-spring period. The UKBAP and many LBAPs generally do not yet differentiate between fen types, and because of this reporting is currently expected to be at this generic level with the aggregation of all occurring types. For the purpose of this guidance, reference is made to floristic composition and landform (which are intended to assist in differentiating between fen and non-fen vegetation/habitat).

Table 16. Characteristics of open fen types for reporting.

Reed Bed Fen	Other Fens
• *Phragmites australis* dominant/pure stand (specifically NVC type S4 with few associate species)	All types of open fen vegetation qualify at a location either occurring as single type or as aggregate of several types. Vegetation comprising conspicuous species e.g.: Sphagnum mosses, *Juncus subnodulosus, Schoenus nigricans,* sedges such as *Carex rostrata.* Basin Fen • Either moss-sedge-ericoid mosaics (*Sphagnum* mosses, *Carex rostrata, Erica tetralix*) or tall swamp (*Phragmites australis*, *Scirpus lacustris*, *Typha* spp, *Cladium mariscus*). Likely NVC types S27-28, M4-5, M7-9. Valley Fen • Moss-sedge-ericoid mosaics as basin fen or stands of sedges-rushes (*Schoenus nigricans, Juncus subnodulosus*). Likely NVC types S6-7, S15-17, S19, S25, M6-7, M9-14. Floodplain fen – similar to basin fen. Likely NVC types S2-5, S13-20, S24-28, M9. Springs/flushes, runnels & drains • Moss-sedge-rush mosaics. Likely NVC types M7, M10-13, M29, M34-38. Other Open-Water Transitions. Likely NVC types S1-3, S8-10, S25, S24, S28, M5 Grazing/management history may drive some fens towards

	grassland/meadow characteristics Invasion by woody species may drive shift towards wet woodland Where S4 is <2ha in extent, include vegetation as other fen type as appropriate)
Landform/Hydrological Type: - typically, as open water/transition as shallow lakes etc (standing water throughout year) - but also in basins, valleys and floodplains	Landform/Hydrological Type: - basin fen - valley fen - floodplain fen - springs/flushes - runnels/drains - mixtures of these and mosaics with other habitats within a site
• >60% vegetative cover (density) of *P. australis* (quadrat size 10x10m)	>40% fen vegetation cover + <10% non-wetland species (quadrat size 2x2m to 10x10m as appropriate to vegetation pattern and form etc)
• minimum area of 2ha to qualify as reed bed, minimum mapping unit of 0.25ha (must be intact/continuous stand if smaller/dissected categorise as fen swamp or other wetland as appropriate)	• minimum mapping unit of 0.25ha (must be intact/continuous stand, include all fen vegetation types as single recording unit. Include entire spring lines/flushes and spring complex with associated/transitional semi-natural vegetation or geological outcrop)
• minimum recording width 5m (if less categorise as tall reed fen*)	
• <20% cover of other wetland vegetation (e.g. other swamp, fen, carr woodland, wet grassland, open water) (can include these other vegetation/habitats types when integral part of reed bed (e.g. succession, transitions, pattern etc))	• <20% cover of other wetland vegetation (reed bed/swamp, carr woodland, wet grassland, open water) (can include these other vegetation/habitats types when integral part of fen (e.g. succession, transitions, pattern etc))

Table 17. Recording and Reporting.

Reed Bed Fen	Other Fens
• Use aerial photographs (need ground trusting: 1:3,000 scale recommended; best flight dates July/August)	• Use aerial photographs (need ground truthing: 1:3,000 scale recommended; best flight dates July/August)
• Follow up with GPS ground survey (survey dates July/August)	• Follow up with GPS ground survey (survey dates July/August)
• report reed bed and other fen types separately when occur together and where each separately meet qualifying criteria (Where borderline qualification, reporting priority depends on allocation of 'marginal' types etc, preference to be given according to Local BAP, restoration objectives etc)	• report fen and reed bed swamp separately when they occur together and where each separately meet qualifying criteria. If borderline, defer to Local BAP, restoration priorities etc and record your reasons.
• reporting size categories; <2ha; 2-10ha, 11- 20ha; >20ha (size indicative of quality. As continuous stands with breaks [e.g. tracks, ditches] no greater than 10m wide and less than 5% recording area)	• reporting size categories; <1ha; 1-2ha; 2-10ha; 11-20ha; >20ha (Size indicative of quality. As continuous stands with breaks [e.g. tracks, ditches] no greater than 10m wide and less than 5% recording area)
• Minimum reportable areas = 0.25ha	• Minimum reportable areas = 0.25ha

Conclusions

In formulating this guidance it is hoped that planners and practitioners alike will be more aware and stimulated by the diversity of opportunities that mineral extraction sites offer for a range of types of fen creation over and above simple water bodies and the now ubiquitous NVC S4 *Phragmites australis* reed bed. With more imagination we can bring diversity to our wetland restoration and move away from the mundane and more of the same! There is also greater opportunity to achieve fen restoration in restoration schemes than is currently being panned for. We need more fen and can contribute to this important and neglected wetland group.

As an incentive for industry there is more to be gained in perfecting fen creation. Many mineral deposits are located in or near to statutory protected wetland areas such as European Special Areas of Conservation or UK SSSIs. Consent to extract these deposits will require compensation by creating replacement areas either within the restored sites and/or elsewhere. A proven ability to create fens will be the only way such deposits will be granted planning consent for mineral extraction in the future given the more demanding nature conservation planning policies used to judge the merits of schemes (Office of Deputy Prime Minister, 2005).

Acknowledgements

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References

Brassington, R. 1988. Field Hydrology. John Wiley & Sons, Chichester.

English Nature. 2005. Getting Wetter for Wildlife. English Nature, Peterborough. Giles, N. 1992. Wildlife After Gravel: Twenty Years of Practical Research by the Game Conservancy and ARC. Game Conservancy, Fordingbridge.

Haslam, S.M. 1972. Biological Flora of the British Ilses: Phragmites australis. Journal of Ecology 60, p 585-610. http://dx.doi.org/10.2307/2258363.

Hawkes, C.J and P. Jose' 1996. Reed bed Management for Commercial & Wildlife Interests. RSPB, Sandy.

Howden, N.J.K., C.E.L. Humphries, and R.N. Humphries, 2006. Coastal Squeeze & Maintenance of Wetland - Pilot Study. English Nature, Peterborough.

Humphries, R.N., P.J. Horton, and R. Foster, 2000. p 376-385. In Daniels, W.L., and S.G. Richardson (eds.) Proceedings, 2000 Annual Meeting American Society for Surface Mining and Reclamation, Tampa, Florida. ASMR, Lexington.
https://doi.org/10.21000/JASMR00010376
Humphries, R.N. 1980. The development of wildlife interest in quarries. p 197-207. In Reclaiming Limestone and Flourspar Workings for Wildlife. R.N. Humphries and T.T. Elkington (eds.). Reclamation Review Special Edition, 3, (4).

Humphries, R.N. 1982. The establishment of vegetation on quarry materials: physical and chemical constraints. p 55-61. In B. N. K. Davis (ed). Institute of Terrestrial Ecology Symposium 11. ITE, Monks Wood.

Humphries, R.N. and L. Guarino, 1987. Soil nitrogen and the growth of birch and buddleia in abandoned chalk quarries. Reclamation & Revegetation Research, 6, (1), p 55-61.

Humphries, R.N. and T.A. Rowell, 1994. The Establishment and Maintenance of Vegetation on Colliery Spoils. British Coal Corporation, Eastwood.

Humphries, R. N., P.R. Benyon, and R.E. Leverton, 1995. Hydrological performance of a reconstructed (wet) heath soil profile. Land Contamination & Reclamation, 3, 20, p 101-103.

Humphries, R.N. 2000. Biodiversity, Curse or Opportunity. Mining Quarrying & Recycling 29, p 26-29.

Joint Nature Conservation Committee. 1995. Guidelines for Selection of Biological SSSIs. JNCC, Peterborough.

Joint Nature Conservation Committee. 2004. Common Standards Monitoring for Lowland Wetland Habitats. JNCC, Peterborough.

Meade, R. and R.N. Humphries, (eds.) 2007. Mineral Extraction and Wetland Creation. Natural England, Peterborough.

Mengel, K and E.A. Kirby, 1978**.** Principles of Plant Nutrition. International Potash Institute, Berne.

Miyazaki, T. 1993. Water Flow in Soils. Marcel Dekker, New York.

Office of Deputy Prime Minister. 2005. Planning Policy Statement 9: Biodiversity & Geological Conservation. The Stationery Office, Norwich.

Roberts, A.C. & G. Elliot 2007. The Hanson-RSPB Wetalnd Project. In Meade, R. and R.N. Humphries, R. N. (eds.) 2007. Mineral Extraction and Wetland Creation. Natural England, Peterborough.

Rodwell, J. S. (ed) 1991. British Plant Communities: Volume 2 Mires and Heaths. Cambridge University Press, Cambridge.

Rodwell, J. S. (ed) 1992. British Plant Communities: Volume 3 Grasslands and Montane Communities. Cambridge University Press, Cambridge.

Rodwell, J. S. (ed) 1995. British Plant Communities: Volume 5 Aquatic Communities, Swamps and Tall-herb Fens. Cambridge University Press, Cambridge.

Street, M**.** (undated). The Restoration of Gravel Pits for Wildfowl. ARC, Bristol.

Treweek, J., P. Jose', and P. Benstead, (eds.) 1997. The Wet Grassland Guide. RSPB, Sandy.

Ward, D. 1992. Reed beds for Wildlife. Proceedings of a Conference on Creating and Managing Reed Beds with Value to Wildlife. Information press, Oxford.

Wheeler, B.D. and M.C.F. Proctor, 2000. Ecological gradients, subdivisions and terminology of north-west European mires. Journal of Ecology 88, pp 187-203. http://dx.doi.org/10.1046/j.1365-2745.2000.00455.x.

Wheeler, B.D. and S.C. Shaw, 1995. A focus on fens – controls on the composition of fen vegetation in relation to restoration. In B.D. Wheeler, S.C. Shaw, W.J. Fojt & R.A. Robertson (eds.) Restoration of Temperate Wetlands, p 49-72. Wiley, Chichester.

Wheeler, B.D. and S.C. Shaw, 2000. A Wetland Framework for Impact Assessment at Statutory Sites in Eastern England. Environment Agency Research and Development Technical Report W6-068/TR1.

ANNEX 1. Table of NVC Mire and Swamp plant communities with estimates of the comparative nutrient regime and base status with which they are often associated.

This Annex is included to help match design choices to the situation to be restored, and the materials and water supplies available. It is developed from the JNCC's (2004) Common Standards for Monitoring Lowland wetland habitats by the authors.

NVC community or sub-community	Oligotophic	Mesotrophic	Eutrophic	Base rich environment	Vulnerable to excessive N+P	Vulnerable to N or P	Source of information:
M1 *Sphagnum auriculatum* bog pool community	+			N	YYYY	N	Wheeler & Shaw 2000
M2 *Sphagnum cuspidatum/recurvum* bog pool community	+			N	YYYY	N	Wheeler & Shaw 2000
M3 *Eriophorum angustifolium* bog pool community	+			N	YYYY	N	Wheeler & Shaw 2000
M4 *Carex rostrata-Sphagnum recurvum* mire		+		N	YY	YY	Wheeler & Shaw 2000
M5 *Carex rostrata-Sphagnum squarrosum* mire		+		N	YY	YY	Wheeler & Shaw 2000
M6 *Carex echinata - Sphagnum recurvum/auriculatum* mire		+		N	YY	YY	Wheeler & Shaw 2000
M7 *Carex curta-Sphagnum russowii* mire		+		N	YY	YY	Wheeler & Shaw 2000
M8 *Carex rostrata-Sphagnum warnstorfii* mire	+	+		(Y)	YYY	Y	Wheeler & Shaw 2000
M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire	+	+		(Y)	YYY	Y	Wheeler & Shaw 2000
M10 *Carex dioica - Pinguicula vulgaris* mire	+	+		Y	YYY	Y	Wheeler & Shaw 2000
M11 *Carex demissa-*	+			Y	YYYY	N	Meade interpretation of

Saxifraga aizoides mire							NVC
M12 *Carex saxatilis* mire	+			Y	YYYY	N	Meade interpretation of NVC
M13 *Schoenus nigricans - Juncus subnodulosus* mire,	+	+		Y	YYY	Y	Wheeler & Shaw 2000
M14 *Schoenus nigricans - Narthecium ossifragum* mire	+	+		(Y)	YYY	Y	Wheeler & Shaw 2000
M15 *Scirpus cespitosus-Erica tetralix* heath	+			N	YYYY	N	Rodwell 1992
M16 *Erica tetralix-Sphagnum compactum* wet heath	+			N	YYYY	N	Rodwell 1992
M17 *Scirpus cespitosus-Eriophorum vaginatum* blanket mire	+			N	YYYY	N	Wheeler & Shaw 2000
M18 *Erica tetralix-Sphagnum papillosum* raised and blnket mire	+			N	YYYY	N	Wheeler & Shaw 2000
M19 *Calluna vulgaris-Eriophorum vaginatum* blanket mire	+			N	YYYY	N	Wheeler & Shaw 2000
M20 *Eriophorum vaginatum* blanket and raised bog	+			N	YYYY	N	Wheeler & Shaw 2000
M21 *Narthecium ossifragum - Sphagnum papillosum* valley mire	+			N	YYYY	N	Wheeler & Shaw 2000
M22 *Juncus subnodulosus--Cirsium palustre* fen meadow	+	+		Y	YYY	Y	Wheeler & Shaw 2000
M23 *Juncus effusus/acutiflorus-Galium palustre* rush pasture		+		N	YY	YY	Wheeler & Shaw 2000
M24 *Molinia caerulea-Cirsium dissectun* fen meadow	+	+		(Y)	YYY	Y	Wheeler & Shaw 2000

M25 *Molinia caerulea-Potentilla erecta* mire		+		N	YY	YY	Wheeler & Shaw 2000
M26 *Molinia caerulea-Crepis paludosa* mire	+	+		Y	YYY	Y	Wheeler & Shaw 2000
M27 *Filipendula ulmaria-Angelica sylvestris* mire		+	+	N	Y	YYY	Wheeler & Shaw 2000
M28 *Iris pseudacorus-Filipendula ulmaria* mire		+	+	N	Y	YYY	Meade interpretation of NVC
M29 *Hypericum elodes - Potamogeton polygonifolius* soakway	+	+		N	YYY	Y	Meade interpretation of NVC
M30 Related vegetation of seasonally inundated habitats		+		N	YY	YY	Rodwell 1992
M31 *Anthelia julacea-Sphagnum auriculatum* spring mire	+			N	YYYY	N	Rodwell NVC
M32 *Philonotis fontana-Saxifraga stellaris* spring	+			(Y)	YYYY	N	Rodwell 1992
M33 *Pohlia wahlenbergii* var. *glacialis* spring	+			N	YYYY	N	Rodwell 1992
M34 *Carex demissa-Koenigia islandia* flush	+			N	YYYY	N	Rodwell 1992
M35 *Ranunculus omiophyllus-Montia fontana* rill	+	+		N	YYY	Y	Meade interpretation of NVC
M36 Lowland springs and stream banks of shaded situations (various)				N			
M37 *Cratoneuron commutatum-Festuca rubra* spring	+			Y	YYYY	N	Rodwell 1992
M38 *Cratoneuron commutatum-Carex nigra* spring	+			Y	YYYY	N	Rodwell 1992

S1 *Carex elata* swamp		+	+	N	Y	YYY	Wheeler & Shaw 2000
S2 *Cladium mariscus* swamp	+	+		(Y)	YYY	Y	Meade interpretation of NVC
S3 *Carex paniculata* swamp		+	+	N	Y	YYY	Wheeler & Shaw 2000
S4 *Phragmites australis* swamp and reed beds		+	+	N	Y	YYY	Wheeler & Shaw 2000
S5 *Glyceria maxima* swamp			+	(Y)	N	YYYY	Rodwell 1995
S6 *Carex riparia* swamp		+	+	N	Y	YYY	Rodwell 1995
S7 *Carex acutiformis* swamp		+	+	N	Y	YYY	Wheeler & Shaw 2000
S8 *Scirpus lacustris* ssp. *lacustris* swamp	+	+	+	N	YY(YY)	YY(YY)	Rodwell 1995
S9 *Carex rostrata* swamp	+	+		N	YYY	Y	Rodwell 1995
S10 *Equisetum fluviatile* swamp	+	+	+	N	YY(YY)	YY(YY)	Rodwell 1995
S11 *Carex vesicaria* swamp		+	+	N	Y	YYY	Wheeler & Shaw 2000
S12 *Typha latifolia* swamp		+	+	N	Y	YYY	Rodwell NVC
S13 *Typha angustifolia* swamp	+	+		N	YYY	Y	Rodwell 1995
S14 *Sparganium erectum* swamp		+	+	N	Y	YYY	Rodwell 1995
S15 *Acorus calamus* swamp		+		N	YY	YY	Meade interpretation of NVC
S16 *Sagittaria sagittifolia* swamp			+	N	N	YYYY	Rodwell 1995
S17 *Carex pseudocyperus* swamp		+	+	N	Y	YYY	Rodwell 1995

S18 *Carex otrubae* swamp			+	N	N	YYYY	Rodwell 1995
S19 *Eleocharis palustris* swamp	+	+		N	YYY	Y	Rodwell 1995
S20 *Scirpus lacustris* ssp. *tabernaemontani* swamp			+	N	N	YYYY	Meade interpretation of NVC
S21 *Scirpus maritimus* swamp			(+)	N	N	YYYY (saline)	Meade interpretation of NVC
S22 *Glyceria fluitans* water margin vegetation		+		N	YY	YY	Rodwell 1995
S23 Other water margin vegetation (variable)							
S24 *Phragmites australis*-*Peucedanum palustre* fen		+	+	Y	Y	YYY	Wheeler & Shaw 2000
S25 *Phragmites australis*-*Eupatorium cannabinum* tall-herb fen		+	+	(Y)	Y	YYY	Wheeler & Shaw 2000
S26 *Phragmites australis*-*Urtica dioica* tall herb fen		+	+	(Y)	Y	YYY	Wheeler & Shaw 2000
S27 *Carex rostrata*-*Potentilla palustris* fen	+	+		N	YYY	Y	Rodwell 1995
S28 *Phalaris arundinacea* tall herb fen			+	N	N	YYYY	Wheeler & Shaw 2000