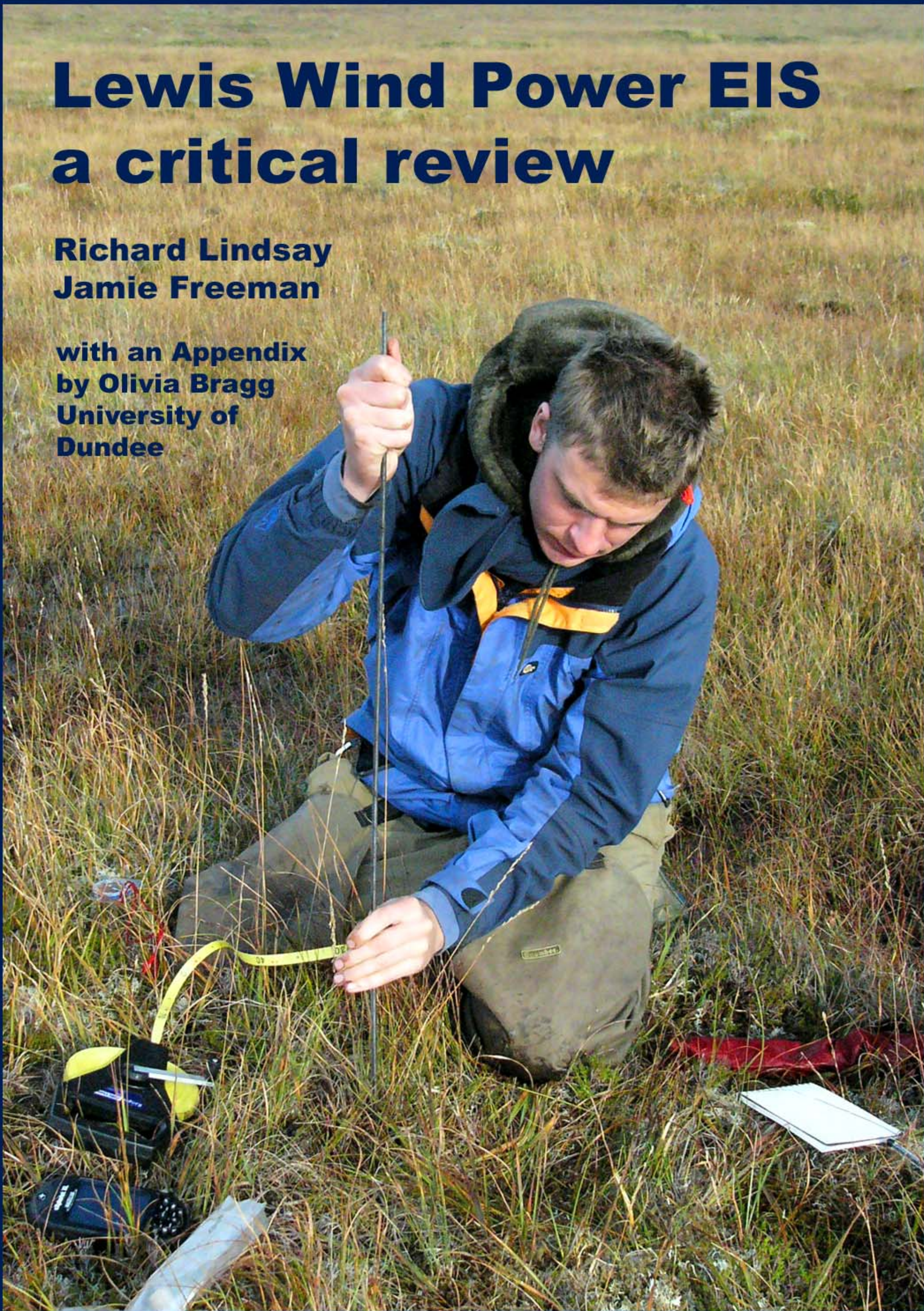
Lewis Wind Power EIS a critical review

Richard Lindsay
Jamie Freeman

with an Appendix by Olivia Bragg University of Dundee



Peatland Research Unit
School of Health & Bioscience
University of East London

Lewis Wind Power (LWP) Environmental Impact Statements (EIS) 2004 and 2006 – A Critical Review

R A Lindsay and J Freeman

with a hydrological review annex by
O M Bragg
University of Dundee

March 2008

Peatland Research Unit
School of Health and Bioscience
University of East London

ACKNOWLEDGEMENTS

The present report is the culmination of four years' work with Royal Society of the Protection of Birds (RSPB). This work has been funded by the RSPB and the University of East London, and the authors gratefully acknowledge this fact.

We are particularly grateful to Anne McCall, RSPB Planning Development Manager, for initiating and managing RSPB's contribution to the work, and for her unfailing support, advice and patience during the course of the last four years. We are also grateful to Richard Evans (RSPB) for providing us with relevant datasets and for his helpful comments on various drafts of the several documents that have been produced in the course of this work.

Fieldwork on the Isle of Lewis was made very straightforward thanks to the help of many people. Martin Scott, RSPB Conservation Officer for the Western Isles, provided much useful help and guidance during preparation for the fieldwork programme, then provided much additional valuable advice during our stay on Lewis. Thanks are also due to Sheena Dunn for helping to organise accommodation for us in Stornoway. Iain Mcleod and Zoe Brown also provided much useful local information.

We thank Melissa Marr and Stuart Connop of the UEL Peatland Research Unit (PRU) for proof-reading the final document and making valuable comments on earlier versions of the present report. We would also like to thank Professor David Humber and Dr Neville Punchard, successive Heads of School, for their continuing support for this work over the last four years. ShirleyJohnson and Gareth Lewis (UEL Knowledge Dock) are also acknowledged for ensuring that the project administration ran smoothly. Finally Martin Dashper (UEL was a great source of assistance in resolving a number of IT-related issues.

We received much helpful advice while working on this and pervious reports and as such we would like to acknowledge Adnan Zainorabidin (School of Engineering, University of East London), Professor Joseph Holden (University of Leeds), Dr Sarah Crowe (University of the Highlands & Islands), Dr Alan Dykes (Kingston University), Dr Andrew Coupar (Scottish Natural Heritage), Ben and Alison Averis (East Linton), Alastair Crowle (Natural England), and Paul Culyer (Countryside Council for Wales), for providing information, photographs, comment or guidance about particular issues. Any errors that remain in the present report are, needless to say, entirely our own.

Finally, we are grateful for the images and information sent to us by Martin Collins, of Derrybrien, Co. Galway, and David Bruce, from Views of Scotland. We are also very grateful to Claire Grey, of Getmapping.com for her work in providing us with detailed aerial photo imagery of Britain.

Contents

1 INTRODUCTION 25
1.1 Background 25
1.2 Purpose of the Present Report 27
1.3 Layout of the Present Report 28
1.4 The use of extensive quotes 29
2 GENERAL COMMENTS ABOUT THE LWP EIS DOCUMENTS 31
2.1 The Purpose of the EIS (1) – to inform consultation and decision-making 31
2.2 Impact Assessment – boundary conditions define the system 32
2.3 Impact Assessment – real sites, real issues 34
2.4 Impact Assessment – impact interactions 35
2.5 Impact Assessment – recognising and retaining uncertainty 36
2.6 Impact Assessment – appropriate descriptive systems 38
2.7 Impact Assessment – a planning process based on established evidence39
2.8 Impact assessment : the need for scientific controls 41
3 INFRASTRUCTURE 42
3.1 Micrositing 42
3.1.1 Micrositing and the assessment process 42
3.1.2 Micrositing and scale of impact 43
3.1.3 Micrositing and decision-making 46
3.2 Infrastructure dimensions 47
3.2.1 Infrastructure – the lack of a single definitive table 47
3.2.2 A confusion of tables 48
4 CONSTRUCTION 51
4.1 Road construction 51
4.1.1 Road design parameters and peat 52
4.1.2 Floating roads – construction methodology 58
4.1.3 Rockfill roads – construction methodology 65
4.1.4 Road construction – the 'observational method' 67
4.1.5 Road drainage requirements – floating roads 73
4.1.6 Rockfill drains and drainage 84
4.2 Turbine construction (and other excavated infra-structure, except for excavated roads) 84
4.2.1 Trial excavations 85
4.2.2 Construction methods for turbine bases (and trial pits, and other excavated infrastructure) 92
4.2.3 Dewatering of turbine excavations 96
4.3 Powerlines 101
4.3.1 Buried power cables 101
4.3.2 Overhead power lines 103
5 GEOLOGY, HYDROGEOLOGY and HYDROLOGY 115
5.1 Peat depths 115
5.1.1 LWP peat depth map 115
5.1.2 Missing peat depths 120
5.1.3 Relationship between peat depth and infrastructure 121
5.1.4 Peat depth data – a question of presentation 125
5.2 Description and classification of peatland systems 125
5.2.1 Catchments, landform and blanket mires 126
5.2.2 Mire 'catchments' – the macrotope 131
5.2.3 Individual mire units – the mesotope 133
5.2.4 The microtope – self regulation and stability 140
5.2.5 LWP Peat Erosion Classes 143
5.2.6 Hydrological Zones 154
5.2.7 Mesotopes – the missing link 164

5.3 Causes of erosion ... 179
5.3.1 Lewis peatland erosion – not atypical of British blanket mire ... 179
5.3.2 Causes of peatland erosion – the wider evidence ... 183
5.3.3 Peat pipes and erosion – the LWP evidence ... 184
5.3.4 ‘Peat-pipe degradation’ – inappropriate application of a model ... 188
5.3.5 Peat pipes as constructive features – an alternative model ... 193
5.4 Eco-hydrology of peatlands and peatland drainage ... 198
5.4.1 Measurements of peat moisture content ... 199
5.4.2 Surface water, groundwater and drainage ... 202
5.4.3 The acrotelm and drainage ... 204
5.4.4 Acrotelm drainage and the 50 m ‘Gilman buffer’ ... 212
5.4.5 The catotelm and drainage ... 213
5.4.6 Drainage, peat pipes and erosion ... 215
5.4.7 The Farr Dipwell Studies ... 216
5.5 Water crossings ... 216
6 HABITATS ... 222
6.1 Setting the scene – a mire landscape of international significance ... 222
6.2 Perceptions of the Lewis peatlands ... 224
6.2.1 Peatland erosion : the positive view ... 225
6.2.2 Peatland erosion : the negative view ... 226
6.2.3 The Lewis Wind Power view of blanket mire erosion ... 227
6.3 Peatlands, burning and erosion ... 231
6.3.1 Evidence for burning within the Lewis peatlands ... 235
6.3.2 Significance of the burning record for Lewis peatlands ... 242
6.4 Vegetation of Lewis peatlands ... 246
6.4.1 Extent of ‘dry heath’ on former blanket mire ... 248
6.4.2 LWP survey methodology : quantitative imprecision ... 260
6.5 ‘Active blanket bog’ within the development area ... 269
6.5.1 The official statutory agency definition of ‘active blanket bog’ ... 269
6.5.2 The LWP approach to defining ‘active blanket bog’ ... 271
7 PEATSLIDE RISK ASSESSMENT ... 279
7.1 The LWP EIS approach to peatslide risk assessment ... 280
7.1.1 Peatslide risk - the LWP approaach ... 281
7.1.2 Mexe-Probe California Bearing Ratio (CBR) measurements and hand augering ... 282
7.1.3 Slope stability analysis ... 287
7.1.4 Peatslide Hazard Mapping ... 299
7.2 Peatslide incidents – lessons from elsewhere ... 309
7.2.1 The Pollatomish peatslides ... 310
7.2.2 The Derrybrien peatslide ... 310
7.2.3 Key relevant issues from Pollatomish and Derrybrien ... 312
7.2.4 ECJ Prosecution : Derrybrien ... 313
7.2.5 Peatslide research ... 313
7.3 LWP Peatslide Risk Assessment ... 316
7.3.1 Beinn Dhail locality ... 317
7.3.2 West of Loch Bhatandip locality ... 318
7.3.3 Abhainn Dhail locality ... 320
7.3.4 Spealltrabhat to Bhruthadail locality ... 321
7.3.5 North of Loch Bhatandip ... 323
7.3.6 Allt Hogaraid locality ... 324
7.3.7 Engineering solutions : summary of failings ... 326
7.4 Implications for peat stability at the LWP windfarm ... 326
7.4.1 UEL assessment of peatslide risk ... 327
7.5 Engineering and real-world construction ... 331
7.5.1 Failure at the limits of knowledge ... 331

7.5.2 Assessment of engineering proposals 332
8 DIRECT AND INDIRECT IMPACT ASSESSMENT 334
8.1 Failures of the LWP EIA 337
8.2 UEL impact assessment : an alternative to the LWP EIA 338
8.2.1 Limitations to an alternative EIA 338
8.2.2 UEL (constrained) EIA : information used 339
8.2.3 UEL (constrained) EIA : general comments 339
8.2.4 Impact zone : complete LWP infrastructure 340
8.2.5 Micrositing 341
8.2.6 Sites of hydrological concern 344
8.2.7 UEL (constrained) EIA : Zones of Concern (ZoCs) 345
8.2.8 Impact zone and surface hydrology (vegetation and nanotopes) 350
8.2.9 Impact zone and microtope changes : microtope-mesotope zone of concern (MZoC) 357
8.2.10 UEL (constrained) Potential Zone of Impact (UEL PZI) : direct and indirect effects 362
8.3 Impact on 'active' blanket bog 368
8.4 Loch Mor an Starr 373
8.4.1 A 'window' into the surrounding bog water-table? 373
8.4.2 Location of wind turbines 375
8.4.3 Contamination of Loch Mor an Starr 379
8.4.4 Draining of Loch Mor an Starr 381
8.4.5 Loch Mor an Starr : summary 385
9 CUMULATIVE EFFECTS and IMPACT INTERACTIONS 386
9.1 Landslide risk assessment : a case-study 387
9.1.1 Landslide 'hazard' 387
9.1.2 Landslide 'risk' 387
9.1.3 The LWP approach : 'likelihood' and 'consequences' 389
9.1.4 UEL Peatslide Susceptibility Mapping and Consequences 390
10 CONCLUSION 394
11 REFERENCES 395
12 Appendix 1 Appraisal of Appendix 11E of the Lewis Wind Farm Proposal: Farr Dipwell Studies 409
13 Appendix 2 Quadrat data obtained by UEL 430
14 Appendix 3 : Sites of Hydrological Concern 443
15 Appendix 4: Listing of ZoCs 457
16 Appendix 5: Listing of MZoCs 460
17 Appendix 6: Detailed views of possible SAC boundary threats 517

List of Figures

Figure 1. Effect of sinuosity on roadline length 45
Figure 2. Abandoned school construction project on peat. 60
Figure 3. Floating road with evidence of sinking. 61
Figure 4. Crane accident arising from failure of floating road. 64
Figure 5. Patterns of water flow across peatland surface. 76
Figure 6. Ponding alongside a floating road.. 77
Figure 7. Cross-drains associated with a floating road. 80
Figure 8. Sediment-treatment issues associated with wind-farm construction. 83
Figure 9. Trial turbine excavation ENV4. 86
Figure 10. Trial turbine excavation ENV6. 87
Figure 11. Trial turbine excavation ENV9. 87
Figure 12. Trial turbine excavation PN1. 88
Figure 13. Trial turbine excavation PN2. 88
Figure 14. Trial turbine excavation PN3. 89
Figure 15. Ground conditions at Turbine G42. 89
Figure 16. Ground conditions at Turbine G41. 90
Figure 17. Ground conditions at Turbine G52. 90
Figure 18. Ground conditions along route of power lines - erosion....................... 113
Figure 19. Ground conditions along route of powerlines : pool system. 114
Figure 20. Contrasting peat depths for a section of roadline. 117
Figure 21. UEL-derived peat depths. 119
Figure 22. UEL-derived peat depths in vicinity of Turbine G54. 119
Figure 23. Locations for missing or unreadable LWP peat deths. 121
Figure 24. Range of peat depths associated with roadline. 123
Figure 25. Range of peat depths associated with turbine bases. 124
Figure 26. Catchment line cutting through watershed mire system. 129
Figure 27. Eco-hydromorphological hierarchy for describing mire systems........... 132
Figure 28. Contrast between LWP catchments and UEL macrotopes. 134
Figure 29. Macrotope boundaries, with two demonstration mesotope maps. 137
Figure 30. Detail of mesotopes for northern demonstration macrotope. 138
Figure 31. Details of mesotopes for southern demonstration macrotope. 139
Figure 32. Microtope patterns visible within mesotope boundaries. 140
Figure 33. LWP Erosion Class boundaries as microtope boundaries. 141
Figure 34. Macrotope, mesotope and microtope (LWP Erosion Class) boundaries for southern demonstration macrotope. 144
Figure 35. Gully density and ground variability within LWP Erosion Classes. 148

Figure 36. Revegetation of gullies within LWP Erosion Class 7. 150
Figure 37. Examples of mis-match between LWP Erosion Class and condition on the ground. 151
Figure 38. Mis-match between LWP Hydrological Zones and ground conditions. . 157
Figure 39. Mis-match between LWP Hydrological Zones and mesotopes – northern demonstration mactrotope. 160
Figure 40. Mis-match between LWP Hydrological Zones and mesotopes – southern demonstration mactrotope. 161
Figure 41. Mis-match between Hydrological Zone and Erosion Class.................. 162
Figure 42. Ladder fen/eccentric mire – ground view. 169
Figure 43. Comparison between Lewis ladder fen at Turbine G49 and Australian patterned fen. 171
Figure 44. Comparison between Lewis ladder fen/eccentirc mire and Australian patterned fen. 172
Figure 45. Mis-match between ladder fen and LWP Target Notes. 173
Figure 46. LWP HSA polygon boundary identifying ladder fen. 174
Figure 47. Distribution of ladder fens close to windfarm infrastructure. 175
Figure 48. Ladder fen/eccentric mire featured by LWP EIS. 177
Figure 49. Ladder fen with proposed windfarm infrastructure. 178
Figure 50. Severe erosion at Kinder Scout, Peak District. 181
Figure 51. Peat pipe associated with water-filled pool system. 188
Figure 52. Examples of peat pipes on Lewis : 1. 194
Figure 53. Examples of peat pipes on Lewis : 2. 194
Figure 54. Examples of peat pipes on Lewis : 3. 195
Figure 55. Example of stream becoming overgrown by active peat growth. 195
Figure 56. Detailed views of Lewis sink hole and peat pipe. 196
Figure 57. Peat pipes in the Pennines – aerial view. 197
Figure 58. Appearance of fresh-dug drain and long-established drain in blanket bog. 205
Figure 59. Response of bog water table to increased rates of surface run-off. 210
Figure 60. Behaviour of water table at particular locations on Cors Caron NNR, mid-Wales. 211
Figure 61. Water crossings, roadway and ground conditions. 218
Figure 62. Water crossings and erosion at Loch Mor an Starr. 218
Figure 63. Distribution of burning impact according to the LWP HSA field data. ... 236
Figure 64. Distribution of known fires and present ground conditions – example. . 238
Figure 65. Relationship between LWP HSA recorded fire intensity and surveyor. 239
Figure 66. Approximate boundary of UEL-recorded fire within SAC. 240
Figure 67. Ground conditions at UEL-recorded fire within the SAC. 241

Figure 68. 'Character' and 'differential' species used to separate 3 NVC vegetation types. 253
Figure 69. Ground conditions within an example of Erosion Class 8 and H10b 'dominance'. 258
Figure 70. Complexity of ground within LWP HSA polygons. 261
Figure 71. Examples of vegetation recovery and re-wetting within erosion systems. 265
Figure 72. Summary diagram of nanotopes found on Lewis peatlands. 265
Figure 73. Summary nanotope diagrams for LWP HSA Polygons 2947 and 4188. 267
Figure 74. Summary nanotope diagrams for LWP HSA Polygon 3653. 268
Figure 75. UEL estimate of 'active blanket bog' within the LWP HSA. 277
Figure 76. Sites identified by LWP as possibly having soft sub-peat strata. 285
Figure 77. Illustration of layering typically found in the Lewis peat profile. 286
Figure 78. Illustration of parameters associated with slope stability. 289
Figure 79. Factor of Safety for Loch Bhatandip. 294
Figure 80. Generalised Factor of Safety for Lewis blanket mire, assuming 3 m peat depth. 296
Figure 81. Distribution of blanket mire within the LWP HSA having potentially significant peatslide risk. 305
Figure 82. Example of UEL-derived peatslide-hazard map. 307
Figure 83. Peatslide issues at Beinn Dhail. 318
Figure 84. Peatslide issues at West Loch Bhatandip. 319
Figure 85. Peatslide issues at Abhainn Dhail. 321
Figure 86. Peatslide issues at Spealltrabhat to Bruthadail. 322
Figure 87. Peatslide issues at 'North of Loch Bhatandip'. 324
Figure 88. Peatslide issues at Allt Hogaraid. 325
Figure 89. Localities identified by UEL as potentially 'at risk' of slope failure. 329
Figure 90. Example of ground conditions assicated with proposed roadline. 335
Figure 91. Map showing ground directly affected by proposed LWP infrastructure. 341
Figure 92. 'Area of Search' for potentially sensitve areas given LWP requirements for micrositing. 344
Figure 93. Distribution of areas identified by UEL as being of hydrological concern. 346
Figure 94. Distribution of UEL 'Zones of Concern'. 347
Figure 95. Zone of Concern – Example 1. 348
Figure 96. Zone of Concern – Example 2. 348
Figure 97. Zone of Concern – Example 3. 349
Figure 98. Zone of Concern – Example 4. 349
Figure 99. Relationship between humification and permeability in peat. 354

Figure 100. Erosion at Butterburn Flow, Cumbria, northern England. 358
Figure 101. Distribution of UEL Mesotope-microtope Zones of Concern.............. 361
Figure 102. Detailed view of an example Mesotpe-microtope Zone of Concern. .. 362
Figure 103. Distribution of factors contributing uniquely to sections of the UEL 'Potential Zone of Impact' (PZI). 364
Figure 104. Extent of UEL Potential Zone of Imact (UEL PZI)............................. 365
Figure 105. Example of contribution made by differing factors to the UEL PZI. 367
Figure 106. 'Active blanket bog' within the UEL PZI. 368
Figure 107. Map of UEL PZI on 'active blanket bog' in the northern part of the proposed LWP development... 369
Figure 108. Example of ground where the UEL PZI extends into the SAC........... 371
Figure 109. Distribution of potential boundary issues for the SAC........................ 372
Figure 110. Breakwater and collapse features at Loch Mor an Starr.................... 374
Figure 111. Route of overhead powerlines., northern Loch Mor and Starr. 376
Figure 112. Potentially-affected watercourses entering Loch Mor an Starr. 377
Figure 113. Detailed view of issues, north Loch Mor an Starr. 378
Figure 114. Detailed view of issues, central Loch Mor an Starr............................ 378
Figure 115. Detailed view of issues, south Loch Mor an Starr.............................. 379
Figure 116. Ladder/percolation fen, north Loch Mor an Starr. 384
Figure 117. MZoCs and Loch Mor an Starr.. 384
Figure 118. Potential peatslide corridors.. 392
Figure 119: SAC boundary issues – overview map 517
Figure 120. SAC boundary issues – Area 1... 518
Figure 121. SAC boundary issues – Area 2... 519
Figure 122. SAC boundary issues – Area 3... 520
Figure 123 SAC boundary issues – Area 4.. 521
Figure 124 SAC boundary issues – Area 5.. 522
Figure 125 SAC boundary issues – Area 6.. 523
Figure 126 SAC boundary issues – Area 7.. 524
Figure 127 SAC boundary issues – Area 8.. 525
Figure 128 SAC boundary issues – Area 9.. 526
Figure 129 SAC boundary issues – Area 10.. 527
Figure 130 SAC boundary issues – Area 11.. 528
Figure 131 SAC boundary issues – Area 12.. 529
Figure 132 SAC boundary issues – Areas 13 and 14. 530

List of Tables

Table 1: Infrastructure dimensions 48
Table 2: Changes to the LWP development proposal 49
Table 3: Sizes of turbine hardstandings 50
Table 4: Road construction methods – design considerations 53
Table 5: Road construction – design parameters 55
Table 6: Location of trial-pits 86
Table 7: Transmission-line pylons - dimensions 105
Table 8: Trasmission-line pylons – volumes of excavated peat 107
Table 9: Erosion Classes - definitions 147
Table 10: Bog pool classification 152
Table 11: Peatland hierarchy and LWP equivalents 165
Table 12: Extent of H10b – revised estimates 256
Table 13: UEL Peatland Research Unit quadrat summary 257
Table 14: Relative NVC cover for LWP polygons 259
Table 15: Area totals for infrastructure, GPZI and ZoCs 357
Table 16: Area totals for UEL Potential Zone of Impact (UEL PZI) 366

EXECUTIVE SUMMARY

The present report has been commissioned from the University of East London Peatland Research Unit by the RSPB. This is in response to the proposal from Lewis Wind Power to construct a wind farm consisting of 181 turbines (originally 234 turbines), plus access roads and other associated infrastructure, within the Lewis Peatlands Special Protection Area (SPA).

The report consists of ten chapters and six appendices. One of these appendices has been provided by Dr Olivia Bragg, University of Dundee, and considers the details of a technical appendix presented by LWP as part of its revised development proposal set out in the LWP 2006 EIS documents. Other than Dr Bragg's contribution, the present report has been written by Mr Richard Lindsay, Head of Wildlife Conservation and the Peatland Research Unit at the University of East London, and Mr Jamie Freeman, Research Assistant within the UEL Peatland Research Unit.

The Executive Summary is set out below according to the chapters in the main body of the present report, and cross-referencing is provided to particular sections of the report to enable the reader to refer directly to the relevant text in the main report.

Chapter 1 : Introduction

The UEL Peatland Research Unit (PRU) was originally commissioned by the RSPB to provide comments on an EIS linked to a proposal by Lewis Wind Power to build 234 wind turbines within the Lewis Peatlands SPA. One of the present authors provided comments on this LWP 2004 EIS (Lindsay, 2005). Lewis Wind Power then submitted a revised proposal for 181 turbines and infrastructure, still largely within the Lewis Peatlands SPA, and so the RSPB commissioned the UEL PRU to examine the EIS accompanying this revised proposal. A number of issues emerged in the course of reviewing the original 2004 proposal, and were encountered again when looking at the LWP 2006 EIS for the revised proposal. To address these adequately, the UEL PRU undertook a period of fieldwork on Lewis in October 2006. An interim report was produced on the basis of this by the UEL PRU (Lindsay, 2007), but the present report brings together into a single document the range of issues raised during review of the two LWP EIS documents, informed by the detailed field- and remote-sensing evidence gathered by the UEL PRU (Section 1.1).

A critique of the first two UEL PRU documents (Lindsay, 2005, 2007) has been produced by Dr Tom Dargie (Dargie 2007a, 2007b). Some errors have been highlighted by this critique and have been addressed in the present report. For the remainder, the issues raised are more matters of judgement or opinion. The present report has thus not been altered in the light of Dargie (2007a, 2007b), other than to correct errors and to provide brief points of clarification.

The present report is intended as a review of evidence presented by LWP within its three main EIS documents – LWP 2004 EIS, LWP 2005 Transmission Line Addendum (TLA), and LWP 2006 EIS. It attempts to judge the degree to which the LWP EIS documents adequately assess the potential impact of the proposed development on the peatland habitat. It is not intended as an alternative to the LWP

EIS documents, although some EIS work has been undertaken to highlight the consequences of adopting approaches that differ from those used by LWP.

Chapter 2 : General comments about the LWP EIS documents

Although an EIS is designed to aid the decision-making process, particularly in relation to potential environmental impacts arising from construction and operation of the proposed development, the LWP EIS documents do not provide some of the basic information needed to make such judgements. Thus (Section 2.1):

- there is no table that provides at least indicative dimensions for all elements of the infrastructure;
- no information is provided for possible impact-distances associated with construction of overhead power lines;
- peat depth data are missing for more than 7% of the road-line, and for the entire route of the overhead power lines.

An EIS is meant to provide as complete a view as possible of the environmental impacts likely to occur should the proposed development go ahead. Ecological responses and interactions mean that it is often important to consider worst-case events, and to consider them in an integrated way. However, the LWP ES documents tend to set out examples which are only appropriate for typical, or even best-case conditions (Sections 2.2, 2.3 and 2.4).

The ‘uncertainty principle’ is recognised as being a key part of environmental decision-making, and the LWP EIS documents do highlight some areas of uncertainty. Unfortunately such uncertainty tends to be provided within technical sections, and when the same information is presented in summary form elsewhere, the element of uncertainty is often lost – suggesting a certainty which does not in fact exist (Section 2.5).

An EIS should give confidence in its predictions and conclusions. This is normally achieved by using well-established methods and theories for assessing key issues. For a number of topics that are central to the assessment of character, condition and potential impact for the peatland habitat, the LWP EIS documents elect not to adopt this approach. They instead choose to develop their own methods that have not been validated through scientific peer-review, and embrace theories that are currently unproven (Sections 2.6 and 2.7).

Chapter 3 : Infrastructure

The LWP EIS documents refer to the need for the flexibility provided by micrositing when deciding precisely where to place elements of infrastructure. Although micrositing is generally assumed to result in a reduced environmental impact, this is not necessarily the case. What micrositing undoubtedly does is increase the area that must be *assessed* for potential environmental impact (Section 3.1.1). Furthermore, the actual footprint of the LWP development could be increased by anywhere between 8.6% and 18.5% because a sinuous road covers more ground than a straight road, and turbines set back further from the access road require longer connecting road sections (Sections 3.1.2 and 3.1.3). This issue is not addressed at all by the LWP EIS documents.

Furthermore, the flexibility of micrositing can only produce less environmental impact if all relevant environmental information is gathered and features of environmental significance are correctly identified. This appears not to have been the case in the LWP EIS documents, particularly in relation to peat depths, and recognitions of a major peatland type (Section 3.1.3). More will be said about both of these issues later.

Reference has already been made to the lack of basic, consistent information about the dimensions of the proposed infrastructure within the LWP EIS documents. This is considered in more detail in Section 3.2.

Chapter 4 : Construction

Section 4.1 : Roads
Four methods of construction are proposed for the (in effect) permanent road system required for the LWP development. One of these involves the upgrading of existing crofting tracks, and thus has little relevance to the peatland habitat. The remaining three methods, for use specifically on peat, are excavation, 'floating' roads, and rockfill.

LWP's own review of road construction methods for peat considers six different methods, including piling and pre-loading, but does not consider rockfill at all. Of the methods considered, only piling and excavation are identified as definitely providing the necessary functionality. Piling is not then mentioned further, and excavation is considered only for areas of thin peat.

The favoured methods for deeper peat are thus rockfill – for which no evaluation of functionality is given – and 'floating' roads. This latter method is identified as having many disadvantages and is assessed with a rather lukewarm "for consideration where it meets functionality", yet this construction method will be used on 70% of the road network. No supporting scientific literature is cited in relation to either rockfill or 'floating' roads. This is because very little has been published about the long-term behaviour and environmental impact of such methods. In short, in environmental terms these selected construction methods are best described as 'experimental' (Section 4.1.1).

What published scientific literature there is about roads constructed over peat makes clear that both short- and long-term subsidence is almost inevitable, and this will occur to different degrees and at different rates along a road length. This variable subsidence tends to have significant operational and environmental consequences (Section 4.1.2). These issues are not mentioned or addressed by the LWP EIS documents.

There are also significant concerns in relation to the use of rockfill roads on the deepest, wettest peats, as proposed by the LWP EIS documents. Loading of substantial quantities of rock directly into the peat surface in a very wet peatland is likely to have significant implications for slope stability and peatslide risk (Section 4.1.3). This possibility is neither acknowledged nor discussed in the LWP EIS documents.

The assumption that 'floating' roads require no side-drainage means that the LWP EIS documents do not consider the potential environmental effects of such drainage. Where the roads do sink, fresh road material will be needed and drainage will be required to keep them operational but the impact of this drainage on water management and sediment control is not addressed (Section 4.1.5.1).

Section 4.2 : Turbines

It is acknowledged by the LWP EIS documents that there is a degree of uncertainty about the geotechnical character of the peat to be excavated from turbine locations. Consequently it is proposed that some trial excavations be undertaken from a variety of 'typical' ground conditions to reveal more of these geotechnical issues. The six listed trial pits do not in fact lie in 'typical' ground, but are all located in highly atypical conditions. The value of this exercise is thus highly questionable (Section 4.2.1).

Although certain aspects of the methods to be used for construction of turbine bases remain obscure (Section 4.2.2), a potentially more serious issue concerns drainage and treatment of discharge water from the turbine excavations. Several stages of water control and treatment are described in the LWP EIS documents, but it seems that the finest suspended materials can only be removed by flocculation. The environmental implications for this, especially in terms of public water supplies, are not mentioned at all (Section 4.2.3).

Section 4.3 : Power lines

Although some sections of the power lines will be buried beneath or alongside the windfarm roads, slightly more than 30 km of power lines will be constructed as overhead transmission lines, carried on pylons, and will not follow the line of windfarm roads. In order to construct the pylons and install the transmission lines, it will be necessary to construct a temporary access road along a route which is almost entirely dominated by blanket bog.

The LWP EIS documents contend that, because the roadway is only temporary and the transmission lines are strung at some height above the ground, there will be virtually no environmental impact to the peatland. However, the LWP documents also acknowledge that the ground is often very eroded and uneven, and so it will be necessary to 'level' the route of the temporary road surface. Such levelling involves digging out sections of peat which, once removed, cannot be satisfactorily replaced (Section 4.3.2.3).

In addition, the transmission-line route crosses a number of pool systems and other forms of very difficult ground. The route for the vehicles will necessarily be obliged to find a more circuitous route than that finally followed by the transmission lines, thereby adding significantly to the length of this temporary roadway.

The lack of any peat-depth data for the route of the overhead transmission lines also makes it difficult to assess potential impacts caused by either the roadway or by excavation for the pylon bases. The LWP EIS documents predict that any impact from construction of the power lines will show rapid reversion to pre-existing conditions. Consequently the transmission lines and their pylons do not appear at all in the tables of environmental impacts. This view is either highly optimistic or just simply incorrect. It is more likely that at least some sections of this 'temporary' roadway will be visible for some years to come.

Chapter 5 : Geology, hydrogeology and drainage

Section 5.1 : Peat depths
It has already been mentioned that peat-depth data are missing for around 7.5% of the development roadline and for 100% of the overhead transmission lines. For those wishing to assess the accuracy of LWP EIS predictions in relation to the peatland habitat, the position is even worse because the peat-depth data that *are* supplied as part of the LWP EIS can be interpreted with only the greatest difficulty, and in some cases the data cannot be read at all. Given the fundamental importance of such a dataset to the assessment process on this site, such a failure to provide clearer data (even after repeated requests) represents a major consultative failing (Section 5.1).

Section 5.2 : Description and classification of peatland systems
Given that blanket mire peatland dominates at least 85% of the development area, an assessment of potential habitat impacts very much depends on the adoption of classification systems that are capable of describing the biological diversity and ecological functioning of the blanket mire environment. A great many such systems exist. It is therefore most unfortunate that the LWP EIS documents choose not to use any of these and instead devise their own system of description and classification (Sections 5.2.1 – 5.2.6).

The LWP approach begins badly by using catchments as the largest mapping unit, apparently in the mistaken belief that catchments are recommended for such peatlands by the Ramsar Convention, whereas in fact the Ramsar guidance merely states that catchments should be used for peatlands 'where appropriate'. Catchments are not appropriate units of description for blanket mire peatlands (Section 5.2.1).

A long-established system of classification entirely appropriate to blanket mire systems, and indeed to all mire ecosystems, forms the basis of official guidance to the UK conservation agencies (Section 5.2.1 – 5.2.5). This same system has been employed in various forms since the early 1980s in many parts of the world, and now features in Ramsar Convention guidance for peatlands (Section 5.2.1.1).

The LWP EIS documents acknowledge the existence of this classification system, but then explicitly choose not to use it, preferring instead to devise a novel system based on Erosion Class, specifically designed to describe the features observed by LWP in the Lewis Peatlands. The system developed by LWP has its origins in the description of erosion from the early 1960s, but that was for research into the nature of erosion. By explicitly putting erosion at the heart of its descriptive system, LWP has thereby devised a system that is capable of describing and assessing states of erosion, but is a very poor system for describing blanket bog in any other state – particularly relatively wet, undamaged mire, or mire showing vigorous vegetation recovery (Section 5.2.5).

Furthermore, close examination of the LWP mapping units for these Erosion Classes reveals that the mapping system used often results, within any particular Erosion Class polygon, in the inclusion of significant areas that clearly do not form part of that particular Erosion Class. Consequently the area calculations made for Erosion Classes must be regarded as indicative only, but it also often means that less-eroded or un-eroded ground is overlooked in this way (Section 5.2.5.2) and is thus perceived to be rarer than it is. Field survey by the UEL PRU confirmed this finding, as is discussed later in this summary.

The present UEL PRU report gives a demonstration of how the established hydromorphological system of mire classification can be used to describe the blanket mire habitat of the Lewis peatlands in terms of its eco-hydrological character and function (Sections 5.2.2 – 5.2.4).

The other classification unit devised for the LWP EIA – namely Hydrological Zones - is one that has no real basis in any existing peatland literature (Section 5.2.6). The four identified zone types are defined on the basis of an amalgam of landscape and hydrological features, but precisely how these are translated into boundaries on the ground is never made clear. Indeed examination of how these boundaries lie within the landscape merely adds to the confusion (Section 5.2.6.1). Correlation of these Hydrological Zones with both the hydromorphological classification system and with LWP's Erosion Classes reveals a similarly poor linkage (Section 5.2.6.2).

The already-weak value of these Hydrological Zones is further undermined by the fact that they do not feature at all in the LWP EIS Habitats Chapter, and were thus presumably not considered helpful. The fact that these zones then play such a major role in assessing potential impact is an issue of very great concern.

A somewhat converse circumstance arose from the UEL PRU field survey in 2006, because an important type of peatland system – ladder fen/eccentric mire - was found to occur widely within the LWP development area, but this type was completely overlooked in the LWP EIS documents and features only obliquely in the original LWP Habitat Survey. In all, a total of some 25 such sites were found to lie adjacent to or on the actual line of the proposed LWP development (Section 5.2.7.3). These are significant partly because they are considered to be of very high conservation value (they are listed by the JNCC as examples of 'active blanket bog' for the purposes of the EU Habitats Directive), but their very wet nature also means that they pose significant engineering challenges. Unfortunately in some cases, major elements of the LWP development infrastructure are proposed for such areas (Section 5.2.7.4).

Section 5.3 : Causes and significance of erosion

The LWP EIS documents suggest very strongly and repeatedly that the blanket mires of Lewis are undergoing erosion of an atypical kind and as a result are also unusually dry within the British context. The northern part of Lewis is described as one of the most severely eroded peatlands in Britain. It is, however, difficult to find published evidence supporting this proposition. Indeed evidence of much more severe erosion elsewhere in Britain is relatively easy to find (Section 5.3.1).

The LWP EIS documents provide a remarkably detailed description of a de-watering process associated with the development of underground 'peat-pipes'. While the description provided by the LWP EIS documents is extremely detailed, it is also extremely difficult to find any published evidence documenting this process. Certainly the LWP EIS documents provide no supporting evidence for this process on Lewis.(Section 5.3.3). Nonetheless this de-watering process is used repeatedly to explain the claimed 'atypically' dry and eroded nature of the Lewis peatlands (Section 5.3.4). This is in marked contrast with the conclusions of an SNH survey of the adjacent SAC, where erosion and drying are attributed to the effects of burning.

While the LWP EIS documents provide no evidence for the peat-pipe and de-watering sequence, the present report offers some evidence that, while peat pipes are undoubtedly common in the Lewis peatlands, and elsewhere, they may not necessarily always be the 'destructive' features so strongly suggested (though not demonstrated) by the LWP EIS documents. This UEL evidence is based on the UEL PRU fieldwork and remote-sensing work carried out on Lewis, but also on fieldwork undertaken elsewhere in Britain (Section 5.3.5).

Section 5.4 : Eco-hydrology of peatlands and peatland drainage

The main evidence presented in the LWP 2006 EIS for potential eco-hydrological impacts resulting from the LWP development, are the results obtained from a hydrological study at Farr Wind Farm, which is a wind farm built on blanket peat during 2005 and 2006. This hydrological study is assessed and discussed in detail by Dr Olivia Bragg in Appendix 1 of the present report. Essentially, her conclusions are that the results obtained from the Farr Wind Farm study cannot adequately sustain the limited zone of environmental impact claimed by the LWP EIS documents (see Appendix 1 and Section 5.4.7 of the present report).

This chapter begins with a section that looks at measurements of moisture content taken by LWP from some drained peat. These are claimed to show that drainage has hardly altered the moisture content at all. In fact these measurements show no such thing, in part because no figures are provided for moisture contents prior to drainage, and also because all the moisture values given are much lower than LWP's own figures for typical moisture contents of Lewis peat (Section 5.4.1).

The present report then looks at the mechanisms of peatland drainage, firstly in the lower catotelm of the peat, then in the surface acrotelm zone (Sections 5.4.2 and 5.4.3). The LWP claim (in part supported by the results from Farr Wind Farm, or so LWP believes) that drainage only affects peatlands over distances of a few metres is shown to be sometimes true in the lower catotelm layer, and that in peatlands this is often referred to as the 'groundwater' layer.

However, the living surface depends on the water-table behaviour in the upper acrotelm layer, and the present report makes clear that the various authorities cited by the LWP EIS documents all agree that drainage has its main, and often extensive, impact in this layer (Section 5.4.3). Measurable drainage impacts in this layer are acknowledged by these authors to be capable of extending beyond 50 m. The present report also presents evidence suggesting such change across a distance of 80 m and possibly further.

A review of Gilman's '50 metre zone', referred to by both LWP and SNH as a safe buffer distance, reveals that in fact Gilman identifies the possibility of change in even groundwater levels (i.e. the catotelm) and in the peat profile itself due to slumping and oxidation, over distances greater than 50 m. If the underlying catotelm changes over this distance, acrotelm effects are likely to extend further than this (Sections 5.4.4 and 5.4.5).

The LWP EIS documents give very precise details of how de-watering caused by peat pipes and gully erosion can produce very large areas of such dry peatland that there is considered (by LWP) to be little or no active peat formation. Given that a gully is in effect a drain, it is not easy to reconcile this description with the assertion that drainage impacts would only be felt across distances of 2.5 m or so (Section 5.4.6).

Section 5.5 : Water crossings

This chapter then closes with a review of the proposed strategies within the LWP development for managing crossing points where water must pass over, under or through the windfarm roadline. Several formal water crossings are identified by the LWP EIS documents, and it is stated that special structures will be put in place here. There is also a commitment to provide a water crossing wherever the roadline crosses a water channel. Given the very large number of erosion gullies that must be crossed by the roadline, and the complexity of channels associated with some of the proposed water crossings, it is not at all clear how the system of formal crossings will work. In addition, settlement ponds are regarded as unsafe for the dominant Hydrological Zone, so this raises the question of how so many potential water crossings will be supplied and maintained with technology such as Siltbusters® (Section 5.5).

Chapter 6 : Habitats

Section 6.1 : A mire landscape of international significance
This chapter of the present report begins by emphasising the international significance of the Lewis peatlands in terms of the types of mire systems found here, but also the fact that the LWP development proposals lie almost entirely within the boundaries of two international conservation designations – SPA and Ramsar.

Section 6.2 : Perceptions of the Lewis peatlands
This section of the present report examines the assertion made by the LWP EIS documents that the Lewis peatlands are undergoing a progressive degradation sequence linked to peat-pipe collapse, initiation of erosion, and associated drying of the blanket bog environment. The two key issues here are that LWP considers this degradation sequence to be a natural process, and that this degraded, eroded bog is of low conservation value. There is an inconsistency in the logic here, because *if* erosion is a natural process then eroding bog (and all the sequences of erosion) are of conservation value. This would be particularly so if the process on Lewis were in some way unusual. The possibility that erosion is instead caused by burning is dismissed by the LWP EIS documents (Section 6.2.3).

Section 6.3 : Peatland, erosion and burning
This section begins by reviewing a range of published literature concerning the possible origins or the extensive blanket mire that is found in so much of this habitat across Britain and Ireland. The LWP EIS documents do not explore any of this literature, apparently because burning is regarded as only a minor, rather transient factor in the dynamics of the Lewis peatlands (Section 6.3.1)

The present document then examines a range of evidence gathered from a variety of sources and from UEL PRU field survey concerning the relatively recent record of fire in northern parts of the Lewis peatlands. This evidence highlights both the relatively common nature of burning even today (with one very recent fire being found by the UEL PRU within the SAC), and the marked evidence of fire damage which was also often associated with significant erosion and surface breakdown. The review also identifies the fact that the LWP Habitat Survey recorded relatively limited signs of burning damage, though sometimes the recording of such damage appears to depend more on the individual surveyor than on the evidence on the ground – in effect, the same ground described by two LWP surveyors is recorded as having evident fire damage by one surveyor, but no signs of burning by the other surveyor (Section 6.3.1).

The significance of fire in explaining the present condition of the Lewis peatlands is then explored, and consideration is given to the recovery rates likely in this area if an area of the bog is damaged by fire. It concludes that recovery times for fire-induced erosion to infill the resulting gullies are likely to be in the order of 200 years at least, but may be very much longer than this. Meanwhile, the LWP EIS documents conclude that burning is not a major factor because SNH has had a Peatland Management Scheme in place for the last decade and this will have reduced incidences of burning. The fact that a major fire occurred in 2003, and the UEL PRU found a substantial fire in 2006, suggests that this confidence is misplaced. It also does not allow for the recovery timescales discussed above (Section 6.3.2).

Section 6.4 : Vegetation of Lewis peatlands

It is the contention of the LWP EIS documents that the Lewis peatlands are dominated by dry peat which supports much dry heath vegetation, particularly consisting of the NVC type H10b. It is worth noting at this early juncture that an SNH survey found no H10b on the peat of the adjoining SAC. The LWP SAC documents state that the (experienced) SNH surveyor had overlooked this vegetation type (Section 6.4.1).

For its part, the LWP Habitat Survey decided early on to separate out a bell heather (*Erica cinerea*)-rich peatland vegetation type as H10b. This is then justified by citing various vegetation accounts, including a paper by one of the present authors, and suggesting that these accounts justify the separation of this vegetation into a dry heath type. This is not the case – these cited papers do not support such a decision (Section 6.4.1.1).

The present report consequently reviews the phytosociological (plant sociology) principles that underpin the National Vegetation Classification (NVC) and thereby identifies that much (though not all) of the vegetation data assigned by the LWP EIS documents to a dry heath H10b NVC type instead fits more comfortably in a blanket mire vegetation type (Section 6.4.1.2).

In the course of explaining this re-assessment of dry heath types in an earlier response to the LWP EIS documents (Lindsay 2007), one of the present authors incorrectly quoted two well-respected vegetation surveyors, Ben and Alison Averis. This was a serious error and the present author has apologised unreservedly for this. However, as a consequence of this, the Averis's were invited by LWP to re-analyse the LWP Habitat Survey data. The result is that the Averis's identify only a small proportion of 'H10b' quadrats as that type, and suggest that the others are either mixtures or blanket mire vegetation types. The proportions they suggest for re-assignment amount to the same proportions identified by Lindsay (2007). Fieldwork by the UEL PRU has also found that areas on the ground described as being dominated by H10b are actually much richer in blanket mire vegetation than suggested by the LWP Habitat Survey dataset (Section 6.4.1.3).

Indeed the methodology used by the LWP Habitat Survey is one that is extremely difficult, if not impossible, to implement in any consistent and meaningful way. The present report highlights the practical difficulties of undertaking such quantitative survey, and suggests that, once again, any numbers obtained from such work can be regarded as merely indicative, at best (Section 6.4.2).

An alternative approach to such vegetation description, based on the hydromorphological classification system in the JNCC guidelines for this habitat, is presented in the present report as an example of the way in which a complex and highly heterogeneous vegetation pattern can be summarised quite quickly and effectively. Quadrat data obtained during the UEL PRU fieldwork are used to illustrate this (Section 6.4.2.2 and 6.4.2.3).

Section 6.5 : 'Active blanket bog' within the development area
This section of the present report begins with a review of the official definitions for 'active blanket bog' in relation to the EU Habitats Directive (Section 6.5.1).

The approach adopted by the LWP EIS documents to defining 'active blanket bog' is then reviewed. However, as LWP does not have the authority unilaterally to revise the official definition of this term, the extensive exercise undertaken by LWP to this end is, alas, irrelevant (Section 6.5.2).

The present authors attempt to provide an estimate for 'active blanket bog' based on the official definition and the data provided by the LWP Habitat Survey, although this is undertaken in the knowledge that there are significant concerns about the quantitative nature of the LWP Habitat Survey dataset. This exercise produces a very cautious estimate for the extent of active blanket mire in the LWP habitat Survey Area (HSA). This estimate amounts to just over 21,000 ha, which is approximately three times the area calculated by LWP using its particular definition of 'active blanket bog' (Section 6.5.2.4).

Chapter 7 : Peatslide Risk Assessment

This chapter of the present report begins by observing that there have been two very substantial peatslides, and something of a flurry of publications about peatslides and peatslide risk in the last three or four years. Two of the most substantial and relevant of these documents to have been published – one about peatslides in Irish blanket mires and the other about peatslides in the Pennines of northern England - are not referred to. Consequently the implications of these documents are not considered within the LWP EIS documents, which is to be regretted.

Section 7.1 : The LWP approach to peatslide risk assessment
The LWP EIS documents firstly consider the information needed to assess whether there are any localities that may be a risk of a peatslide. This involves gathering information about the physical nature of the peat, in particular California Bearing Ratio (CBR) data, along the length of the proposed roadline.

However, the present report points out that no field data appear to have been gathered since 2004 although significant parts of the proposed infrastructure layout have been altered since then. It also points out that the extensive LWP CBR dataset is neither presented nor discussed. The only tangible result of this fieldwork is a map that shows a number of locations where there may be soft sub-peat strata. However, not only is this map not then discussed, it is never actually mentioned in any of the LWP EIS texts. Thus the CBR data are never presented, and their sole tangible output is never discussed (Section 7.1.1 and 7.1.2).

This lack of information about the Mexe Probe CBR data is a great shame because the present report then illustrates the degree to which the peat body of the Lewis peatlands generally contains distinct and sometimes highly complex layering of peat. This layering should have been obvious in the Mexe Probe CBR data, but this information is not provided by the LWP EIS documents (Section 7.1.2).

The present report then considers the approach adopted by the LWP EIS documents to slope stability analysis, by which areas of (particularly soft) sloping ground are assessed for their likelihood of slope failure – *i.e.* of becoming a landslide. This work is somewhat shrouded in ambiguity because it is not made clear what data were used to undertake such an analysis. Furthermore, only a single analysis of slope stability is presented, for a site near Loch Bhatandip (Section 7.1.3.3). More such analyses may have been undertaken, but there is no clear evidence of this.

Consequently a development extending over more than 140 km of a peat-dominated landscape may have been subject to only a single slope-stability analysis. Furthermore, this analysis generated Factor of Safety (FoS) values that give rise to considerable concern. The present report explains that FoS values below 1.4 are generally considered to be at increasing risk of slope failure, and it also illustrates the way in which raised water tables give rise to low FoS values (Section 7.1.3).

The single FoS example given by the LWP EIS documents is calculated by LWP to have an acceptable value of FoS when the bog water-table is 1 m below the peat surface but has a wholly unacceptable value (0.75 – *i.e.* a failed slope) when the water table is at the bog surface. The present report points out that using a water table at 1 m beneath the peat surface to calculate a FoS is unrealistic, because LWP itself has elsewhere acknowledged that even extreme water-table draw-down into blanket peat is generally no greater than 40 – 50 cm, whereas the normal range lies within 10 – 20 cm of the surface. The present report gives two graphs demonstrating the fact that if the water table lies within its normal range, FoS values for much of the Lewis peatlands are likely to be fairly close to the threshold of safety. This is significant not because most peat slopes are naturally about to fail, but because slopes with such low natural values are likely to be extremely susceptible to any form of disturbance (Section 7.1.3.3).

Having said all this, the LWP EIS documents do not make it at all clear how its slope stability analysis work contributes to the LWP EIA assessment.

The LWP EIS documents next describe a process of peatslide hazard mapping. This work involves a peatslide inventory (for which almost no information is provided), geomorphological mapping, peatslide susceptibility mapping (again, little information is provided), avalanche corridor mapping (again, no information is provided), and visits to other windfarm sites (which are not then discussed in any way). The peatslide susceptibility mapping is described as being based on the UNESCO-recommended approach set out by Varnes (1984). The present report points to the very stark difference between what is offered by the LWP EIS documents and the susceptibility maps presented by Varnes (1984), before using LWP's own Habitat Survey data to demonstrate how such an informative peatslide susceptibility map could have been generated (Section 7.1.4.5).

Section 7.2 : Peatslide incidents – lessons from elsewhere

This section of the present report considers what can be learned from experience and research involving peatslide incidents elsewhere. A number of very relevant issues emerge from this review, but few, if any, of these issues are addressed in the

LWP EIS documents. Perhaps the most important single factor to emerge from this review is the fact that zones of seepage are regarded as being particularly susceptible to slope failure if disrupted. Such a zone of seepage is implicated as one of the factors contributing to the enormous bogslide at Derrybrien Wind farm, Co. Galway. The issue of seepage zones is particularly significant because ladder fens, so far un-recognised and un-reported by LWP, are significant zones of seepage.

Section 7.3 : LWP Peatslide Risk Assessment

The LWP peatslide risk assessment identifies what it describes as only 15 localities within the development area where there is any possibility of slope failure. Given the various factors discussed above, this is a difficult claim to accept. Nonetheless, the LWP EIS documents proceed to describe actions to be taken to prevent slope-failure at these 15 sites. Given the prevailing ground conditions, particularly the presence of ladder fens, wet percolation mires, seepage zones, many of the solutions proposed by LWP are simply not appropriate and may cause more harm than good. Each locality is discussed in some detail in the present report.

Section 7.4 : Implications for peat stability at the LWP windfarm

Given the somewhat unsatisfactory treatment of peatslide risk by the LWP EIS documents, as described above, the UEL PRU undertook its own assessment of peatslide risk, employing the same parameters used by LWP, but combining these with parameters used in an assessment of peatslide risk in Ireland, undertaken by the Landslides Working Group of Ireland. The parameters used are given in Section 7.4.1.1 of the present report.

The outcome from the UEL PRU analysis of potential ‘at-risk’ sites is that a total of 97 such localities were identified – almost three times the total maximum number of sites initially identified by the LWP EIS documents (Section 7.4.1.2).

Section 7.5 : Engineering and real-world construction

This chapter of the present report ends with a review of the engineering process, and the fact that while well-established engineering processes such as house construction rarely lead to structural failure, engineering projects involving new approaches and untested techniques could be said almost to rely on failure as a means of identifying which aspects of this novel approach work, and which don’t. This is highly relevant to questions of relatively novel engineering such as, for example, ‘floating’ roads and rockfill construction in wet deep peat, as proposed for the LWP development.

Chapter 8 : Direct and Indirect Impact Assessment

This chapter of the present report begins by emphasising the highly variable nature of the ground within the Lewis peatlands, and the consequent problems of attempting to provide a single width of ‘potential impact zone’ for such ground. It highlights the very real difficulties associated with the LWP EIS assertion that most impacts will be restricted to a 2 m zone bordering the development.

Section 8.2 : UEL impact assessment

In this section of the present report, a possible alternative approach to the LWP method of impact assessment is presented. It firstly identifies all ground directly affected by the proposed LWP infrastructure (Section 8.2.4). It then highlights the fact that micrositing flexibility expands the potential area which must be assessed in terms of its environmental value and potential for disruption. Looking, then, within this 'area of search', ground was assessed using several criteria (such as presence of ladder fen, or evident peat pipes). From this, a total of 199 'areas of hydrological concern' were identified. Every one of the 97 sites already identified as being at risk of slope failure was included within this list of 199 areas of hydrological concern (Section 8.2.6).

These 199 areas were then examined in more detail using field survey data and remote-sensing information to identify an appropriate potential area of impact, referred to as a 'Zone of Concern ' (ZoC). In drawing up these boundaries, several sites became amalgamated. Thus from the original 199 sites, a total of 76 ZoCs were generated (Section 8.2.7).

Consideration then turns from specific localities with evident issues to the general degree of indirect impact likely to be associated with all elements of the proposed LWP infrastructure. A review of acrotelm dynamics (Section 8.2.8.1 to 8.2.8.3) emphasises the very real potential for general impacts to be felt as far as 50 m away from the development.

Consequently the map of total infrastructure is then provided with a 50 m buffer zone, to create a general potential zone of impact (GPZI). The resulting impact areas are then summarised thus (Section 8.2.8.4):

Direct loss to infrastructure	=	555 ha
Total area of GPZI	=	2,625 ha
Total are of GPZI and ZoCs	=	3,154 ha

Thus the area of potential impact so far identified is 3.5 times larger than the 901 ha total 'realistic' area of impact proposed by the LWP EIS documents.

The present report then considers the potential impacts resulting from breakdown of the bog surface pattern, or even of a bogslide, and assembles a set of impact zones where the size of zone is determined by the depth of peat. This creates a set of Mesotope-Microtope Zones of Concern (MZoCs) (Section 8.2.9), which are then combined with the GPZI and ZoCs described above. This produces a total UEL Potential Zone of Impact (UEL PZI) of 5,569 ha, which is slightly more than 6x larger than the 901 ha proposed as a 'realistic' impact zone by the LWP EIS documents.

Section 8.3 : Impact on 'active' blanket bog
The present report next considers the extent to which the UEL PZI supports 'active blanket bog'. Using the definition of 'active blanket bog' assembled in Section 6.5 and overlaying it onto the UEL PZI boundary, it seems that the UEL PZI contains 4,808 ha of 'active blanket bog', compared to 202 ha loss predicted by the LWP EIS documents.

Section 8.4: Loch Mor an Starr
Finally, this chapter of the present report considers the implications of infrastructural development and potential impact in relation to the public water supply of Loch Mor

an Starr. The LWP EIS documents attempt to provide complete reassurance that this water supply will not be affected by the LWP development.

However, issues associated with construction of the overhead transmission lines, which will actually cross the head of the loch and then run along the shoreline, and the presence of several features such as ladder fens and seepage zones along the proposed route of the roadline, suggest that LWP should not be so sanguine about the potential dangers.

Furthermore, when questioned about the possibilities of pollution or sedimentation into the loch, the LWP EIS documents quote the very low rates of water (and thus pollutant) flow associated with catotelm peat. The fact is, such pollutants and sediment loads will be moved along by overland and near-surface flow. Such flow can achieve speeds of more than 800 metres per day, compared with the 15 metres per year cited by the LWP EIS documents (Section 8.4.3).

Section 8.4.4 of the present report considers the potential for slope failure in the deep peat that lies alongside the western shores of Loch Mor an Starr. The landslide hazard criteria used as part of the LWP EIA are applied to this area of deep peat, and it seems that there may be reason for concern should the roadline and power line be constructed along the proposed routes.

Chapter 9 : Cumulative Effects and Impact Interactions

This final chapter looking at potential impacts arising from the LWP proposals considers the questions of hazard and risk. The former is defined as the potential for an impact to occur (Section 9.1.1), while 'risk' is defined as the consequences of such an impact, particularly in terms of cost (Section 9.1.2).

These issues are explored further in Sections 9.1.3 and 9.1.4, and are presented in terms of the potential geographical consequences should a major peatslide occur and enter a river system. The sites considered by the UEL PRU earlier to be at risk of slope failure form the sites of initiation, but then landform maps are used to identify which parts of the landscape and which river system would be affected.

The present report highlights the fact that the LWP EIS documents neither discuss the possibility of any such events and their consequences, nether do they attempt any assessment of the economic consequences of a peatslide occurring within the development area. Given the considerable economic consequences of the very large bogslide that occurred at Derrybrien, Co. Galway, it would seem both a highly pertinent analysis and one that could draw on the lessons learned from the Derrybrien incident.

1 INTRODUCTION

1.1 Background

Lewis Wind Power (LWP) has, since the start of the new millennium, been engaged in a process of applying for planning permission to construct a large windfarm on the Isle of Lewis, Outer Hebrides. This process has resulted in two formally submitted proposals, each accompanied by an Environmental Impact Statement (EIS), as required by the EU Directive on Environmental Impact Assessment (Directive 97/11/EC) given the scale and nature of the proposal.

The first planning submission and associated EIS, submitted in 2004, involved a proposed 234 turbines together with their essential infrastructure, such as roads, transmission lines, quarries and sub-stations (LWP 2004 – and hereafter referred to as LWP 2004 EIS). The Peatland Research Unit of the University of East London (UEL) was asked by the Royal Society for the Protection of Birds (RSPB) to consider the likely consequences of this proposal specifically on the peatland, and to carry out a critical review of the EIS submitted in support of the proposal. That report was submitted to the RSPB in April 2005 (Lindsay 2005).

As a result of comments, discussions, representations and further fieldwork, LWP subsequently presented a modified proposal involving 181 wind turbines, together with their associated infrastructure, in December 2006. In the meantime, the RSPB had commissioned the UEL Peatland Research Unit to undertake its own field research within the proposed development area and assess the findings of the LWP 2004 EIS in the light of this field research. The UEL Peatland Research Unit duly undertook this fieldwork in October 2006.

With the submission of the revised LWP development proposal in December 2006, the RSPB then asked the UEL Peatland Research Unit to provide a critical review of the revised proposal in the light of both the field research carried out in October and the subsequent analysis of the results. Although the revised LWP proposal essentially involved the same layout as set out in the original LWP (2004) proposal but with 53 turbines removed and a few sections of road re-aligned, the revised LWP EIS (LWP 2006 – hereafter referred to as LWP 2006 EIS) contained a significant amount of new supporting material. An interim report was provided to the RSPB by the UEL Peatland Research Unit (Lindsay 2007), but it was not possible to review all aspects of the modified development proposal within the timescales of the planning consultation period, nor to provide a comprehensive and relevant synthesis of the data gathered in late 2006.

During the preparation of the present report, Dr Tom Dargie, author of the LWP 2004 Technical Report of the Baseline Habitat Survey, and Habitats chapter and Carbon Savings chapter for the LWP 2004 EIS, produced a lengthy critique, described as a ‘rebuttal’, of Lindsay (2005) and Lindsay (2007). This critique consists of both a *Technical Rebuttal Report to Lewis Wind Power* and a *Summary Rebuttal Report* (Dargie, 2007a, 2007b). Both documents have been circulated widely by Dr Dargie.

This critique provided by Dr Dargie has made a helpful contribution to the debate by highlighting a number of factual errors in both Lindsay (2005) and Lindsay (2007). Thus, for example, Lindsay (2005) stated that in studies of water-table draw-down in two Minnesota peatlands, Boelter (1972) recorded draw-down of between 5-10 cm at 200m distance from the ditches studied, whereas in fact Boelter (1972) only measured to a maximum distance of 50 m from these two ditches. The 200 m distance stated by Lindsay (2005) is thus clearly incorrect.

Lindsay (2005) also quotes Boelter (1972) as stating that there is no significant draw-down more than 10 metres from [one of] the ditches, whereas what Boelter (1972) actually says in relation to the additional lowering of the water level in one of the ditches is that:

> *"No effect was evident on the water table 20 m from the ditch two weeks later. Up to 10 m, the measured drawdown was only 0.01 m."*
>
> *Boelter (1972)*

Dargie (2007a) also points out that Lindsay (2007) incorrectly attributes a quote to Alison and Ben Averis in their report describing the vegetation of North Harris (Averis and Averis, 1995), concerning the occurrence of dry heath H10b vegetation on peat. This issue is addressed in Section 6.4.1.3 of the present report, but Mr Lindsay acknowledges the error and unreservedly apologises for it.

Dr Dargie also helpfully points out that the Exxon Valdez ran aground on a reef in Prince William Sound, not Prince Regent Sound, as stated in Lindsay (2005).

For the remainder of Dr Dargie's extensive critique, the issues are summarised in Table 1 of Dargie (2007a), and are described by him variously as exaggeration, misrepresentation, use of incorrect methods, judgements, examples or assertions, dubious use of evidence, or use of irrelevant material. Closer examination of the examples set out in Dargie (2007a, 2007b) reveals that in fact almost all of the identified cases actually involve a difference of opinion, a difference in interpretation of the texts under discussion, a difference in interpretation of the evidence available, or arise because Dargie (2007a, 2007b) believes that more evidence must be provided to justify the statements made in Lindsay (2005, 2007).

In the light of this, it is firstly important to be clear that it is not the task of the UEL Peatland Research Unit, nor the RSPB, to undertake a complete EIS for the development. However, it *is* the responsibility of consultees to raise questions about what appear to be gaps in supporting evidence, or to question particular interpretations of evidence when other evidence or interpretations are also available. This is what the present report, and the earlier reports (Lindsay, 2005; 2007), set out to do.

It is thus almost inevitable that there should be apparent disagreement of opinion, interpretation and relevance between the content of the LWP EIS documents and the content of documents that are specificlally designed to be a critique of those EIS statements. Whether the information provided in Lindsay (2005), Lindsay (2007) and the present critique of the EIS documents can legitimately be described as 'exaggeration', 'misrepresentation' or 'distortion' really depends on one's point of view. Readers are left to make their own judgement about this.

Consequently, other than the specific errors identified by Dargie (2007a, 2007b) and mentioned above, which have been corrected where appropriate in the present report, it was not considered appropriate to modify in any significant way the drafted content of the present report in the light of the comments made by Dargie (2007a, 2007b). In places a brief clarifying phrase or sentence has been added, but no more.

One observation will, however, be made about the Dargie (2007a, 2007b) 'rebuttal' documents. Dr Dargie emphasises that Lindsay (2005, 2007) specifically names Dr Dargie as an author of the LWP EIS documents. This is because Dr Dargie is author of the LWP Technical Report describing the original LWP habitat survey, and much of what follows in the main EIS documents appearws to have its origins in what Dr Dargie writes in this Technical Report. Dr Dargie has subsequently been at pains to emphasise that he was only responsible for, in effect, the original habitat survey Technical Report, the EIS Habitats Chapter, and the Carbon Savings Chapter of the LWP EIS documents. His comments in his 'rebuttal' (Dargie 2007a, 2007b) then appear to be based on the assumption that the observations made by Lindsay (2005, 2007) refer *only* to topics covered by Dr Dargie in his chapters. Thus he states:

> *"Boreas Ecology notes here that Mr Lindsay makes no distinction throughout his 2005 and 2007 material, in response to both the LWP 2004 EIS and the 2006 Addendum, between habitat assessment (authored by Boreas Ecology and including ecohydrology) and assessment of hydrology, hydrogeology and geology (authored by Enviros Consulting). Different scales and distances-of-effect operate in these separate assessment studies."*
>
> *Dargie (2007a), para 296*

Lindsay (2005, 2007) makes no distinction between the diiferent sorts of study referred to by Dargie (2007a) because it was assumed that the LWP EIS documents represented an integrated assessment of potential impact that embraced all such topics. Any "distance-of-effect" impacts were assumed to reflect *all* factors impacting on the habitat. Thus the potential range of impacts and impact-distances discussed in Lindsay (2005, 2007) were not based purely on the restricted concept of 'habitat change' *sensu* Dargie (2007a, 2007b). Also taken into account were possible changes to water regimes (and consequent ecological impacts) in gullies, streams and pools, as well as potential consequences of soil instability caused by the development. Such an approach has also been adopted in the present report.

1.2 Purpose of the Present Report

The present report is a review of the evidence presented by the developers of the Lewis Wind Farm proposal as part of the planning application process. As such, the present report is not intended as an 'alternative' EIS, neither does it seek to advocate the conservation of the Lewis peatlands. Its function is to examine the evidence presented by LWP concerning the peatland habitat and consider the extent to which the evidence offered by LWP provides an adequate basis for making a well-informed planning decision

In places, the LWP documents adopt approaches that result in certain types of information being assembled, whereas had other approaches been adopted a rather different and arguably more informative set of information might have been brought together and presented in the LWP EIS documents. The present report thus considers these alternative approaches and presents information based on these to highlight the information-gaps resulting from the particular course pursued by LWP.

The present report is thus a synthesis of comments made so far by Lindsay (2005, 2007) about both the LWP 2004 EIS, the LWP 2005 Transmission Line Addendum (TLA) and the LWP 2006 EIS, together with additional material obtained as a result of fieldwork by the UEL Peatland Research Unit on Lewis. The report additionally provides a more comprehensive assessment of issues that have not, as yet, been adequately reviewed in the various previous reports produced by the UEL Peatland Research Unit.

1.3 Layout of the Present Report

There is a great deal of repetition in different parts of the two LWP EIS documents – an issue that will be discussed later – and thus it makes it difficult to comment in a structured, subject-based way if the strict format of the LWP EIS documents is followed. Consequently the present report takes the broad headings of the two LWP EIS documents and uses these as its main chapter headings. It brings together into the relevant chapters all parts of the two LWP EIS documents relevant to these various headings. It will thus be found that text from several different parts of the two EIS documents may be referred to in a single paragraph of the present report.

It is not reasonable to expect the reader of this present report to seek out and compare simultaneously a variety of texts from the two LWP EIS documents. Consequently the present report, wherever feasible, provides verbatim texts from the sections of the LWP EIS documents being discussed, at or near the start of such discussion. It does so, with key phrases emboldened by the present authors, in the following format (Note: where the original authors have emphasised the text in any way, this will also be made clear):

> *"Based on the findings of the investigations **carried out on peatslide susceptibility** (Chapter 17), potentially unsafe terrain..."*
>
> *LWP 2004 EIS, Volume 6, Appendix 17A, 17A1, para 1*

In order to identify separately any quoted text from sources other than the LWP EIS documents, quotes from such additional sources will be presented in the following format:

> *"Certainly the wetland manager must ensure that the ditch does not intercept surface water from his site and he must satisfy himself that the winter flooding..."*
>
> *Gilman (1994)*

Emboldened text indicates emphasis by the present authors as described above, but where an observation of the present authors is inserted into a quote for clarification, this will appear in square brackets, thus:

> *"Certainly the wetland manager must ensure that the ditch does not intercept **surface** water [i.e. including overland and near-surface flow] from his site and he must satisfy himself that the winter flooding..."*

Gilman (1994)

As reference needs to be made to diagrams and tables given in the LWP documents and there is thus the potential for confusion when referring to, for example, Figure 2 in the LWP 2006 EIS document rather than Figure 2 in the present document, all reference to figures, tables or text in the LWP documents or other cited documents will be distinguished in the following font colour (teal):

...the data displayed in LWP 2006 EIS, Vol.2, Sect.2, Chap. 11, Figure 3 show that...

There is extensive cross-referencing within the present report. Where cross reference is made to whole chapters, this will be referred to as “see Chapter xxx”. Where a particular section within a chapter is being cross-referenced, this will be referred to as “see Section xxxx”.

1.4 The use of extensive quotes

In addition to specific comments about particular topics, several general points need to be made about the two LWP EIS documents. These more general comments form the first part of the present report. Some of these general issues also have a particular bearing on topics considered in more detail subsequently in the present report, and will thus be referred to again later, this time under the appropriate subject headings.

It will be found that other published works have been extensively quoted (not merely cited) in the present report. These unusually lengthy quotes from existing literature are presented for two reasons.

Firstly, in some instances it has been found that interpretation of certain published research findings within the literature, as presented by the LWP EIS documents, does not perhaps wholly reflect what is said in these published sources. Equally, various important topics for which there is an established body of literature are either not referred to at all, or are presented with particular emphases that perhaps do not reflect the body of literature as a whole. Consequently it is probably helpful to the reader if the present report provides key sections of text from these published sources in order to make ready comparison between the original text and the LWP EIS interpretation of the text.

Secondly, unproven theories and new untested research findings form the basis of predicted impacts for a number of critical issues within the LWP EIS documents. Predicting potential environmental impacts is difficult enough even when using well-established ecological models. It is difficult to see how such a major development can justify basing several of its key impact predictions so confidently and exclusively on ideas that have not yet been subject to scientific peer review, or which are still the subject of much scientific debate. Of particular concern is the fact that such unsupported predictions tend to present ‘best-case’ scenarios in favour of the development. There are few, if any, cases where the unresolved models or untested conclusions presented by LWP give rise to an unfavourable scenario for the development. This is unfortunate because it leaves at least an impression that these un-tested theories and models have been chosen precisely because they result in predictions that are consistently favourable to the development proposal.

Had, firstly, the existing body of published knowledge been explored fully in the LWP EIS documents and, secondly, any such additional proposals then been offered as tentative indications of what may occur beyond what is known and reasonably predictable, presentation of these new and untested ideas might have been acceptable. However, the LWP EIS documents do not do this. Key aspects of existing published knowledge are not mentioned, while unproven theories and untested research data are offered as the cornerstone of important impact predictions.

Such use of 'best-case' predictions inevitably results in a distortion of the EIA process towards a minimised scale of predicted impact. The fuller-than-normal quotes from existing literature given within the present report, as referred to above, are thus provided because such literature tends to provide a degree of balance when set against the generally best-case views presented in the LWP EIS documents.

2 GENERAL COMMENTS ABOUT THE LWP EIS DOCUMENTS

2.1 The Purpose of the EIS (1) – to inform consultation and decision-making

Given the size and scale of the proposed LWP windfarm development, and the transposing of Council Directive 97/11/EC (the EIA Directive) into UK law, there is a legal requirement that LWP undertake an Environmental Impact Assessment (EIA) of the development proposal and present the findings of this as an Environmental Impact Statement (EIS).

Article 6 of Directive 97/11/EC [revised] requires that:

> *1. Member States shall take the measures necessary to ensure that the authorities likely to be concerned by the project by reason of their specific environmental responsibilities are given an opportunity to express their opinion on the information supplied by the developer and on the request for development consent. To this end, Member States shall designate the authorities to be consulted, either in general terms or on a case-by-case basis.* ***The information gathered pursuant to Article 5 [the EIS] shall be forwarded to those authorities****. Detailed arrangements for consultation shall be laid down by the Member States.*
>
> *2. Member States shall ensure that any request for development consent and* ***any information gathered pursuant to Article 5 [the EIS] are made available to the public*** *within a reasonable time in order* ***to give the public concerned the opportunity to express an opinion before the development consent is granted****.*

The EIS is thus a key document in the deliberation process, representing the main body of information used to inform decision-making, and representing the main mechanism for consultation about the proposal with the community at large, whether this be statutory bodies or members of the public. As such, an EIS should set its information out clearly and logically, allowing ready access to all relevant information.

In a number of important ways, the LWP 2004 EIS and LWP 2006 EIS documents fail significantly in this respect. These failings include:

- the presentation of tentative theories and descriptions as established fact;
- the presentation and interpretation of information in ways that do not wholly reflect the nature of the data, or the original data sources;
- the presentation of key data in ways that cannot be interpreted or assessed;
- simple organisational issues such as the use of an un-necessarily complicated layout for the documents, with information repeated in several different places but expressed inconsistently;
- the lack of any internal consistency in terms of figures that quantify basic infrastructural elements – many numbers are presented in different places

within the EIS documents but figures for the same infrastructural element may vary from place to place without explanation;

- finally, and most serious of all, significant key data which should play an essential part in informing the decision-making process are quite simply absent.

The failure to provide documents that allow genuine consultation over the clear and unambiguous facts means that it is difficult to see how the 'competent authorities' (those involved in the planning decision) can make an informed judgement about the proposal. The complaint here is not simply that to read the documents is 'difficult'. It is actually impossible to determine the dimensions, nature or scale of several key factors.

Furthermore, given the over-complicated nature of the EIS documents, and the failure to provide consistent information across the various sections, there is a very real need for the reader to be able to make ready comparisons across different sections of text from these two documents. However, it is perhaps symptomatic of the whole approach adopted by LWP that all three key documents are pdf-format files with password protection, thus preventing the copying and pasting of different paragraphs together to permit such comparison. If LWP genuinely wanted the range of consultation and widespread assessment of their EIS documents that is required by the planning process, these EIS documents should have the same open-access policy as is found in the EU's, the UK Government's, and statutory agencies' own websites and pdf documents.

The specific failings of the EIS documents in this regard will be dealt with in more detail under the relevant sections of the present report, but some examples here will suffice to indicate the nature of the problem:

- there is no single comprehensive table that provides indicative dimensions for all basic infrastructure;
- in many cases tables that do exist contradict each other, provide information in different formats which prevent direct comparison, or conflict with dimensions used in impact assessment;
- impact assessments purport to consider all directly-impacted areas, but provide no figures for the direct impacts resulting from, for example, construction of transmission lines;
- a surprisingly high proportion of the proposed infrastructure has no associated peat-depth information;
- the peat-depth information presented within the EIS documents is almost impossible to read and interpret in its presented form, despite the fact that peat depths represent one of the key information-sets for this EIA exercise.

2.2 Impact Assessment – boundary conditions define the system

Much of the impact evaluation described in the LWP EIS documents is based on impacts that arise from average or typical prevailing conditions, rather than focusing on extremes likely to be experienced during the life of the development (and beyond, where infrastructure will remain afterwards). Such an approach shows a failure to understand one of the most important features of ecological, indeed biological, systems – namely, boundary conditions.

Maxima and minima form the controlling elements for a great number of biological and ecological systems. Most deciduous trees of temperate Europe are limited in their distribution not by the *average* seasonal conditions, but by whether there is a *minimum* of 120 days to the growing season – *i.e.* where the air temperature is greater than +10°C (Walter 2002). Indeed, as Crawley (see Imperial College portal website) observes:

> *"In terms of plant growth, it is not the monthly average, but the extremes of daily temperature that matter most."*
>
> *M J Crawley : Imperial College portal website*

McVean and Ratcliffe (1962) provide an extended examination of the relationship between Scottish Highland vegetation and the effect of maxima or minima in climate factors such as temperature. They emphasise that for various arctic-alpine species, maximum summer temperatures can be the critical factor limiting their distribution.

Geomorphological systems also display many responses that are governed by extremes. The formation of gravel bars in rivers to form braided streams results from periods when the river is in spate (often from snow-melt) and where there is a plentiful supply of eroded material (typical of rivers emerging from glaciers). During spate conditions in late spring, great quantities of this eroded material start moving downstream, carried by the large volumes of water derived from snow-melt draining from the glaciers or snow-fields in the mountians. As river volumes subside in late spring and summer there is insufficient energy to transport heavier materials such as gravel and pebbles, and so they are left to form fresh gravel bars within the river.

A river of this type may change its shape every year, or even every time there are spate conditions. The morphology of such a river may be difficult to explain if it is only observed during conditions of average flow. Only by taking into account extreme (and sometimes quite brief) spate conditions does it become possible to understand the morphological dynamics of this river type and the behaviour of its sediment load. Clearly such a scenario has considerable relevance to the LWP windfarm proposals – specifically in relation to possible increased 'flashiness' and sedimentation patterns of the north Lewis drainage system.

Closer to the issues of the Lewis peatlands themselves, Ingram's (1982) Ground Water Mound Theory for raised bog systems takes as one of its limiting parameters the *driest* year experienced by a raised bog during its development, while Clymo and Hayward (1982) demonstrate the critical effect that duration of drought has on a range of *Sphagnum* species. Some, such as the major peat former *Sphagnum papillosum*, were rendered "incapable of resuscitation" after drought periods of only 16 days.

From these various examples, it should be obvious that many ecological or biological conditions are influenced more importantly, and governed more generally, by boundary conditions (*i.e.* maxima and minima) rather than average conditions. This is certainly the case, as already alluded to, with peatland ecosystems and water-table behaviour, where it is generally the extremes of water budgets that have more significance than average behaviour. This is a key point, explored in more detail later in the present report.

In contrast, it is clear that the LWP EIS documents often take average conditions as the basis for much of their impact assessment work, rather than the extremes. Thus:

- the LWP tables of risk assessment are dominated by broad generalisations across the four 'Hydrological Zones' rather than looking at the particular conditions prevailing within each identified example of each Hydrological Zone;
- figures for average, or typical, rates of water movement through peat are cited to counter concerns about hydrological effects on Loch Mor an Starr, whereas the more critical issue is the behaviour of overland flow during periods of high rainfall;
- similarly, the predicted zone of potential infrastructure impact is based on data which represent, in effect, average responses to such impacts, thus taking no account of extremes in ground conditions – *e.g.* some affected areas are lochs, some are areas of dry hagging, others are extremely soft and waterlogged ground with very high values of hydraulic conductivity - yet such variability do not appear to have been taken into account when defining the possible impact zone;
- proposals for sediment control, already questionable in terms of infrastructure capacity, become even more so when viewed in terms of heavy/extreme rain events.

To a reader who knows the ground and is familiar with the actual nature of infrastructure associated with windfarms, the LWP EIS documents thus appear, to a greater or lesser extent, biased towards best-case scenarios. Had the LWP EIS documents also explicitly considered 'worst-case' scenarios, they would have focused more on realistic extremes and the ways in which the proposed infrastructure might deal with these, rather than setting up rather simple scenarios (*i.e.* moderate, average conditions) that can be easily dealt with.

2.3 Impact Assessment – real sites, real issues

Developing the theme of the previous section further, an EIS that claims to be a 'realistic' assessment of potential impact can reasonably be expected to tailor its impact assessments to the specific nature of the ground involved. In other words, such an assessment would not adopt a single-value zone of impact uniformly throughout the development zone. Different parts of the development area will possess different characteristics and thus display different impact responses. For example it would be reasonable to expect that an area of very deep, wet peat, would display a different impact response to that shown by an area of relatively thin, very dry peat.

This issue is addressed in more detail in various places later in the present report, but as a general overall comment about the two LWP EIS documents, it is clear that there is an undue and unwise reliance upon such generically uniform impact zones. These zones have been derived, in effect, from extremely simple and (as will be seen later) debatable modelling, in particular of the peatland ecosystem. If one employs a simplistic model that ignores the fine detail of reality on the ground, one should expect a simplistic answer. It is not reasonable to expect, nor to claim, that one's answer is 'realistic' under such conditions. Nevertheless, this is precisely what both LWP 2004 EIS and LWP 2006 EIS documents proceed to do.

2.4 Impact Assessment – impact interactions

There is no denying that the LWP 2004 EIS and LWP 2006 EIS between them represent an enormous amount of work. The two documents embrace a very large range of issues and present a considerable quantity of data. This information is then integrated with legislative and policy frameworks which are themselves covered in some detail.

It is therefore all the more surprising that, despite this considerable amount of work, both documents fail to address one of the most important aspects of Directive 97/11/EC – indirect and cumulative impacts, and impact interactions.

Indeed these aspects are regarded as such a key part of the EIA process that the European Commission has provided a very substantial guidance document about the subject (European Commission 1999) to assist those undertaking an EIA. This EC guidance document describes a number of different possible approaches to assessment of impact interactions and cumulative impacts. It emphasises that these various approaches are not to be seen as mutually exclusive - they should rather be used as a series of mutually-supportive, complementary approaches. The EC guidance document also recognises that, because science is now reliant on specialists within particular areas, it can be difficult to ensure that one specialist group of an EIS integrates its findings with all the other specialist groups involved. Without such integration it is difficult to ensure that the EIA process has taken into account the issue of impact interactions:

> *"There may be a tendency for experts to complete their own chapters of an Environmental Statement in isolation from other experts. This runs against the nature of many cumulative and indirect impacts, and impact interactions, because they often involve more than one scientific discipline or environmental receptor.* ***Care should be taken to ensure that when producing the Environmental Statement, that effective communication is translated into the report.****"*
>
> *European Commission 1999*

However, a review of the contents pages (and their associated sub-contents and Appendix/Annex contents pages) for both LWP 2004 EIS and LWP 2006 EIS fails to identify any section explicitly devoted to impact interactions – arguably the most important and meaningful issue of all when dealing with an assessment of impacts on ecosystems. As Lindsay and Bragg (2004) observe in their review of the massive bogslide at the Derrybrien Wind Farm in Co. Galway, Ireland:

> *"In the century or more since Ernst Haeckel first coined the term 'ecology' and in the 65 or so years since Tansley (1935) first defined the concept of 'ecosystem', our appreciation of the complexity that underlies ecological systems has increased in equal measure with our increased knowledge and understanding. Ecology certainly has*

direct linkages and impacts, but, ***for any given ecosystem, there are many, many more links that are either indirect or cumulative, or which result from a variety of interactions****. Consequently it is reasonable to assume that an accurate view of the likely ecological impacts of a development can only be obtained by addressing these linkages and interactions.* ***It is an issue that can (and should) be explored in some depth within an EIA****."*

Lindsay and Bragg (2005)

LWP 2006 EIS, Volume 2, Section 2, Chapter 10 (10.12.3) does address cumulative effects in the sense of cumulative impacts on the freshwater ecosystems of the development site. The treatment is brief but to the point. There is no equivalent section for the peatland habitat, however. Indirect and cumulative impacts are considered only in terms of the narrow, highly constrained zone of predicted hydrological impact surrounding the proposed infrastructure. LWP 2006 EIS, Volume 2, Section 2, Chapter 11 (11.7) also address the issue of cumulative impacts in a very constrained sense, taking these firstly to mean cumulative impacts from *additional* windfarm proposals, and secondly cumulative impacts from other forms of established land use in the area.

The question of possible cumulative impacts from the LWP development itself is addressed only by stating that monitoring will be undertaken. However, the point about an EIS is that it is designed to aid decision-making *prior* to a development taking place. Consequently it is self-evident that an EIS should address the possible indirect and cumulative impacts, and any possible impact interactions, *prior* to consent being given, rather than simply undertaking to monitor for such impacts should the proposal be granted consent.

Given the extensive body of information gathered as part of the EIA process, there should have been ample scope for a whole section devoted to an integrated overall view of indirect and cumulative effects, and impact interactions. Thus, taking just one example, there are issues about proposed construction methods that have a significant bearing on peat depth and height of water table. These in turn have a bearing on possible drainage requirements, or issues of slope stability, which themselves have possible implications for stream-water quality, disruption of active bog habitat, loss of breeding wader habitat, sediment loading and maintenance of important fish populations. Nowhere is there an attempt to bring these issues together into such an integrated overall assessment. The lack of such a section represents a very substantial failing on the part of the two LWP EIS documents.

The lack of such an integrated approach on the part of the LWP EIA is perhaps best exemplified by the comment made by Dr Dargie in his 'rebuttal' to Lindsay (2005, 2007), and already quoted in Section 1.1 of the present report (Dargie, 2007a). His comment appears to emphasise the compartmentalised nature of responsibilities adopted within the LWP EIA exercise, and the resulting similarly compartmentalised view of impacts within the LWP EIA team.

2.5 Impact Assessment – recognising and retaining uncertainty

Uncertainty is inevitable within an EIS because the process is concerned with prediction rather than with established and measurable fact. What is important is how an EIS deals with this uncertainty. It is obviousy desirable that an EIS should provide predictions based on the best predictive models available. However, an EIS should also make clear the degree of uncertainty or debate associated with such predictions. Confident statements asserting that a given outcome will occur, without any acknowledgement of associated uncertainties, sit uncomfortably within an EIS. This is in part because it is rarely the case that ecological systems and industrial-scale developments can make such completely predictable bed-fellows, but it is also because such unqualified certainty is not helpful to the decision-making process for which the EIS has been prepared. Decision-makers must be made as aware of the *un*certainties in the proffered predictions as they are of the predictions themselves if a reasoned and informed judgement is to be made.

It is certainly true that on many occasions within the two LWP EIS documents, uncertainty about possible processes or effects is expressed. A selection of these can be drawn out to highlight the types and levels of uncertainty identified:

> *"**Peatslides which were unrecorded for either reason may present problems** during or after construction work causing extra costs to be incurred for stabilisation and remedial works. Therefore, it is essential that the results of the current work be considered only as a guide to assist decision making and broad design considerations."*
>
> *LWP 2004, Vol. 3, Chapter 17, para 26*

> *"In most peatslides, a complex chain of events contributes towards movement and **attempts to identify all of the contributing factors are usually fraught with difficulty**."*
>
> *LWP 2004, Vol. 3, Chapter 17, para 31*

> *"Field investigations indicate an intermediate zone of **uncertain geotechnical characteristics**."*
>
> *LWP 2006, Vol. 2, Sect. 2, Chapter 10, para 23*

These identified areas of uncertainty are helpful in the sense that they highlight occasions where the predictive aspects of the Lewis EIA process may not be so reliable. They merit special consideration in terms of identifying 'worst-case' scenarios involving features, or areas, that may be affected. At the same time they highlight what further work may be required prior to a planning decision.

All too often, however, while both LWP EIS documents are ready to identify areas of uncertainty in some parts of the EIS documents, these uncertainties and the implications of these uncertainties then fail to feature in subsequent impact assessments.

Thus, given the context of the several quoted uncertainties about peatslide risk quoted above, it is somewhat surprising to find, in the section titled "Management of Peatslide Risk", the following confident statement:

> *"As discussed in Section 17.4, peatslide prone areas have been identified and avoided where possible, resulting in **only 15 areas which have any potential vulnerability**."*
>
> *LWP 2004, Vol. 3, Chapter 17, para 40*

The author is stating unequivocally that there is no potential for any other area within the development to be at risk. This is despite the significant range of uncertainties acknowledged above. Such an assertion is both unrealistic and contrary to good EIA practice. Indeed it appears to be an example of promoting a somewhat optimistic 'best-case' position, rather than reflecting what is actually known. Later in the present report an alternative view of peatslide risk will be offered for the LWP development proposal.

2.6 Impact Assessment – appropriate descriptive systems

It has already been made clear that developers are generally encouraged to adopt tried-and-tested methods of description, evaluation and prediction for use in an EIS. In doing so, the developer then has no need to validate the methods adopted for the EIS. This is because such validation has already been undertaken by the wider scientific community. The body of existing literature provides helpful context for, and insight into, the particular issues raised by the particular development proposal.

By choosing instead to devise completely new methods for an EIS, a developer runs the risk of not being able to draw on any store of existing literature and thus being unable to present predicted impacts within a wider context of experience. Equally, the approach suffers from the inherent weakness that any such novel methods have not benefitted from peer-review by the wider scientific community, and thus give rise to the possibility that the methods adopted are not in fact fit-for-purpose. The final difficulty with such an approach is that decision-makers in effect have only the assurances of those who devised the methods that they are indeed fit-for-purpose, whereas these same decision-makers can have some confidence in methods that have gone through the process of scientific peer-review.

Despite these substantial areas of concern, the LWP EIS documents devise their own methods of description and assessment for a range of key issues. Well-established descriptive methods already exist, so there was no fundamental need for LWP to devise its own systems. For whatever reasons, the LWP team appears to have felt unable or unwilling to apply these established systems to the prevailing conditions.

The three main existing systems largely ignored by the LWP EIS documents are:

- the internationally recognised system of identifying and describing peatland ecosystem units – the mire mesotope;
- [this is replaced by a classification system that has only limited functional value, is difficult to apply consistently, and sits uneasily with the other major hydromorphological descriptive system employed by the LWP team, namely catchments];
- the internationally recognised classification system for describing the functional hierarchy of peatland systems from small-scale surface features to mire landscapes;
- [this system is not replaced by anything, and thus the various descriptive elements used by the LWP team for the peatland ecosystem are not – indeed to some degree cannot – be integrated into an understanding of each

peatland system as a functioning ecological entity; this results in some very significant aspects of the peatland habitat being overlooked or misread];

- the definition of 'active' blanket bog agreed at EU level and disseminated through the JNCC;
- [the definition of 'active' bog has been the subject of considerable work across the EU, and guidance on the definition of this habitat category is now in place; the LWP EIS documents are not the forum in which to open a debate about such an issue].

All three aspects are examined in more detail later in the present report. For the moment it is enough to observe that by choosing not to adopt appropriate existing systems, the LWP EIS documents are less internally coherent and significantly less informative than they could otherwise have been. Had existing systems been used, it would have been possible to use the context of other studies in order to judge possible scales of impact. By instead devising other, novel systems with which to assess possible impacts, there is little established body of information and evidence on which to draw – the results of the EIA for Lewis tend to sit in isolation.

2.7 Impact Assessment – a planning process based on established evidence

The next general criticism of the two LWP EIS documents to some extent follows logically from Section 2.6 of the present report, because where the LWP documents reject established systems, they are left with the choice of either not replacing them with anything (as in the case of the peatland hierarchy), or of proposing a novel system of their own.

Such an approach, however, is rarely appropriate within the context of an EIA and its associated planning application. The whole purpose of an EIA is to make the best predictions possible concerning the likely impacts of a proposed development. If a novel system of description or assessment is proposed within an EIS, without first having been subject to widespread peer review and testing, how can there be any confidence that this system is capable of providing accurate guidance?

Notwithstanding the inappropriateness of such a step, the LWP EIS documents propose not just one but several untested ideas and approaches without presenting any supporting evidence for these. The first and most striking of these is a unilateral attempt to re-define the term 'active' blanket bog. For this to be accepted, and for the UK to make planning decisions on the basis of this re-definition, it is likely that such decisions would ultimately require the UK Government to justify its position to the European Court of Justice. It is reasonable to assume that in such circumstances, the UK Government would wish to feel confident that such a definition had been widely tested and, ideally, adopted throughout the EU. That is not currently the case, nor likely to be the case in the foreseeable future.

Another untested and unproven theory is used to suggest that much of the peatland habitat within the proposed development zone is in a state of inexorable decline. This theory is based on the idea that the widespread erosion seen in the Lewis peatlands results from natural pipes in the peat. The proposal is described thus:

> *"...the key relationships **seem to be associated with a progressive degradation sequence** ... There seem to be many cases of former Class 1 areas with extensive pool systems suddenly being de-watered to form a Class 7 area of mire. The unconsolidated material growing in pools then collapses to form dry pools, which then form gullies as narrow former walls are removed by an evolving gully network. Over time, the remaining high ground lacking pools dries to form rectilinear blocks with much dry heath vegetation. **The de-watering event is probably sudden and may well involve evacuation of material by subterranean pipe systems** which are occasionally visible as collapsed hollows in peats adjacent to wet peatland types."*
>
> *LWP 2004 EIS, Technical Report, Section 5.2*

Frequent use of the words 'seem' and 'may' are very telling, because no evidence is then presented to support this detailed description. There are undoubtedly pipes in the peat, and there are undoubtedly drained pools. However, the LWP EIS documents make only a single attempt to present 'evidence' in support of this model. This consists of a single oblique aerial photo that does indeed show a line of 'sink holes' – but such lines are open to other interpretation, as is discussed later in the present report.

The two LWP EIS documents do not stop there, however. It is then suggested that the widespread erosion seen throughout the Lewis peatlands is caused by this process, and that significant areas of these peatlands are consequently and inexorably drying out. If little evidence is presented to support the pool-collapse theory, even less is presented to support this model of widespread, natural ecosystem collapse.

Such an unsupported proposal might not matter if it were not then used as a key finding of the LWP EIA work. Although discussion about this proposal in LWP 2006 EIS, Vol. 5, Appendix 11b, Section 11.4 is relatively balanced and accepts that the proposal does not fit with currently-available evidence, the story becomes very different in the subsequent LWP 2006 EIS, Vol. 5, Appendix 11b, Section 11.5, where it is abruptly presented as an established fact:

> *"...**drying as a result of natural hydrological de-watering processes** is by far the most significant factor affecting habitat condition."*
>
> *LWP 2006 EIS, Volume 5, Appendix 11b, Section 11.5*

More will be said later in the present report about this question. For the moment it is sufficient to highlight the way in which an untested and unproven theory is used as a major part of the LWP EIS argument, being elevated from speculative theory to established fact in key parts of the LWP EIS documents. The model's currently speculative nature, the absence of any attempt to present supporting data, and the fact that it has not benefited from the scrutiny of scientific peer review, means that it has no real place as such a prominent 'finding' of this EIA process.

2.8 Impact assessment : the need for scientific controls

At several places in the LWP EIS documents, examples are given of particular features, or of particular studies, that are presented as evidence demonstrating little or no habitat change associated with drainage works. Data are presented for the moisture content of two peat-cutting faces, one old, one new, to demonstrate the limited effect of such a draining face on the bog water-table (LWP 2004 EIS, Vol.3, Chapter 10 : 10.3.6.5) , while the Galson Estate peat road is cited as having produced virtually no impacts on the adjoining peatland (LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 74 and Plate 11.1). However, the simple fact is that neither example in the LWP EIS reports attempts to provide any evidence of what conditions were like *before* these impacts took place.

The whole basis of the scientific method is that while an experiment is carried out on one sample, another sample remains undisturbed (the 'control'). The impact of the experiment is then measured by comparing the condition of the control with the condition of the experimental object. It is very tempting to look at an area in its present state, subsequent to impact, and conclude that there has been no change because there is no obvious sign of change, but without evidence of what was there before, it is impossible to draw such a conclusion.

Thus, for the particular examples given above, the figures obtained for moisture content are only of value if compared with figures for moisture content of the same area of peat prior to the cutting of the peat face. Equally, the statement that the Galson Road has had little impact on the adjacent blanket bog is only valid if data obtained prior to construction of the road can be presented for the undisturbed blanket bog.

Any information within an EIS that is presented as evidence for change, or lack of it, is thus only relevant and justified if:

- evidence can be presented for the 'before' and 'after' condition;
- the evidence for such 'before' and 'after' conditions is gathered in a way that can reasonably be expected to reveal any change, or lack of change.

Otherwise, any such evidence cannot be relied on even though there might be an *appearance* of stability.

3 INFRASTRUCTURE

3.1 Micrositing

As already alluded to in Section 2.1 of the present report, it is surprisingly difficult to obtain from the two LWP EIS documents the precise scale of infrastructure required for this proposed development. It is inevitable that there will be a degree of uncertainty (given the scale of the development) about the precise dimensions of various infrastructure elements. The question of infrastructure *scale* is obviously important, and will be considered in due course. However, it is also important to address the fact that there is uncertainty about the actual *location* of this infrastructure because of a process known as 'micrositing'. The resulting locational uncertainty arising from this is considered first, below.

The LWP EIS documents introduce the issue of locational uncertainty by expressly stating that micrositing of infrastructure may require a repositioning of up to 100 m in the light of "unforeseen ground conditions":

> *"However, it is likely that during construction of the wind farm* ***minor changes (<100 m) in the location*** *of wind turbines and other infrastructure (roads, temporary compounds, concrete batching plants, and substations) may be needed* ***due to unforeseen ground conditions*** *or be* ***advisable in order to further minimise environmental impact****."*
>
> *LWP 2006 EIS, Vol. 2, Sect. 4, Part 2,*
> *Outline Briefing Note 1, para 1*

3.1.1 Micrositing and the assessment process

Micrositing flexibility is standard practice in large developments, but it nevertheless has a very significant effect on the EIA process because it means that there is a zone of uncertainty extending up to 100 m around every part of the windfarm infrastructure. It is commonly understood that there is uncertainty associated with predicting the scale of effects caused by the *presence* of development infrastructure. What is less widely understood is that micrositing, and the resulting uncertainty about where the infrastructure itself will be placed, also has significant implications for the impact-assessment process.

The general assumption about micrositing is that the locational flexibility provided by micrositing will be used by the developer to ensure that, for any given location, the position of 'least impact' will be used. This assumption itself assumes:

- that all significant features are identified correctly by the developer;
- that the developer understands the nature and scale of potential impacts associated with any given part of the infrastructure;
- that environmental constraints are always accorded priority over engineering/construction constraints in the micrositing process, even in the face of "unforeseen ground conditions".

These assumptions may not always be correct. A micrositing position may be chosen simply because it is the best engineering option. Alternatively, the micro-site may be selected because it avoids a recognised bird nesting site but the chosen location then instead results in the direct loss of some other feature of ecological interest that was not identified by the developer.

While this may seem a somewhat hypothetical concern, there is ample evidence from the LWP EIS documents (or more strictly from the features that are missing from these documents) that important ecological features have not been adequately identified during the EIA survey process. Given this failing on the part of the EIA, it is thus particularly important that *consultees* examine the full range of interest-features that lie within the limits of this micrositing zone. Direct, indirect and cumulative effects, and impact interactions, should be considered in relation to the possible establishment of infrastructure anywhere within this zone.

A turbine-base location, for example, has a micrositing 'circle of uncertainty' with a diameter of 200 m, and the turbine could be sited anywhere within this 200 m circle. Thus any features of interest, value or concern within this circle must be identified and assessed. Furthermore, it is important to recognise that because the turbine *could* be placed anywhere within this circle; the outer edge of the circle is arguably as likely a location as the centre. The EIA process must therefore work on the basis of a worst-case scenario, with the turbine being built at the outer edge of the micrositing zone. Consequently any direct, indirect or cumulative effects resulting from this turbine construction are assumed to start at the outer margin of this micrositing circle. All features of interest that lie within the micrositing zone, *plus* those that lie in any identified zone of direct, indirect or cumulative impacts *beyond* the micrositing zone, should be adequately identified.

3.1.2 Micrositing and scale of impact

Addition of a micrositing zone does not mean that the footprint of the development will necessarily be larger – the roads, turbine bases and other infrastructure will be no wider than before. However, the layout geometry nevertheless does have potentially significant implications for the size of the development in terms of its overall footprint. Specifically, the development footprint may be increased as a result of micrositing for two distinct reasons. These two causes are explored below.

3.1.2.1 Infrastructure access

The first and most obvious effect of micrositing is that a turbine (for example) may be placed up to 100 m further from its presently-indicated position. In order to reach this new, more distant location, the roadline will need to be extended. Consequently in a worst-case scenario, every item of infrastructure may require an extra 100 m length of road.

Given such a worst-case scenario, with 181 turbines, 1 control building, 8 sub-stations, 8 temporary compounds, and four batching plants, this could add as much as 20 km to the roadline. Clearly this will not happen (or at least the odds are very high that it will not happen). Nonetheless, it is not appropriate for an EIS to assume that if micrositing decisions lengthen some road sections this will be exactly cancelled out by decisions to shorten other lengths. There is the worst-case *potential* for the roadline to be lengthened by up to 20 km and this should be acknowledged and addressed in the EIS as an upper possible limit of impact. Such a possibility is not considered within the LWP EIS documents.

In addition to the above fairly-evident consequence of micrositing, there is, however, another potential source of increased impact that arises from micrositing decisions about the roadline itself. It is not an immediately-evident issue, but it has the potential to have as much, if not more, impact on the development footprint than the simple extension of road-lengths to access re-positioned infrastructure. It arises from the geometry of a sinuous road.

3.1.2.2 Sinuous roadlines

The issues arising from a sinuous roadline are most easily understood by considering two lengths of string. One length is 20 cm long, and laid down in a straight line. The other length is 30 cm long but is laid in a snaking shape with several shallow curves so that it also extends for a distance of only 20 cm. Thus the net distance covered by both lengths of string is 20 cm, but the amount of ground actually covered by the sinuous piece of string is greater by 1/3. This represents a very substantial increase in the amount of ground directly in contact with the string.

It is perhaps not widely appreciated that, in this way, even a small amount of deviation from a straight road centre-line can add to the total length of road (and thus extent of habitat) directly affected by a development. A set of fairly simple scenarios can be used to illustrate the effect of a road that weaves from side to side within a 200 m micrositing corridor.

Take, for example, a road that weaves from one edge of the micrositing corridor to the opposite edge along a 1 km length of road – *i.e.* 2 curves per km. Given the number of features that may need to be avoided (as detailed further in later sections of the current report) along the proposed development route, this may be a fair reflection of the general pattern that develops on the ground. Such a curve can be seen in Figure 1.

The 2-curve sinuosity shown in Figure 1 has a significant effect on total road length for the development. Two curves (*i.e.* curving from one side of the micrositing zone to the other) every kilometre results in a total increase in road length of 8.6%. The pattern of three curves per kilometre also shown in Figure 1 results in an 18.5% increase in road length.

Using the lower of these two sinuosities (which gives an increased length of 12 km for the LWP road proposal), it is possible to calculate an area based on:

- an additional road length of 12 km;
- a Potential Zone of Impact (PZI) of 50 m width either side of the road centre-line for this extra length.

It is instructive to compare the resulting additional area involved – **120 ha** – with the figures quoted for predicted “actual likely” long-term disturbance:

> *“The summation of **all permanent loss resulting from development is therefore 200 ha** due to wind farm infrastructure*

***and 40 ha due to very long-term disturbance** effects over 35 – 40 years. **This actual likely figure of 240 ha** for all permanent loss..."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 80

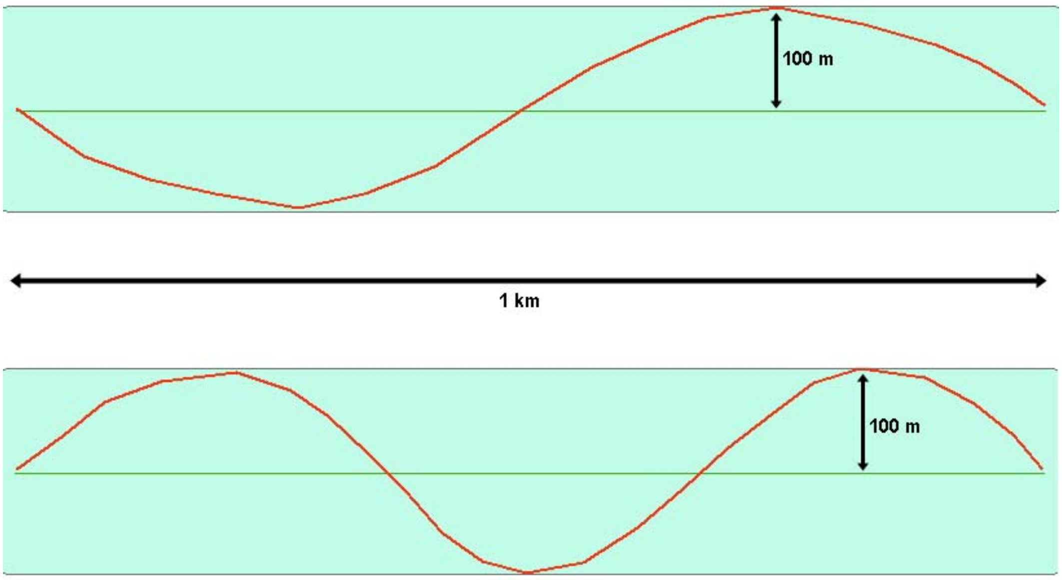


Figure 1. Effect of sinuosity on roadline length
Effect of providing 100 m micrositing buffer zone along road corridor, with two scenarios of road sinuosity. The upper illustration shows a road curving twice in a distance of 1 km, the lower illustration shows the road curving three times over a distance of 1 km. The central road-line is shown in green, the micrositing buffer is shaded light blue, and the curving road line is shown in red.

In other words, simply adding a modest degree of sinuosity to the road line could result in an additional area of impact that is equivalent in size to 50% of the predicted "actual likely" area of long term disturbance. To take a more extreme example, but nonetheless an example that might reflect reality over some sections of the route, a three-curve sinuosity per kilometre results in a total increased PZI area of **260 ha**, thereby exceeding LWP's total predicted "actual likely" area of disturbance.

The actual route will not have a *constant* sinuosity of 3 curves per kilometre, nor even of 2 curves per kilometre, but it is quite likely to have a combination of straight stretches and more or less sinuous sections. Some of these sections may even exceed 3 curves per kilometre. Where there are sinuous sections, they will add to the total road length and thus add to the area of disturbance.

It is consequently important to recognise this issue as part of the impact assessment process, particularly on a development of this scale because as developments become bigger this proportional increase in area due to sinuosity becomes more and more significant in terms of absolute area affected. The sections of the LWP EIS documents dealing with impact assessment, however, make no reference to this issue. In the LWP EIS documents, micrositing is only ever mentioned in relation to the development and construction process, never in relation to potential impacts, despite the fact that it will almost certainly add to the total area of ground affected by the development.

3.1.3 Micrositing and decision-making

The purpose of micrositing is, of course, to ensure that there is sufficient flexibility in the placement of infrastructure that areas of importance can be avoided. Thus in theory, the impact of the development on the interest of a site should be *reduced* by such measures even though the total area of development may increase as a result. However, the EIA *process* must be applied to this larger micrositing area to ensure that all possible features of interest are correctly and adequately identified so that micrositing decisions are as fully-informed as possible. It is neither sensible nor sufficient simply to assume that all micrositing decisions eventually made on the ground will inevitably result in the 'safest, least environmentally-damaging' location.

There may be many reasons why a less-than-satisfactory location is chosen for any particular section of road; for example, peat depths (which can vary a great deal over distances of 100 m) combined with gradients may render much of the micrositing corridor in a particular location less than optimal. The alternative positions may be equally sensitive in relation to other features of interest. The site engineer and site ecologist would thus need to make a joint assessment of the problem and come to some agreement. The final decision may be an unsatisfactory compromise because, ultimately, the road has to go somewhere. Should engineering requirements prevail, such laudable attention to safety would in no way diminish the fact that significant ecological interest may have been lost as a result.

In the case of micrositing, there is of course a dual need both to inform the planning process and to ensure that operational decision-making should be as well-informed as possible. It is worth noting, therefore, that peat-depth data are not currently available for the micrositing corridor, only for the centre line of the road. It is very obvious from the depth measurements obtained for the development site that profound changes in peat depths can occur within distances of 100 m. Peat depths towards the outer limit of the micrositing corridor may thus be very different from those indicated by the road centre-line. Peat depth has potentially significant implications for both engineering and ecological issues and it should consequently play a key part in both the assessment process and the subsequent operational decisions. Unfortunately the present lack of such data means that the planning/assessment stage must proceed without such information.

Furthermore, it is clear that there are many features of ecological interest within the proposed development area that have not been adequately recognised by the LWP EIS process as significant environmental features. Indeed in some cases these features appear not to have been recognised at all (see, for example, Sections 5.2.7.3 and 7.3.5). This raises additional concerns about the micrositing process. If a feature has not been flagged up as important, it may be inadvertently damaged or destroyed because its importance is not fed into the decision-making process. In the light of the apparent failure on the part of the LWP EIS documents to recognise such areas, it is all the more important that such features lying within the potential impact zone are at least highighted by consultees *prior* to any decisions within the planning process.

3.2 Infrastructure dimensions

Given that LWP have stated their requirement for micrositing flexibility, and notwithstanding LWP's failure to address the issues of this wider impact zone, it is clear that the assessment process of the EIS requires a micrositing buffer to be added to all plan dimensions of the development infrastructure. The question is, what exactly are these dimensions? The answer to this question, as suggested at the start of the present chapter, is surprisingly difficult to find.

It is in fact impossible to obtain definitive infrastructure dimensions from the two LWP EIS documents, even in an indicative sense. Given that the infrastructure is the most basic and tangible aspect of the development proposal, such a situation is surprising. There is no shortage of figures, although some are not easy to find. The problem is that the figures are not consistent with each other, and to make things worse they are often presented in different forms in different locations. As documents that are provided specifically to aid the decision-making process, such a basic failing in the two LWP EIS documents is not a trivial issue.

The main physical components of the development can be simply listed:

- new site roads;
- turbine bases;
- turbine hard-standings;
- sub-station (permanent) compounds;
- control building;
- temporary compounds;
- batching-plant compounds;
- overground transmission lines;
- rock-source quarries.

3.2.1 <u>Infrastructure – the lack of a single definitive table</u>

It is far from clear why the indicative dimensions for each part of the development infrastructure, as listed above, cannot simply be presented in a single table. However, such a table does not exist in either of the two LWP EIS documents. Various tables list some of the items above, but many only give numbers of the particular features, rather than dimensions. Even when dimensions are given, comparison between tables from different sections of the EIA documents often reveals discrepancies between them, leaving the reader no clearer as to what the actual dimensions will be. Obviously there are differences in such tables between the LWP 2004 EIS and the LWP 2006 EIS, reflecting the reduced scale of development proposed in the LWP 2006 EIS. However, these differences again generally concern *numbers* of infrastructural elements rather than their individual dimensions.

3.2.2 A confusion of tables

As an example of the difficulties involved in identifying definitive dimensions, the table of infrastructure dimensions given in the LWP 2006 EIS Non-Technical Summary provides the following information (conveniently also providing a comparison between the original and revised proposal) – shown here as Table 1:

Table 1: Infrastructure dimensions
Dimensions of development infrastructure (table adapted from LWP 2006 EIS, Vol. 1, Table1)

Infrastructure	Original proposal	Revised proposal description
Permanent wind monitoring masts	11 monitoring masts 90 m (295 ft) high and free standing	No change
Wind turbines	234, 3 MW wind turbines, 100 m (330 ft) diameter rotor on a 90 m (295 ft) tower, giving a tip height of 140 m (460 ft)	181, 3.6 MW wind turbines, 107 m (350 ft) diameter rotor on a 86.5 m (284 ft) tower, giving a tip height of maximum 140 m (460 ft)
Wind Turbine foundations	each 22 m x 22 m x 2 m (72 ft X 72 ft X7 ft)	No change
Wind turbine hardstandings	234	181
Site road	Approximately 169 km (105 miles), typical running width 5 m (17 ft)	Approximately 141 km (88 miles), typical running width 5 m (17 ft)
Control building / Visitor centre	One	No change
Electrical substations	9, two different sizes	8, two different sizes
Overhead electrical transmission system	32.5 km, typically on 27m lattice towers	30.6 km, typically on 27m lattice towers
Temporary site compounds	Eight, each 50 X 50 m,	No change
Temporary concrete batching plants	Four, (plus 12 alternatives)	Four, (plus 10 alternatives)
Rock Source Areas	Five, (Plus 1 alternative)	No change

What is evident from Table 1 is that of the 10 items for which ground-area dimensions could be given, only three are actually provided with such dimensions. The remainder are described only in terms of number of features. There is no real excuse for this; all the missing dimensions are provided in some form at other points in the text of the LWP EIS documents. The difficulty for consultees is that these dimensions are not always to be found in the most obvious places and are not always in agreement with each other.

Another set of numbers is produced as LWP 2006 EIS, Vol. 2, Sect.1, Chap.6, Table 6.4, shown below as Table 2. This is described as the “development footprint”. In fact this is not a footprint because a footprint would normally involve an *area*, whereas most of the values given are again merely lengths or numbers. One area figure *is* given, however, and represents a total area for “hardstandings, turning areas, lay-bys and foundations”. Given as 45 ha for the revised development proposal, there is no explanation as to how this figure was derived.

Table 2: Changes to the LWP development proposal
Changes to wind farm layout and “development footprint”, based on LWP 2006 EIS: Table 6.4

Infrastructure	Original (LWP 2004, and 2005b)	Proposed (LWP 2006)
Wind turbines	234	181
Hardstandings, turning areas, lay-bys and foundations	565,000 km2 / 57 ha	449,000 km2 / 45 ha
Site Roads	169 km	141 km
Transmission Line	32.5 km	30.6 km
(Within S36 boundary)		
Underground Cable	28.4 km	29.6 km
Substations	9	8

Confusingly, LWP 2006 EIS, Section 2, Chapter 11, 11.6.1.1, para 53 instead provides an area of 36.2 ha for: "Excavation, backfilling and restoration of 181 turbine bases and associated hard standing”. No reference is made to the figure of 45 ha given in LWP 2006 EIS, Table 6.4, so it is difficult to reconcile these two areas.

In an attempt to provide some firm basis for the dimensions of the hardstandings, the diagrams provided for the two different types of hardstanding given in LWP 2004 EIS: Figure 7.8 were used by the UEL Peatland Research Unit to calculate areas for these structures. Table 3 gives the resulting totals.

It will be immediately obvious from Table 3 that the total area (ha) values obtained from the diagrams of the two hardstanding types do not correspond with the values quoted in either the LWP 2006 EIS, Table 6.4 given above (45 ha), or the area given in LWP 2006 EIS, Section 2, Chapter 11, 11.6.1.1, para 53 (36.2 ha). Thus in relation to the turbines and hardstandings, we now have three different infrastructure figures – 32.1 ha, 36.2 ha and 45 ha. For subsequent impact assessments, the figure of 36.2 ha is used by the LWP 2006 EIS document, and there is no further reference to the larger area of 45 ha provided by LWP 2006 EIS, Table 6.4 in any of the subsequent impact discussions or tables. Equally, the use of 36.2 ha rather than 45 ha is never explained.

The example cited here simply serves to demonstrate that there is little clarity, consistency or transparency in the figures provided by the LWP EIS documents for the infrastructural elements of the proposed development. The figure of 45 ha for all hardstanding construction may be correct, but there is no way of judging this, and if it is correct, then why does the impacts section of the LWP 2006 EIS document use a value of 36.2 ha? In absolute terms the areas involved may be relatively small but they are not negligible.

The more important point is that both EIS documents fail to provide the necessary level of clarity, consistency and transparency required for consultees and decision-makers to be sure that the figures under consideration are the correct figures and are being understood in the correct way. A single master table of *indicative* infrastructure dimensions could have entirely resolved this difficulty. Questions of infrastructure dimensions will re-appear later in this report when the issue of development impact is considered.

Table 3: Sizes of turbine hardstandings
Calculation by the UEL Peatland Research Unit of hardstanding areas, based on LWP 2004 EIS: Figure 7.8, and numbers of turbines listed in LWP 2006 EIS, Section 1, Chapter 7, Table 7.2

Hardstanding type	Area (sq m)	Total no	Total area (sq m)	Total area (ha)
Type A	1617	114	184,338	18.4
Type B	2047	67	137,149	13.7
Totals	3664	181	321,487	32.1

4 CONSTRUCTION

Actual construction of the LWP proposals will involve a number of separate infrastructure elements. Many of these elements have a bearing on issues such as hydrology, habitat impact or peat stability. However, the layout of the LWP EIS documents means that to some extent such issues are dealt with separately from the core processes of construction. This is not entirely satisfactory, and probably contributes in part to the failure of the LWP EIS documents to address adequately issues of cumulative impact and impact interaction.

However, this present report retains the broad format of the LWP EIS documents in order to permit relatively easy cross-referencing with these two documents. Consequently the main elements of construction will be considered here while associated issues such as hydrology or peat stability will be considered in more detail in their own respective chapters. It is nevertheless intended that indirect and cumulative impacts and impact interactions will be highlighted where appropriate, and that a more integrated picture will be provided towards the end of the present report.

In considering the construction activities necessary for this windfarm proposal, it is possible to group such activities into four main categories:

- continuous permanent surface construction – largely made up of floating and rockfill roads, and electrical cabling;
- permanent excavated construction – consisting of *e.g.* turbine bases, sub-station compounds, excavated roads;
- temporary excavated construction – consisting of *e.g.* batching plants, temporary compounds; and
- intermittent surface/excavated construction – essentially the roadway for the pylon lines.

These four categories are considered in detail below.

4.1 Road construction

Four types of road are proposed for the LWP development, but two of these road-construction methods are intended for use over ground where the peat is less than 1 m deep. Thus "crofters' track upgrade" involves possible excavation of peat alongside existing crofting tracks, already generally on mineral ground, in order to make such tracks sufficiently wide and robust that they can support regular use by construction and maintenance traffic. This may have a bearing on some aspects of peatland interest, but without clear details of what is intended, it is difficult to say more. Indeed the absence of fundamental information about a number of aspects of construction has significant implications for the evaluation of possible impacts with respect to all four methods of road construction.

LWP 2006 EIS, Vol.2, Sect.1, Chap.7, Table 7.1 provides anticipated proportions of use for the four road types, with "Floating Road" taking up by far the largest part of the road network, at 70%. The remaining three methods are divided up equally across the remaining network, at 10% each. No indication is given of *where* these various techniques will be used, however. The absence of a map that shows at least indicatively where the three main construction methods may be employed poses significant problems for the impact assessment process. This is because each method has its own particular implications for hydrology, ecology, slope-stability and carbon budgets. Furthermore the individual significance of these issues varies with the nature of the ground over which the different construction methods are used.

The present chapter will examine the details of the construction methods proposed and explore the relationship between these methods and the direct implications of these for the peatland habitat in a general sense. For the remainder of this section it is assumed that all methods except the upgrading of croft roads will, in effect, be on peat soils which are more than 0.5 m thick because this is the threshold used by the LWP EIS documents for adoption of these other methods. Use of this threshold means that roads other than upgraded croft roads will be constructed on ground which falls within the various international definitions of 'peatland'. As such, various generic issues can be identified for each construction method. The question of distance over which impacts may be felt relates both to construction method and local ground conditions. This question is not addressed here, but will be examined in later chapters of the present report.

4.1.1 Road design parameters and peat

In this section, the three forms of road construction to be employed on peat are examined in terms of the construction methods proposed and the likely implications of these for peatland ecosystem processes. It is perhaps instructive, however, first to look at the decision process by which the proposed construction methods were arrived at by LWP. The decision matrix used for this by the LWP EIS documents is set out in LWP 2004 EIS, Vol.6, Appendix 6A, but is reproduced here in modified form as Table 4, which differs in one significant respect from the table given in LWP 2004 EIS, Vol.6, Appendix 6A. Namely, Table 4 explicitly highlights the various construction methodologies in terms of their stated ability to meet the functionality required of the road.

Thus Table 4 presents piling as the method most able to provide a stable working road surface across peat. Excavation of the peat and complete or partial backfill with rockfill are identified by LWP as the next-most reliable methods. Both these methods are acknowledged as capable of achieving the desired engineering objective. However, piling is dismissed as too expensive to contemplate in this case, while excavation is recognised as having significant negative environmental impacts resulting from such extensive peat removal.

Method No.3 (pre-loading) acknowledges the benefits resulting from compressing and consolidating the peat, prior to construction of the roadway itself. It is common engineering practice when building semi-permanent or permanent structures on such soft deposits as peat to 'pre-load' the peat with a weight that, in effect, squeezes some of the water from the peat and begins to re-align such fibres as exist. An extensive body of engineering literature exists about the problems of compression and consolidation in relation to peat soils, and the issue is considered in more detail in Section 4.1.2 below. Other than the table in LWP 2004 EIS, Vol.6, Appendix 6A, however, there is no acknowledgement in the LWP EIS documents of this common working practice, nor discussion of the reasons for its widespread use, nor consideration of the possible implications of not using such practice in the case of the proposed LWP development.

Table 4: Road construction methods – design considerations
Design considerations for different types of road construction (table adapted from LWP 2004 EIS, Vol.6, Appendix 6A,). Green shading highlights the ability of the method to meet functional needs. Yellow shading highlights peatland habitat issues and other areas of uncertainty.

Method	1. PILING		2. EXCAVATION		3. PRE-LOADING	4. FLOATING
	Vibro stone or vibro-concrete columns	Piled raft	Complete excavation of peat, fully replaced by rockfill	Complete excavation of peat, partly replaced by rockfill	Pre-loading with sand to consolidate peat	Direct Construction on Peat: "Floating Roads"
Description	regular grid of columns in peat; geogrid/geocell placed on columns	concrete piles sunk through the peat; road supported on rigid concrete slab or flexible geo-textile mattress	peat excavated; fully replaced by rockfill.	peat excavated; partly replaced by rockfill.	load peat surface with sand; induces compression and consolidation; results in increased peat strength; road constructed on consolidated surface.	geotextile laid directly on unconsolidated peat surface; rockfill road laid directly on geotextile'floats' on peat surface.
Advantages	some peat left in place; impacts on adjacent peatland reduced	some peat left in place; impacts on adjacent peatland reduced.	proven method adopted on Lewis stabilises peat.	minimal traffic movements; shortest schedule; best use of materials; proven and cost effective method.	peat left in place; bearing capacity adequate on shallow peat.	peat left in place; impact on adjacent peatland reduced.
Disadvantages	long schedule; major vehicle movements to import fill for construction platform; extremely costly.	long schedule; major vehicle movements; large quantities of concrete required; design information required early; extremely costly.	large-scale peat removal results in significant environmental impact; large quantities of rock fill required	large-scale peat removal results in significant environmental impact; impedes local drainage	long schedule; large-scale traffic movements to import fill; uncertain engineering; adverse effects on local hydrology.	peat may not have sufficient bearing capacity in some locations; potentially unsuitable on deep soft peat; unsuitable on steeply sloping ground; large volumes of imported fill required.
Assessment	fulfils functionality; very expensive; requires major import of rock.	fulfils functionality; very expensive; long build-time.	meets functionality; least cost; significant volumes of rock import; significant volumes of peat spoil.	meets functionality; least cost; significant volumes of peat spoil; environmental impact	uncertain functionality; very high cost; high disturbance; significant import of sand.	for consideration where it meets functionality.

Piling (though expensive), excavation (though environmentally damaging) and pre-loading (though time-consuming) are all well-established technologies when constructing on peat soils (*e.g.* Hobbs, 1986; Edil, 1997; McManus, Hassan and Sukkar, 1997; Rahadian, Satriyo and Peryoga, 2003; Konovalov and Zekhniev, 2005; and see, for example, recent Eng-Tips Forum discussion thread). In contrast, there is remarkably little supporting published literature, and there are relatively few case-studies, regarding semi-permanent structures constructed to 'float' on peat in the way proposed in the LWP EIS documents. It is worth highlighting here the fact that windfarm roads are in effect permanent structures because the intention is generally to leave the tracks in place on decommissioning. Despite the paucity of supporting evidence for the method, and in spite of the acknowledged problems of constructing roads on peat (*e.g.* Hanrahan, 1964; Attohokine, 1992; Nichol and Farmer, 1998; Seppällä, 1999; O'Mahony, Ueberschaer, Owende and Ward, 2000), the technique has become virtually the standard approach for windfarm proposals on peat soils during the last decade or so.

The adoption of 'floating road' construction methods is presented by the LWP EIS documents without any attempt at explanation or exploration of the issue. There is no discussion about the relative merits of other, more established approaches, although floating roads represent the least certain and proven of all the construction methods considered in Table 4. This uncertainty is perhaps not so immediately evident in the original LWP 2004 EIS, Vol.6, Appendix 6A, but can be more clearly seen in Table 4. The extensive catalogue of limitations regarding its use also testifies to the problems already recognised in relation to what is, in effect, still an experimental technology. Yet this method is proposed not just for odd sections of the road development - floating roads will be the major type of road construction for the development (70% of the constructed road length).

It is very telling that neither of the LWP EIS documents provides any supporting evidence from the scientific literature – whether engineering or ecological – relating to the use of floating roads on peat. The only evidence presented in the LWP EIS documents consists of the studies described in LWP 2006 EIS, Vol.5, Appendix 11e. More will be said about these studies later in the present report. Forestry Civil Engineering (FCE) provides guidance on the design of roads constructed across various substrates including peat, but recognise that there is little supporting published literature in terms of long-term road performance, and particularly in relation to eco-hydrological impacts.

The Lewis Wind Power proposal is not unusual in opting for floating roads as its favoured road construction technique, but it is important to understand that it does so without any attempt to justify and support this choice. Indeed LWP's own decision-matrix does little to support the choice – if anything, the matrix does quite the opposite. The major physical impact of the LWP development is thus presented without any discussion and assessment of, or supporting evidence for, the construction method proposed. This is quite extraordinary given the scale of the proposed development and the environmental sensitivity of the area involved.

Notwithstanding this lack of supporting evidence, the LWP EIS documents then set out specific design parameters for the three chosen construction methodologies to be used when building new site roads. The parameters for these three methods are shown in Table 5.

Table 5: Road construction – design parameters
Specified design parameters for new road construction, as given in LWP 2006 EIS, Vol.2, Sect.4, OCMS4, Table 4.1.

Design	Typical site conditions	Design Parameters		
		Peat Depth (m)	California Bearing Ratio @ 50 cm depth	Cross Slope
Excavated Road	Shallow areas of peat with steep cross slope simple drainage conditions	<1 m	N/A	<3°
Floating Road	Deep, flat, stable areas of peat	≥1 m	>0.5 %	<3°
Rockfill Road	Shallow and deep areas of wet, weak peat, steeper cross slope	≥1 m	≤0.5 %	<20°

These various parameters are reviewed briefly below in relation to the three construction techniques proposed.

4.1.1.1 Excavated Roads

The "Excavated road" construction technique is proposed for gentle slopes with thin peat. In general on Lewis these two criteria tend to be mutually exclusive – flat or gently-sloping ground tends to result in deeper peat formation – but there are a few areas where both criteria are found together. Thus the technique is regarded as relevant to only 10% of the total road length (LWP 2006 EIS, Vol.2, Sect.1, Chap.7, Table 7.1). It nevertheless means that around 14 km -15 km of road length (allowing for a modest degree of sinuosity in the route) may be excavated. This is not a trivial distance.

Some of the excavated route may be on very shallow peat, but, given the shallow gradients of the design specification, it is likely that a reasonable proportion will support peat deposits approaching 1 m in thickness. These thicknesses in turn are likely to link with adjacent areas of deeper peat. Consequently there may be issues either of wider hydrological impact or of compromised slope-stability, particularly where such shallower peat forms the 'toe' of a potentially unstable slope (see Section 7.3.1).

4.1.1.2 Floating Roads

Overall, floating roads are predicted to make up 70% (99 km) of the total constructed road length, thereby representing the major road construction type within this development (LWP 2006 EIS, Vol.2, Sect.1, Chap.7, Table 7.1). Interestingly, LWP 2004 EIS, Vol.3, Chapter 7, Table 7.1 adds a constraint to the use of 'floating roads' by stating that this method is unsuitable for Erosion Classes 6 and 7. It is not clear why these two classes should be considered "unsuitable" whereas Erosion Classes 1 to 5 are considered "suitable" – no explanation is given for such categorisation.

Nonetheless, the exclusion of Erosion Classes 6 and 7 alone means that some 25% of the total road corridor is thereby classed as unsuitable for 'floating road' construction.

'Floating roads' are anticipated to form 70% of the road network, and Erosion Classes 6 and 7 occupy 25% of the total route (this 25% being sections of the route by definition classed as 'unsuitable for floating roads'). This leaves a contribution of only 5%, or 7 km, for sections of road classed as unsuitable for floating road construction due to other limiting factors alone, such as slope, thin peat, or very high water content. This represents a very small proportion of 'unsuitable' ground lying outside Erosion Classes 6 and 7.

As mentioned above at the start of Section 4.1, in addition to the 70% of the route to be provided for by floating roads, upgrading tracks will take 10%, excavated roads will also take 10%, and rockfill roads the remaining 10%. Crofters' tracks to be upgraded already generally lie on thin peat or mineral soil, and so are mainly classed by the LWP Habitat Survey Area (HSA) Geographic Information System (GIS) dataset as Erosion Class 0. Thus, if upgraded crofters' tracks will provide an anticipated 10% of the route (LWP 2006 EIS, Vol.2, Sect.1, Chap.7, Table 7.1), this alone substantially exceeds the length of route remaining after removal of the 70% provided for by floating roads and then the 25% taken up by Erosion Classes 6 and 7. Furthermore, there will undoubtedly be sections of excavated and rock-fill road-line where the Erosion Class is neither 6 nor 7. Consequently it seems that there is not enough road-length available, within the anticipated 30% (42.3 km) assigned to construction methods other than floating-road construction, to accommodate ground unsuitable for floating roads, either because it is Erosion Class 6 or 7 or because of other factors.

In other words, there are clear internal inconsistencies within the LWP EIS figures for road types, the defined constraints on each type, and their anticipated proportional contribution to the site-road network. As things stand, it seems that either floating roads will provide significantly less than 70% of the total road network, or, as seems more likely, some sections of floating road will be constructed across Erosion Classes 6 and 7 despite the claimed unsuitability of such ground. The explanation for this apparent contradiction may lie in the way in which Erosion Classes have been mapped. This is an issue explored later in Sections 5.2.5.2 and 6.4.2.

Beyond the question of Erosion Classes 6 and 7, the floating-road method is regarded as unsuitable for:

> *"Shallower and deep areas of wet, weak peat"*
> *LWP 2006 EIS, Vol.2, Sect.1, Chap.7, Table 7.1*

In some ways this is quite surprising because the natural first assumption on seeing the term 'floating road' is that such deep wet areas would be precisely what the method was designed for. It is interesting that areas of wettest, weakest peat are not considered capable of supporting a floating road. The crucial question is "how wet is too wet?" Clearly the boundary between wet areas regarded by LWP as being capable of supporting a floating road, and wet areas that are regarded by LWP as *in*capable of supporting a floating road, is a key threshold. It is not, however, explained, defined or discussed at any point in the LWP EIS documents.

4.1.1.3 Rockfill Roads

Although only anticipated for some 10% of the road network, this method is perhaps the most curious of all those proposed. In part, this is because it is a method that does not even feature in the decision matrix set out in LWP 2004 EIS, Vol.6, Appendix 6A and Table 4 above. Furthermore, it is the method proposed for precisely the areas of “deep, wet, weak peat” identified as unsuitable for construction of floating roads, and thus has probably the most obvious direct linkages to questions of slope-stability.

It can be seen from Table 5 above that not only is this method to be used on peat so wet that has the lowest load-bearing index (the California Bearing Ratio), it is also anticipated that the method will be used on slopes of up to 20°. Both parameters raise major issues of slope-stability (see Section 7.1.3). However, the construction method proposed does not feature in the decision matrix set out in Table 4, and there is therefore no assessment of the characteristics, nor advantages and disadvantages, of the proposed method.

A method somewhat related to rockfill construction *is* listed in LWP 2004 EIS, Vol.6, Appendix 6A and Table 4, but the crucial difference between what is listed there and what is proposed for the Lewis wind farm is that the method in the decision table involves excavation of the peat first, *followed* by partial or complete rockfill. The method proposed for the Lewis wind farm in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 14 involves no such excavation. The rockfill is simply tipped into the wet peat until the summit of the rock mound is level with the peat surface.

Not only is this LWP rockfill method not evaluated within LWP’s own decision matrix, but no explanation, justification, supporting evidence or discussion is provided concerning the proposed approach. For a technique intended for use on what are likely to be the most sensitive and challenging areas within the whole development, the lack of any review of, or justification for, the method even within LWP’s own evaluation tables represents a failing of very considerable proportions for the LWP EIS documents.

There is one other curious thing about the proposed rockfill construction method. LWP 2004 EIS, Vol.3, Chap.7, Table 7.6 lists the volumes of peat spoil that will be generated by various construction activities. It lists ‘Rockfill roads’ as generating 1,284,000 m^3 of peat. This suggests that, at least initially in 2004, the intention was to excavate the peat first, then backfill with rock material. In contrast, LWP 2006 EIS, Vol.2, Sect.1, Chap.7, Table 7.4 provides the same information for generated peat volumes for the revised LWP proposal, but in this case the simple category of “Roads” generates only 159,200 m^3. This suggests that the idea of excavation followed by rockfill was abandoned somewhere between the LWP 2004 EIS and the LWP 2006 EIS. This change in methodology is not explained nor are the implications discussed anywhere in the LWP 2006 EIS.

The two methods of road construction with the greatest likelihood of having a significant environmental impact – at least on the peatlands – are the two techniques discussed above. The detailed construction methodologies proposed for, and the implications of, floating and rockfill roads are thus explored more thoroughly below.

4.1.2 Floating roads – construction methodology

4.1.2.1 Floating roads and subsidence

What is not generally appreciated in relation to peatlands is that simple drainage of the upper layers of peat always causes subsidence in the peat. This happens because when the water table within a peat bog falls (as a result of drainage), the peat of the upper layer (which is now de-watered) is no longer floating within, and thus supported by, the bog water table. Consequently this de-watered peat acts as a weight, or load, on the remainder of the peat column. As Dr Olivia Bragg has observed in relation to another windfarm development on peat:

> *"If you weigh something in air and then in water, you find that it weighs less in water. This reduction in weight is equal to the weight of water displaced. Peat has a similar density to water, and so it will weigh virtually nothing when immersed in water (i.e. when it lies below the bog water table). In contrast, the peat will weigh the same as an equal volume of water when it is in air (i.e. when it is above the water table)."*
>
> *Dr Olivia Bragg, University of Dundee (pers. comm.)*

It is this gain in weight that allows a dry layer of peat at the bog surface to act as a load on the remaining depth of peat and causes it to compress.

The practical result of this – *i.e.* an increased load on the main body of peat when the upper layers are de-watered - leads to subsidence of the bog surface as water is squeezed from the underlying peat, and fibres become re-aligned by the forces of compression. This is a widely-recognised phenomenon. In engineering circles, probably the most frequently-cited account of the process is the review by Hobbs (1986). However, in an even earlier paper, Van der Molen (1975) observes that a 1 m lowering of the water table in a peatland (thereby turning this drained 1 m thickness of peat into an unsupported load) will increase the load on the lower layers by 9,813 N/m^2, resulting in significant compression which can be observed as ongoing surface subsidence. The UN Food and Agriculture Organisation currently cite an increased weight of 1 g/cm^2 for every cm of water-table drawdown in peat soils, and point to the fact that this secondary compression, combined with oxidative loss of the de-watered peat, often represents a serious constraint to agricultural development of peat soils (UN FAO website).

The pressure exerted on the peat below a layer of dried peat is acknowledged as an issue by the LWP 2006 EIS when discussing possible habitat impacts in relation to drainage and the wind farm infrastructure, but the issue is promptly dismissed because:

> *"This effect is probably very limited* ***on microbroken and gullied peats****, since these have already undergone such lowering."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 68*

However, no evidence is presented to demonstrate that this is the case, and the point does not address the question of a load consisting of road-construction materials. If a simple load of dried peat is sufficient to cause such subsidence, how much more marked will be the load, and consequent subsidence, resulting from construction of a 'floating road' using a substantial thickness of crushed rock? Besides, what of the substantial areas of ground where there is no micro-erosion or gullying? This possibility is never mentioned.

In practice, such a roadway does not 'float' on the peat. It steadily sinks into the peat under its own weight – whatever the condition of the peat. The more the road is used, the more it will sink, but it will sink even without use, simply because it is a load. Of course crushed rock is denser than peat/water, and will remain so even as it sinks into the water table of the bog. Some of the weight will be lost according to Archimedes' Principle, but the crushed rock will nonethless remain denser than the water/peat matrix. It will thus continue to sink until such time as the compressed peat beneath reaches the same density as the rockfill material of the road – assuming this point is ever reached.

Problems resulting from construction on peat are well documented (*e.g.* Hanrahan, 1964; Attohokine, 1992; Jones, Maddison and Beasley, 1995; Nichol, 1998; Gould, Bedell and Muckle, 2002). Nichol and Farmer (1998) examine the case of the A5 London to Holyhead trunk road where it passes over an area of peat near Cerrigydrudion, North Wales. This stretch of road was originally constructed by Thomas Telford in 1819, by 'floating' the roadway on brushwood, stones and clay. In the intervening 180 years, the road has continued to undergo differential settlement and constant repair, with fresh layers of carriageway added to keep the surface above the surrounding bog. In consequence, this section of road now has a carriageway thickness of up to 2 m in places, to compensate for this settlement. It is estimated that the peat itself has compressed by some 1.6 m during this time, and as Nichol and Farmer (1998) observe:

> *"...in the longer term the extra deadload has produced further settlement and exacerbated the problem which exists."*
>
> *Nichol and Farmer (1998)*

Some acknowledgement of this process is perhaps given in LWP 2006 EIS, Vol.3, Chapter 7, Figure 7.4, where the base of the crushed rock mass is drawn in such a way as to suggest that the central mass of road material has sunk some way into the peat. This can be compared with the very simplistic (and misleading) straight-line rockfill-base of LWP 2004 EIS, Vol.4, Chapter 7, Figure 7.4 and LWP 2004 EIS, Vol.6, Appendix 7A, Diagram 7A.1, which suggest that the rockfill will sit squarely on the peat surface. However, the illustration in LWP 2006 EIS, Vol.3, Chapter 7, Figure 7.4 appears to be largely as shown in the original LWP 2004 EIS diagrams except for an arbitrary degree of indicated compression. This diagrammatic representation of compression and consolidation (if this is indeed what it is) is not associated with any attempts to calculate, or even describe, a mechanism for calculating the degree to which a crushed rock load is likely to compress the peat.

As discussed earlier above, the fact that peat compresses under load is a well-established aspect of engineering on peat. The consequences of not acknowledging such constraining behaviour, either by piling or pre-loading, can be considerable. Figure 2 shows an example of a major construction project that has suffered just such consequences.

Figure 2. Abandoned school construction project on peat.
Recently-built 'flagship' school in Ushuaia, Tierra del Fuego, Argentina, constructed ('floated') directly on peat soil without the use of piling. A large drain associated with the remaining peatland can be seen in extreme right of photo. The school was closed as soon as it opened because of settlement in the underlying peat. The school has remained empty ever since for safety reasons and is now likely to be demolished.

Photo (c) R A Lindsay 2005

Bangkok's new Suvarnabhumi International Airport is an even more spectacularly embarrassing example of the same problem. It is currently estimated to need £22 million in repairs and much of the airport cannot currently be used. The airport was built on Cobra Swamp, an extensive peatland system. As Sumet Jumsai, one of Thailand's foremost architects has observed:

> *"Nature is now taking its toll in this swamp ... The bottom line is that ... the runways and* ***any structure not on piles will be subject to differential settlement and cracks****."*
>
> *(The Times, January 30 2007 – see Times Online)*

4.1.2.2 Methods of preventing or minimising subsidence

If peat is 'pre-loaded' prior to construction, rather than using piles as suggested in The Times article, the problems are reduced but not resolved. Pre-loading means that when the final load (the road) is applied, the rate of peat compression and water release is much reduced, but not prevented altogether. It is thus not a total solution to the problem of compression. Pre-loading mainly limits the initial phase of rapid compression; as long as there is a load applied to the peat, secondary compression will continue to occur until the load density and density of peat beneath are equal. This means that the peat surface, and its load, will continue to sink, albeit at a slower rate, until this point of equal density is reached (if ever).

If this process is to be prevented altogether, the construction must be supported on piles that reach through the peat to a more solid sub-base. Neither pre-loading nor piling are considered viable options by LWP 2004 EIS, Vol.6, Appendix 6A. Consequently it can be said with some certainty that the floating roads of the LWP development will sink, and will do so at varying rates depending on the depth, density and water content of the peat in any given location.

Natural England, for example, has evidence from a floating road constructed 10 years ago on peat in the Pennines. The roadway has sunk at least 0.5m, and in some places considerably more, in the 10 years since it was installed (Alastair Crowle, pers. comm. – see Figure 3).

Figure 3. Floating road with evidence of sinking.
A floating road constructed across blanket peat at Bowes Moor, northern England. The road surface can be seen to lie significantly below the bog surface along this stretch of road, whereas when the road was built the running surface itself was some 30-40 cm above the bog surface.

Even LWP 2006 EIS, Vol.5, Appendix 11E acknowledges that significant sinkage has already occurred on various sections of road at the Farr windfarm site. Curiously, the implications of this for the Lewis wind farm are not discussed, despite this evidence from LWP's own observations.

In practice, the method of 'floating road' construction is a form of 'pre-loading', but the load in this case is the development road itself, and the period of resulting compression and consolidation occurs during the working life of the road, rather than prior to road construction. As such, floating road construction can perhaps be more accurately described as a quick, cheap and somewhat disingenuous version of pre-loading.

4.1.2.3 Floating roads : operational benefits and consequences

The operational issues facing a developer when contemplating construction over peat are usefully summed up by an MoD Guidance Note:

> *"Subgrades of peat are **highly compressible and have very little bearing capacity**. Pavements constructed on them can suffer from **serious differential settlement**, so peat should usually be removed and **replaced with a suitable fill**. A possible option is to **surcharge the peat with fill to reduce the short term consolidation** substantially. But this **may make a long and phased construction necessary** and in the long term the **performance of the pavement will be less certain**; there may be **localised failures** and general **loss of shape**."*
>
> *Ministry of Defence (1994)*

By instead using a technique called 'floating roads', the question of compression and consolidation of the peat is avoided. The developer is saved the time and expense of applying the pre-load, there is no period of waiting while consolidation occurs, and there is no implicit acceptance that the road surface will sink – quite the opposite – it is implied that the road will 'float'. In contrast, the use of pre-loading as a construction technique by definition forces the developer to acknowledge that compression and consolidation of the peat will take place. It raises significant questions with regard to environmental impact, additional transport costs, sources and supplies of pre-loading materials, and of course substantially extends the construction period.

In particular, by proposing the method of 'floating road' construction:

- there is no need to address the question of sources and supply for the pre-loading materials (normally sand, which could represent a significant environmental issue in its own right);
- pre-loading requires almost twice the number of vehicle journeys compared with floating road construction, because first the pre-load must be applied along the route, then all the vehicle journeys necessary for road construction begin after the defined period of settlement;
- significant issues to do with potential hydrological impacts and sediments loadings must be dealt with during the pre-loading phase, then further addressed during roadway construction;
- pre-loading may take a year or more, whereas a floating road can be constructed immediately, without such delays;
- the problems associated with settlement become difficulties that only emerge after consent has been given and construction begins;
- any problems that do emerge during the working life of the development can thus be dealt with in an *ad hoc* way, as and when necessary, because the

inevitable problems of settlement have not been subject to planning scrutiny and control.

While these all represent substantial advantages to the developer, they do little for the assessment of likely environmental impacts. Simply by using the term 'floating road' and all that the word 'floating' implies, the developer is able to present a development proposal involving a substantially reduced construction programme and an implied much lighter environmental footprint. The subsequent reality of the environmental – and indeed operational – consequences arising quite predictably from this approach are found to be precisley those that are associated with pre-loading. The difference in the case of the 'floating' road is that the road itself sinks, rather than the pre-loading material, while the consequent environmental and operational issues have conveniently (for the developer) by-passed the original decision-making process.

In reality, 'floating' roads that subsequently sink can soon become a significant operational, as well as environmental, issue. This is because LWP 2006 EIS, Vol.2, Sect.4, OCMS4, para 4.6 states that all roads must be in a suitable condition, or capable of being brought into suitable condition, for use by heavy machinery such as cranes. A road that has a tendency to sink, especially if it sinks unevenly, is a significant operational problem in terms of ongoing maintenance to the required standard. There are also likely to be environmental consequences either because of the pre-emptive actions required or through accidents that result. All of this is over-and-above the consequences for the hydrology and ecological condition of the wider peatland habitat surrounding a sinking road.

Such observations are based on actual events on existing windfarms. Thus at the 4-year-old Derrybrien Wind Farm, Co. Galway, large vehicles have now slipped from the floating roads and fallen into the adjacent bog on two separate occasions. The most recent involved a six-axle crane (see Figure 4). It does not require much imagination to picture the potential impact of both the accident and then the subsequent recovery process. Such accidents are increasingly likely if the road suffers differential subsidence under load, and has a general tendency to sink increasingly beneath the surrounding bog water-table.

Lindsay and Bragg (2004) consider the range of issues associated with floating roads as constructed on peat by the forest industry in Ireland, and highlight the considerable number of factors that influence the performance of such roads:

> *"Where roads are laid directly onto peat (i.e. they have a peat subgrade), a range of engineering issues must be addressed, including subgrade drainage, materials consolidation, potential failure due to hydraulic pressure, and bearing capacity (Highways maintenance website).* ***Since peat deforms easily under mechanical pressure, roads with peat subgrades are inherently weak***[1]*. This means that they are vulnerable to excessive wear as a result of the flexing or deformation of the road that occurs as each vehicle passes. This effect can be reduced by making the road thicker than it would need to be on a strong subgrade, so that the weight of the vehicle is spread over a greater area. However,* ***the design of these roads is complicated by the singular***

[1] The California Bearing Ratio (CBR) for peat is 2-4%, as compared with a CBR value of 15-30% for strong subgrades.

engineering properties of peat*[2]*, which mean that both the bearing capacity and the stability of a peat road will vary with weather conditions and between different time frames. *An investigation carried out in County Mayo in 1996 showed that a vehicle moving along a peat road caused it to flex by different amounts in winter and summer, and that the amount of deformation also varied with the thickness of the peat substratum...In particular, because deflection increases under wet, warm conditions,* ***the summer is the most dangerous time for heavy traffic in terms of the degree of peat deformation*** *that results (O'Mahony et al., 2000)."*

Lindsay and Bragg (2004)

Figure 4. Crane accident arising from failure of floating road.
A six-axle crane that slipped off the floating road into the adjacent blanket bog at Derrybrien Wind Farm, Co. Galway. Note how the fabric of the road has given way under the weight of the crane, and led to this infrastructure failure.

Photo © M.J.Collins 2007

None of these issues is adequately addressed by either of LWP EIS documents. 'Floating roads' are simply presented as the appropriate engineering solution without further elaboration, despite:

[2] In particular, the deformation modulus of peat decreases with water content and increases with the degree of decomposition.

- the low level of confidence that emerges from LWP 2004 EIS, Vol.6, Appendix 6A in relation to this method;
- the range of complicating issues discussed above;
- the remarkably limited quantity of supporting scientific literature (none of which is provided by the LWP EIS documents) for the method as anything more than an experimental technique in terms of a method of construction;
- the almost-total absence of scientific literature examining the ecological consequences of floating road construction.

4.1.3 Rockfill roads – construction methodology

The proposed use of rockfill for up to 10% of the road construction represents another example of the way in which the LWP EIS documents lack internal consistency. The technique is proposed for, in effect, two opposite ends of the construction spectrum – relatively thin peat on steep slopes up to 20°, and extremely wet "weak" peat, generally deeper, on level ground or more gentle slopes. It is this latter end of the spectrum that is the cause of particular concern.

The proposed method involves dumping large volumes of 'oversized' rock directly onto the peat surface. The rock sinks through the peat to the bedrock/till beneath, and then more rock is added until the rock-pile is sufficiently large that it protrudes through the peat surface and can thereby form a solid base for the road.

The LWP 2006 EIS Outline Construction Method Statement for rockfill roads states that:

> *"The access road [to the rockfill section] will be constructed using either floating or excavated construction as close as is possible to the area where **the peat condition is such that floating road construction becomes impractical**."*
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 14*

By definition, areas of wet, weak peat where the "peat condition is such that floating road construction becomes impractical" will also have marginal stability. Indeed it is instructive to examine LWP's own peat stability calculations in the light of the ground conditions expected for this method of construction. In the LWP 2004 EIS Peatslide Risk Assessment, a relatively simple set of slope-stability calculations is presented and discussed. The key measure of stability is given as the Factor of Safety (FoS). This is a widely-used scale for which values less than 1 are understood to show incipient instability (though 1.4 is often taken as a precautionary measure).

FoS values were calculated for an area close to Loch Bhatandip where the peat appeared to be about to fail. Using parameter values obtained from this exercise, these parameters were then used to test the sensitivity of the various parameters as a whole. It was observed that:

> *"The results indicated, for example, that whereas variations in unit weight made little difference, changes in the depth of the water table were profound. **Raising the depth of the water table from***

***1 m to 2 m (ground level) reduced the factor of safety from 1.826 to 0.742**."*

LWP 2004 EIS, Vol.3, Chapter 17, para 10

If the peat on which rockfill construction is to be employed consists of peat that is so wet that "floating road construction becomes impractical", it can safely be assumed that the water table is very high indeed. It is then reasonable to question what values of FoS would be associated with such areas of wet, weak peat, and what effect the dumping of oversized rocks would have on such an area. The statement in LWP 2006 EIS, Vol.2, Sect.2, Chapter 17 (17.4.1) is highly relevant to this question:

"Where the peatslide risk assessment has identified areas of marginal stability, the following special mitigation and management would be applied:

- *no concentrated loads, such as excavated material from wind turbine foundation excavations, shall be placed on marginally stable ground"*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 17 (17.4.1)

The dumping of excavated material from a turbine base onto the moderately deep blanket peat of Cashlaundrumlahan is one of the identified triggers for the massive bogslide that occurred at Derrybrien, Co. Galway, during construction of the wind farm there (AGEC, 2004; Lindsay and Bragg, 2004; Creighton 2006). Such concentrated loading is recognised as a major contributor to bearing failure in peat soils. Yang and Dykes (2006) observe, in reviewing a variety of bog slides and bog flows, including the bog slide at the Derrybrien Wind Farm, Co. Galway, that:

*"...**if stress is applied to peat**, water will initially be forced out of the pore spaces. However, if the saturated hydraulic conductivity is low ... then the pore water pressure will instead increase in situ, possibly to the point at which cellular water starts to be expelled into the pore spaces. With the overall water content already in excess of [the liquid limit], **rapid softening of the peat and associated deformation and failure may then be expected**."*

Yang and Dykes (2006)

Indeed the creation of peat stockpiles is even recognised within the LWP development as a potential stability issue, and special measures are proposed to ensure that such loading does not give rise to instability:

*"Special measures relating to stockpiles would be undertaken. **The proposed peat repository sites would be selected on the basis of geotechnical criteria** and a geotechnical engineer would supervise construction of subsoil storage mounds where appropriate."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 17, para 11

There is thus a clear recognition that concentrated loads placed suddenly on weak peat can give rise to instability, yet the proposed rockfill construction method not only does precisely this, but it explicitly targets such actions on ground characterised by wet, weak peat. Such ground is, according to LWP's own slope stability model, likely to have a low Factor of Safety. There is a clear conflict here between proposed road construction methods and peatslide risk-avoidance, but neither of the LWP EIS documents acknowledges this, comments on this, attempts to explain this, or explores the implications for stability or potential impacts.

4.1.4 Road construction – the 'observational method'

The 'Observational Method' is cited in many places by both of the LWP EIS documents as the key factor that will manage risk during the development. The method is described (from CIRIA Report 185) in LWP 206 EIS, OCMS 4 thus:

> *"The Observational Method in ground engineering is a continuous, managed, integrated process of design, construction control, monitoring and reviews that enable previously defined modifications to be incorporated during or after construction as appropriate.* ***All of these aspects have to be demonstrably robust****."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4 (4.2.1)*

4.1.4.1 The Observational Method : background to the method

The description given above is fine as far as it goes, but it can be expressed more clearly and perhaps more honestly thus: "when we don't know exactly what is going to happen, we will proceed cautiously, observing as we go. If, as a result of doing something, we observe signs of undesirable consequences, we will act to prevent, minimise or contain the results of the consequences." A such, this alternative definition is no less robust than the official definition quoted by LWP. Both recognise that the fundamental heart of the Observational Method is a tightly-defined predictive model.

The predictive model is created prior to the start of construction. During construction, very detailed measurements are taken and compared continuously against the predictive model. Any measurements that deviate from those predicted by the model are taken to indicate the need for investigation, action and modification of construction methods. See, for example, Finno and Calvello (2005); van Baars and Vrijling (2005); Chapman and Green (2004); Sakurai, Akutagawa, Takeuchi, Shinji and Shimiju (2003).

How does this translate into practical management of the LWP development proposal? Not very well, apparently...

As Sakurai *et al*. (2003) observe:

> *"Observational methods* ***have evolved from basic visual procedures, conducted on site****, to sets of sophisticated procedures using modernized measuring instruments and computer-based back analysis techniques."*
>
> *Sakurai et al. (2003)*

If the Observational Method is to be applied in the modern sense (rather than using basic visual procedures) to the LWP development, there needs to be a detailed, comprehensive model (or set of models) describing the way in which the peat and other components of the development are predicted to react during and after the development. This would then be combined with a set of detailed field measurements which are compared with the model(s) on a continuous basis. Working practices are then adjusted accordingly if model and field data so indicate. Such a rigorous and tightly-controlled process is not what we find in the LWP EIS documents. The proposed approach instead harks back to the days of "basic visual procedures".

4.1.4.2 The Observational Method – the LWP approach

Focusing only on road construction for the moment, what is the stated procedure for constructing the LWP windfarm roads? In fact only the barest details are provided in the LWP 2006 EIS, but the LWP 2004 EIS is a little more informative. It states, for the setting out of roads:

> *"The route of new tracks will be pegged out well ahead of construction operations, preferably 500 – 1000 m in advance of required operations, depending on the terrain. This will allow for deviations to the centre line of the road of up to 25 m, minimising impacts if adverse conditions not previously identified are encountered. This will also define the construction corridor that will be offset 15 m either side of the centre line of the road. The construction corridor will be marked out using blue rope and posts and once defined construction vehicles or personnel will not be allowed outside the corridor. Setting out will be carried out in conjunction with the on-site ecologist."*
>
> *LWP 2004 EIS, Vol.3, Chapter 7 (7.3.1.2)*

There is no mention of instrumentation or measurements designed to provide data that can be compared with a model through back-analysis techniques. There is no mention of a model either. It is not therefore clear precisely what form of Observational Method the (presumed) site engineer, and the on-site ecologist will be employing. The lack of detailed information also makes it impossible to judge whether the proposed method of construction, modelling of construction, and monitoring of the system, are wholly suitable, wholly inadequate, or some indeterminate position between these.

The reader is, however, left with the distinct impression from the various references to the 'Observational Method' scattered through the LWP EIS documents, that the approach envisaged for the LWP development consists largely of Sakurai *et al*.'s (2003) "basic visual procedures conducted on site". This is a level of working from which Sakurai *et al*. (2003) are at pains to distance themselves, emphasising that the modern Observational method has evolved far beyond these early, rather crude approaches.

Details of a more identifiable Observational Method approach are provided by both LWP EIS documents within the Chapters on Peatslide Risk Assessment. However, LWP 2004 EIS, Vol.3, Chapter 17 makes it clear that at this stage in the development proposal, the application of the Observational Method referred to applies essentially to observing and monitoring peatslides while they are occurring:

> *"For a particular slope or peatslide, the primary objective of a monitoring programme is to* ***determine whether or not the peatslide is active and if so, where it is moving and the rate at which it is moving****. Monitoring instruments will be located and installed such that the overall picture of slope movement can be defined."*
>
> *LWP 2004 EIS, Vol.3, Chapter 17 (17.7.2)*

In reality, given the recent examples of sudden, dramatic and extensive peatslope movements such as at Pollatomish, Co. Mayo and Derrybrien, Co. Galway, (Creighton, 2006a; Lindsay and Bragg, 2004), the eventual recovery of such instrumentation from the final resting place of the peatslide debris is likely to be more informative than any readings (if any) that the instruments are able to provide at the time of the slide about "where it is moving and the rate at which it is moving".

There is a subtle shift of emphasis in the chapter on Peatslide Risk Assessment in the LWP 2006 EIS, compard with the LWP 2004 EIS, in that the later version no longer states explicitly that the monitoring is designed primarily to measure active peatslides. Nonetheless, it does still cite LWP 2004 EIS, Vol.3, Chapter 17 as the source of information about monitoring. It then goes on to state:

> *"Monitoring instruments would be installed such that the overall picture of slope movement could be defined. Monitoring would typically cover:*
>
> - *magnitude, rate, location and direction of deformations by using crack gauges, extensometers, GPS, multipoint liquid level gauges, inclinometers or multiple deflectometers;*
> - *pore pressures and piezometric levels by using piezometers, tensiometers; and*
> - *hydro-meteorological parameters by using rain gauges."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 17, para 14*

Within this paragraph there is ambiguity about when exactly such instrumentation would be employed. If it were employed along all stretches of road and around all infrastructure involving disturbance to peat, *and* it were then matched with predictive models of stability and slope movement, then this would represent a set of working practices that conform to the modern definition of the Observational Method.

However, this is clearly not the intention. Just a little later in the same chapter it is made clear that such monitoring will only be undertaken on the (originally 15) locations that are both close to the development and identified as being at risk of instability by the LWP 2004 EIS Peatslide Risk Assessment:

> *"Overall the revised proposal has led to a reduction in areas vulnerable to ground movement being crossed by wind farm infrastructure.* ***These areas have been identified and would be subject to additional survey work as well as careful management and monitoring****."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 17, para 19*

If peat soils were a well-understood engineering medium, floating roads were a well-proven method, and the mechanisms of peat slides were largely understood, such an approach might still be acceptable as the Observational Method. This is very far from the case, however. As even the LWP 2006 EIS acknowledges:

> *"In general, areas of peatslide risk have been avoided. However a management plan is still required **as this area is still not well understood at present**."*
>
> *LWP 2006 EIS, Vol.2, OBN12 (Construction), para 16*

The extent to which the subject of peatslide risk is "not well understood" is explored at length in Chapter 7 below. For the moment, it is sufficient to observe that existing understanding of peatslide risk is so imperfect that most of the area could be described as "at risk". True application of the Observational Method would involve establishing instrumentation all along the infrastructure corridor, rather than limiting such instrumentation to only 15 or so locations that have been tentatively (and imperfectly – see Chapter 7 below) identified as being at risk. Moreover, as has been said before, such instrumentation would be linked to a well-defined predictive model. Measurements would then be tested continuously against this model during the course of construction and – most importantly – into the foreseeable future, because instability may be triggered at any time. As has already been observed in Section 2.5:

> *"In most peatslides, a complex chain of events contributes towards movement and **attempts to identify all of the contributing factors are usually fraught with difficulty**."*
>
> *LWP 2004, Vol. 3, Chapter 17, para 31*

4.1.4.3 The Observational Method – after the windfarm?

The admission quoted above is particularly forthright in its recognition of the unknown factors influencing mass movements in peat. However, it also therefore throws into sharp focus a further set of questions about the long-term implicatons of the LWP development. It is stated in the decomissioning documents that the roads will remain when the windfarm reaches the end of its working life:

> *"Site roads **would not be removed**; they would remain for the use of the people of Lewis (with an approriate code of conduct re recreational access in place). The environmental impact of site road removal is greater than that of leaving the roads in place."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 3, para 13*

Firstly, and acknowledging that conditions giving rise to peatslides are not well known, these roads may not, in reality, therefore "remain for the use of the people of Lewis". Unless ongoing commitments are made regarding the Observational Method linked to ongoing maintenance and management into the indefinite future, the people of Lewis may find that at least some sections of road do not 'remain' but instead find themselves on the move. Breakdown of the established drainage system, continued settlement of road material into the peat, ponding around choked water-crossings, all are capable of rendering the peat more susceptible to slope-failure once LWP is no longer actively managing the site. In other words, if the roads are to remain beyond the life of the windfarm, so must the Observational Method and associated management.

4.1.4.4 Observational method and decommissioning

Looking again at the quote from the decommissioning statement above, a second point emerges:

> *"Site roads would not be removed; they would remain for the use of the people of Lewis (with an approriate code of conduct re recreational access in place).* ***The environmental impact of site road removal is greater than that of leaving the roads in place****."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 3, para 13*

The final statement of the quote above is made without any supporting evidence. It is simpy assumed that it is more environmentally dangerous to leave the roads than to remove them, but this may not be the case. There have been cases where roads on peat have been removed. However, if the roads were to be removed, it would be vital to continue with the Observational Method during removal, and afterwards, to assess whether the peatland systems were re-establishing a natural stability or whether further intervention might be necessary.

Clearly it is in the financial interests of LWP to convince everyone that it is best to leave the road system in place, because removing almost 181 km of road would undoubtedly be very expensive. However, from an environmental point of view such a conclusion is by no means either obvious or optimal. In assuming that the environmental costs of road removal would be too great (and also assuming that this is a generally-agreed position), LWP is nevetheless freed from having to consider, within its EIA, the relative impacts involved in leaving or removing the road. It is also thereby relieved from a commitment to bear the eventual costs of such removal.

4.1.4.5 The Observational Method and its consequences

There is, however, an additional layer of complexity inherent in the LWP development proposals. This is because the Observational Method requires production of a detailed predictive model, careful monitoring of actual events, then, finally and most importantly, a strategy for responding appropriately should the field evidence point to undesirable trends.

The difficulty for the LWP development, particularly though not exclusively in relation to rockfill roads and floating roads, is that the actions proposed are very difficult to reverse or modify once carried out. It is thus hard to see what strategy might be adopted should instability be detected by the Observational Method.

For example, let us assume that the Observational Method is correctly applied and that both predictive model and detailed instrumentation are in place. The first pile of rockfill is dumped into the deep, wet peat, and all seems fine. With the next pile of rockfill, however, the instrumentation indicates that stability is being compromised.

What now? Should one attempt to dig out the rocks which are now lying somewhere beneath 3 m of very wet peat? Might this not simply induce even more significant signs of instability...?

Similarly, the laying of a geotextile and dumping of rockfill onto the geotextile to form a floating road may proceed safely during the initial stages, but let us assume for the moment that, when the final layers of road material area laid down, the monitoring system indicates the onset of instability. At this point, sending in a digger to dig out the rockfill from the peat/geotextile surface will add further loading pressures and thus almost certainly compound the problems of instability. If the ground has become unstable, it is unlikely to be capable of supporting such machinery by this stage.

In other words, the construction process contains certain stages that are very difficult if not impossible to reverse, and these stages are the basic, fundamental steps of the construction technique. It may not be possible to 'work around' such problems. The rockfill dumping either remains stable or it does not; the floating road layer floats safely, or it does not. On those occasions when they do not remain stable, the process of attempting to undo the problem can simply exacerbate the problem.

So what might such a response strategy consist of? Retreat and attempt a different road-line, thereby doubling the area affected? What if this new attempt also shows signs of instability? A third attempt...?

The LWP 2006 EIS addresses this question fairly bluntly in one respect:

> *"Based on the monitoring data, the performance of a slope would be assessed. If the assessment indicates that the peatslide is active or potentially unstable, two strategies are applicable. The first one is* ***to do nothing and accept the consequences of failure*** *if small and unlikely to result in a significant environmental impact. Secondly,* ***the slope could be stabilised and further monitoring performed*** *to verify the effectiveness of stabilisation works."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 7, para 15*

In other words, the first strategy would involve simply allowing events to follow their course without further intervention. The second strategy involves intervention to stabilise the slope, but this scenario is by implication the apporach that would be adopted if the failure is large and environmental consequences serious. It is precisely these conditions that would be most difficult to control, if stability were found to be compromised.

No details are given of mechanisms that could be used to regain control under such circumstances. It would be very interesting to learn what exactly this might involve, because it is well-known that most slope-stabilising methods are not appropriate for unstable peat soils. Unfortunately no details are given so it is impossible to make any judgement about whether the slope-stabilisation methods alluded to by LWP might be successful.

Given that this is the primary strategy for dealing with peat slopes should they show signs of instability, the omission of such information is a major oversight and failure of the consultation process. If no such appropriate and effective methods are in fact available, then this itself represents a key failing in the consultation process (because the absence of such techniques should be made clear) and a failure in the operational strategy for the development.

4.1.5 Road drainage requirements – floating roads

The LWP EIS documents contain strikingly contradictory statements about the effect of road construction on surface drainage. These contradictory statements are used in different parts of the EIS documents, in some places arguing that road construction will have little effect on the eco-hydrology of the blanket bog habitat because floating roads have little impact on surface-water movement. Other sections, in contrast, argue that the roads will encourage bog growth because water will be ponded alongside the road. Other sections, by way of further contrast, state that drains will be required and these drains will provide a means of safely managing the hydrological (and potential sediment and stability) issues arising from road construction.

There is a real sense that different pictures are being painted when particular issues are being addressed in different parts of the EIS documents in order to present a best-case scenario in each case. Unfortunately these various pictures contradict each other, and thus cannot all be correct.

4.1.5.1 The need for a drainage system

One of the often-stated claims for the use of ‘floating roads’ on peat is that they are more environmentally friendly because such roads do not need side drains (*e.g.* Saorgus Energy Ltd., 2000). This claim is not correct for a variety of reasons. One of the most important of these is explicitly acknowledged by the LWP 2004 EIS document and implicitly by the LWP 2006 EIS document:

> *“Floating roads are built on top of the peat and rock fill roads are built within the peat, however, for both designs the road surface protrudes above the surrounding peat land. As such, **they will disrupt the surface water flows across the peat lands**.”*
> *LWP 2004 EIS, Vol.3, Chapter 7 (7.5.3.2)*

> *“**Drainage ditches will be required alongside any road, which cuts off the natural drainage across it**.”*
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 28*

These observations are entirely correct. Indeed, it is stated repeatedly in the account of the detailed hydrological study at Farr Wind Farm, provided as LWP 2006 EIS, Vol.5, Appendix 11E, that surface-water flows represent the most dynamic component of water movement in a peat bog. Stewart and Lance (1983) emphasise the same point, and conclude that the main function of moorland drainage is the more rapid removal of surface water. It achieves this by in effect, short-circuiting the normally rather unhurried process of surface seepage, instead directing such surface water into drains where it can flow away much more rapidly.

The eco-hydrological effects of such surface-water disruption will be considered in detail in Chapters 5 and 6 of the present report. For the moment, it is sufficient simply to consider the change in surface flow patterns resulting from construction of a floating road, particularly in the form of construction proposed by the LWP EIS documents. Thus the proposed solution to the resulting disruption of surface flows is given in the LWP 2004 EIS document as:

> *"...Therefore, it **may be necessary to provide crossdrains** (Figures 7.4 and 7.6) to ensure that any surface water flow is not impeded."*
>
> *LWP 2004 EIS, Vol.3, Chapter 7 (7.5.3.2)*

In contrast, the LWP 2006 EIS document suggests that there will be little or no disruption to surface-water flows because floating roads are sufficiently porous to such flows:

> *"Generally floating or rockfilled roads **will not have drainage ditches** alongside them. This is because they are on "top" of the ground so **surface run-off can flow through and under the road**."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 23*

No supporting evidence is provided to justify the claim that surface water will continue to flow largely unimpeded through the material of the floating road. Indeed from the discussion in Section 4.1.2 of the present report, concerning pre-loading, settlement and compression of peat, it should be evident that at least the peat itself will become significantly less porous once the weight of road materials is placed on it. Similarly, the geotextile matting combined with the increasingly finely-ground rockfill material of the road will become less and less permeable over time. Without evidence to the contrary, the statement that surface water will continue to flow through and under the floating roads is in direct contradiction to these very evident inhibiting factors.

The LWP EIS documents themselves contradict this view on more than one occasion. Thus in discussion about drainage and impacts on catchment flows, the LWP 2006 EIS states:

> *"The methodology for the road construction has provided a range of systems designed ... **to retain water in the vicinity of the road** and **to slow water flow**, minimising erosion potential and **encouraging the growth of bog species and maintaining wet land habitat**."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 109*

Discussion about the likely effects of road construction on the habitat provide an even more explicit recognition that un-drained roads will pond water along their upslope margins:

> *"...there **will be local impoundment of surface water flow along the edges of road batters on the upslope side of a floating road**. Wetter habitats will develop, **including bog pool vegetation if the ponding is relatively permanent**."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 68*

However, both of these views obviously contradict the view that drainage will be needed in order to manage the disruption to surface-water flows caused by road construction.

The same section of LWP 2006 EIS does then, however, acknowledge the possibility of drainage alongside floating roads, while the need for cross-drainage in certain circumstances is identified in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4. The circumstances under which such drains would be installed are discussed (using a decision-matrix) in a later section of the same OCMS - LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4 (4.5.7). The working assumption is that such cross-drains will be installed “at least every 100 m”, although LWP 2004 EIS, Vol.3, Chapter 7 (7.5.3.5) had originally stated that cross-drain spacing “will be nearer to 50 m over most of the site”.

4.1.5.2 Drainage and surface flows

Whatever the final decision about the frequency of cross-drains (presumably using the drain-spacing decision matrix referred to above), the use of such drains will result in a fundamental change in surface-water behaviour for the peatland system. Under natural conditions, surface waters will seep steadily and relatively evenly through the surface layer of a peat bog. Indeed, it is because surface conditions give rise to slow and steady seepage that substantial deposits of peat are able to accumulate in areas of high rainfall (and thus in areas with otherwise high erosive potential). The nature and significance of the surface and deeper layers of peat, known respectively as the *acrotelm* and *catotelm*, are discussed further in Chapters 5 and 6.

The pattern of surface-water flow across a peatland is one of the characteristic features of the ecosystem. Indeed, as will be explored in more detail in Chapter 5, the nature of this pattern is one of the ways in which different units of blanket mire are characterised, but for the moment we are concerned only with the fact that diffuse surface flow helps to provide stability to the peatland surface and resist erosive forces.

A typical pattern of surface flow can be illustrated as shown in Figure 5(a), where there is a general diffuse flow along the prevailing descending gradient, generally towards the closest stream or other water body. The effect on the pattern of surface flow of adding a floating road, with culverts at intervals, can be seen in Figure 5(b).

It can be seen from Figure 5 that there are many potential consequences from the action of adding a floating road with culverts across a bog surface, even without considering in detail the potential ecological impacts of this. To put it simply, a volume of water which had formerly diffused over a wide area is now largely concentrated through (in the case of Figure 5) two culverts. Thus the bog surface (and associated vegetation) below the culvert outflows becomes subject to many more times the volume and speed of water flow than previously.

At the same time, areas of bog surface downslope from the road but not associated with culvert outflows are now cut off from their former supply of surface seepage. Conversely, similar areas upslope are not capable of readily shedding the incoming surface seepage and will thus tend to pond water. This establishes a highly undesirable hydrological imbalance across the road. Indeed one of the main operational recommendations and changes at Derrybrien, Co. Galway, following the bog slide there, was that the whole area be 'drained robustly' throughout in order to avoid such ponding, and now all roads, whether floating or not, have drains (AGEC, 2004).

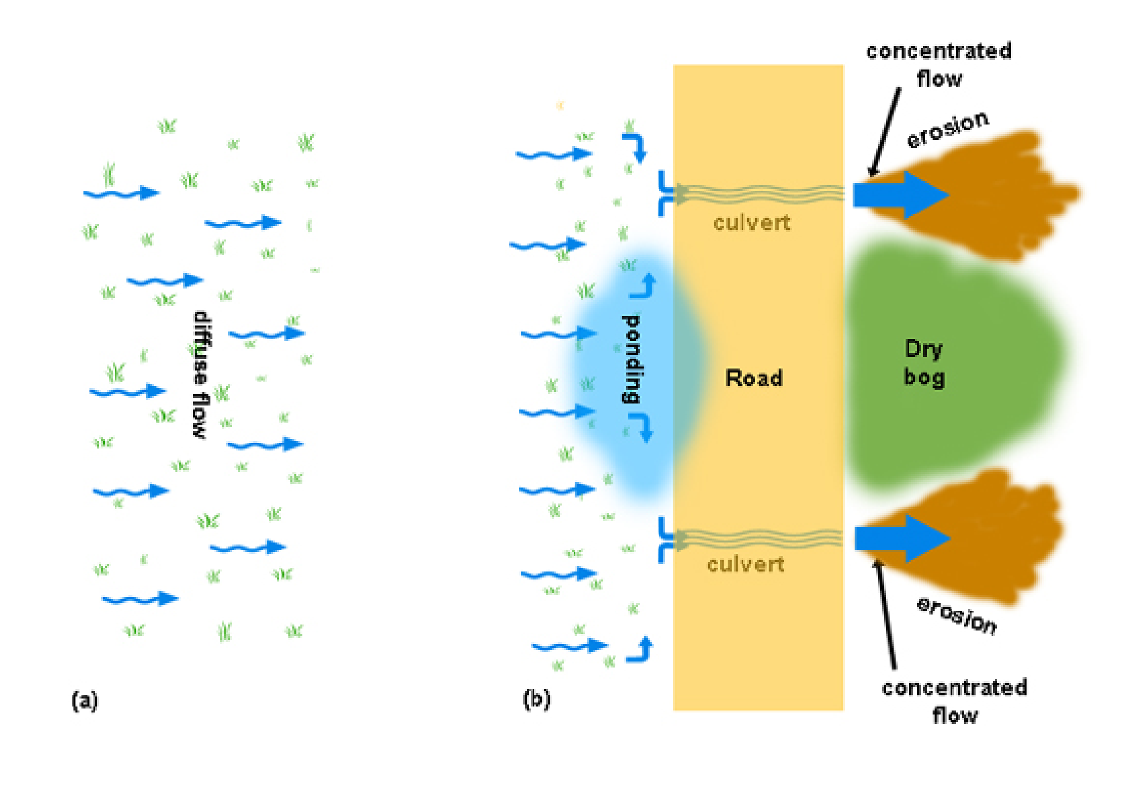


Figure 5. Patterns of water flow across peatland surface.
Patterns of surface-water flow across a peatland surface. **(a)** Pattern of flow associated with undisturbed peatland surface. **(b)** Pattern, and consequences, of water movement when surface flow is channelled through intermittent cross-drains beneath a 'floating road' and then released downslope to flow across the bog surface.

R A Lindsay (c) 2007

As an example of such conditions, Figure 6 illustrates the result of building a 'floating road' across blanket peat in northern England. Amongst other things, the influence of water-table height on Factor of Safety values, as discussed in Section 4.1.3 above, is clearly of relevance here.

Furthermore, one of the primary recommendations from the engineering review (AGEC, 2004) of the bogslide at Derrybrien was:

> *"**Avoidance of uncontrolled concentrated water flow**. All water discharged from excavations during work shall be directed into suitably designed drainage lines."*
>
> *AGEC (2004)*

One key difference between much of the blanket bog on Lewis compared with the idealised bog shown in Figure 5 is that the Lewis peatlands are extensively dissected by erosion gullies. While this means that water flows across the bog surface are not as diffuse as they would be on a non-eroded site, a high proportion of the gullies have been found to contain vigorously-growing bog vegetation. Consequently although flows within these gullies are channelled, these flows are significantly more diffuse than flows in non-vegetated gullies or drainage ditches.

Figure 6. Ponding alongside a floating road.
Ponding along the upslope margin of a floating road constructed across Bowes Moor, northern England. Part of the geotextile mat on which the road chippings have been placed can be seen in the bottom left of the photograph.

Nonetheless, this pattern has important implications for the management of surface drainage in relation to road construction. If there is to be no side-drain along the upslope side of a floating (or rockfill) road, then the individual erosion gullies will result in focused, localised erosion of road material wherever they are crossed by the roadway. This would suggest that each gully would require a cross-drain beneath the roadway if the pattern of flow in these erosion gullies is not to be disrupted and the road is not to suffer from localised erosion. Given the density of erosion gullies, this would call for a great many more cross-drains than is suggested by the LWP EIS documents.

Alternatively, erosion gullies could be led into a drain cut alongside the upslope side of the roadway. This side-drain would then to some extent buffer the concentrated flows from individual gullies, thereby protecting the road-line itself. The accumulated water is then fed into cross-drains. Such a scenario would seem to be more in tune with the 50 m – 100 m pattern of cross-drains envisaged by the LWP EIS documents.

It does, however, suggest that every section of floating road will require a drain along its upslope side, despite the claim that floating roads do not require drains. There are significant implications too for areas downslope from the road, as will be explored below, and in Section 8.2.8.3 of the present report. Given the wholesale adoption of a robust drainage system at the Derrybrien (Co.Galway) wind farm in response to the catastrophic bogslide there, it is interesting to note that LWP 2006 EIS, OCMS 4 does recognise at least the possibility that drainage will be needed for floating roads on Lewis:

> *"If there is considered a need, identified as part of the observational method, for a drainage ditch and a more formalised drainage system this will be carefully designed and follow the principles set out in this document."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 25*

Despite this recognition of possible need, the widespread adoption of such road drainage across the LWP development (remember, floating roads are anticipated to make up 70% of all road construction) is not a factor considered at any length by the LWP EIS documents. In effect, it seems that the LWP EIS documents do not consider it necessary to explore issues of road drainage because 'floating roads need no drains'. It seems that any possible eco-hydrological consequences of road-side drainage, should it be found necessary, are regarded as being addressed by the reported investigations at Farr Wind Farm described in LWP 2006 EIS, Vol.5, Appendix 11e. They are certainly not addressed explicitly anywhere else in the LWP EIS documents, despite the frequent acknowledgement that some drainage might be necessary.

4.1.5.3 Management of drainage waters

The hydrological work at Farr Wind Farm is reviewed in Annex 1 of the present report, so attention here will focus on the drainage systems proposed for the LWP development. The general policy for drainage ditches is set out quite clearly in OCMS 4 of the LWP 2006 EIS document:

> *"Drainage **ditches will be required alongside any road, which cuts off the natural drainage across it**. **No water from a drainage ditch will be discharged directly to a watercourse**. Instead it will pass through a sand filter, filter strip, silt trap, settlement pond or other best practice pollution control feature. **Drains will not be ended directly into natural channels, ephemeral streams or old ditches.** Where velocities are expected to be high and erosion a problem the ditch will be rock armoured and intermediate check dams installed."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4 (4.5.5)*

Two statements made here, and elsewhere in the LWP EIS documents, concerning the management of drainage waters appear on face value to represent a considerable (one is tempted to say impossible) challenge. If drainage is required alongside or across floating and rockfill roads, it is stated that:

> *"no water from a drainage ditch will be discharged directly to a watercourse"*

LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 28

and:

> *"drains will not be ended directly into natural channels, ephemeral streams or old ditches".*
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 28*

The difficulty arises because much of the development area, as discussed above, consists of a great many erosion channels in various states of regeneration. The road lines, and any associated drainage ditch, will cut across these erosion gullies. Any such road-side drains are, incidentally, most likely to be installed upslope from the road, as indicated in, for example, the recommended Forestry Civil Engineering design (see FCE website) It is stated (LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 30) that:

> *"wherever a cross-drain crosses the road, a catch-pit will be installed in the drainage ditch ... a check dam and catch-pit will be installed as part of the **inlet** works for cross drains".*

Meanwhile LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4 (4.5.9) states that:

> *"**discharge** from the drainage system would be to ground or to natural gullies or ditches"*

This last statement directly contradicts the statement in OCMS 4 (4.5.5) cited above in which it is said that no drainage outflows would enter directly into natural channels. If the check-dam and catch-pit are on the inflow side of the cross-drain, then the outflow of such a drain must indeed be into natural gullies or to ground, as indicated in LWP 2004 EIS, Vol.4, Chapter 7, Fig. 7.9 for an excavated road. In reality, therefore, it seems that any cross-drains are almost inevitably going to feed onto the downslope sections of erosion gullies severed by the road.

This means two things:

- concentrated water flows will be directed into certain erosion gullies with significant consequences for increased erosion and decreased vegetation regeneration;
- in the area of the cross-drain outflow, any outwash from the road itself will be carried directly into such gullies without going through a catch-pit.

It might be argued that LWP 2004 EIS, Vol.4, Chapter 7, Fig. 7.9 shows a soakaway "reinforced with geogrid or stone" and thus the erosive power of the water will be dissipated, but the problem lies not merely with the force of the outflow water; in mineral ground perhaps the dissipated water would indeed soak away, but this is a peat soil, which is already saturated, and this extra water will not simply soak away. The entire volume will flow off the stone and into the nearest erosion gully downslope. It is this volume that is a problem in terms of both erosion and vegetation recovery. Examples of precisely such problems can be seen from Bowes Moor, northern England, in Figure 7.

Figure 7. Cross-drains associated with a floating road.
Cross-drains associated with a floating road constructed across Bowes Moor, northern England. The photograph on the left gives an idea of the volumes of water that are concentrated at the cross-drains, while the photograph on the right shows the way in which the peat is eroded by such volumes. As the road has sunk into the peat, the outflow channel has dug steadily deeper into the peat.

A further issue can be identified in terms of pollution from rockfill finings out-washing from the road. It might be argued that the proposed 5 m wide batter along the edge of a floating road on the LWP development site will prevent the outwash of road finings from entering the outflow of the cross-drain. However, this batter is no more than 30-40 cm high, and the cross-drain itself must be at least 20 cm in diameter, leaving only around 10-20 cm of peat on top of the cross-drain. As this peat lies above the bog water table, it will certainly shrink as it lies above the natural bog-water table (one summer's shrinkage can reduce a cut peat turf to 65% of its original size). It will then steadily oxidise. It is quite possible that these batters will exist as significant features, absorbing road outwash, for only a relatively small proportion of the total windfarm life. Indeed addition of mineral solutes to peat assists in its more rapid breakdown through oxidation, so out-washing of the road material itself is likely to result in even more rapid oxidative breakdown of the batters.

Curiously, the batters are also claimed, in some unexplained way, to be designed both to:

> *"...dissipate any run-off from the road and **direct it to a discharge point**"*
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 35*

What exactly this means is not clear. A wide, relatively smooth expanse of bog vegetation re-lain onto a sloping batter will tend to create diffuse water flows downslope off the batter. Does this statement therefore mean that there will be some form of channels built into the batters, or will there in fact be a collecting ditch (*i.e.* drain) dug along the downslope foot of each batter? No further explanation is given, but it does suggest that the batters are not seen as, nor will be constructed as, simple broad zones of diffusion. This may be significant in terms of channelled water flow, movement of sediment, and a number of other important issues, but without further clarification it is impossible to say.

4.1.5.4 Road settlement and drainage

One thing not addressed at all by the LWP EIS documents – because of the belief that 'floating roads' will actually float – is the problem of road settlement onto the cross-drains, causing them to sink below the bog water table. If they do this, the drainage system will cease to function and upslope ponding will again occur. What LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 24 actually says is that:

> *"Where cross drainage is required across a floating road the culvert **will be founded on a suitable bearing stratum** and the road level reinstated with rockfill."*
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 24*

No explanation is given for what "a suitable bearing stratum" means. However, assuming it means that a bed of rockfill is laid along the line of the trench dug for the culvert, this will itself be lying on peat, and the whole structure – peat, bearing stratum and culvert – will be subject to settlement caused by compression and consolidation of the underlying peat.

There are obvious implications arising from such drainage effects in terms of potential hydro-ecological impacts. These are addressed in the next two chapters and Appendix 1 of the present report, as is the exploration of this issue in terms of the evidence presented from Farr Wind Farm by LWP 2006 EIS, Vol.5, Appendix 11e. For the moment, it is sufficient to observe that the issues of drainage in relation to floating roads are touched on in the LWP EIS documents only to the extent of indicating that if the Observational Method identifies the need for drainage, then drains will be installed according to the methods set out here. In reality, the reference to 'Observational Method' presumably means that if roads are seen to pond water, then drains will be added as necessary.

This raises an interesting scenario that will be explored in more detail in Chapters 5 and 7, but can be encapsulated thus: After construction, a section of road is seen to be ponding water, potentially dangerously, and a decision is thus made to provide the road with a side-drain to relieve this ponding pressure. Where does the machinery stand safely to dig the drain, if a high water table renders peat (and the road constructed upon it) less stable?

This is not to imply that all ponding will render the roads unstable and unusable, but it is possible that in certain localities, particular levels of ponding may have stability issues. It certainly seems that such ponding and its mechanical release played some part in the bogslide at Derrybrien Wind Farm, Co. Galway. This possibility, and the many other issues raised above, are not addressed at all by the LWP EIS documents.

4.1.5.5 Drainage and management of sediment loads

One final point worth making here concerns the use of drainage techniques that are largely designed for *average* conditions rather than those closer to worst-case scenarios. Typical check-dams, catch-pits and use of straw bales have all been demonstrable failures under conditions of high rainfall on windfarm sites such as Derrybrien, Co. Galway and the Braes of Doune (see Figure 8). While both sets of photos in Figure 8 come from groups who are regarded by many as hostile to wind farm development, the fact remains that the photographs require explanation. If this is what is occurring on sites visited by, or known to, the LWP engineers (as described in LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 61), it would be reasonable to expect informed comment within the relevant sections of the LWP EIS documents about the evident on-site (and off-site) issues observed on these two wind farms.

No such comments are provided. Lessons learned from the reported visits to other wind farm developments are not discussed in the LWP EIS documents. Thus no evidence is presented about the likely sediment loadings that different sizes of catch-pits and settlement ponds are capable of removing. Nor is any attempt made to discuss why straw bale barriers have failed in some circumstances on other sites. Straw bales are simply presented as the solution, without further justification, elaboration, or examination of worst-case scenarios – despite having had the opportunity to draw on the evidence available from other established developments.

Moreover, it is stated (LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 37) that filter devices such as straw bales will be removed at the end of the construction period. This presumably means that the effects of heavy rain, and of vehicle movements, on sediment release will be left to the catch-pits alone. If this is to be the case, it is even more important that the issue of catch-pit capacity is fully and effectively addressed if the question of fine-sediment loading, as seen in Figure 8, is to be adequately dealt with.

Figure 8. Sediment-treatment issues associated with wind-farm construction.
Drainage issues at Braes of Doune, Scotland, and Derrybrien, Co. Galway, Ireland. (a) Silt traps (top centre of photograph) with associated straw bale barriers. Line of bales displaced (orange arrow) by force of water flow. (b) Mr John Phillips examining displaced straw-bale silt-trap at Derrybrien, Co. Galway. The bales have been displaced by the force of water flowing down the stream during periods of high flow. (c) Typical rate of water flow in Garvald Burn, Braes of Doune, after heavy rain, with high proportion of suspended sediment. (d) Rock taken from stream bed of the Garvald Burn, Braes of Doune. The layers of sedimentation caking the rock are very evident. The scale bar in the background is marked in 5 cm interals.

4.1.6 Rockfill drains and drainage

Many of the issues raised in relation to floating roads also apply to rockfill roads. Additional issues of instability caused by sudden loading of wet peat by rockfill material have already been dealt with in Section 4.1.3 above. However, it is worth making one additional observation about the LWP EIS documents in relation to drainage management for rockfill road construction.

Rockfill construction involves laying a floating road in a hammerhead as close to the rockfill section as the weak peat will safely allow. When the rockfill material is dumped onto/into the peat it is recognised that there will be 'liquid outflow' as peat is displaced by the rockfill material. The bulk of the displaced liquid will not, as stated, be water; it is most likely to be a peat/water colloid. Given that the construction infrastructure will be sitting on the hammerhead, it is not at all clear how this 'liquid outflow' will be contained and managed, despite the confident but opaque statement that:

> *"The bulk of the displacement will be water. Any water displaced to the surface* ***will be dealt with appropriately****. This will include preventing any runoff from reaching a watercourse."*
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 14*

If it is not possible to take machinery onto the area prior to rockfill loading, how will any liquid displacement be dealt with, appropriately or otherwise? No description is given for any 'appropriate' method for dealing with displaced 'water' – in fact most probably an amorphous liquid slurry that flows in a highly uncontrolled way.

4.2 Turbine construction (and other excavated infra-structure, except for excavated roads)

Turbine construction requires by far the largest element of excavation in the LWP development, with 181 turbine bases to be excavated and then backfilled. The most up-to-date details of turbine-base construction are given in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1 (Turbine bases). There are various issues of concern that arise from this document, including aspects of construction and dewatering.

It is worth noting that the majority of other infrastructure requiring ground excavation (other than the excavated roads) adopts much the same construction method as that described for turbine excavation. Consequently the issues raised here can be taken also to apply to these other elements of the development infrastructure (*e.g.* temporary compounds, permanent compounds, batching plant compounds). The present report will not therefore contain separate sections describing the implications for each of these constructed features.

As turbines (and other excavated infrastructure, though this is not explicitly stated) are proposed for a wide range of ground conditions, it is stated in LWP 2006 EIS, Vol.2, Sect.4, Part 2, Outline Briefing Note 6 that several trial excavations would be carried out to test the proposed construction methods prior to work starting on the actual turbine bases themselves. The proposed methods for conducting these trial turbine excavations raise much the same areas of concern as for the main turbine bases themsleves, but also introduce a number of additional issues. The construction issues will be dealt with in Section 4.2.2, but it is worth first looking at the nature of these proposed trial excavation sites.

4.2.1 Trial excavations

Excavating a series of trial pits prior to attempting construction of a full turbine base is a very sensible approach, given the variability and difficult nature of the ground involved. However, the success of this methodology relies on the selection of appropriate locations on which to test the proposed techniques. It is essential that test sites truly reflect the conditions that will be encountered when full construction begins, otherwise the main outcome of the trials will be a number of undesirable consequences:

- adoption of an inadequate or inappropriate set of design parameters based on performance in the trial sites rather than the conditions found on-site;
- adoption of inadequate or inappropriate methodologies capable of performing within the trial-site conditions, but not under on-site conditions;
- a false sense of confidence in proposed methods, and
- a consequent failure to anticipate and prepare for on-site, worst-case circumstances.

The text describing the excavations (LWP 2006 EIS, Vol.2, Sect.4, Part 2, Outline Briefing Note 6) is self-contradictory. First it talks of three excavations and then abruptly states that there will be six excavations. However, the table which lists details of the trial pits gives six locations, so it will be assumed that all six will in fact be investigated. The relevant parts of the table are presented in Table 6 below.

The sites are stated as having been selected in part to reflect the range of 'hydrological zones', which are land-class types created as the main approach to hydrological characterisation in the LWP EIS documents. The relevance and utility of such zones is discussed in the next chapter of the present report, but for the moment it is sufficient to observe that the locations chosen are some of the poorest, least typical examples of even these zones.

Close examination of the proposed localities for the trial pits reveals that they do not reflect the type of conditions that prevail at many turbine locations. Indeed, such trial-pits cannot be regarded as a serious attempt to test the proposed methods under real ground conditions, so poorly do they reflect both the on-site conditions and the 'hydrological zone' types that they are said to represent. The majority of the test sites lie in peat cuttings close to roads or tracks. Only one site is associated with somewhat deep peat, but even this is a relatively simple area of blanket peat with few of the real issues likely to be encountered when construction starts.

The actual locations of these trial pits, together with photographs of ground more typical of the development area, can be seen in Figure 9 to Figure 17. From these it can be seen that although Trial Pit ENV9, for example, is described as being characteristic of a 'perched pool' hydrological zone, there is no sign of any 'perched pools' within the vicinity, and that the trial pit in fact lies almost right next to a roadway and is surrounded by domestic peat-cutting banks.

Table 6: Location of trial-pits
Details of locations for trial-pit excavations (table based on Table 6.1 of LWP 2006 EIS, Vol.2, Sect.4, Part 2, Outline Briefing Note 6)

Site	Easting	Northing	Likely depth	Hydrological zone
ENV 4	149921	960044	2.4m	Fluvial
ENV6	133083	947251	1 to 1.5m	Lake Network
ENV9	153890	958944	Deep >2m	Perched pool
PN1	134060	934325	Deep > 2m	Lake Network
PN2	137075	933700	Average 0.9m (peat cuttings)	Perched Pool
PN3	139550	933750	Average 0.4m (peat cuttings)	Perched Pool

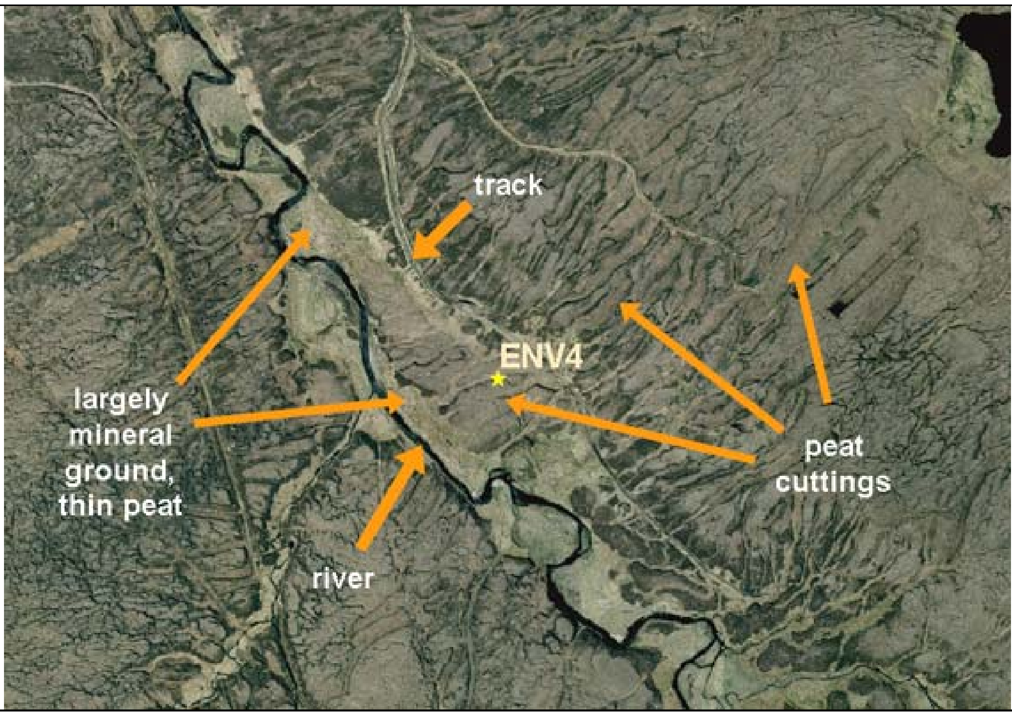


Figure 9. Trial turbine excavation ENV4.
Trial excavation ENV4. No measured peat depth data are available for this location, but in such a location, peat depths are unlikely to be greater than 2 m and may be much less. Table 6, however, (based on LWP Table 6.1) gives the 'likely depth' as 2.4 m, which actually seems rather unlikely.

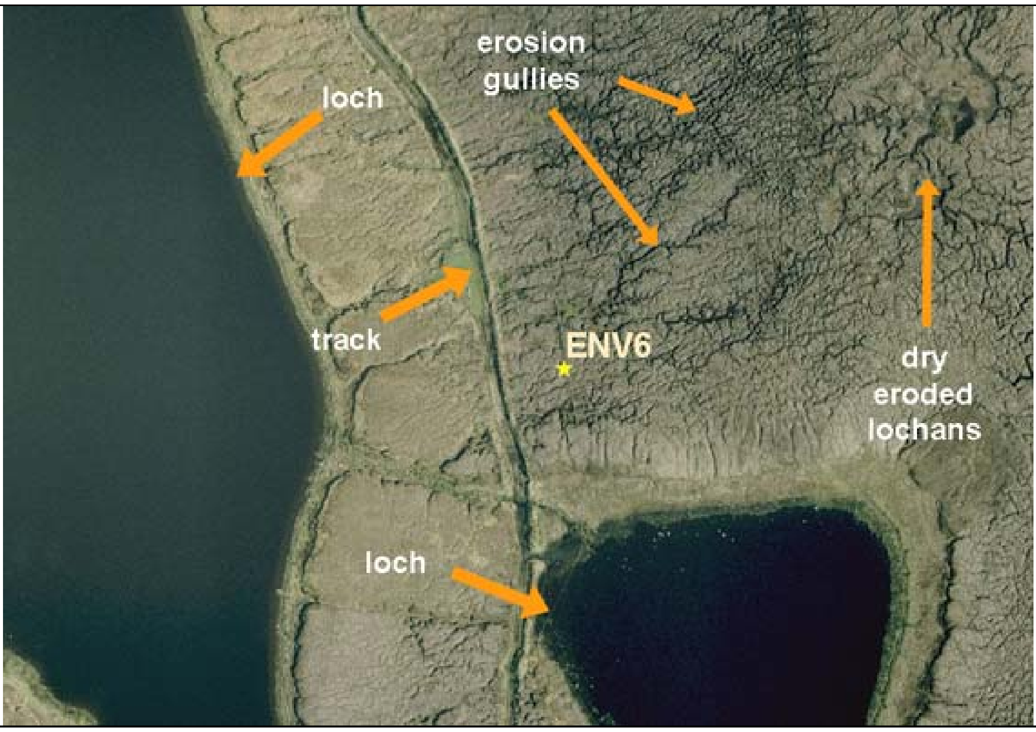


Figure 10. Trial turbine excavation ENV6.
Trial excavation ENV6. Track is recorded as 0 m peat by LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3. Distance from track to ENV6 is 35 m. Peat depth given as 1-1.5m in Table 6, based on LWP estimates of peat depth.

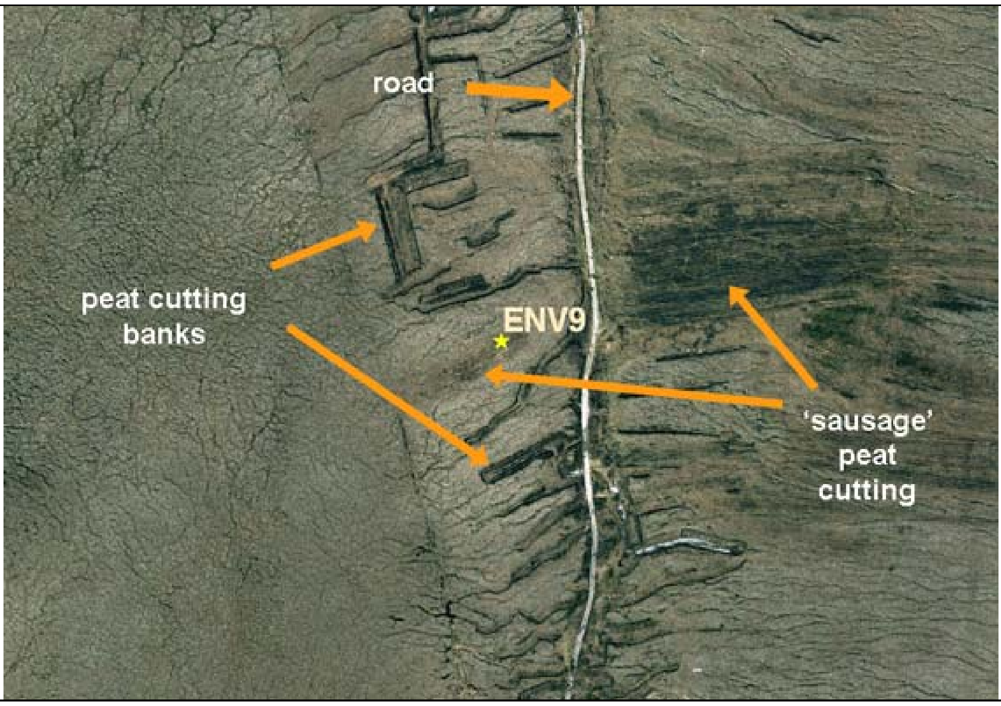


Figure 11. Trial turbine excavation ENV9.
Trial excavation ENV9. Peat depth given as 2 m by LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3, but >2 m by Table 6. Also described as 'perched pool' hydrological zone, but in reality lies within old peat cuttings (peat banks and 'sausage' cutting) alongside road.

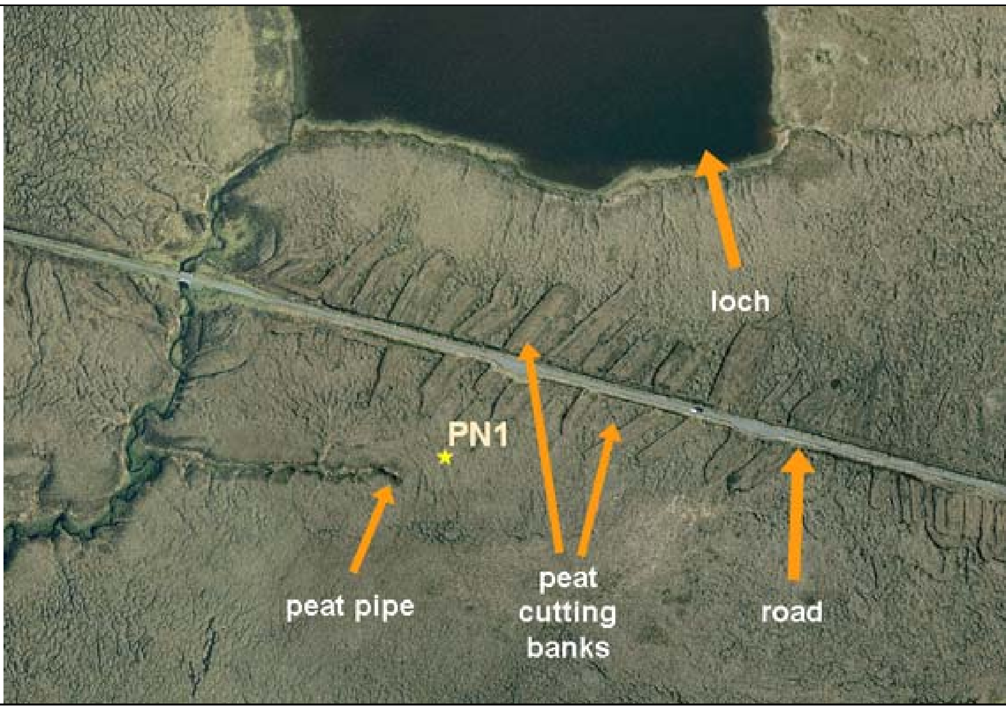


Figure 12. Trial turbine excavation PN1.
Trial excavation PN1. No peat depth data from LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3, but >2 m by Table 6. Also described as 'lake network' hydrological zone, but in reality lies adjacent to old peat cuttings (peat banks) alongside road.

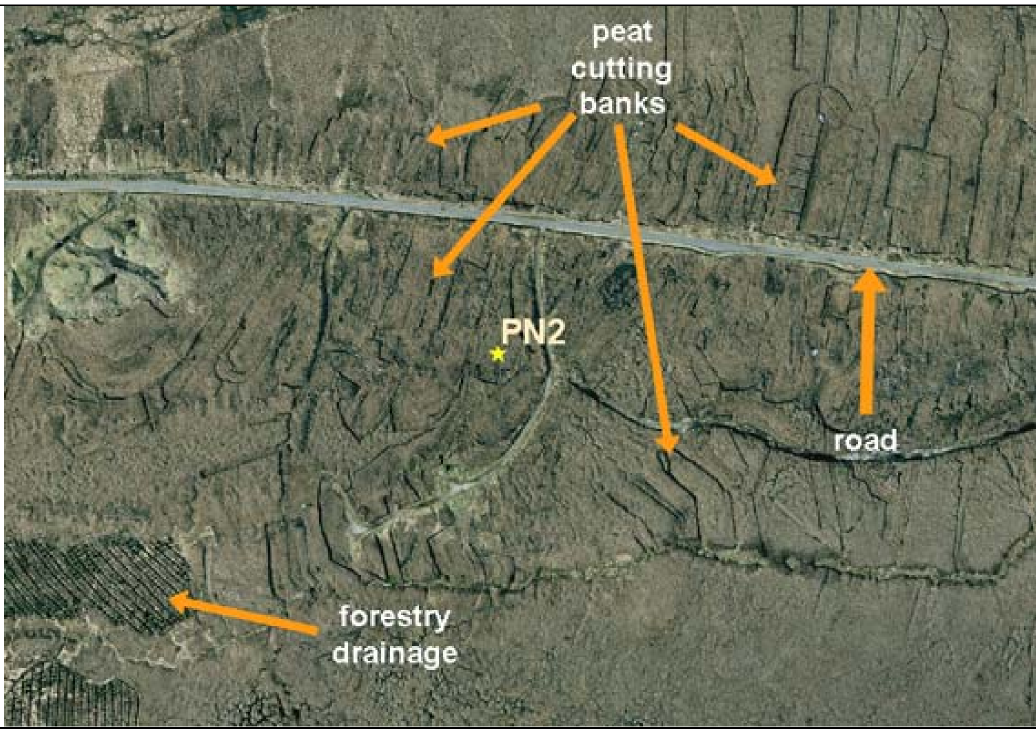


Figure 13. Trial turbine excavation PN2.
Trial excavation PN2. No peat depth data from LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3, but given as 0.9 m by Table 6. Also described as 'perched pool' hydrological zone, but in reality lies within old peat cuttings (peat banks) alongside road.

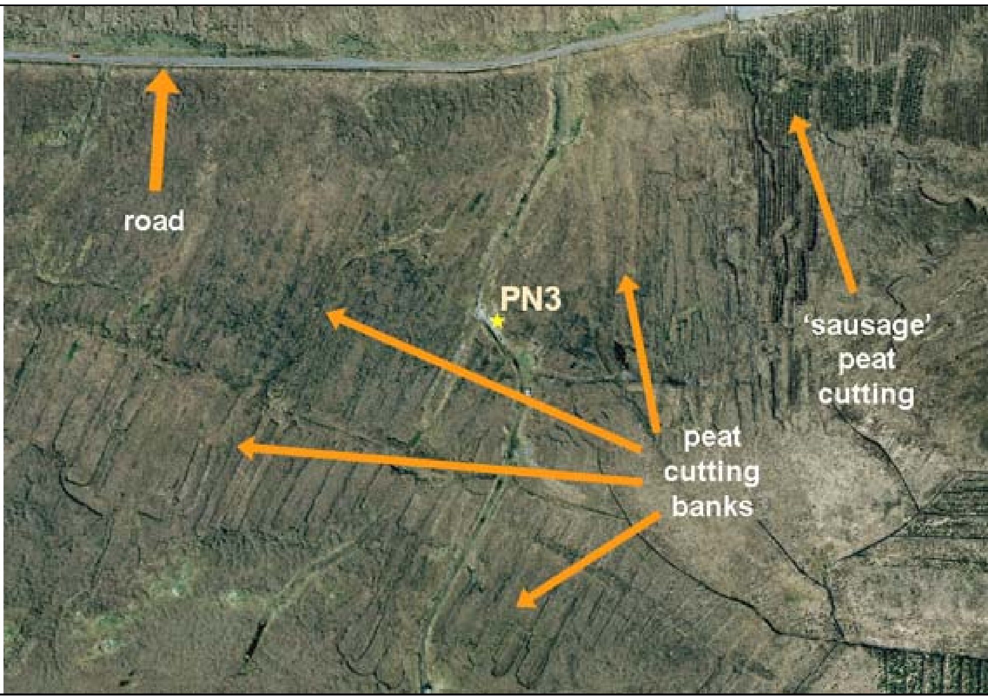


Figure 14. Trial turbine excavation PN3.
Trial excavation PN3. No peat depth data from LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3, but given as 0.4 m by Table 6. Also described as 'perched pool' hydrological zone, but in reality lies within old peat cuttings (peat banks and 'sausage' cutting) alongside track.

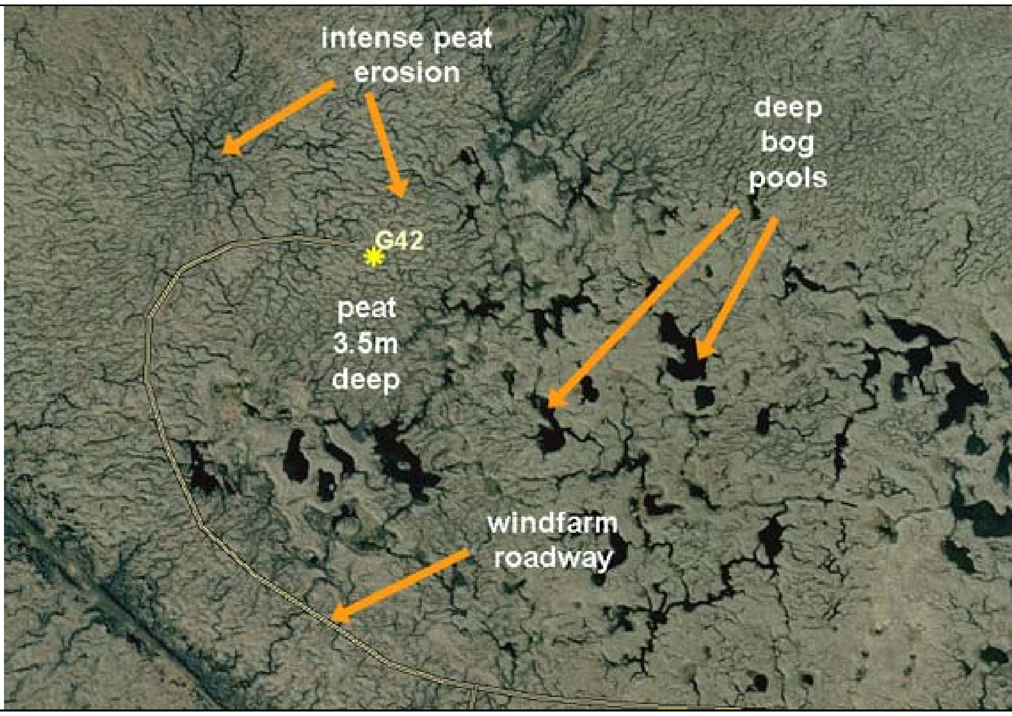


Figure 15. Ground conditions at Turbine G42.
Turbine G42 and roadway. Peat depth given as 3.5 m by LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3. Described as 'perched pool' hydrological zone by LWP 2006 EIS, Vol.3, Chapter 10, Fig.10.5. Compare this 'perched pool' system with Figure 13 and Figure 14. Note combination of intense erosion, deep bog pools and deep peat.

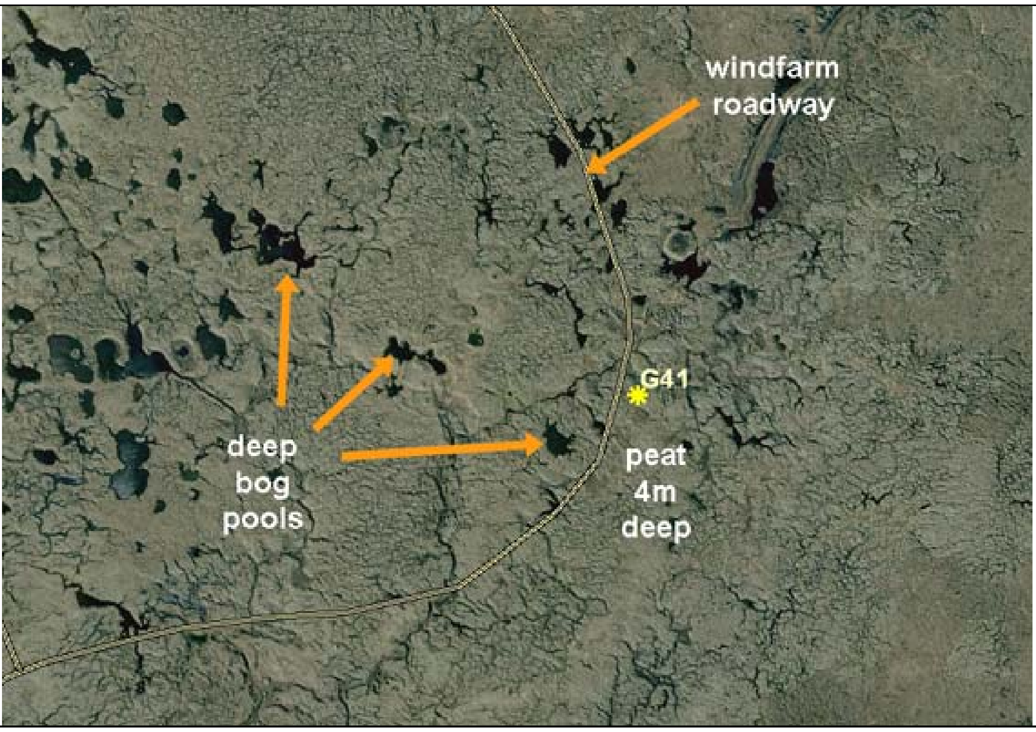


Figure 16. Ground conditions at Turbine G41.
Turbine G41 and roadway. Peat depth given as 4 m by LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3. Also described as 'perched pool' hydrological zone by LWP 2006 EIS, Vol.3, Chapter 10, Fig.10.5. Note combination of deep bog pools and very deep peat.

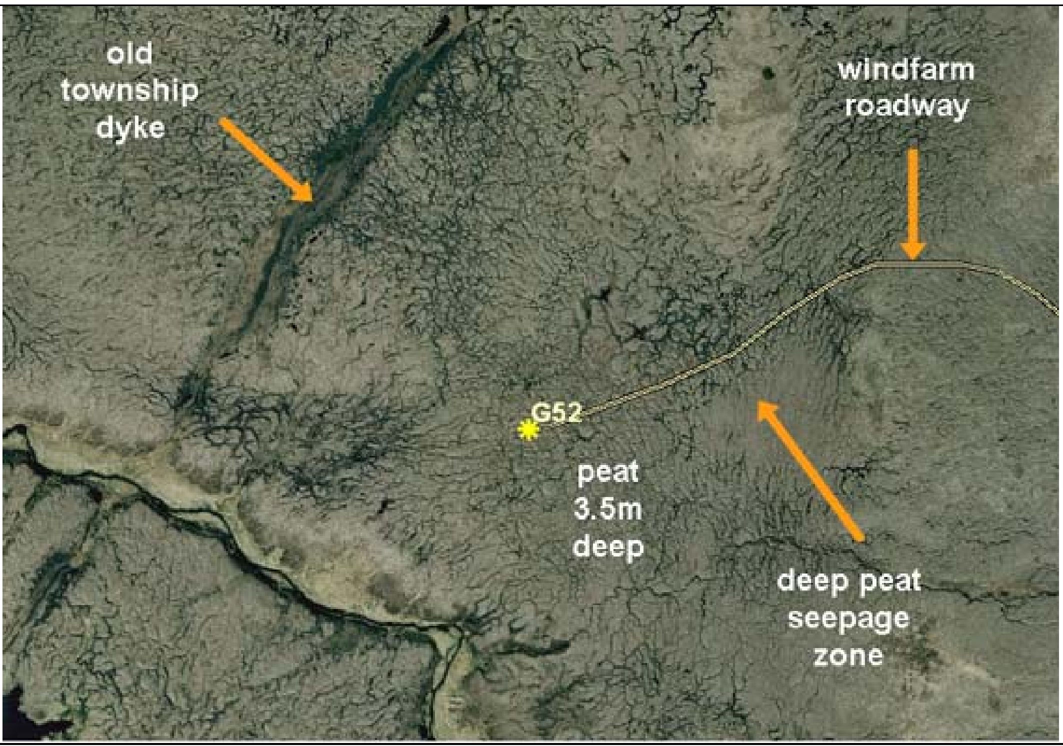


Figure 17. Ground conditions at Turbine G52.
Turbine G52 and roadway. Peat depth given as 3.5 m by LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3. Described as 'stable fluvial network' hydrological zone by LWP 2006 EIS, Vol.3, Chapter 10, Fig.10.5. Note combination of intense erosion, seepage zone, and deep peat.

Indeed the given grid reference places it right in the middle of some former 'sausage' cutting peat fields (peat is extruded from a slot cut into the bog by a Difco blade). As such, the test area is likely to have some unexpected complications of its own, but not complications typical of what will be found over most of the development area.

As mentioned at the start of this section, there are issues about construction of these trial-pits that raise environmental concerns, but these are largely similar to the issues of construction for the full turbine bases, and will thus be discussed in Section 4.2.2 below.

The range of eco-hydrological experimental work proposed for the trial pits is set out in LWP 2006 EIS, Vol.2, Sect.4, Part 2, OBN 6 (6.4.2.3 and 6.4.2.4) and LWP 2006 EIS, Vol.2, Sect.2, Chapter 10 (10.11.2 and 10.11.3). The range of proposed investigations is quite extensive and ambitious. It includes proposals for:

> *"Additional work investigating peat* ***water table level****,* ***peat sub-surface flows****,* ***rate of dewatering*** *and* ***moisture content*** *assessment from the peat face ... in order to inform drainage and dewatering management, this would include the* ***establishment of a series of dipwells****. Trial pits would* ***be excavated within each hydrological zone to investigate these characteristic****s. Other information on the nature of the peat and* ***the effects that runoff through flow and pipeflow may have on local stability of the underlying substrate****, could also be obtained from the next phase of geotechnical investigations. [Work includes:]*
>
> - *investigations into* ***short and long term effects on drainage*** *for the surrounding peat bog, including erosion;*
> - *a* ***detailed monitoring plan*** *to cover monitoring before, intensive monitoring during the trial and at intervals afterwards to look at long term effects;*
> - *installation of piezometer transects with* ***regular monitoring of water levels in the surrounding bog****;*
> - ***monitoring of vegetation*** *during the backfill phase."*

While such work has the potential to produce some very valuable results, the regrettable fact is that the sites chosen are very different from the majority of ground that will be affected by the windfarm development. Consequently a great deal of what is learned may not be directly relevant to the practical issues on-site, and conversely the opportunity to obtain such relevant and really valuable information will have been missed because of the choice of sites for the trial pits.

Furthermore, the heavy reliance on dipwells to provide hydrological data indicates a failure to recognise the most appropriate forms of measurement for such work, and would moreover represent a missed opportunity of considerable significance. This is an issue that is explored in some detail by Appendix 1 of the present report in relation to comments on the Farr Wind Farm study, which was a detailed study reported on in LWP 2006 EIS, Vol.5, Appendix 11e. Similarly, piezometer data gathered for only four weeks, and then intermittently thereafter (as proposed), should be viewed in the light of the observations made by Dr Olivia Bragg in Appendix 1 of the present report.

By the very choice of such locations to carry out trial excavations, LWP is demonstrating a lack of understanding of what is likely to be important during the construction and ongoing maintenance of the development, both in terms of engineering challenges and eco-hydrological impacts. The suggestion that the locations chosen will, for example, shed much useful light on the real examples of 'perched pool networks' indicates a very poor understanding of even LWP's own rather singular classification systems for the major habitat. The fact that LWP's own figures for peat depths at Trial Pit ENV9 do not agree is also perhaps symptomatic of the muddled thinking that lies behind the proposed trial-pit investigations.

4.2.2 Construction methods for turbine bases (and trial pits, and other excavated infrastructure)

The proposed method of construction for turbine bases (and, broadly speaking, trial pits, compounds and pylon bases) is given in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1 (Turbine bases). It sets out a series of construction steps, and then provides a substantial amount of information about the dewatering methods that would be adopted. The question of dewatering will be addressed in Section 4.2.3 below.

The key steps in construction can be summarised as:

- digging of 'temporary' cut-off ditches around the perimeter of the excavation;
- construction of rock dam (cofferdam) around perimeter of excavation;
- excavation of peat within the cofferdam;
- construction of turbine base;
- backfilling of excavation.

Four of these stages raise significant environmental questions.

4.2.2.1 'Temporary' cut-off ditches

It is stated in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1 (Turbine bases), para 17 that once the turbine base is completed and backfilled, the cut-off ditches will also be back-filled. No explanation is given as to how this would be done. Would the peat which was removed when constructing the cut-off ditches then be subsequently replaced? Can it thus be assumed that the ditches will be constructed by removal of discrete blocks of peat, including the vegetated surface? No information is provided.

What is clear is that even if the ditches are constructed by removing discrete blocks of peat, there will be oxidation of the blocks, and of the ditch sides, between extraction and replacement. Consequently it can be assumed that the extracted blocks will not fill the ditch line as they once did and thus the ditch line will continue to act as a drain. It would thus be sensible to add a series of waterproof dams constructed according to designs given in Stoneman and Brooks (1997) at regular intervals along the drain lines after they have been back-filled, in order to slow down and pond water seeping along the line. Stagnation of this water will encourage re-growth of *Sphagnum* which can then control water movement in a more natural way.

The foregoing considers cut-off ditches within relatively simple, smooth blanket bog. What of conditions where there is extensive erosion, or alternatively where there is very wet, weak peat? Thus Turbines G42, G41 and G52 have a fairly complicated ground structure, as already seen in Figure 15, Figure 16 and Figure 17 respectively. Construction of an effective cut-off ditch in such ground would be much more difficult because of the various erosion gullies and haggs, while restoration of such ground would not be feasible using the original materials. Consequently it would be necessary to introduce new peat to infill the cut-off ditches, but this new peat would then be subject to the erosive force of water channelled along erosion gullies that have been interrupted by the cut-off drain. It is very difficult to see how a drain can be 'restored' under these conditions without giving rise to additional problems of erosion and sediment flow.

Indeed the problems arising from cutting across an established erosion complex have implications for more than just the cut-off ditch. The backfilled material of the turbine base as a whole is likely to be subject to similar inflows from upslope erosion gullies. It is not clear how this inevitably rather loosely-packed material will resist such erosive forces. Do such difficulties mean that for some, or maybe all, of the turbine bases these cut-off drains will actually need to remain operational for the life of the windfarm (and beyond)? The issue is not addressed by the LWP EIS documents.

It seems that LWP 2006, EIS, Vol.2, Sect.4, Part 3, OBN 6 (Hydrology : Operational) will only be written after planning consent has been given, which seems rather extraordinary for such an important document. It is assumed, for example, that this document would shed important light on the question of ongoing drainage needs for infrastructure. In the absence of such a document, it is not possible to establish whether such drains may in fact be permanent features and will continue to dewater the peat around the turbine throughout the life of the windfarm. Where a turbine has been constructed in wet bog habitat, this would be a particular concern. The influence of drains on blanket peat is addressed in Section 5.4 of the present report.

4.2.2.2 Construction of rock dam/cofferdam

It appears that the use of a stone cofferdam to delimit the bounds of excavation and provide a stable face during excavation is restricted to construction of turbine bases. No mention is made of such a technique in relation to the temporary or permanent compounds. Steel shuttering is mentioned as a possibility for maintaining the stability of the excavation face when constructing pylon bases.

Whatever the extent of cofferdam use, there is an important issue of construction that must be clarified and considered. LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1 (Turbine bases) para 6 states simply that a rock dam (subsequently called cofferdam) would be constructed "around the perimeter of the foundation". No description is given of the construction technique to be used for this structure.

One might assume that a trench will be dug and that stone will be tipped into this trench until it forms a stable wall reaching from basal sediments to ground surface. Where the peat is perhaps 1 – 2 m deep, this might be a feasible option, but where the peat is 3 m or even as much as 5 m deep (for certain turbines) it is difficult to see how such a technique would work effectively. As quickly as the trench is dug, the lower parts are likely to collapse under their own weight. If the peat is particularly soft and wet, even a trench 2 m in depth may be impossible using this method, and attempting to use such a method would almost certainly have hydrological effects over a wider area.

If, instead, it is intended that the method for such deeper, wetter excavations will be the same as is proposed for rockfill roads, there are additional points to consider. As the diagram for rockfill roads indicates, the rockfill material does not form a straight-sided column of material, but must instead settle into a wedge-shape that reflects the stable angle of repose for the material when it is under load beneath the liquid peat. Thus in deep peat the cofferdam shape is likely to take up a very considerable volume. This will mean substantial volumes of liquid peat are displaced during construction, but no description is provided of the way in which this liquid peat will be contained and managed, nor is there any comment about the implications of such displaced liquid for stability of the peat as a whole.

Indeed there are more fundamental questions of stability when using this rockfill method. As discussed in Section 4.1.3 above, the loading of deep wet peat with heavy materials such as the cofferdam stone can result in bearing failure, as seen at Derrybrien Wind Farm, Co. Galway. The possibility that cofferdam construction may result in stability issues for the peat is neither mentioned nor discussed, despite the fact that some turbines are located in areas of exceptionally deep, very wet peat.

4.2.2.3 Backfilling of turbine bases

It is not stated whether the cofferdam would be removed prior to backfilling of the excavation, or whether the material of the dam in effect eventually forms part of the backfill. Indeed there is no clear statement at all about whether backfill would be with peat or with rockfill. Both options appear to be kept open, without any explanation about why one might be chosen over the other in any given case. However, LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1 (Turbine bases) para 10, and LWP 2006 EIS, Vol.3, Chapter 2, Fig.2.7, indicate that at least the surface of the backfill would be covered with peat turfs. OCMS 1 (Turbine bases) para 10 also refers to the possible need for batters on the side of excavations, but no explanation is given as to why and under what circumstances such batters might be needed. No indication of these batters is given in LWP 2006 EIS, Vol.3, Chapter 2, Fig.2.7, nor in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1 (Turbine bases), Diagram 1.1, nor in LWP 2004 EIS, Vol.4, Chapter 7, Fig.7.8. The relationship between such batters, backfill and the cofferdam is thus also unclear.

The eventual fate of the cofferdam is important because if it is left in place while the remainder of the excavation is backfilled with peat, then the dam itself is likely to act as a very large sub-surface drain all around the turbine base. However, in the absence of any clear indication (because we await LWP 2006, EIS, Vol.2, Sect.4, Part 3, OBN 6: Hydrology - Operational) of the drainage regime envisaged for the turbine bases while they are in operation, it is rather difficult to make any assessment of what some of the more ambiguous construction details mean, and of what the possible drainage implications might be for these during the life of the windfarm.

Thus, for example, if the turbine bases are to be backfilled with peat, does this mean that there is no intention to drain the bases of the turbines once they are in operation? Given that there are widely-recognised issues of reduced tower stability due to buoyancy, possible acid-water attack of the concrete, and possible leaching of lime from the concrete, the effective flooding of a turbine base beneath up to 3 m of highly acidic peat waters would seem to be an undesirable engineering outcome. It is thus difficult to believe that backfilling with peat to the original ground level will be an acceptable option for turbines constructed in deep peat. It seems far more likely that rockfill material will be used for this – but it is impossible to find confirmation one way or another about this.

There are other important but un-answered engineering questions about the backfilling of turbine bases. Thus, for example, it is stated that floating roads will be the dominant form of road construction, and that they will be used wherever the peat is 1 m deep or more on relatively gentle slopes. It is therefore likely that many turbines will be serviced by stretches of such floating road. These same turbines will, however, have hardstandings that will be built on rockfill. It is stated that hardstandings will be so constructed in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1: Turbine bases, para 23. This explains why they and the smaller area of the turbine bases are between them given as one of the major sources of excavated peat within the peat management plan (1,011,300 m^3 of peat excavated, and only 155,700 m^3 re-used in restoration, according to LWP 2006 EIS, Vol.2, Sect.1, Chapter 7, Table 7.4). It makes sense from an engineering perspective to build on rockfill because the hardstandings are the areas where large vehicles such as cranes will stand during both construction and any subsequent maintenance work. A solid foundation for the hardstandings is essential.

If the hardstandings are built on solid rockfill, and the adjacent floating roads are precisely that – floating on soft, deep peat – it is inevitable that, over time, the floating road will sink through compression, consolidation and probably oxidative wastage driven by drainage. As a result, there will be an increasingly marked difference in level between the road and the hardstanding. This is clearly unsatisfactory for several reasons.

One solution to this dilemma would be to continue loading new material onto the floating (sinking) road to keep a uniform level between the road surface and the hardstanding areas. The effect of this, of course, would be to cause further sinkage as the load is increased. It may also have implications for slope stability. The alternative would be to design-out the possibility of sinking roads adjacent to turbine bases by only using rockfill or excavated roads alongside turbines. It may be that this is the intention, but it is not clear from the LWP EIS documents. If it is not currently the intention, then such a strategy, if adopted, has the potential to increase substantially the volume of peat excavated in the course of the development. It also brings with it the prospect of excavated or rockfilled road construction being used much more extensively than is currently suggested.

Questions must be raised, however, over the technical feasibility of such an approach. By definition, those areas most likely to experience significant compression and slumping are those with the deepest, wettest peat. It does not seem likely that excavation and backfill of roads would be desirable or even feasible under such circumstances because of the depth and wet nature of the peat. Concerns have already been raised about slope-stability in relation to rockfill construction methods on such deep, wet peat.

The options for such stretches of road adjacent to hardstandings would thus appear to be somewhat limited – with in fact none of the presented options giving a satisfactory solution. The issue is not explored at all by the LWP EIS documents, presumably because it is believed that roads will 'float'. Unfortunately this is not a valid assumption.

4.2.3 Dewatering of turbine excavations

The guiding principles for dewatering of turbine-base excavations are set out in LWP 2006 EIS, Vol.2, Sect.1, Chapter 7, para 19 and comprise the following commitments:

- excavations to be kept open for as short a time as possible;
- continuous dewatering of excavations while open;
- interception of surface flow from uphill side of the excavation;
- water to be treated using settling systems, with possible use of flocculants, before being discharged to ground or watercourses.

These principles raise certain environmental concerns, particularly in relation to the water treatment process, but such concerns are perhaps best articulated in terms of the practical details set out in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1: Turbine bases (1.4). These practical design principles can be summarised thus:

> *"Excavations [while open] will be kept dewatered. The foundation excavation will be designed to be gravity draining where local topographical conditions allow. Where this is not possible, pumping will dewater the excavation. A* ***sump will be installed*** *in the lowest corner,* ***from which water will be pumped out to a treatment system****. Water will be pumped from sump to treatment plant."*
>
> *"****Cut-off ditches*** *may be dug around the perimeter of excavations to prevent water ingress. These ditches* ***will flow directly to treatment plant****."*
>
> *"****No water*** *from foundation dewatering operations* ***will be discharged directly into a watercourse****. Where necessary,* ***settlement tanks, systems such as siltbusters, or settlement lagoons*** *will be constructed."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1: Turbine bases (1.4)*

Thus the proposed route for water which is gathered from the excavation, treated and then discharged, is described as:

- To sump pump;
- To 1st settlement pond/tank (flocculation if required);
- To Siltbuster or equivalent;
- To 2nd settlement pond/tank (flocculation if required);
- Through straw bales, silt fence or Sedimat;
- Discharge to ground or local ditch or gully.

This sequence of steps raises a number of issues, considered below.

4.2.3.1 Sump capacity

It is clear that if a sump is to be the focal, receiving point for the excavation drainage-system, this sump must be large enough to cope with likely *maximal* flow rates *and* with likely volumes from the excavation even under extreme rainfall conditions. If the sump is not of sufficient capacity, the resulting overflow will be uncontrolled and thus become potentially dangerous in terms of sediment loading, water scour, and/or slope-stability.

4.2.3.2 Capacity of sump pump

The capacity of the sump pump will also be a critical issue because the volume that it is able to remove from the sump will reduce the volume that the sump must contain under high rates of input. Of course, if the pump should become blocked, or fail for some other reason, there would need to be a standby pump ready, and an operator /automated system capable of starting up the standby pump when necessary. If such backup is not provided, pump failure is likely to mean that the sump overflows and water/sediment flows direct into local watercourses. It is precisely this type of systems failure, for example, that led to release 100 million litres of raw sewage from the Seafield pumping station into the Firth of Forth in late April 2007 (New Civil Engineer, 26 April 2007).

4.2.3.3 Treatment plant capacity

The treatment plant will need to be of sufficient capacity to cope with both the sump pump and inputs from the perimeter ditches during periods of heavy rainfall. Heavy, high-energy rainfall is also, of course, when most sediment is moved. As already emphasised in Section 2.2, the critical parameter with natural systems is rarely the average, but more often the maximum or minimum conditions experienced. Consequently the treatment system must be capable of dealing simultaneously with large volumes of water and large sediment loads.

4.2.3.4 Use of flocculants

With regard to use of flocculants, it is stated that:

> *"**Flocculants** are available, have been used effectively at other wind farm sites, and if used appropriately can flocculate fines such as blue clays. **Settlement systems will be designed for flocculants to be added easily**. Flocculants **will be available on site and with emergency response teams**."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1,*
> *OCMS 1: Turbine bases (1.4)*

Flocculants may have been used "effectively at other wind farms" but no evidence is presented as to their benign environmental effects. Without such evidence it must be assumed that the word "effectively" refers only to their efficacy at flocculating suspended solids rather than to any ecological acceptability

However, the emphasis on flocculants is understandable, given the design parameters of the other treatment methods proposed, as will be discussed below. For the moment, it is sufficient to question how the flocculant process will work in practice, given that there will be 181 turbines, *plus* the permanent compounds, *plus* a very large number of cross-ditches scattered throughout the site (the very large number of treatment plants potentially required across the development site is discussed in Section 5.5 below). How will all of these be adequately and simultaneously supplied with flocculants during a heavy rain event? Mention is made of ‘emergency response teams’, but there is 141 km to cover.

Furthermore, almost 50% of the development area is dominated by a Hydrological Zone that is described as ‘unsuitable for settlement lagoons’ and will thus require the use of formal treatment plants at all localities. If water crossings are established at 100 m intervals, as stated, then there could be a need for 700 treatment plants within this Hydrological Zone alone to deal with water crossings, never mind other features within the development area that require a formal treatment plant. Supplying upwards of 1,000 treatment plants with flocculant, along a 141 km route, does not on the face of it seem operationally feasible, given that all these devices may need to be supplied during a public holiday, in the middle of the night, in a whole gale.

These are basic operating questions and should be addressed at this stage in the planning process rather than at some undetermined time post-approval, as is proposed for LWP 2006, EIS, Vol.2, Sect.4, Part 3, OBN 6: Hydrology - Operational). Such questions have a direct bearing on consultees’ ability to judge possible environmental impacts. If the site-operating system cannot provide for the management of several hundred individual treatment works simultaneously, how can the development avoid releasing significant quantities of sediment into local watercourses? If a management system has been devised to deal with such a scenario, it should be described now, so that its likely robustness can be judged.

4.2.3.5 Inability to use settling ponds/lagoons

> *“It is unlikely that settlement lagoons could be successfully utilized in peat environments [because] certain areas have been assessed as having a* ***probable high risk of downward head*** *[and thus potential for instability].”*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1,*
> *OCMS 1: Turbine bases, para 15*

> *“Where the ground is shown to be* ***too weak to support a silt or settlement pond*** *then a proprietary system such as* ***a siltbuster*** *will be used. This system could be located on a hardstanding at wind turbine excavations or other suitable bearing surface.”*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1,*
> *OCMS 1: Turbine bases, para 20*

It is of very considerable significance that areas of the windfarm development have been identified as being unable to support the hydraulic pressures associated with settling lagoons/ponds. The full scale, and thus implications, of this constraint have already been alluded to above, and will be considered further in the next Chapter. For the moment it is sufficient to note that this is stated to be the case, and consider the proposed alternative solutions – namely a Siltbuster(TM) or equivalent proprietary system.

4.2.3.6 SiltbusterTM treatment of sediment-laden waters

A Siltbuster(TM) is a closed metal tank which contains a series of plates past which sediment-laden waters are forced. The plates trap much of the sediment, resulting in discharge water that has substantially lower levels of particulate matter, However, the process does not remove all sediment. The various models available claim to remove "in excess of 90% of particles of greater than 20 micron (μ) plus a proportion of the finer material" (see Siltbuster website).

What does this mean in terms of sediment removal? Particles of 20 μ are obviously fairly small, but how small in relation to the kinds of sediment that might be expected from construction and operation of the LWP proposed development? A particle size of 20 μ lies mid-way between the standard upper and lower dimensions for silt (2 μ to 50 μ), and thus represents 'medium silt' (see useful Siltbuster website 'Table of particle sizes'). Smaller particles may be fine silt, clays or colloids. Thus more than 90% of coarse sands, fine sands, coarse silt and medium silt will be removed by Siltbuster(TM) treatment, together with an undefined but smaller proportion of fine silts, clay particles and colloidal material. Conversely, it also means that a significant proportion of fine silts, clay particles and colloidal materials will still be present in the discharge waters of a Siltbuster(TM). Such particles are likely to be present in some quantity in waters flowing from the turbine excavations (and, indeed, all forms of excavation within the development).

As can be seen from the Siltbuster website referred to above, the performance of a Siltbuster in relation to these smaller particles can be significantly improved if flocculants or chemical treatments are permitted as part of the water-treatment process. However, it is unlikely that such treatment would be environmentally acceptable in this case. As discussed above in Section 4.2.3.4, the LWP EIS documents provide no evidence of environmental acceptability for such treatment; the only justification provided being the assertion that flocculation has proved "effective at other wind farm sites." There are also the operational issues referred to above of supplying flocculants across the potentially-large number of treatment units.

4.2.3.7 Straw bales and SedimatsTM/silt fences

Given that sediment treatment plants will not remove all sediment, the next step in water treatment is likely to be filtering through Sedimats(TM), straw bales, or silt fences. The practical, site-management problems of straw bales have already been alluded to and illustrated in Section 4.1.5.

Sedimats(TM) are designed to be laid on a stream bed. Particles being washed downstream then become trapped within the matting. However, this mechanism only applies really effectively to particles that move by 'saltation', which is a process by which particles are repeatedly plucked from the stream bed by the current, then deposited a little further downstream. In this way they make their way progressively downstream in a series of little hops. Finer particles that remain permanently in suspension will tend to float over the matting without becoming entangled.

Silt fences consist of permeable fabrics that can be erected as a fence around an area to be dewatered. The base of the fence is embedded in the ground, and the sediment-laden water passes slowly through the fence material, depositing much of its sediment as it goes. However, the parameters of such a fence mean that particles as large as medium sand (400 μ) can still pass through the fabric. A high-end design specification (for example, Siltbuster Ltd's Terrastop™) is described as being capable of "intercepting up to 86% of suspended solids" (Siltbuster Ltd website). The materials suggested for this final stage of filtration are thus even less capable of dealing with fine sediments such as clays than the preceding Siltbuster™ treatment.

Consequently there is a real possibility that when water is finally discharged from the water treatment system, it will still contain significant amounts of silt, clays and colloids. This may go some way towards explaining the sediment-laden waters, and sediment deposits, illustrated earlier in Figure 8. The final stage in the sequence of water treatment thus requires us to consider where this discharge water will go.

4.2.3.8 Final discharge of treated water

Despite the implied suggestion in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1: Turbine bases (1.4) that discharge water would not be released into existing natural watercourses, the final stage of the water treatment process makes it clear that water will indeed either be discharged to ground, or into existing watercourses. Clearly what was actually meant by such statements is that water would first be treated, *then* released into existing natural watercourses.

As far as discharge to ground is concerned, this represents a highly undesirable option because there are significant issues of surface erosion and peat stability to consider. As already discussed in Section 4.1.5, one of the primary recommendations from the engineering review (AGEC, 2004) of the bogslide at Derrybrien was:

> *"**Avoidance of uncontrolled concentrated water flow**. All water discharged from excavations during work shall be directed into suitably designed drainage lines."*
>
> *AGEC (2004)*

Meanwhile Forestry Civil Engineering have made it clear, in their official comments on a windfarm proposal at Lochluichart, that in their view uncontrolled release of water onto a peat surface can lead to loss of stability. The alternative solution – namely releasing water into natural drainage channels - means that such channels are likely to become associated with much higher energy levels of water movement and thus be significantly more susceptible to initiating or rejuvenating erosion processes. Discharge levels are also likely to mean the halting, or even the retreat of, any vegetation recovery within erosion gullies used for discharge. This issue will be considered further in Chapter 6.

As discussed above, in both examples of discharge, the environmental consequences may also, with time, include significant sediment accumulation of fine particulate and colloidal matter within the downslope or downstream environment.

None of the issues discussed here is addressed by the LWP EIS documents. The techniques and approaches suggested by those documents are simply presented without comment, as solutions. There is little attempt at critical analysis or consideration of the implications for environmental impact assessment. Many key questions are also left unanswered, or remain ambiguous, without further explanation.

4.3 Powerlines

Although the layout of electrical infrastructure for the LWP development undergoes modification between LWP 2005 Transmission Line Addendum and LWP 2006 EIS, the latter document makes clear (LWP 2006 EIS, Vol.2, Sect.1, Chapter 7, para 47) that the methods of construction remain the same as those given in the LWP 2005 Transmission Line Addendum.

The powerlines necessary for the development will be installed using two distinct approaches. The first involves conventional overhead powerlines supported on pylons. The second method involves burying the power cables in pipes either alongside or beneath the roadway. The main issues to be raised about the way in which the LWP EIS documents deal with powerlines concerns the overhead lines. The buried power cables in effect have the same environmental footprint – and thus the same issues – as those explored in relation to road construction. There are, however, certain aspects that require further consideration even with buried power cables, and these will therefore be addressed before turning to the larger issues of the overhead powerlines.

4.3.1 Buried power cables

The description of methods to be used for installing underground cables is, in effect, set out in LWP 2005 Transmission Line Addendum, Table 5.1, along with associated diagrams. This table is largely a repeat of LWP 2004 EIS, Vol.6, Appendix 7B (confusingly entitled "Methods of Road Construction"), except there is a rather odd omission from the more recent table. There is no trace of the main method for laying underground cabling – namely "burial in the road verge" - as listed in the original LWP 2004 EIS, Vol.6, Appendix 7B. One can only assume that this has been omitted in error because it is listed as a technique on the opening page. This is a rather unfortunate error given that this table is a key source of information about such underground cabling.

4.3.1.1 Burial in road verge

The details of construction provided in LWP 2004 EIS, Vol.6, Appendix 7B for power-cable burial in the roadside verge do not marry up with the illustrations referred to (Figures 7.4 - 7.7, LWP 2004 EIS, Vol.4). Nor do they agree with the revised illustration for floating roads provided by LWP 2006 EIS, Vol.3, Chap.7, Fig.7.4. Specifically, they disagree in one important respect from the official descriptions - the cable pipes clearly lie beneath the level of the original peat bog surface. If this is the case, then clearly a trench for the cables must be dug alongside the roadway. No real indication is given about the width or depth of this trench – only a vague indication is provided by the illustrations. Equally the various measurements given in LWP 2004 EIS, Vol.6, Appendix 7B for thicknesses of material to be used give no indication of how these relate to any trench depth. Neither is it clear what the relationship is between the pipes, the trench and any geotextile mat.

This is an important issue because one of the stated benefits of using floating roads is that there is no need to cut into the bog surface – everything is laid onto the surface. If a trench almost 50 cm deep must be dug for the cable pipes, even though it is infilled afterwards it still represents a substantial intrusion into the peat matrix and creates a potential conduit for preferential water movement. That such preferential water flow can – indeed is likely to – occur is demonstrated by the fact that LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 37 identifies the need to prevent such flow:

> *"Where cable trenches run along the road regular impermeable barriers (at least every 500 m) will be* ***installed to ensure that there is no drainage path along the cable****."*
> *LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 37*

4.3.1.2 Burial beneath the roadway

Burial of cables *beneath* the roadway is described as an option for occasions where road construction is constrained in terms of width, either because of physical barriers or because there are ecological-impact constraints. At least, that seems to be what is intended. Unfortunately the wording of both LWP 2004 EIS, Vol.6, Appendix 7B and LWP 2005 Transmission Line Addendum, Table 5.1 appears to be scrambled at this point and makes no sense. The criteria for use may actually therefore be somewhat different.

Whatever the criterion for adopting this method, the consequences of using this method along stretches of floating road should have been considered. According to LWP 2004 EIS, Vol.4, Chapter 7, Fig.7.21 the high voltage cable duct will be laid directly onto the geotextile membrane which is itself laid directly on the bog surface. The ducts will be surrounded by a layer of sand and rock-dust to a depth of 10 cm. The whole assembly will then lie beneath a 1.1 m depth of rockfill (measured from the upper surface of the duct) onto which the road surface is constructed. The ducts will be either pre-cast cement or corrugated plastic.

No dimensions are given for these ducts, although there is a suggestion that duct lengths may be connected at 200 m intervals. This may be the case for plastic ducts but presumably concrete duct lengths will be much shorter. Meanwhile the diameter of the ducts determines the total height of the road above the general ground surface and thus the weight of material acting as a load on the peat surface.

This final point is the critical issue, because, as discussed in Section 4.1.2.1 above, a floating road will undergo differential compression and consolidation. The extent of such processes will depend on the load applied and the character of the peat in any given location. Consequently the substantially greater weight of material associated with cabling installed *beneath* the roadline is likely to cause even greater rates of differential sinkage than on other sections of floating road. Moreover, and perhaps more critically, because the sinkage will be variable along the road length, considerable pressures and consequent warping are likely to be experienced by the cabling ducts. Pre-cast cement in particular has little capacity to warp, and may thus fracture. Equally, such warping may put significant strain on connections between sections of the ducting, even in the case of corrugated plastic.

Provision must therefore be built into the construction protocol to anticipate and deal with such compression and consolidation, but there appears to be no recognition of this need within the protocols set out in the LWP EIS documents. Spare ducts are designed into the construction process, but these spare ducts will suffer equally from compression and consolidation so are not likely to provide a solution in this case. Given the serious disruption that would result from a broken cable duct or connection, it would seem essential that the issue be adequately addressed.

4.3.1.3 Cable ploughing

Cable ploughing will be used on peat where there is no road nearby. It uses a machine to slice the peat apart and insert the cable into the slot created. The slot is then allowed to close together, burying the cable. There are eco-hydrological issues here about preferential movement of water along the cable, and re-opening of the slot during dry weather.

However, one of the primary operational challenges for this method is the fact that so much of the ground is eroded or covered with bog pools. It is difficult to see how such a technique could be applied if it needs to cross an intensely gullied area, or a pool system, such as those shown in Figure 16 or Figure 17 above. If this technique cannot be used, then what method is proposed where there is no road? No alternative is offered, should cable ploughing prove impractical.

4.3.2 Overhead power lines

There are two broad issues in relation to construction of the overhead power lines. Firstly, there is the question of how much peat will be extracted during construction of the pylon bases. Then there is the question of what impact the construction process will have on the peatland environment, particularly given the heavy emphasis on the use of temporary roads for much of this construction stage. These temporary roadways are presented as a way to avoid creating a semi-permanent roadway while constructing the overhead power line. Both of these issues merit detailed examination, partly because the LWP EIS documents are contradictory about the detail, and partly because it is the detail on the ground that will determine the success or otherwise of the proposed 'temporary' measures.

4.3.2.1 Scale of infrastructure excavations

The first and most obvious problem in relation to the overhead power lines is that there are many contradictory statements about how they will be constructed and what volumes of peat would be involved. In LWP 2005 Transmission Line Addendum, Chapter 5, the following successive descriptions are given:

> *para 6: "...the tower base would be* ***excavated as one hole*** *with dimension of between 7 x 7 m and 17 x 17 m at the base, dependent on the type of tower."*
>
> *para 12: "...Each tower would require a concrete foundation under each of the four feet. To minimise the volume of excavated peat and the volume of water, which might have to be removed during excavation,* ***four openings will be excavated rather than one large trench****, wherever possible."*

> *para 21: "...Depending on the depth of excavation **it is likely that one excavation will be dug at each base**, rather than four separate holes for each leg of the tower."*
> *LWP 2005 Transmission Line Addendum, Chapter 5*

These three descriptions are all taken from the same chapter in the LWP 2005 Transmission Line Addendum (TLA). The reader is thus left none the wiser about whether the pylons will each require a single large excavation, or four smaller excavations.

This is not the only problem for the pylon lines. For almost the entire content of LWP 2004 EIS, LWP 2005 TLA and LWP 2006 EIS, it seems that the overhead lines are to all intents and purposes invisible in terms of area impacts,. LWP 2006 EIS, Vol.5, Appendix 11d provides a series of tables detailing the impact-areas associated with the windfarm infrastructure. Although it details impact values for items as small as 0.01 ha, and many items listed are less than 1 ha in extent, there is no mention of the area of ground taken up by the pylon bases, either as absolute loss or temporary disturbance. Nor is there mention of the 'temporary' (though as we shall see, potentially permanent) disturbance caused by laying the temporary roadway used to install both the pylons and the overhead power cables.

Indeed even the number of pylons, and numbers of pylon types, is somewhat obscure because conflicting numbers are given in different places within the LWP 2006 EIS. Thus in LWP 2006 EIS, Vol.2, Sect.1, Chap.2, para 30 the total number of pylons is stated to be "approximately 137", while in Vol.5, Appendix 18b, para 9 the total number is given as "approximately 134".

No indication is given about the numbers of different types of pylon – terminal pylon, standard pylon, deviation pylon. However, LWP 2005 TLA, Doc.4, Vol.1, Chapter 7, para 34 does state that the towers will be spaced at intervals of 225 – 300 m. Consequently it is possible to deduce an approximate number of standard towers using the layout map, and then identify the necessary numbers of termination and deviation towers from the nature of the layout. This exercise suggests that the estimate of 137 pylon towers given above is the most likely indicative total number.

Taking the total number of towers to be 137, it is then possible to produce a total listing of tower numbers for the various tower types. It is important to do this because each pylon type has its own size of base footprint, and it is therefore impossible to calculate a total overhead transmission line pylon footprint unless the relative proportions of different tower types can be determined. This calculation is provided below as Table 7. It is not a table provided by the LWP EIS documents.

Based on the figures in Table 7, it can be seen that the area of direct disturbance through excavation of the pylon bases apparently amounts to a little over 1 ha. This is greater than the area of the Control Building, yet the figure is not given in any estimates of impact extent. Indeed LWP 2006 EIS explicitly states that loss of ground to the transmission route as a whole is excluded from the impact tables presented:

> *"These totals ignore further impacts due to the transmission line route. This will involve **a few hundred square metres** for pylon bases, **a larger area (uncertain but small) for disturbance following buried cable restoration**, and a further uncertain but **small amount of habitat change**. Overall, these will marginally*

*increase loss, disturbance and change totals in Tables 11.9, 11.10 and 11.11. The changes **do not affect any impact magnitudes or change any level of significance**."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 91

Table 7: Transmission-line pylons - dimensions
Numbers and basal dimensions for overhead transmission pylons. Numbers are calculated on basis of 250 m between standard towers, and the mapped end-points and changes of direction shown on the transmission-line route. Basal dimensions deduced from LWP 2005 TLA, Doc.4, Vol.1, Chapter 5 and Vol.2, Figs.3.3 and 3.4.

Pylon/tower type	Number	base x-dim (m)	base y-dim (m)	area (m^2)	ha
Termination tower	10	17	17	2,890	0.29
Standard tower	107	7	7	5,243	0.52
Deviation tower 1-30°	7	10	10	700	0.07
Deviation tower 31-60°	6	10	10	600	0.06
Deviation tower 61-90°	7	17	17	2,023	0.2
Totals	137			11,456	1.15

Thus the area likely to be taken up by pylon bases is not, as suggested above by LWP, likely to be "a few hundred square metres". Table 7 reveals that the area is more likely to be closer to 11,000 sq.m. Quite a difference – indeed an order of magnitude larger.

So, if the area of the Control Building (1 ha) can be incorporated into the calculations of habitat impact in the various LWP EIS documents, there seems no logical reason to exclude figures arising from construction of the transmission lines. Indeed there is arguably a greater need to incorporate the figures for pylon bases and disturbance from buried cables than the area occupied by the single Control Building. This is because the transmission line is a construction feature that, while amounting to a relatively small ground-plan area in total (effectively the same as the Control Building), the transmission line nonetheless extends over a very large geographical area.

If the direct and indirect impacts amount to even a few tens of metres at each pylon locality, the pylon network will certainly have a greater cumulative effect than that arising from the Control Building. This is in part because the Control Building is a single large object and thus its 'edge effect' is very much smaller than the many small pylon bases. A single object of 1 ha has a perimeter of 400 m, while 137 pylon bases totalling 1 ha have individual perimeters of approximately 9 x 9 m which amounts to a total edge-length of 4932 m – again, an order of magnitude larger.

The other reason that the cumulative effect of the transmission line will certainly be greater than that of the Control Building is that the transmission line inevitably impacts on a much wider variety of ground conditions than the single, contained entity of the Control Building. There is thus the possibility of involvement with very wet, weak peat, high-quality bog vegetation, serious erosion, and a great variety of other factors that have significant implications for the relative width of impact zone in any given locality.

However, the failure to include area values for transmission lines in the formal impact tables is compounded by the fact that there is real confusion and uncertainty about the *volumes* of peat resulting from excavation for the pylon feet. A volume of 1,000 m^3 per tower is given as the "worst-case scenario":

> *"The standard tower base will require foundations approximately 7-17 m wide and up to 3.5 m deep (as shown in Figure 3.3).* ***This would result in the disturbance of an area of up to 20 m^2*** *of peat bog habitat.* ***Worst-case estimates require up to 1000 m^3 of peat removal for each tower base*** *(but see Chapter 5). Deviation, junction or termination towers (see Figure 3.3 and 3.4) would result in the disturbance of an area of peat bog up to 30 metres square."*
>
> *LWP 2005 TLA, Doc.4, Vol.1, Chapter 7, para 34*

These various numbers make no sense. "Up to 1,000 m^3 of peat removal for each tower base" would mean (for an average peat depth of 2.1) that the dimensions of each excavation would be nearly 22 x 22 m. This would mean an area of around 480 m^2 per tower, and a total of 6.6 ha for the 137 towers anticipated.

However, in LWP 2005 TLA,Doc.4, Vol.1, Chap.5, para 12 we find dimensions given for the volume of peat excavated if a single hole is dug for the tower base, and also the volumes if a hole is excavated for each leg:

> *"Where this [excavation of individual feet] is possible, the volume of peat excavated for a standard tower* ***would be approximately 25 m^3 instead of the 230 m^3 which would be required from a single large excavation****. For a termination tower* ***the volume of peat would be approximately 90 m^3 for four small excavations reduced from 700 m^3 for a single large trench****. This would* ***significantly reduce the worst-case volumes of 700 or 1000 m^3*** *assumed during the environmental impact assessments..."*
>
> *LWP 2005 TLA,Doc.4, Vol.1, Chapter 5, para 12*

Accepting these volumes at face value, it is possible then to assemble these differing figures, then calculate total peat volumes associated with these various scenarios. The resulting volumes are presented in Table 8 below. It is instructive to compare the values obtained in Table 8 with those listed in LWP 2006 EIS, Vol2, Sect.1, Chapter 7, Table 7.4, which gives the volume of peat excavated for pylon bases as 12,400 m^3. No total volume in Table 8 is even remotely similar to 12,400 m^3. Of the three total volumes listed, one is smaller than 12,400 m^3 while the other two values are substantially larger than this.

Table 8: Trasmission-line pylons – volumes of excavated peat
Calculations of peat volumes to be excavated during construction of bases for transmission-line pylons. The various values provided reflect the varying information provided by LWP 2005 Transmission Line Addendum (TLA).

Pylon/tower type	Values given in table to right represent either no. of towers, or m^3 of peat	Standard tower	Deviation tower 1-30° dimensions estimated	Deviation tower 31-60° dimensions estimated	Deviation tower 61-90°	Termination tower	Totals (no. or m^3)
	Number of towers	107	7	6	7	10	137
Peat volume (m^3) for excavation of 4 individual legs : for dimensions, see 'single tower values' : dimensions given by LWP 2005 TLA, Doc.4, Vol.1, Chap.5, para 12	Single tower volumes	25	50	50	90	90	
	Total volume (m^3) for all towers	2,675	350	300	630	900	4,855
Peat volume (m^3) for excavation of one large base : for dimensions, see 'single tower values' : dimensions given by LWP 2005 TLA, Doc.4, Vol.1, Chap.5, para 12	Single tower volumes	230	420	420	700	700	
	Total volume (m^3) for all towers	24,610	2,940	2,520	4,900	7,000	41,970
Total volume (m^3) for development, based on "1,000 m^3 per tower (worst-case scenario)" : LWP 2005 TLA, Doc.4, Vol.1, Chap.7, para 34							137,000

It is not easy to explain such a result. The number of turbines agrees with the total number indicated in the LWP EIS documents, and the various possible extraction volumes are exactly as set out in the same documents. Perhaps most significantly, the "worst-case" value of 137,000 m^3 is based on the possibility that 1,000 m^3 would need to be excavated at every tower.

This possibility is explicitly recognised in LWP 2005 TLA, Doc.4, Vol.1, Chapter 7, para 34. However, it is not discussed, or even calculated as a total amount – it is only ever mentioned in relation to a single pylon excavation, with no attempt to consider the wider implications of this figure for the management of peat volumes on-site. It is incumbent upon an EIS to consider and explain the possible implications of precisely such worst-case scenarios, and thus the lack of such discussion represents another significant failing on the part of the LWP EIS documents.

4.3.2.2 Sealing end compounds

It is rather surprising that LWP 2005 TLA, Doc.4, Vol.1, Chapter 6, in describing the construction process for the transmission lines, makes no mention of the sealing-end compounds for these transmission lines. It is only in LWP 2005 TLA, Doc.4, Vol.1, Chapter 7, where the habitat impacts of these transmission lines are discussed, that we find a need for:

> *"...9 – 10 sealing end compounds adjacent to proposed sub-stations..."*
>
> *LWP 2005 TLA, Doc.4, Vol.1, Chapter 7, para 6 (7.1.2.1)*

No information is provided about the dimensions of these permanent compounds, although there is repeated recognition within LWP 2005 TLA, Chapter 7 that these will represent permanent habitat loss over-and-above that accounted for in the sub-station permanent compounds. The only indication of size appears in a later statement about peat volumes:

> *"...Re-use of excess peat (estimated maximum of 182,000 m^3) excavated from tower bases **and** sealing end compounds."*
>
> *LWP 2005 TLA, Doc.4, Vol.1, Chapter 7, para 34*

If we assume that the volume of peat excavated from *tower bases* is the 12,400 m^3 discussed in Section 4.3.2.1 above, this leaves a peat volume of 169,600 m^3 for the sealing end compounds. Taking an average peat depth of 2.1 m, this gives a total area of 80,762 m^2, or 8 ha, for these compounds. This again is not a trivial area, and is almost twice the combined size of the substation compounds, which are explicitly listed in the various tables of habitat loss (*e.g.* LWP 2006 EIS, Vol.5, Appendix 11d).

It must be emphasised that this area estimate for the sealing-end compounds is based on a set of assumptions which may be wrong. However, it is probably the best that can be done, because the LWP EIS documents provide no further illumination. The existence of such sealing end compounds is acknowledged in the LWP 2006 EIS, but no further information is provided about their dimensions. It is stated that the compounds are illustrated in LWP 2005 TLA:

"At terminal points, larger footprint towers would be required to take the additional physical loading. These ***also require a cable sealing end compound (see Figure 3.4, Volume 2, LWP 2005b)*** *where the transmission lines are routed underground."*

LWP 2006 EIS, Vol.2, Sect.1, Chapter 2, para 31

However, reference to LWP 2005 EIS, Vol.2, Figure 3.4 reveals that there is no such illustration of a 'compound' as such. There is a small photograph labelled as "Photograph showing a typical termination tower" but there is no mention, or indication, of a sealing end compound. If this is the illustration of such a compound, as referred to by LWP 2006 EIS, Vol.2, Sect.1, Chapter 3, para 31, then it is wholly uninfomative because it is impossible to judge the nature or scale of this element of infrastructure.

Given the acknowledged existence of sealing end compounds, it is not clear why they do not then appear in any recognisable way in any of the impact calculations. Once again, like the pylon bases themselves, they appear to be invisible to the EIA process and to any calculation of impacts arising from transmission line construction.

4.3.2.3 'Temporary roadways' during construction

It is stated (with illustrations) that excavation of the pylon bases and stringing of the power cables will be achieved using temporary roadways which are laid onto the peat surface and then removed after construction has been completed. The illustrations show large boards being laid onto a fairly level peatland surface, and under these circumstances it is possible that damage may indeed be relatively limited. However, the potential degree of actual harm depends entirely on the particular conditions prevailing in each section of the temporary roadway. A good level surface may in fact represent an extremely wet percolation mire with very low bearing capacity, providing a highly unsuitable surface for traffic movements.

In the case of the Lewis peatlands, the problems are likely to include several such examples as this, but in addition there is the major issue of erosion and the highly broken, gullied ground that must commonly be crossed. There is explicit recognition of this problem in the LWP EIS documents, which state:

"In areas where peat has been worked or is ***eroded in gullies, the route would have to be prepared, with an excavator working from the temporary road, to create a more level route****. The top layer would be carefully laid aside to be replaced afterwards or as detailed in the peat management plan for the area."*

LWP 2005 TLA, Doc.4, Vol.1, Chap.5, para 18

The transmission line is excluded from virtually all considerations of impact because it is claimed that the construction method will result in only temporary disruption. On the basis of the description above, it is clear that such a claim is entirely false.

Firstly, if the excavator is trying to create a "more level route" through an erosion complex, the most realistic approach would be to slice off everything above the level of the gully bottoms and create a level trench cutting through the bog at that depth. It might be possible to slice off just part of the hagg and use this to fill the adjacent gullies level with the newly-sliced hagg top, but this depends on the relative proportions of hagg top and gully width (there would need to be like-for-like volumes), and would still create a trench through the peat, albeit a shallower trench.

The most important point about moving peat around in this way, however, is that once the peat has been excavated, it cannot realistically be "replaced afterwards". Slicing off sections of erosion complex to make a level surface is one thing. Trying to re-assemble the pattern of ridges and gullies back to their former structure, and ensuring that they then remain stable, is something quite different and really quite difficult if not impossible.

Consider a realistic scenario created by the suggested working method. A proportion of each erosion hagg destined to lie beneath the first trackway board is sliced off and laid into an adjoining erosion gully, thereby blocking the gully and creating a more-or-less level surface. Of course there is no guarantee that the available haggs will provide enough peat to infill the gullies, in which case presumably haggs either side of the trackway would be used to provide this extra peat. Equally, the gullies may not be so wide or numerous that they absorb all the peat cut from the hagg tops. In this case, having cut some, or all, of the hagg tops (it is of course necessary to cut them all to the same depth if a level surface is to be created), the excess peat must be stored somewhere – presumably in other adjacent gullies. The wooden track section is laid, and the digger moves on to create the next section of roadway.

Once a section of trackway is laid, it is likely to be there for some time – certainly days, probably weeks, and possibly even months, because the machinery for constructing the pylons and stringing the cables must be able to travel out and back along the track to the latest position of construction. During this time there will certainly be significant rain events. The erosion gullies associated with the trackway are now blocked with plugs of peat. Substantial water pressures are likely to build up around these plugs, with nowhere to go. Some peat plugs may actually be washed away, generating increased sedimentation downslope. If so, how will these displaced plugs be replaced afterwards? They will presumably need to be replaced if the trackway is to remain stable.

Finally, when the transmission-line work is complete, the trackway can be removed and the plugs progressively dug from the erosion gullies. These plugs will not have the same dimensions as when they were first cut. They will have suffered water loss, oxidative wastage of the peat, and water scouring, and will thus be much smaller than when they were dug. Consequently it will not be possible to replace these peat plugs back onto the erosion haggs and expect them to knit together. Quite the reverse, in fact. They are likely to suffer further oxidation and erosion at the joints between the re-assembled plugs during dry periods because as peat dries it is known to crack along lines of existing weakness – such as cut faces. This re-opening along lines of weakness renders the peat liable to breakdown of the peat block and gives rise to increased sediment loads downstream.

In creating a "more level route" in the way proposed, the excavator is in effect causing severe long-term disruption to the peatland habitat along the powerline route. There is no possibility of subsequently putting the peat back into the typical shapes of gullies and haggs, so the only realistic option would be to remove the plugs and take the peat elsewhere (as is hinted at by LWP 2005 TLA, Doc.4, Vol.1, Chap.5, para 18). Simply placing quantities of peat back onto the surface in the hope that it will not subsequently be washed away into local watercourses is not a realistic or acceptable option. Equally, leaving the plugs of peat in place within the gullies is not an option for the same reason.

Consequently the condition of the peatland surface along the proposed overhead transmission route, before and after construction, are questions of considerable significance for any assessment of potential habitat impacts. If the route were to be across entirely smooth ground, the proposed construction method might indeed produce little lasting damage. However, the roughness and complexity of the terrain is explicitly acknowledged by the LWP:

> *"This **high degree of surface roughness** over most of the Lewis peatland is observed to be due to three features. First, the vegetation types **include hummock forming species such as Rhacomitrium which together with other forms of peat mounds vary from around 0.3-0.5 m high and up to 2 m high** in certain places. Secondly, **water pools, which vary widely in shape and dimension but are typically around 1 m deep**. The third and **most significant factor affecting surface roughness involves erosion channels, hags, ridges and gullies** that are typically **around 0.5 m deep with many steep-sided gullies as much as 4 m deep**."*
>
> *LWP 2004 EIS, Vol.6, Appendix 10D, para 29*

The overhead transmission lines run for 30.5 km, across some extremely challenging peatland terrain, so the potential impact of these powerline routes is both substantial and extensive. Given the following assessment, for example:

> *"...**Rapid reversion** to pre-existing habitats and habitat quality is likely **on ground affected by temporary roads** (probably on a 1 – 3 year timescale)..."*
>
> *LWP 2005 TLA, Doc.4, Vol.1, Chap.7, para 46*

...it would appear that the LWP EIS documents do not recognise the likely degree of long-term damage that will occur along the transmission-line route. It would seem that this is another example where the assessment of likely impact is being made on the basis of a hypothetical concept of blanket bog, rather than looking at the actual ground conditions to be faced by the construction team. It will be an enormous challenge to provide a level surface over eroded ground in such a way that permanent harm does not occur, yet this challenge is not discussed in any way within this context.

To obtain some idea of just what a challenge this will be, it is worth looking at some sections of the proposed overhead transmission-line route. Figure 18 shows some typical examples of these conditions. It is also evident from Figure 18 that the transmission lines cross a number of bog pool systems. In some places the systems are highly complex and clearly have very high water tables (see Figure 19). It is not explained how the roadway will negotiate such features, but they will clearly have a major influence on the challenges faced by the construction team when the time comes to cross such areas.

Some explanation from LWP of the issues in advance would:

- give confidence that the potential environmental consequences of crossing such ground are recognised, have been considered, and that appropriate measures have been incorporated into the construction methodology, and

- would provide the construction crew with the opportunity to plan ahead adequately and thus prepare for a range of eventualities on such ground. The fact that such eventualities do not seem to have been considered during production of the EIS documents is a source of considerable concern.

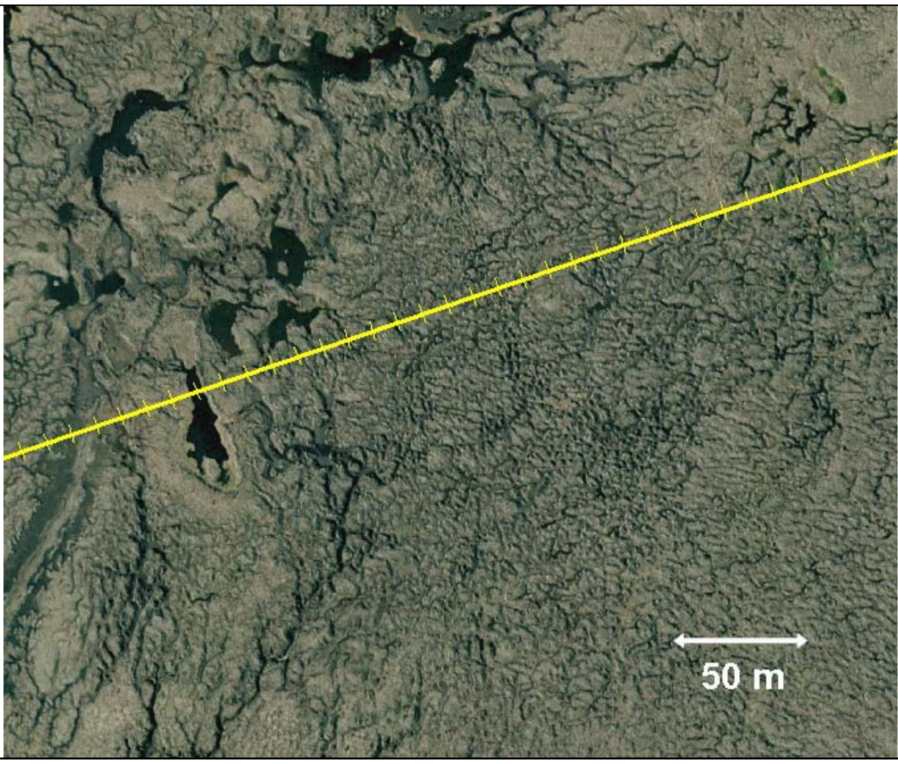
Given the acknowledged scale of erosion within the proposed development area, it is therefore likely that much of the 'temporary' trackway would become a semi-excavated trench, and specifically a semi-excavated trench that was not readily amenable to restoration. Furthermore, it is clear from Figure 18 and Figure 19 that the trackway itself will not be able to follow the eventual straight route of the transmission lines. This is because at times the lines must pass over lochans, lochs and other features that cannot support a roadway, temporary or not. The trackway will thus be forced to weave its way round these features.

The total length of such a temporary road is likely to be significantly longer than the route indicated for the overhead transmission lines because it will be considerably more sinuous than the final direct line of the transmission cables. With a permanent roadway, it is possible simply to infill many features with crushed rock, but this is not an option for the temporary trackway. Consequently it is likely that the trackway will have to weave its way around many more features than would be the case for the permanent roadway simply because it is not possible to provide adequate support for the trackway sections across such features. If so, then the route is likely to be highly sinuous across a significant proportion of its length.

Looking again at the sinuosity calculations given in Section 3.1 above, it is quite possible that the roadway would be sufficiently circuitous that it incorporates up to 4 curves per kilometre. As such, the length could increase by between 19% (3 curves per kilometre) and 33% (4 curves per kilometre).

The total stated length of the overhead transmission route is 30.6 km. Taking the mean of the sinuosity values above (26%), this means that the 'temporary' roadway for the overhead transmission lines may finally prove to be something closer to 40 km in length (specifically 38.6 km). Assuming for the moment, as a 'worst-case scenario', that the whole length of this roadway would also need to be dug to the lowest level of erosion gullies with no real prospect of subsequent restoration, and assuming that the roadway is a uniform 3 m wide along this length, the total area affected by direct disturbance would be approximately 12 ha. If the road is 5 m wide, as suggested for "poor peat" (LWP 2005 TLA, Doc.4, Vol.1, Chapter 5, para 17), then the total area is approximately 20 ha. The real area is likely to be somewhere between these two figures (*i.e.* say,16 ha).

There is thus a distinct possibility that the 'temporary roadway' laid down for transmission-line construction will result in permanent damage to habitat along a 40 km length of the development and totalling around 16 ha in extent. Such a possibility is not even acknowledged, never mind discussed, in the LWP EIS documents. Clearly there is then also the potential for indirect effects to extend beyond this line of direct damage. The significance of indirect effects in relation to the transmission lines, habitat impacts, stability issues and security of water supplies at Loch Mor an Starr, will be explored further in Chapters 5, 6 and 7.



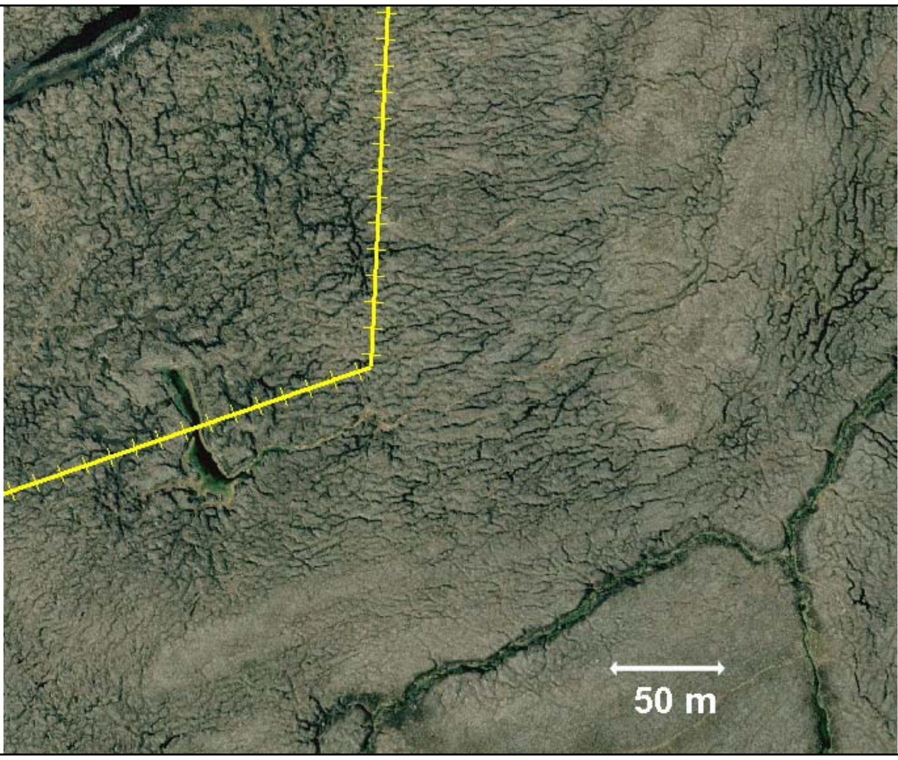


Figure 18. Ground conditions along route of power lines - erosion.
Aerial view of overhead transmission line (yellow line), centred on NB 416532 **(top)** and NB 426535 **(bottom)**, showing the degree of erosion, and consequent surface undulation, that the temporary roadway used to construct the transmission line must be laid across. It can be seen that the route also crosses various lochans. Water shows as black on this image, bare peat shows a mid-grey, vegetated peat (the bulk of the image) shows as light grey/brown.

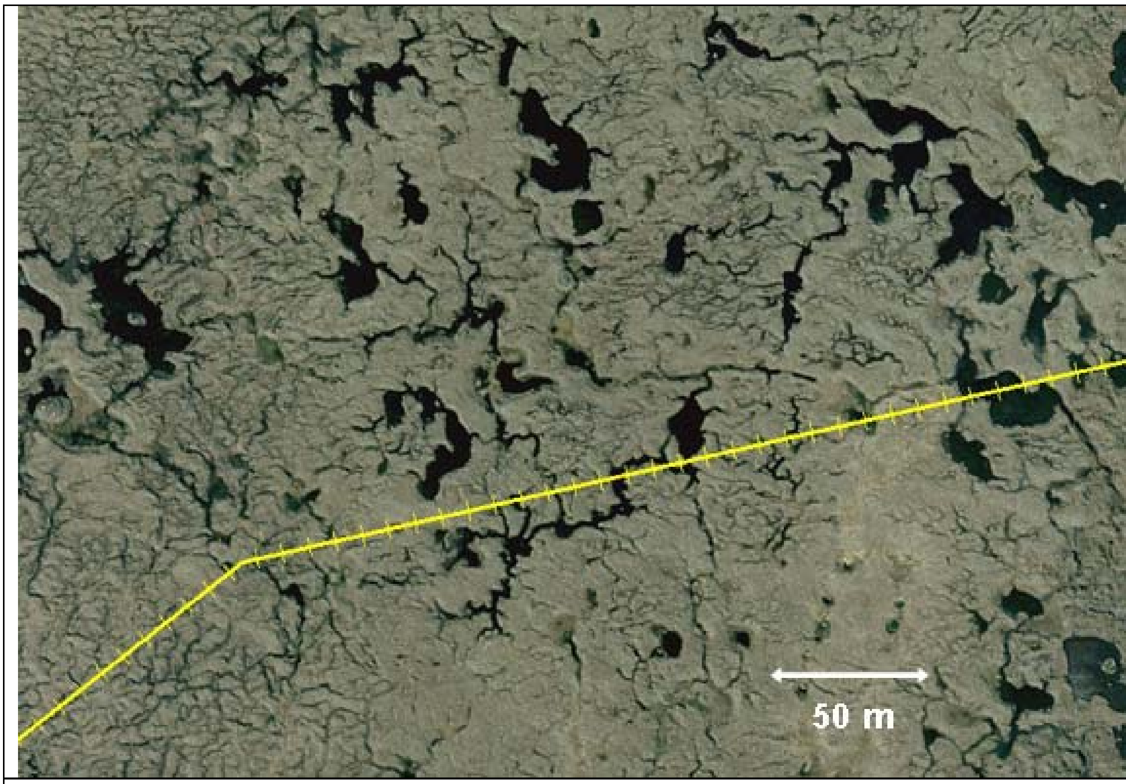


Figure 19. Ground conditions along route of powerlines : pool system.
Aerial view of overhead transmission line (yellow line), centred on NB 433556, showing the range of pool shapes and sizes that the temporary roadway used to construct the transmission line must be laid across. Water shows as black on this image, bare peat shows as mid-grey, vegetated peat (the bulk of the image) shows as light grey/brown.

4.3.2.4 De-watering of pylon bases

Given the kind of ground that the pylon-line construction team are likely to encounter, it is fairly evident that water management (specifically the removal of water from the pylon-base excavation) will be a significant on-site issue during construction. LWP 2005 TLA, Doc.4, Vol.1, Chapter 5, para 25 states that necessary dewatering of excavations would follow the methods described in the LWP 2004 EIS. The subsequent LWP 2006 EIS states instead that the detailed prescription for drainage of pylon line excavations is as set out in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 1 (Turbine bases). Consequently much of what has already been discussed in Section 4.2.3 above will apply to the de-watering of pylon-tower excavations.

5 GEOLOGY, HYDROGEOLOGY and HYDROLOGY

This chapter embraces a variety of topics, but a broadly hydrological theme runs through all of them, uniting them at both a fundamental and practical level. Given the almost complete dominance of blanket mire across the proposed development area (somewhere between 79% and 95% of the original LWP EIS Habitat Survey Area, depending on the section or data used in the LWP EIS documents – see Chapter 6), it should come as no surprise to find that such hydrological linkage is provided by this blanket of peat and its associated hydrological characteristics.

Key issues to be considered in the present chapter are:

- LWP peat depth data;
- the systems used to describe and classify the peatland habitat;
- identification of key peatland types;
- causes of erosion;
- eco-hydrology of peatlands and peatland drainage;
- water crossings.

5.1 Peat depths

For the purposes of site layout, construction, maintenance and at least some aspects of ecological impact, the depth of the overlying peat mantle is a fundamentally important factor. The deeper the peat, the more complex the construction process becomes. This is in part because the potential consequences of instability increase markedly with increasing depth of peat because deeper areas of peat tend to have more complex surface structures and often support significant amounts of open water. While it is by no means inevitable that open water is always present on deeper peats, the presence of such bodies of ponded water across many areas of deep peat is an issue that poses significant challenges for construction activities if they are proposed for such peat deposits. Consequently it is vital that an accurate and comprehensive picture of peat depths is obtained for any development proposal involving peat soils.

5.1.1 LWP peat depth map

As part of the EIA process, LWP did undertake an extensive programme of peat-depth mapping. Depth data were also obtained by LWP from other sources, but these data relate only to a limited number of additional locations. Some of these additional data included a summary analysis of peat cores taken to determine the degree of humification (structural nature as a result of decomposition) of the peat. In total, the data presented in the LWP EIS documents comprised:

- peat depth measurements taken by LWP at 50 m intervals along the length of the LWP 2004 road proposal, to the maximum depth of peat encountered (LWP 2004 EIS, Vol.6, Appendix 10B, para 12);

- peat depth measurements to a maximum depth of 4 m for a limited number of locations, gathered by Enviros in 2003 (LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3a);
- peat depth measurements to a maximum depth of 3 m for a limited number of locations, gathered by AMEC in 2002 (LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3a);
- probing data to a maximum depth of 1 m, taken in the course of the LWP habitat survey; this was undertaken across the whole Habitat Survey Area (LWP 2004 EIS, Vol.7, Technical Report, Sect.10, Appendix 1, Task 2).

From this it can be seen that only one dataset – the depths taken along the road line – provide a picture of the actual peat depths across much of the immediate development area. The other three sets of peat data are of limited value for a variety of reasons. The HSA survey, for example, covered a very wide geographical area and could have given an extremely valuable picture of the peat thickness across the whole of the potential development area. However, the survey chose to use only a 1 m probe to measure peat depths. This means that the HSA survey data can provide little more than a broad separation of peatland habitat from non-peat habitat and can say little about the main bulk of the peatland mantle.

The other two surveys provide a somewhat better picture of peat depths. They at least identify peat depths up to 3 m or 4 m, but unfortunately the number of samples is so small that their utility is extremely limited, especially given the highly variable nature of peat depth and peat structure, as can be seen in, for example, LWP 2004 EIS, Vol.4, Chapter 10, Fig.10.3b.

It is worth noting that the various datasets do not always agree with each other. This is probably also a reflection of how variable the nature of the peat deposit tends to be. Thus in an area centred on NB 325468, it can be seen from Figure 20 that the data obtained from detailed probing along the road-line give depths of up to 3.5 m for a polygon recorded as part of the HSA survey. In contrast, the HSA survey recorded this same polygon as having a maximum peat depth of only 80 cm.

To summarise, it is clear that the road-line dataset is the primary source of information about peat depths used by the LWP EIA. The other datasets are simply too fragmentary or limited in their scope to contribute much to the EIA process. However, there are several very serious difficulties with the road-line dataset, and with the way in which it is presented. These difficulties are explored below.

5.1.1.1 Peat-depth map symbology

It is a source of very considerable concern that the information obtained from the road-line peat-depth survey is presented in such a way that renders the data extremely difficult, and in some places impossible, to interpret accurately.

The peat depth maps for the road-line dataset (LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d) use a set of symbols so small, and so similarly shaded for many of the depth categories, that it is virtually impossible to distinguish one depth from another by eye. The shallowest and the deepest categories do stand out to some extent from the remainder, but the general blue shading for all depth classes, and the relatively subtle differences in size between classes, mean that determination of peat depth from these diagrams can only be obtained by the most careful scrutiny.

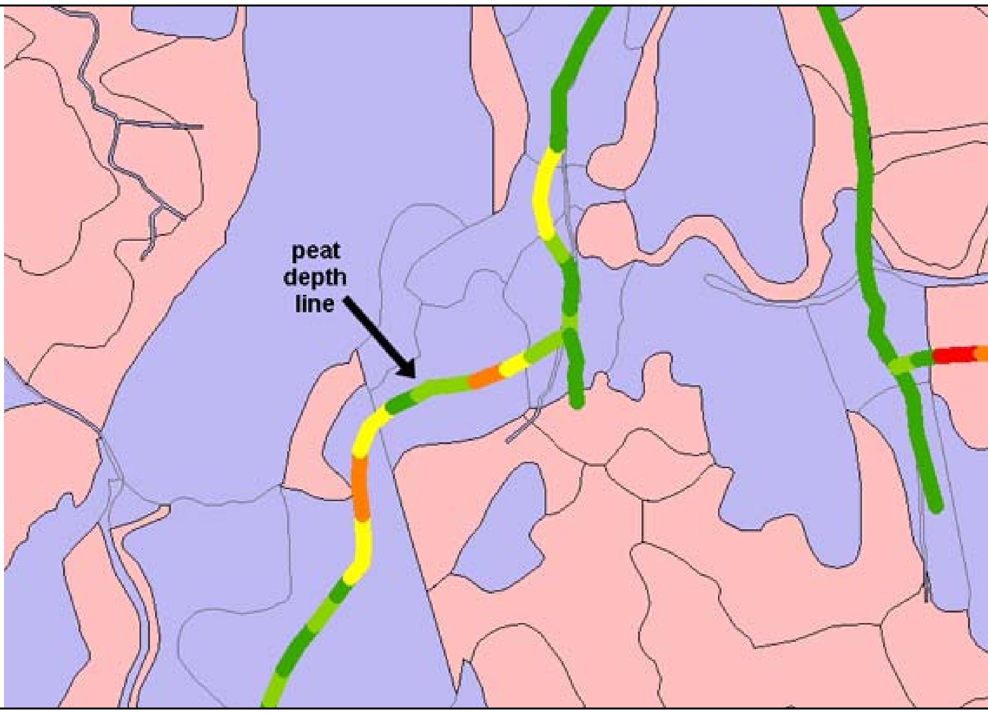


Figure 20. Contrasting peat depths for a section of roadline.
Map of LWP windfarm area centred on NB 325468, showing the mapped polygons from the HSA habitat survey exercise, together with the line of peat depths obtained from probing along the proposed roadline. The HSA polygons are shaded blue or pink, according to maximum recorded peat depth: blue = less than 1 m depth; pink = more than 1 m depth. The depths along the road-line are shaded according to depth categories: light green = 0-0.5 m; mid-green = 0.51-1.5 m; yellow = 1.51-2.5 m; orange = 2.51-3.5 m; red = 3.51-4.5 m. There are obvious mis-matches between the datasets. Thus, the blue HSA polygon containing the arrowhead indicates a maximum peat depth of less than 1 m for this polygon, but the road-line data crossing the polygon include a stretch shaded orange, indicating a maximum depth of up to 3.5 m for this same polygon. Roadline depths based on data presented in LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d.

As discussed earlier in Section 2.1, such poor presentation of the data is a highly unsatisfactory state of affairs for such an important dataset. The EIS is a document intended to inform the consultation and impact-assessment process, but this most vital dataset is all-but unreadable. There is no justification for this. The data are obviously derived from a digital dataset, and with the utilities available through modern digital cartography and GIS, the dataset could have been displayed with great clarity. This was not done, and one can only speculate as to why it was not done.

A simple tabular listing of National Grid Reference and peat depth for each depth record would at least have enabled consultees to create their own digital version of the dataset. Curiously, however, such a table is not provided, despite the considerable number of data tables provided by the various LWP EIS documents for other aspects of the EIA.

Perhaps most frustratingly, repeated requests to Lewis Wind Power for a digital copy of the dataset have been refused, despite LWP's relative willingness to provide other datasets in digital format. As a result, it has been necessary to undertake the not-inconsiderable task of reading the diameters of each circle presented in LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d and manually converting these into values that can be used to create a digital dataset of peat depths for the development area.

One problem encountered while undertaking this conversion task was that some peat-depth symbols were obscured by the symbols used to indicate a turbine. Consequently peat depths at turbine locations were often simply not readable. As a result, the derived digital dataset necessarily has a significant number of gaps where the depth data could not be determined from LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d.

To summarise this unsatisfactory situation:

- not only is the LWP-supplied dataset only available in a form that is, in all practical terms, unreadable and thus unusable;
- many of the most critical depth values, around the turbine bases, are actively obscured.

Despite these difficulties, a digital dataset based on the LWP road-line data was eventually generated by the UEL Peatland Research Unit. This derived dataset forms the basis of much that follows in the remainder of the present report (thus emphasising the core nature of this information). The data are displayed in Figure 21 below. It is evident from Figure 21 that, because the development area is so large, a map showing the whole development area cannot give any more than a general picture of peat-depth distribution. However, a more detailed view for a single portion of the development (Figure 22) shows how such data can be displayed in an informative way.

5.1.1.2 Accuracy of map data and variability of habitat

It has already been observed above that there are some apparent mis-matches between the HSA survey depth data and the road-line survey data. It is also evident that there is considerable variation in peat depth over very short distances throughout the site. The road-line depth data, though representing the most extensive dataset generated for peat depths by the LWP EIA work, are based on records taken at 50 m intervals, and only along the road-line itself.

During the course of the fieldwork carried out in autumn 2006 by the Peatland Research Unit of the University of East London, additional peat depth measurements were taken at various locations across the proposed development site. Although most of these depth measurements agreed reasonably well with those given by LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d, in one location a measurement of 4.5 m was obtained within 11 m of the road centre-line, yet LWP's road-line data give a peat depth of only 3 m at the centre-line. Consequently it seems that it is impossible to say with any confidence what the nature of the peat might be only 30 or 40 m to the side of the road-line – a distance well within LWP's original Potential Zone of Impact (PZI). This raises questions about whether a single line of depth measurements can be regarded as adequate for the purposes of the LWP EIA.

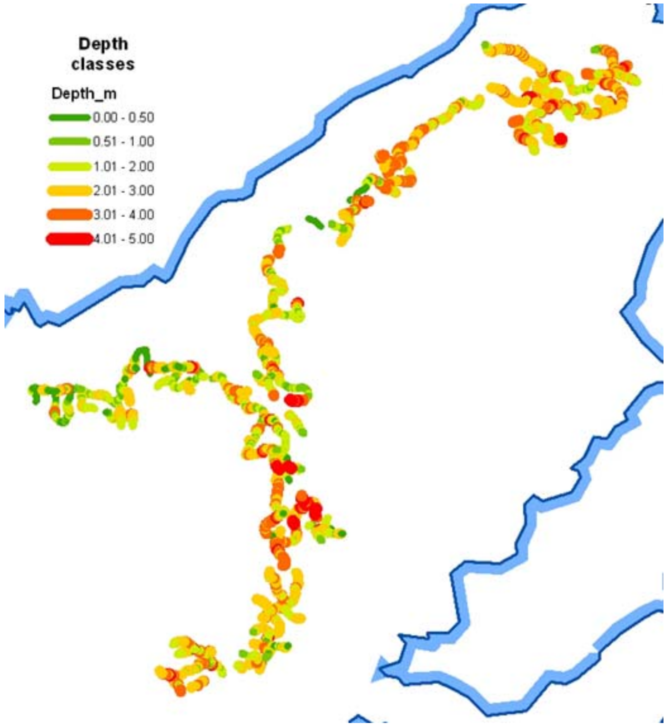


Figure 21. UEL-derived peat depths.
Symbolised map of peat depths for the proposed LWP windfarm road-line and turbine bases. Data have been derived from the information displayed in LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d.

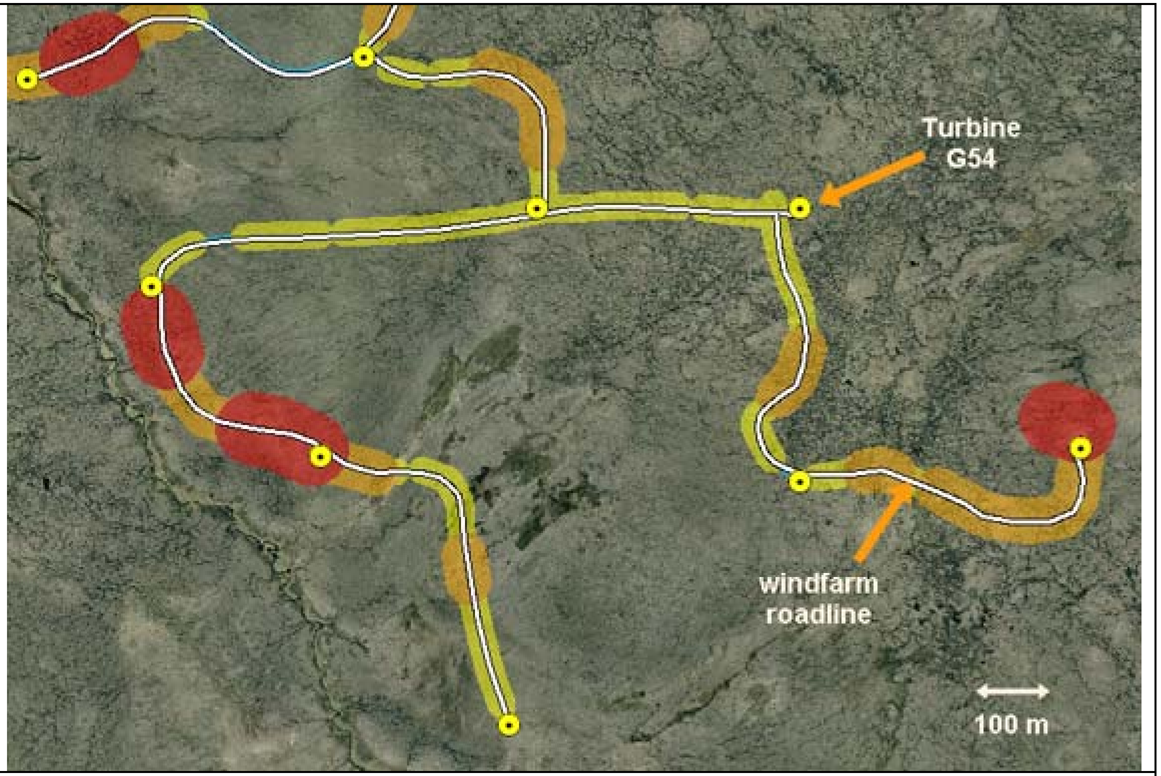


Figure 22. UEL-derived peat depths in vicinity of Turbine G54.
Symbolised map of peat depths for the proposed LWP windfarm road-line and turbine bases in the vicinity of Turbine G54 and overlain onto aerial photographs for the area. The windfarm road-line is shown as a white line, turbines are shown as yellow circles. Peat depths are displayed as: blue = 0.51-1.5 m; yellow = 1.51-2.5 m; orange = 2.51-3.5 m; red = 3.51-5 m.

5.1.2 Missing peat depths

It is not entirely satisfactory that judgements of potential impact must be based on only a single narrow line of depth measurements taken from the road-line. It is completely unacceptable that for certain sections of the proposed development there are no peat depth measurements at all.

This has come about, in part, because of re-alignments to the windfarm layout between the LWP 2004 EIS and the LWP 2006 EIS, as discussed below. Nonetheless, it is difficult to understand why the relatively small amount of necessary fieldwork could not have been undertaken as part of the revision process.

5.1.2.1 Depths missing along road-line

In the revision from the original development set out in 2004 and the revised development presented in 2006, certain sections of the original development proposal were removed, while other sections were replaced by alternative routes. Unfortunately, there does not seem to have been any associated re-assessment of peat depth along these new sections of development.

This information-gap is not trivial. It amounts to a total of 10.5 km, which represents some 7.5% of the whole road network. Add to this the sections of the development where the peat-depth data are not visible on LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d, which amount to a further 3 km, and the total length over which it is not possible to comment, or make impact judgements, amounts to 13.5 km, which represents 10% of the total road and turbine network (see Figure 23).

5.1.2.2 Peat depths and the overhead transmission lines

The difficulties do not end with the road-line, however. Presumably because LWP expect to build a temporary road when constructing the overhead transmission lines, and regard the pylon bases as negligible impacts, there appears to have been no attempt to measure peat depths along the proposed routes of the overhead transmission lines.

From the review of issues concerning transmission-line construction given in Section 4.3.2 above, it should be evident that the depth of peat along the route of the overhead transmission lines is of very great significance. As will become evident in later sections of the present report, the potential impact of the overhead transmission lines may be substantial and of some real concern to a range of consultees. Peat depth is likely to have a major bearing on the potential scale of such impacts.

The absence of any such depth data for a set of infrastructure that will extend across 32.5 km of mainly peatland habitat (LWP 2005 TLA, Non-Technical Summary), represents a very considerable failing on the part of the LWP EIS documents.

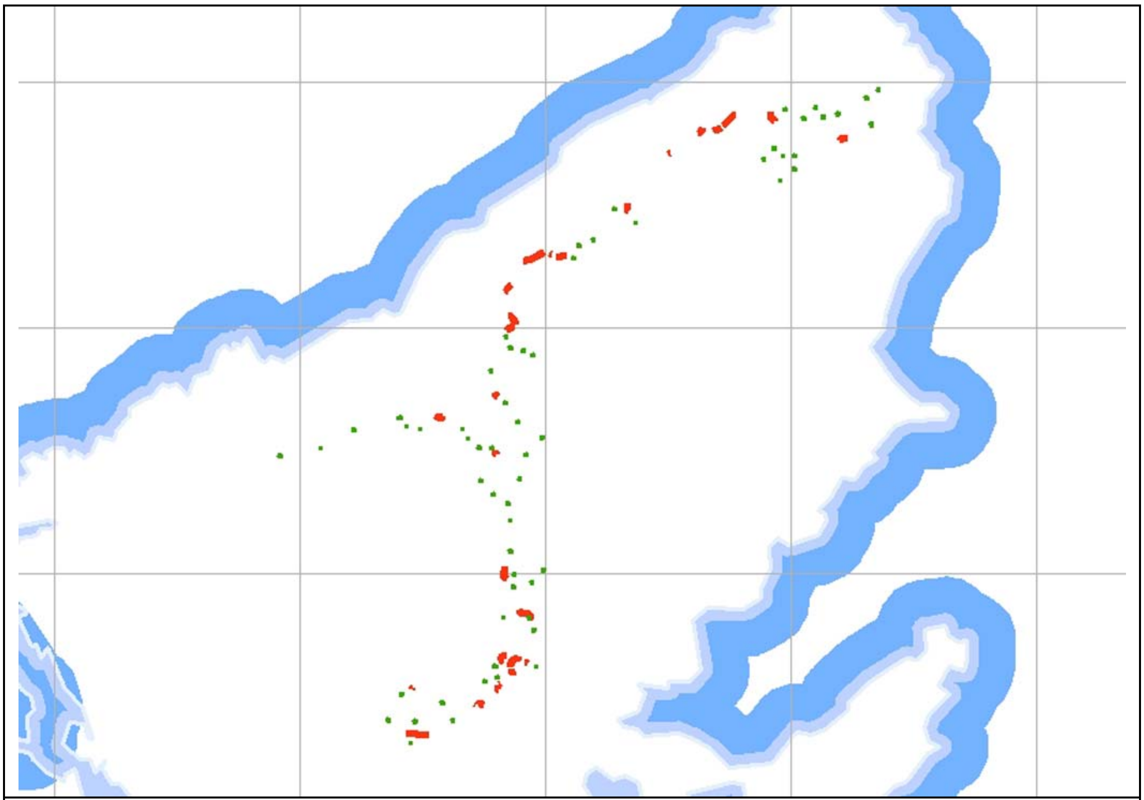


Figure 23. Locations for missing or unreadable LWP peat deths.
Symbolised map of road sections where peat depths for the proposed LWP windfarm road-line and turbine bases are either missing or impossible to read from LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d. Red = missing data; Green = locations where the LWP data cannot be distinguished because the symbols on LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d are obscured. The coastline is shown as concentric blue shading. The OS National Grid is displayed in grey as 10 km squares.

5.1.3 Relationship between peat depth and infrastructure

Having created a usable, if incomplete, map of peat depths derived from LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d, it is useful then to look at the resulting limitations of the dataset before proceeding to use the data to assess possible impacts.

It is extremely unfortunate that, for one of the key elements of infrastructure, namely the turbines, the original peat data are partially obscured and therefore this critical issue cannot be assessed as effectively as it should be. However, at least the symbols indicating the deepest peats were not entirely obscured – enough could be seen to determine the size of symbol being used. It is thus still possible to make an assessment of those turbines associated with the deepest peats. In terms of ecological impact and slope-stability, such deep peats are probably of most concern, and so these at least can be accurately assessed.

To summarise, areas for which precise depths are not available, or are not usable, are those which:

- simply have no peat depth data;
- are turbine locations where the peat depth is less than 4 m or so in depth and where the depth symbols is thus obscured by a turbine symbol in LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d;
- locations that are obscured in some other way on LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d;
- now lie off the proposed development route and are thus of no further interest.

Although the precise depths for many turbines cannot be read directly, it is nonetheless possible to construct an estimated likely depth, based on peat depths from adjacent sampling locations. Thus:

- A 50 m buffer was placed around each turbine base, and sections of the peat dataset subsequently captured within this buffer. As depth measurements were taken by LWP every 50 m along the road-line, this buffering step should have captured the nearest readable depths to a turbine, even if the depth at the location of a particular turbine was unavailable;
- In the case of the turbine bases, there may be as many as three 50 m road sections allocated to the turbine. This occurs if the turbine sits at a 'T'-junction in the road-line. The more usual circumstance is that a turbine location has two road sections (and thus associated depths) allocated to it;
- The depth at the obscured turbine base is taken to be the average of the two or three nearest depth readings. The accuracy of this average will depend on how variable the peat thickness is at this point.

In this way, it has been possible to construct a table that contains measured peat depth values, or estimated values, for a large proportion of the proposed development site. Each of these values is associated with a 50 m section of roadway. It is thus possible to summarise the data into depth classes and then count the number of road sections falling into each depth class. In fact the data presented in LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d are already given in depth classes, so these same classes can be used for this exercise.

In order to exclude those road sections, and depths, that no longer form part of the 2006 revised proposal, the dataset was clipped using a 50 m buffer created from the 2006 revised road-line, thereby excluding all data no longer relevant to the new development proposal.

Certain data gaps remain, and must be borne in mind when considering the results shown below. There are thus:

- the 7.5% length of road-line for which no data exist;
- some turbine bases for which no data are available;
- almost the whole length of the overhead transmission lines.

The data for road sections (in 50 m sections) and peat depth can be seen in Figure 24.

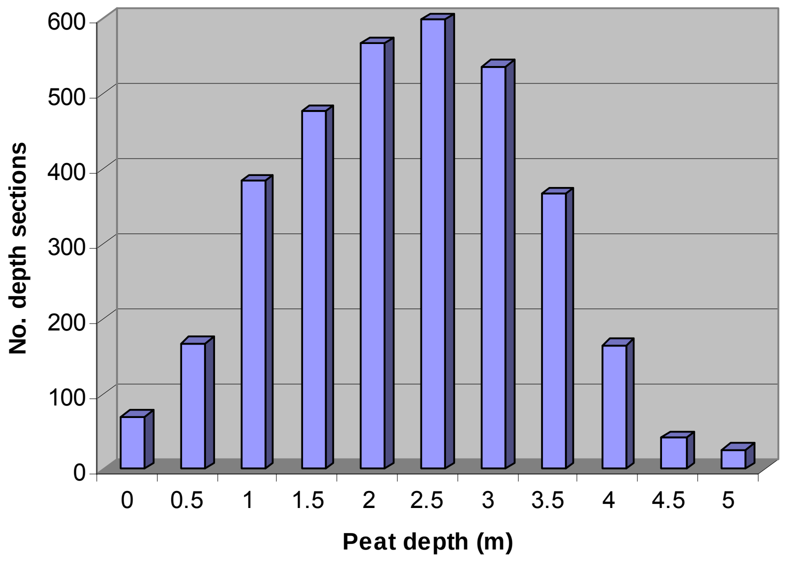


Figure 24. Range of peat depths associated with roadline.
Chart showing frequency of road sections (50 m lengths) associated with the 11 classes of peat depth derived from data presented in LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d. There are various gaps in this dataset, explained in the text. It is not therefore a true reflection of all depths associated with the proposed road-line of the LWP development.

It is interesting to note that the overall shape of the data is almost, but not quite, a bell-shaped (or 'Gaussian') distribution. Such bell-shaped curves are common in Nature where, for example, a species performs best within its optimal environment and performs progressively worse at either ends of the environmental spectrum.

This, is not, however, an ideal distribution from the perspective of either construction or potential environmental impact. It means that the major single group of peat depths is thus the middle depth class, and almost as many road sections lie above this depth as lie below. Thus the largest single class (2.5 m) represents a depth of peat greater than the ceiling height of most modern living rooms, and almost half of the remaining road sections have a peat thickness twice or even three times this height.

The preferred option would have been that the distribution of peat depths showed a sharp 'skewing' to the left, towards the shallow end of the depth range, with perhaps just a few rogue depths extending out into deeper peat. This would have indicated that the development had done its best to avoid areas of deep peat. There is some degree of skewing in this direction. Indeed the total pattern may be more skewed in this way because it is the smaller depths that tend to be obscured on the LWP peat-depth map. However, any such skewing towards the shallower depths is still not what could be called a major trend. This is unfortunate, and suggests that the development layout, revised though it is, could have done much more to focus on shallower peats.

Turning now to the turbine bases, the derived data can be seen in Figure 25.

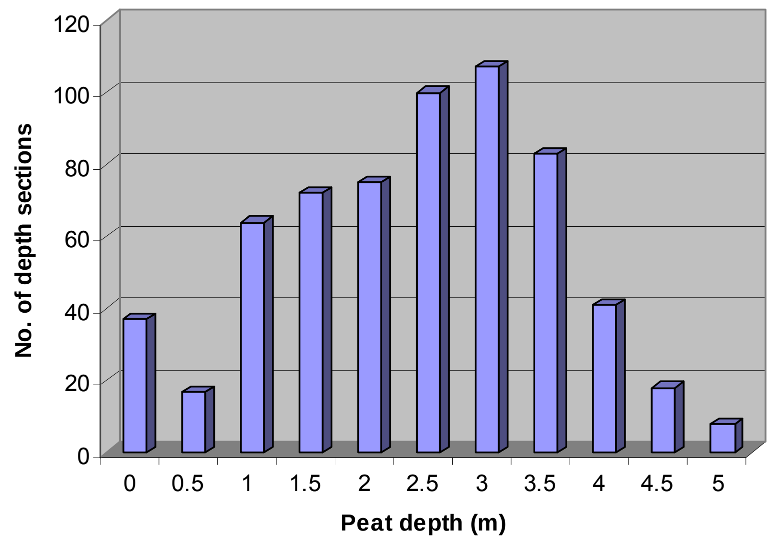


Figure 25. Range of peat depths associated with turbine bases.
Chart showing frequency of road sections (50 m lengths) associated with turbine bases divided amongst the 11 classes of peat depth derived from data presented in LWP 2004 EIS, Vol.4, Chapter 10, Figs.10.3a-d. There are various gaps in this dataset, explained in the text. It is not therefore a true reflection of all depths associated with the proposed turbine bases of the LWP development.

The chart for peat depth at turbine bases undoubtedly shows more of a skewed distribution than that seen in Figure 24, but the problem is that the peak of this skewed curve lies even further over to the right – into deeper peat – than is the case for the road-line. The single largest class of peat depth for turbine bases emerges as 3 m, closely followed by 2.5 m, and then 3.5 m. Between them, these deep peats account for just under 47% of all depths at or around the proposed locations for LWP's turbine bases. This is far from ideal, and presents major implications for construction, stability, habitat impact and sediment control, given that the turbine bases represent the major excavation programme of the LWP windfarm development.

It seems, then, that there are some substantial challenges for the development to address. What additional challenges the overhead transmission lines might bring remains to be seen, as indeed it does for around 7% of the main road-line because for these areas there are currently no depth data at all. It is fair to say that the scale of these identified challenges does not emerge from reading the LWP EIS documents. Indeed, the picture presented is quite the reverse, as is discussed in the next section.

5.1.4 Peat depth data – a question of presentation

As indicated above, the range of peat depths found to be associated with the windfarm infrastructure poses a series of significant challenges in terms of hydrology, ecology, engineering and slope-stability. Yet in the LWP EIS documents, we find the statement that:

> *"**Very deep peat is comparatively rare**, occurring over only 1% of the surveyed area."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 21*

In fact the peat depth survey was conducted along a *line*, and thus the statement quoted above is somewhat disingenuous because the actual 'surveyed area' is extremely small. In effect, the statement that "Very deep peat is comparatively rare" encourages the reader to believe that very deep peat is indeed comparatively rare throughout the development area. This is very far from the case. As we have seen, just a short distance from the measured depths there may be very different depths from those obtained. Deep peat may in fact extend over considerable distances within the general area. The only dataset that could have given a more complete picture of the peat depth across the area as a whole is the HSA data, but unfortunately this is only able to indicate whether or not peat is deeper than 1 m.

Recognising and acknowledging this limitation in the available data is an important part of the EIA process because, if an incident such as a peat slide should occur, the extent of deep peat within the vicinity is likely to have a significant bearing on the resulting scale of the episode. While the roadline itself may lie on only 2 m of peat, just downslope there may be a substantial area where the peat is more than 5 m deep. Such a scenario is quite possible in such a landscape. The wording of the LWP EIS documents instead suggests that the peat-depth question has been addressed and is not an issue. This is epitomised by the following confident opening statement:

> *"A **full** hydrological, hydrogeological and geological impact assessment has been undertaken for the Lewis Wind Farm proposal (LWP 2006)."*
>
> *LWP 2006 EIS, Vol.2, Sect.4, Part 2, OBN 6 (Construction), para 1*

It has not. For more than 7% of the total road-line, and practically all of the overhead transmission line, even the depth of peat is entirely unknown. This means that for 25% of the combined total lengths of windfarm roads and overhead powerline routes (the buried powerlines follow the roads) there are no peat-depth data at all.

5.2 Description and classification of peatland systems

It is acknowledged by the LWP EIS documents that blanket peat occupies something between 80-90% of the proposed development area (83% : LWP 2004 EIS, Vol.7, Technical Report Summary; 87% : LWP 2004 EIS, Vol.7, Technical Report, Sect.5, Results : Erosion Classes). It would therefore seem reasonable to expect that the main descriptive and assessment systems used in the EIA process would be centred upon this dominant type, and employ the most appropriate elements of accepted and established systems of description. Such 'standard' methods of habitat description are generally considered to be those recommended by the official conservation agencies, and in particular the guidelines provided to those agencies by the Joint Nature Conservation Committee (JNCC). Thus the National Vegetation Classification (NVC) was originally established at the behest of the then official conservation agency (the Nature Conservancy Council) for use in conservation survey, assessment and management. The JNCC now recommends the use of this system as the standard method of vegetation description for conservation purposes throughout the UK, and it is now widely used as the standard method of vegetation description in EIA work within the UK.

Similarly, guidance is given by the JNCC in relation to habitat description and evaluation. Such guidance is based on the best science available. It is then developed through widespread consultation within the official conservation agencies and is then produced on behalf of, and with the agreement of, the conservation agencies by the JNCC. As such, this guidance has the explicit endorsement of all the official UK conservation agencies. Indeed changes to this guidance would require the agreement of all the official conservation agencies. Furthermore, this guidance represents the means by which the official conservation agencies can demonstrate in a court of law that their decisions in relation to site survey, evaluation and selection are reasonable and have a sound basis in science.

As such, there are clear advantages to a developer in adopting such guidance. It has already been subject to considerable scrutiny and peer review, it has been devised to be practical, applicable, and to provide valuable scientific insight into the nature of the habitat under consideration, and is accepted in law as a reasonable approach to the survey and evaluation process.

The decision by LWP to pursue alternative, novel approaches at the earliest stage in the Lewis Wind Farm EIA process thus represents an unfortunate choice of direction. It is a direction that leads the EIA to place undue emphasis on features that provide little real insight into the character of the land involved or of the possible consequences resulting from the proposed development on that land.

This section of the present report will consider the justification for adopting such novel but essentially limited assessment systems, and the consequences of following the chosen schemes. It will also demonstrate the benefits to be gained by adopting a more mainstream approach to the description of blanket mire ecosystems.

5.2.1 Catchments, landform and blanket mires

It is of the utmost importance for the effectiveness of an EIA that the fundamental units of description are correctly chosen from the outset. If the wrong units are adopted, it becomes extremely difficult subsequently to organise other related information in meaningful ways.

5.2.1.1 Descriptive systems – official guidance for peatland habitats

A very clear set of guidance about the use of appropriate descriptive units for blanket mires is available from the JNCC (1994). The system has also been described by

Lindsay (1995) and Joosten and Clarke (2002). The JNCC guidance is acknowledged by the LWP EIS documents, although incorrectly described as being based largely on the work of Lindsay *et al*. (1988) in the Flow Country. In fact the original guidance was initially drafted by the NCC Chief Scientist, Dr Derek Ratcliffe, and the later guidance was drawn up by a UK steering committee.

Indeed the JNCC system is also incorrectly referred to (LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 28) as "a hydro-morphological system used by SNH", attributed to Lindsay (1995). The system is in fact a UK-wide system, managed by the JNCC and produced by the steering committee referred to above. It is based on published scientific approaches to peatland description, some elements of which go back more than 100 years, but are most widely acknowledged as being brought together largely by Sjörs (1948) and Ivanov (1981). By the mid-1980s, the fundamental concepts of the habitat hierarchy devised by these two authors had already been adopted for national peatland inventory work by countries such as Canada (Wells and Zoltai, 1985; Norway (Moen, 1985), Estonia (Masing, 1982), Sweden (Göransson *et al*., 1983) and of course Russia (Ivanov, 1981). Oddly enough, though Britain was instrumental in providing the current terminology for this hierarchy through Thompson and Ingram's tanslation of Ivanov (1981), Britain was rather later than some in adopting the whole hierarchical system, but it finally did so in 1989 (Nature Conservancy Council, 1989). Since then the system has been set out in the *Wise Use of Mires and Peatlands* (Joosten and Clarke, 2002) as the framework for summarising:

> *"...the inherent tendency of mires to develop complex surface patterning and ecosystem diversity on various spatial and organisational levels."*
>
> *Joosten and Clarke (2002)*

Joosten and Clarke's (2002) publication (generally referred to as the 'Wise-Use Guidelines for Peatlands') forms part of Resolution VIII.17 from the 8th Ramsar Conference of Parties (CoP) held in Valencia, Spain, in November 2002. Article 11 of Resolution VIII.17 adopts an agreed set of *Guidelines for Global Action on Peatlands*, within which Paragaraph 23 recommends the Wise-Use Guidelines for use by Contracting Parties in ensuring the wise use and management of peatland ecosystems.

Irrespective of the origins and status of the hydro-morphological system, the LWP EIS documents chose not to use it. The basis for their rejection of this system is explored further below. For the moment, it is sufficient to observe that the LWP EIS documents choose to establish their own system for describing the development area and thus, inevitably, the expanse of blanket bog that dominates it.

5.2.1.2 Catchments and blanket mire

After considering the geology (including peat depth) of the proposed development area, and then the general question of peat hydrology (of which, more below in Section 5.4), LWP 2004 EIS, Vol.3, Chapter 10, (10.3.7) describes the approach adopted for "Surface water features and catchment mapping." It states that:

> *"The analysis of the study area has been broken down to a* ***catchment level*** *so that a* ***risk assessment can ultimately be***

***applied at the local hydrological scale** for the purposes of informing mitigation and management measures."*
LWP 2004 EIS, Vol.3, Chapter 10, (10.3.7)

This opening statement does not bode well for effective impact assessment, mitigation or management issues relating to the dominant blanket mire habitat because catchments are precisely the wrong concept to apply when dealing with blanket mire. Catchments are central to the assessment of river basins and all things pertaining to rivers, and they even have relevance to certain aspects of blanket mire eco-hydrology. They are also fundamental to the assessment of impacts in fen peatlands, and Ramsar Resolution VIII.11 states:

> *"**Where appropriate and desirable**, peatlands designated as Ramsar sites should include entire catchments, so as to maintain the hydrological integrity of the peatland system."*
> *Ramsar Resolution VIII.11, Annex, para 18*

However, in the specific case of blanket mire, catchments are not the appropriate unit to use because they suffer from one very serious flaw as major units of assessment.

This is because, in landscapes where blanket mire tends to form, areas with the gentlest gradients are also the areas that naturally tend to have slowest surface-water flows. This in turn means that the most waterlogged ground is often found on the broad watershed plateaux forming the *boundary* between adjacent river catchments. Being so waterlogged, these broad plateaux tend to form some of the deepest areas of peat and are typically dominated by systems of bog pools in northern and western Scotland.

The catchment divide, or watershed, thus tends to run right through the middle of all this deep peat with its pattern of bog pools. The same is true for spurs and saddles that form drainage divides for localised areas within a catchment – all of these features tend to give rise to significant depths of peat. The catchment boundary, however, bisects all of these features. As such, it is a very poor instrument for describing and assessing these peatland systems

Without in any way diminishing the very real importance of catchments for describing possible impacts on freshwater ecosystems and their associated biodiversity, and even for describing groundwater-fed fen peatlands, it must be said that, in a landscape so dominated by blanket mire habitat, the appropriate fundamental landscape unit for description and impact assessment should be one that focuses on the key components of the blanket mire ecosystem, rather than fish or fen.

A typical example of the problem can be seen in Figure 26, where the boundaries of LWP Catchments 10 and 11 cut through a very evident watershed pool system. It is extremely difficult to provide an integrated picture of risk management or impact assessment when the core functional entity (*i.e.* the watershed bog pool system) is thus divided into portions. Looked at another way, if something bad happens to this single watershed pool system, the fish in *both* Catchments 10 and 11 will suffer.

Catchments may be of value when considering peatland systems that are fed by groundwater (*i.e.* fens) because groundwater behaviour upstream from the fen is likely to have an effect on the fen. However, the 'upstream' part of the catchment for a blanket bog system is the sky, because blanket bogs are purely rain-fed.

‘Catchment’ is therefore a concept with limited value when describing a watershed blanket mire such as that shown in Figure 26. The mire unit functions as a distinct hydro-morphological entity almost *despite* the catchment line. Consequently a different approach to classification and description is most usefully invoked when describing peat bog systems, particularly when dealing with extensive peatlands such as blanket mire landscapes.

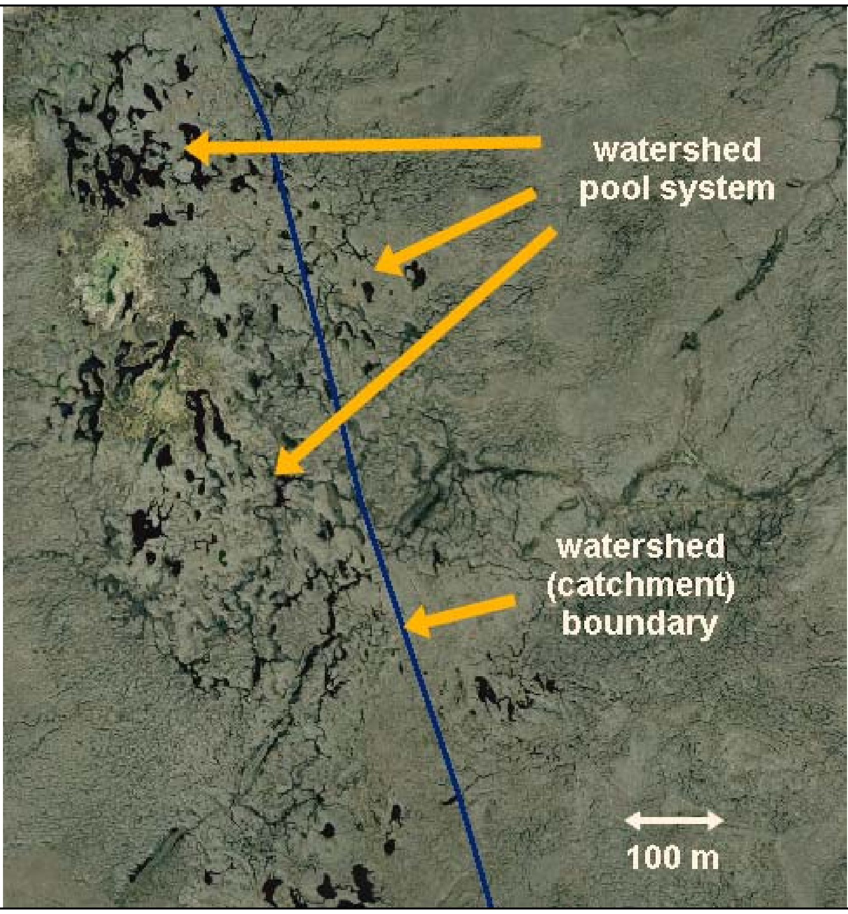


Figure 26. Catchment line cutting through watershed mire system.
Aerial photograph of watershed pool system at NB 441566, with catchment boundary (dark blue line) cutting through the bog pool system. The catchment line separates LWP Catchments 10 and 11.

That such a ‘blanket mire-friendly’ classification system exists, and is well-developed, is acknowledged by the LWP EIS documents:

> *“A **comprehensive hierarchy for bog classification** has been developed (Ivanov, 1981) and **currently applied to the Scottish environment** (Lindsay et al., 1988; JNCC, 1998; Lindsay, 1995).”*
>
> *LWP 2004 EIS, Vol.3, Chapter 10, para 65*

As observed earlier, the system is in fact applied to the whole of the UK (and indeed widely throughout the world), and was adopted almost 20 years ago by the NCC as the official descriptive system for Britain (NCC, 1989). Notwithstanding the suggestion by LWP that the system is only applicable on a more limited basis, and recognising that the Outer Hebrides are part of the Scottish environment, there would seem to be a very strong argument for adopting such a system as the central basis for the LWP EIA. Indeed, turning this argument around, it would seem that, for this very large, highly contentious development, a compelling case ought to have been assembled to justify *rejection* of the system used by official conservation agencies if that was to be the approach decided upon by LWP.

It is fair to say that the LWP EIS documents do not present – indeed make no real attempt to assemble - such a case. Despite this, they choose to discard this existing and established system, replacing it with an alternative approach devised uniquely for the Lewis windfarm EIA by LWP.

If a strong argument can be presented for an alternative to the official descriptive system, and this alternative can be shown to be as robust and functionally useful as the official system, there is a case for adopting it *in parallel* with the official system if, by doing so, a greater understanding is gained of the possible development impacts on the habitat. However, the alternative presented by LWP is neither robust nor functionally useful. The limited degree of understanding arising from the system adopted by LWP in relation to potential impact processes restricts the capacity of the LWP EIS documents to make meaningful assessments of likely impact. One of the most serious problems with the chosen system is that a great deal of Lewis EIA work is consequently devoted to the assessment of inappropriate features, as will be explored in detail below.

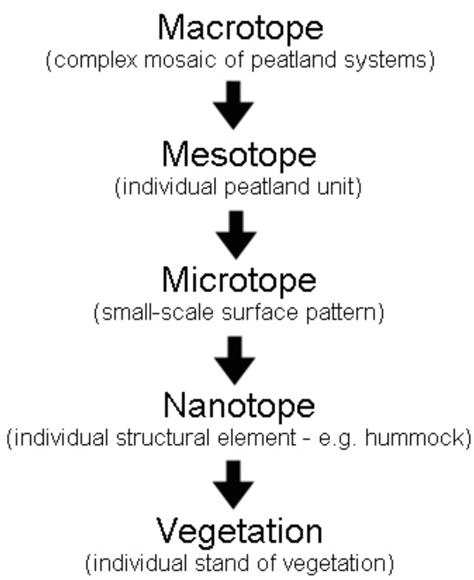
It is quite wrong to imply, as the LWP EIS documents do, that the hydromorphological system of classification is only appropriate for areas such as Caithness and Sutherland (LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 67). While Gimmingham (1997) highlights the benefits that came from establishment of the official system there is no suggestion that it applies uniquely to Caithness and Sutherland:

> *"...it was not until there was a serious threat to the survival of blanket mires in the 'flow country' of Caithness and Sutherland that* ***it was fully realized how little was known of the ecology of this bog type****, of which Scotland holds a major proportion of the world's resource. The Nature Conservancy Council (and its successor bodies) set about remedying this situation, and* ***their work has yielded much new information on the continuum of variation in community composition throughout the area and in the hydrological peat entities (mire mesotopes and microtopes) present*** *(Lindsay et al. 1988)."*
>
> *Gimmingham 1997*

Just how patently absurd the suggestion is that the system only applies effectively to Caithness and Sutherland can be seen from the fact that one of the surveys cited extensively by the LWP EIS documents clearly demonstrates the use of the system on the peatlands of Lewis, and across an even wider area of Lewis than that involved in the LWP HSA (Everingham and Mayer, 1991). On this basis, there would appear to be no justification for LWP's decision to develop a completely new system to underpin the EIA. Evedringham and Mayer (1991) had demonstrated that the system could be applied to the Outer Hebrides, and the LWP EIS documents make use of their findings – but at the same time reject their approach to the Lewis peatlands without explanation.

The nature of the alternative system adopted by LWP, and the consequences of adopting it, are discussed below. Before doing so, however, and the better to understand what exactly has been lost by this decision, it is worth devoting a little time to an exploration of the way in which the official UK hydro-morphological system can be used to provide a functional description of the Lewis peatlands.

The system consists of a hierarchy of levels based on structure, hydrology and ecology. From the highest level, at the landscape scale, each succeeding level provides a finer level of descriptive and functional detail down to the vegetation found on an individual bog hummock. While the individual components are explored in more detail below, the hierarchy is set out in Figure 27 but can be summarised thus:



5.2.2 Mire 'catchments' – the macrotope

The 'catchment' of a blanket bog is almost the landscape-inverse of a catchment for a river. Blanket bogs generally sit on the high points of the landscape and shed water down to the rivers below, while rivers sit at the bottom of drainage basins and receive all this shed water. In a river catchment the lowest point (the river channel) runs down the centre of the catchment, while in a blanket bog the lowest points (often rivers) are found at the very edges of the system while the highest watershed ridge forms the central spine of the system.

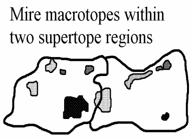
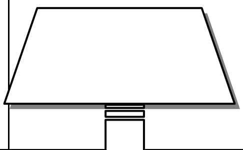
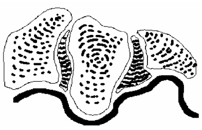
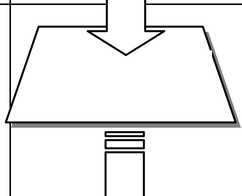
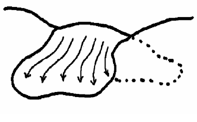
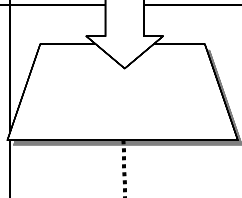
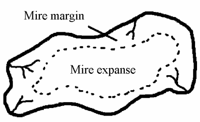
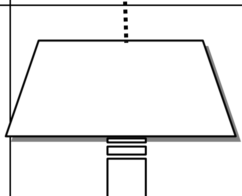
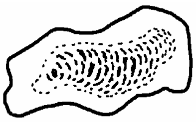
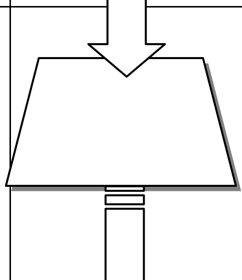
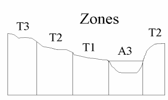
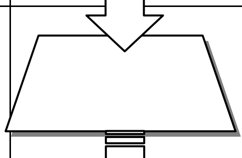
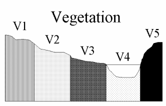
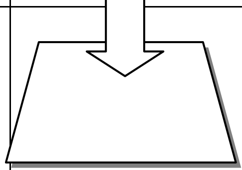
Feature	**Hierarchical level**	**Description** *and alternate names*	**Source of description** *and method of evaluation*	**Utility for classification and evaluation**
		Position of linked mire units within the regional land-scape.	IMCG 1998 *landscape analysis*	Regional overview
		Assemblage of hydrologically linked mire units. (*complex* : Sjörs, 1948, Moen 1985)	Ivanov 1981 *aerial photo-graphy, hydro-topography*	Identification of boundary for minimum, hydro-logically sound, conservation unit
		Distinct, recog-nisable hydro-topographic unit (*synsite* : Moen 1985, *Level 2, Form* : Zoltai and Pollett 1983)	Ivanov 1981; Lindsay *et al* 1988; *air photos, mire morphology*	Identification of individual, recognisable units for comparison
		Distinction between mire-margin and mire expanse (*mire sites* : Moen 1985)	Sjörs 1948 *air photos, vegetation morphology*	Recognition of two or more distinct parts; in Europe, the margin often partly removed
		Repeated surface pattern - *e.g.* pool system (*mire features* : Moen 1985, *surface physiognomy* : Zoltai and Pollett 1983, *hummock-hollow mosaic* : Tansley 1939)	Ivanov 1981 *air photos, fractal geometry, image recogn^{n}*	Identification of hydrological character and naturalness; source of com-parative diversity
		Individual surface features (*e.g.* hummock, pool)	IMCG 1998 Lindsay 1995, -*et al.* 1985, 1988 Ivanov 1981 *field survey*	Source of niches for individual species; com-parison of diver-sity and damage
		Distribution of vegetation within surface structures	A large literature exists, but see Sjörs 1948, Moen 1985, Eurola, Hicks and Kaakinen 1983, Lindsay 1995	Source of comparative diversity; indicator of "naturalness"

Figure 27. Eco-hydromorphological hierarchy for describing mire systems.
Hierarchy of peatland eco-hydromorphology, describing the seven functional and descriptive levels comprising the hierarchy. Example illustratons are provided for each level on the far left, and the hierarchy is displayed next to this. The various terms that have been applied to the hierarchy are shown in the central column, then to the right of this is a description of how these are identified and described. The column on the right summarises the utility of each level.

Lindsay *et al.* (2003)

In simplified form, a river catchment can be thought of as a wash-basin with its lowest point at a drain-hole in the centre, whereas a bog system is more like a tent, highest in the mid-section and shedding water in all directions to the ground. As with any tent, there are different slopes and shedding surfaces, and in some places there may be tendencies for water to collect somewhat, but ultimately all the water falling on the tent makes its way from the high points of the tent down to ground level at the edges. If the tent is a complex family tent with two or more 'rooms' there may be many interconnected surfaces. These each shed rainwater in particular directions and at different speeds, but always in the general direction of the ground. The surface panels are interconnected to make a watertight whole, and loss of one of these interconnected surfaces can radically alter the pattern of flow across other parts of the tent, as well as spelling disaster for the family beneath.

This inverted catchment model, shaped like a (generically hypothetical) tent, has been widely adopted around the world as the essential functional unit of peatland hydro-morphology and conservation. It is termed the 'macrotope', and forms the uppermost level of the integrated hydromorphological hierarchy.

The macrotope is defined as a complex of individual peatland units that are directly linked by their hydrological connections. The outer boundary of a macrotope would normally be made up of features that mark the edge of the continuous peat mantle. Thus rock faces, mineral ground, streams and rivers running over the mineral sub-soil, lakes on mineral soil, or substantial road structures (though not necessarily 'floating' roads), and even the sea-coast, can all form sections of a macrotope boundary.

The inverse nature of the relationship between catchments and mesotopes can be seen in Figure 28, which displays the catchment boundaries defined by LWP 2006 EIS, Vol.3, Chapter 10, Fig.10.4, together with a set of macrotope boundaries drawn up for Lewis by the UEL Peatland Research Unit.

5.2.3 Individual mire units – the mesotope

5.2.3.1 Mesotopes, landform and morphology

To understand the next level of detail in the bog hierarchy – the individual mire unit, or 'mesotope' – we must return to our analogy of the family tent. There may be a section of the tent for the parents, and a smaller section for the children. Each section has its own domed roof, and there is thus a sort of 'saddle' between these two sections of roof. Extending from the parental section there may also be an awning. The roof of this awning has a uniform gentle slope extending out from the complex curves of the main tent. Each roof section thus sheds water in its own particular way, some parts receiving water from other parts, but all ultimately dependent upon the integrity of the tent as a whole to continue functioning and thereby helping the family to enjoy their holiday.

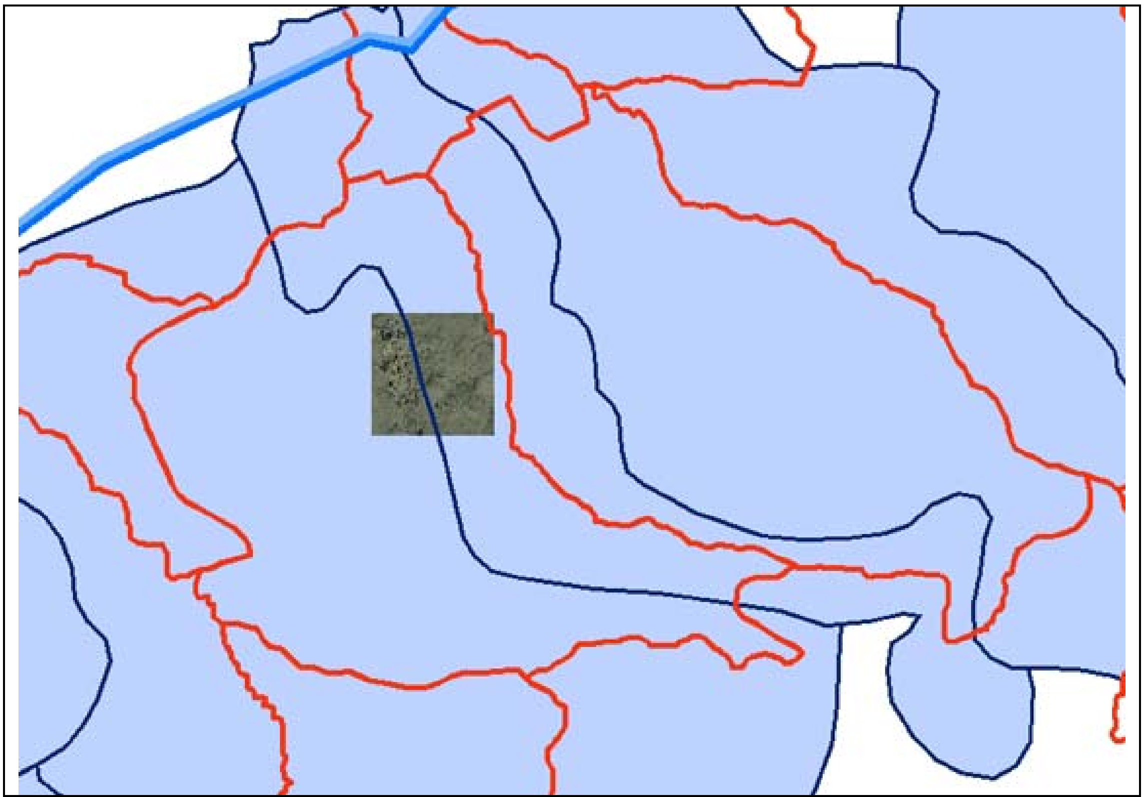


Figure 28. Contrast between LWP catchments and UEL macrotopes.
The catchments drawn up by LWP (LWP 2006 EIS, Vol.3, Chapter 10, Fig.10.4) shown as pale blue shading with dark blue boundaries (the blue lines in top left are part of the coastline). Macrotope boundaries drawn up by the UEL Peatland Research Unit are shown in red. The aerial photograph of watershed pool system at NB 441566, and shown in Figure 26, is also displayed. Note the catchment boundary (dark blue line) cutting through the bog pool system shown in the photograph, and the way in which microtope boundaries appear as the 'inverse' of catchment boundaries.

If the tent is the mire macrotope, then the individual roof panels, the awning, and indeed the walls, represent individual mire units, or 'mesotopes'. Each has a distinct morphology and pattern of water flow, but each relies on connections with the other tent panels to continue functioning effectively and form a stable and functioning whole (the macrotope). The shapes of the individual panels, and the characteristic pattern of water flow for each, combine together to define the mesotope type:

- the domed roofs are watershed mires;
- the saddle between them would be a saddle mire;
- the awning roof would be a spur mire;
- the side panels would be valleyside mires;
- and the junctions between them may be streams if the gradient is steep, or various types of fen mesotope if the gradient and water volume are less extreme.

This, quite simply, is the hydro-morphological typology set out in the JNCC (1994) guidance.

5.2.3.2 LWP and mesotopes – the claimed difficulties

The individual mesotope units of a blanket mire are thus defined purely on landform and nature of water flow, *not* on the basis of bog pool distribution in relation to landform as incorrectly stated in LWP 2004 EIS, Vol.7, Technical Report, para 5.2. This incorrect assumption seems to explain, at least in part, LWP's subsequent failure to adopt the official UK descriptive system for blanket mire habitats, and LWP's decision instead to devise an alternative set of descriptors unique to the Lewis Wind Farm EIA.

At this point it is perhaps worth considering the statement made by LWP about mesotopes, and repeated throughout all the LWP EIS documents, from LWP 2004 EIS, Vol.7, Technical Report, para 5.2 to LWP 2006 EIS, Vol.5, Appendix 11B, para 67. These all state that:

> *"...there is only a* ***weak correspondence in the HSA between peatland 'mesotope' types and distribution in relation to landform****, as summarised in JNCC guidelines for SSSI selection (JNCC, 1994)."*

It is particularly difficult to understand how such a conclusion could have been arrived at and why LWP thus felt unable to apply the official UK system of a hydro-morphological hierarchy, because all ground has 'landform' by definition, even if it is a flat plain. It is thus possible to take any area of the landscape anywhere on the planet and, if it is peat covered, break it down into the various landform components that equate to the broad mesotope types.

Furthermore, the number of broad landform shapes is relatively limited. Some areas possess combinations of characters and so can be classified as such – *e.g.* watershed-valleyside, or watershed-spur. This amalgamation generates a wider range of options, but still the range is not large. A relatively simple list of categories is therefore available, and it should be possible to assign all areas of the landscape to one of these categories.

More than 30 years ago, Goode (1972) was describing the way in which the Nature Conservancy used hydro-morphological types for the identification of peatland nature reserves. Ratcliffe (1977) also used hydro-morphological types to describe key peatland sites throughout Britain. Goode and Lindsay (1979) are acknowledged by the LWP EIS documents as having described the peatlands of Lewis using hydro-morphological types. Everingham and Mayer (1991) are cited at length by the LWP EIS documents, and their 'Table 1' provides a fairly comprehensive categorisation of hydromorphological types for the whole of the Lewis peatlands, including the whole of the LWP HSA. The JNCC description of the system for classifying hydro-morphological types in bogs is likewise recognised and referred to repeatedly throughout the LWP EIS documents.

It is not at all clear why the LWP EIA programme could not simply build on the information already provided by the dataset assembled for a large part of Lewis by Everingham and Mayer (1991). No explanation is offered as to why Everingham and Mayer (1991) were able to use the hydromorphological system to identify mesotopes on Lewis but the LWP EIA programme was not (it is worth pointing out that the work by Everingham and Mayer essentially involved rapid reconnaissance survey and thus focused only on mesotopes). No specific examples of the difficulties implied, nor demonstrations of the “weak correspondence” between hydromorphological type and landform, are presented by the LWP EIS documents to justify the abandonment of a recommended, well-established descriptive system.

5.2.3.3 Mesotopes – a demonstration

To demonstrate how readily the process of mesotope definition may be undertaken, two of the macrotopes defined by the UEL Peatland Research Unit (see Figure 29) have been sub-divided to create a series of mesotopes based on landform and consequent surface-water flow patterns. One of these macrotopes lies within the HSA surveyed by the LWP survey team. The other more northerly macrotope lies outside the HSA boundary but within the boundaries of catchments and ‘Hydrological Zones’ (see below) drawn up as part of the LWP EIA process.

As described above in relation to the family tent, the nature of each mesotope is defined by its general surface morphology and resulting pattern of surface-water flow. It is possible to reveal the pattern of this surface-water flow by displaying what are known as ‘flow lines’ in a technique described and demonstrated in detail almost 30 years ago by Ivanov (1981).

The general morphology of the unit is defined by the pattern of terrain contours. The flow lines are then drawn as lines that cut these contours at right angles, flowing downslope (obviously). The result of this process for the two demonstration macrotopes and their mesotopes is shown in Figure 30 and Figure 31.

From these illustrated examples it can be seen that the two macrotopes contain watershed mires, saddle mires, spur mires, valleyside mires, and even some fen mesotopes. Note that these fen units are mesotopes in their own right, rather than (as erroneously suggested by LWP 2004 EIS, Vol.6, Appendix 10D, para 108) being a part of the valleyside flow mesotope.

The mesotope thus represents what is often generally recognised as an individual mire unit. In some cases these may have individual names, such as Tom Arnval or Tom Dubh na Liana Baine. The mesotope unit has an area that can be broadly identified as the core mire expanse, and a more-or-less evident marginal or transition zone where either this unit ends and adjacent connected units begin, or where the peat mantle (and thus the macrotope) ends.

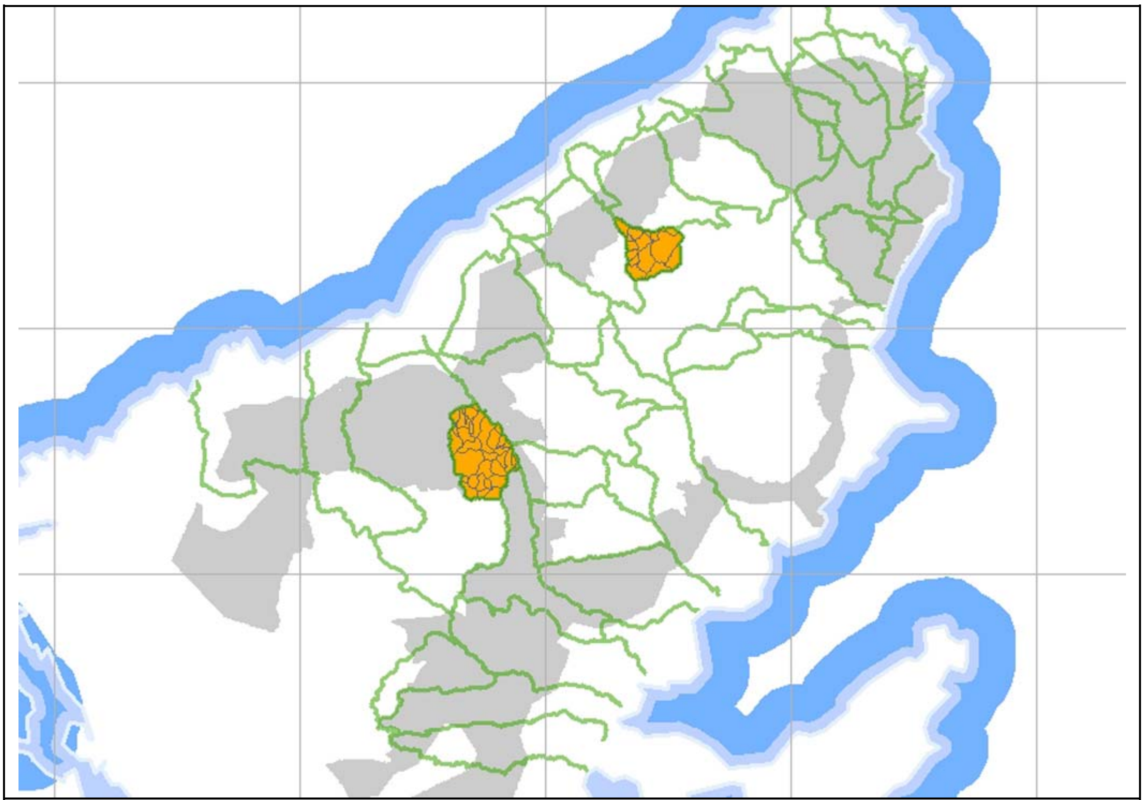
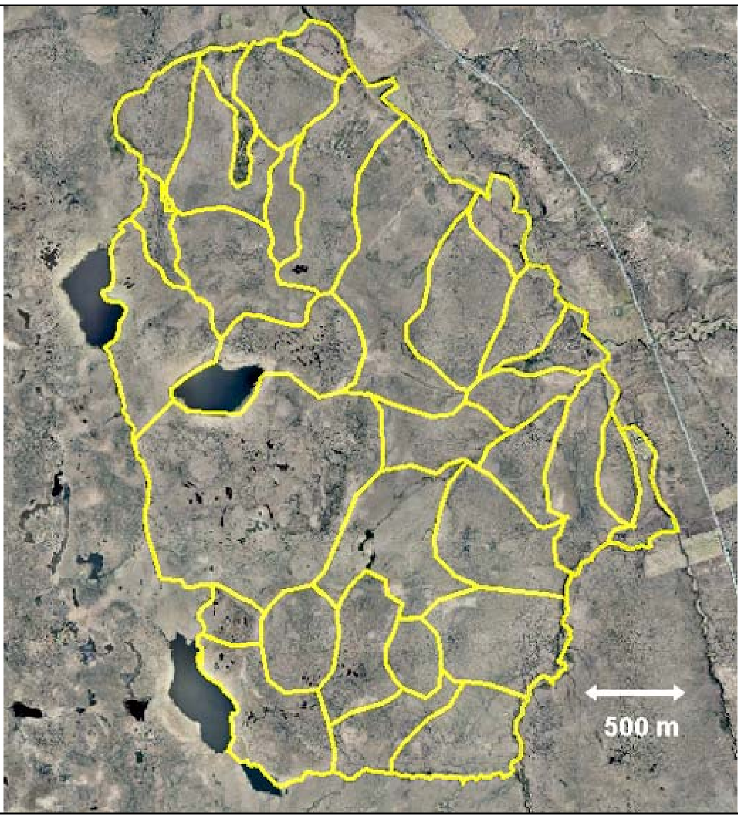


Figure 29. Macrotope boundaries, with two demonstration mesotope maps. Macrotope boundaries (green) drawn up for the whole of northern Lewis by the UEL Peatland Research Unit. Two macrotopes have been sub-divided into mesotopes (orange, with black sub-boundaries). The LWP HSA is shown as the grey shaded area. It can be seen that the more northerly of the two macrotopes lies outside the HSA boundary. The more southerly macrotope lies entirely within the HSA boundary and thus also within the proposed development zone. The coastline is shown as concentric blue shading. The OS National Grid is displayed in grey as 10 km squares.

Figure 30. Detail of mesotopes for northern demonstration macrotope.
The northerly macrotope of the two indicated in Figure 29. **(Top left)**: the whole macrotope boundary with mesotope boundaries indicated (white); **(Bottom left)**: the northwestern region of the macrotope, indicating the range of mesotope types identified by the UEL Peatland Research Team; **(Top right)**: the southeastern region of the macrotope, with flow lines (dashed pale blue) indicating general direction of surface-water flow, and mesotope boundaries indicated; **(Bottom right)**: the southeastern region of the macrotope, indicating mesotope boundaries and mesotope types.



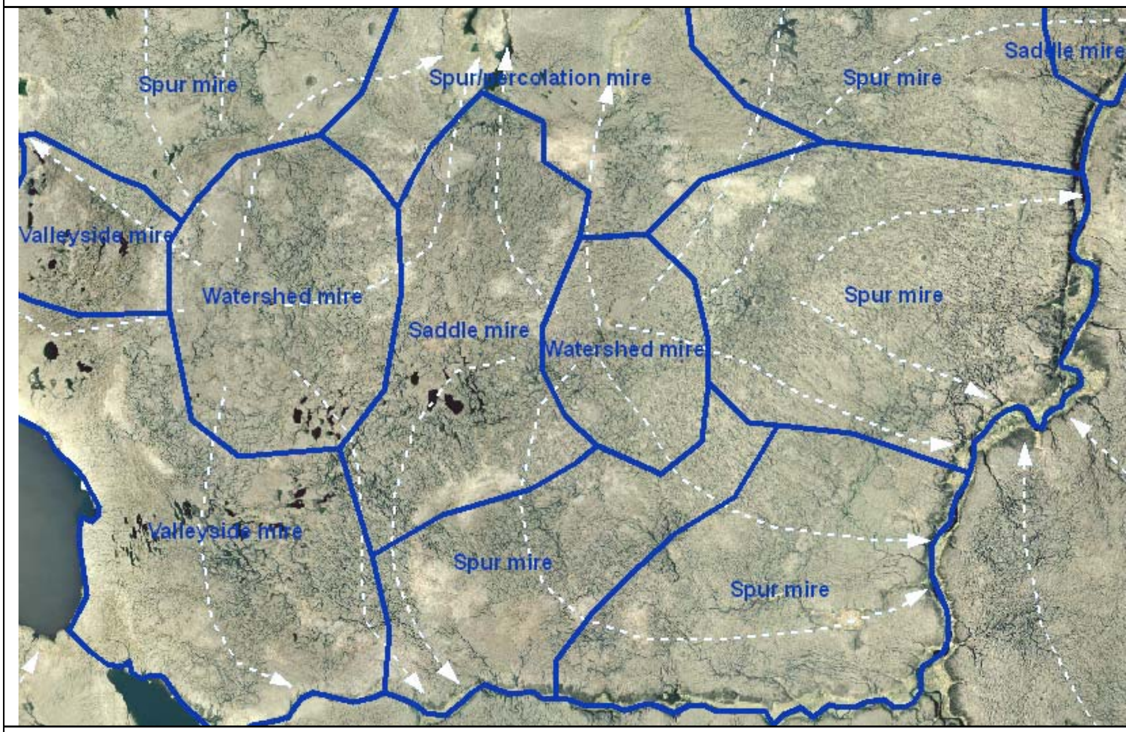


Figure 31. Details of mesotopes for southern demonstration macrotope.
The more southerly macrotope of the two indicated in Figure 29. **(Top)**: The whole macrotope boundary with mesotope boundaries indicated within; **(Bottom)**: The southern region of the macrotope, with mesotope boundaries shown in dark blue together with the range of mesotope types identified by the UEL Peatland Research Unit using flow lines (dashed pale blue) which indicate general direction of surface-water flow.

5.2.4 The microtope – self regulation and stability

A close examination of the boundaries drawn up in creating the mesotopes, with mesotope boundaries overlain onto an aerial photograph, reveals that there is another evident level of variation, or pattern, displayed by each area enclosed within a mesotope boundary (see Figure 32).

This pattern (or patterns) represents the next level of finer-scale detail in the descriptive hierarchy for peatlands. This fine-scale pattern is widely used in describing peatland ecosystems (*e.g.* Sjörs, 1948; Ivanov, 1981, Moen, 1985; Wells and Zoltai, 1985; NCC, 1989; Lindsay, 1995; Joosten and Clarke, 2002).

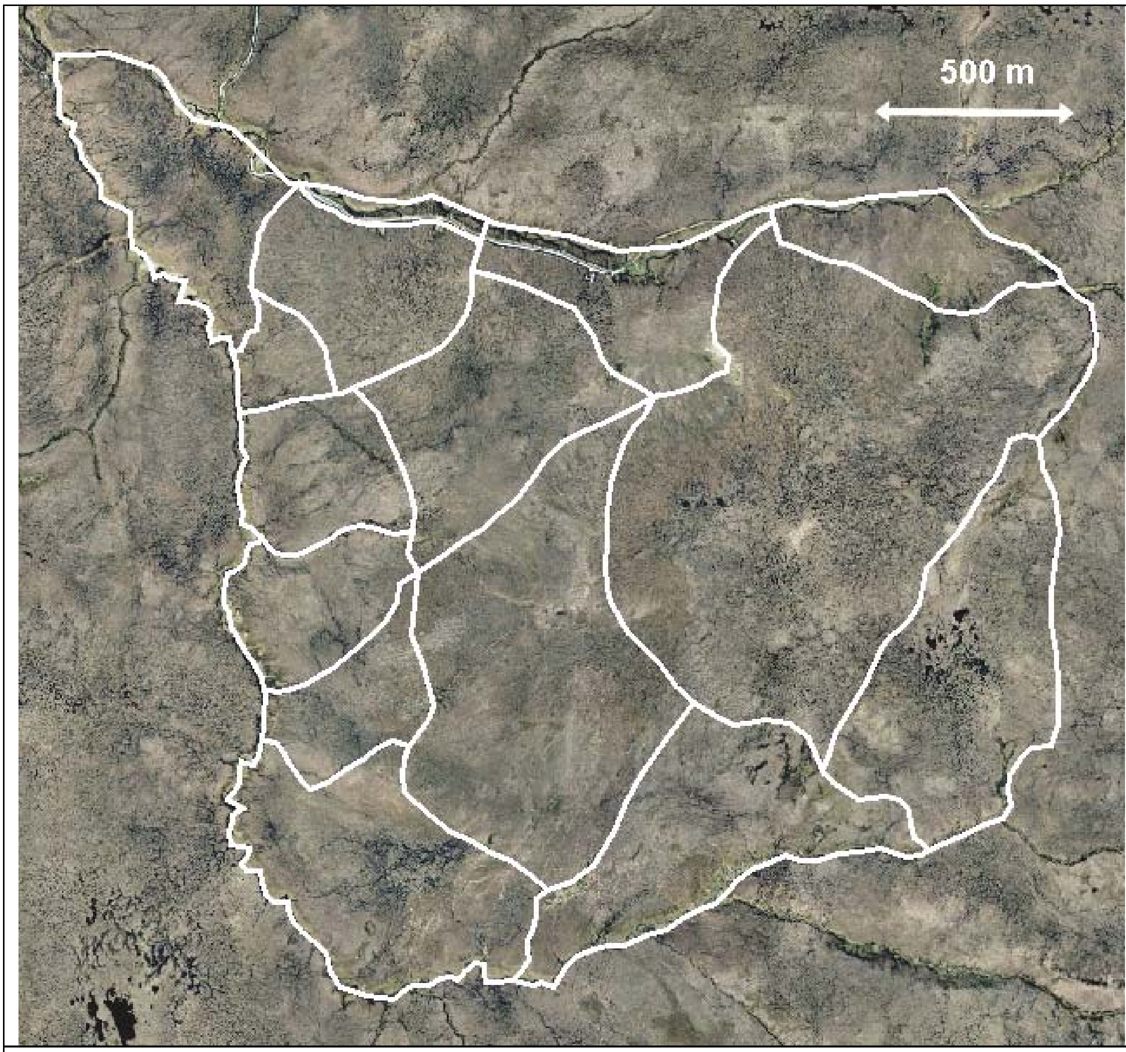


Figure 32. Microtope patterns visible within mesotope boundaries.
The macrotope shown in Figure 30, displayed over an aerial photograph. Internal mesotope boundaries are also shown (white boundaries). Note how the surface 'texture' of the ground varies between and within mesotopes. This texture, or 'microtope', is created by repeated patterns of small-scale surface features such as bog pools, hummocks and hollows, and (in this case) erosion gullies.

Closer examination of the mesotopes defined in the more southerly macrotope – *i.e.* the macrotope that lies within the HSA area – reveals much more clearly the very evident small-scale patterning that provides significant diversity *within* an individual mesotope or 'mire unit'. This finer level of structural detail is highlighted in Figure 33 and arises from repeated patterns created by even smaller-scale individual structures. The repeated patterns are termed 'microtopes', and the individual structures that make up these patterns (*e.g.* individual hummocks, hollows, ridges) are called 'nanotopes' (Joosten and Clarke 2002). The nature of microtope patterns, and the nanotope composition of these, represent one of the most important and far-reaching aspects of bog hydro-morphology and eco-hydrology.

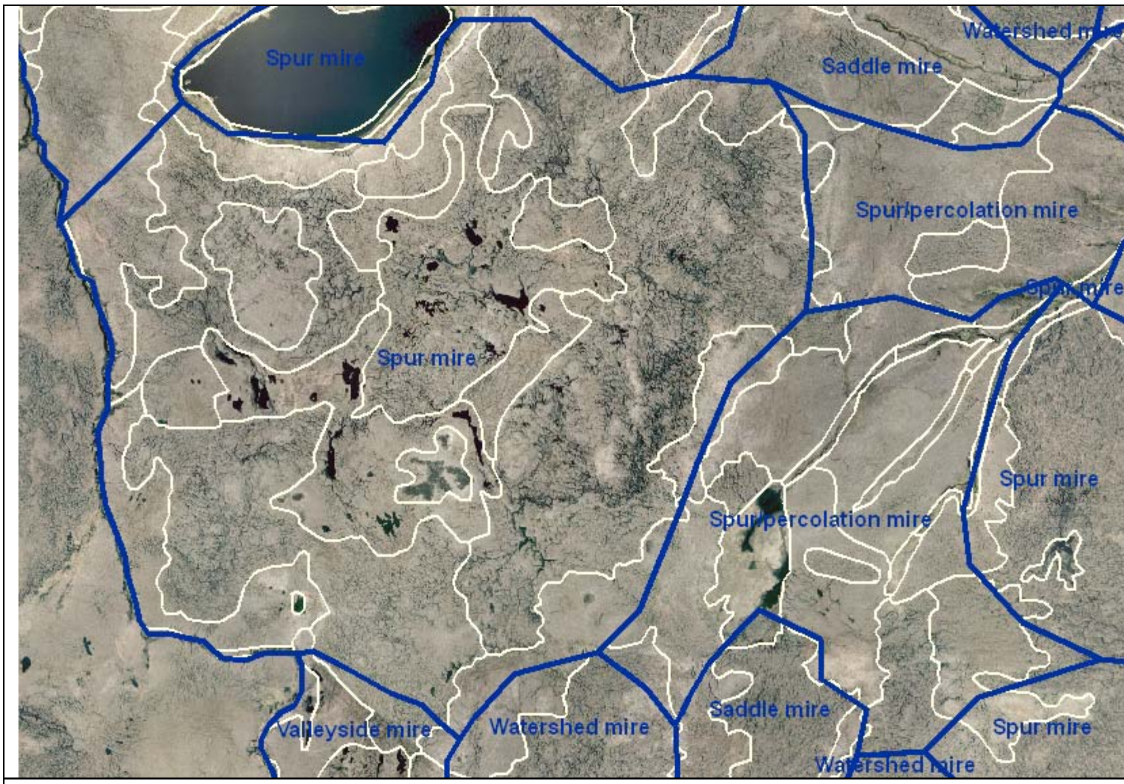


Figure 33. LWP Erosion Class boundaries as microtope boundaries.
Part of the macrotope shown in Figure 31, displayed over an aerial photograph. Internal mesotope boundaries are shown and labelled (dark blue), along with pale boundaries that, in effect, delimit microtopes - regions of distinctive surface textures, whether smooth, with pools (black shapes) or complex erosion networks. Note how the surface 'texture' of the ground varies between and within mesotopes, but is largely uniform within the mirotopes. This texture, or 'microtope pattern', is created by repeated arrangement of small-scale surface features such as bog pools, hummocks and hollows, and (in this case) erosion gullies.

To summarize a range of complex but rather elegant research, Goode (1970, 1973), Ivanov (1981), Belya and Clymo (1998) and Couwenberg and Joosten (2005) demonstrate that hummocks and ridges on a bog surface act to control water movement, while aquatic zones such as pools and hollows allow water to flow fairly freely. When these structures are arranged in repeated patterns, their proportions and character provide a robust, but at the same time finely-tuned, self-regulating system for controlling water flow across the bog surface even in the face of substantial fluctuations in climate. The system achieves this by subtle adjustments to microtope patterns.

Essentially, peat bogs have maintained remarkably steady growth through the various climate changes that have occurred during the last 7,000-8,000 years, by adjusting the proportion of different nanotope features that make up the small-scale microtope patterns. Barber (1981) used the long-term record stored in peat to investigate the theory of hummocks collapsing to form hollows, and hollows growing into hummocks in an eternal cycle ('hummock-hollow regeneration cycle'). He found that this long-held theory was in fact incorrect. Instead what emerged from the peat archive was clear evidence that surface patterns had changed many times in the past as they responded to shifts in wet or dry climate phases. In this way the bog system could be shown to have maintained a largely constant rate of peat growth at least through the uppermost 1 m of the peat archive, accumulated during the last 2,000 years.

Crawford (1997) similarly emphasizes that:

> *"Bogs are important sources of information for the reconstruction of climatic history. Their* ***surface topography is highly sensitive to changes in moisture and serves as an indicator of how oceanicity has varied with time****. Many British bogs have profiles that show changes in bog surface vegetation from wet lawn to pool and hummock topography as the hydrological element of the oceanic environment fluctuates through the centuries (Barber 1981)."*
>
> *Crawford (1997)*

Furthermore, the dynamics, origins and development of microtopography have all been the subject of considerable research effort since the early stages of peatland science, and continue to stimulate much peatland research today (*e.g.* Weber, 1902; Osvald, 1923; Sjörs, 1948; Goode, 1970; Masing, 1982; Glaser, 1992; Standen *et al.*, 1998; Karofeld, 1999; Couwenberg and Joosten 2005).

It is thus fairly important that an EIS involving significant areas of peatland habitat recognises the significance of this level of habitat description and ecosystem function. Furthermore, it should understand how this level of ecosystem structure can be used to assess both the present condition and the likely response of the bog system to potential impacts.

Oddly enough, and apparently independent of any link to literature about the significance of microtopes and nanotopes, the LWP EIS documents do in fact make use of the microtope concept, but they do so without displaying any evidence of understanding about the significance of this structural level. Indeed, ironically, the LWP EIS documents reject the hydro-morphological hierarchy in favour of a classification system of LWP's own devising, a system that focuses on types of erosion pattern. The irony is that erosion patterns are a form of microtope, and the microtope boundaries shown in Figure 33 above are actually the boundaries of LWP's Erosion Classes, although the LWP EIS documents do not recognise this. It is suggested by them that, for the Lewis peatlands, the system of LWP-derived Erosion Classes is "more appropriate" than the established hydro-morphological hierarchy used by the official conservation agencies (LWP 2004 EIS, Vol.7, Technical Report, para 5.2).

Meanwhile, Figure 33 and Figure 34 (below) clearly show that these surface patterns form descriptive (and one may assume functional) sub-units within the larger mesotope boundaries which themselves lie within larger macrotope boundaries. These surface patterns at the sub-mesotope level are precisely what would normally be defined as 'microtopes', but the (almost) direct cross-linkage between Erosion Class and microtope level seems to be completely lost on the authors of the LWP system.

Thus, as Winston Churchill once remarked:

> *"Man will occasionally stumble over the truth, but most of the time he will pick himself up and continue on."*

So the LWP EIS documents instead persist with the notion that the peatland hierarchy offers little of relevance or value. Consequently the LWP EIS documents fail to spot the potential value of the Erosion Class system for describing ecosystem functioning, and impact sensitivity, at least at the microtope level. Thus a major opportunity for the Lewis Wind Farm EIA is lost.

5.2.5 LWP Peat Erosion Classes

As observed above, the Peat Erosion Classes derived for the LWP EIA assessment essentially represent various distinct types of microtope pattern. As such, they are undoubtedly valuable as a means of classifying and describing different areas of ground within the LWP development area. The thinking behind their derivation, however, also means that a number of difficulties are associated with the LWP version of the system.

5.2.5.1 Erosion classes - a distorted focus

There is an unfortunate tendency within the LWP EIA approach, and in the EIS documents as a whole, to focus on damage and degradation of the blanket nire landscape, rather than on features that are either relatively undisturbed or which are showing significant recovery. This arises because the LWP classification and descriptive system is based solely on degree of 'degradation'.

This problem is particularly marked in relation to the relatively natural systems that occur within the proposed development area. There is very little discussion at all, anywhere in any of the LWP EIS documents, about such areas, their character, composition, or significance for potential impact evaluation. The most detailed account consists of only a single sentence found in LWP 2006 EIS, Vol.5, Appendix 11C, para 10. The account of Erosion Class 1 (*i.e.* relatively natural systems) given in what the LWP EIS documents offer as the most detailed of the descriptive tables for the Erosion Class system (LWP 2006 EIS, Vol.5, Appendix 11B, Table 11B.3) is, if anything, even briefer. It is difficult to see how anyone can be expected to read the LWP EIS documents and draw conclusions about potential impacts on such relatively undisturbed areas if (almost) no information is provided about these areas.

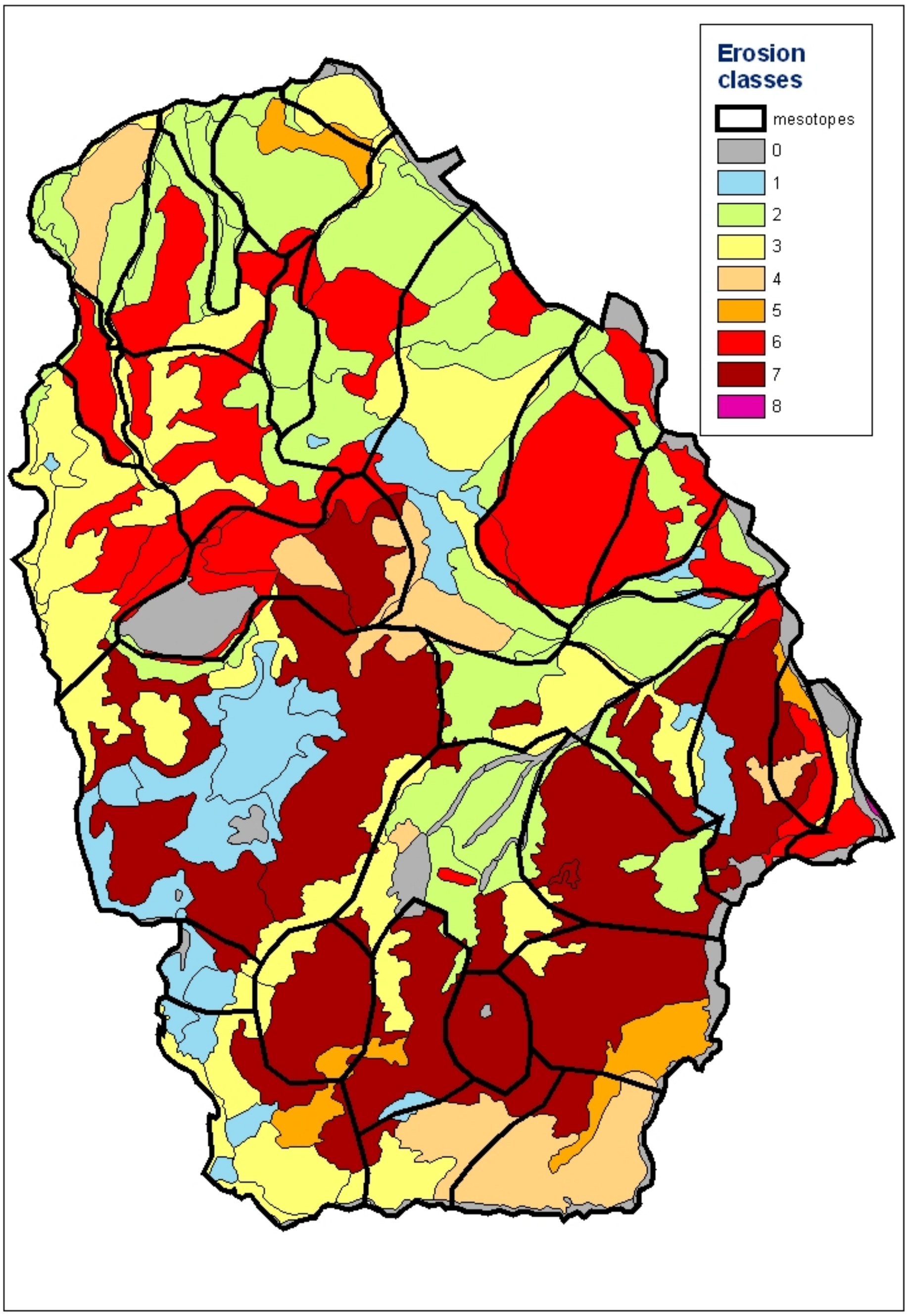


Figure 34. Macrotope, mesotope and microtope (LWP Erosion Class) boundaries for southern demonstration macrotope.
The more southerly macrotope shown in Figure 29. Internal mesotope boundaries are shown as thick black lines. Peat Erosion Classes identified during the course of the HSA survey by LWP (LWP 2004 EIS, Vol.7, Technical Report and GIS dataset) are displayed as colour categories (see legend). Note how the black mesotope boundaries often enclose several Erosion Classes. The latter in effect represent microtope patterns within the mesotope units. The macrotope boundaries were derived by the UEL Peatland Research Unit entirely without reference to the LWP map of Erosion Classes, yet it can be seen that there is a reasonable degree of correspondence between the two datasets – distinct groups of microtope patterns lie within individual mesotope boundaries. In other words, the LWP Erosion Classes largely represent microtope sub-units of the UEL mesotopes.

Relatively undisturbed mires *are* described elsewhere in terms of siting constraints. Similarly, the need to avoid Erosion Class 1 ground if possible is at least recognised in discussions on site layout. However, despite recognising the desirability of avoiding damage to such ground, the practical needs of the development over-ride this criterion, and it is thus acknowledged by the LWP EIS documents that some areas of Erosion Class 1 ground will be potentially affected by or used for construction (LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 51). Exactly what these effects might be is not explored in the LWP EIS documents.

This surely represents a very considerable failure of the EIA process as carried out by LWP. If the LWP EIS documents had demonstrated that there were no relatively undisturbed areas within the vicinity of the proposed development, it would be reasonable to find that no substantial comment is made about such areas other than to note their absence. However, the LWP EIS documents make clear that relatively undisturbed areas of ground (Erosion Class 1) do exist, and some will be directly affected by the development. Consequently there is a very real need for the EIS to provide clear and detailed information about such areas, and to clarify the likely impacts resulting from the proposed development. The absence of such information is difficult to explain.

That there is fairly extensive evidence of relatively natural peatland will be demonstrated below, but it is also important to re-iterate the fact here that, throughout the LWP EIS documents, the presence, character and extent of such natural and near-natural peatland systems is all-but ignored. Consequently almost all comments about quality of ground, and all potential impact statements and calculations, also ignore the presence of such areas.

This is yet another imbalanced aspect of the LWP EIS documents. If only the eroded peatlands are repeatedly referred to and addressed in the impact evaluation, the potential impacts on more natural systems are lost in the implied suggestion that there is very little undamaged ground anywhere within the development area.

5.2.5.2 Definition of Peat Erosion Classes

Accepting that the classification of erosion is to be used as one of the defining datasets, it is reasonable then to assume that the EIA defines the various classes accurately and effectively. Of critical importance is the distinction between Erosion Classes that are actively eroding and those that show significant recovery. As will be discussed in the next chapter, this step is critical. This is because the EU Habitats Directive has identified ‘active blanket bog’ as a ‘priority habitat’. Guidance about this priority habitat, provided by the JNCC, indicates that eroded blanket bog with vegetation recovery in the gullies may be classed as ‘active blanket bog’. The implication is that eroded bog with bare, active gullying would not qualify as priority habitat.

The question is particularly relevant to Erosion Classes 4, 5, 6 and 7 as defined by the LWP EIS documents, because these classes are largely distinguished through their different intensities of dissection and degrees of vegetation recovery in the gullies. Various tables are presented within the LWP EIS documents, and some differ from others in terms of the information presented. Some of the critical information can only be found in the document text rather than in what are presumably supposed to be defining tables. Why this should be is not at all clear.

The key information is distributed across LWP 2004 EIS, Vol.7, Technical Report, Chapter 4, Table 2, LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, Table 11.3, LWP 2004 EIS, Vol.7, Technical Report, Chapter 4.4, LWP 2004 EIS, Vol.7, Technical Report, Chapter 5.1, and LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 23. Only by assembling information from all of these is it possible to obtain a clear and full description of each Erosion Class. This has been done below for the four classes – 4, 5, 6, and 7 (see Table 9).

The definitions given by LWP appear reasonably straightforward, in the sense that the four Erosion Classes represent two forms of gully intensity combined with two conditions of erosion and recovery - namely gullies that are still actively eroding, and gullies which are stable and/or re-vegetating. There are two issues that merit careful examination in terms of the way in which the LWP EIS documents identify Erosion Classes on the ground:

- the determination of gully intensity; and
- the assessment of re-vegetation.

The determination of gully intensity can be accomplished by examining aerial photographs. Alternatively, it can be assessed by ground survey. The former has the advantage that the whole patch (polygon) can be viewed and thus a reasonable average estimate made of gully intensity across the whole polygon. However, it is not easy to distinguish the scales of dissection given in Table 9 (*i.e.* 10 m and 20 m) when using aerial photographs at the 1:10,000 scale used by the LWP survey (LWP 2004 EIS, Vol.7, Technical Report, para 4.1).

The second option, that of assessing intensity through field survey, has the advantage of being able to assess the intensity accurately in any one locality, but it is much more difficult to judge whether the area walked over truly reflects the average intensity across the polygon as a whole, because only limited areas of a potentially large polygon can be seen at any one time.

To illustrate the problem, Figure 35 shows an area from the northern part of the windfarm development (NB 437561). Within the photo, plotted at the 1:10,000 scale used by the field surveyors for the LWP HSA survey (LWP 2004 EIS, Vol.7, Technical Report, para 4.1), it is not really possible to distinguish between gullies spaced at 10 m and 20 m intervals. Equally, in several of the polygons, the intensity of gullying varies considerably, thus hampering ground-based estimations.

Given the evident practical difficulties of mapping these (in effect) microtope patterns at the 1:10,000 scale used by the LWP survey team (a scale of 1:3,750 would have been far more appropriate), it is hardly surprising that the available evidence points to a high degree of variability on the ground within any given Erosion Class polygon. Not all ground in an Erosion Class 7 polygon consists of closely-spaced gullies with no vegetation recovery. Significant areas of relatively smooth ground can be seen in all Class 4 – 7 polgons. If these areas of non-eroded ground were to be excluded from their current Erosion Classes and instead added to Classes 1 – 3, the total for the non-eroded categories would probably increase substantially. This would in turn have the potential to alter significantly the perception given in the LWP EIS documents of the Lewis peatlands as wholly eroded. What this means is that the area totals given by the LWP EIS documents for each Erosion Class cannot be regarded as anything more than very rough estimates.

Table 9: Erosion Classes - definitions
Table of LWP Erosion Classes for Classes 4 – 7, based on information assembled from LWP 2004 EIS, Vol.7, Technical Report, Chapter 4, Table 2 and LWP 2004 EIS, Vol.7, Technical Report, Chapter 4.4. Yellow highlighting indicates key aspects discussed below.

Class	Original surface	Gullying pattern and intensity	NVC relationships
4	Heavy dissection, gullies every 20 m	Rectilinear and/or dendritic network, variable gully width and depth, vertical peat faces (haggs) very common.	M15c or M17b dominant on original surface, frequent *Racomitrium* hummocks, small amounts of M15c. Well-vegetated gully floors; M1 and/or M3 in gully floors which seem stable or might be re-vegetating.
5	Heavy dissection, gullies every 20 m	Rectilinear and/or dendritic network, variable gully width and depth, vertical peat faces (haggs) very common.	M15c or M17b dominant on original surface, frequent *Racomitrium* hummocks, small amounts of M15c. Little or no M1 and/or M3 in gully floors which generally lack vegetation and are clearly eroding.
6	Very heavy dissection into blocks or narrow lines, gullies every 10 m	Rectilinear network of gullies, often quite wide, variable depth, sometimes cut to underlying mineral soil.	Drier mire types (M15c and/or M17b), perhaps heath (H10b), dominant on upstanding blocks which are remnants of original peat surface. Vegetated gully floors; M1 and/or M3 in gully floors which seem stable or might be re-vegetating.
7	Very heavy dissection into blocks or narrow lines, gullies every 10 m	Rectilinear network of gullies, often quite wide, variable depth, sometimes (rarely) cut to underlying mineral soil.	Drier mire types (M15c and/or M17b), perhaps heath (H10b), dominant on upstanding blocks which are remnants of original peat surface. Little or no M1 and/or M3 in gully floors which generally lack vegetation and are clearly eroding.

The other main issue for the defined Erosion Classes concerns the distinction between Classes 5 and 7 as 'actively eroding' and Classes 4 and 6 as 're-vegetating'. The issue first emerged when examining the photographs of Erosion Classes presented in LWP 2004 EIS, Vol.7, Technical Report, Section 11, Appendix 2. The close-up photographs shown in LWP 2004 EIS, Vol.7, Technical Report, Section 11, Appendix 2, Figures A2i of Erosion Class 5 and A2m of Erosion Class 7, appear to show in both cases that the gullies are in fact substantially vegetated. This is in direct contrast with the description for Erosion Class 7 given in Table 9 above, that such areas "generally lack vegetation and are clearly eroding", and in other descriptions provided for this Erosion Class:

*"It is likely that there is **little or no active peat formation for most of Erosion Class 7** and there is usually erosion in gullies, with peat being transported from the polygon into adjacent ground or into the bog drainage system as suspended sediment and dissolved material. This evidence **suggests that Erosion Class 7 terrain is currently a carbon source**, not a carbon sink..."*

LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11C, para 10.

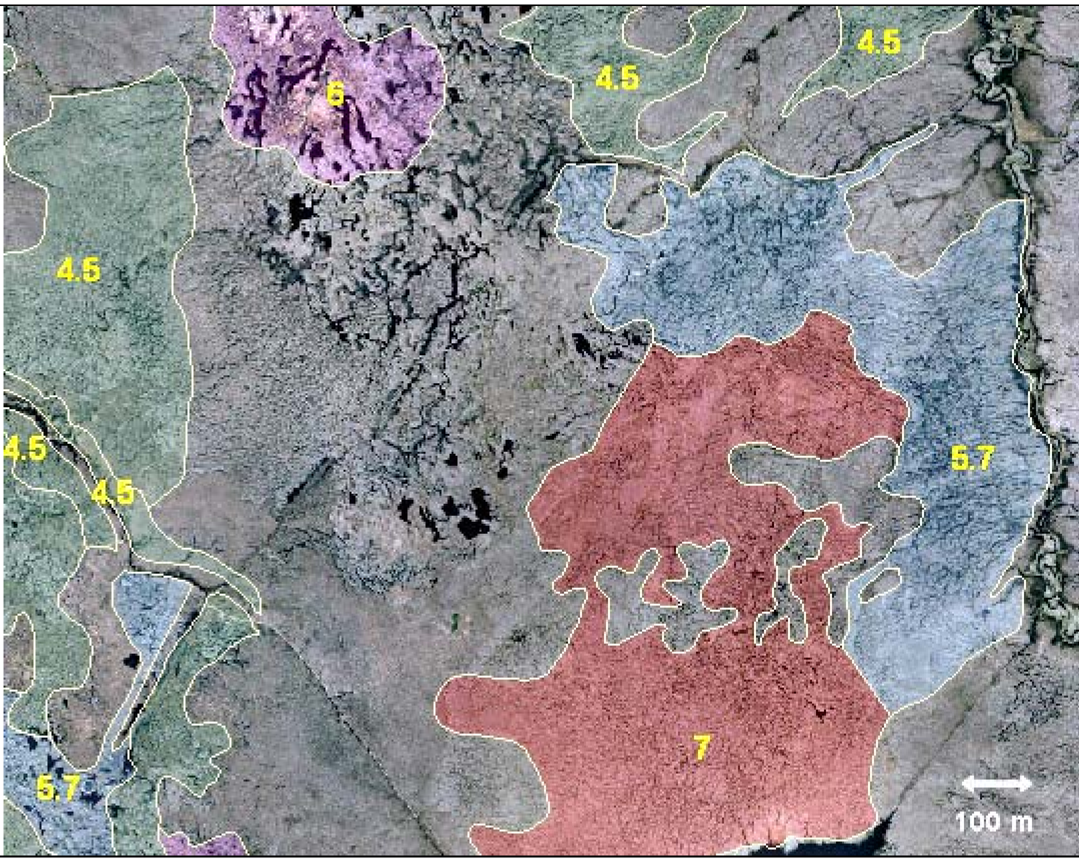


Figure 35. Gully density and ground variability within LWP Erosion Classes.
An area in the northern part of the LWP windfarm development (NB 437561), with LWP Peat Erosion Classes 4 – 7 plotted over an aerial photograph. Erosion Classes (and sub-classes) are indicated by yellow labels and colour shading: green = Class 4; blue = Class 5; purple = Class 6 and red = Class 7. The image is displayed at approximately 1:10,000 scale, *i.e.* the same as used by LWP field surveyors. Class 7 erosion is reported to have gullies every 10 m, while Erosion Class 4 has gullies every 20 m. It is evident that such distinctions cannot be made from this scale of photograph. Note, however, that within the area designated as Class 5.7 the intensity varies quite markedly, with some significant areas of relatively smooth ground. It appears, then, that intensity varies even within an Erosion Class.

Examination of a detailed aerial photograph covering an area classed as Erosion Class 7 by the HSA GIS dataset reveals that in fact there *are* signs of gullies dominated by bare peat, but this makes up only in a small portion of the ground classed as Erosion Class 7 within this polygon [Polygon SEQID 4767 from the LWP HSA GIS dataset] (see Figure 36). For the most part, it is evident that the gullies are well vegetated, with dense swards of common cotton grass (*Eriophorum angustifolium*) and probably significant areas of *Sphagnum* bog moss, based on what the UEL Peatland Research Unit found elsewhere in Erosion Classes 5 and 7 (see below).

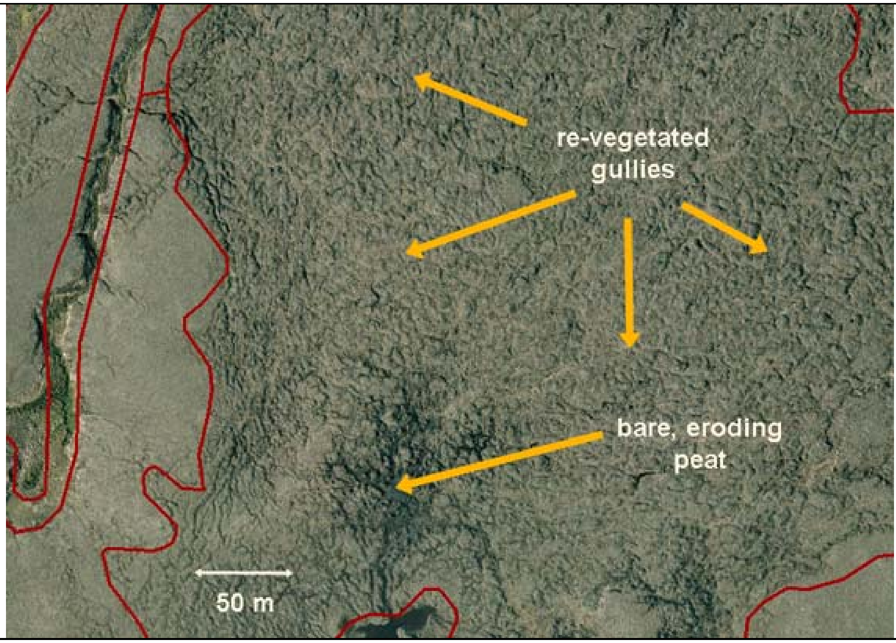
Clearly such evidence has great significance for the area calculations of eroding blanket bog in the Lewis peatlands. If much of the large polygon described above should in fact be classed as Erosion Class 6 rather than Erosion Class 7, then potentially the area of stable or re-generating bog is generally much more extensive than suggested by the figures presented in the LWP EIS documents. It also has significant implications for the extent of ground that might suffer negative impacts from the development. While a bare peat gully may not be so badly affected by a change in water regime or siltation rates, a vegetated gully certainly would be so affected.

Finally, when the UEL Peatland Research Unit undertook its own fieldwork on the Lewis peatlands in autumn 2006 and visited several localities mapped as part of the LWP HSA survey, various issues emerged. Some of these are dealt with in the next chapter of the present report, but those relevant to the immediate question of Erosion Class identification will be considered here (and see Figure 37):

- An area defined as Erosion Class 5 was visited (NB 352341: Polygon SEQID 3653) and found to have vigorous, *Sphagnum*-rich gullies throughout. Quadrat data were taken and are presented in Appendix 2 of the present report.
- An area defined as Erosion Class 6 was visited (NB 483583: Polygon SEQID 670) and found to be a large area of very low-relief percolation mire with no sign of gullying or any real damage of any kind, other than some traces of burning. The peat was 4.5 m deep, and the ground was extremely wet and soft. This is a relatively undamaged natural system, and should be classed as Erosion Class 1. Quadrat data and ground photos were taken and the quadrat data are presented in Appendix 2.

Both examples are significant for a number of reasons:

- both belong to Erosion Classes different from the ones they have been assigned;
- in both cases the correctly re-assigned class is of a higher conservation value than the originally-assigned class;
- if these errors are repeated elsewhere, it may have substantial implications for the assessment of overall habitat quality and potential impact assessment;
- a natural area of high conservation quality was completely mis-classified and appears to have gone unrecognised;
- this same natural area consists of very wet deep peat and thus has significant potential to be a problem for both construction and conservation impact.



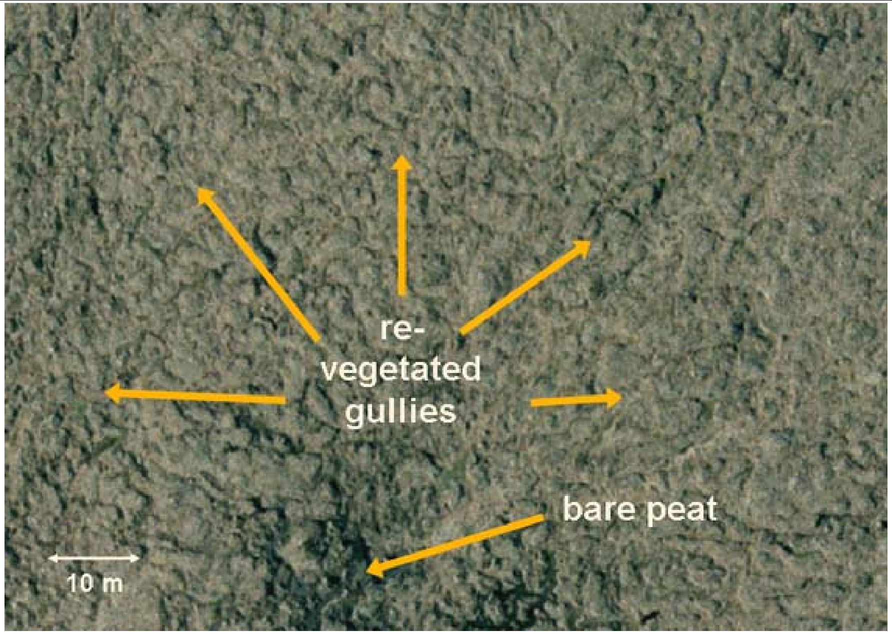
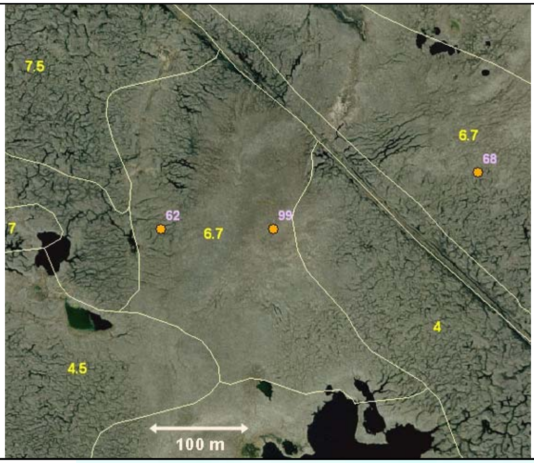
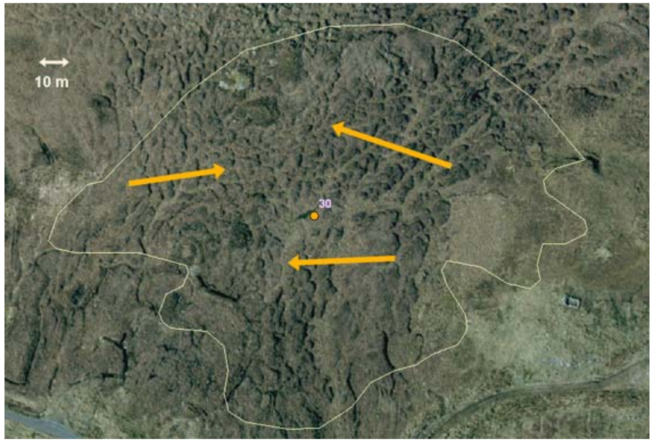


Figure 36. Revegetation of gullies within LWP Erosion Class 7.
Two views of an area in the northwestern part of the LWP development area, centred on NB 379443, which has been classed as Peat Erosion Class 7 within the LWP Habitat Survey Area GIS dataset. The main polygon so classed (bounded by the red line) is SEQID 4767 in the GIS dataset. It can be seen that there is a distinct area of bare peat erosion to the bottom-centre of the larger-view photograph (left), but closer examination of the major part of the area (right) reveals that almost all gullies are evidently well-vegetated. This does not tally with the description of Erosion Class 7 as generally lacking vegetation. It would suggest that much of this polygon should not have been classed as Erosion Class 7.





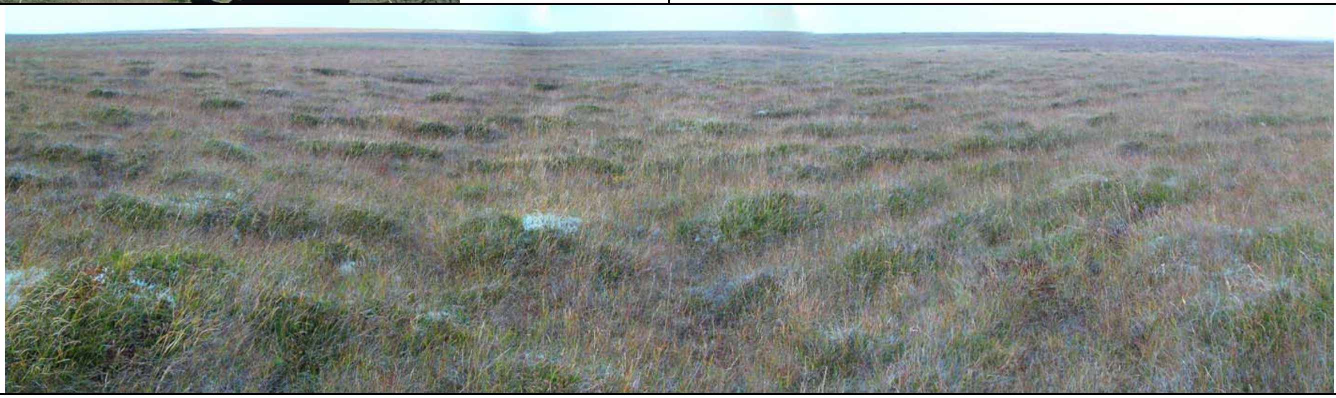


Figure 37. Examples of mis-match between LWP Erosion Class and condition on the ground.
Views of two sites in the LWP development area visited by the UEL Peatland Research Team in autumn 2006. **(Top left)**: Aerial photograph of percolation mire at NB 483583, forming the central smooth area in the photograph. It is assigned to Erosion Class 6.7, as can be seen from the yellow label. It should really be Erosion Class 1. Orange dots with mauve labels are locations of UEL quadrat data. **(Bottom)**: The same percolation mire seen in panorama from ground level. Note the low-relief patterning and absence of gullies. **(Top right)**: Area of eroded blanket bog at NB 352341, classed as Erosion Class 5. The gullies are full of vigorous bog vegetation (orange arrows), and the polygon should thus be re-classified as Erosion Class 4. UEL quadrat symbol as before.

5.2.5.3 Microtope patterns – 'bog pool classes'

Strangely enough, despite LWP's early decision to focus on erosion classes and ignore the JNCC peatland hierarchy, within the LWP 2004 EIS, Vol.7, Technical Report there is a brief account of a bog pool classification system. Apparently this classification system was used during the LWP HSA survey programme. It is mentioned just twice: firstly in the list of attributes to be attached to each polygon (LWP 2004 EIS, Vol.7, Technical Report, Appendix 1, Table A1.1), where a brief comment refers the reader to LWP 2004 EIS, Vol.7, Technical Report, Appendix 1, Table A1.2 : 'Bog Pool Classes'. Then LWP 2004 EIS, Vol.7, Technical Report, Appendix 1, Table A1.2 sets out a series of definitions for identifying different bog pool assemblages in just the way that might be done if a formal microtope assessment were being undertaken. The proposed classes are set out in Table 10 below.

Table 10: Bog pool classification
Definitions of 'bog pool classes', taken from LWP 2004 EIS, Vol.7, Technical Report, Appendix 1, Table A1.2

Class	Character
1	Small, shallow and well-vegetated oval depressions, rather randomly scattered or aligned mainly downslope and fed or interconnected by shallow rills, often without surface water after a moderate period without rain.
2	Moderate to large oval pools, quite deep, with patchy emergent aquatic vegetation and usually with a discontinuous cover of floating or submerged *Sphagnum*, developed as part of watershed or saddle mire mesotopes
3	Small to moderately-sized linear pools, variable depth, orientated at right angles to a clear slope, often interconnected, and often accompanied by hummocks and low ridges
4	Small, moderate and large pools of variable shape formed within large shallow depressions, often connected by water tracks with abundant *Narthecium ossifragum*, random distribution, sometimes with hummocks on intervening ground.

Data for this classification are indeed featured in the GIS attributes attached to each HSA polygon, but other than that, there is no further mention of this bog pool classification in any of the subsequent LWP EIS documents.

Examining the way in which this classification was mapped, it perhaps becomes clear why this is so. For example, areas of erosion gullies have, for example, in places been classed as 'linear pools' while in other areas the same category has been used for areas that have genuinely linear pools. This suggests that the field surveyors were not sufficiently familiar with the range of surface patterns commonly found on blanket mire systems to be able to apply this classification accurately and consistently. Some of the data associated with this classification seem fairly sensible, but not enough to make the results meaningful, perhaps explaining why this particular information set was not taken further.

If so, it is a great shame, because a valuable opportunity was missed here. By amalgamating the Peat Erosion Classes with Bog Pool Classes and then applying the resulting surface pattern classification in a sufficiently consistent way, it would have been possible to generate a set of information that would have given a very useful picture of the LWP EIS area at the microtope level.

The failure of this system is in some senses more worrying, however, because it raises questions about why the LWP field surveyors failed to recognise key features of the blanket bog habitat in a consistent way. While not the best classification of bog pool types, the categories in Table 10 above should not have caused undue problems for the field surveyors. It should thus have been possible to generate a useful, consistent dataset. The fact that the GIS data derived from the LWP HSA survey show such erratic results suggests that there may have been some unresolved issues here.

This is an issue of some concern, particularly as it also appears to have a bearing on the assessment of impacts, as will be examined in Chapter 8.

5.2.5.4 Nanotopes – the building blocks of a mire

The most widely-known characteristic of peat bogs is that they have a surface dominated by 'hummocks and hollows'. Indeed it was the supposed relationship between these two features that gave rise to the popular theory of the 'hummock-hollow regeneration cycle' which was widely cited as a classic model of cyclical ecosystem processes in ecological textbooks until very recent times. This model was first assembled, perhaps somewhat erroneously, from the ideas and comments of Swedish mire ecologist Hugo Osvald (Osvald, 1925, 1949) by Arthur Tansley and Harry Godwin. These two early luminaries of ecology then went on successfully to promulgate this model throughout the English-speaking mire community (*e.g.* Godwin and Conway, 1939; Tansley 1939).

The fact that the theory was wrong had remarkably little effect on its popularity. Even quite recent publications about mires still refer to the 'hummock-hollow cycle', but it was the painstaking work of Barber (1981), referred to in Section 5.2.4 above that eventually demonstrated the generally false basis of the theory and revealed instead the value of 'hummocks and hollows' as indicators of climate change.

Sjörs (1948) meanwhile, had earlier identified a range of microtopes and nanotopes for Swedish mires, and described the close relationship that existed between individual nanotope 'levels' (hummock, lawn, carpet, hollow) and the mire water table. Ivanov (1981) expressed very clearly the extremely small vertical scale that separated the vegetation of one such 'level' from that of another level:

> *"The maximum differences in mean long-term [water] levels which does not lead to a change in the quantity or floristic composition of mire plant communities is very small. For several varieties of moss cover it is less than 4-5 cm."*
>
> *Ivanov (1981)*

While this is expressed from the perspective of changing water tables and the consequent effect on mire vegetation, the phenomenon can be looked at the other way round; the very close relationship that exists between bog water-table and fine-scale vegetation patterns means that such vegetation patterns can be used as biological indicators of the bog water-table and its behaviour. Thus the *Guidelines for Selection of Biological SSSIs* (NCC, 1989) gives details of the relationship established between nanotope ('microform') type, vegetation type and water table position for British bog systems (Table 20 : NCC, 1989). Nanotopes (and their associated vegetation patterns), in other words, can be used as a guide to bog condition and the general behaviour of the water table in any given microtope.

The LWP EIS documents consider the position to be otherwise:

> *"However, no detailed information is available on the specific hydraulic charcteristics of the Lewis Peatlands,* ***particularly in regard to peat water table level*** *and other information that would assist in assessing the possible effects of both passive and active dewatering."*
>
> *LWP 2004 EIS, Vol.6, Appendix 10C, para 32.*

Intelligent use of the nanotope 'zone' system (rather than the Hydrological Zone system) could have provided much valuable information about these issues by using the nanotopes and vegetation as sensitive biological indicators. The fact that nanotope 'zones', as defined in Lindsay, Riggall and Burd (1985), NCC (1989) and Lindsay (1995), are not used by the LWP HSA survey means that a great deal of vital information is not then gathered for the LWP EIA. Haggs and gullies, both part of the wider nanotope catalogue, are generally the only nanotope elements recorded as present by the LWP EIS documents, and are in any case recorded using the rather simplistic and generalised approach of the LWP-defined Erosion Classes. This in turn has important consequences for the collection, classification and evaluation of vegetation data. These consequences are examined in the next chapter of the present report.

5.2.6 Hydrological Zones

In the absence of such descriptive tools as macrotope and mesotope (or rather, having rejected these as the tools of choice), the LWP EIA evidently found itself lacking a descriptive level. It needed one that was larger than an Erosion Class, but was not a catchment because it was clear that most watershed peatland systems would be fragmented by catchment boundaries.

The LWP EIA consequently devised four categories of landform which are larger than Erosion Classes but generally smaller than catchments. The landform units are described as being characterised by, and differentiated on the basis of, their topography and dominant hydrological features and processes (LWP 2004 EIS, Vol.6, Appendix 10D, para 81). So far, this sounds remarkably like the criteria used to define mesotopes.

However, subsequent detailed definitions of these four categories suggest that the peatland habitat has played a relatively minor role in their origins. Thus the definition of the first category – 'HZ 1 : Mature Stream Network' – is as follows:

> *"Well-defined, smooth and continuous* ***river systems and tributaries*** *with only gentle riffles and no rapids or waterfalls. The* ***river channel is obvious and channel migration, if occurring, is restricted to a well-defined floodplain****. Surface flow characteristics are* ***typically gravel bedded larger streams*** *at the base of valleys. High reaches of rivers can also come under this*

classification if the gradients are low. The larger of these systems are ***important salmonid fisheries as discharge and in-channel morphology*** *are sufficient to have created a variety of habitats and holding grounds."*

LWP 2004 EIS, Vol.6, Appendix 10D, para 85

There is no mention of peat at all in this definition, although the zone covers almost 25% of the total 'catchment area' involved with the LWP windfarm proposal (LWP 2004 EIS, Vol.6, Appendix 10D, Table 10D.6).

Hydrological Zone 2 : 'Energetic Stream Network' is defined thus:

*"****River system and its tributaries are well defined****, often formed in deep gullies.* ***Waterfalls and rapids dominate****, interspersed by deep pools. The* ***river channel is prone to significant changes*** *and will often split around groups of rocks or small islands. Surface flows* ***include incised deep fast flowing peat-bedded channels*** *often partially grown over. This type of environment is dominant in several of the* ***smaller catchments where large gradients provide the energy for fast gully flow****. Where deep erosion is occurring land stability issues may be relevant."*

There is at least a brief mention of peat here, and reference to 'channels' that lie in the peat - presumably a reference to areas of peat erosion. However, the definition also contains much that is of little of relevance to the peatland habitat. HZ 2 occupies 12% of the total 'catchment area', which is a small proportion of the total area if this HZ is intended as the main zone embracing the widespread gully erosion claimed to dominate the development area. Mention of rivers, waterfalls and rapids in the definition above suggests that the zone in fact has a rather different, non-peat focus.

Thus more than 1/3 of the total study area has been accounted for by two zones that appear to offer relatively little in terms of insight, understanding or functional relevance to the habitat that covers around 85% of the study area. One point of interest here is the acknowledgement that peat-bedded channels may become partially grown over. This point will be re-visited later in the present chapter.

The third zone, Hydrological Zone 3 : 'Topographic Loch or Lochan Network' has the following definition:

"In this environment the ***predominant hydrological features are lakes lochs, either linked in series by a series of small streams or independent of any obvious inflow or outlet****, particularly during dry periods. These lakes are features* ***set within the topography in natural depressions in the underlying geology****, and therefore adjacent lakes can be at significantly different elevations and flow between them can be energetic. These lakes* ***often exist in bowl shaped depressions in the peat*** *where the peat has continued to be built up around the banks. Breaks in the bowl exist at inflows and outflows. The capacity of the depression in which the lake sits is therefore much greater than the lake itself. This property means significant*

storage is possible within the lake system, which would act to attenuate flooding."

As these lakes are defined as lying on the mineral sub-soil rather than sitting in the peat in the manner of typical dubh lochain or bog pools, this zone appears to be more concerned with features on mineral soils than with the core issues of the blanket mire environment. Occupying almost 17% of the total catchment area, it brings the total area of hydrological zone lacking explicit peatland focus to 53% of the total catchment area. In other words, more than half of the hydrological zonation devised appears to have relatively little peatland focus, despite the fact that, by LWP's own admission, somewhere between 80% and 90% of the development area is dominated by peatland habitat.

The final zone, Hydrological Zone 4 : 'Perched Pool Network', has the following rather more extended definition:

> *"The dominant features in this environment are* ***small pools sometimes linked in series, but often found apparently independent of other water features****. They are* ***perched on top of the peat*** *and therefore the bed of the pools and lakes lochs are not solid. This environment forms in flat areas where drainage is difficult. The surrounding area is typically saturated even away from pools making access difficult.* ***Perched peat networks are generally located on high plateaux*** *where large lochs cannot form due to the topography. Because of their location such zones are* ***often found at the headwater of most rivers and streams****. Where erosion across watersheds has cut into pool complexes, many* ***pools can become completely drained****, exposing flat expanses of bare peat. However, where pool complexes are affected this way* ***it is common to find many small pools which are apparently unaffected, retaining their normal water table despite drainage of pools nearby*** *(Goode and Lindsay, 1979)."*

Hydrological Zone 4 is clearly focused on the peatland environment, unlike the other three Hydrological Zones, but its focus is explicitly on the areas of high plateaux, where watershed mire dominates. What of the remaining much larger expanses of blanket mire habitat that do not lie on high plateaux and which lack the more evident forms of patterning? This definition provides little illumination here.

Indeed the zones as a whole represent a set of landform categories that are nebulous and ill-defined both in terms of their basic character and their boundary conditions – where does an 'energetic stream network' become a 'mature stream network' or a 'perched pool network'?

Such questions become more relevant and pressing when the actual pattern of hydrological zone boundaries is examined against the backdrop of the proposed windfarm landscape. It would seem reasonable to expect that a Hydrological Zone named 'Mature Stream Network' would be fairly tightly associated with main stream networks, according to the definition provided above. This is not the case, which raises major questions about the definition, character and utility of these zones. Indeed the definition of Hydrological Zone boundaries appears to be based on a process that follows no obvious logic – this difficulty is explored in some detail below.

5.2.6.1 Hydrological Zones and landform

The spatial distribution of Hydrological Zones is displayed in LWP 2006 EIS, Vol.3, Chapter 10, Figs.10.5a-d. From these maps it can be seen, for example, that Hydrological Zone 1 extends into the landscape a very considerable distance from the course of the 'mature streams' that supposedly define the zone. For much of the area covered by HZ 1 there appears to be very little relationship with a 'mature stream network'. Indeed Figure 38 reveals that HZ 1 not only extends out across substantial parts of the blanket mire landscape, it even reaches to the highest parts of the watershed, dominating the summit and sharing a proportion of this watershed with the more logical HZ 4 ('perched pool network').

No explanation is provided about the detailed basis of hydrological zone mapping other than the rather vague, indeed rather intriguing, statement that these zones were mapped:

> *"... on the basis of topography, surface and sub-surface moisture conditions and the nature of the dominant hydrological features and processes."*
>
> *(LWP 2004 EIS, Vol.6, Appendix 10D, para 81)*
> *(LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 26)*

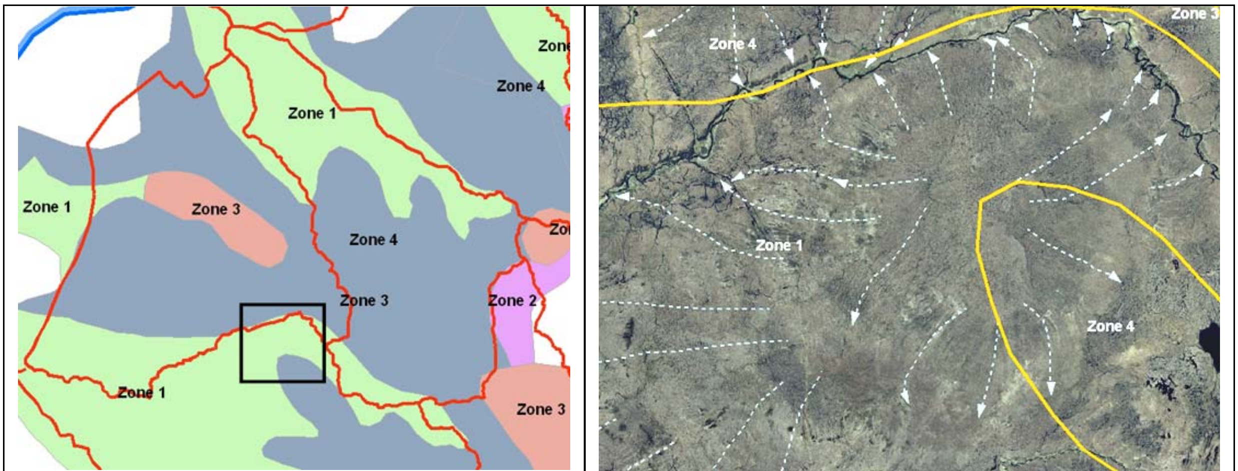


Figure 38. Mis-match between LWP Hydrological Zones and ground conditions.
Extent of different Hydrological Zones within the north-central part of the LWP development. **(Left)**: General map of this area, showing the pattern of Hydrological Zones and, in particular, the extent of Hydrological Zone 1. Red lines are macrotope boundaries and thus tend to indicate main rivers and streamcourses. Note the considerable distances over which HZ 1 extends beyond the line of such streamcourses. HZ 1 = pale green; HZ 2 = mauve; HZ 3 = peach; HZ 4 = blue. Double blue line in top left = coastline. Black box indicates boundary of close-up aerial view. **(Right)**: Close-up aerial view centred on NB 390491. Flow lines are shown as pale blue dashed arrows. HZ boundaries (orange lines) show that HZ 1 extends all the way to a watershed summit where it forms a border with HZ 4, while a very considerable expanse of general blanket bog ground is also included within HZ 1 ('Mature Stream Network').

The present authors are left wondering precisely what is meant by the phrases "surface and sub-surface moisture conditions" and "dominant hydrological hydrological features and processes"? Does it mean that sub-surface moisture conditions have in some way been measured? If so, how frequently, at what depths, and how exactly where the measurements taken? Do "surface moisture conditions" mean that flow lines were constructed? If so, how were they used to define HZ boundaries, and why could they not instead have been used to define mesotopes? And what exactly are the "dominant hydrological features" that result in such large expanses of HZ 1 at considerable distances from any stream line? Certainly the remarkable range of implied datasets would represent a scientific resource of considerable value for the understanding of blanket mire hydrological processes.

The answer to these questions may, alas, be somewhat more prosaic and much less valuable. The most recent map of Hydrological Zones (LWP 2006 EIS, Vol.3, Chapter 10, Figs.10.5a-d) extends right across northern Lewis and the Lewis Peatlands SAC. Given that detailed survey of the area by LWP has only been undertaken within the HSA, and explicitly excludes the SAC, this would suggest that delineation of Hydrological Zones has not in fact been based on field data. The alternative explanation is that maps and aerial photographs have been used, but if they have, then how, for example, have "sub-surface moisture conditions" been determined?

Delineation and definition of macrotopes and mesotopes is possible using maps and aerial photographs, and is achievable using the transparent methodologies set out in the present report. Consequently any fairly competent person with some knowledge of peatland ecosystems should be able to generate a reasonably repeatable set of macrotopes and mesotopes for any given area. It is designed to be a robust yet fundamentally informative system, and as such has formed the basis of much large-scale (and fine-scale) mapping of peatland resources in, for example, the former USSR (Ivanov 1981).

In contrast, it is difficult to see how the definition and delineation of the hydrological zone system used in the LWP EIS documents is to any degree similarly repeatable, robust or informative. Without further explanation the system is unusable by others and to a considerable extent meaningless as a basis for assessing habitat condition and potential impact effects. Yet even *with* such further explanation it would remain a fundamentally un-informative system in terms of the insights and understanding it is able to provide about habitat type, condition and susceptibility to impact. This is because the basis of the hydrological zone system is essentially based on *water bodies* rather than the dominant habitat type within the development area – namely the *peatland* ecosystems which (as if it needed re-stating) cover somewhere between 80% and 90% of the ground involved.

5.2.6.2 Hydrological Zones and mesotope types

The definition and delineation of Hydrological Zones is apparently based, as discussed above, on features such as topography, surface moisture conditions and hydrological processes. As such, it would seem reasonable to expect some correspondence between hydrological zone types and mesotopes. Indeed LWP 2004 EIS, Vol.6, Appendix 10D, para 104 states that:

> *"The classification of Hydrological Zones for the purposes of this assessment was predominantly based on topographic-hydrological features. Nevertheless, because these factors are interrelated with the morphological development of the blanket bog, a good correlation between classification systems*

[Hydrological Zones and hydro-morphological system] can be observed."

LWP 2004 EIS, Vol.6, Appendix 10D, para 104

To see just how good this correlation is, it is instructive to overlay the map of Hydrological Zones onto examples of the mesotopes described and displayed in earlier sections of the present chapter.

Figure 39 illustrates the overlapping of mesotopes and Hydrological Zones for the more northerly of the macrotopes introduced in Figure 29. From this it is immediately evident that examples of watershed mire mesotopes are found in every hydrological zone. Meanwhile saddle mires are found in three of the four zones and spur mires in two of the zones. In other words, there is a very poor correlation between hydrological zone and mesotope type. Given the basis on which Hydrological Zones are reported by LWP to have been defined, this is a somewhat surprising result from this particular macrotope.

Assuming for the moment that such a poor match between the two systems can be explained by some peculiarity of this particular macrotope, the link with our other mesotope-macrotope assemblage may prove more fruitful. This is the more southerly macrotope from Figure 29, and lies wholly within the HSA. It may thus more completely reflect the type of ground for which the Hydrological Zones were originally defined.

Figure 40 shows the resulting overlap between mesotope and hydrological zone in this more southerly macrotope. Once again, there is no evident link between mesotope and hydrological zone. The Hydrological Zones cut across mesotopes and appear capable of embracing any or all of the mesotope types. There is no evidence from this macrotope that any meaningful link exists between hydrological zone and mesotope type. Indeed it is difficult to see that the Hydrological Zones provide any useful degree of insight or understanding about the peatland units involved.

Turning finally to the linkage between hydrological zone and Erosion Classes, Figure **41** shows the overlap between hydrological zone and, in effect, microtope. Once again there appears to be little to link the two systems despite the following observation:

"Figures 10.5 and 10.6 ***map the Hydrological Zones and the Peat Erosion Classes****. These two maps,* ***although created by different methods and for different purposes should be complementary****. The Hydrological Zones correspond to some degree to the peat Erosion Classes because* ***the slope and hydrology, being the major transportation mechanism, is crucial in determining differing types and degrees of erosion****. This relationship is shown in Table 10D.8."*

LWP 2004 EIS, Vol.6, Appendix 10D, para 112

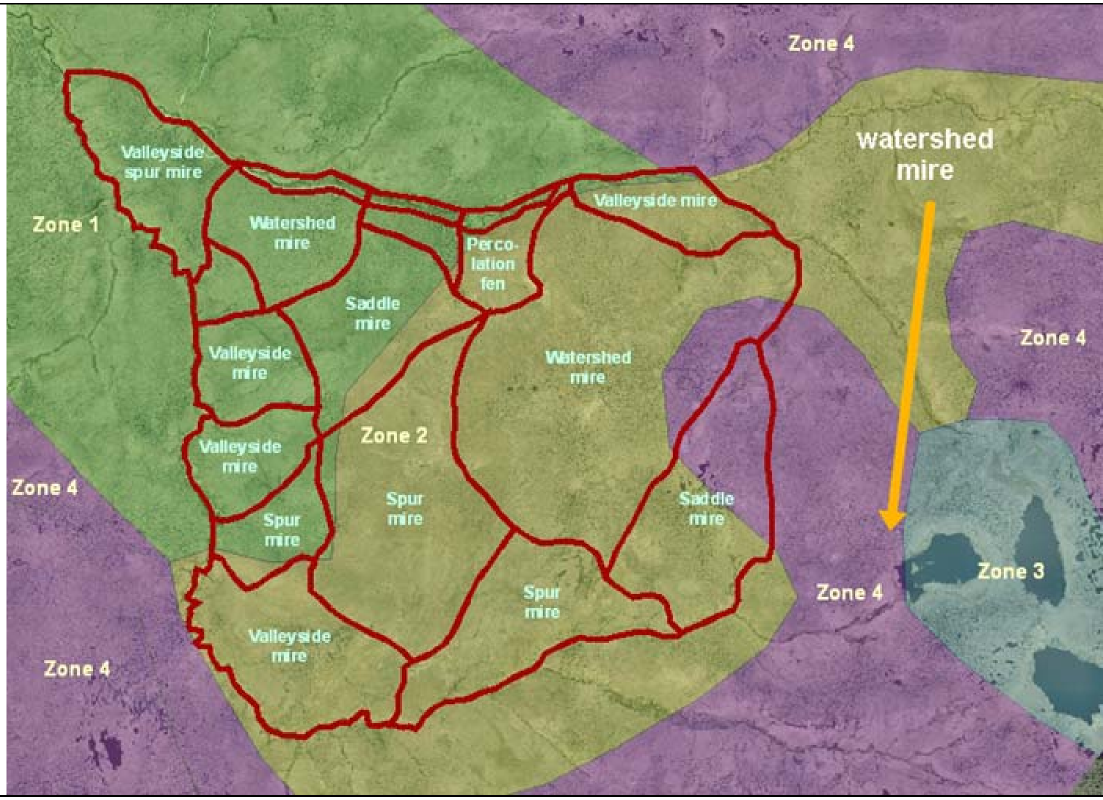
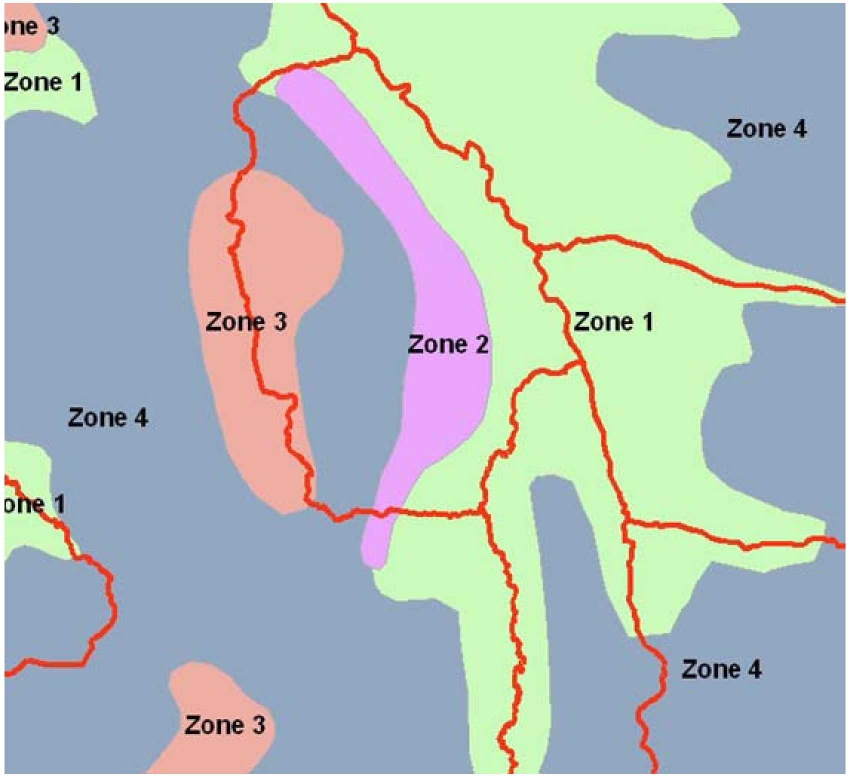


Figure 39. Mis-match between LWP Hydrological Zones and mesotopes – northern demonstration macrotope.
Mesotope boundaries (dark red) and mesotope types (pale blue labels) for the more northerly macrotope shown in Figure 29. Also displayed are the Hydrological Zones for the area: HZ 1 = green; HZ 2 = yellow; HZ 3 = pale blue; HZ 4 = purple. It can be seen that there are two watershed mires indicated within the macrotope boundary, each in a different hydrological zone, while a third watershed mire is indicated (orange arrow) as lying just outside the macrotope, and straddling Hydrological Zones 3 and 4.



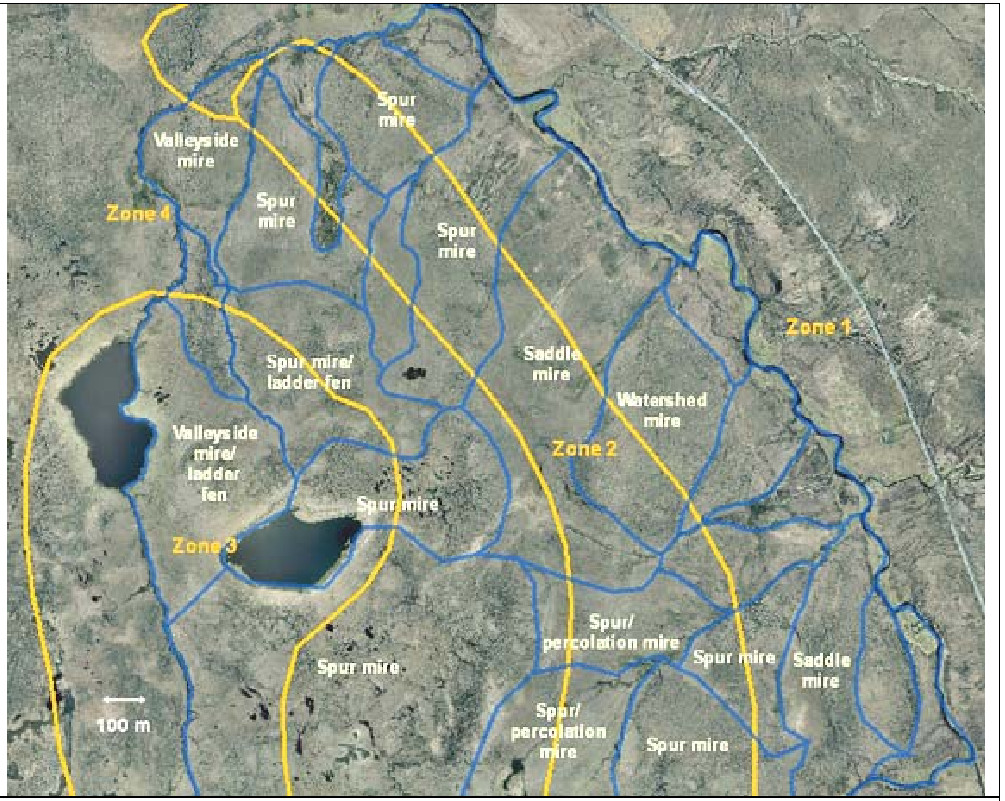


Figure 40. Mis-match between LWP Hydrological Zones and mesotopes – southern demonstration mactrotope.
Extent of different Hydrological Zones within the area of the more southerly macrotope shown in Figure 29. **(Left)**: General map of this area centred on the macrotope, showing the pattern of Hydrological Zones and, in particular, the extent of Hydrological Zone 1. Red lines are macrotope boundaries and thus tend to indicate main rivers and streamcourses. Note the considerable distances over which HZ 1 extends beyond the line of such streamcourses. HZ 1 = pale green; HZ 2 = mauve; HZ 3 = peach; HZ 4 = blue. **(Right)**: Close-up aerial view of northern part of the macrotope. Mesotope boundaries are displayed in dark blue, while mesotope types are shown as cream labels. Hydrological zone boundaries are shown as orange lines.

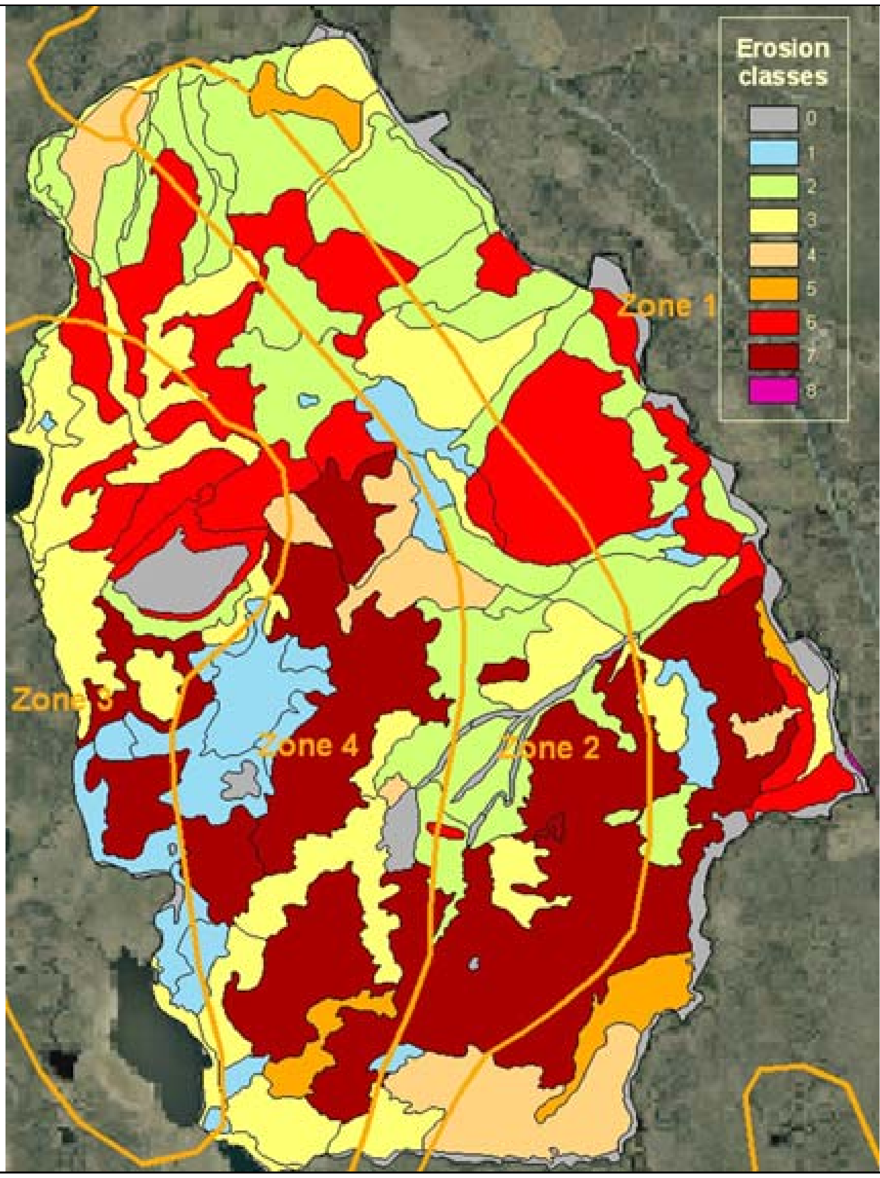


Figure 41. Mis-match between Hydrological Zone and Erosion Class. Extent of different Hydrological Zones within the area of the more southerly macrotope shown in Figure 29 combined with Erosion Classes identified by the LWP HSA survey. Hydrological zone boundaries are shown as orange lines. It can be seen that clear gradients exist in the distribution pattern of Erosion Classes, but there is a poor correspondence with the distribution of Hydrological Zones. Every Erosion Class occurs in every hydrological zone.

In fact LWP Table 10D.8 shows a fairly poor relationship between the two categories – Erosion Class and Hydrological Zone - very much reflecting the picture seen in Figure 41. There *is* a very obvious series of spatial trends in the distribution of erosion/microtope types, but these trends are not at all reflected in the distribution of Hydrological Zones. Every Erosion Class is found in every Hydrological Zone. Little appears to be gained by putting these two datasets together.

The fact is, Hydrological Zones do not really correspond to any other form of habitat and landscape classification. They do not correspond with catchments because some of the zones are, in effect, partial catchments while other zones are quite the inverse, being more like partial macrotopes. Hydrological Zones were created because there was a perceived need:

> *"...to identify potential* ***sensitivities at a smaller than catchment scale*** *to the different pressures which are likely to be experienced during the construction and operation of the wind farm,* ***primarily those which might cause erosion and hydrological disturbance to the integrity of the blanket bog****."*
>
> *(LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 65)*

However, because definition of the zones is largely water-body oriented rather than peatland-focused, their correspondence with identifiable bog types is so poor that they provide little helpful information about potential "erosion and hydrological disturbance to the integrity of the blanket bog". Hydrological Zones are not catchments, nor macrotopes, nor mesotopes, nor do they show any relationship between any of these three well-defined landscape and peatland entities.

In mentioning the need for a class of objects that can contribute to an assessment of erosion risk, LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 65 highlights the need to provide a linking unit between the scale of catchment and Erosion Class. However, as is obvious from Figure 41 and LWP 2004 EIS, Vol.6, Appendix 10D. Table10D.8, the link between Erosion Class and Hydrological Zone is very weak.

Despite this, the one area where the LWP EIS documents themselves make use of the linkage (however weak) between Erosion Class and Hydrological Zone is in identifying Hydrological Zone 2 as being particularly at risk from erosion. This judgement about Hydrological Zone 2 is neither discussed nor demonstrated; it is merely stated that the zones were used along with a number of other criteria.

Consequently there is very little solid evidence in any of the LWP EIS documents that clearly demonstrates the functional utility of Hydrological Zones. The zones are indeed used to define degrees of risk, but this is done without any actual link being demonstrated between zone character and risk factor. One is left wondering "What exactly is the *purpose* of the Hydrological Zones?"

Perhaps the most telling response to this question is the observation that there is <u>not a *single* reference</u> to Hydrological Zones in any of the various 2004, 2005, and 2006 LWP EIS documents concerned with habitat description and assessment. This says much about a descriptive system supposedly devised to:

> *"...****identify potential sensitivities*** *at a smaller than catchment scale to the different pressures which ... might cause erosion and hydrological* ***disturbance to the integrity of the blanket bog****."*
>
> *(LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 65)*

If even LWP's own author(s) for the habitats chapters can find no use for Hydrological Zones, it is difficult to see why anyone else should find them useful as a tool for understanding the nature of the ground involved, the relationship between that and the development proposal, and the possible impacts that may result. The range of habitats found within the development area forms the core of the EIA focus for this development, yet LWP's own EIS documents then make clear that the identified Hydrological Zones contribute nothing to this core issue.

It is thus reasonable to question whether Hydrological Zones are able to provide any meaningful guidance in relation to risk assessment, as set out so extensively and with such detail in, for example, LWP 2006 EIS, Vol.2, Sect.2, Chap.10. Given that many of the risk issues are directly related to condition of the associated habitat, the quite striking lack of endorsement for (or at least complete failure to find a use for) Hydrological Zones by the author of the LWP habitats chapters brings into question the whole basis of the risk-assessment process set out in LWP 2006 EIS, Vol.2, Sect.2, Chap.10. This is an issue that will be re-examined in later chapters of the present report.

5.2.7 Mesotopes – the missing link

5.2.7.1 Gap analysis – highlighting what is missing

It is clear that an EIA of the LWP windfarm development area needs more than just the small-scale units of Erosion Class, or microtope, to provide a meaningful description and assessment of the ground associated with 141 km of roads and other infrastructure. It is also clear, and recognised by LWP, that catchments are not the appropriate entity for this larger unit of description. But if Hydrological Zones are of little functional value, what else might then be used?

Macrotopes provide distinct, largely-autonomous entities, but, like catchments, they are rather too large and heterogeneous to be of value in defining the specifics of possible impact, or in helping to design avoidance strategies as part of the development proposal. Looking at the peatland hydrological hierarchy and the equivalence of systems adopted by the LWP EIS documents, set out in Table 11, we are led logically back to the mesotope as the unit that sits most usefully between the concept of macrotope/catchment (they being mirror images of each other) and the small scale of the erosion pattern/pool class, or microtope.

One point brought home very strongly by Table 11 is that the LWP EIS documents really do have major gaps in the information they provide. There is no information presented at the 'mire unit' level, for example, which in effect means that the LWP EIS becomes blind to such features.

There is also clearly another gap at the nanotope level. Given that nanotopes represents such small-scale features - namely individual examples of hummocks, haggs, ridges, hollows and pools - it might be concluded that such features have little part to play in the impact assessment of an area stretching across more than 140 km of the landscape.

Such small-scale features might seem trivial in such a context. In fact such a conclusion would be wrong. The next chapter of the present report explores the very significant consequences resulting from an absence of precisely this level of information within the LWP EIS documents.

Table 11: Peatland hierarchy and LWP equivalents
Peatland hydrological hierarchy and the closest equivalent descriptive system used by the LWP EIS documents.

Hierarchical level	LWP usage
Macrotope **[linked complex of mire units]**	Catchment (inverse) and 'Hydrological Zone' [very poor equivalence]
Mesotope **[mire unit]**	Mentioned, but not used
Microtope **[linked complex of small-scale structural elements]**	Erosion Class [good equivalence, but incomplete]
Nanotope **[small-scale structural element]**	Mentioned, but not used
Vegetation	National Vegetation Classification (NVC)

5.2.7.2 Mesotope character – putting the small pieces together

Having already considered mesotopes as individual components, or panel-groups, on a large family macrotope camping tent, there is one final stage in the analogy that we can pursue. For this analogy to work, the tent must be both transported to the tropical rainforest and transformed onto a bushcraft structure worthy of Ray Mears. Our tent can retain the same shape as before, but now the frame is made from woven branches and lianas. The critical difference is that the canvas is now made from various leaves taken from the trees and bushes growing in the jungle.

Anyone who has watched the construction of a bushcraft shelter made from materials to hand knows that the key to making the shelter rainproof lies in the selection and correct positioning of the leaves that will cover the shelter. The leaves must be neither too small (otherwise they do not have the strength to resist the rain), nor too large (otherwise they cannot follow the shape of the shelter and therefore cannot be shaped into a rainproof design). Having selected the correct size-range of leaves, these are then each notched and hung on the frame so that they overlap facing downwards like lizard scales. Those leaves on the steep sides of the shelter can be relatively small because they do not experience the full force of the rain. Those on the domed or sloping roof must be larger and stronger precisely because they experience the full force of the rain. Indeed it is possible to place a few oversized leaves on the crown, or ridge, of the shelter as added protection.

Thus, by looking at the shape and arrangement of the leaves on any part of the structure, it would be possible to say whether you were looking at the walls, roof or ridge, and you would be able to determine which way the rainwater is going to flow. Precisely the same principles apply to our peatland systems, even to the extent of being able to determine direction of water flow.

The final completed shelter is equivqalent to the entire, independent entity of the macrotope. Other adjacent shelters built by other members of our village would represent other, largely independent macrotopes. The individual ‘panels’ of the shelter would be the mesotopes, which combine to create the macrotope. The panels (mesotopes) on our shelter each have a particular design of leaves, with perhaps a slightly different shape of leaf along the edges where one panel ends and another begins, thereby ensuring a rainproof joint between panels. The leaf patterns on the panels represent the microtope patterns, which not only have a characteristic repeating motif just like the leaves, but this motif also indicates the direction of surface-water flow, as the leaf pattern does on our shelter.

This microtope pattern can also give clues as to the nature of the mesotope as a whole. In the case of our shelter, the leaf pattern gives clues about the shape of the shelter panel - whether the panel (mesotope) comes from the roof or the wall, for example. For the mesotope, the microtope pattern gives landform clues as to whether the mesotope is a bog or a fen, a watershed mire or a valleyside mire.

Thus a zone of rounded pools within a mesotope will generally indicate an area of relatively deep peat lying on the level crown of a watershed, whereas a zone of more linear, arcuate hollows and ridges will indicate a gentle slope, with the downslope direction being at right angles to the arcuate lines of pools and ridges. Often, patterns become much more muted, or even reduced to a featureless surface, on areas of thinner peat.

The advantage of this relationship between surface design and functional character is that much of this can be identified from high-quality aerial photographs. It is even possible, where the patterns are sufficiently large, to do so from satellite imagery. Consequently it is possible to produce tentative description of a peatland site prior to visiting it in the field. It is even possible – indeed is a practical necessity in vast peat-rich regions such as Canada and Russia (National Wetland Working Group, 1988; Ivanov 1981) – to generate peatland ecosystem maps of whole areas based on these surface designs, then test the tentative ecological descriptions by visiting only a few sample areas.

The purpose of this somewhat extended discourse on jungle shelters is to emphasise that even large areas of quite complex and extensive peatland habitat can be surveyed and assessed relatively easily from a desk – at least to a tentative level – provided there is access to good-quality aerial photographs. Such photographs should be around 1:5,000 scale if most microtope patterns are to be detected, but scales up to 1:25,000 can still give a picture of the larger pattern types. Ideally the photographs would consist of stereo-pairs so that the 3-D shape of the landscape can be seen, but contour maps will often do just as well (usually at scales of between 1:25,000 and 1:10,000 for surveying British peatlands). Indeed recent advances in computing now mean that the easiest source of 3-D terrain information is a digital terrain model (DTM) which can be manipulated using a geographic information system (GIS). Obviously the other thing required is a certain amount of peatland expertise and a familiarity with aerial-photo interpretation.

Thus, armed with a set of aerial photographs, a DTM, some peatland expertise and an understanding of aerial photo interpretation, it is relatively easy to produce a remarkably detailed map of the peatland habitats that may be affected by the proposed LWP windfarm development. The basic working units of this map would be mesotopes, characterised by their microtopes, with tentative descriptions of nanotopes and even vegetation for each mesotope. Meanwhile the wider hydrological linkages would be brought together as macrotopes. This map would then be used to guide field survey, and would ultimately form the integrated heart of all construction planning and impact evaluation, whether for bog vegetation, peat stability, salmonid populations, dunlin breeding pairs, or landscape evaluation.

Unfortunately, this was not done – at least not by Lewis Wind Power. There is instead a rather revealing comment:

> *"However, the nature of the peat hydraulic processes within the Lewis environment are less well understood ...* ***It is unclear how useful the mesotope classification would be to future hydrological/hydraulic investigations****; however, it will provide a useful basis for more detailed site investigations before the commencement of each of the construction phases."*
>
> *LWP 2004 EIS, Vol.3, Chapter 10, para 170*

After reading the above sections, it should be very clear that it would have been better to use the mesotope classification system at a much earlier stage than just prior to "the commencement of each of the construction phases". By that time, it is far too late in the planning and decision-making process.

5.2.7.3 The missing mesotopes – ladder fens and the UEL Lewis peatland survey

As will be obvious from the information already provided in this and previous chapters of the present report, the University of East London (UEL) Peatland Research Unit has undertaken a significant proportion of the work necessary to produce the kind of integrated, peatland-focused map described above. Recent survey (autumn 2006) has even provided the opportunity for a valuable range of ground-truth sampling which has confirmed, or in some cases led to a re-assessment of, tentative descriptive and functional categories.

What has emerged from this work in relation to comparisons with the information presented by the LWP EIS documents, is perhaps best illustrated by the peatland mesotope type known as 'ladder fens'.

Ladder fens represent a sub-type within the larger group of fens known world-wide as 'patterned fen', which are themselves a very distinctive form of 'percolation fen'. In percolation fens, water typically emerges as a spring, then percolates through the upper layers of the peat mass, rather than flowing over the peat surface. This is the '*Durchströmungsmoore*' of Steiner (1992, 2005) and Joosten and Clarke (2002). Patterned fen peatlands are found on every continent except the Antarctic landmass. They are particularly extensive in, but by no means exclusive to, circumboreal regions. In Canada they are known as 'string mires' (National Wetland Working Group, 1988) while in Finland the term 'aapa mire' is applied to many of these sites (Ruuhijärvi, 1962; Laitinen, Rehell and Huttunen, 2005).

Strongly-patterned bog systems are well known for Britain and have been widely described, perhaps the most extreme examples of these being the 'eccentric mires' described in the JNCC SSSI selection guidelines for bogs (JNCC, 1994), whereas Charman (1993) observes that until about 20 years ago patterned fens were thought not to exist in Britain. However, Lindsay *et al.* (1988) then reported finding a number of relatively small distinctively-patterned fens while undertaking survey in Sutherland, northern Scotland. After site-visits with Canadian peatland specialists, it was suggested by the late Dr. Stephen Zoltai that the sites were analogous to small oceanic patterned fen types in Newfoundland known as 'ladder fens' (Lindsay *et al.* 1988).

Charman (1993, 1994, 1995) has since examined Scottish examples in considerable detail and has concluded that they are not entirely analogous and should thus be known simply as 'patterned fen'. However, the name 'ladder fen' has stuck, and now this site type is found in the JNCC guidance for both SSSI selection (NCC 1989) and selection of sites under the EU Habitats Directive (JNCC website).

Whatever the name used (and to conform with the JNCC guidance the type will be called 'ladder fen' in the present report), there is no doubt that the type itself is a very distinctive form of peatland. It is also considered to be a relatively rare type of peatland in Britain, being restricted to the far north and west of Britain. Lindsay *et al.* (1988) classed the type as 'rare', at least in Caithness and Sutherland, and recommended that all known examples in Caithness and Sutherland should receive statutory protection, which they duly did. Charman (1993) lists 18 sites for Sutherland, but observes that the "The total extent and number of potential patterned fen sites in the study area [Sutherland] was unknown..."

There is no doubt that ladder fens have a restricted geographical distribution within Britain. The most southerly example known to the present authors is on the Isle of Mull, Argyll. The type is not recorded at all for central, eastern or southern Scotland, and there are no records for England or Wales.

Charman (1993) describes the distinctive features of a ladder fen as:

- "Some expression of fen development, with signs of nutrient enrichment and/or water movement, with vegetation appreciably different from the surrounding blanket mire vegetation;
- Transverse linear pools or hollows and ridges in an approximately regular arrangement."

It is worth adding that the term 'transverse linear' does not mean ruler-straight; the pools and ridges often snake to a considerable degree, but their overall direction is nevertheless straight. This separates ladder *fens* from strongly-patterned eccentric bogs such as Claish Moss or Kentra Moss, Lochaber, western Scotland. Such bog sites have distinctly arcuate pool and ridge patterns, although there is something of a continuous gradient between these extremely wet eccentric bog systems and the strongly patterned ladder fens. It seems that the distinct linearity of pattern in the fen arises because the fen system is confined within its collecting valley and water runs straight through this valley, whereas eccentric mires are somewhat domed and thus the pools arc around the contours of the dome. It is worth repeating here that pools and ridges, whether bog or fen, always lie at right angles [*i.e.* across] the direction of water movement.

This last point is important because it emphasises that ladder fens are zones of distinct water collection and seepage, much more so than the blanket mire habitat that surrounds them. The implications of this are far-reaching and will be explored further below, and in Chapters 7 and 8.

Why is a detailed account of ladder fens presented here?

Quite simply, because the UEL Lewis peatland survey has found that the number of ladder fen (or ladder fen/eccentirc mire transition) mesotopes on Lewis is really quite remarkable. Some examples may be closer to eccentric mire in character, while others are quite clearly more ladder fen, but between them these sites form a major contribution to the biological diversity of peatland systems in the Outer Hebrides. They also, equally importantly, represent major engineering challenges.

By now the reader may be quite curious to know what one of these patterned fen peatland systems actually looks like, especially as it is associated with issues of such significance. How exactly would you know whether you were looking at a ladder fen? As Charman (1993) indicates, the essential feature is the *microtope* – *i.e.* the repeated pattern of essentially linear ridges and hollows.

First, though, a picture from ground level of a ladder fen on Lewis (see Figure 42). The striking thing about the scene is that it is not particularly striking. Very little obviously separates it from much of the blanket mire around it. It is only when the same scene is viewed from above that the microtope patterns become strikingly obvious.

Figure 42. Ladder fen/eccentric mire – ground view.
A ground-level photograph of a ladder fen within the Lewis Peatlands SAC at NB 471519. The pale green and chestnut colouration comes predominantly from purple moor grass (*Molinia caerulea*), which is particularly abundant in the ladder fen. Otherwise, there is little at this time of year (Oct. 2006) to distinguish this area from the surrounding blanket mire. The aerial view from Google Maps, however, reveals just how dramatically this mesotope differs from the surrounding ground. Press CTRL+click on the link below to see the site on Google Maps.

R A Lindsay (c) 2006

http://maps.google.co.uk/maps/ms?ie=UTF8&oe=UTF-8&hl=en&msa=0&t=k&om=1&msid=106670694346380455163.00043b0c3b325c62c2402&ll=58.382841,-6.328554&spn=0.00522,0.014462&z=16

To emphasise the value of the microtope in identifying such peatlands, Figure 43 and Figure 44 consist of aerial photographs from Fraser Island, off the Queensland coast of Australia, alongside aerial photographs of the Isle of Lewis. The two islands lie in different hemispheres, and one enjoys a subtropical climate while the other enjoys a rather cooler and damper climate, but both possess patterned fens which resemble each other to a remarkable degree. The vegetation creating the Australian patterned fen contains no *Sphagnum* bog moss; it consists instead of plant families that do not even occur in the northern hemisphere, yet the patterns created – the microtope and mesotope (and indeed the macrotope) are essentially the same.

One major difference between the Antipodean and Scottish sites, however, is that the 'pools' of the patterned fen on Fraser Island dry out completely for part of the year, leaving wide flat expanses of sand covered with a thin layer of organic matter. These dry pools are separated by very long but extremely narrow ridges (1 m width, but many tens or hundreds of metres long) that rise abruptly from the dry sandy pool. In contrast, the ladder fens of Lewis very rarely dry out precisely because they are an area of water collection in a highly oceanic region. The resulting regular rainfall and its subsequent seepage into the ladder fen system means that they probably remain wetter longer than any other part of the blanket mire landscape during drought.

The key thing about these sites is that they are almost completely overlooked by the LWP EIS documents. Certainly there is no mention anywhere of 'ladder fens'. This appears to be for a complex mixture of reasons. Partly, it may reflect the focus on degree of damage inherent in the system of Erosion Classes. It certainly reflects the lack of a 'mesotope' and 'microtope' concept to guide the survey methodology. Finally, it also seems that such sites were quite simply not recognised for what they were.

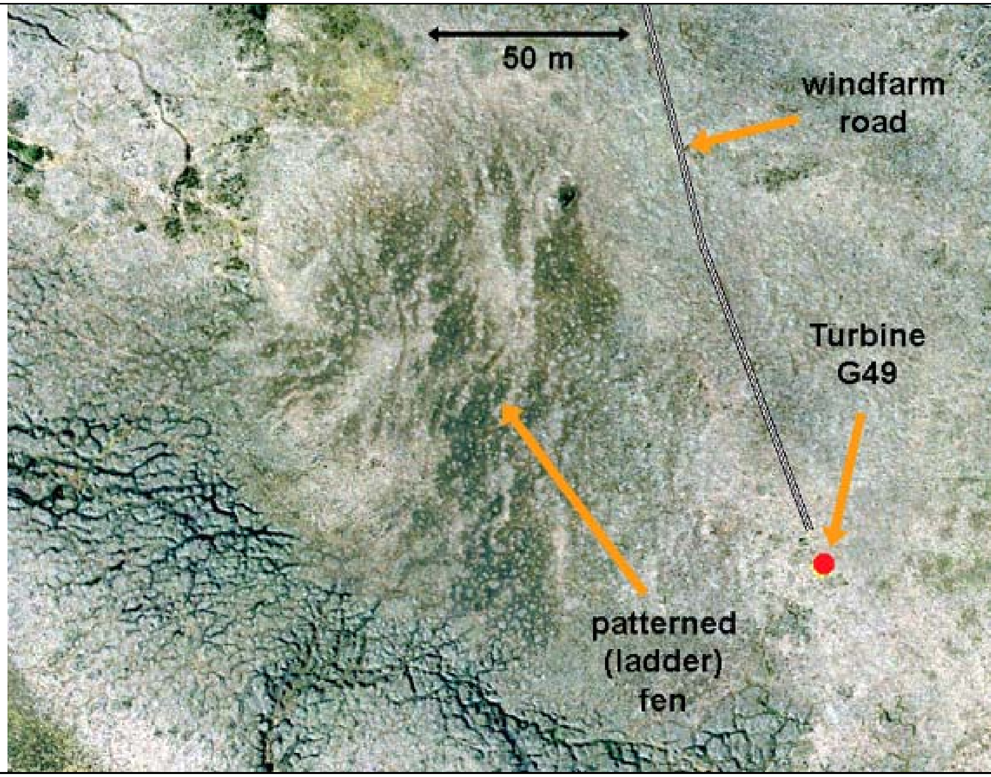
http://maps.google.co.uk/maps/ms?ie=UTF8&oe=UTF-8&hl=en&msa=0&ll=-25.208824,153.056631&spn=0.038052,0.055017&t=k&z=14&om=1&msid=106670694346380455163.0004393ea816184e51e9a	

Figure 43. Comparison between Lewis ladder fen at Turbine G49 and Australian patterned fen.
Examples of patterned fen from Fraser Island, Australia, and Lewis wind farm development area at proposed site of Turbine G49. **(left)**: Press CTRL + click on the URL to go to Fraser Island on Google Maps. Read the description provided on the left, then zoom in particularly to the lower of the blue flags, and click on the flag to read the description. Compare this with... **(right)**: A ladder fen lying close to Turbine G49 of the LWP development. The long pale sinuous 'strings' are ridges of peat, while the elongated dark patches between are hollows or pools which are often relatively shallow 'mud-bottom hollows' (Sjörs, 1948) or 'A2 hollows' (Lindsay, Riggall and Burd, 1985). On Lewis the strings of the ladder fen are created by *Sphagnum* and sedge remains, and are rich in purple moor grass (*Molinia caerulea*) and bog asphodel (*Narthecium ossifragum*).

http://maps.google.co.uk/maps/ms?ie=UTF8&oe=UTF-8&hl=en&msa=0&ll=-25.208824,153.056631&spn=0.038052,0.055017&t=k&z=14&om=1&msid=106670694346380455163.0004393ea816184e51e9a

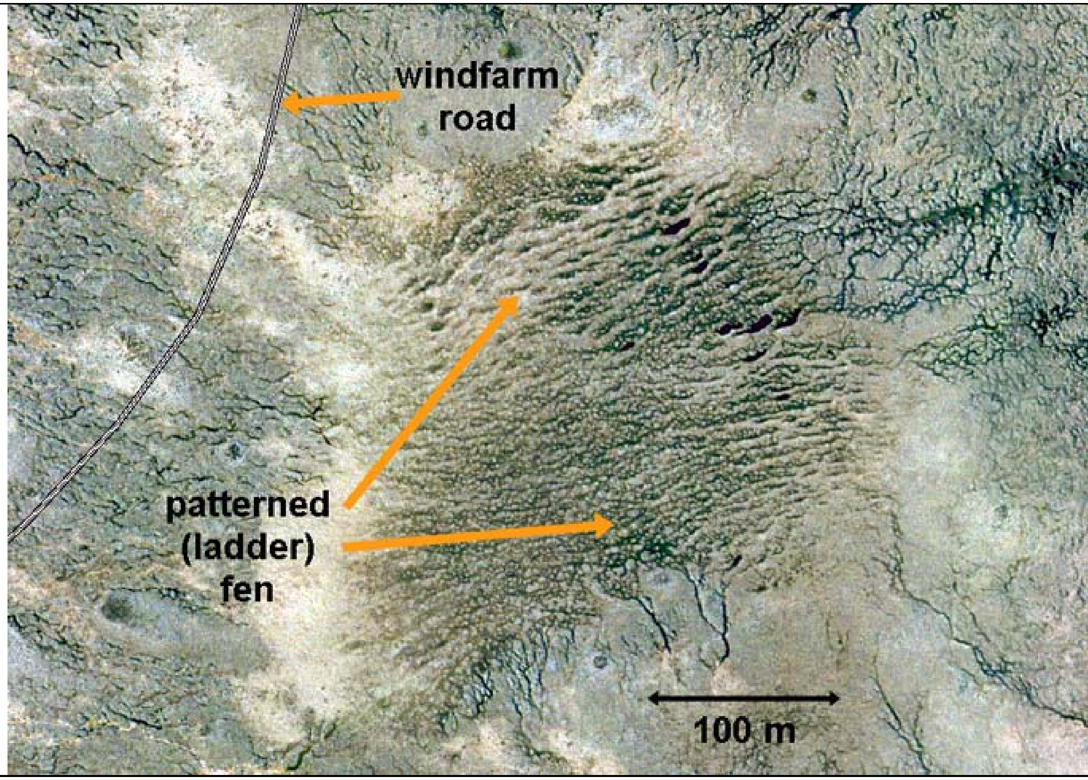


Figure 44. Comparison between Lewis ladder fen/eccentirc mire and Australian patterned fen.
Examples of patterned fen from Fraser Island, Australia, and well-developed ladder fen from southern-central part of the Lewis wind farm development area. (left): Press CTRL + click on the URL to go to Fraser Island on Google Maps. Read the description provided on the left, then zoom in particularly to the upper blue flag, and click on the flag to read the description. Compare this with... (right): Strongly-patterend ladder fen close to the LWP road-line at NB 396375. The long pale sinuous 'strings' are ridges of peat, while the elongated dark patches between are hollows or pools which are often relatively shallow 'mud-bottom hollows' (Sjörs, 1948) or 'A2 hollows' (Lindsay, Riggall and Burd, 1985). On Lewis the strings of the ladder fen are created by *Sphagnum* and sedge remains, and are rich in purple moor grass (*Molinia caerulea*) and bog asphodel (*Narthecium ossifragum*).

To take that final point first, because the LWP HSA survey informs all subsequent planning and actions for the LWP windfarm development proposal, it is possible to point to very evident ladder fens where the survey has not merely failed to note their presence, but has actually described the ground quite inappropriately. Thus in Figure 45 we can see that although there are two LWP target notes in the near-vicinity of the ladder fen shown in Figure 43, there is no target note for the ladder fen itself. What is particularly interesting is that the polygon as a whole, though curiously classed as Erosion Class 2, is also described as having a ‘rilled surface : common’. This matches entirely with the surface features of a ladder fen, although the only description provided, in LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 36, leaves things very ambiguous. Frustratingly, however, this category is never subsequently used in any part of the LWP EIS documents; it simply disappears.

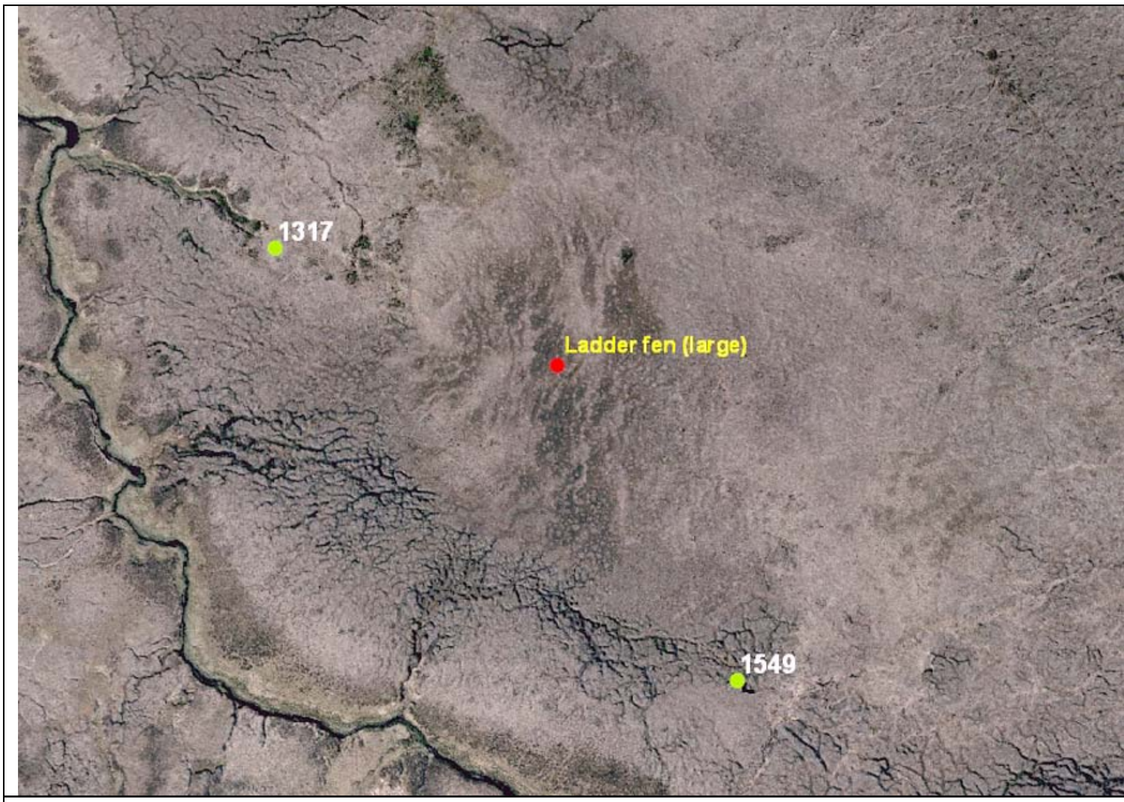


Figure 45. Mis-match between ladder fen and LWP Target Notes.
The ladder fen shown in Figure 43, together with Target Notes recorded by LWP 2004 EIS, Vol.7, Technical Report, Appendix 6. Target Note 1317 notes detailed comments about the evident stream line running to the north west, but nothing about the ladder fen to the south east. Target Note 1549 simply notes “Dissected M17b/H10b and M19a on gentle slopes.” The polygon as a whole is assigned to Erosion Class 2, Bog Pool Class 1, and is (very interestingly) noted as having a widespread ‘rilled’ surface.

In contrast, the ladder fen shown in Figure 44 is identified quite explicitly by a polygon boundary within the LWP HSA survey map, but is then classed as Erosion Class 1, Bog Pool Class 0, and no rills are recorded. No target note is provided for the area (see Figure 46).

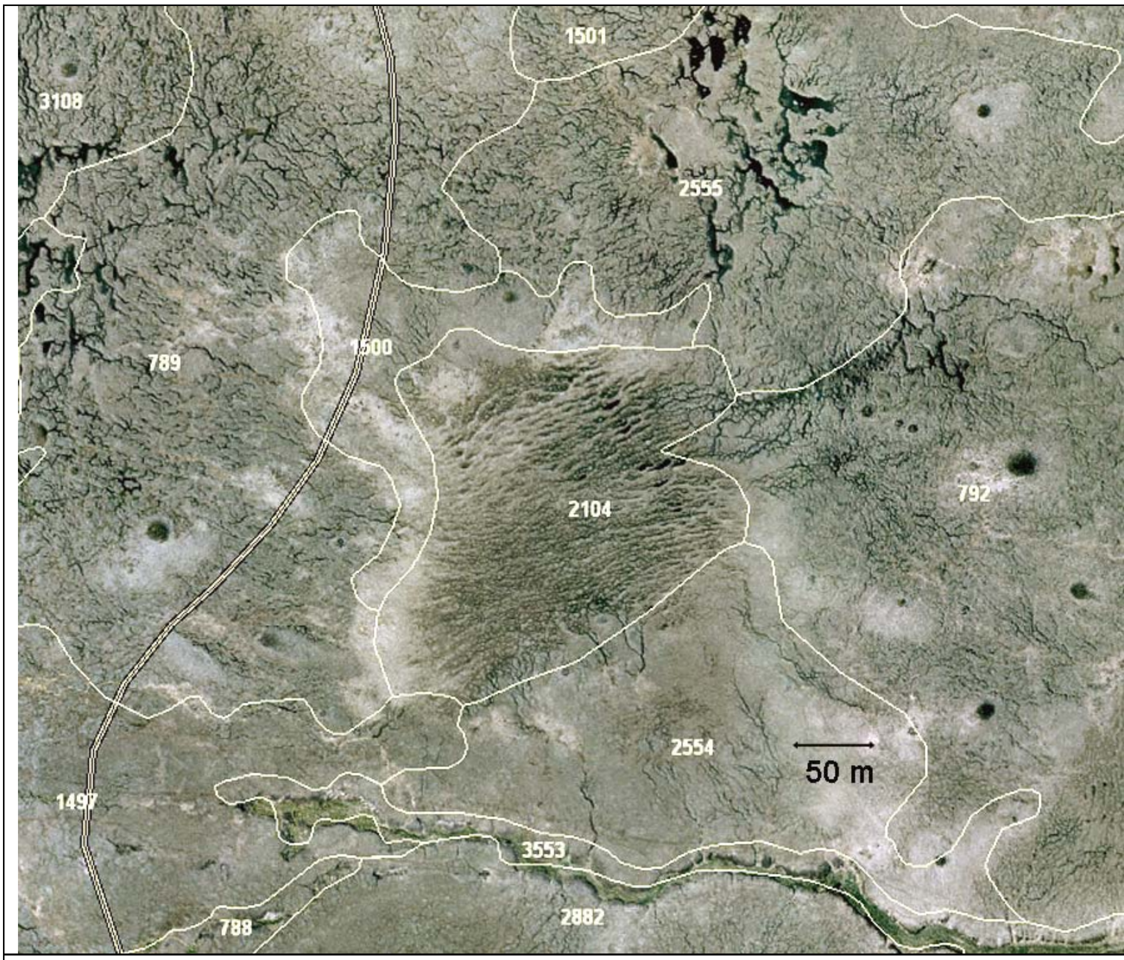


Figure 46. LWP HSA polygon boundary identifying ladder fen.
The ladder fen shown in Figure 44, together with the polygon boundaries generated by the LWP HSA survey. No target notes are recorded for this scene. The ladder fen can be seen labelled '2104', which is the SEQID number within the LWP GIS dataset. It is recorded as being Erosion Class 1, Pool Class 0, and with no 'rills'. Note the proposed road-line running to the west (left) of the ladder fen, indicated as a double white-and-black line.
Aerial photo, Lewis © Getmapping.com 2006

To give an idea of just how widespread ladder fens are within the LWP development area, Figure 47 identifies the locations of all such sites identified during the UEL Peatland Research Unit's aerial-photo and field survey reconnaissance of the immediate development area. It can be seen that they occur throughout most parts of the development area, although the section of development that connects the far northern concentration of roads and turbines with the central area has no ladder fens within the vicinity of the development. Such sites are sparse in the far west and the north, and clearly have their centre of distribution in the central part of the LWP proposed development. It is worth noting that ladder fens are even more widespread within the LWP HSA as a whole.

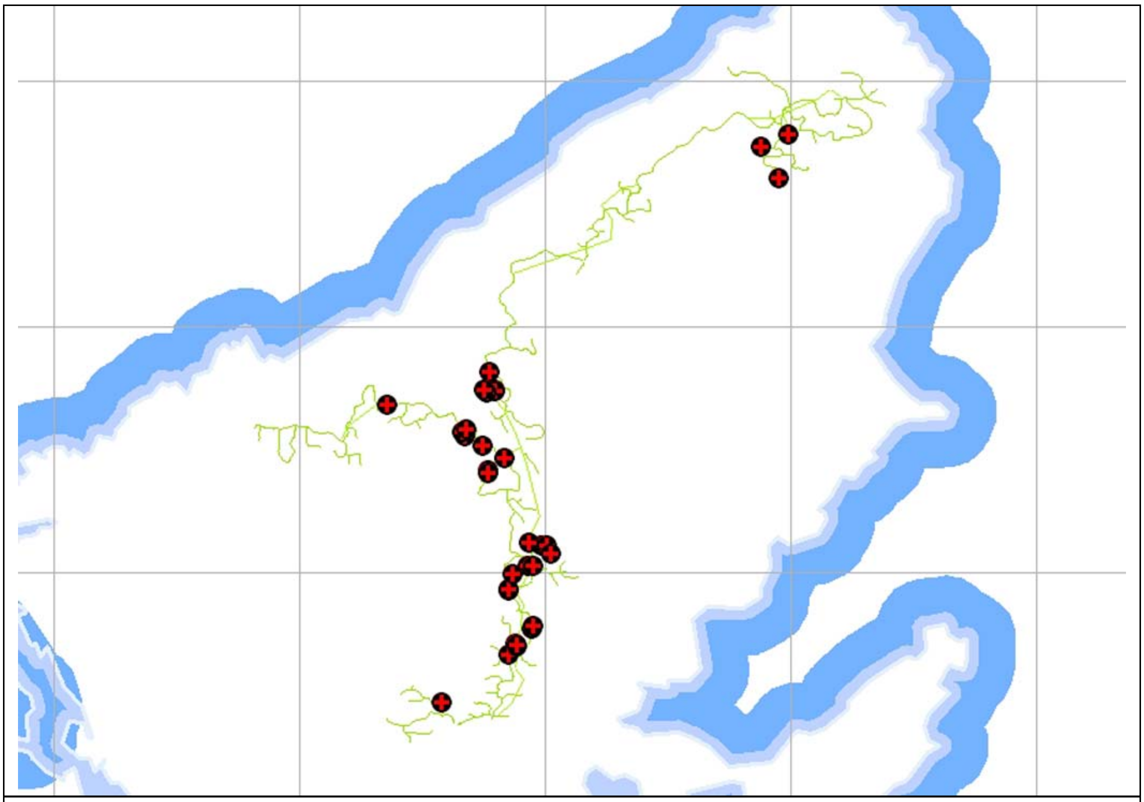


Figure 47. Distribution of ladder fens close to windfarm infrastructure.
Distribution of ladder fens lying on or close to the infrastructure of the proposed LWP wind farm development, as recorded by the UEL Peatland Research Team reconnaissance survey. Ladder fens are denoted by red and black crossed circles. The road-line and overhead transmission lines of the LWP development proposal are indicated by thin green lines. The coastline is shown as concentric blue shading. The OS National Grid is shown in grey as 10 km squares..

There is a certain irony about the fact that the present report highlights the failure of the LWP HSA survey to identify ladder fens, because one of the present authors failed to do precisely this himself on the same site almost 30 years ago. Goode and Lindsay (1979) display an annotated aerial photograph of central Barvas Moor, indicating various examples of mire patterning. Amongst other things, they highlight a mire system labelled as: "linear patterns on sloping mire" and they describe how:

> *"Where the gradient of the mire surface is greater* ***the pools are oriented at 90° to the direction of slope so that there is a series of alternating pools and ridges****. This type of pattern occurs in places around the margins of watershed mires and on some of the valleyside mires that have not been subject to erosion.* ***It is referred to as linear pool and ridge patterns to distinguish it from the more irregular patterns of the watershed mires****. In these linear patterns the pools are generally less than 0.4 m deep and are frequently covered by aquatic species of Sphagnum."*
>
> *Goode and Lindsay (1979)*

While it is true that linear patterns of an *arcuate* kind occur on the margins of watershed and valleyside mires, the fact remains that the mire system highlighted in their "Plate 1" is the very same ladder fen as that shown in Figure 42 above. In their defence, it would be another 10 years before ladder fens came to be recognised in Britain, and indeed this discovery itself was made by one of the same authors (Lindsay *et al*., 1988).

The point about this rather salutary tale (at least for one of the present authors) is that 30 years ago this particular mire type was not known for Britain and thus it was simply regarded as a distinctive microtope type within the wider mesotope unit. Since 1988 the type has been recognised as a distinct mire type (and thus a mesotope system) in its own right. Lindsay *et al*. (1988) provide a clearly labelled illustration of a ladder fen as a distinct mesotope lying between two valleyside mire mesotopes (their 'Figure 7'). The fenland chapter of NCC (1989) illustrates ladder fens as a key fenland type ('Figure 3'), and Lindsay (1995) again provides a labelled illustration of the type sitting between two valleyside mire mesotopes (his 'Figure 2'). Indeed Meade (1997) cites ladder fens as one of the reasons that blanket '<u>mire</u>' is preferable to blanket '<u>bog</u>' when talking about extensive peat-covered landscapes.

In addition, JNCC guidance for both active blanket mire and transition mires, as priority habitats under the EU Habitats Directive, makes explicit mention of ladder fens and states:

> *"Ladder fens form an integral part of some blanket bogs and have a* ***characteristic surface patterning, with narrow pools and intervening low, narrow ridges parallel to the contours****. Associated with this structure is a more species-rich flora than that of the surrounding mire expanse. This is due to local flushing of mineral nutrients through these fen areas, in contrast to the surrounding vegetation, which receives all its nutrients through precipitation, i.e. is ombrotrophic. Ladder fens may also be referable to 7140 'Transition mires and quaking bogs'."*
>
> *JNCC website: SAC selection - 7130 Blanket bogs*

There is thus little justification today for failing to recognise this mire type, and perhaps it is even more ironic, given the experience of one of the present authors, that the same thing should happen again with a photograph in one of the LWP EIS documents. In the course of illustrating the various Erosion Classes used in the assessment, LWP 2004 EIS, Vol.7, Technical Report, Appendix 2, Figure A2b and LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, Plate 11B.13 both show an oblique aerial photograph captioned as:

> *"Type 1 intact mire with bog pools and dubh lochans, encircled by Type 6 erosion, north of Loch Mor an Starr (NB 3939)."*

This same system can be seen in Figure 48 below, from which the tell-tale pattern of ladder fen 'strings' can be seen snaking through the site. It is not the most typical of ladder fens, and appears to be in an advanced state of development to eccentric bog, with the slightly arcuate shape of the 'strings' and the unusual presence of large bog pools within the body of the ladder fen.

As such, this site highlights the fact that in these Lewis sites there is an ecological continuum which has, at one end, the distinct ladder fen structures described by Charman (1993), and at the other the striking patterns of typical eccentric mires, which in Britain are rare bog systems typified by Claish Moss National Nature Reserve, Argyll (JNCC, 1994). Nonetheless, the influence of water flow can still be seen in the 'string' pattern, and the vegetation can be expected to have a particularly high frequency of purple moor grass (*Molinia caerulea*) on the strings due to the steady seepage of water (Jefferies, 1915), with the possibility of sedges such as *Carex lasiocarpa*, *C. rostrata* or *C. limosa* in the linear hollows. More importantly, both types are considered to be rare and of high conservation value, both are explicitly described in the JNCC SSSI Guidelines for Bogs (JNCC, 1994) and both are characterised by a high degree of water percolation and thus high water tables.

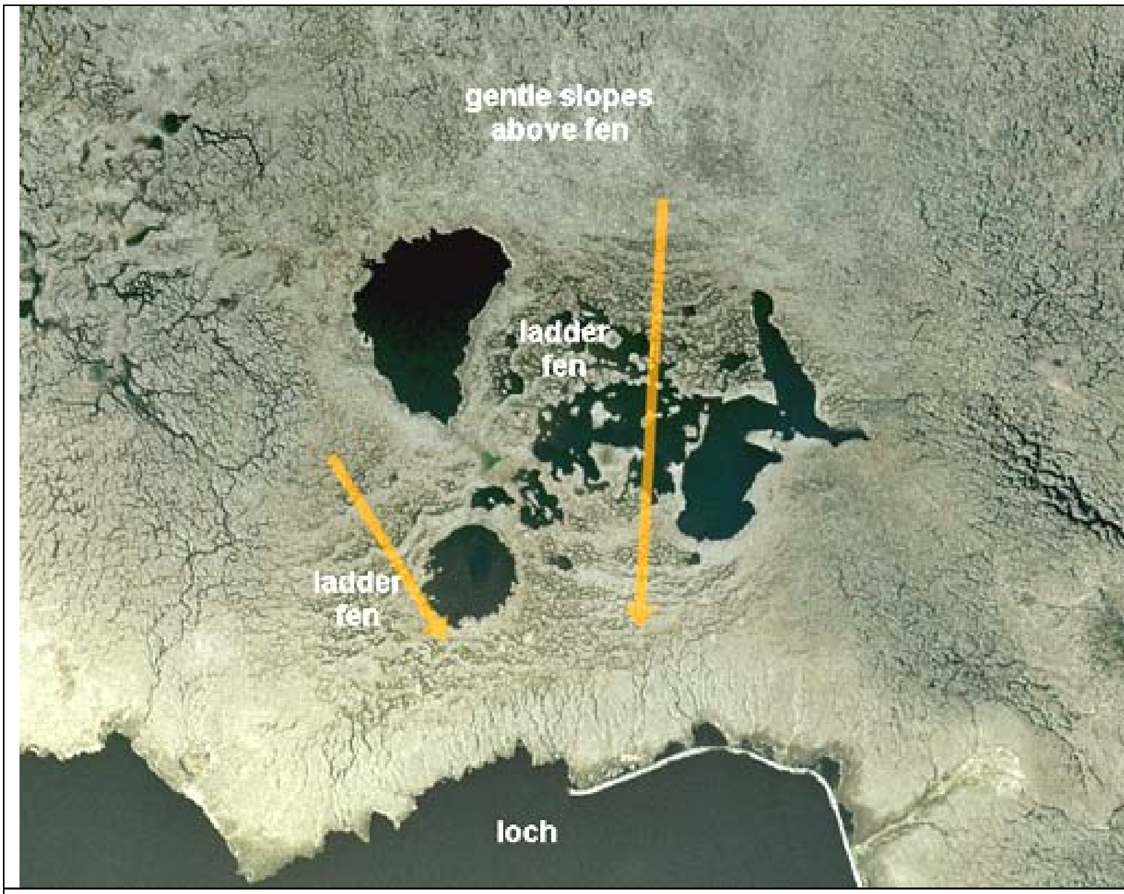


Figure 48. Ladder fen/eccentric mire featured by LWP EIS.
A pool system illustrated by LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, Plate 11B.13 as 'Type 1 Erosion Class'. In fact this system is probably a transitional type between ladder fen and 'eccentric mire', with water seeping (or emerging from a spring) from the slopes above the site (to the top of the photograph), and then percolating through the system in the direction of the orange arrows towards the loch at the bottom of the photograph. It is a somewhat atypical system because ladder fens do not usually have large bog pools or 'dubh lochain'. The pattern of pale-coloured, narrow 'strings' and darker pools suggests, however, that the site is indeed a ladder fen/eccentirc mire transition.

Aerial photo © Getmapping.com 2006

It is perhaps worth noting that the windfarm road-line runs along higher ground above this site. A significant proportion of water likely to be passing through the site would be groundwater fed by springs together with substantial near-surface flows. Consequently the potential for hydro-chemical disruption to this presented 'type site' for Erosion Class 1 by upslope construction activities should be investigated.

5.2.7.4 Ladder fens/eccentric mires and LWP windfarm infrastructure

The fact that such sites were not specifically noted during the LWP HSA survey appears to mean that they have not featured in planning stages of the windfarm site layout, either for the LWP 2004 EIS or for the subsequently revised layout presented in the LWP 2006 EIS. Evidence for this supposition is provided by the fact that several areas of infrastructure actually cross or lie within a ladder fen.

Given that (most of) the road-line and turbine bases were measured for their peat depth, it is a matter of some surprise that the particularly wet nature of these mesotope types was not picked up during the peat-depth survey. Nonetheless, as can be seen in Figure 49, parts of the proposed infrastructure have nevertheless been laid out as though such sites do not exist.

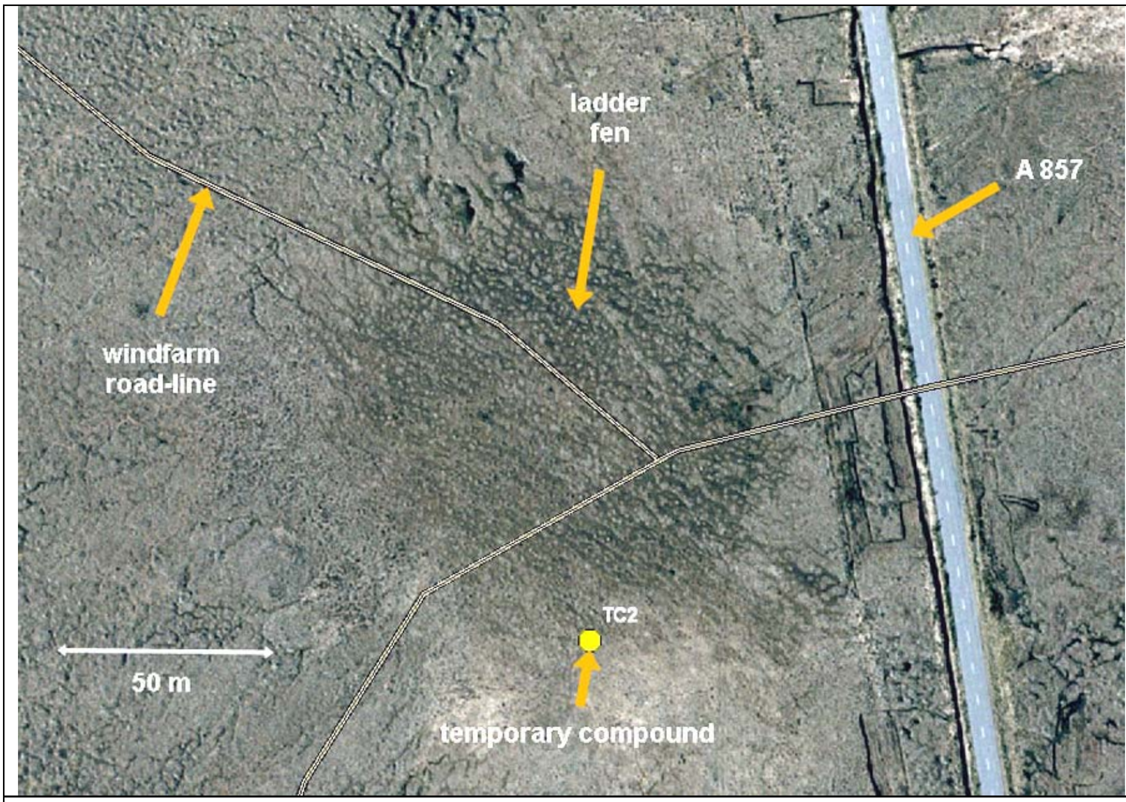


Figure 49. Ladder fen with proposed windfarm infrastructure.
Ladder fen at site of proposed windfarm road junction, NB 389410. Temporary Compound TC2 is also located within the margins of the ladder fen. LWP windfarm road-line is shown as a pale yellow double line, the main A875 road is shown as a steel grey line on the right of the photograph, and the temporary compound is shown as a yellow dot. These various features are indicated by orange arrows. The peat depth at the junction is 5 m.

Aerial photo (c) Getmapping.com 2006

Whilst the failure of both LWP surveys (the LWP HSA survey and the LWP peat-depth survey) to pick out ladder fens means that significant components of biodiversity and conservation interest have been overlooked in the LWP EIS documents, the implications for construction are also considerable. It can be seen from Figure 49 that a fairly major programme of construction is proposed for the middle of a ladder fen that sits on 5 m of extremely wet peat.

Consequently the fact that such mire mesotopes have not been identified until now is likely to be of considerable significance for any proposed construction activities, as well as representing a significant gap in the catalogue of biodiversity for the development area. The presence of these sites is likely to increase the difficulties for, and possible impacts from, construction quite substantially, even with the flexibility provided by micrositing.

This is an important issue that will be explored further in Chapter 7 (Peat Stability), Chapter 8 (Direct and Indirect Impacts) and Chapter 9 (Cumulative Impacts).

5.3 Causes of erosion

One of the most perplexing aspects about the information presented in the LWP EIS documents is the approach adopted towards erosion. Specifically, this concerns the repeated presentation of a mechanism claiming to explain the origin of widespread erosion in the Lewis peatlands. The proposed mechanism is presented to the exclusion of all other possibilities, yet no attempt is made at any stage to provide any evidence to support the proposal. Essentially it is claimed that the erosion found on Lewis arises through a form of internal collapse caused by the development of natural piping. This idea is somewhat similar to the process by which karst limestone landscapes display surface-collapse features, except in the case of limestone these features develop because water within the limestone dissolves away the rock itself along lines of weakness. In some cases these lines of weakness result in 'sink-holes' down which surface drainage water disappears into the underlying bedrock. On other occasions, where large amounts of sub-surface limestone has been dissolved away to form caves or caverns, roof-collapse of such features can result in dramatic collapse of the overlying ground surface. In general, it seems that the mechanism advanced by LWP to explain peatland erosion on Lewis is more on the scale of individual sink-holes than of wholesale surface collapse.

The proposed mechanism is not entirely novel. Early writers about blanket mire erosion talk of the effects of headward erosion by stream-courses into the body of the blanket bog mantle, and conclude that such a process would be capable of triggering gully erosion across the expanse of blanket mire. Such mechanisms have been proposed on many occasions (*e.g.* Bower, 1962; Tallis, 1985) but have never been convincingly demonstrated.

5.3.1 Lewis peatland erosion – not atypical of British blanket mire

As will be explored in more detail in the next chapter of the present report, factors such as burning have generally been regarded as the prime cause of widespread erosion in British blanket mires. This is an important point, because it is sugegsted by LWP 2004 EIS, Vol.6, Appendix 10E, para 1 that widespread erosion of blanket peat is a phenomenon especially peculiar to the Lewis peatlands.

It is stated in LWP 2004 EIS, Vol.6, Appendix 10D, para 28 that:

> *"...the peatland of north Lewis is widely acknowledged as* ***one of the most severely eroded peatlands in Britain****, with eroded conditions dominating the blanket bog in the wind farm area by at least 60%."*

It is difficult to find published evidence of this opinion. Indeed it is acknowledged by LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 32 that "erosion of peatlands is a widespread phenomenon in Britain", while Goode and Lindsay (1979), for example, do not suggest that the extensive erosion they report from the Lewis peatlands is in any way exceptional. The blanket mires of Shetland, and those of the Monadhliaths, are at least as eroded as those on Lewis. Lindsay *et al*. (1988) identify 5 out of their 15 'site types' for Caithness and Sutherland as being eroded types, in particular describing their Site Type 12 thus:

> *"****The type is widespread because it covers a large proportion of ground*** *including both entire mire units and much of the intervening thinner peat between major systems ... It is* ***fair to say that this is one of the most extensive peatland types in the region (and, indeed, elsewhere in Scotland)****..."*
>
> *Lindsay et al. (1988)*

In an overview of blanket mire erosion in Scotland, Coupar, Immirzi and Reid (1997) show that of 9 regions examined, the Outer Hebrides were exceeded by five other regions in terms of the percentage of blanket mire affected by gully erosion. Eastern Scotland showed far higher levels of gullying, while Shetland was recorded as having almost three times the extent of gully erosion recorded for the Outer Hebrides.

Despite this, and despite the acknowledgement in LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 32, referred to above, that erosion is widespread in the blanket mires of Britain, LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 29 claims that the Lewis peatlands are in some way 'atypical' because they contain:

> *"...erosional forms and relationships which are not covered adequately in existing British accounts of blanket bog topography – water relationships."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 29*

Precisely what is meant by "blanket bog topography–water relationships" in terms of "erosional forms and relationships" is not made clear because the text goes on to talk about the "weak" linkage of hydro-morphological types to the Lewis peatlands. As has been discussed earlier, hydromorphological types relate to the mesotope level while patterns of erosion are a feature of the microtope level. There seems therefore to be a degree of 'mixing apples and pears' here. In so doing, the suggestion is thereby created that the Lewis peatlands are in some way 'atypically' eroded and dry.

Patently this is not the case; it is very difficult, if not impossible, to find corroborating evidence from the published literature to support the argument that the Lewis peatlands are in any way 'atypical' in terms of the nature or degree of their ersosion. Certainly the line of argument used by LWP is not the one to demonstrate such a unique nature. There is no shortage of relatively dry blanket peat throughout Britain – as is made clear in the descriptions given in Rodwell (1991) for all the main blanket and raised mire NVC types; his account of M20 is particularly bleak. Meanwhile for examples of *really* intense erosion, it is only necessary to visit the summit of Kinder Scout in the Peak District. The present-day scene along the summit ridge, as shown in Figure 50, shows a scale of erosion far more spectacular than anything found in the Lewis peatlands.

It is not clear what picture the LWP HSA survey team had in mind for 'typical' blanket bog in Britain prior to carrying out the Lewis survey, but the impression one gets is that they expected wide, almost continuous, expanses of pool-rich blanket mire. In this, they seem to have been unduly influenced by the best parts of the Flow Country of Caithness and Sutherland, which does indeed have considerable expanses of such ground. But then this is why the Flow Country has been proposed by the UK Government as a possible World Heritage Site; the variety and extent of pool-rich blanket mire is outstanding not just in a UK context, but in a global context. In actual fact, however, even the Flow Country has enormous areas of *relatively* dry eroded bog, far exceeding the area of pool-rich bog in total extent, as indicated in the quote above from Lindsay *et al*. (1988).

Figure 50. Severe erosion at Kinder Scout, Peak District.
The summit of Kinder Scout, in the Peak District, northern England. The evident scale of erosion and loss of peat material here is very much greater than the degree of erosion encountered on any of the Lewis blanket mires.

It is as though the LWP survey team had not expected to find such extensive tracts of eroding bog, and this appears to have coloured their whole perception of the area. Thus we find the often-repeated statement within the LWP EIS documents that:

> *"**Wet ground is only locally common**, with bog pool vegetation (M1, M3) occurring in true bog pools, as well as in gullies."*
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 45*

> *"<u>Dry and possibly atypical peatlands (LWP emphasis)</u> : The bulk of the survey area is made up of **relatively dry peat surfaces**, which contain varying densities of gullies. Ignoring lochs, flushes, streams and rivers and the wettest types of blanket bog (Erosion Class 1), **relatively little of the remaining surface is really wet**."*
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 67.*

However, such descriptions could be applied to the vast majority of blanket bog in Britain. Indeed there is also an important element of self-fulfilling prophesy here, because it is surely rather inevitable that if we:

> *"...ignore ... the wettest types of blanket bog (Erosion Class 1)"*

...it is almost axiomatic that:

> *"...relatively little of the remaining surface [will be] really wet."*

It is tempting to sense in this form of wording a desire to emphasise that the peatlands of Lewis are extraordinarily – indeed, unusually - dry, eroded and degrading. Why this should be is not clear, because in fact LWP's own survey information demonstrates that much of the ground is actually showing signs of vigorous recovery. By far the larger proportion of LWP Erosion Classes is defined as being stable and displaying recovery of vegetation in the gullies. Indeed this general trend is supported by comments such as:

> *"Areas can however recover; evidence from Lewis (T. Dargie pers. comm.) suggests that **severe erosion events in the past are now stable and accumulating peat bogs** [sic]."*
> *LWP 2004 EIS, Vol.6, Appendix 10D, para 67.*

As such, the comment that:

> *"There is **strong evidence of a changing balance** in the vegetation types of the HSA in relation to the type and degree of surface wetness and blanket bog erosion..."*
> *LWP 2004 EIS, Vol.2, Sect.2, Chapter 11, para 24*

...is almost certainly correct but not in the sense that was intended. From the evidence of the LWP EIS documents themselves, and confirmed by the UEL Peatland Research Unit field survey, this changing balance is quite clearly towards conditions of *increasing* surface wetness and re-vegetation of eroded systems rather than the reverse.

Even the community of *Racomitrium lanuginosum* and *Erica cinerea* which is used by the LWP EIS documents to highlight the 'exceptionally dry and unusual' nature of the Lewis peatlands is also recorded from many peatland areas in the north west of Scotland. This is an issue explored at some length in the next chapter of the present report so we will not dwell on it here. Suffice it to observe that it is not necessary to invoke an exceptional set of conditions to explain the condition of the Lewis peatlands, because their eroded condition is not in any way exceptional.

5.3.2 Causes of peatland erosion – the wider evidence

While there has been relatively little argument about the general *processes* of erosion, it is true that the factors which *initiate* erosion have been the subject of long-standing and lively debate Even such respected authorities on the subject as Dr John Tallis, University of Manchester, can be found musing first one way, then another, sometimes in the same scientific paper, about the triggers of erosion (*e.g.* Tallis, 1985).

Part of the problem is that there are relatively few documented examples of un-eroded blanket mire being transformed into eroded blanket mire with the added good fortune of having someone on hand to record events. Consequently it has generally been necessary to look at existing conditions and attempt to re-construct the events leading up to the present observed condition.

Such *'a posteriori'* approaches can be useful in the absence of clear ongoing examples demonstrating cause-to-effect, but they can also invite the construction of models or theories that have a less-than-solid grounding in fact. Perhaps one of the most celebrated examples of *'a posteriori'* deduction is Archbishop James Ussher's calculation that the Earth was created on 23 October 4004 BC. Even Lord Kelvin's subsequent calculation, based on rates of heat loss, suffered from the same fundamental weakness. His conclusion (after many amendments to initial estimates) was that the Earth must be about 24 million years old, but this *a posteriori* calculation was also flawed because Kelvin knew nothing of the radioactive thermo-nuclear processes occurring beneath the Earth's crust (Bryson, 2003).

The difficulty in *dating* the Earth, of course, is that no-one was present to make a note of the time at the moment of creation, and there was only one single moment (or period) of creation, so it is an event that must inevitably be studied *a posteriori*. This is also generally the case with peatland erosion because relatively few examples of the initiation process have been documented in modern times – the vast majority of eroding blanket mire appears to have been already well-established long before scientific investigations began with, for example, Osvald's (1949) review of British and Irish blanket mires.

Normally, peatlands are rather good at recording what has happened to them in the past, but, as Tallis (1985) observes, it is the irony of peatland erosion that, by its very nature, significant parts of the very record that might hold clues to the process are lost from the system. However, by so-to-speak chasing after these departing clues, it is possible instead to examine locations in which the eroding peat finally comes to rest, such as in stream-courses and lake sediments. It may thus still be possible to piece together a picture of events from these mobilised fragments of the ecosystem.

Tallis (1985) used evidence of slumped peat blocks found in streamcourses, together with measurements of peat accumulation in several adjacent areas of blanket mire in the Pennines, to re-construct the onset of an erosion phase which he dated to somewhere between 1,000 and 1,200 years before present (BP). He concluded that erosion in this case was initiated by instability at the blanket bog margins which then led to gully development upslope across the main mire surface. However, though one of the (relatively) more enthusiastic supporters of natural instability as a cause of peat erosion within the recent literature, Tallis (1985) then admits that the absence of clear, widespread evidence of instability features or events is something of a difficulty for this argument, given the widespread nature of blanket mire erosion. He is therefore careful to avoid the suggestion that instability might be the only cause of peat erosion and qualifies his conclusions with a cautionary note that recognises the difficulty of using such data *'a posteriori'*.

Bragg and Tallis (2001) review the various factors that have been linked to, and invoked to explain, the widespread erosion found throughout British and Irish blanket mires. They describe the phenomenon of pool linking to pool as intervening ridges are broken down through a variety of postulated actions or processes, and observe that the mechanism also requires an outlet to allow the water to drain away. They observe that such outlets may be sub-surface pipes or the uppermost point of headstream extension. Lindsay *et al*. (1988) cite a specific example of a watershed bog pool in Caithness being drained by the creation of an artificial pipe, but observe that the phenomenon of dewatering by natural sub-surface pipes may be 'more abundant'.

It is significant that in the most detailed and recent investigation so far into peat pipes and their relationship with the blanket mire landscape around them, Holden and Burt (2002) do *not* suggest that pipes bring about wholesale collapse of pool systems. They observe that Bower (1962) is one of the earliest to suggest that peat pipes could lead to gully development in blanket mires. They also note that four areas within their own study site (Moor House National Nature Reserve, north Pennines) possessed bog pools, and all were associated with peat pipes, but there is no suggestion that any of the four pool systems showed evidence of drainage and collapse because of these pipes. Indeed Holden and Burt (2002) conclude that:

- water flow through peat pipes is essentially derived from acrotelm seepage and overland flow;
- flow rates in pipes are (unusually) no faster than any of the other pathways available for water flow in blanket peat;
- many pipes effectively cease to flow after run-off from identified rainfall events has died away, thus suggesting that there is no widespread drainage of the surrounding catotelm.

5.3.3 Peat pipes and erosion – the LWP evidence

The LWP EIS documents, however, having clearly become convinced of the 'exceptional' nature of blanket mire erosion across Lewis, invoke a mechanism of erosion that is presumably itself regarded as sufficiently exceptional to provide a means by which the special circumstances of the Lewis peatlands can be explained. That no evidence is ever presented to support this theory never seems to constrain the LWP EIS documents, which repeatedly present the mechanism as the established cause of peatland erosion in Lewis.

It is first established that the mechanism involves:

*"...a **progressive degradation sequence**. That sequence is not necessarily linear (i.e. proceeding in the order, say, erosion class 1 to 3 to 4 to 5 to 6 to 7). Indeed, it is more likely that a sequence of 1 to 7 to 6 is possibly commonest. There **seem to be many cases of former class 1 areas with extensive pool systems suddenly being de-watered to form a class 7 area of mire**. The unconsolidated **material growing in pools then collapses to form dry pools, which then form gullies as narrow former walls are removed by an evolving gully network**. Over time, the remaining high ground lacking pools dries to form rectilinear blocks with much dry heath vegetation. The **de-watering event is probably sudden and may well involve evacuation of material by subterranean pipe systems** which are occasionally visible as collapsed hollows in peats adjacent to wet peatland types. If the site is in a depression then run-on from adjacent slopes may allow a rise in the catotelm, followed by a vegetation succession in gullies to form class 6 conditions."*

LWP 2004 EIS, Vol.7, Technical Report, Chapter 5.2

Although various LWP HSA target notes refer to 'sink holes' and 'collapse features', none of these is invoked or used as practical demonstrations of the theory expounded above. Indeed very little use is made of any existing literature which at least suggests the possibility that pipes sometimes collapse and may then cause erosion of the surrounding bog. For example, in their detailed study of peat pipes in the Pennines, Holden and Burt (2002), cited by the LWP EIS documents but not as evidence of collapse, describe how they mapped the lines of their underground peat pipes by, amongst other things, "watching for occasional collapsed sections which allowed the pipe to become visible".

However, Holden and Burt (2002) do not suggest that widespread erosion can be, or is, caused by such peat pipes. Indeed the LWP EIS documents explicitly conclude that the data presented by Holden and Burt (2002) demonstrate relatively limited impact on the surrounding peatland from peat pipes:

*"Importantly however, the pipeflow appears to be strongly dependent on rainfall events, with flows increasing relatively quickly (within 1 hr) after commencement of rainfall and slowing when rainfall ceases, although they maintain low flow for longer than most of the other rapid runoff production processes within the catchment. **Pipes do not therefore 'leak' or act to drain the peatland**."*

LWP 2004 EIS, Vol.6, Appendix 10D, para 57.

Curiously, almost the only evidence presented by the LWP EIS documents in support of the 'pipes leading to collapse' theory, is a reference to Goode and Lindsay (1979), who cite the description by Bowes (1960) of a large 'bog slide' that occurred on Lewis at some unknown date prior to 20th November 1959. It is stated that:

*"More recently however, it has been suggested that exposure of the catotelm occurs when gullies form due to the collapse of **underlying structures such as pipes and preferential channels which could be formed when lochs develop an***

> ***'excess head', causing water to force its way through amorphous peat (Goode and Lindsay, 1979**; D. Nichols pers. comm.)."*
>
> *LWP 2004 EIS, Vol.6, Appendix 10E, para 1*

Goode and Lindsay make no reference whatsoever to 'pipes' or 'preferential channels'. The sequence and mechanism behind the bog slide is described thus by Goode and Lindsay (1979):

- a narrow retaining wall of peat became saturated during an extended period of rain;
- this caused it to lose its footing on a 15° slope;
- pressure of water in the loch behind wall then forced the dam down the slope;
- considerable quantities of water and peat were thus released onto the hillside.

Bowes (1960) gives more detail, having investigated the site shortly after the event, and concludes that cracking of peat in the retaining wall during the preceding dry summer had created routes for subsequent rainwater to infiltrate to the peat-mineral interface. This water acted as a lubricant on which the peat wall could slide downslope. The mechanism thus involves contraction cracks, but there is no mention of pipes.

With regard to the link between peat pipes and erosion, it is not known what evidence was presented to LWP by "Nichols (pers. comm.)". Details are not provided by the LWP EIS documents.

The only example of supporting scientific literature cited by the LWP EIS documents thus gives no support to the proposed model of peat-pipe dewatering because it does not state what is claimed in the LWP document. Even the indirectly-cited paper of Bowes (1960) does not provide any explicit or implicit support for the idea that peat pipes can cause dewatering by internal collapse.

The collapse described by Bowes (1960) is a classic bog slide where drying cracks merely allowed rainwater to reach the base of the peat; there was no 'internal' collapse into the mouth of an excavated hole and subsequent drainage into this hole, as postulated by the peat-pipe model. The entire bog simply slid sideways downslope because it was freed from the friction of the underlying sediments.

A further reference to Goode and Lindsay (1979) suggests rather obliquely that there is some evidence to support a linkage between sub-surface erosion and watershed mire and valleyside mire mesotopes, as:

> *"...these mesotopes may support the hydrological processes, which can act to excavate the peat beneath the surface."*
>
> *LWP 2004 EIS, Vol.6, Appendix 10E, para 4*

Goode and Lindsay (1979) certainly present no evidence for such a sub-surface 'excavation' theory, so it is not at all clear where this particular idea has come from.

No other literature or field evidence is presented for the broader peat-pipe dewatering theory, other than an oblique aerial photograph used on three occasions within the LWP EIS documents. The captions for these three occasions make interesting reading:

The earliest caption states:

> *"Erosion Class Type 4 (Moderate gully density, gullies with peat formation). Note linked sink holes indicating presence of subterranean pipe system."*
> *LWP 2004 EIS, Vol.7, Technical Report, Appendix 2, Fig.A2h*

The subsequent 2004 and 2006 EIS documents state, respectively:

> *"Collapsed subterranean pipes as shallow depression lines and circular hollows, probably draining extensive watershed pool system (NB4255)."*
> *LWP 2004 EIS, Vol.6, Appendix 11B, Plate 11B.24*

> *"Collapsed subterranean pipes as shallow depression lines and circular hollows, probably draining extensive watershed pool system (NB4255)."*
> *LWP 2006 EIS, Vol.5, Appendix 11B, Plate 11B.24*

Thus we begin with a scene containing sink holes that indicate the line of a subterranean pipe system (no argument there). This picture then becomes a scene of "collapsed subterranean pipes" that are "probably draining [the] extensive watershed pool system." No evidence is presented for collapse, and the claim that the pipe is in some way draining the watershed pool system around it runs counter to several forms of evidence to the contrary:

- the statement cited above (LWP 2004 EIS, Vol.6, Appendix 10D, para 57) that Holden and Burt's (2002) "pipes do not therefore 'leak' or act to drain the peatland";
- Goode and Lindsay's (1979) observation that "where [watershed] pool complexes are affected ... by erosion it is common to find many small pools which are apparently unaffected, retaining their normal water-table despite the drainage of large pools nearby."
- the lack of any evident signs of extensive de-watering of the actual watershed pool system illustrated in the LWP photographs; indeed the presence of large water-filled pools and a smooth, non-eroded 'buffer zone' between the line of the peat pipe and the pools does not fit the LWP description of extensive dewatering by "collapse" features (see Figure 51);
- the fact that an alternative model of peat-pipe formation exists for the type of pipe shown in the LWP photographs; this model is discussed in more detail below.

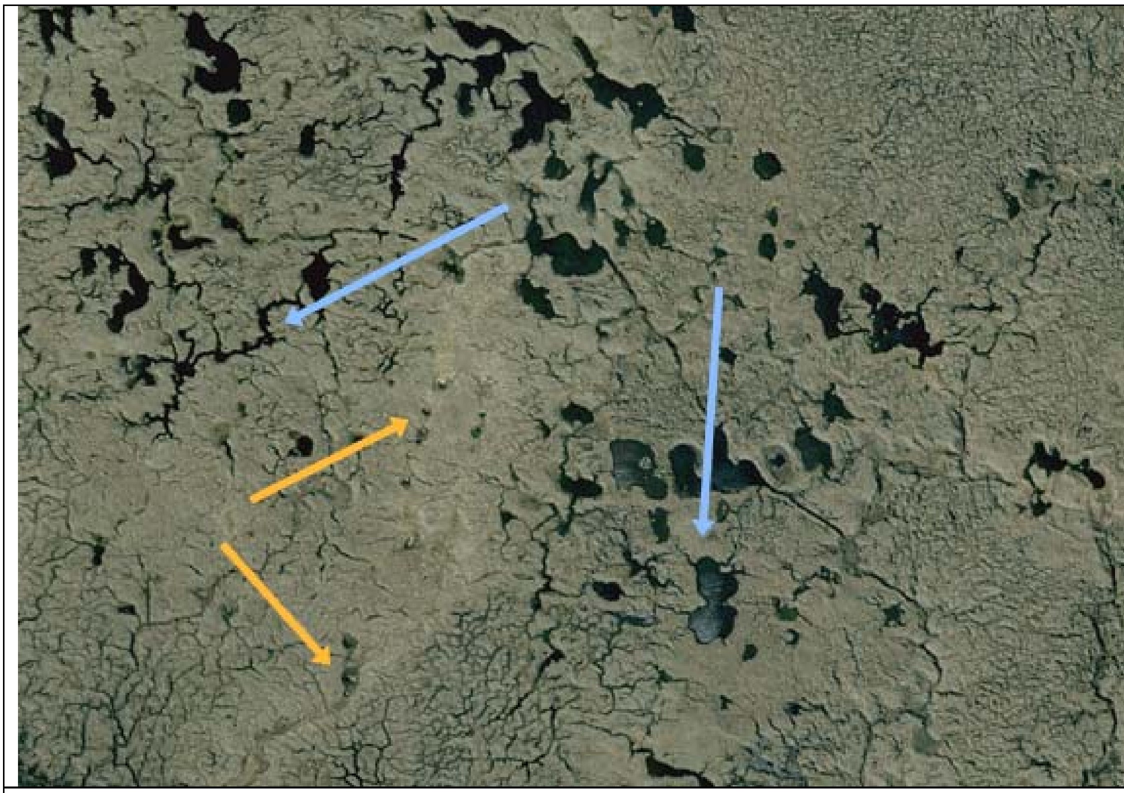


Figure 51. Peat pipe associated with water-filled pool system.
Line of sink holes (and thus presumed peat pipe) within pool system at NB4355. This same system is illustrated in Plate 11B.24 in the LWP (2004)ES. Note the relatively smooth ground associated with the sink holes (orange arrows), and the high water table in the pools arrowed blue on the right. Blue arrows point to water-filled pools evident in Plate 11B.24 of the LWP (2004) ES.

As indicated at the start of the present section, the theory that peat pipes *can* cause blanket mire erosion is not new. Conway (1954) was one of the first to suggest that blanket peat, because of its topographic location, would tend to develop to a point where internal drainage systems might ultimately lead to instability – sometimes of a catastrophic nature. This broad concept has then been developed by Bower (1962), Bostock (1980), Boatman (1983) and Lindsay *et al*. (1988), including evidence of watershed pools dewatered by peat piping. However, at no point is it demonstrated that such mechanisms are the sole, or even the main, cause of erosion.

5.3.4 'Peat-pipe degradation' – inappropriate application of a model

The idea that the eroded blanket mire landscape of Lewis can be entirely explained by natural dewatering through peat pipes represents a logical step far beyond what has so far been demonstrated or even suggested in existing scientific literature. Had the LWP EIS documents provided tangible evidence of such a ubiquitous link, this would have helped the argument considerably although the evidence would still require scientific peer review. Such evidence is not provided. Furthermore, the argument for universal peat-pipe collapse comes with the admission that:

> *"The above **dewatering mechanisms are not proven** ... recent **research does not yet link with the above de-watering ideas**.*

*It **also does not link with other approaches to blanket bog hydrology**, including the hydromorphological hierarchy required for designating blanket bog as a biological SSSI."*
LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 74

It is difficult to understand why such an untested and unsupported proposal is given this level of prominence in an EIS for such a major planning application. How does this untested, unproven idea fit with the requirements of Article 5 (as amended) of Directive 97/11/EC?

Despite this evident and fundamental series of weaknesses, the story of peat-pipe collapse is nonetheless set out repeatedly in considerable detail throughout the various LWP EIS documents. Thus:

"There is a linkage between areas of bog pools, the distribution of erosional classes, the location and extent of wet and dry bog types ... The linkage seems to be associated with a progressive degradation sequence (that is, replacement of very wet peatland of very high nature conservation value with forms which are drier and lack the surface characteristics of very wet types). Gully development, especially in erosion classes 4, 5, 6 and 7, is so widespread that the peat watertable surface is lowered by drawdown by perhaps 0.3 m or more in summer, producing a dry peat surface with characteristic lichen-rich and dry mossy vegetation types (M17b, M15c, H10b NVC types). This fall in watertable is the key outcome of degradation and results in very large areas, perhaps up to two-thirds of the HSA, which are probably so dry that there is little or no active peat formation on such ground."
LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 68

"The degradation sequence ... infers an approximately linear sequence (that is, proceeding in the order, say, of increasing dissection from erosion Class 1 to 3 to 4 to 5 to 6 to 7). However, in terms of the processes involved in degradation, an area does not have to move in sequence in this manner. Indeed, it is more likely that a switch from 1 to 7 to 6 is possibly very common in the HSA. There seem to be many cases of former Class 1 areas with extensive pool systems suddenly being de-watered to form a Class 7 area of mire. The unconsolidated material growing in pools then collapses to form dry steep-sided depressions, which then form gullies as narrow former walls are removed by an evolving gully network. Over time, the remaining high ground lacking pools dries to form rectilinear blocks with much dry heath vegetation."
LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 69

"Dewatering involving evacuation of many pools and dubh lochans, followed by formation of high-density gully systems, results in the bog watertable perhaps falling by up to 30 - 50 cm. This leaves almost all of the former acrotelm dry and much of the upper catotelm much reduced in wetness for most of the time, with the former upper catotelm peat aerated, at least in part, in its upper part. The acrotelm is thus transformed by dewatering from a

thin upper aerated zone (say, 1 - 10 cm thick) to a deeper aerated zone (perhaps up to 30 – 50 cm thick) made up of peat which is dry or only partly saturated. There is still seasonal variation in peatland watertable level, but winter peaks probably never saturate the upper levels except during and immediately after significant rainfall. Rainfall inputs to a much drier and thicker acrotelm, punctured by a rill and gully network, then moves quickly over the upper bog surface and through the gully system with a much faster throughput (lower residence time) than occurs on very wet blanket bog. The result is a peatland which has a much drier surface, a lower watertable and faster precipitation throughput than the very wet conditions that existed before dewatering. Hydrological relationships and their associated vegetation types in such eroded peat, dominate over much of the HSA, but are not discussed in depth by Lindsay (1995)."

LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 71

The above quotes are provided more or less in their entirety because they contain *so much* detail for the dewatering process. Specific values are given for the depth to which the water table falls, and a clear linkage is claimed between areas of bog pools and the distribution of erosional classes. The transformation of the acrotelm is described in detail, with values for water-table behaviour, and the changing behaviour of the water-table residence-time is outlined. The seasonal behaviour of the bog water-table is described, and the resulting condition of blanket bog hydrology is explained.

No measurement, evidence or supporting literature is presented to support any of these remarkably detailed descriptions. Perhaps some of the values cited are based on the Farr Dipwell Study described in LWP 2006 EIS, Vol.5, Appendix 11E, but if they are based on the Farr work, no indication is given of this.

And finally, despite the complete lack of any supporting evidence offered at any stage in the preceding several paragraphs, the mechanism of 'natural dewatering' by peat pipes is presented throughout the LWP EIS documents as the established natural cause of dewatering, and thus apparently the only tenable explanation for the dry and eroded nature of the Lewis peatlands:

*"Overall, **drying as a result of natural hydrological de-watering processes is by far the most significant factor** affecting habitat condition."*

LWP 2004 EIS, Vol.7, Technical Report, Chapter 6.2

*"Burning was probably much more extensive in the past when seasonal stock grazing and use of now-abandoned shielings was widespread. It will undoubtedly have had a considerable effect. However, **much of the dry character and high extent of dry wet heath and blanket bog vegetation is best explained in terms of hydrology**, not historical management by burning."*

LWP 2004 EIS, Vol.7, Technical Report, Chapter 6.2

*"The **most promising link with dewatering probably lies with subterranean pipe systems**, which seem important in the overall water balance of blanket bogs (see Chapter 10). However, the causes(s), frequency and extent of influence of dewatering,*

including the pathways of transport of water and much unconsolidated amorphous peat, are major unknowns. As a general comment, basic hydrological research is required to clarify and expand on these relationships."

LWP 2004 EIS, Vol.3, Chapter 11, para 44

"Results show the following:
That ***drying impacts on blanket bog are very extensive*** *(heavy and moderate evidence, 73% of blanket bog) and that light impacts or absence of drying effects are restricted to 27% of blanket bog.* ***Natural erosion is the principal direct cause of drying on blanket bog*** *and manmade drains are generally rare."*

LWP 2004 EIS, Vol.3, Chapter 11, para 46

Despite the comments made by Lindsay (2005) about the theory of 'natural dewatering' during consultation over the LWP 2004 EIS, and the observation that the peat pipe illustrated by the LWP documents has a possible alternative expanation for its formation, the subsequent LWP 2006 EIS shows little sign of having re-considered the arguments and/or made any effort to support the peat-pipe dewatering model with evidence. Thus the LWP 2006 EIS simply re-states what are by now becoming remarkably familiar statements:

*"**The most promising link with dewatering might involve subterranean pipe systems**, which seem important in the overall water balance of blanket bogs (see Chapter 10 of this volume (LWP)). However, the cause(s), frequency and extent of influence of dewatering, including the pathways of transport of water and much unconsolidated amorphous peat, are major unknowns."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 36

*"Habitat effects due to altered hydrology under disturbance and change above are not necessarily new phenomena for the vegetation types of North Lewis. Switches to drier and wetter conditions, as well as drainage effects around ditches, have **direct parallels in the vegetation changes related to natural dewatering processes which seem extensive in North Lewis peatlands**."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 69

*"**Gully development following de-watering, as a natural process, is very extensive**, with large areas (72.9% of blanket bog extent) having moderate and heavy drying impact as a result ... Most [ditches] are choked by strong bog moss Sphagnum growth. They are unimportant as a cause of drying peat habitat. **Natural erosion is the principal direct cause of peat drying**."*

LWP 2006 EIS, Vol.5, Appendix 11B, para 81

One of the most obvious aspects of the peat-pipe dewatering model that is never satisfactorily explained, even at a hypothetical level, is how peat pipes can explain all the observed erosion. The model in effect says that most eroded bogs on Lewis must have at least one major peat-pipe system causing this dewatering, and thus it would be reasonable to expect that all stages of sink-hole development, collapse, and dewatering could be found fairly readily throughout the Lewis peatlands, given the very large number of examples available.

In fact many areas of erosion show no sign of peat piping or sink holes. The extent of erosion within each mesotope also requires that every mesotope had been influenced over its *whole* area by such piping and dewatering – in other words that such drainage effects can extend across entire mesotopes. In addition, the theory raises the question of whether all erosion everywhere in Britain is caused by peat-pipe collapse. If not, then why should the mechanisms behind erosion in Lewis differ from the mechanisms of erosion in, for example, western Sutherland, especially as the appearance of the resulting erosion is so similar?

These questions are important because they highlight several potential weaknesses in the peat-pipe dewatering model, and it is thus precisely these questions that demand evidence to corroborate the peat-pipe dewatering model and refute alternative mechanisms. Such evidence is not, however, provided by the LWP EIS dcouments.

Indeed, having raised the question of other models, what is not as widely repeated within the LWP EIS documents is the observation that:

> *"This **conclusion [about the natural drying process] is very different from the interpretation of results from the adjacent SAC, where the long-term impacts of burning are blamed for frequently poor condition**. Burning was probably much more extensive in the past when seasonal stock grazing and use of now-abandoned shielings was widespread. It will undoubtedly have had a considerable effect."*
>
> *LWP 2004 EIS, Vol.7, Technical Report, Chapter 6.2*

...but the acknowledgement of burning as a possible cause of erosion is immediately quashed, again without any attempt to provide contrary evidence to that presented by the SAC survey (Dayton, 2003)...

> *"However, much of the **dry character and high extent of dry wet heath and blanket bog vegetation is best explained in terms of hydrology**, not historical management by burning."*
>
> *LWP 2004 EIS, Vol.7, Technical Report, Chapter 6.2*

Indeed burning is firmly dismissed as a significant factor:

> *"Burning the heather, previously a common agricultural practice to encourage fresh shoots more suitable for livestock, leaves fine ash that blocks flow pathways through the matrix of the peat. **Although this practice has been reduced on Lewis it is not currently considered a major problem** (T. Dargie, pers. comm.)."*
>
> *LWP 2004 EIS, Vol.5, Appendix 10D, para 65*

Dayton's findings are again dismissed in the LWP 2006 EIS:

> *"On the basis of results of survey from the HSA, the dry character and high extent of blanket bog, wet heath and some dry heath vegetation in the SAC are best explained in terms of hydrology, not historical management by burning."*
>
> *LWP 2006 EIS, Vol.5, Appendix 11b, para 84*

As will be explored further in the next chapter of the present report, this view does not accord with SNH's condition assessment of the SAC, where burning is regarded as a significant issue.

5.3.5 Peat pipes as constructive features – an alternative model

The underlying assumption in the LWP EIS documents is that peat pipes are necessarily and invariably destructive features, linked to collapse and degradation of the overlying blanket bog habitat. The fact that no actual examples are presented, demonstrating evident collapse and obviously-linked erosion, perhaps points to the difficulty of finding such phenomena because they are comparatively rare or even absent. Evidence for the theory may be widespread, but there is no way of knowing because such evidence is not presented by the LWP EIS documents.

An alternative model of peat pipes and sink holes has, however, been previously presented along with at least some tentative supporting evidence. Lindsay (2005, 2007) presents a model of peat pipes as constructive features which result from vigorous bog growth rather than from bog collapse. The model will be outlined briefly here, and some evidence presented, although it must be understood that this is only a working hypothesis based on a range of observations in different parts of Britain, rather than a proven mechanism.

In speculating about the processes by which peat pipes may form, Holden and Burt (2002) comment that development of water channels through hare's-tail cotton grass (*Eriophorum vaginatum*) can become roofed-in by overgrowth of peat. The present authors have also witnessed a number of occasions where an established stream-line, flowing on the mineral sub-soil, has become almost completely roofed-in by the growth of deep peat on either bank of the stream-line.

It seems that if the peat grows sufficiently vigorously, then the stream-line may indeed become completely roofed over and vanish from view, other than as a faint linear indentation within the peat blanket, apart from occasional areas which, for one reason or another, remain open as small 'windows' into the stream below. Examples of such conditions are presented here as Figure 52, Figure 53, Figure 54, Figure 55 and Figure 56, including six sites from the Lewis peatlands and one (the ground photos) from Plantlife International's Munsary Peatlands Reserve in Caithness.

Holden and Burt (2002) observe that peat pipes are not, however, found solely at the interface between the mineral and the peat and thus the simple story that streamcourses running over mineral soil become overwhelmed by surrounding peat growth is clearly not the whole story. It may, of course, mean that some stream-lines become overwhelmed while they flow over a peat surface, as suggested above by Holden and Burt (2002), but this does not explain the sometimes tortuous route that many (most?) pipes appear to follow, according to those authors. Holden and Burt (2002) are also hesitant to suggest how such unpredictable routes through the peat might develop. These mechanisms await further study.

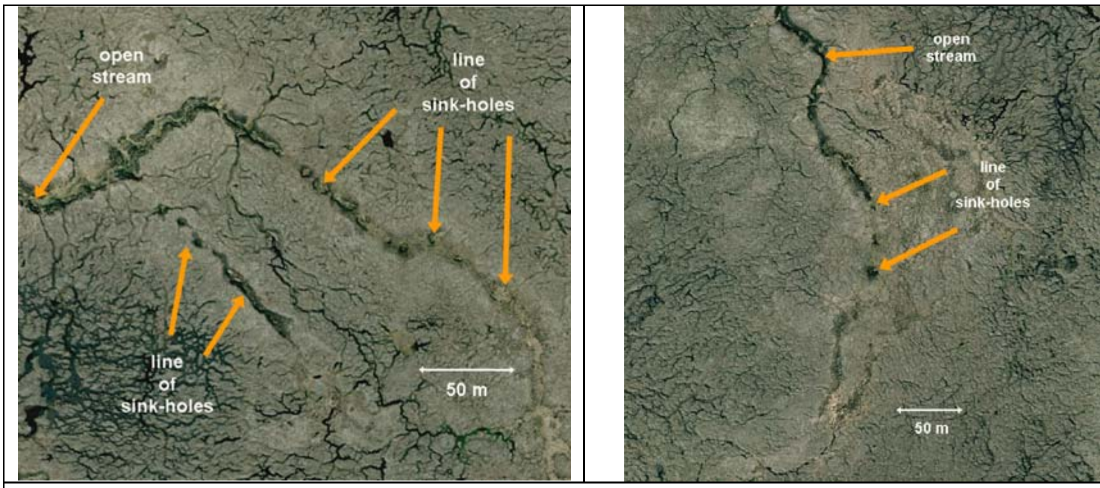


Figure 52. Examples of peat pipes on Lewis : 1.
(Left): Line of sink holes (and thus presumed peat pipe) associated with the headwaters of a stream-line at NB 526582. **(Right)**: Line of sink holes and seepage line associated with the headwaters of a stream at NB 534581.

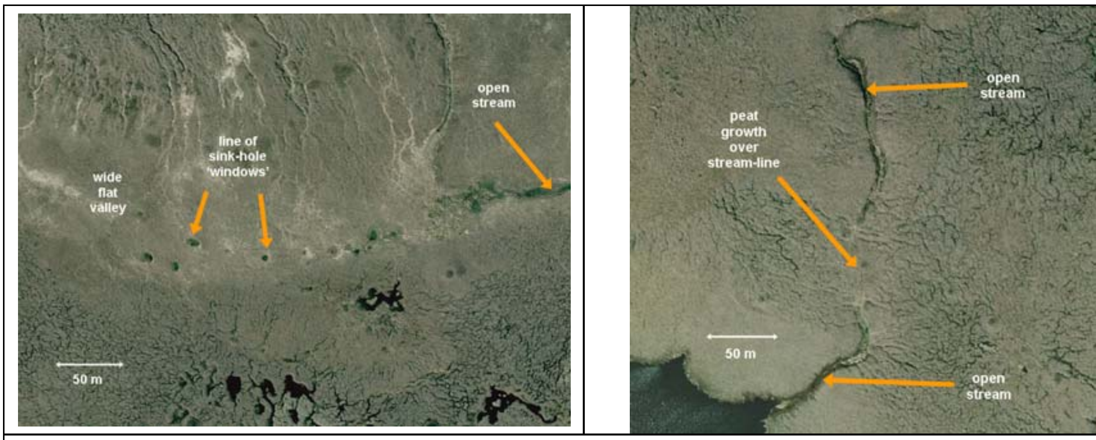
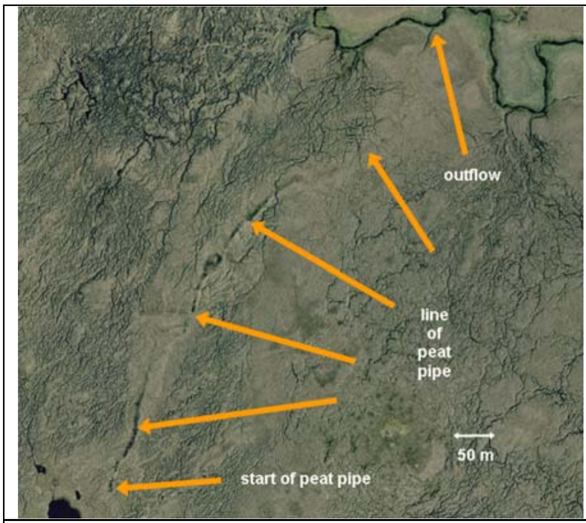


Figure 53. Examples of peat pipes on Lewis : 2.
(Left): Line of flushed sink hole 'windows' associated with the wide valley and headwaters of a stream-line at NB 428425. The green colour of the 'windows' indicates somewhat base-rich vegetation. **(Right)**: Stream-line completely smothered by peat growth across part of its length at NB 422422. The upper part of the stream-course is partly a semi-exposed peat pipe which disappears beneath the deep peat that smothering the stream-line, before emerging to empty into the loch.



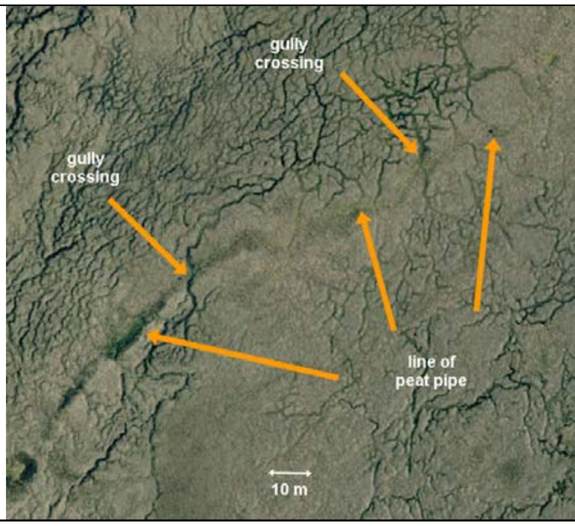


Figure 54. Examples of peat pipes on Lewis : 3.
(Left): Line of a presumed peat pipe, extending for almost 800 m with no clear sink holes along its length. A single sink hole seems to form the beginning of the pipe at NB 318436. **(Right)**: Curiously, the line of the pipe appears to cut across (beneath) several erosion gullies, with neither feature apparently responding to this crossing point.

Aerial photo © Getmapping.com 2006

Figure 55. Example of stream becoming overgrown by active peat growth.
Stream-line in blanket mire at Plantlife International's Munsary Peatlands Reserve, Caithness (ND 219442). (Left): View downslope along the stream-line. The green vegetation in the centre of the photograph has formed a bridge over the stream-line, while open water remains visible in the near foreground. (Right): A closer view of the stream-line, showing the depth to the water level. Just slightly upstream from this point, the stream-line is covered by a short length of peat bridge.

Photo (c) R A Lindsay 2005

Figure 56. Detailed views of Lewis sink hole and peat pipe.
(Top left): Sink holes linked to peat pipe, with one sink hole arrowed (orange) at NB 448568. **(Top right)**: View of arrowed sink hole at ground level, with Jamie Freeman photographing bottom of sink hole. There is no evidence of jumbled 'collapse' material. There is instead a fairly smooth slope down to the base of the hole. **(Bottom left)**: View of sink hole base, with small stream running out from hole in peat, flowing over peat ridge then plunging 20 cm to mineral sub-soil, before vanishing into another hole. **(Bottom right)**: Close-up of small stream about to vanish into downslope hole, flowing on mineral sub-soil.

It is sufficient for the moment to note that there are tangible examples of all stages in the apparent overwhelming of established streams by surrounding peat growth. If anything, such features thus seem to be a creation of vigorous, active peat growth rather than being a factor in a degenerative phase of peat dynamics.

One thing worth noting in particular is the apparent extraordinary length of the presumed peat pipe in Figure 54. It extends for 770 m. Remarkably, it appears to follow a route that is independent of surface erosion gullies, which cross it at various places without apparent effect. This emphasises the need for caution when considering the possible area of impact when features such as peat pipes are involved. It is an issue that will be considered further in later chapters.

It is also worth contrasting the above evidence with the pipe structures identified for Moor House National Nature Reserve by Holden and Burt (2002). One of the longest pipes investigated by these authors (Pipe 11) is described as arising in a pool system and ending in an open gully system. The nature of the ground associated with this pipe can be seen in Figure 57, from which it is evident that the character of the peat-pipe line is somewhat different from that observed in northern Scotland. There are no ‘windows’ to the stream below, but there are instead what appear to be linear crack-like features which may indicate the line of Pipe 11.

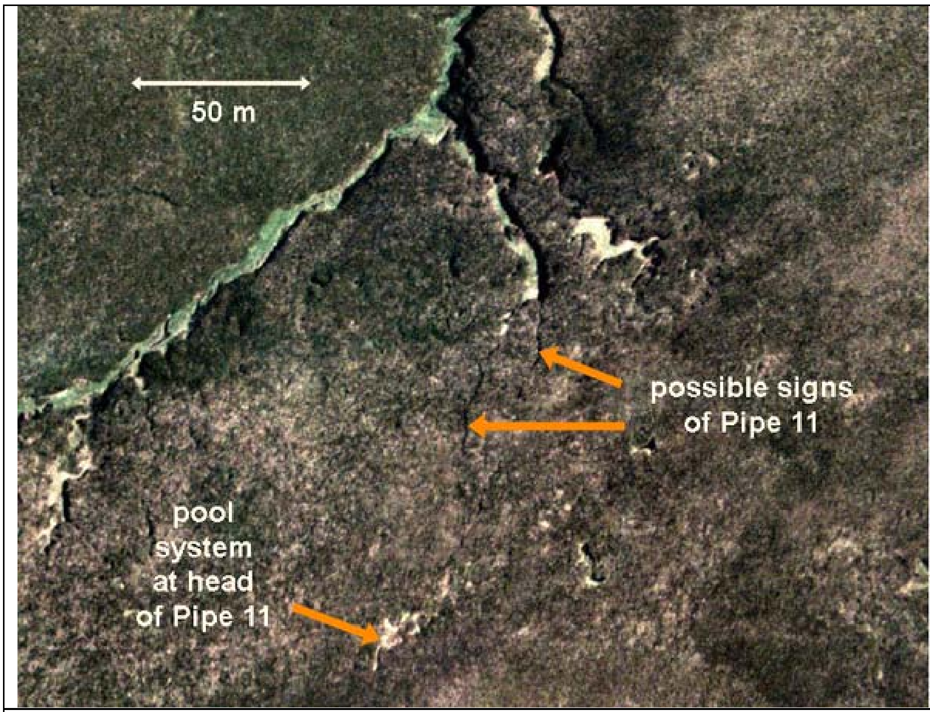


Figure 57. Peat pipes in the Pennines – aerial view.
Ground beneath which Peat Pipe 11, described in Holden and Burt (2002), runs through Moor House National Nature Reserve, north Pennines, UK. Aerial photograph is centred on National Grid Reference NY 768321. Pipe 11 begins in the pool system (arrowed orange), and then empties into the green gully-stream-line in the upper-centre of the photograph. Long narrow lines can be seen associated with the (approximate) course of Pipe 11. These may be cracks, or seepages, or simple surface depressions associated with Pipe 11.

As Holden and Burt (2002) indicate, so little work has so far been undertaken into the nature and hydrology of peat pipes in blanket peat that it is very difficult to generalise, or to make further comment on the apparent differences between Holden and Burt's (2002) peat pipes and those observed on Lewis.

The examples of Figure 52 to Figure 56 from Lewis and Caithness are thus not proof of an alternative explanation for the peat pipes of Lewis, but they do present several tangible examples of the way in which it is *possible* that streams may become overwhelmed by vigorous peat growth and thus become a peat pipe. This is an area of ongoing research, both into the physical nature of peat pipes, which obviously by their very nature are not easy to map, and their hydrological significance for blanket mire systems. Holden, Burt and Vilas (2002) demonstrate one possible way forward in terms of mapping the physical dimensions and extent of peat-pipe systems using ground penetrating radar (GPR), though they highlight the current intensive nature of sampling, and consequent improvements in technology necessary to make this a system suitable for large-scale mapping. They conclude by observing:

> *"The application is limited, however, in that GPR demonstrates the presence of pipes but does not establish their hydrological importance or connectivity."*
>
> *Holden, Burt and Vilas (2002)*

What is lacking from the LWP EIS documents is any set of locality descriptions, measurements, target notes or even photographs that clearly demonstrate LWP's proposed linkage between peat pipes, sudden collapse of pools, and subsequent widespread breakdown of entire bog systems (mesotopes). Furthermore, there is no attempt in the LWP 2006 EIS to address the questions about peat pipes and erosion raised by Lindsay (2005) when commenting on the LWP 2004 EIS document.

5.4 Eco-hydrology of peatlands and peatland drainage

The LWP EIS documents have four main strands to their argument about the distance over which drainage and other hydrological impacts are likely to occur:

measurements of peat moisture levels in cut peat faces within the development area;
the review of wetland hydrology published by Dr Kevin Gilman, CEH;
published figures for the hydraulic conductivity of peat, particularly by Boelter (1965, 1972) and Holden and Burt (2002);
detailed hydrological studies carried out at Farr Wind Farm, Inverness-shire.

The key document of these four is undoubtedly now regarded by LWP as the report from the investigations carried out at Farr Wind Farm, presented as LWP 2006 EIS, Vol.5, Appendix 11e : Farr Dipwell Studies. The work described is extensive, detailed and to some extent employs specialist methodologies. It was thus considered more appropriate by the authors of the present report that a fully qualified peatland eco-hydrologist should review the Farr Wind Farm work. Consequently Dr Olivia Bragg, University of Dundee, has prepared an assessment of the work at Farr. This has been produced independently from the remainder of this report. Dr Bragg's analysis of the Farr Dipwell Studies is presented as Appendix 1 of the present report.

The Farr dipwell work will thus not be commented on further, other than to pick up various points made by Dr Bragg about that study, and the conclusions which then have relevance for the impact evaluations of the LWP 2006 EIS.

Consequently the present section will focus on the other three sets of information provided by the LWP EIS documents, namely the peat moisture studies, the published figures for hydraulic conductivity in peat, and the review of wetland hydrology by Gilman (1994).

5.4.1 Measurements of peat moisture content

Both LWP 2004 EIS, Vol.3, Chapter 10 (10.6.3.5) and LWP 2004 EIS, Vol.6, Appendix 10D, paras 70-74 present the same data obtained from two peat-cutting faces on Lewis. One face was relatively freshly cut (NB 401531) while the other face was an old face that had weathered significantly (NB 325448). Peat samples were taken at a depth of 0.2 m from both locations, at distances of 0 m, 0.5 m, 1 m, 1.5 m, 2 m, 3 m, 4 m and 6 m from the cut face. These samples were then used to calculate moisture content of the peat. The results are presented as a graph of % moisture content against distance from cut face (LWP 2004 EIS, Vol.3, Chapter 10, Diagram 10.1 and Vol.6, Appendix 10D, Diagram 10D.1).

As no data table is produced to accompany the graph and the LWP EIS documents are password-protected, it is not possible to reproduce the diagram here, short of reading the figures as carefully as possible from the diagram and creating a new graph. However, the essentials of the two moisture curves are simple enough to describe:

- Both curves show that moisture content is much lower close to the peat faces than is found at distances of 1 m or more away from the faces. The figures rise from 67% moisture content near the face to around 85% at 1 m distant from the face.
- Interestingly, the figures at the peat face are not the lowest moisture contents obtained. After rising to a moisture content of 86% at 1.5 m from the peat face, the moisture content of the fresh peat face falls to a low of 63% at 2 m.
- The fresh-cut face then shows another rise, to 81%, at a distance of 3 m from the face.
- Moisture content for the fresh-cut face then tails off gradually to 75% at 6 m.
- The older face, in contrast, rises to a moisture content of 87% at 1.5 m, then falls to 72% at a distance of 4 m.
- Finally moisture content associated with the older face rises again to 87% at 6 m distance from the face.

These results are most illuminating. They are presented by LWP 2004 EIS, Vol.6, Appendix 10D, para 72 as showing, firstly:

> *"...that cutting through the peat will result in the peat face drying out by approximately 20%. The final moisture content of the relatively new cutting and the older cutting is similar (65-68%)*

suggesting that any drying of a newly cut peat face occurs within a year and reaches equilibrium."

and secondly (LWP 2004 EIS, Vol.6, Appendix 10D, para 74) that there is:

"...no significant lowering of the water table within 5 m from the cut face."

The first thing to understand about these figures, and these interpretations, is that the moisture content of undisturbed blanket peat is generally greater than 90%. Indeed LWP 2004 EIS, Vol.7, Technical Report, Chapter 3, p.2 observes that Moores and Stevenson (undated) recorded moisture contents of peat samples in excess of 90%, even though they are sampling in areas rich in *Racomitrium lanuginosum* and thus, presumably, not the wettest of bog surfaces. Meanwhile LWP 2004 EIS, Vol.6, Appendix 10D, para 26 notes that:

"Typical moisture contents [of peats in the area] ***range from 90% to 100%****, but in localised pockets of amorphous peat, the moisture content is considerably higher and* ***frequently exceeds 1000%****."*

It is also worth noting that in Ireland, the main peat extraction body, Bord na Mońa, has this to say about industrial peat extraction and moisture content:

"Before development work starts on the bogs they are surveyed and a drainage plan is designed to suit the subsequent production system. For Bord na Móna the plan generally involves a network of parallel open drains 15m apart ... In the milling operation a thin layer of peat, usually about 15mm deep, is cut from the surface of the bog where it is left to air dry over a period of a few days. This layer of peat is called a crop. ***Typically the water content of the crop after milling is about 80%****."*

Bord na Mońa (2001) and website

Given this context, the figures for % moisture content presented in LWP 2004 EIS, Vol.3, Chapter 10 (10.6.3.5) and LWP 2004 EIS, Vol.6, Appendix 10D, paras 70-74 take on a new light:

- the entire series of moisture contents for both peat faces lies significantly below the 90%$^{+}$ values that would normally be expected as a minimum for a sample of blanket peat in Lewis;
- indeed the values obtained largely lie below the 80% moisture content regarded as the drying target required prior to gathering up a milled peat crop from an industrially-worked bog in Ireland.

The methodological problems associated with this moisture-sampling exercise mean that it is not really possible to draw many conclusions from the data, other than:

- without a % moisture content from a typical area of uncut bog, these figures are to some extent meaningless – or at least they lack a decent reference point from which to make a comparison;
- in the absence of any information about the nature of the bog surface examined (nanotopes and vegetation) it is difficult to draw any conclusions about the shape of the moisture curves after the first 1 m or so from the cut face, because features such as a hummock or hollow, *Sphagnum*-rich ground or bare peat, would each influence the result enormously;
- the resulting data suggest that the transect used was much too short, like looking at someone's ECG from 3 mm away and becoming alarmed that the trace is flat, when in fact you are merely looking at the brief pause between heartbeats;
- the whole body of peat associated with these cuttings appears to be extraordinarily dry, possibly as a result of being cut...?

These are the confident observations of LWP 2004 EIS, Vol.3, Chapter 10, para 52:

> *"The results **indicate that cutting through the peat will result in the peat face drying out by approximately 20%**. The final moisture content of the relatively new cutting (approximately 1 yr old) and the older cutting is similar (65-68%), suggesting that any **drying of a newly cut peat face occurs within a year and reaches equilibrium**, (that is, does not get any drier with age)."*
> *LWP 2004 EIS, Vol.3, Chapter 10, para 52*

Some of the above statement is indeed literally correct, but the *implications* and *context* of these facts are neither explored nor even presented. Within the same LWP EIS document, figures of 90%-1000% moisture content have been described as the norm, yet no connection is then made with presented values which fall as low as 67%. It is implied that a 20% fall in moisture content is somehow insignificant. The problem lies with the fact that the wrong 20% is being considered. It appears that the 20% referred to is the fall from 85% to 65% at the cut peat face. What should be of much greater concern is the 20% fall from 95% to 75% across the whole length of the transect.

The remainder of LWP 2004 EIS, Vol.3, Chapter 10, para 52 concludes thus:

> *"The results indicate that effects of peat cutting and peat **drying remain close to the peat face, with no significant lowering of the water table within 5m** from the cut face."*
> *LWP 2004 EIS, Vol.3, Chapter 10, para 52*

Again, this statement is literally correct but depends, as we shall see in the next section, on one's definition of 'effects', and 'significant'.

5.4.2 Surface water, groundwater and drainage

These three terms are possibly the most important concepts in peatland eco-hydrology. They are also, alas, the most muddled, misunderstood and mis-quoted. The crux of the story lies with the two-layered nature of a bog system.

Essentially, the lower, thicker layer of peat that gives a bog its shape is known as the catotelm. This mass of peat retains a high water content under most normal conditions. This is partly because the peat is protected from the drying effects of the atmosphere by the second, upper layer of the bog – the much thinner acrotelm. A second reason for the high water content of the catotelm is that water usually flows through catotelm peat extraordinarily slowly. A rate of 80 cm per day would be moderately swift for many types of catotelm peat.

The acrotelm is an altogether different environment. Firstly, it is very thin. For many blanket bogs it is no more than 10 cm deep. It is also fairly permeable, so water can flow sideways, down, or up through it relatively quickly, although downwards becomes increasingly difficult as the lower layers of the acrotelm are reached. Typical flow rates for the acrotelm are difficult to give, because, as Gilman (1994) observes, Boelter (1965) recorded permeabilities that ranged from 0.65 cm per day in catotelm peat, then to 33 m per day for a living moss cover (effectively the upper layer of an acrotlem), and even found flow rates so large (because of large spaces within in the layer through which water could travel easily) that he was unable to obtain a meaningful permeability value.

For the Pennines of northern England, Holden and Burt (2002) have undertaken what has been the most comprehensive survey to date of peat pipes and their hydrology. In setting out the context for their work, Holden and Burt (2002) present a conceptual model of water flows in blanket bog, based on a synthesis of published work concerned with Pennine blanket mire hydrology. This conceptual model for the Pennines has an acrotelm with a thickness of 10 cm and an underlying catotelm of 2.5 m thickness, sitting on an impermeable clay base. Holden and Burt (2002) give typical rates of seepage (hydraulic conductivity) for a Pennine acrotelm, ranging from 10^0 cm s^{-1} to 10^{-4} cm s^{-1}. The fastest rate means that seepage occurs at more than 860 m per day, while the slowest value is equivalent to little more than 0.8 m per day.

It is important to understand that these differing rates of throughflow do not necessarily reflect differences between sites; it is just as likely that such differences can be found on a single site between surface elements lying within quite close proximity to each other. Thus a soft, *Sphagnum papillosum*-rich area of T1 low ridge (*sensu* JNCC, 1994) will certainly have a much higher rate of throughflow than an adjacent area of somewhat trampled, *Calluna/Eriophorum vaginatum*-dominated, T2 high ridge (*sensu* JNCC, 1994).

Turning now to Holden and Burt's (2002) conceptual catotelm, they give typical hydraulic conductivities for Pennine blanket peats as 10^{-6} m s^{-1} to 10^{-8} m s^{-1}, which equate to throughflow rates of just over 8 mm per year down to a rate of less than 0.1 mm per year. While these values emphasise the usually very slow rate of water movement through the catotelm, it is important to understand that, just like the acrotelm, the catotelm is not a uniform material. It can display considerable variability in structure and composition, with associated implications for the hydraulic conductivity of particular layers within the catotelm. The highly variable nature of this layering in the Lewis peatlands is emphasised thus:

"Exposed faces in road cuttings reveal ***a well-banded or laminated structure in the peat profile*** *with marked variations in thicknesses of individual layers over short distances. Typical moisture contents range from 90% to 100%, but* ***in localised pockets of amorphous peat, the moisture content is considerably higher and frequently exceeds 1000%*** *(Dr D. Nichols, pers. comm.)"*

LWP 2004 EIS, Vol.6, Appendix 10D, para 26

Moreover, the whole thrust of Holden and Burt's (2002) paper is that the catotelm is not a uniform, homogeneous structure but is instead often perforated by natural pipes that run, generally rather tortuously, through the body of the peat, as discussed in Section 5.3.5 of the present report. Holden and Burt (2002) demonstrate that such peat pipes play a significant role in assisting water to move through the peat body. Importantly, they also emphasise that overland flow, which arises when the acrotelm becomes full (at least conceptually in their model[3]), also plays a major part in moving water downslope through a peat-dominated catchment.

Various issues emerge from the foregoing:

- water flow through the acrotelm layer can be remarkably rapid. Some of the most freely-flowing examples of acrotelm structure would permit throughflow to cover a distance of 1 km in little more than a day;
- such a uniformly porous acrotelm would rarely be encountered because the acrotelm generally consists of different microtope components, such as ridges and hollows, that each possess different conductivities (indeed this is the basis of the 'strip-ridge' structure that provides a mechanism for eco-hydrological homoeostasis in bog systems, as discussed in Section 5.2.4 of the present report);
- water seepage through the catotelm is very slow, but can be much more rapid in certain peat layers, or when there are peat pipes;
- there is an important distinction to be made between 'surface water' that in fact means water flowing *within* the surface layers of a bog (*i.e.* throughflow in the acrotelm), and 'surface water' that truly represents water flowing *over* the surface of the bog (*i.e.* saturation-excess overland flow);
- given these identified sources of variation, it is not therefore meaningful for studies into drainage impacts to work on the basis of a single value for the hydraulic conductivity of either the acrotelm or the catotelm in real-life examples. Even conceptual models acknowledge that the rate of throughflow may vary by several orders of magnitude, depending on the prevailing conditions. This is an important point that is considered below.

To return, therefore, to the question of drainage, it is quite true that cutting a ditch into catotelm peat will not lower the water table far into the catotelm, no matter how big the ditch. Catotelm water losses will always be slow, but the key factor is that the

[3] In practice it is not necessary for the whole acrotelm to become saturated before overland flow begins; such flow is likely to be seen in lower parts of the microtope pattern as these become saturated even while other elements such as high ridges and hummocks remain unsaturated.

catotelm peat suffers slumping (because the water supporting the peat matrix has been lost – as discussed earlier in Section 4.1.2.1). The catotelm peat will also undergo oxidative wastage (because it is now exposed to the atmosphere).

Consequently as the water table falls slowly into the catotelm, so the cut face of the catotelm sinks down to follow it. There is thus rarely a stage when the catotelm is left 'high and dry' because it just keeps sinking downwards, chasing the falling water table. The actual *shape of the ground*, however, is changing because of this progressive slumping and steady loss of peat soil through oxidation (Coupar, Immirzi and Reid, 1997).

In exposing the deeper (catotelm) peat to oxygen along the ditch sides, the presence of the drain causes the peat water table to fall back from the drain face into the catotelm peat during dry weather. This fall may be only a centimetre or so, but that centimetre of catotelm peat then becomes subject to aerobic decomposition, probably for the first time since it was originally laid down as peat. Consequently this newly-dry peat is partly or wholly lost as decomposition products (mainly water and carbon dioxide) through oxidative wastage.

Each time the drain face dries out, a little more peat is lost, even though the water table never falls more than a few centimetres into the catotelm peat, and so the drain gradually widens and the peat in the immediate vicinity of the drain sinks. What is far less intuitively obvious, however, is that a drain in peat also causes the peat *beneath* the drain to shrink (Egglesmann, 1975) through consolidation of the peat. These various processes often causes drains to lose their ideal profile. Consequently it is standard practice to have a regular programme of drain maintenance. Just such a programme is specified in LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS 4, para 41, which states that regular maintenance activities will include clearing of drainage ditches – which means that still more peat is lost from the ditch as the slumped peat is removed.

The effect of this, over time, is that the ditch sinks deeper into the peat and the bog surface on either side of it (including the adjacent road surface) is slowly dragged down with it. The effects in any one locality are unpredictable because, as Egglesmann (1975) demonstrates, compression and consolidation are highly dependent upon the nature of the peat being drained, and this can vary substantially within distances of less than a metre. Thus the road and ditch system will tend over time to sink into the peat in a variable way, more in some places than others, but all parts showing this trend to a greater or lesser degree.

5.4.3 The acrotelm and drainage

The critical thing about drainage is what it does to the acrotelm. The acrotelm is of course where the living vegetation is found, and we have already learned from Ivanov (1981) that changes to maximum water levels of only 4-5 cm can result in replacement of one type of moss cover with another vegetation type.

Let us return, therefore, to the guidance produced by Bord na Mońa for industrial peat mining:

> *"Undrained bog, or virgin bog as it is called, has a water content of approximately 95%.* ***Bogs are drained to reduce the water content of the surface and increase bearing capacity****. This*

permits the use of larger and therefore more economic machines in the production process and also substantially reduces the amount of water that has to be removed from the peat during drying.
***Reducing the water content of the surface of a bog from 95% to 80% removes more than 75% of the water from the surface layer**."*

(Bord na Mońa, 2001)

Figure 58. Appearance of fresh-dug drain and long-established drain in blanket bog. Process of drain enlargement and deepening over time on blanket peat, central Sutherland. The photograph on the left shows a recently-dug 'moorgrip' drain. The photograph on the right shows a long-established drain with associated deepening of drain-base, erosion of ditch sides (clearly this drain has not been maintained for a very considerable time), and dominance of woolly hair moss (*Racomitrium lanuginosum*) showing as pale patches in the adjacent vegetation, indicating that the bog surface is relatively dry. Moorland drains are not normally dug in dry vegetation; it may thus be reasonable to assume that the vegetation prior to drainage was wetter than at present.

Photos (c) (left) J B Ratcliffe 1982; (c) (right) R A Lindsay 1983

It requires no great imagination to visualize how profoundly the living vegetation of the acrotelm is likely to be affected by removal of "more than 75% of the water from the surface layer." Consider too the notion that the moisture content of the tested cut peat faces described above in Section 5.4.1 was largely at or below 80% across both transects.

The LWP EIS documents cite various studies, including those of Boelter (1972), and Stewart and Lance (1983, 1991), and Gilman (1994), who all observe that the main effect of drainage is to speed up removal of 'surface water' during periods of high water table. We have seen in Section 5.4.2 above that this term has the potential to be highly ambiguous. Does removal of 'surface water' refer to removal of overland flow, or does it mean removal of surface *throughflow*, or does it in fact mean both? The difficulty is that these publications make no clear and explicit distinction between the two versions of 'surface flow'. Boelter (1972) talks of both "surface or near-surface fibric horizons", but makes no specific mention of 'overland' flow. Gilman (1994) considers the question of 'throughputs' and 'surface flow', but he then confuses the issue by mixing together the same concepts referred to by Boelter (1972):

> *"When this* ***surface or near-surface flow****, for instance* ***through the undecomposed vegetation of bog-mosses*** *or* ***through a network of runnels*** *between Molinia caerulea (purple moor-grass) tussocks, is intercepted by open drains, the still higher conveying capacity of the drains* ***serves to remove excess water*** *and keep the water level from rising higher."*
>
> *Gilman (1994)*

It is not clear what distinguishes 'surface' from 'near-surface' flow. Is the former 'overland flow' while the latter is intended to mean 'acrotelm throughflow'? No explanation is provided. The two examples given, however, clearly represent these two differing differing conditions – the former describes acrotelm throughflow, whilst the latter is obviously overland flow. As such, Gilman's (1994) examples tend to re-inforce the idea that his discussion about 'surface flow' combines these two types of flow into a single concept. There is also the question of what is meant by the 'excess water' being removed by drains. Does this refer to overland flow, or is a fully saturated acrotelm also considered 'excessive'?

Whatever the confusion about 'surface', 'near-surface' or 'excess' water, when he talks about groundwater drawdown only being measurable for a distance of some 5-50 m Gilman (1994) does consistently refer to 'groundwater' (*i.e.* he appears to equate 'groundwater drawdown' with drawdown into the <u>catotelm</u>). By implication, this also suggests that Gilman (1994) equates the process of 'removing excess water' and 'preventing rising water levels' with actions concerned with effects on surface layers, involving more rapid loss of *both* overland flow *and* near-surface acrotelm flow – *i.e.* the major effect of drainage is that it empties the acrotelm.

To bring some clarity to the vexed question of 'surface flow', we can turn again to Holden and Burt, although in this case we must look to their paper on runoff production in Pennine blanket peat (Holden and Burt, 2003). They identify that within the Trout Beck catchment at Moor House, 81.5% of runoff volume occurs as overland flow, 17.7% occurs within the upper 5 cm of the peat, and almost all the measurable remainder occurs at depths between 5 cm and 10 cm. From this it is clear that 'surface flow' in Trout Beck blanket peat consists of overland flow and acrotelm throughflow in a ratio of rather more than 4:1, at least on moderate slopes. The story is not so clear on more gently sloping areas within the study plot. What does emerge, however, is the nature of this 'overland flow', because Holden and Burt (2003) provide a small explanatory note when describing this phenomenon:

> *"Here overland flow (or at least surface ponding) was recorded by a network of 250 crest stage tubes..."*
>
> *Holden and Burt (2003)*

Thus it appears that at least a proportion of measured 'overland flow' actually consists of standing water ponded behind microtope elements, and that this water eventually seeps away through or around these elements by acrotelm throughflow. If so, then there is an extremely close coupling between overland flow and acrotelm throughflow and it perhaps does not therefore make much sense to try to separate these when considering the potential effects of drainage. Both surface ponding and acrotelm throughflow are short-circuited in the presence of a drain.

Holden, Evans, Burt and Horton (2006) shed some valuable light on just how dramatically this drainage short-circuit process can alter the hydrological characteristics of a typical blanket mire. In re-examining and re-measuring the four blanket peat catchments originally studies by Conway and Miller (1960), Holden *et al*. (2006) demonstrate that the two undrained catchments show much the same response as Holden and Burt (2003) found for the Trout Beck. Runoff is dominated by overland flow (averaging 78.5% between the two catchments) together with a small proportion derived from acrotelm throughflow within the upper 10 cm of the peat (20.5% averaged between the two catchments). This gives an overland-to-throughflow ratio of just under 4:1, which is remarkably similar to that obtained for the Trout Beck catchment.

In contrast, Holden *et al*. (2006) found that the artificially drained catchment derived only 37% of its runoff from overland flow. Acrotelm throughflow within the upper 10 cm also gave rise to 37% of runoff, giving an overland-to-throughflow ration of 1:1. Significantly, however, peat depths between 10 cm and 1 m contributed as much as 26% to the total runoff volume in the artificially drained catchment.

This final figure is most telling. In the absence of drainage, at least 99% of all runoff has direct contact with the living surface vegetation. In the presence of drainage, more than a quarter of all throughflow no longer interacts directly, if at all, with this living surface.

The findings of Holden *et al*. (2006) in effect confirm the somwhat ambiguous but implied suggestion by Gilman (1994) that the real impact of drainage is felt by the living surface of vegetation and the shallow acrotelm immediately beneath it. Indeed although Gilman (1994) is cited by the LWP EIS documents as the key authority for the use of a 50 m buffer zone in relation to drainage and peatlands (because this is stated to be the limit of measurable drainage influence), more careful reading of Gilman (1994) reveals that almost all of his comments relate to the drawdown of water into the humified layer of the *catotelm*, rather than the effect of drainage on the *acrotelm*.

It would be possible now to devote several pages of the present report to a detailed review of Gilman's comments about surface-water hydrology, but a few key points will instead be drawn out here. Should the present reader wish to explore the detail of Gilman's (1994) descriptions, you are encouraged to refer to his section on "Throughputs" in his Chapter 3, as well as to his concluding Chapter 5. Read these with the understanding that 'water-table draw-down' means draw-down into the *catotelm*, and that descriptions of 'surface water' refer to the behaviour of water in the *acrotelm*. In so doing, the reader may find that much of what is written in the LWP EIS documents can be seen in a rather different light.

To repeat Gilman's (1994) observations again, but this time also in a different light, he is at pains to emphasise the considerable effect of drains on the pattern of surface-water hydrology:

> *"When this surface and near-surface flow is intercepted by open drains,* ***the still higher conveying capacity of the drains serves***

to remove excess water and keep the water level from rising higher*. This is the secondary function of arterial drainage:* ***to remove floodwaters as rapidly as possible*** *and prevent the development of an anoxic zone in the upper soil."*

Gilman (1994), p. 63

Echoing the observations of Ivanov (1981) about the sometimes substantial effect on wetland vegetation of small-scale surface water hydrology (4-5 cm, cited earlier in the present report), Gilman (1991) observes that:

"Nicholson et al. (1989) reported a drawdown of only 70 mm [7 cm, compared with Ivanov's 4-5 cm] *at the mid-point between grips* [moorland drains]*. However* ***there is evidence to show that the most significant effects of moor-gripping are through the interception of surface and near-surface*** [i.e. acrotelm] ***water****."*

Gilman (1994), p.64

Given these cited values of draw-down, it is worth repeating that Holden and Burt (2002) recorded a *total* acrotelm thickness of only 10 cm in Pennine blanket peats. Highlighting the importance of water-table draw-down for wetland vegetation types, Gilman (1994) also then states that :

"Much of the decline of summer water table may be attributed to transpiration demand: over the daylight hours plant roots extract water from both saturated and unsaturated zones and water is re-distributed at night...The net effect is a decline in the water table. ***The maximum extent of this decline ... is an important factor in determining the plant community****..."*

Gilman (1994), p. 53-54

The observation about *maximum* extent of water-table decline mirrors the comments of Ivanov (1981) but contrasts sharply with the statement made in the LWP EIS documents about water tables and vegetation control:

"The primary control of vegetation type in British blanket bog is ***generally agreed to be the long-term average water level****"*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 37

No supporting literature is offered in support of this statement.

Evans *et al.* (1999) also highlight the importance of shallow acrotelm water levels on peatland-species performance, observing:

"Bogie et al. (1958) demonstrated that Calluna efficiently recovers nutrients only from depths of less than 15 cm. Eriophorum roots in contrast may withdraw water from depths of up to 50 cm."

Gilman (1994) summarises his thoughts on surface-water [acrotelm] drainage thus:

"Against this must be set the ***probable influence of ditches on***

***surface water**, particularly in the winter, which **reduces flooding and the prevalence of very high groundwater levels by intersecting the natural and semi-natural network of shallow surface channels**, ranging from drainage grips and natural 'water tracks' to the runnels between the tussocks of purple moor grass (Molinia caerulea)."*

Gilman (1994), p.94

Ivanov (1981) might disagree about whether it is winter or summer conditions that are critical, and indeed Gilman even contradicts his own comments about the significance of *maximum* water-table decline on wetland vegetation, but the core message is clear, re-enforced by a concluding:

*"The **layered structure of some mires*** [essentially bogs]*, in which a zone of high permeability occurs near the surface, **can extend the influence of the ditch, and the cutting of drains across a previously undisturbed peat expanse will draw down the water table permanently into the lower layer**, the catotelm ... Certainly **the wetland manager must ensure that the ditch does not intercept surface water from his site**."*

Gilman (1994), p.96

To clarify the pattern of acrotelm change in response to drainage, as described above, it is perhaps helpful to examine an actual record of the water table from an undisturbed blanket bog in Argyll (Coladoir Bog, NM 5329) (see Figure 59).

The natural water level trace in Figure 59 shows two peaks corresponding to days of rain, and between them several downwards steps that represent diurnal rhythms of evapotranspiration during the day and then limited losses at night. Contrasted with this natural trace is a theoretical trace drawn to illustrate the effect of emptying the acrotelm more rapidly in the presence of a ditch, as indicated by the several descriptions of this process given above.

Taking another actual example of water-table behaviour, but this time looking at the critical parameters of maximum and minimum water-table position within the acrotelm, Figure 60 shows the behaviour of these parameters at Cors Caron National Nature Reserve, in mid-Wales (SN 680635). A series of 'Walrags', which are instruments designed to record the maximum and minimum positions reached by water table between readings (Bragg *et al*. 1994), were installed at Cors Caron some years ago. Walrag 2 is positioned 135 m into the bog from the cut edge, and sits in relatively typical raised bog habitat. Walrag 3 is similar, but positioned at only 85 m from the cut edge.

Walrag 6 lies at the north end of the site. Like Walrags 2 and 3 it sits within the main body of the bog, and lies 150 m from the cut edge of the bog. However, the significant difference between Walrag 6 and the others is that Walrag 6 sits within an area that suffered a very serious fire some years ago. Perhaps most significantly for Lewis, this burnt area now displays the only example known to the present authors of an erosion complex on strictly lowland raised bog in Britain (some mires intermediate between raised bog and blanket bog in Scotland are known to display erosion). Walrag 6 therefore sits within a distinct example of severe micro-erosion ('microbroken' bog).

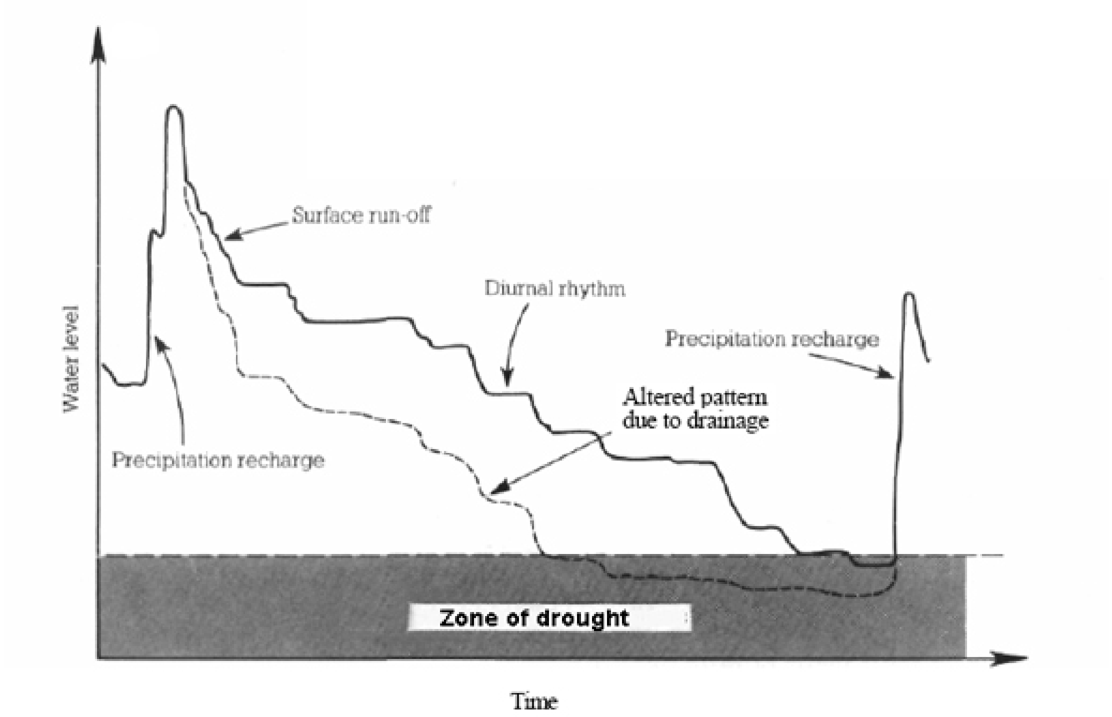


Figure 59. Response of bog water table to increased rates of surface run-off. Water-table plot for the natural blanket mire Coladoir Bog, Argyll (NM 5329), showing a rise in the water table following rain, then rapid loss through surface run-off, and eventually settling into a diurnal step-shaped rhythm of daylight where losses occur through evapostanspiration, and darkness when losses are minimal. The water table just falls into a hypothetical 'zone of drought' before rising rapidly again with the next rainfall. In contrast, a hypothetical water-table plot is provided for the acrotelm in the presence of a drain, which causes more rapid run-off. Consequently the steady diurnal rhythm of loss brings the water-table down into the 'zone of drought' much sooner, leaving the bog surface (and its associated vegetation) to experience several days of drought before being re-supplied by the next rainfall. In other words, in the presence of a drain, drought periods are longer and more frequent.

Adapted from Lindsay *et al.* (1988)

What is clear from Figure 59 is that Walrag 3, located closer to the artificially-cut edge of the bog (a cut peat face acts essentially as a one-sided drain), not only shows a wider range of water-table movement than Walrag 2 which is further from this cut edge, but also cannot sustain as high a water table by some 5 cm (Figure 60: top right and bottom-right). The water table never reaches the bog surface in Walrag 3 (Figure 60 : top right), whereas it can be seen that in Walrag 2 the water table reaches the surface on two occasions (Figure 60 : top left). The maximum fall in the water table for Walrag 3 is 35 cm, which is some 12 cm deeper into the peat than the maximum fall recorded for Walrag 2.

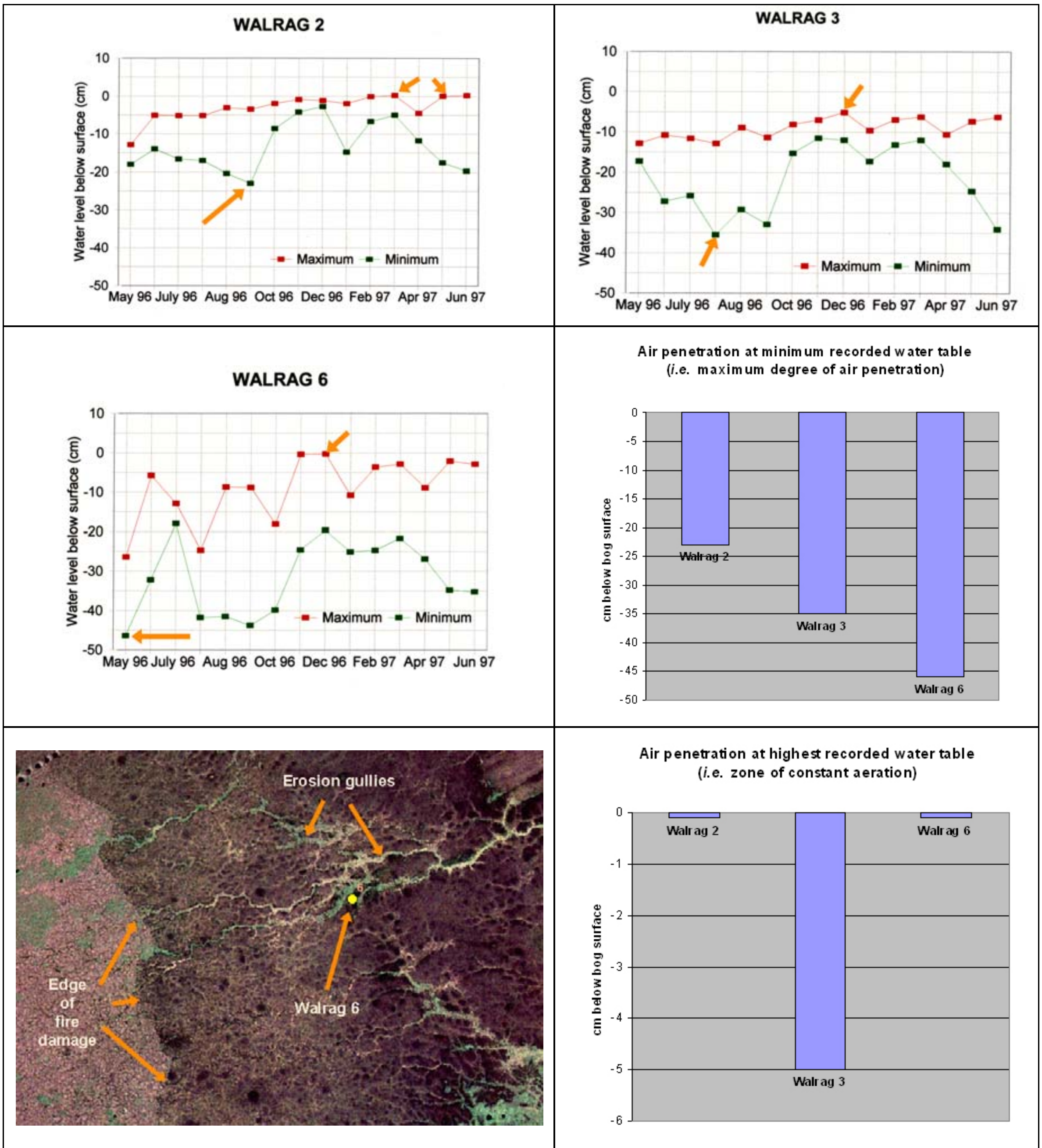


Figure 60. Behaviour of water table at particular locations on Cors Caron NNR, mid-Wales. Data for water-table behaviour at Cors Caron National Nature Reserve, mid Wales (SN 680635). The three graphs display data obtained from Walrags (Water Level Range Gauges – Bragg *et al*., 1994) installed in the raised bog some years ago. The data displayed cover the period May1996 – June 1997. Orange arrows highlight maximum or minimum heights achieved during the recording period. The two bar charts represent simple analysis of the Walrag data to draw out some salient features of the water-table behaviour. **(Top left)**: Data for Walrag 2, positioned 135 m from cut edge of bog. **(Top right)**: Data for Walrag 3, positioned 80 m from cut edge of bog. **(Centre left)**: Data for Walrag 6, located in a burnt, eroded area of the bog, 150 m from cut edge. **(Centre right)**: Maximum air penetration recorded for each Walrag during 12 month run of data. **(Bottom left)**: Aerial photograph of Cors Caron NNR in vicinity of Walrag 6, showing the edge of fire damage (dark is burnt bog), and the pattern of micro-erosion and gullying. Walrag 6 is shown as a yellow dot. **(Bottom right)**: Chart of Walrag data showing air penetration during the highest level attained by the water table at the three Walrag locations during the 12 month run of data.

Data supplied courtesy of Countryside Council for Wales; Aerial photograph (c) Getmapping.com 2006

These are not large values from the perspective of an engineer wishing to drain the peat body, but it is worth again recalling Ivanov's (1981) observation that, in a peatland, changes to water-table maxima and minima of only 4-5 cm can result in the replacement of one moss community with another. The surface vegetation at Walrag 3 clearly spends more time with lowered water tables and longer periods in a drought zone than does the vegetation at Walrag 2. The explanation for this is probably that it is located closer than Walrag 2 to the cut peat face of the bog edge, by some 50 m. Of course we cannot say whether Walrag 2 itself is close to displaying a natural water-table behaviour, because we have no data for parts of the bog nearer the central crown. Perhaps Walrag 2 is also affected, but to a lesser extent than Walrag 3.

Of particular relevance to the hydrological behaviour of the Lewis blanket peats is the response of Walrag 6. This Walrag sits within a relatively mild erosion complex, and is located some 150 m from the cut edge of the bog. Consequently it is located significantly further away from the draining edge of the bog than is Walrag 2. One might therefore expect the water table to show a response rather similar to that of Walrag 2, but it most emphatically does not.

Walrag 6 displays a quite dramatic behaviour, relative to the behaviour of Walrags 2 and 3. When it falls, it does so to depths of almost 50 cm, and although the water table is able to rise as high as the bog surface occasionally, it can be seen that the range of fluctuation between maximum and minimum water level each month is very much greater than that shown by Walrag 2. With the data available, it cannot be said whether this is a result of changes brought about by burning, or by erosion, or both in combination (or indeed by some other less obvious factor). All that can be said with some certainty is that the Walrag that sits within the burnt, eroded part of Cors Caron displays a very different behaviour from other Walrags located in parts of the bog that are free from recent burning and are not eroded.

5.4.4 Acrotelm drainage and the 50 m 'Gilman buffer'

One final point must be clarified here before considering the question of Gilman's (1994) comments on drainage and catotelm effects. The LWP EIS documents cite Gilman's '50 m' zone as the basis of the outer buffer of influence – the PZI. The LWP EIS documents state on more than one occasion:

> *"The **50 m buffer** was chosen, in agreement with SNH, because British research on wetland hydrology (Gilman, 1994) suggests that **the effects of a drain on a wet peatland are unlikely to be measurable over that distance**, and that **most change in peatlands occurs within 50 m of the drain edge and probably over a much shorter distance** in many circumstances."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 50*

Gilman actually states:

> *"At all three sites the influence of the water level in ditches on **groundwater level** in the adjacent peat is shown to be confined to a narrow strip no more than 50 m wide."*
>
> *Gilman (1994), p.94*

> *"Data from Cors Erddreiniog, West sedgemoor and Wicken Fen, featured in this book ... confirm the conclusion of Boelter (1972) that the zone of influence of a ditch on **groundwater levels** is very limited."*
>
> *Gilman (1994), p.95-96*

Gilman (1994) speaks only of influence to the *groundwater* levels, whereas LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 50 speaks of the effects of a drain *on a wet peatland*, and states that *most change in peatlands* occurs within 50 m. These are two very different things. The LWP EIS documents seem to suggest that Gilman's (1994) buffer zone refers to *any* change on a peatland, whereas Gilman himself is very careful always to make clear that he is talking *only* of groundwater drawdown. Indeed he is at pains then to emphasise the real possibilities of change within the environment of the acrotelm. He also discusses in some detail the issues of changes to the ground surface due to slumping and oxidative wastage. These caveats provided by Gilman (1994) in relation to his observations about the effects of drainage are not mentioned by the LWP EIS documents. This is, to say the least, regrettable.

5.4.5 The catotelm and drainage

The issue of 50 m as a zone of influence relates entirely to drawdown in the catotelm peat. As Gilman (1994) observes of the results obtained by Boelter (1972) in measuring water-table draw-down in bog peat:

> *"**Once the water table was drawn down into moderately well-humified (hemic or mesic) peat**, the low permeability meant that the zone of influence of the ditch did not extend beyond 5 m.*
>
> *Gilman (1994), p.64*

The 'mesic', well-humified peat referred to is obviously the catotelm peat, and what is interesting about both Boelter's (1972) results and Gilman's (1994) data is that on some occasions it has been possible to bring about water-table changes in the *catotelm* across distances of up to 50 m:

> *"The ditch in the more undecomposed peat of the Floodwood bog was much more effective. Since these peat materials have higher hydraulic conductivities, water movement was much more rapid and **the ditch influenced the water table elevation the entire length of the** [50 m] **transect**."*
>
> *Boelter (1972)*
>
> *"In less humified (fibric) peat, **the hydraulic gradient towards the drain extended 50 m**."*
>
> *Gilman (1994), p.64*

Gilman's own data from three fen-peat sites shows that in early summer he recorded a clear hydraulic gradient within 'catotelm' fen peat at West Sedgemoor extending for a distance of more than 50 m from a field drain. However, from that date the water level in the drain was artificially raised above the water-table in the field and retained there during the remainder of the summer, thereby providing a vital 109 mm of recharge to the peat by inflow from the ditch. Without this, the peat would have experienced a water-deficit of $^{-}$84 mm. Such groundwater re-charge is not an option for most blanket mire acrotelms (or even catotelms) de-watered by drainage. However, the work again emphasizes that even humified catotelm peat *can* be drained over distances of 50 m or more.

Whilst it is evident that both Boelter's (1972) work concerning a lowland bog, and Gilman's (1994) account of fenland, both deal with peatland systems that are different in character from the blanket mires of Lewis, the same fundamental processes occur on all peat soils.

Furthermore, Holden and Burt's (2002) use of hydraulic conductivity values as high as 10^0 cm s^{-1} for their conceptual model of Pennine blanket mire emphasises that even in blanket mire it is possible to find acrotelm surfaces that have undergone little humification and are thus as conductive or even more so than Boelter's (1972) fibric peat.

Such fibric peat is typical of the vigorous vegetation recovery observed within erosion gullies on Lewis. The extent of these according to LWP's own EIS documents has already been highlighted in earlier sections of the present report, while the next chapter of the present report amplifies on both the nature and extent of such recovering vegetaiton. As such, it is reasonable to assume that the observations of Boelter (1972) and Gilman's (1994) comments about high-permeability mires, do have direct relevance to the Lewis peatlands.

Indeed Gilman's (1994) evidence for surface slumping, and the observations made earlier about slumping and oxidative wastage associated with a drain that is maintained as a functioning, well-managed water conduit, are supported by measured evidence for slumping as a result of drainage on blanket mire in northern Scotland. Townend, Shotbolt, Anderson and Townend (1998) present evidence demonstrating just how far this effect can be seen even within blanket mire. At Rumster Forest, in Caithness, the ground surface was surveyed in some detail prior to planting with conifers in 1966. By 1996, the peat surface showed measurable slumping up to 40 m from the forest edge.

If the catotelm is affected over this distance, what then is the zone of influence on the acrotelm, which generally has a hydraulic conductivity two or even three orders of magnitude greater than that of the catotelm?

The simple answer is that we don't yet know. Holden (2005) and Holden *et al*. (2006) offer some valuable insight, and point to possible ways forward, in terms of modelling certain parts of this story. However, far more research is still needed into the behaviour of acrotelm water tables and associated living vegetation when under drainage stress.

Clear predictions of a holistic nature – *i.e.* synthesising *all* effects of drainage – *and* at a resolution claimed by the LWP EIS documents – *i.e.* accurate to a few metres – will only become possible through the development of research programmes that integrate information about hydrology, microtopography, plant ecology, palaeo-stratigraphy, engineering and land-use history, to the necessary level of detail.

Much drainage research to date has been carried out simply in order to determine whether it is possible to lower groundwater levels (*i.e.* catotelm water levels) sufficiently to be able to exploit the peatland in some way. A fall of 4-5 cm into a layer that is only 10 cm thick for a few weeks during the summer is not the kind of water-table change that has, until recently at least, driven much of the published work on peatland hydrology and drainage. Nonetheless it is precisely this kind of relatively minor alteration in hydrological behaviour which is acknowledged by such authorities as Ivanov (1981) as being capable of inducing significant peatland vegetation change.

5.4.6 Drainage, peat pipes and erosion

It is interesting to note that the LWP EIS documents are quite clear about the effects of drainage when describing the process of erosion, gully development and the effect of peat pipes. Thus:

> *"**Gullying drops upper level of peat water table (catotelm) by at least 50 cm**, allowing large extents of dry heath and dry forms of bog to develop."*
> *LWP 2004 EIS, Vol.7, Technical Report, Section 4.4*

> *"Gully development, especially in Erosion Classes 4, 5, 6 and 7, is **so widespread that the peat watertable surface is lowered by drawdown by perhaps 0.3 m or more in summer, producing a dry peat surface with characteristic lichen-rich and dry mossy vegetation types** (M17b, M15c, H10b NVC types). **This fall in watertable is the key outcome of degradation and results in very large areas, perhaps up to two-thirds of the HSA, which are probably so dry that there is little or no active peat formation** on such ground."*
> *LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 68*

> *"Dewatering involving evacuation of many pools and dubh lochans, followed by formation of high-density gully systems, **results in the bog watertable perhaps falling by up to 30 - 50 cm. This leaves almost all of the former acrotelm dry** and much of the upper catotelm much reduced in wetness for most of the time, with the former upper catotelm peat aerated, at least in part, in its upper part. **The acrotelm is thus transformed by dewatering from a thin upper aerated zone (say, 1 - 10 cm thick) to a deeper aerated zone (perhaps up to 30 – 50 cm thick)** made up of peat which is dry or only partly saturated. **There is still seasonal variation in peatland watertable level, but winter peaks probably never saturate the upper levels** except during and immediately after significant rainfall. Rainfall inputs to a much drier and thicker acrotelm, punctured by a rill and gully network, then moves quickly over the upper bog surface and through the gully system with a much faster throughput (lower residence time) than occurs on very wet blanket bog. **The result is a peatland which has a much drier surface, a lower watertable and faster precipitation throughput than the very wet conditions that existed before dewatering**."*
> *LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 71*

This account reads as a very clear account of drainage, caused in LWP's description by gullies, but the description could equally apply to the effect of drains. Indeed the theory of peat-pipe dewatering talks of individual pools collapsing and then in some way causing an outward ‘ripple’ in the sense that the whole mire surface is gradually sucked into this one (or perhaps a few) collapsed pipe systems. For this to happen, the effect of these collapsed peat pipes would have to extend over distances that (given a typical mesotope size) amount to somewhere between 500 m and 1.5 km.

Such a mechanism does not sit easily with the notion that:

> *“In the case of indirect change, literature review on blanket bog response to ditching, together with dipwell studies at Farr Wind Farm and modelled comparison of the Farr and North Lewis sites, suggest that* ***most impact will occur within 2 m of the edge of disturbed ground. Allowing for a small amount of effect beyond this limit, setting 2.5 m as the actual likely average distance of change****, actual ‘losses’ due to indirect change could be of the order of only 70 ha.”*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 80*

There appears to be a fundamental internal conflict within the LWP EIS documents. On the one hand, a few scattered peat pipes within each mesotope are sufficient to result in wholesale collapse of the mesotope ecosystem and bring about widespread dry vegetation types that are no longer peat forming. On the other hand, the effects of excavation, construction, maintenance and decommissioning of the windfarm infrastructure, in some cases involving peat which is up to 5 m deep, will be limited to an ‘actual likely’ zone of only 2.5 m wide.

It seems that these two theories cannot co-exist in the same document. One, or the other, must be wrong. Or perhaps both could be wrong. What is clear is that both cannot be right.

5.4.7 The Farr Dipwell Studies

The Farr Dipwell Studies offered the opportunity to start providing some valuable data at a scale more relevant to the fine-scale eco-hydrological work required to illuminate the questions of blanket mire drainage. It is therefore entirely understandable if some sense of frustration shows through in Dr Bragg’s review of the report produced about the research (see Annex 1). As she says, some valuable opportunities have been lost, and not an enormous amount has been gained, as yet.

Dr Bragg’s report speaks for itself. It just remains to observe here that basing the LWP EIS predicted ‘realistic’ impact zone of 2 m, 2.5 m, 5 m, 10 m or even 50 m, on such work would appear to be somewhat premature.

5.5 Water crossings

The final topic for this chapter can be dealt with fairly briefly. It concerns the proposed management of water crossings within the development area.

The topic is considered sufficiently important to merit its own Outline Construction Method Statement : OCMS 5 “Water Crossings”. This document set out the process by which a water-crossing construction type will be selected for a given water crossing. LWP 2006 EIS, Vol.2, Sect.1, Chapter 7, para 14 sets out the anticipated scale and nature of the need for water crossings:

> *“It is anticipated that139 water crossings would now be required.*
> *In summary four different crossing techniques are proposed;*
> *• Pipe Culvert (see Figure 7.12, Volume 3 (LWP 2006));*
> *• Box Culvert (see Figure 7.13, Volume 3 (LWP 2006));*
> *• Armco bridge (see Figure 7.22, Volume 3 (LWP 2006)) and*
> *• Bridge (see Figure 7.14, Volume 3 (LWP 2006))”*
> *LWP 2006 EIS, Vol.2, Sect.1, Chapter 7, para 14*

A map is provided of proposed water crossings as LWP 2004 EIS, Vol.4, Chapter 7, Fig.7.15, but this relates to the original windfarm proposal. A revised map of anticipated crossings is not provided as part of the LWP 2006 EIS. It is thus rather difficult to determine how the figure of 139 water crossing would now be needed, compared with the 162 anticipated for the original proposal. Nonetheless, examination of the original LWP 2004 EIS, Vol.4, Chapter 7, Fig.7.15 reveals that the number of anticipated crossings is based on an assumption of need that is often divorced from the reality of conditions on the ground.

Take, for example, the area shown in Figure 61. Given that the commitment to formal water crossings extends down to the scale of quite small erosion gullies, it is difficult to see exactly how the question of water crossings would be dealt with in this case. The presence of peat gullies indicates that there is already substantial movement of water through this network, and any road constructed across it would significantly disrupt the pattern of flow. Some areas would become ponded, while others are starved of water. The pattern would change unless every gully visible along the road line were to be given a formal water crossing of an adequate size.

There is then the question of settlement ponds or Siltbusters. LWP 2006 EIS, Vol.6, Appendix 10F and LWP 2006 EIS, Vol.2, Sect.4, Part 3, OBN 7 (Pollution Control) commit the development to having settling ponds or Siltbuster technology at every water crossing. It will be obvious to most readers that this is unlikely to be a realistic option here (depending, of course, on how the criteria would be applied in terms of selecting gullies for a formal watercourse structure).

A somewhat different issue is highlighted by the stream-courses and gullies shown in Figure 62, which lie at the bottom end of Loch Mor an Starr. The most northerly, quite distinct, watercourse has not been assigned a formal water crossing structure by LWP 2004 EIS, Vol.4, Chapter 7, Fig.7.15, despite the fact that it would seem to be a very strong candidate and a rather more practicable option than other more diffuse water tracks. It is therefore rather surprising to find that the lower-central watercourse has been allocated Water Crossing No.62. The difficulties involved in constructing a formal water crossing for this water track begin with that most basic of questions – where is our watercourse?

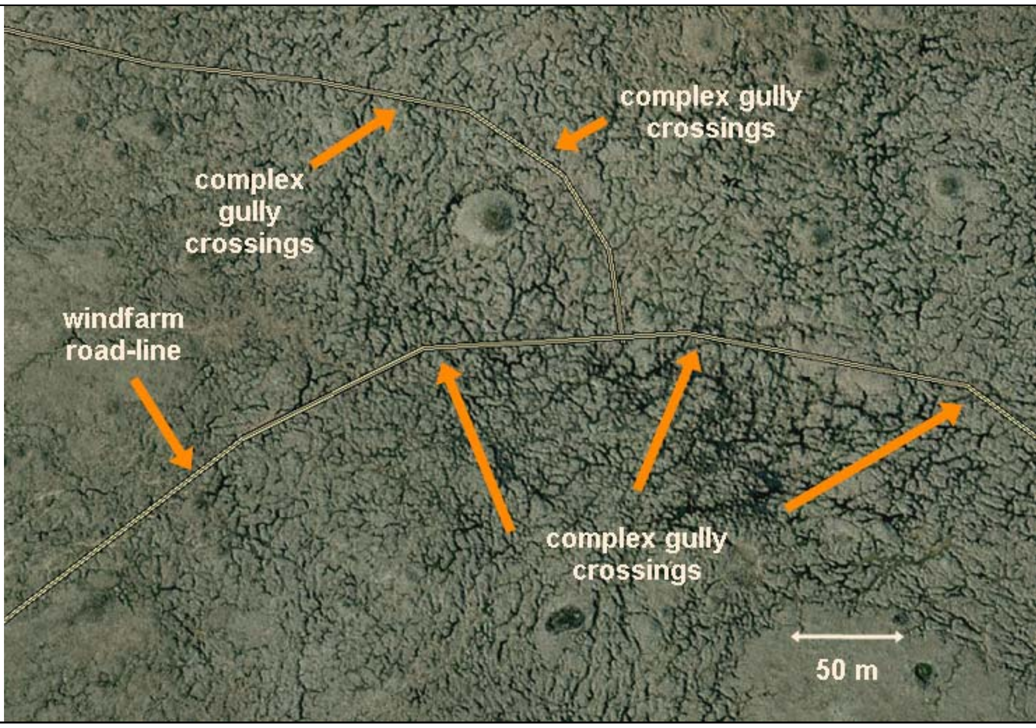


Figure 61. Water crossings, roadway and ground conditions.
Section of proposed LWP windfarm road-line which crosses an area of intense gullying at NB 389406. It is not clear how the guidance for construction of formal water crossings would apply in this case. The commitment to settling ponds for each water crossing further complicates the issue, particularly as this area lies within Hydrological Zone 4 (see text).

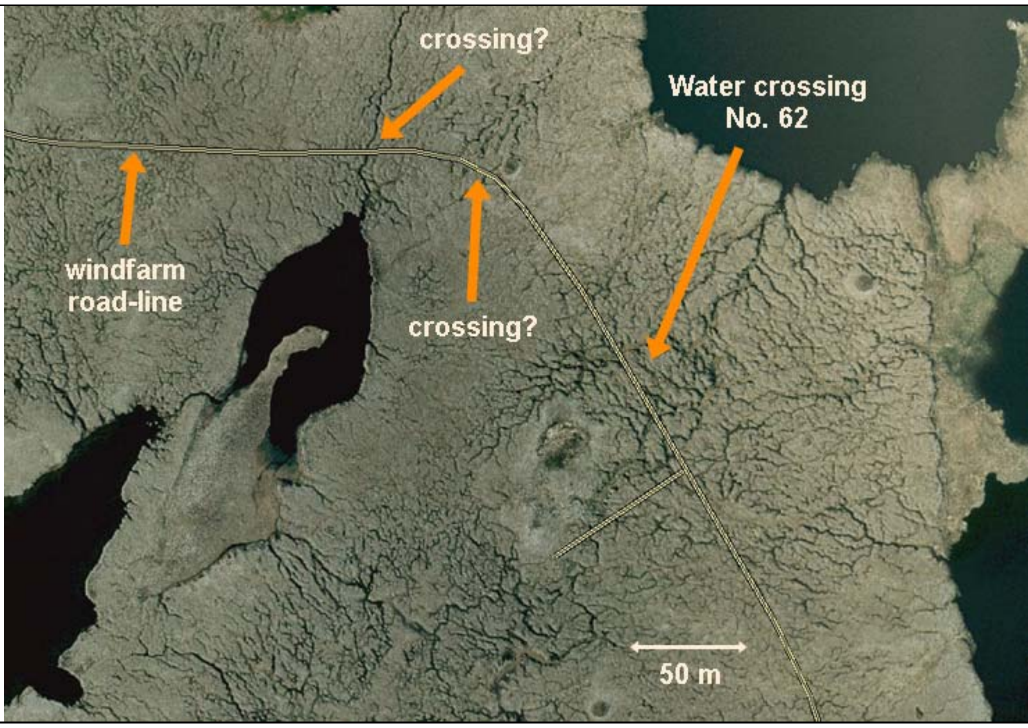


Figure 62. Water crossings and erosion at Loch Mor an Starr.
Section of proposed LWP windfarm road-line which crosses an area of significant gullying at the south end of Loch Mor an Starr. Orange arrows highlight three distinct areas where water-tracks cross the road-line and enter Loch Mor an Starr. Only one of these, the most southerly of the three, has been allocated a formal water crossing (Crossing No.62).

It can be seen from Figure 62 that there are at least five reasonably distinct crossing points resulting from the diffuse nature of this water-track complex. Does 'Water Crossing No.62' mean that there would be just a single formal crossing? In which case what would happen to the remainder of the water tracks? Would they be blocked off by the road and their water fed in some way to the single water crossing? That would mean a substantial increase in flow, and thus erosive energy, for the outlet channel of the chosen stream line. Given that Loch Mor an Starr is a public water supply and serious concerns over the maintenance of water quality have been expressed by both SEPA and Scottish Water, this concentration of erosive energy would need to be looked at very carefully.

If, alternatively, as a result of following the OCMS guidance, it is envisaged that there would be a number of formal water crossings, where exactly would such crossings be built, given the multiplicity of channels associated with this headwater area? Would every gully be given a formal water crossing? If so, this immediately raises the issue of settling ponds, because the whole of this area is classed as Hydrological Zone 4 and serious doubts are expressed by the LWP EIS documents about the safety of settling ponds in this Hydrological Zone.

Specifically, LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 73 observes that:

> *"Hydrological Zones 3 and 4 are areas where the disposal of excess water into settling ponds has* ***the potential to develop a downward pressure 'head' and result in 'bog bursts'****. Such natural effects have been observed in the upper Watershed Mire mesotope, which is correlated with Hydrological Zone 4 (Perched Pool Network)."*

As a result, LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 179 states that:

> *"...Areas where the disposal of excess water into settling ponds has the potential to develop a downward pressure 'head' and result in 'bog bursts' are likely to be limited to certain areas of the site. Such natural effects have been observed in the upper Watershed Mire mesotope, which is correlated with Hydrological Zone 1* (Perched Pool Network). In the absence of any information against this, this area was considered to be of highest risk of this effect occurring ... However,* ***the use of settlement ponds in this environment is unlikely to be practical and other sediment control would be applied, therefore mitigating this risk."***
>
> **[presumably a typing error, as Perched Pool Network is HZ 4]*

With regard to the particular concerns raised over Loch Mor an Starr, LWP 2006 EIS, Vol.2, Sect.2, Chapter 10 (10.11.4.3) rather surprisingly (given the concerns raised above about settling ponds) then describes a range of measures to reduce the pollution risk in the Loch Mor an Starr catchment:

> *"The design principle behind all drainage systems on site is that* ***no water from dewatering and drainage operations would be discharged directly into a watercourse or a waterbody in this***

***catchment**. The wastewater would **be treated by settlement pond, silt buster (or equivalent), flocculated if required**, or in some cases taken off site."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 10 (10.11.4.3)

This is a specific description of solutions for Loch Mor and Starr. Almost all the development proposed for the immediate vicinity of the loch lies within Hydrological Zone 4, with the remainder lying in Hydrological Zone 3 which is likewise highlighted as being at risk from settling ponds (LWP 2006 EIS, Vol.2, Sect. 2, Chapter 10, para 73). There would therefore appear to be no case for the use of settling ponds, and it seems strange that they should have been mentioned at all.

However, the fundamental operational problem remains; would siltbuster technology be used on *every* water crossing? That is a significant number of siltbuster units, all of which require infrastructure (hardstanding *etc.*) to operate, and a substantial amount of management. It is difficult to picture precisely what kind of total infrastructure package would be needed to deal with just these three water crossings, but it would seem to be quite substantial and rich in complex operation issues.

Even then, as we have already seen, siltbuster technology is only able to deal with the finer sediment sizes by chemical flocculation – again, rather surprisingly, proposed as an option despite Loch Mor an Starr's function as a public water supply. In the absence of such flocculation techniques, siltbuster technology cannot prevent the finest sediments from entering the loch – and the finer the sediment the more likely it is to remain in suspension and diffuse throughout the loch.

These are all very practical issues relating to a particular site over which specific concerns have been raised. The generic nature of the proposed solutions to these specific concerns fails to make clear how the practical operational questions would be dealt with.

Indeed, in a general sense, the LWP EIS documents set out some reasonably clear *procedures* for dealing with water crossings, but there is nothing that addresses the reality of what must be tackled. It should presumably have been possible to include at least one or two examples of water crossings and settlement systems, together with associated monitoring data, that demonstrate the practical success of the proposed methods on other sites. This would provide some degree of confidence that the designs and procedures which look fine on paper can actually be translated into practical solutions on the ground. It is all very well for Leonardo da Vinci to draw a design for the world's first helicopter; it is quite another to transport 25 oil workers and their luggage to an oil platform in the North Sea at night in the pouring rain.

Perhaps the proposed designs and procedures are sufficiently rugged and robust. The problem is that no attempt is made within the LWP EIS documents to demonstrate the fact. Clearly it is not feasible at this consultation stage for LWP to give practical demonstrations of solutions on a site for which they do not yet have planning consent. However, this makes it all the more important that proposed methods and solutions are robustly supported by suitable evidence from sites where these systems have been used successfully. It is not enough simply to state that:

*"LWP **engineers have made specific visits to a range of wind farm sites** throughout Scotland and Ireland and to construction works on the Western Isles **in order to investigate the issues**, and **have developed a range of Outline Construction Method***

> ***Statements to demonstrate the engineering practices** that would be used to address and manage the risks identified for this proposal.”*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 61*

What is needed within the LWP EIS documents is tangible evidence of what was found during these visits, a discussion outlining the successes and identified problems, and then a transparent translation of this information into a set of Outline Construction Method Statements. Unfortunately none of this can be found in the LWP EIS documents.

6 HABITATS

A significant range of habitats occurs within the proposed LWP windfarm development area, as detailed by LWP 2004 EIS, Vol.7, Technical Report, Appendix 3. This catalogues a total of 121 'land cover types' identified during the LWP HSA survey programme. Some of these land cover types consist of 'buildings', or 'quarry', or mixed plantation woodland. Others include vegetation such as perennial rye-grass (*Lolium perenne*) grasslands, or gorse (*Ulex europaeus*) and bramble (*Rubus fruticosus agg.*) scrub.

By far the most common land cover types, however, are various forms of peatland or 'mire' habitat. The remainder of the present chapter will thus confine itself to this single predominant habitat and landscape type.

6.1 Setting the scene – a mire landscape of international significance

Peat is the waterlogged, undecomposed remains of plant material laid down *in-situ*, while a peatland is an area with a peat deposit. Waterlogging may be caused by groundwater flows, in which case the peatland is a *fen*, or result from an excess of direct rainfall alone, in which case the peatland is a *bog*. Both conditions are found on Lewis, but the more extensive type is bog – specifically blanket 'mire' – that cloaks at least 85% of the LWP windfarm development area with a varying thickness of peat (as discussed in the previous chapter).

One of the most distinctive features of a 'mire', which is the internationally-accepted term for any peat-forming system, is that the vegetation clearly consists of species known to have peat-forming potential. It is important to note that peat-forming *potential* is the critical issue, rather than a demonstrable formation of peat, because the two standard definitions of a 'mire' acknowledge explicitly, or as a footnote, that it is extremely difficult to prove that peat accumulation is actually taking place on any given site:

> *"A 'mire' is a wetland that supports a vegetation which is normally peat forming."*
>
> *International Mire Conservation Group*
> *mire terminology workshop : 1992*

> *"A 'mire' is a peatland where peat is currently being formed.*
> *[It is difficult to test in practice whether or not peat is accumulating. The dominance in the vegetation of species, whose remains are found in peat, can together with the incidence of almost permanently waterlogged conditions, be taken as good indicators of peat formation.]*
>
> *Joosten and Clarke (2002)*

The issue of peat accumulation has received much attention in recent years because the EU Habitats Directive (Directive 92/43/EEC) recognises peat bogs as a threatened habitat in need of EU community action, but states that priority actions should be devoted to 'active' examples of the habitat. Initially, this was assumed to mean 'currently and demonstrably accumulating peat', but the impossibility of implementing such a definition soon made it necessary to provide definitions of 'active raised bog' and 'active blanket bog' that took into account the issues of peat-forming potential enshrined in the definitions given above.

It is probably worth re-iterating here that both forms of blanket bog – active and non-active – are listed in Annex I of the Habitats Directive as being:

> *"Natural habitat types of community interest whose conservation requires the designation of special areas of conservation."*

Consequently, although there is currently considerable effort being devoted to the conservation of 'active blanket mire', it should be emphasised that both 'active' and 'non-active' blanket mire must be retained in, or restored to, 'favourable conservation status' This means that:

> *"The natural range of the habitat, and areas within that range, must be stable or increasing ... and that the structure and function necessary for the long-term maintenance of the interest are in place and are likely to remain in place for the foreseeable future."*
>
> *Directive 92/43/EEC : Article 1*

Clearly extensive damage to blanket bog, whether active or not, is contrary to this legal obligation imposed on all EU Member States.

Both the question of 'active' blanket bog, and the international obligations linked to blanket bog, are important issues that will be explored in more depth within the present chapter, and then again in Section 8.3 of the present report.
It is also worth highlighting here that peat bogs (blanket bog and raised bog) are not the only peatland habitat type identified as being of EU community importance. Directive 92/43/EEC Annex I also identifies a number of other peatland ecosystem types requiring community action. In total, three defined peatland types are of specific relevance to the blanket mire landscape of Lewis:

- 7130 Blanket bogs (* if active bog) – [* habitats require priority action]
- 7140 Transition mires and quaking bogs
- 7150 Depressions on peat substrates of the *Rhynchosporion*

The last of these three is not so much a mire type in its own right, being instead more of a microtope and nanotope type (see previous chapter) formed within the mesotopes and macrotopes of the blanket mire habitat.

Category 7140 'Transition mires and quaking bogs' are described thus within the JNCC Habitat accounts (see JNCC website):

> *"Transition mires and quaking bogs can occur in a variety of situations, related to different geomorphological processes: in flood plain mires, valley bogs, basin mires and the lagg zone of raised bogs, and as regeneration surfaces within mires that have been cut-over for peat or areas of mineral soil influence within 7130 Blanket bogs (e.g.* ***ladder fens****)."*
>
> *JNCC website*

while within the definition of 'blanket bog' we find the following description:

> *"****Ladder fens*** *form an integral part of some blanket bogs and have a characteristic surface patterning, with narrow pools and intervening*

low, narrow ridges parallel to the contours. Associated with this structure is a more species-rich flora than that of the surrounding mire expanse. This is due to local flushing of mineral nutrients through these fen areas, in contrast to the surrounding vegetation, which receives all its nutrients through precipitation, i.e. is ombrotrophic. Ladder fens may also be referable to 7140 Transition mires and quaking bogs."

JNCC website

From this it is clear that although ladder fens are recognised partly by their distinctive microtope patterns, they represent distinct mesotopes within the overall blanket mire landscape. However, as we have seen in the previous chapter, until now the type has been generally overlooked on Lewis. Discovery by the UEL Peatland Research Unit of many examples within the overall blanket mire landscape has thus significantly enhanced the international importance of the Lewis peatlands within the context of Directive 92/43/EEC. Again, the issue will be explored further in the present chapter and in Chapter 8 of the present report.

The practical result of Directive 92/43/EEC is that large sections of central Lewis have been put forward by the UK Government for designation as the Lewis Peatlands Special Area for Conservation (SAC). The SAC then forms part of the Natura 2000 network of sites protected under Directive 92/43/EEC 'The Habitats Directive'.

The LWP development proposals lie entirely *outside* the boundary of this SAC. However, overlapping with the SAC is a larger area designated under Directive 79/409/EEC – 'The Birds Directive' – as a Special Protection Area (SPA). This SPA, together with the SAC, form part of the EU-wide Natura 2000 network of protected sites. Parts of the SPA that extend beyond than the boundaries of the SAC form a 'halo' of blanket mire landscape that is designated exclusively as an SPA. This designation reflects both the importance of the bird populations found within this 'halo', and the importance of the habitat for maintaining these bird populations. The LWP development proposals lie almost entirely *within* the exclusive halo of the SPA.

Additionally, the whole combined area of the SAC and SPA has been designated as a wetland of international importance under the Ramsar Convention. This designation reflects the fact that the expanse of blanket mire landscape found across northern and central Lewis is certainly the largest continuous area of such habitat in the UK after the Flow County of Caithness and Sutherland. Given that this latter area has been proposed as a World Heritage Site, it is understandable that the Lewis Peatlands (as a whole landscape entity, not the formal Lewis Peatlands SAC) should itself be regarded as being of global significance.

6.2 Perceptions of the Lewis peatlands

On reading the various LWP EIS documents, one is left with a strong sense that six essential features characterise the peatlands of the proposed LWP development area (as perceived by LWP):

- the peatlands are eroded to an unusual degree;
- there is consequently very little 'typical wet bog'

- the vegetation is generally of an unusually dry type;
- extensive areas of former blanket bog are now dry heath;
- human impact has been minimal, at least in recent times;
- the widespread state of evident habitat disintegration results from a natural and ongoing process of degradation in which naturally-formed pipes in the peat cause dewatering of entire mire systems.

Assuming for the moment that this is an accurate picture of the Lewis peatlands, or at least of the peatlands exclusively within the SPA (because LWP did not carry out survey within the SAC), this description can be interpreted in one of two ways – which we shall call for the moment the 'positive' and 'negative' views:

- Firstly, the 'positive' view: If it has indeed now been proven that this eroded landscape and dewatering sequence is a natural part of blanket mire dynamics, this is extremely interesting and of very considerable value, not only for conservation, but also in wider economic terms because of what it implies for a range of cross-sectoral interests including land management, quality of public water supplies, and even for climate change.
- Alternatively, the 'negative' view: Peatland erosion is a degenerate phase in the dynamics of blanket bog systems, a sequence of degradation where the key parameters of biodiversity, habitat function and ecosystem health are reduced to a very low state, perhaps to recover again at some indeterminate time in the future, but with no guarantee of this.

These two contrasting views are considered in more detail below.

6.2.1 Peatland erosion : the positive view

The positive view of erosion as a natural dynamic process of the habitat means that all stages of the erosion process are of conservation interest. Given that the nature of this dynamic process is currently so poorly understood, it would be particularly important to conserve a full set of examples displaying the complete range of stages in the erosion process.

As such, the variety of erosional forms described from the LWP HSA would offer excellent opportunities to ensure that this full collection of conditions was conserved. Furthermore, if it were the case that erosion is a natural, fundamental part of the dynamics of blanket bogs, then a considerable amount of effort and resources currently being devoted to the restoration of eroding blanket mires (*e.g.* Moors for the Future website) could be re-directed elsewhere.

The implications for sectoral interests such as water companies would be less attractive, however. This is because blanket peat erosion results in the expenditure of substantial sums on systems to deal with the results of peat erosion. Such issues include problems with water colour, reduced reservoir capacity because of eroded peat sediment, and the clogging of water-management infrastructure (such as reservoir outflows) by mobilised peat. Water companies would thus need to budget accordingly.

The establishment of blanket mire erosion as an entirely natural process could also have implications for work on climate change and soil-carbon balance, given that blanket mire represents the single most significant soil-carbon store in the UK. If it can be shown that blanket mire erosion is an entirely natural process, then the carbon lost from the soil-carbon store through erosion would not contribute to UK emissions figures. If, on the other hand, the blanket mires of the UK are eroding due to anthropogenic influences, the carbon lost from the soil-carbon store through erosion does indeed represent a source of anthropogenic carbon release. Such losses would need to be added to the carbon-emission totals for the UK.

6.2.2 Peatland erosion : the negative view

The negative view of peatland erosion takes the same proposed natural process of erosion, but considers the whole thing to be largely or entirely negative – a case of Nature 'gone bad', as it were. It is not easy to present a rational or logical series of consequences for this view. If erosion is natural, then how can this be 'bad' (*i.e.* of low conservation value), and why would there be a need to 'stop it going bad'? This is like saying that coastal cliff erosion is bad. It may indeed be bad news for those living on the edge of a cliff, but this is a different issue. True, the *rate* of cliff erosion may be increased or reduced by human intervention, but the simple existence of erosion is a natural consequence of geomorphological processes.

If peatland erosion is a natural process then there is little justification (a) for regarding it is a negative, degenerative process, or (b) for stepping in and attempting to slow down, halt, or even reverse this perceived natural 'degradation'. Besides, the sheer scale of the habitat means that management intervention, designed specifically to work against the natural grain of the ecosystem process to prevent erosion, is almost certainly doomed to failure.

The 'natural degeneration is bad' view is, frankly, a difficult argument to sustain at a philosophical level, because the basis of nature conservation is founded on the principles of maintaining or restoring natural processes as far as possible. Sometimes ecosystems go through natural phases of what seem to be catastrophic change. Thus the devastating population crashes that occur from time-to-time in some small mammal populations can seem catastrophic, but in fact they are just part of the natural prey-predator cycle. Equally, sand-dune systems undergo phases of 'blow-out' where huge sections of dune effectively collapse and become mobile. It would be fruitless to try and intervene by artificially shoring up the small-mammal population in some way. Equally, it would be wrong to regard the dune blow-out as 'degradation' of the ecosystem.

It is true that nature conservation sometimes makes a policy decision that natural processes will be held in check at a certain stage in ecosystem development. Thus a fenland system may, given time and a lack of human intervention, develop to a wet woodland on peat. However, if the open fenland is seen as a conservation priority, then the woodland development may be held back by conservation management to retain the open fen stage, perhaps by mowing of the vegetation (*e.g.* Moen, 1990; Wheeler and Shaw, 1995; Foster and Procter, 1995).

For a blanket mire on Lewis the theory and practice are more straightforward because blanket mire is, by and large, considered to be the natural climax habitat type. Consequently the conservation objectives and the natural ecological dynamics of the habitat support each other. But if the natural ecosystem dynamics of blanket bog result in a sequence that is perceived as collapse or degradation of that ecosystem, how should conservation respond? How does conservation theory help in the face of this perceived loss of conservation value?

In practice the appropriate conservation response is really quite simple: don't change the habitat, change the *perception*. If blanket mire erosion is part of the natural cycle, then the various stages of erosion have as much conservation interest as the stages prior to initiation of erosion. The underlying principles behind nature conservation thus lead clearly and inevitably back to the first of our two responses – the 'positive' view.

The whole of the foregoing discussion is predicated on the LWP suggestion that the current eroded state of the Lewis peatlands has arisen through a natural process of habitat breakdown. If this proposal is not correct, if instead the presently-eroded condition of the Lewis blanket mires has been caused by human intervention, then the above debate about natural processes, ecosystem degradation and conservation value become entirely irrelevant. The key question, therefore, is whether evidence exists for a link between human action and blanket mire erosion? It appears to be the opinion of the LWP EIS documents that there is no evidence for such a link. This assertion, and the LWP view of blanket mire erosion, is considered next.

6.2.3 The Lewis Wind Power view of blanket mire erosion

As discussed at the start of Section 6.2, the LWP EIS documents set out a very clear preception of the Lewis peatlands, or at least the peatlands within the LWP HSA boundary. A common theme runs through all the LWP EIS documents, and is a theme that quite explicitly identifies the Lewis peatlands as unusually eroded, specifically by natural phenomena. Such erosion means that they are consequently dominated by unusually dry vegetation types. Whereas the discussion in Chapter 5 considered the proposed erosion mechanism as a hydrological process, in this current chapter we are more concerned with the perceived effects of this process on the condition of the blanket mire ecosystem, in particular the vegetation and surface wetness. The perceived effects (*sensu* LWP) are perhaps best expressed in the words of the LWP EIS documents themselves:

> *"...the key relationship seems to be associated with a* ***progressive degradation sequence****. ... Over time, the remaining high ground lacking pools dries up to form rectilinear blocks with much dry heath vegetation."*
>
> *LWP 2004 EIS, Vol.7, Technical Report, para 5.2*

> *"****The degradation sequence****, as set out in the order of erosion classes, infers an approximately linear sequence (that is, proceeding in the order, say, of increasing dissection from erosion Class 1 to 3 to 4 to5 to 6 to 7). However,* ***in terms of the processes involved in degradation****, an area does not have to move in sequence in this manner."*
>
> *LWP 2004 EIS, Vol.3, Chap.11, para 35*

> *"The result is a surface with less microtopography apart from prominent mounds formed by the moss Racomitrium*

lanuginosum, most of which seem to ***develop after degradation****..."*

LWP 2004 EIS, Vol.3, Chap.11, para 38

"There is a linkage between areas of bog pools, the distribution of erosional classes and the location and extent of wet and dry bog types ... The linkage appears to be ***associated with a progressive degradation sequence*** *(i.e. replacement of very wet peatland of very high nature conservation value with forms which are drier and lack the surface characteristics of very wet types)."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 30

"This fall in watertable is ***the key outcome of degradation*** *and results in very large areas, perhaps up to two-thirds of the HSA, which are probably so dry that there is little or no active peat formation on such ground."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 30

"Overall, ***drying as a result of natural hydrological de-watering*** *processes is by far the most significant factor affecting habitat condition ... On the basis of results of survey from the HSA, the dry character and high extent of blanket bog, wet heath and some dry heath vegetation* ***in the SAC*** *are best explained in terms of hydrology, not historical management by burning."*

LWP 2006 EIS, Vol.5, Appendix 11b, para 84

This series of descriptions, taken from all phases of the LWP EIS documents, sets out a profoundly 'negative' view of the blanket mire habitat in the sense used in Section 6.2.2 above. This is a habitat that is undergoing ecosystem collapse through natural processes. The final quote even attempts to embrace the whole of the SAC into this vision of a doomed environment.

The conflicting internal logic inherent in such a 'negative' vision of the blanket mire landscape has already been discussed. It is nevertheless worth observing that, had the LWP HSA clearly established beyond doubt that the extensive peatland erosion of Lewis is a natural phenomenon, this would have been a major finding with profound implications for the conservation evaluation of blanket bog systems not just on Lewis but potentially elsewhere in Britain, Ireland, Norway and even Tierra del Fuego, Argentina.

During evaluation of the Flow Country blanket bogs during the 1980s (Lindsay *et al*. 1988), the status of erosion was at that time (as indeed it is again now) the subject of some debate. It was consequently noted by Lindsay *et al*. (1988) that examples of erosion should be conserved alongside examples of non-eroded blanket bog because erosion may prove to be a natural process, and a series of 'type' locations were identified for the area.

It seems that the authors of the LWP documents have read Lindsay *et al*. (1988). They have thus presumably seen that this was the recommended approach to eroded blanket bog, given that it might be a natural phenomenon. However, the LWP documents are far more definitive than Lindsay *et al*. (1988) felt able to be about the status of erosion in Lewis – for them, it is definitely a natural part of blanket bog dynamics. The LWP EIS documents might thus reasonably have been expected to acknowledge the need, as highlighted in Lindsay *et al*. (1988), to include eroded types as valued conservation features.

This does not happen. Instead, eroding sites appear to be collectively regarded as lacking any conservation value as peatland systems, despite forming the key parts of what the LWP EIS documents claim to be a 'natural sequence'. Such a response is entirely without logic – indeed, as discussed above, it displays a serious internal contradiction. Erosion cannot be both 'natural' and 'degraded'.

Returning to the final point of the LWP quote given above, the opinion of LWP is clearly that this picture of 'natural sequence of erosive degradation' should also be applied to the SAC. The argument begins by dismissing Dayton's (2003) findings to the contrary. It is thus probably worth pointing out that the LWP survey specifically excluded ground that lay within the Lewis Peatlands SAC. LWP has not surveyed any part of the SAC.

Consequently the LWP EIS documents can only speculate about the condition of the SAC based on the data available from Dayton (2003), and are not really in a position to make any judgement about the relative condition of the ground within the SAC. Any comparisons with conditions found within the SAC can only be made in a fairly general sense based on published accounts of the peatlands within the SAC (*e.g.* Goode and Lindsay, 1979; Everingham and Mayer, 1991; Dayton, 2003). Certainly LWP is in no position to refute the observations of such an experienced fieldworker who had carried out field survey throughout the whole of the SAC, at least not without presenting its own SAC survey evidence in support of its contrary view.

The fact that LWP did not undertake survey within the SAC is acknowledged thus:

> *"**No habitat survey was undertaken in the SAC** and information on the ecology of this area was supplied courtesy of SNH (Dayton 2003)."*
>
> *LWP 2004 EIS, Vol.3, Chapter 11, para 8*

Without further explanation or elaboration about why no comparison survey was undertaken by LWP in the SAC, the subsequent LWP 2006 EIS then comments on the survey of the SAC by Dayton (2003):

> *"Prior to NVC survey of the HSA, the only NVC mapping covered the habitats of the adjacent Lewis Peatlands SAC in a survey which overlapped in time with that of the HSA (Dayton 2003). That survey ...used a similar field methodology to the HSA baseline for recording vegetation and land management impacts. However ... **the SAC study is less comprehensive**. In addition, **the SNH system for recording the extent of NVC types in polygons representing NVC mosaics is not suitable for calculating the area of individual NVC types** and **this prevents detailed comparison of HSA results with those for the Lewis Peatlands SAC**. The habitat survey for Lewis Wind Farm and the Lewis Peatland SAC are the only detailed fieldbased NVC mapping sources ... and **it is unfortunate that they are not directly comparable**."*
>
> *LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 18*

The final point made about the lack of direct compatibility between the Dayton (2003) survey and the LWP HSA survey can be directed both ways. It is implied that the regrettable incompatibility arose because Dayton's (2003) survey was less detailed than the HSA survey programme, and is thus somehow at fault. However, LWP's decision to adopt a different survey method from that applied to the SAC was taken in the full knowledge that the standard SNH method for mapping NVC involves the use of NVC mosaics within polygons. It would certainly have been possible for the LWP HSA survey to have consulted with SNH and Dayton to check the method to be used for the SAC. It was thus LWP's subsequent decision to devise an approach unique to the LWP HSA survey that made the results "not directly compatible". Indeed the LWP EIS documents describe a whole series of non-standard decisions about survey methodology made unilaterally by the LWP EIS team, thus inevitably generating a dataset that would lack compatibility with *any* standard SNH habitat survey, not merely Dayton's (2003).

Moreover, where Dayton's (2003) results differ from those found in the LWP HSA programme, it is consistently assumed that Dayton's (2003) results differ because her methods are "less comprehensive", and that her conclusions are therefore incorrect. An alternative explanation, at least meriting consideration and discussion, is that the LWP HSA results differ from Dayton's (2003) results because the LWP data and/or conclusions are incorrect. Such a possibility is never considered in the LWP EIS documents. Quite the contrary, in fact: the 'negative' view that the Lewis peatlands are a landscape degenerating largely because of natural 'de-watering' is advanced as the only reasonable model for both the proposed development area *and* the whole of the SAC, despite Dayton's (2003) conclusions based on actual survey, and despite the fact that the LWP survey team did not themselves carry out any survey within the SAC.

The weaknesses in presention of the original argument about peat pipes and ecosystem collapse has already been reviewed in the previous chapter. Now it seems that the LWP EIS documents are sufficiently confident of their own findings and theories that they feel able to reject the findings of an experienced field surveyor and apply their assessment across the whole of the SAC without any form of supporting evidence from the area.

Given Nikki Dayton's range and depth of peatland fieldwork experience, it would be entirely reasonable to suggest that perhaps the LWP EIS team might consider at least the possibility of modifying their models and hypotheses to bring them more into line with Dayton's (2003) conclusions.

As things stand, the LWP EIS documents choose to promote a theory of erosional collapse for which they provide no supporting evidence. Instead of then considering the implications of 'natural' erosion for conservation value, which would be a logical consequence if the theory were correct, they then rather illogically choose to view the consequences of this theory merely as a 'negative' example of simple ecosystem degradation leading to low conservation value. Finally, they entirely dismiss the specific evidence gathered, and conclusions arrived at, by several experienced peatland field ecologists for the peatlands of Lewis as a blanket mire landscape largely influenced by a history of regular fire damage (*e.g.* Goode and Lindsay 1979; Everingham and Mayer, 1991; Dayton, 2003).

It is thus worth turning at this point to SNH's Condition Assessment for the Lewis Peatlands SAC. This records that:

> *"Burning is identified as the main threat to the site. The trend*

*selected for the wet heath and blanket bog features is **unfavourable recovering**. Wet heath is unfavourable on account of the absence of the bryophyte layer in some areas as a result of burning. Blanket bog is in unfavourable condition for the same reason, and also because of erosion which, while possibly natural in origin, is exacerbated by burning and possibly grazing."*

SNH Condition Monitoring Form : Lewis Peatlands – 1st Dec. 2004

This assessment raises three important points. Firstly, it makes clear that burning is considered to be the main problem on the site. The area is considered to be degraded and therefore in 'unfavourable' condition mainly because of fire damage. Secondly, peatland erosion as a natural phenomenon is acknowledged as a *possibility* but no more than that. It is certainly not advanced as the primary reason for the site's unfavourable condition. Finally, the assessment considers that the Lewis Peatlands are displaying significant signs of recovery from the identified causes of damage.

What, then, is the story about peatlands, burning and erosion on the Isle of Lewis – indeed on blanket mires throughout Britain? The LWP EIS documents have a decided view on this, but before examining this view it is worth considering the evidence available for burning impacts on blanket mires in general, then looking at the link between fire and the Lewis peatlands, finally looking in particular at the evidence for the proposed LWP development area.

6.3 Peatlands, burning and erosion

Although Tallis (1985) has concluded from evidence gathered at some blanket mire sites that inherent instability may sometimes be an important factor in causing erosion, he is careful to emphasise that this is far from being a universal explanation. Indeed he makes clear that there is ample evidence to the contrary by observing:

*"Several large areas of massive peat erosion at the present day **are known to have been caused by catastrophic accidental fires in the last 40 years**, and a number of similar areas are also suspected to have been burnt at some time (Tallis, 1981)."*

Tallis (1985)

It is worth noting here that Tallis (1985) also mentions the probability of an earlier fire history for the Pennines, in which Mesolithic hunters used fire as part of the strategy for managing wild game in these upland areas. Lindsay *et al*. (1988) also cite an example of peat erosion apparently caused by burning in the manner of the documented cases described by Tallis (1985) above. A peatland area of clearly-patterned bog pools was identified prior to field survey from aerial photographs taken in the 1940s. The site, at Loch Rimsdale, was subsequently visited during the Flow Country field survey programme in 1980. It was found to have only an intense erosion pattern, together with abundant evidence of fire damage.

Bragg and Tallis (2001) cite "datable erosion events relating to wildfires" on blanket mires, and note that:

"...the occurrence of carbonised material in the peat suggests that ***burning*** **[of blanket mire]** ***at least has been a regular feature over several thousand years****. Thus, at Alport Moor, fifteen bands of carbonised material were traced across an 8-m long profile spanning the last 2800 years (Tallis and Livett, 1994)."*

Mackay and Tallis (1996) cite the difficulties experienced by sporting estates after World War I in obtaining sufficient manpower to maintain traditional moorland management methods. They conclude that this resulted in widespread adoption across the Forest of Bowland of poor management practices, including burning regimes that were less than carefully-controlled than in the past. They identify in particular a catastrophic (and probably unintentional) wildfire that took place around 1921 as one of the key factors contributing to the present eroded condition of blanket peats in the area.

Approaching the question from a different angle, Stevenson, Jones and Battarbee (1990) examine the evidence of peat sedimentation rates within lakes that lie in blanket-mire dominated catchments. They also make provisional linkages between sedimentation rates and charcoal remains found in these sediments, and conclude that in their study site (the Round Loch of Glenhead, Galloway, SW Scotland) there is clear evidence for initiation of erosion between 300 and 500 years ago, and they observe that preliminary evidence points to a link with a distinct peak in charcoal remains.

Moores and Stevenson (undated) undertook a range of coring within the Lewis peatlands as part of an investigation into the behaviour of *Racomitrium lanuginosum* within the blanket bog nanotope pattern. The site of their main core, which formed the basis of their detailed analysis of macrofossil remains, pollen and charcoal within the peat archive, lies within 40 m of the proposed LWP windfarm road-line at Loch Mór a' Chócair (NB 350350). Their analysis revealed a record of charcoal extending throughout the length of the peat core (which spans the past 10,365 years), leading them to observe that:

"The diagram shows a ***consistent presence of charcoal remains throughout the cor****e, indicating that* ***there has been burning in these environments for millennia****."*

Moores and Stevenson (undated)

They found a good correlation between charcoal remains and subsequent sharp rise in *R. lanuginosum* remains at the highest peak of charcoal abundance, dated at 5,823 years ago, but the relationship with *R. lanuginosum* in later stages in the core shows no such clear linkage. They observe a strong peak in *Racomitrium* abundance in the uppermost few centimetres of the peat column, but find no directly-related strong peak in the charcoal record. They thus conclude that burning has not been a significant factor in determining the distribution of *R. lanuginosum* at the site in very recent times. It is worth observing, however, that Moores and Stevenson's (undated) data show a distinct peak of charcoal particles in all but the largest sizes (thus probably indicating a local fire or fires) from around the mid-1800s, while the *Racomitrium* record shows a dramatic rise around the time of the Great War (approximating from the calibrated dates provided), some 70 or so years later. The key question is therefore the sequence and timescale of response after these fires. Could it take a *Racomitrium*-dominated erosion complex around 70 years to develop after a period of burning? Tallis (1995) records a rather mixed and inconclusive pattern of Racomitrium growth, burning and erosion.

Racomitrium lanuginosum is undoubtedly a very characteristic feature of eroded blanket mires in Britain, and its presence in the peat archive is generally taken to indicate the possibility of fire-induced erosion in blanket mire sites. The LWP EIS documents regard its abundance throughout the proposed LWP development area to be simply a reflection of the widespread erosion and consequent drying of the peat.

Having commented on the extensive stands of *Racomitrium lanuginosum* vegetation within the Lewis peatlands, Goode and Lindsay (1979) observe that:

> *"A similar kind of vegetation on eroded peat, in which Rhacomitrium is dominant, was described in Caithness by Crampton (1911). The Rhacomitrium-rich facies is regarded by Ratcliffe (1964) as characteristic of disturbed and rather dry areas of blanket peat in western Scotland. Birks (1973) suggests that 'it appears to reflect drying of the bog surface resulting from a complex of factors* ***including repeated moor-burning****, grazing and subsequent gully and sheet erosion'."*

Goode (1974), Spence (1979) and Rodwell (1991) also record (and in the case of Spence, illustrate) the type as a significant component of the eroded blanket mires of Shetland. Lindsay *et al.* (1988) similarly identify such *Racomitrium*-rich erosion as a widespread type across Sutherland, extending as far east as Caithness, and also comment on the frequent link with evidence of burning.

Goode and Lindsay (1979) conclude that:

> *"Most areas of peatland vegetation in Lewis are profoundly affected by grazing, muirburn and peat erosion ... It is doubtful if any of the places where there is peatland vegetation in Lewis are entirely unaffected by one or other of these influences, as* ***even the wettest mires may be grazed and burnt during dry conditions****."*

McVean and Ratcliffe (1962) comment that hagg and gully erosion of blanket peat is found not just in the Highlands of Scotland but is "equally widespread on hills elsewhere in Britain". They go on to say that:

> *"The chief agents of peat erosion are undoubtedly wind and water but the factors which caused the onset of this degeneration are far less obvious. Some ecologists believe that human activity of one kind or another was largely responsible for initiating bog erosion. Others contend that the process is mainly climatically controlled and presents a natural end-point to bog growth. It* ***may well be that both sets of factors have been responsible but in the Highlands we have found plenty of evidence to support the first view****....*
>
> *...****Bogs bearing Trichophoreto-Eriophoretum typicum often show fire degeneration more by changes in floristic composition than by active peat wastage*** *... Such changes involve a decrease in Sphagnum cover, increased tussock formation in the vascular plants, and often the development of large mounds*

of Rhacomitrium lanuginosum on the drying bog ... Around the south-east end of Loch Meadie in Sutherland ... a continuous carpet of Rhacomitrium occupies at least one square kilometre of moorland leaving only a sparse scattering of Calluna vulgaris and Trichophorum cespitosum ***except in those places that have escaped the full effects of fires*** *...*

... ***During a dry spell in spring and summer it is possible to burn even the wettest Sphagnum-dominated bog and this surface disturbance combined with marginal interference probably explains the degeneration of many pool and hummock complexes****. Although some examples, such as the Strathy Bog described by Pearsall (1956), have escaped serious interference,* ***the majority have been burned and show every stage of drying and wastage****. The pools of the drying bogs are mostly bare of vegetation and rounded, with steep, scoured sides, and they look rather like salt-marsh pans. There seems often to have been an appreciable drop in water table and later stages of the degeneration show pools becoming confluent, drying out and finally leading to a disruption of the entire bog surface by irregular systems of haggs...*

... Only in a few places such as the north end of Ben Clibreck and Ben Hutig in Sutherland are there extensive areas of Calluneto-Eriophoretum which ***show little signs of hagging. It is significant that these show equally little sign of burning*** *and have large stands of the fire-sensitive shrub-rich facies."*

McVean and Ratcliffe (1962)

Eroding blanket mire is thus not only widespread throughout western and northern Scotland, it has also been consistently linked to evidence of burning as one of the primary causes for this habitat type. Indeed if the scientific literature is reviewed to identify occasions where erosion of whole mire systems (*i.e.* mesotopes) or substantial parts thereof have been *observed* to undergo a transformation from relatively 'intact' bog to eroding bog, these observed examples relate almost exclusively to burning, as is readily acknowledged in the literature cited in the present section. Burning, as an important factor in the story of blanket mire erosion, should thus be given due prominence in any condition assessment of a blanket mire landscape such as the Lewis peatlands.

In the course of presenting the theory that the extensive erosion seen in the Lewis peatlands is almost exclusively a natural process caused by peat piping, none of the LWP EIS documents addresses, comments on, or attempts to reconcile such a theory with, this existing body of literature. No cogent reason is provided to explain why the LWP EIS documents apparently dismiss as irrelevant this large body of literature which points to other potential mechanisms of peat erosion, and in particular to burning as one of the main demonstrated causes of blanket peat erosion throughout upland Britain.

The only justification given by the LWP EIS documents for not considering burning as anything more than a minor impact within the proposed LWP development area is that there is claimed to be very little current evidence for fire impact in the area. This statement is made despite acknowledging that fire damage is recorded as a major factor in the adjacent SAC, despite the record of charcoal in Moores and Stevenson (undated), and despite the description of widespread burning impacts by Goode and Lindsay (1979) and Everingham and Mayer (1991). These publications are all cited by the LWP EIS documents and were thus presumably read by the LWP EIS authors.

6.3.1 Evidence for burning within the Lewis peatlands

The LWP EIS documents are quite categorical in their statements that burning is of little consequence for the Lewis peatlands, and that evidence for burning is quite scarce. The idea that burning might be a major, if not the main, cause of blanket mire erosion is thus rejected in favour of the theory that erosion is a natural consequence of peat piping within the peat. Given the unsupported (and thus necessarily tentative) nature of the LWP thesis about peatland erosion, it would seem reasonable to have expected some discussion that also considered:

- the continuous charcoal record in the peat archive analysed by Moores and Stevenson (undated);
- the effects of the acknowledged large fire that occurred in 2003 (of which more below);
- the fact that Everingham and Mayer (1991) recorded widespread evidence of vegetation change resulting from burning within the Lewis peatlands;
- the attribution of erosion condition in the Lewis peatlands by Goode and Lindsay (1979) largely to burning effects;
- Averis and Averis's (1995) observation, in describing the blanket bogs of North Harris, that: "Burning of heaths and blanket mire appears to have been extensive in the past";
- the various tangible examples cited in the peatland scientific literature (*e.g.* Tallis, 1981, 1985; Lindsay *et al.*, 1988; Maltby *et al.*, 1990) of erosion caused directly by burning;
- the very large body of other literature (some of which has been cited or quoted in the previous section) that discusses the link between burning and erosion.

There is no such discussion or review in any of the LWP EIS documents.

What *is* provided by the LWP EIS documents – or at least the LWP 2004 EIS, Vol.7, Technical Report and the associated LWP HSA GIS dataset - is an evaluation of burning impacts within the HSA area. Using an abridged version of the SNH land management impact survey method (MacDonald et al., 1998), burning was assessed on a four-point scale of severity, from 'no impact' to 'high impact' (LWP 2004 EIS, Vol.7, Technical Report, Appendix 1, Table A1.5).

The resulting map of burning impacts is reproduced here as Figure 63, covering the revised area of the proposed LWP development. What is so striking about the map is the large area of ground recorded as showing no impact from burning. This does not tally well with description given by Goode and Lindsay (1979), the account of the Lewis peatlands produced by Everingham and Mayer (1991), an account of the peatlands of Harris by Averis and Averis (1995), nor the recent field survey and assessment undertaken by the UEL Peatland Research Unit.

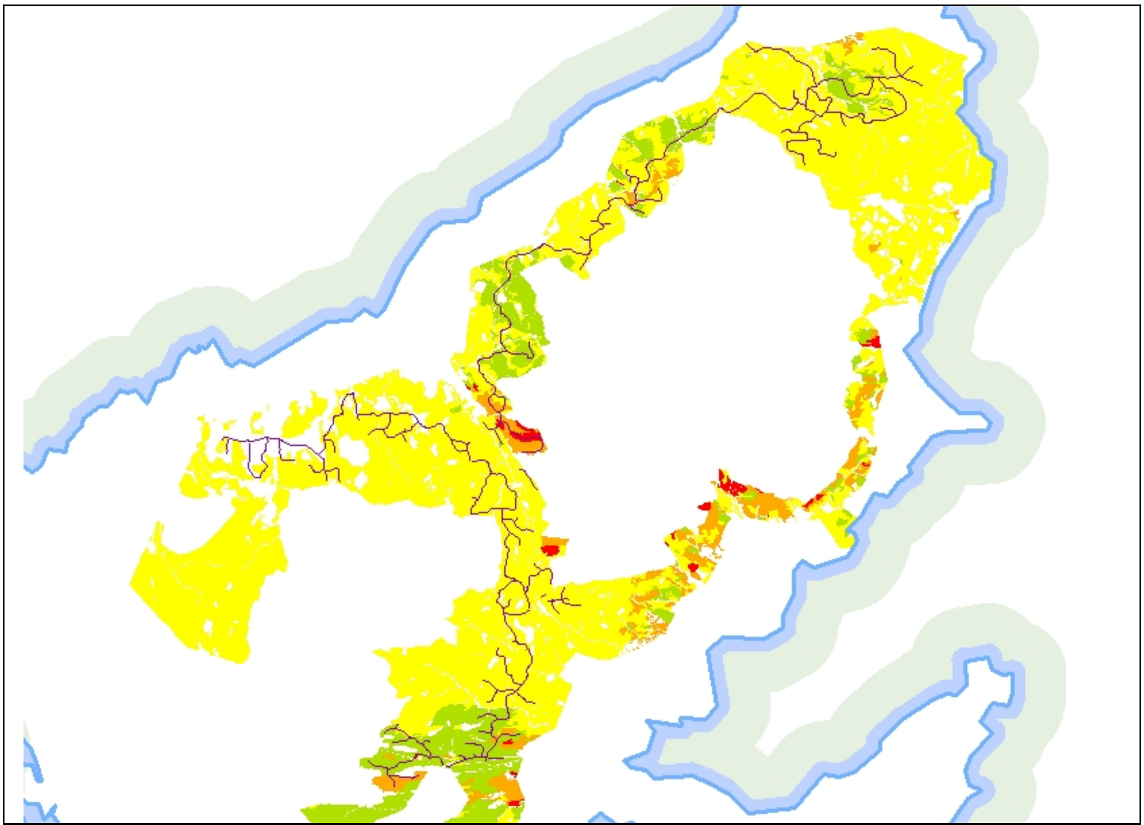


Figure 63. Distribution of burning impact according to the LWP HSA field data. Map of revised LWP windfarm road-line (dark line) displayed over categories of 'blanket bog burning impact' from the LWP HSA survey programme. Yellow = no impacts; Green = light impacts; Orange = moderate impacts; Red = high impact. Areas not classified as blanket bog for this item in the dataset (*e.g.* lochs) have been left blank. Coastline is shown as pale blue concentric lines.

The LWP 2004 EIS, Vol.7, Technical Report, para 6.2 comments on the occurrence of an extensive fire that occurred within the HSA in spring 2003 during the course of the survey. Some ground that was burnt had been surveyed the previous year. However, the decision was made not to re-survey this ground the following year.

This represents a missed opportunity of very considerable proportions because the data obtained could have helped to shed some light on the precise impacts of fire on the blanket mire ecosystem here on Lewis. As a result of this decision, there is no comparative information available for 'before' and 'after' conditions, nor does the LWP EIS GIS dataset therefore fully reflect the extent or severity of this fire because part of the dataset for this area was obtained prior to the fire.

What the LWP 2004 EIS, Vol.7, Technical Report, para 6.2 does do is suggest that the fire had relatively little impact:

> *"The only exception [to the normally relatively small fire events] was* ***a large fire which occurred on Barvas Moor in spring 2003*** *and even here* ***there had been a rapid regrowth of vegetation*** *at the time of survey in late June."*
>
> *LWP 2004 EIS, Vol.7, Technical Report, para 6.2*

No comment is made about what *type* of vegetation had re-grown on the areas that were surveyed after the fire. Equally, LWP is unable to say what the vegetation of these areas was *prior* to the fire. It only has data for the vegetation prior to the fire from ground that it chose not to re-survey. LWP could have seen the fire as an opportunity to assess the comparative impact of fire and gone back to the previous year's ground again to re-survey it where it had been burnt.

Instead LWP merely surveyed burnt ground that had no prior survey data, and drew positive and unsupported judgements about how much the fire had resulted in vegetation change. This is very much to be regretted. Moreover, the very positive comment about "rapid vegetation regrowth" encourages the reader to assume that the vegetation had recovered rapidly from the fire when in fact there is no real way of knowing what changes the fire may have caused. Such statements should have no place in an EIS.

In contrast to the LWP view of burning, evidence for widespread fire impacts and significant habitat change within the Lewis peatlands can be found fairly readily if looked for. Discussion with local residents revealed that there had been at least two other fires in the general vicinity of the 2003 fire over the last 20 or 30 years. These, and the large 2003 fire, together with a fourth very recent fire encountered by the UEL Peatland Research Unit in October 2006, are shown overlapping with the LWP HSA GIS dataset for fire impacts in Figure 64.

The fire indicated on Figure 64 as around 25 years old ("1980s?") can be seen to lie on an area classed as 'free from burning impacts' in the LWP HSA GIS dataset. Closer examination of this ground (Figure 64 : bottom photos) reveals that, despite the LWP HSA classification, the reported area of the fire is intensely eroded. Indeed it is some of the most intense erosion observed by the UEL Peatland Research Unit within the proposed LWP development area. The condition of this ground within the reported borders of the fire, combined with the reported intensity of the fire, lend weight to the argument that the observed erosion is burning-related.

The fire map shown in Figure 64 : top left, combines the areas of known fires with those areas identified by LWP as showing some fire damage. This combined area reveals quite an extensive pattern of burning within the context of fires recent enough or severe enough to have left evident signs of damage even within the definitions used by the LWP survey. The northern part of the proposed development area, and the area south of Barabhas, appear on this combined map to be largely free from burning impacts.

However, given that the LWP HSA survey also recorded the ground which is known to have been severely burnt in the 1980s as showing 'no evident burning impacts', it raises questions about the LWP HSA mapping of burning impacts:

- did the LWP HSA survey in general significantly underestimate signs of burning? and/or
- do different perceptions of burning presence and intensity exist between surveyors within the LWP HSA survey team?

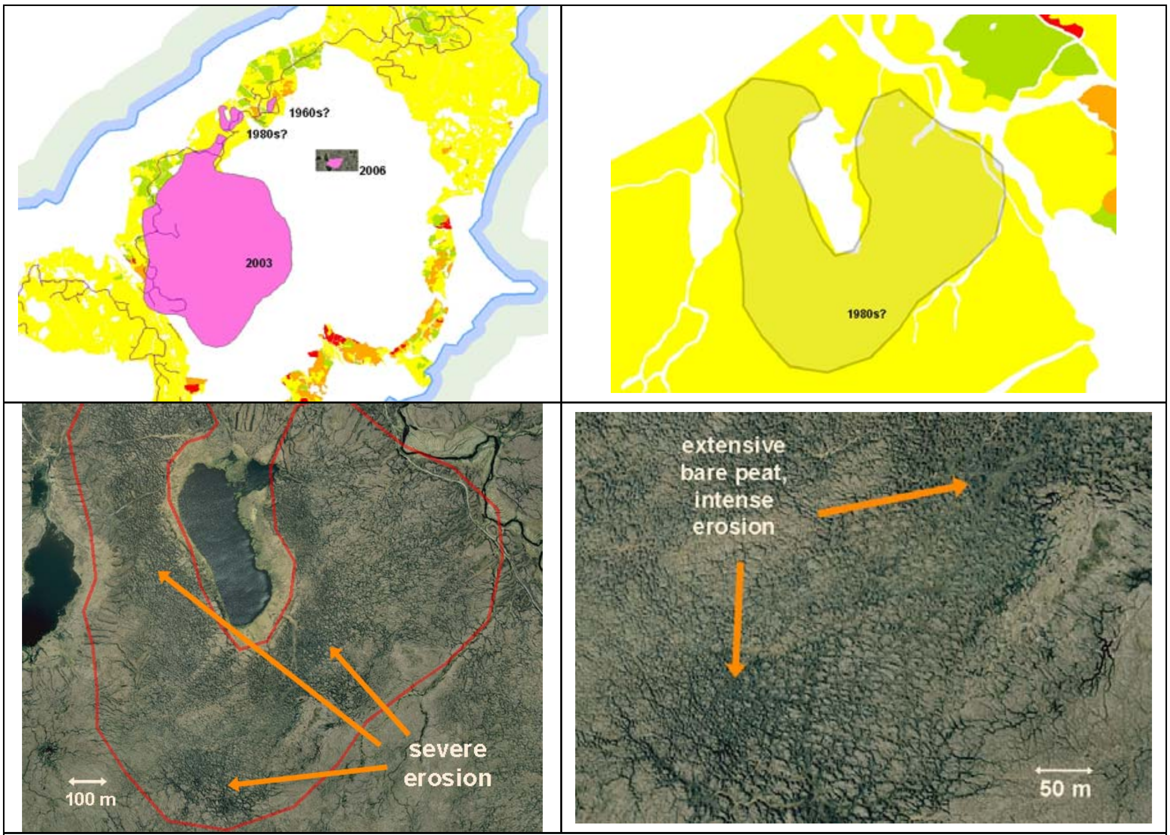


Figure 64. Distribution of known fires and present ground conditions – example. Examples of significant burning impacts within the LWP HSA. (Top left): Map of 'blanket bog burning impacts' from the LWP HSA survey programme. Yellow = no impacts; Green = light impacts; Orange = moderate impacts; Red = high impact. Areas not classified as blanket bog for this item in the dataset (*e.g.* lochs) have been left blank. Proposed LWP windfarm road-line is shown as a dark line. Coastline is shown as pale blue concentric lines.Purple shading indicates fire events recorded by the UEL Peatland Research Team. Date of fire is indicated. The fire in 2006 is displayed over an aerial photograph. (Top right): Yellow shading represents the category 'blanket bog no burning impacts' according to the LWP HSA GIS dataset; The blue-grey boundary and faint grey shading represents the area identified by local residents as having suffered a serious fire approx. 25 years ago. (Bottom left): Aerial photograph of '1980?' burnt area indicated in illustrations above. (Bottom right): Close-up of area indicated as having been burnt ('1980?') in illustrations above. Note the very severe erosion.

With these questions in mind, it is thus instructive to look more closely at the third and oldest of the additional fires (1960s?) shown originally in Figure 64 : top left. Figure 65 repeats the same overview map showing the location of additional fires, but then the remaining images in Figure 65 focus on this oldest of the three fires reported by local residents.

Firstly, it can be seen that the area of burnt ground, still visible on the 2006 aerial photograph, corresponds very well to the approximate boundary given by local residents.

More significantly, the pattern of LWP HSA burning categories for this area appears not to reflect the actual pattern of burning. The boundary between 'burnt' ground and non-burnt' ground appears instead to relate to the boundaries between individual field surveyors, rather than to the obvious pattern of burning. Surveyor 1 found evidence of fire damage, while Surveyor 2 did not, across the same area of burnt ground. It is also worth noting that Surveyor 2, who did *not* record any burning impacts within this area, was the same surveyor who recorded ‘no burning impact’ for the area of the 1980s(?) fire.

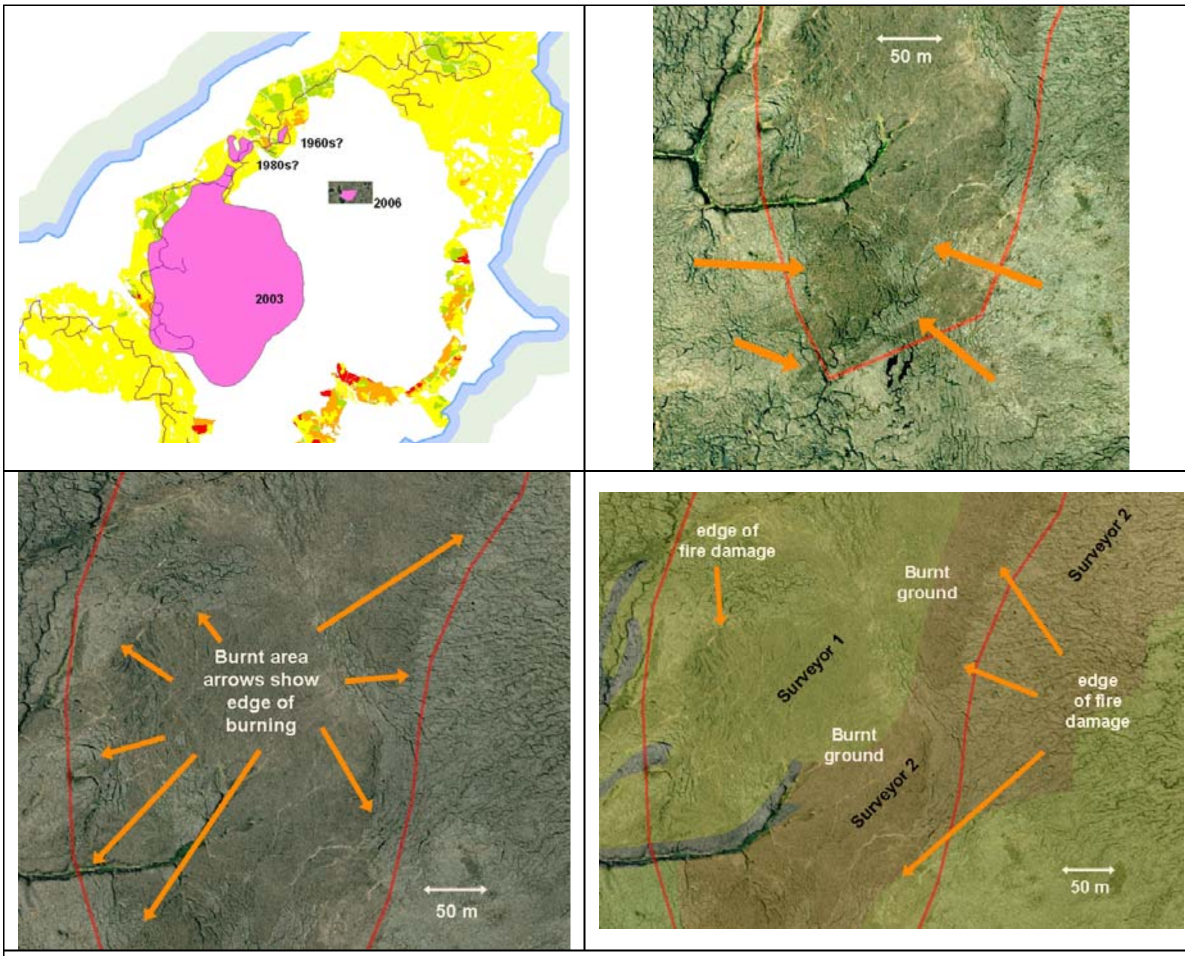


Figure 65. Relationship between LWP HSA recorded fire intensity and surveyor. Variable recording of burning impacts within the LWP HSA. **(Top left)**: Map of ‘blanket bog burning impacts’ from the LWP HSA survey programme. Yellow = no impacts; Green = light impacts; Orange = moderate impacts; Red = high impact. Areas not classified as blanket bog for this item in the dataset (*e.g.* lochs) have been left blank. Proposed LWP windfarm road-line is shown as a dark line. Coastline is shown as pale blue concentric lines. Purple shading indicates fire events recorded by the UEL Peatland Research Unit. Date of fire is indicated. The fire in 2006 is displayed over an aerial photograph. **(Top right)**: The red boundary represents the area identified by local residents as having suffered a serious fire approx. 40 years ago. Note the dark ‘trails’ and patchiness of the darker burnt areas (arrowed orange), cutting across obvious physical features on the ground. This is a typical sign of burning. **(Bottom left)**: Central part of burnt area indicated by local residents, showing extent of burnt patch indicated by orange arrows. **(Bottom right)**: Central part of burnt area, with colour shading representing polygons surveyed by different LWP HSA surveyors as well as degree of burning indicated by the LWP HSA GIS dataset. Pale Yellow = no burning; Pale brown = moderate burning impacts. Note how the boundary between these two scales of impact also reflects the boundary of surveyors, not the actual boundary of burning as indicated by orange arrows in the adjacent photograph and in this colour-shaded image.

This is not the only example within the LWP HSA GIS dataset where burning boundaries appear to arise from differences between surveyors rather than from actual differences on the ground. Examination of the entire LWP HSA GIS dataset reveals that, where there are changes in surveyor, it is not unusual to find that there is also a change in recorded burning intensity.

The fourth area of burning, noted during the UEL Peatland Research Unit fieldwork in autumn 2006, concerns an area within the SAC. It is mentioned here partly because it helps to corroborate the findings of Dayton (2003) that fire is indeed a feature of the SAC peatlands. It is also discussed here because it demonstrates so clearly how several mesotopes or parts of mesotopes can lose the integrity of their microtope patterns as a result of fire damage, leading to the development of gullying.

The area involved can be seen in Figure 66, and a series of ground photographs is shown in Figure 67.

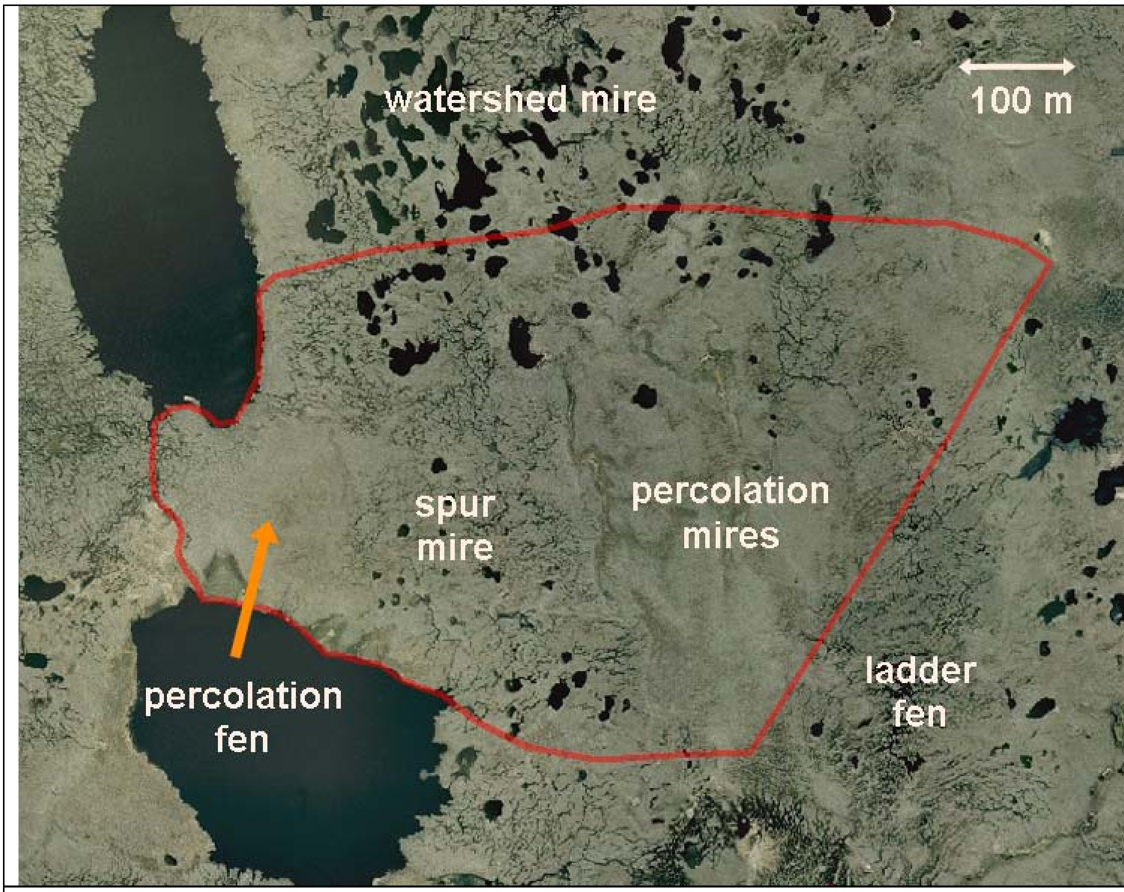


Figure 66. Approximate boundary of UEL-recorded fire within SAC.
The area mapped on the ground using GPS by the UEL Peatland Research Unit in October 2006 as having been recently burnt. The area is centred on NB 468523 and the boundary of the fire is shown in red. The right-hand boundary is approximate as it was not investigated in detail. The fire had obviously occurred earlier in the same year – perhaps mid-summer. It was almost certainly caused by human action as ‘quad-bike’ tracks were found running through the area. Mesotope types have been indicated. Ground photos from the percolation fen and the spur mire mesotopes are shown in Figure 67.

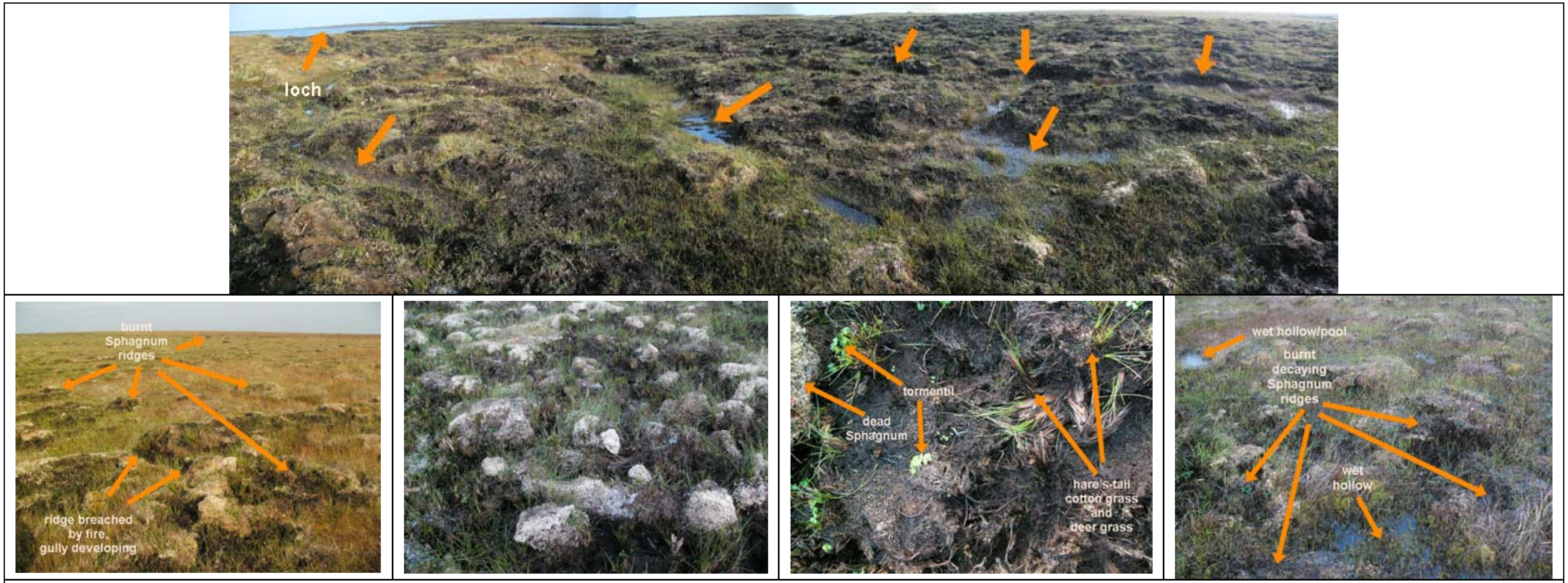


Figure 67. Ground conditions at UEL-recorded fire within the SAC.
Examples of significant burning impacts within the Lewis Peatlands SAC. **(Top)**: Panorama of fire damage on spur mire region shown in Figure 66. Note numerous gullies (orange arrows), in some cases originating very evidently from breakdown of ridges through fire damage. **(Bottom far left)**: View of spur mire region showing area where ridge has been destroyed by burning, with incipient gully formation. **(Bottom left)**: Example of former *Sphagnum*-rich area now dominated by grey decomposing mounds of *Sphagnum*, and fresh roots of hare's-tail cotton grass (*Eriophorum vaginatum*) and deer grass (*Trichophorum cespitosum*). **(Bottom right)**: Close-up of typical burnt surface, with patch of dead *Sphagnum* visible on left, bare peat/ash across most of the area, and rapid growth of tormentil (*Potentilla erecta*), hare's-tail cotton grass (*Eriophorum vaginatum*) and deer grass (*Trichophorum cespitosum*). **(Bottom far right)**: Area of wet percolation fen shown in Figure 66, with evidently high water table but nonetheless extensive fire damage across the ridges, leading to breakdown of the microtope pattern. Photographs taken in October 2006.

It can be seen from Figure 67 that a considerable breakdown of surface microtope pattern has occurred as a result of the fire. Ridges have been breached, incipient gullies have been formed. Extensive *Sphagnum* swards have been killed by the heat of the fire. It is worth noting that even the area of extremely wet percolation fen, which had a low-amplitude microtopography and many water-filled hollows, has nonetheless suffered considerable fire damage, thus demonstrating McVean and Ratcliffe's (1962) comment cited earlier that even the wettest parts of a mire can burn readily after a period of dry weather.

A number of important issues emerge from this review of information and the presented images concerning fire damage:

- the map of burning impacts provided in the LWP HSA GIS dataset under-estimates the distribution and intensity of burning impacts;
- this under-estimate is more significant with some surveyors than with others;
- the degree of burning severity in many polygon groups changes with a change in LWP HSA surveyor, suggesting that different surveyors perceived the degree of burning impacts differently;
- the evidence of fire damage persists on aerial photographs for 40 years or more, even if the fire was not severe enough to result in widespread erosion;
- the contention that burning plays only an inconsequential part in determining the character of the blanket mire landscape appears to be contradicted by evidence of severe erosion in those areas known to have suffered a serious fire;
- the evidence of fire damage on eroded ground appears to be much more difficult to see on aerial photographs, although it would be reasonable to look first at areas of severe erosion for evidence of burning on the ground.

6.3.2 Significance of the burning record for Lewis peatlands

6.3.2.1 The past fire record – an agreed impact

It is clear from the previous section that fires occur fairly regularly across the Lewis blanket mire landscape. Some of these fires are fairly localised in extent, others are very extensive. Many, such as the one found in the SAC by the UEL Peatland Research Unit, probably go largely or wholly un-recorded.

As for fires in the past, the peat archive shows an unbroken record of charcoal particles from the beginnings of peat formation around 9,000 years ago right up to the present day (Moores and Stevenson, undated). The smaller charcoal particles recorded by Moores and Stevenson (undated) are almost certainly the result of fires elsewhere in the peatlands of Lewis or Harris. However, the larger the particles recorded, the more likely it is that these represent fires at Moores and Stevenson's (undated) sample site. Even the most recent records from the archive show particles of moderate size from around the mid-1800s, suggesting that the specific area may have last been burnt around 150 years ago, while the continuing charcoal record indicates that fires continued to the present day in the surrounding peatlands. This archive record accords with the observed pattern of fires noted by the UEL Peatland Research Unit, either in discussion with RSPB and local residents, or from examination of recent colour aerial photographs.

Meanwhile the LWP HSA GIS dataset itself also suggests that there is still a reasonably widespread pattern of burning, with the most severe examples occurring nearer to the townships and to Stornoway. However, as has been noted above, the record of the LWP HSA GIS dataset appears to be partial only, in that known fire incidents have been missed despite their sometimes apparently severe impact on the blanket mire mesotopes involved.

It is observed within LWP 2004 EIS, Vol.7, Technical Report, para 6.2 that:

> *"**Burning was probably much more extensive in the past** when seasonal stock grazing and use of now-abandoned shielings was widespread. **It will undoubtedly have had a considerable effect**. However, much of the dry character and high extent of dry wet heath and blanket bog vegetation is **best explained in terms of hydrology, not historical management by burning**."*
>
> *LWP 2004 EIS, Vol.7, Technical Report, para 6.2*

If it is accepted that burning was "much more extensive in the past" and that it "undoubtedly had a considerable effect" (in other words, *all* parties appear to agree that burning *has* been extensive), the most critical issue to establish is the recovery time from such fire damage. Accepting for the moment the suggestion that fire incidents have been much-reduced in the last few decades (itself a questionable position, given the evidence above), is the fire-recovery time for blanket bog on Lewis sufficiently short that most evidence of fire-damage would now have vanished?

It is implied, in the quote above, that the blanket bogs recover quite quickly once regular burning has ceased. Consequently any character seen today reflects only the current set of environmental conditions and impacts.

It is thus valuable to review what is known about the rate of recovery from fire in peat bog systems, and specifically in eroding blanket mire systems. Again, given the lack of supporting evidence for LWP's thesis that burning plays little part in the present character of the Lewis peatlands, and the fact that there is a substantial body of literature that suggests otherwise, it is reasonable to expect the LWP EIS documents to have looked at the question of recovery rates. This is especially so, given that rapid recovery forms such a central part of LWP's argument.

6.3.2.2 Evidence of peatland recovery from fire

Lindsay and Ross (1994) provide evidence of recovery after a severe fire on a lowland raised bog in northern England. Their results indicate that, even under relatively benign climate conditions, *Sphagnum* itself is unlikely to re-establish vigorous growth until 10-20 years after serious fire damage, assuming that there are surviving remnants of *Sphagnum* from which new shoots can develop.

This accords with the observations of Clymo and Duckett (1986) that re-growth of *Sphagnum* tends to be from axial buds which may be 15 cm below the burnt surface.

Growth from these axial buds can take several years before the new *Sphagnum* shoots reach the surface and begin to re-establish a *Sphagnum* carpet, as observed by Lindsay and Ross (1994). There is thus a lag period of some years after a fire during which the *Sphagnum* carpet is re-assembling itself. If the fire was sufficiently hot to kill even the axial buds, re-establishment is likely to take much longer.

The data from Lindsay and Ross (1994) come from a lowland site where the climate is relatively warm and humid and thus conducive to *Sphagnum* growth. Climate conditions in blanket bog regions are much harsher, and recovery rates will thus be slower. McVean and Ratcliffe (1962) emphasise the way in which increasing altitude *and* latitude reduce temperatures and shorten the growing season for various species and vegetation types of the Scottish Highlands.

Much of the Lewis peatlands may be close to sea level (compared with the Scottish Highlands) but they are a full 1° north of the Cairngorms and more than 3° north of the recovering raised bog site described by Lindsay and Ross (1994). Furthermore, McVean and Ratcliffe (1962) and Hunter and Grant (1971) emphasise that wind exposure also reduces effective temperatures and growth rates in western Scotland.

Consequently it is reasonable to assume that recovery of the blanket bog vegetation after a significant fire such as the one observed within the SAC in 2006 may result in a period of at least 10 years before the original *Sphagnum* species begin to re-establish themselves as a significant component of the vegetation, and this period may be considerably longer. Given typical rates of peat accumulation of around 1 mm per year, re-development of the original nanotope structures and microtope patterns will then take several decades and possibly centuries.

If the fire creates an erosion pattern, there is additionally going to be a period of destabilisation and breakdown while erosion gullies and haggs develop. Depending on the severity of the erosion (and by implication, the severity of the original fire), this may become an area of catastrophic erosion where peat is lost to such an extent that the underlying sub-soil is exposed. This is the position now reached on parts of Kinder Scout in the Peak District, and illustrated earlier in Figure 50, Chapter 5 of the present report. Alternatively, and more typically of what appears to be happening on Lewis as well as on many parts of the Pennines, the erosion gullies may eventually begin to choke with fresh *Sphagnum* growth and begin to infill. There is thus a post-fire period of active erosion which may last several hundred years (or more), but this is then replaced (for reasons not currently well understood) by a period of recovery.

The timescale for infilling a series of hydrologically-dynamic erosion gullies depends on the scale of vegetation re-growth, the rate of peat accumulation, and the depth of the erosion gullies. Field evidence of actual recovery rates for eroding blanket mire systems is provided by work on re-vegetation in the southern Pennines. These studies have recorded peat accumulation rates as high as 8 mm per year (Evans *et al*. 2006 : Moors for the Future website; Crowe, 2007), which, if sustained, would mean that a 1 m gully could be fully infilled within about 125 years. Crowe (2007) states that around 5 mm per year is a more realistic rate of peat accumulation within such vigorously re-vegetating gullies. This gives a timescale of 200 years to infill a gully of 1 m depth. Gullies of this depth are common across the Lewis peatlands, but so too are gullies significantly deeper than this.

The timescales for gully recovery emerging from the work in the southern Pennines assumes an absence of any perturbations such as dry summers which may bleach and kill the *Sphagnum*, or heavy rainfall eroding the thin, fresh peat deposits. Indeed Evans *et al*. (2006) clearly do not expect recovery to be so linear, or so simple, because they present a model of erosion recovery to the *natural* condition for an eroding blanket bog system that envisages a recovery time of some 5,000 years.

Thus, at both a theoretical and practical level, if burning is to be dismissed as a possible cause for the widespread erosion seen in the Lewis peatlands today, it would be necessary to show that there has been no significant burning across the area during the last 200 years at least – but potentially for as long as 5,000 years.

Given these long timescales, it is telling that LWP 2004 EIS, Vol.7, Technical Report, para 6.2, acknowledges that burning was much more extensive and significant "in the past", while LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 82 is more specific, and states that:

> *"It is likely that burning was more common in earlier decades and even centuries but* ***at present an SNH Peatland Management Scheme is probably quite effective at reducing fire incidence****."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 82*

Experience from the southern Pennines indicates that recovery from erosion caused by burning is unlikely to have happened within "decades". The SNH Peatland Management Scheme, meanwhile, has been running for less than a decade, and yet even today it is clear that fires continue to occur, so this cannot be invoked as a mechanism whereby any trace of erosion caused by burning could have vanished.

The LWP EIS documents quite simply do not present a convincing case for burning as an irrelevance to the question of erosion. Both lines of argument used by the LWP EIS documents fail to grasp the long-term nature both of vegetation recovery from fire, as shown by Lindsay and Ross (1994), and the timescales involved in recovery of eroded blanket mire, as set out by Evans *et al*. (2006 – Moors for the Future website) and Crowe (2007).

LWP contends that "drying as a result of natural hydrological de-watering processes" is far more significant than burning impacts. Given the various lines of evidence presented above, it would seem that:

- LWP's own mapping of burning impacts underestimates the extent of burning;
- fires continue to occur on the Lewis peatlands, and demonstrably cause breakdown of the surface microtopography;
- the cited 'decline' in burning practices, and thus consequent vegetation recovery, in the last several decades would make little difference to the modern-day extent of evident erosion because timescales of recovery are too long;
- burning has been demonstrated as a long-established occurrence on the Lewis peatlands, datable back several thousands of years, and is acknowledged as such by the LWP EIS documents;
- burning is widely recognised as capable of causing blanket mire erosion;
- the proposed alternative explanation for erosion on Lewis, namely a 'natural' process of dewatering through peat pipes, has not been demonstrated, either on Lewis or anywhere else, as a mechanism that can and does bring about widespread erosion of blanket mire systems.

To summarise: the LWP position states that burning is not an issue either in the SPA *or* the SAC, and is not the cause of the erosion seen across much of the Lewis blanket mire landscape. The observed erosion is instead caused by a process of natural de-watering.

In contrast, the evidence from the Lewis peatlands themselves is that fires continue to occur on the peatlands. Some of these are extensive and some are severe. The published literature contains a number of postulated mechanisms whereby blanket mire erosion may be initiated, but burning is virtually the only mechanism repeatedly shown to have caused erosion.

Ockham's Razor states that "the simplest or most obvious explanation of several competing ones is the one that should be preferred until it is proven wrong". The simplest and most obvious explanation for the extensively eroded state of the Lewis peatlands would appear to be burning, given the evidence available, but this possibility is neither explored nor discussed by the LWP EIS documents.

One of the main reasons that the LWP EIS documents do not see burning as an issue is undoubtedly that the LWP HSA survey identified so little evidence of burning impacts. Evidence that the LWP HSA survey itself may have missed many signs of burning has been discussed above.

Indeed precisely what *was* recorded by the LWP HSA survey is the subject of the next section of the present report, because data gathered about the level of burning impacts are not the only field data that are a source of concern; important questions also arise regarding the vegetation data and the way that they were gathered and interpreted. This in turn affects the way that the vegetation of the proposed LWP development area is both described and perceived.

6.4 Vegetation of Lewis peatlands

At the start of Section 6.2, six key descriptive characteristics were listed as summarising the LWP EIS view of the Lewis peatlands. Two of these concern the present character of the vegetation:

- the vegetation is generally of an unusually dry type;
- extensive areas of former blanket bog are now dry heath.

Thus:

> *"...the **bulk of the survey area is made up of relatively dry peat** surfaces which contain varying densities of gullies ... Over time, the remaining high ground lacking pools dries to form rectilinear blocks **with much dry heath vegetation**."*
> *LWP 2004 EIS, Vol.7, Technical Report, para 5.2*

> *"...gully development following de-watering, as a natural process, is very extensive, with large areas of moderate and heavy drying*

impact as a result ... ***much of the dry character and high extent of dry wet heath and blanket bog vegetation*** *is best explained in terms of hydrology..."*

LWP 2004 EIS, Vol.7, Technical Report, para 6.2

"Two ***dry forms of wet heath and blanket bog predominate*** *... Together these occupy more than half of survey area [sic] ... In addition, H10b Calluna vulgaris – Erica cinerea dry heath, Racomitrium lanuginosum sub-community is also common as a* ***third dry habitat (8.5% of survey area)*** *... These three types* ***make up almost 60% of the survey area and show the unequivocally dry character of most of the original surface****, especially when heavily gullied ... The H10b dry heath type is not recorded in the adjacent SAC survey ... It is likely that the SAC survey overlooked this type."*

LWP 2004 EIS, Vol.7, Technical Report, para 7.2

This same basic story is repeated throughout the various LWP EIS documents, but the essential facts do not vary sufficiently to warrant repeating several more quotes of almost identical wording. It is worth perhaps just providing two more, this time from the most recent of the LWP EIS documents (which largely repeat what is said in the original Technical Report) but which also add the following:

"The NVC types M15c and M17b usually dominate, ***with H10b along gully edges (the driest ground), the latter spreading out over all of the upper bog in cases of the most intense dissection*** *(and the most marked fall in bog watertable)."*

LWP 2006 EIS, Vol.5, Chapter 11, Appe4ndix 11B, para 72

*"****These dry forms of blanket bog vegetation (H10b, M15c, M17b)*** *were re-examined carefully as part of work for this Addendum.* ***Their status as dry vegetation types was validated*** *using statistical tests operating on an independent moisture index. This further analysis showed that these types represent modified forms of blanket bog, [specifically] drying of former wet blanket bog..."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 23

The message comes through fairly clearly – 'unequivocally' even – that almost 60% of the blanket bog vegetation is very dry, with some of it becoming wet heath rather than 'typical' blanket bog, and a significant amount (almost 9%) even being transformed into dry heath habitat.

Possibly the most striking part of this message is the idea that the blanket mires could now be so dry that they have ceased to be blanket mire and have become dry heath instead. This is an extraordinary claim, especially as it concerns more than 2,100 ha of 'former' blanket mire or almost 9% of the total survey area.

6.4.1 Extent of 'dry heath' on former blanket mire

It is worth starting any consideration of the claim that 'blanket bog has become dry heath' by observing that Dayton (2003) is acknowledged by the LWP EIS documents as having found no such 'dry heath' in the adjoining SAC. The explanation offered is that she failed to identify it correctly. This, too, is a remarkable claim, given Nikki Dayton's depth of knowledge and experience.

However, the reader may recall that the LWP HSA survey had issues with Dayton's survey approach:

> *"That survey [Dayton, 2003] was undertaken on behalf of SNH and used a similar field methodology to the HSA baseline for recording vegetation and land management impacts. However, there is much less emphasis on the environment of SAC mapping polygons and, **overall, the SAC study is less comprehensive**."*
> *LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 18*

6.4.1.1 LWP HSA survey approach to Erica cinerea-rich bog vegetation

Taking up the LWP EIS explanation of why Dayton (2003) failed to spot 'dry heath' vegetation:

> *"**It is likely that the SAC NVC survey overlooked this type** and this is understandable because the M15c Cladonia spp. sub-community has a high frequency and cover for Racomitrium lanuginosum (Rodwell, 1991). The constancy of Erica cinerea, in association with high Racomitrium cover ... was recognised early in the 2002 survey and **all surveyors were asked to record such ground as H10b**, as a means of separating it from the much commoner M15c type which is less distinctive and occurs in slightly wetter conditions."*
> *LWP 2004 EIS, Vol.7, Technical Report, para 7.2*

If the LWP HSA survey was hoping to produce results that would be compatible with Dayton's (2003) survey, it is "unfortunate" that this unilateral decision was not discussed with Nikki Dayton. Had this been done, there might have been a great deal less enthusiasm for the perceived (and essentially unexplained) need to 'separate such ground from the much commoner M15c type'.

We will return to other aspects of the unilateral survey methodology later, but for the moment it is important to consider this unilateral decision to identify significant areas of blanket mire ground as 'dry heath' H10b – a decision that clearly conflicts with the NVC mapping decisions used within the SAC. Indeed this decision conflicts not merely with the approach used by Dayton (2003). It is difficult to find any published literature that adopts the same approach.

Goode and Lindsay (1979) describe the vegetation of eroded blanket bog on Lewis as:

> *"...a dry Rhacomitrium-dominated facies of either Trichophoreto-Callunetum as described by Birks (1973) from Skye or a Rhacomitrium-rich facies of Trichophoreto-Eriophoretum as*

described by McVean and Ratcliffe (1962)."

Goode and Lindsay (1979)

There is no mention of dry heath communities, which are described by both the cited authors for other habitats. In LWP 2006 EIS, Vol.5, Appendix 11b, para 6 it is stated that Goode and Lindsay (1979) emphasise how " the abundance of *Erica cinerea* is of interest as this species does not generally occur on deep peat." LWP 2006 EIS, Vol.5, Appendix 11b, para 6 then goes on to state:

> *"The latter point is important, because bell heather (E. cinerea) is of course a normal constituent of dry heath vegetation in western Britain, on mineral soils."*
>
> *LWP 2006 EIS, Vol.5, Appendix 11b, para 6*

Indeed LWP 2006 EIS, Vol.3, Appendix 11b, para 44 then suggests that Goode and Lindsay (1979) describe "dry heath (H10b) analogues" for the Lewis Peatlands. Goode and Lindsay (1979) do indeed observe that "the abundance of *Erica cinerea* is of interest as this species does not generally occur on deep peat." However, they <u>then</u> go on to say:

> *"...It is, however, recorded by Birks (1973) as a component of this association on Skye and is abundant within similar vegetation on peat haggs in Shetland (Goode 1974). McVean and Ratcliffe (1962) record this species from Trichophoreto-Callunetum along the western seaboard of Scotland but not in the Central Highlands of Scotland.* ***It appears that Erica cinerea occurs on areas of eroded peat or actively growing blanket peat only in the most oceanic districts of Britain****."*
>
> *Goode and Lindsay (1979)*

It can thus be seen that Goode and Lindsay (1979) even go so far as to state unambiguously that *Erica cinerea* occurs on 'actively growing blanket bog' – a rather prescient phrase, given the subsequent designation of 'active blanket bog' as a 'priority habitat type' within the European Union Habitats Directive. As for the occurrence of *Erica cinerea* on blanket peat, a number of other species also occur on western blanket bog but are found abundantly in dry heath communities on mineral soil – heather (*Calluna vulgaris*), for example.

Birse (1980) sets out a raw data table, plus a synthetic table (summary table), for the recognised phytosociological plant Association 'Narthecio-Ericetum tetralicis : bog heather moor' identified by J.J. Moore for the highly oceanic regions of Ireland (and Britain). This table contains a *Cladonia uncialis* sub-association, with a variant characterised by *Molinia caerulea*. Within this is then a subvariant with *Potentilla erecta*, but for which the differential species is *Erica cinerea*. The species assemblage of this sub-variant is very similar to that recorded as H10b by the LWP HSA survey team, but is explicitly characterised by Birse (1980) as a sub-variant of blanket bog, rather than of dry heath (for which he presents other tables).

Given the range of existing literature that recognises the presence of *Erica cinerea* and *Racomitrium lanuginosum* in abundance on blanket bog (McVean and Ratcliffe, 1962; Birks, 1973; Hulme and Blyth, 1984; Dayton, 2003); even on 'actively growing blanket bog' (Goode and Lindsay, 1979), it is not entirely clear (and is never satisfactorily explained) why it was felt necessary by the LWP EIS to 'separate' such vegetation from the 'much commoner M15c type' not merely into another mire community but into an entirely different habitat type.

Published literature provides insufficient support (indeed virtually no support) for such a critical yet unilateral decision, and the discussion provided in LWP 2004 EIS, Vol.7, Technical Report, para 7.2 is nowhere near adequate to justify the subsequent definitive statements made in a whole series of locations throughout the various LWP EIS documents. For example:

> *"Gullying ... drops the watertable, perhaps by at least 50 cm, and* ***this allows large extents of dry heath (NVC H10b vegetation)*** *... to develop."*
>
> *LWP 2004 EIS, Vol.7, Technical Report, para 4.4*

> *"In addition,* ***H10b heather dominated dry heath is also common (8.5% of survey area)****, often with prominent raised cushions of Woolly hair-moss Racomitrium lanuginosum, occurring on the dry sides of gullies and sometimes spreading out in heavily eroded areas to cover all or most of the remnants of the original blanket bog surface. These three NVC types (M15c, M17b, H10b) make up almost 60% of HSA extent and show unequivocally the dry character of most of the blanket bog surface."*
>
> *LWP 2004 EIS, Vol.3, Chapter 11, para 24*

> *"Estimating extent is difficult* ***due to the large proportion of H10 vegetation which is developed on blanket bog or on deep peat*** *adjacent to stream lines (all H10 vegetation totals 2738 ha, see Figure 34 in the Habitat Technical Report Volume 7, LWP 2004)."*
>
> *LWP 2006 EIS, Vol.5, Appendix 11c, para 29:*

This separating out of a dry heath NVC type, at least to the extent used in the LWP EIS documents, was questioned by Lindsay (2005) while reviewing the LWP 2004 EIS. Quadrats listed by LWP 2004 EIS, Vol.7, Technical Report, Appendix 5, Table A5.4 as having been allocated to H10b dry heath did not seem to fit this NVC type. Lindsay (2005) examined the species composition of these quadrats and compared them as a whole with the NVC community tables for blanket bog communities published in Rodwell (1991). In particular, Lindsay (2005) considered the quadrat data according to the principles of continental phytosociology – the system described as forming the underlying basis of the National Vegetation Classification (Rodwell, 1991).

6.4.1.2 Using phytosociology – the 'underlying principle' of the NVC

Braun-Blanquet (1932), the founding-father of the Zürich-Montpellier school of phytosociology, introduces the process of defining vegetation groups from quadrat data thus:

> *"When a large number of complete records of well-developed stands within one association are tabulated side by side,* ***the first synthetic character observed is the presence of the species*** –

their more or less regular occurrence in the stands."

Braun-Blanquet (1932) develops this further by observing that no species is so ubiquitously successful that it:

> *"...flourishes or even occurs in every community of a region, no matter how broadly the communities are defined. A natural selection has taken place, and a limitation of species to certain plant communities is easily discernible."*
>
> *Braun-Blanquet (1932)*

He goes on to define the concept of phytosociological 'fidelity', by which the faithfulness to a single vegetation community is measured. The most exclusive species (*treue*) are only ever found in a single community (though not necessarily at high abundance). These are described as 'characteristic species' which can be used to define a given vegetation community with confidence: if they are present, then it must be this community and no other.

In the absence of characteristic species, Braun-Blanquet (1932) recognises the usefulness of what he terms 'differential species', which are not strictly true to one community, but have their main centres of distribution within a small number of closely-related communities.

Braun-Blanquet (1932) then emphasises that:

> *"...floristic criteria cannot be applied mechanically ... It must be noted that the species are* ***not to be reckoned merely as figures in a statistical comparison*** *... Because of their entire sociologic relation they must be evaluated as social units of differing importance ... As in systematic botany, now one, now another, character takes a leading place.* ***Undoubtedly, fidelity is of supreme diagnostic importance****."*
>
> *Braun-Blanquet (1932)*

Subsequently, as Müller-Dombios and Ellenberg (1974) explain, it has become increasingly clear that the concept of an absolutely faithful character species is just that – a concept rather than a reality – because species are found to migrate from one community to another when increasingly large geographical areas are considered:

> *"Recently, the tendency has developed to distinguish associations [vegetation communities]* ***by differentiating species****. This implies dispensing with the requirement of character species for an association. This development results from experience that there are only few character species in the strict sense. However, the alliances [broader 'habitat sub-type' groupings of vegetation] retain their own character species, while orders and classes [broad habitat types] usually show numerous character species."*
>
> *Müller-Dombios and Ellenberg (1974)*

Lindsay (2005) compared the published NVC tables for H10b, M15c and M17b to determine whether there were species that could be described as 'character' or ‘differential’ for each of these three NVC communities, specifically when compared with each other. In other words, was it possible to identify species that were, for example, only found in H10b and never in M17b?

The resulting comparison diagram for H10b and M17b is reproduced here, slightly updated, as Figure 68, from which it can be seen that a number of species commonly associated with bog habitats – for example, common cotton grass (*Eriophorum angustifolium*), hare’s-tail cotton grass (*E. vaginatum*), round-leaved sundew (*Drosera rotundifolia*) and the bog moss *Sphagnum papillosum* – are recorded in the NVC for M17b but not for H10b, and *vice versa* for certain species associated only with H10b.

It is important to understand that the method described here is not the same process as that used to assign vegetation stands to an NVC type in the first place. This is generally achieved by examining the assemblage of species constants, and is frequently assisted by numerical analysis using programmes such as TABLEFIT. Rodwell (1991) observes that ‘preferential’ or ‘differential’ species are most often used to distinguish NVC sub-communities rather than in making distinctions between the main community types such as heath and mire.

However, when dealing with rather species-poor communities that have in addition suffered significant damage, as is the case with the blanket mire and heath communities of Lewis, even the community constants cannot always be relied upon to provide a clear guide to the main community types. Thus when NVC data are input to programmes such as TABLEFIT, the output is presented as a series of probabilities that the data come from particular NVC types.

What is quite striking with such TABLEFIT output in the case of these species-poor communities is that the highest probability for a given dataset may be given as one NVC type, then the next-most-likely suggestion is not given as a different sub-community of the same NVC community but may often be given as a different NVC community or even as a different habitat – heath instead of mire, for example.

The process described above, and illustrated in Figure 68, is therefore employed when a limited number of community possibilities has already been identified using community constants and TABLEFIT, but there remains considerable ambiguity about the community, sub-community, or even habitat to which the sample is best assigned. The approach draws on the basic principle of Braun-Blanquet (1932), and indeed of phytosociology as a whole, that:

> *“...**fidelity is of supreme diagnostic importance**.”*
>
> *Braun-Blanquet (1932)*

By collating the relevant NVC tables given by Rodwell (1991) and ignoring species that are common to all the communities and sub-communities under particular consideration in this example, the process in effect removes the influence of species that represent community constants *within this particular group*. The species that remain are by definition those that tend to occur in only one or perhaps two members of this small group of communities – in other words, they are *differential* or *preferential* to particular members of the community groups under consideration.

	H10a character	H10a differential	H10b character	H10b differential	M17b character	M17b differential
Carex binervis Agrostis capillaris Blechnum spicant	■					
Campylopus paradoxus Galium saxatile Rhytidiadelphus loreus Pleurozium schreberi Dicranum scoparium		■				
Carex pilulifera Festuca vivipera Cladonia furcata Cetraria islandica			■			
Empetrum nigrum nigrum Huperzia selago Cornicularia aculeata Carex panicea Festuca ovina				■		
Eriophorum angustifolium Eriophorum vaginatum Sphagnum papillosum Drosera rotundifolia Cladonia arbuscula Mylia taylori Hypnum jutlandicum Polygala serpyllifolia					■	
Narthecium ossifragum Sphagnum capillifolium Luzula multiflora						■

Figure 68. 'Character' and 'differential' species used to separate 3 NVC vegetation types. Summary species table listing those species (within this particular comparison) that are character species for each of the three NVC types listed here. Also shown are species that are differential species for each group, although not unique to the group. This table can be used to compare the species listed in Table A5.4 of the LWP 2004 EIS, Vol.7, Technical Report for NVC sub-community H10b, with the published NVC tables for both H10 and M17b. The many species common to all three NVC types shown above are not listed here, as they provide relatively little help in making distinctions *between* these types. Species-table data based on tables provided by Rodwell (1991).

It is important to understand that such differential or preferential species are not the same as those described as *differential* or *preferential* within the published NVC tables. These latter differentiating species are identified as such by Rodwell (1991) because they generally help to distinguish sub-communities *within* a particular NVC community. Thus *Drosera rotundifolia* is a preferential species for M17a within the M17 community, and it is also a preferential species for M18a within the M18 community. In contrast, the differential or preferential species identified in Figure 68 are used solely to differentiate between the communities already selected as likely candidates, and these communities may be from completely different sub-communities, communities or even habitat types. On this basis, Lindsay (2005) argued that a proportion of the quadrats listed as H10b in Table A5.4 of the LWP 2004 EIS, Vol.7, Technical Report should be more appropriately listed as being M17b because they contained many of the 'character' or 'differential' species for M17b and few, if any, of the character or differential species for H10b.

The subsequent revised LWP application responded to this suggestion by gathering some additional quadrats from an H10b site and re-analysing the vegetation dataset for H10b, M16c and M17b in terms of ecological indicator values.

LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 23 and LWP 2006 EIS, Vol.3, Appendix 11b, para 43 set out the details of this re-analysis, and conclude that:

> *"The statistical analysis supports the series H10b – M15c – M17b – M17a as a gradient of increasing moisture ... This re-evaluation has confirmed the 2004 interpretation of these types as a moisture gradient largely determined by the degree of erosion affecting the deep peat of the area ... Dry heath (H10b) analogues also seem to have been reported in the Lewis Peatlands (Goode and Lindsay, 1979; Hulme and Blyth, 1984)."*
>
> *LWP 2006 EIS, Vol.3, Appendix 11b, paras 43 – 44*

It is entirely reasonable for LWP to observe that the species involved, and the vegetation groups listed above, do indeed form a moisture gradient. The critical questions are:

- whether the moisture gradient so identified justifies placing the driest communities within a completely different 'dry heath' habitat; or
- whether the dry end of the gradient represents an impoverished form of the original M17 habitat.

As such, although the LWP 2006 EIS analysis is of ecological interest, it provides little additional insight into how such ground should be *classed*, because there are no hard-and-fast rules about assigning vegetation quadrats to NVC types - which is exactly as Braun-Blanquet (1932) observed in relation to phytosociology as a whole.

6.4.1.3 Presence or absence of H10b

In fact it is not so much the *presence* of H10b dry heath on deep peat that is the issue as the extent of ground which it occupies. Lindsay (2005) had reasonably observed that some of LWP's own quadrats did indeed appear to be H10b, but a significant proportion of LWP's quadrats did not appear to fit comfortably in that NVC type and instead appeared to lie closer to M17b. He thus questioned whether the reported total extent of H10b was correct.

In his initial report on the LWP 2006 EIS, one of the present authors (Lindsay, 2006) cites the highly respected ecologists and botanical surveyors Ben and Alison Averis as stating that "H10b never occurs on peat soils". This quote was incorrect, and the author apologises unreservedly for this. What was intended was an observation that nowhere in the report by Averis and Averis (1995) which describes a survey of the upland vegetation around Loch Seaforth, North Harris, do those authors identify H10b as occurring on deep peat. Perhaps, however, it is better to let Ben and Alison Averis correct Lindsay's (2006) error in their own words:

> *"In our 1995 survey in south Lewis and North Harris survey we found H10b 'on well-drained substrates, often on steep slopes facing between south-east and west', and although we did not find it there on deep peat we did not in our report make the above statement that H10b 'never occurs on peat soils'".*
>
> *Ben and Alison Averis, March 2007*

As a result of this error on the part of Lindsay (2006), Dr Tom Dargie subsequently commissioned Ben and Alison Averis to carry out an analysis of the LWP HSA quadrat data which had been assigned to H10b and M15c by the LWP HSA survey team. Also included were various other quadrat data for Lewis, Harris and Shetland Averis and Averis 2007). Their report (from which the above quote was taken) assesses the quadrat data supplied. The report summarise the position thus:

- only two of the ten quadrats recorded by the LWP HSA survey as H10b should actually be classed as such. They consider the remainder to be M15c-M17b (five quadrats), H10b-M15c (two quadrats) and H10b-M17b (one quadrat).
- Some of the seventeen M15c quadrats showed a slight-to-moderate degree of transition to M17b bog. At least one quadrat from this survey is of H10b heath.
- "From the above it follows that not all of the vegetation mapped in these surveys as H10b and M17b does actually belong to these types."

It seems, therefore that Averis and Averis (2007) consider the same proportion of the LWP HSA quadrats to have been wrongly assigned to H10b as Lindsay (2005) had originally proposed, because Lindsay (2005) considered 4 of the 5 quadrats listed in LWP 2004 EIS, Vol.7, Technical Report, Appendix 5, Table A5.4 not to be pure H10b, while Averis and Averis (2007) consider 8 out of 10 quadrats supplied to them not to be pure H10b.

Averis and Averis (2007) conclude thus:

> *"In our experience* ***we have found H10 dry heath to be scarce on deep peat in Britain, and restricted there to small areas on the driest parts of burnt, drained or eroded peat****. We have not surveyed peatlands ourselves in north Lewis or Shetland, so we have no direct detailed first-hand experience of the vegetation in these places (though we have surveyed such habitats very extensively through many parts of the Highlands and Hebrides).* ***It is surprising to us that in the Lewis windfarm survey H10b is mapped for such a large extent (8.5%) of peatland in an area with such a wet climate****. From our examination of the quadrat data* ***it is our opinion that although 'pure' H10b has indeed been recorded correctly here, its total extent must be less than that which has been mapped****, and that* ***some (perhaps most) of the***

vegetation mapped as H10b is actually M15c wet heath or vegetation transitional between H10b and M15c, between M15c and M17b or (less commonly) between H10b and M17b."

Averis and Averis (2007)

According to Averis and Averis (2007) there is thus a strong likelihood that a significant proportion of the 2,113 ha mapped as H10b in the LWP HSA survey area should in fact be assigned to blanket mire vegetation types, or to transition types.

On this basis, and given that the proportion of quadrats considered by Averis and Averis (2007) to be pure H10b match with the proportion suggested by Lindsay (2005), it is instructive to refer back to Lindsay's (2005) Table 2, which presented the revised effect on area totals for the key NVC types based on such a proportional re-assignment. This table is reproduced here as Table 12. It is important to emphasise that this is not a set of figures endorsed by Averis and Averis (2007), in part because they were not asked to re-calculate any such figures, but the revised proportions for pure H10b do match with their observations.

Table 12: Extent of H10b – revised estimates

Revised figures for the extent of certain key NVC types recorded for the HSA – originally presented as Table 2 in Lindsay (2005). Figures were originally revised on the basis of proportions of quadrats listed under these NVC types in the Lewis EIS Technical Report that were subsequently re-assigned according to the phytosociological procedures set out in the text above.

NVC type	EIS area (ha)	% of HSA	Revised area (ha)	New % of HSA
H10b	2113	8.5%	423	1.7%
M15c	6313	25.4%	1894	7.6%
M17b	6236	25.1%	8621	34.7%
M17a	604	2.4%	3722	15%

It seems that the LWP EIS analysis may have been distorted by an over-reliance on numerical methods. The belief that statistical analysis will produce the necessary answers has already been encountered in the re-analysis of LWP data to 'prove' the wet-dry gradient displayed by the quadrat data. While such analysis demonstrates a gradient, it does little to help decide whether part of this gradient should be classed as H10b or not. Similarly, the reliance on numerical methods alone – an approach expressly warned against by Braun Blanquet (1932) – becomes too influenced by certain species values and misses the essential character of the various quadrat groups.

This process of re-analysis by Lindsay (2005) and subsequently by LWP for the LWP 2006 EIS is of considerable significance because the originally-quoted extent of H10b given in the LWP 2004 EIS documents continues to be quoted as an established fact in the LWP 2006 EIS documents. There is no suggestion within the LWP 2006 EIS document that the reported re-analysis by LWP (LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 43) had changed a single hectare of the

2,113 ha originally listed in LWP 2004 EIS, Vol.7, Technical Report, Appendix 3. Thus, the LWP 2006 EIS continues to state:

> *"...These three NVC types* ***(M17b, M15c, H10b) make up almost 60% of HSA extent*** *and show the dry character of most of the blanket bog surface."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 23*

> *"In addition,* ***H10b heather-dominated dry heath is also common (8.5% of survey area)****, often with prominent raised cushions of Woolly hair-moss Racomitrium lanuginosum, occurring on the dry sides of gullies and sometimes spreading out in heavily eroded areas to cover all or most of the remnants of the original blanket bog surface."*
>
> *LWP 2006 EIS, Vol.3, Appendix 11b, para 42*

As mentioned at the start of the present report, the Peatland Research Unit of the University of East London visited Lewis in the autumn of 2006. Part of the UEL fieldwork involved visiting a number of sites that had been classified by the LWP HSA GIS map as being predominantly H10b, or for which H10b was described as being the most extensive single vegetation type. Five areas recorded as H10b were visited by the UEL team, and quadrats were taken. These locations are set out in Table 13, together with the polygon number (SEQID) allocated by the LWP HSA GIS dataset, the Target number used by the UEL survey team, and a listing of the nanotope zones identified by the UEL team. The nanotopes were identified from those given in Table 3 and Figure 5 of JNCC (1994).

Table 13: UEL Peatland Research Unit quadrat summary
Locations of UEL Peatland Research Team quadrats, taken in October 2006, for LWP HSA polygons coded as H10b. Details are given for the OS National Grid Reference, the unique LWP polygon code (SEQID), the unique UEL code (UEL Target No.), and the listing of nanotope zones (see JNCC 1994, Table 3) recorded by the UEL Peatland Research Team.

OS Grid ref.	LWP NVC type	LWP HSA polygon no. (SEQID)	UEL Target No.	Nanotope zones
NB 35282 34172	H10b	670	30	T4, T3, T1, *E1, *E2
NB 48609 58383	H10b	2343	68	T3/4, T2, E1, E2
NB 48398 58325	H10b	3653	99	T3, T2, T1, A1, A2
NB 48281 58325	H10b	3653	62	T3/4, T2, E2, T3, T2, T1, A1, A4
NB 29183 45561	H10b	4188	70	T4, T2, T1, E2, E2(dry)

* E1 and E2 = JNCC (1994) nanotope TA2 – *i.e.* erosion gullies; E1 represents wet vegetated gullies; E2 represents dry gullies

On visiting these locations, it generally did not appear that these areas supported areas of H10b vegetation to the extent suggested by the LWP HSA dataset (see Figure 69).

Figure 69. Ground conditions within an example of Erosion Class 8 and H10b 'dominance'.
Four photographs from Polygon (SEQID) 4188, which is classed as predominantly H10b (40%), and Erosion Class 8. The photos were all taken at, or around, NB 2918 4556 (thus giving 10 m precision to the location). The orange arrows point to dense stands of common cotton grass (*Eriophorum angustifolium*) or, in the case of the most detailed photograph, various individual plants of *E. angustifolium, within a* heather (*Calluna vulgaris*) and cross-leaved heath (*Erica tetralix*) sward beneath which there is occasional *Sphagnum capillifolium* or *S. tenellum*. Although coded as Erosion Class 8, it was clear that many gullies were re-vegetating (though many were not).

The quadrat data for all areas surveyed by the UEL team (not just H10b sites) are set out in Appendix 2. From these data, and from Table 13, it can be seen that all five areas recorded as H10b (by the LWP HSA survey programme) display a considerable variety of nanotopes and species groups. It is accepted that the LWP HSA coding for the vegetation of polygons is based on a composite assemblage of types, with the most extensive listed first, then the second most extensive, and so on. Thus a coding by the LWP HSA GIS dataset of H10b does not mean that the polygon is exclusively H10b. Nonetheless, the coding of these areas as *predominantly* H10b appeared completely inappropriate in most cases when seen in the field.

Table 14 thus displays the relative proportions of NVC types recorded for these five polygons within the LWP HSA GIS dataset. It can be seen that H10b, though described by LWP as the dominant NVC type in each case, varies between 29% and 45% cover, with the highest value being recorded for Polygon SEQID 4188, which is the polygon illustrated in Figure 69.

The evidence from Figure 69, and from the UEL quadrat details provided in Appendix 2, suggests that 45% cover for H10b in this location might reasonably be described as 'generous', particularly in the light of the general comments regarding likely H10b extent made by Averis and Averis (2007). The problems of estimating extent within a mosaic represent another key issue with the LWP HSA dataset, and such difficulties are discussed below in Section 6.4.2.1.

The second key issue with the values presented in Table 14 is that they are without any context, in the sense that it is not at all clear how the various NVC types distribute themselves within the polygon. Is the value for each NVC type derived from many small patches, or does the NVC type occur as a single block, or is it scattered through the polygon as thin ribbons of vegetation? As we shall see, this is another important question, to be considered in Section 6.4.2 below.

Table 14: Relative NVC cover for LWP polygons
Table of % cover values for NVC types recorded by the LWP HSA survey team for five polygons identified as having H10b as the dominant NVC type. 'SEQID' is the unique polygon number assigned by the LWP HSA GIS dataset.

SEQID	670	2343	3653	3653	4188
OS NGR	NB 35282 34172	NB 48609 58383	NB 48398 58325	NB 48281 58325	NB 29183 45561
UEL No.	30	68	99	62	70
H10b	29	30	30	30	45
Bare peat	20				20
M3	13	20	20	20	7
M15a					18
M15c	18	20	20	20	10
M19b	20				
M17b		10	10	10	
M17a		10	10	10	
M1		10	10	10	

6.4.2 LWP survey methodology : quantitative imprecision

Both of the issues mentioned above represent key weaknesses in the survey methodology employed by the LWP HSA survey team. It is worth examining both issues in more detail, because there is a curious irony in the problems associated with the chosen methodology. The method has been constructed to produce very accurate data, yet the result is a set of data that is not only likely to be inaccurate but also ultimately misleading. There has been considerable attention to detail, but unfortunately this attention has been focused on the wrong thing. The LWP methodology has sought to bring rigorous numerical methods to a topic for which such an approach is not well suited, while at the same time ignoring a rather simpler level of detail that could have provided much more insight into the peatland environment. Furthermore, this method could have obtained the necessary data for a great deal less effort on the part of the field surveyors.

6.4.2.1 Estimating cover in a mosaic

It is made very clear in LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B that the approach to mapping of mosaics normally adopted by SNH was not considered sufficiently informative or comprehensive for the purposes of detailed analysis. Thus:

> *"...the SNH system for recording the extent of NVC types in polygons representing NVC mosaics is* ***not suitable for calculating the area of individual NVC types*** *and this prevents a detailed comparison of HSA results with those for the Lewis Peatlands SAC."*
>
> *LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 18*

Consequently:

> ***"Each [NVC] type present was given a visual estimate of its percent cover in the polygon****. As an example, a polygon with three habitats present might be annotated as follows, with types in order of decreasing cover in the polygon: M17b (85) + M1 (10) + H10b (5). The example would represent a polygon with 85% cover of M17b dry blanket bog, 10% cover of M1 bog pool vegetation in the wet floor of peat gullies, with 5% cover of H10b dry heath representing very dry ground on the hagged edge of peat gullies."*
>
> *LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 35.*

Anyone who has undertaken fieldwork in blanket bog landscapes will recognise what a challenge this methodology represents. Indeed it is such a challenge that it explains the very understandable reluctance of SNH to take habitat mapping to this level. Consider for a moment the type of ground being surveyed, and the shapes of the polygons involved. An idea of the difficulties posed by such a methodology can be obtained from Figure 70.

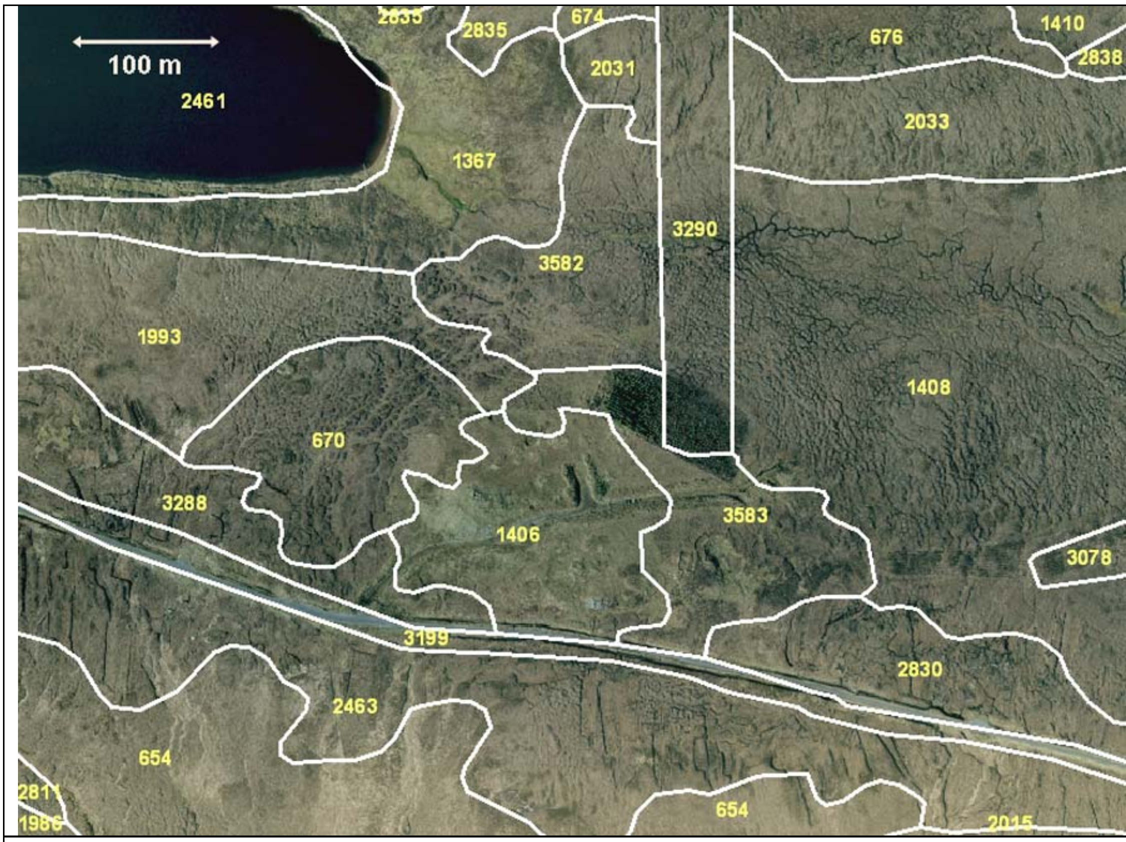


Figure 70. Complexity of ground within LWP HSA polygons.
Aerial photograph of LWP HSA centred on NB 354342. Boundaries of LWP HSA polygons are shown in white, together with the unique polygon number (SEQID) for each polygon. The highly complex nature of the surfaces within most of the polygons displayed is readily seen. Thus Polygon 670 in the middle-left of the photograph has an evidently complex but relatively uniform surface pattern(microtope), whereas Polygon 1993 shows a distinct gradient of microtope pattern from east to west. Polygon 1408 displays a great variety of microtope pattern types within the single polygon. Furthermore, not only are many polygons quite extensive, they also have complex boundaries and many are quite sinuous (*e.g.* Polygon 2463). Estimating relative % cover for different vegetation types within these polygons would be extremely difficult.

Whilst the intent to produce data that are quantifiable is laudable, there are occasions where striving for such rigorous numerical approaches in fact creates quite the opposite of what was intended. Spurious numerical data can be more confusing and, in effect, more inaccurate, than no numerical data at all. It can be seen from Figure 70 that there would be extraordinary difficulties in producing a ‘visual estimate’ of even the individual microtope pattern elements within the aerial photograph. The human mind is notoriously bad at estimating total extent of small fragments scattered across an area. Estimating extent of linear, anastomosing networks (of gullies, for example) is as bad, if not worse. However, the vegetation is then a pattern *within* this microtope pattern so there is yet another layer of complexity to deal with.

The picture is even more complicated when a polygon is not a simple, rather circular shape but instead consists of long sinuous sections or has various complicated offshoots. It is difficult enough to calculate this by detailed image processing of an aerial photograph, but then because the vegetation is not visible on an aerial photograph to the scale necessary for NVC assignment, the final stage of quantifying the vegetation must be done at ground level, in the field. Estimating distances (and thus cover values) in the field is again remarkably difficult, and when these estimates have to take into account sinuous shapes or a variety of offshoots, it becomes an almost impossible task to produce anything that is quantitatively meaningful.

In essence, the idea that rigorous, quantitative estimates of NVC % cover can be obtained for each polygon is a desirable theoretical objective but currently a practical impossibility. This is why SNH does not use quantitative mapping of mosaics – the apparent rigour of such numerical results hides a whole spectrum of difficulties that render such results at best unreliable (and probably unrepeatable), and at worst give a positively spurious picture of the vegetation pattern on the ground.

The difficulty arises in the first place because the LWP habitat survey chose not to make use of the hydromorphological peatland hierarchy discussed at length in Section 5.2 of the present report and set out in the JNCC SSSI Selection Guidance for Bogs (JNCC 1994). This is a great shame because at the level of vegetation description the hierarchy is particularly useful in helping to structure the sampling, analysis and description of vegetation stands.

The utility of this framework is particularly valuable because it helps bring order to what can either appear to be an alarmingly complex pattern of surfaces, or (as is more usually the case) one which tends to be treated in a simplistic way that overlooks much useful information. By using microtope and nanotope zones to structure the approach to vegetation description, the information obtained remains within an established and internally-coherent framework and helps to provide a range of valuable insights into the ecological character of the ground being described.

6.4.2.2 Mapping of vegetation types within nanotope zones

The hydromorphological hierarchy of peatland systems has been invoked at many stages during the present report, but mapping vegetation *within* nanotope zones represents the final, most detailed level of the hierarchy.

Nanotopes have been recognised since the earliest descriptions of peatland systems, and a variety of individual nanotope elements have been identified over the years (*e.g.* Sjörs, 1948; Ratcliffe and Walker, 1958; Goode, 1970; Goode and Lindsay, 1979; Moen 1985). Some of these have been given different names by different authors, and some authors have recognised more structural elements than others. Some names have been used for different elements by different authors. Lindsay, Riggall and Burd (1985) reviewed this problem and proposed that various fairly consistently-recognised elements might be given a simple coding system to avoid the confusion caused by the use of different names for essentially the same features - such as ‘carpet’, ‘lawn’, ‘flat’ and ‘ridge’.

This coding system thus forms the basis for the list of nanotope types listed in the SSSI selection guidance for bogs provided by the JNCC (1994 – Table 3). The point of using these nanotope features as a descriptive part of the hydromorphological hierarchy is that, firstly, they themselves provide a level of functional control at the fine hydrological scale, as discussed above in Section 5.2.5.4, but secondly that they provide the small-scale niches within which the vegetation is then distributed. The vegetation is thus given a physical and hydrological context which can usually provide valuable insights into the reasons for particular vegetation patterns or the presence of particular vegetation types.

Thus, as a specific example, in Britain the oblong-leaved sundew (*Drosera intermedia*) generally occurs within shallow, water-filled hollows that Sjörs (1948) originally (and slightly confusingly) termed 'mud-bottom hollows' – confusingly, because there is no real 'mud' on a peat bog, but the name (like mud) has stuck. These mud-bottom hollows are coded by Lindsay, Riggall and Burd (1985) as 'A2' hollows. Thus, if a bog does not possess A2 hollows, it will probably also not possess any records for oblong-leaved sundew (*Drosera intermedia*). Such hollows are only generally found in bogs towards the west of Scotland, and thus the present distribution of *Drosera intermedia* can be understood in terms of the distribution of the A2 nanotope element within British bogs.

Interestingly, the reverese is also true. If a site has past records of *Drosera intermedia* but the species is no longer present, this can usually be taken as an indication that A2 mud-bottom hollows were probably once present on the site.

The mapping of vegetation within the nanotope zones thus has functional benefits that can provide some valuable insights into the ecological and small-scale hydrological processes currently present on the site, but also potentially give some indication of past events and conditions as well. It is thus very unfortunate that the LWP HSA survey programme did not explicitly record vegetation within the pattern of nanotope zones found across the mire systems. Area-values (or at least approximate estimates of relative abundance) are given for the various NVC types, but as they are not placed in any small-scale hydrological setting it is difficult to make further use of the information.

Indeed the absence of nanotope zoning as part of the LWP methodology for the vegetation survey seems to have rather distorted the approach to the gathering of species data. Essentially, the vegetation data are presented as either coming from erosion hagg tops, or from gullies. It is difficult to find any mention of other structural elements within the various descriptions of vegetation sampling and characterisation. The result of this rather 'dichotomous' sampling (and indeed apparently dichotomous view of the vegetation distribution) is that quadrat sampling seems to have focused mainly on two nanotope elements within the available range of nanotope zones. These zones are the T4 erosion hagg top and the TA2/E2 erosion gully. Consequently it is hardly surprising that the 'original bog surface' is described as being extremely dry and lacking in such typical bog species as *Sphagnum*. If the T4 hagg topswere the main elements sampled, then by definition this will generate data of a very dry nature.

The important point here is that the nanotopes of the Lewis blanket mires consist of much more than just T4 erosion hagg top and TA2/E2 erosion gullies. Even within the 'worst' of the polygons sampled – namely Polygon 4188, illustrated above in Figure 69 – there is a range of nanotope structures, as can be seen in Appendix 2, Target note 70. There are T4 hagg tops, T2 'high ridge', T1 'low ridge' and two forms of TA2 erosion gully – E1 fully vegetated and E2 dry gully with some vegetation. Within the T2 high ridge there are small amounts of bog typics such as *Sphagnum capillifolium*, *S. subnitens* and *S. tenellum*, while at the T1 low ridge level these species are significantly more abundant, forming extensive patches in places. Within the E1 erosion gully, there are extensive swards of common cotton grass (*Eriophorum angustifolium*) but within this there are also patches of *Sphagnum subsecundum*.

Thus the actual pattern of vegetation for Polygon 4188 is not a picture dominated by huge swathes of H10b vegetation, but rather a mosaic in which relatively small areas of T4 hagg top may support H10b, but around these hagg summits there are less-dry areas of original surface (see Figure 69, above) which support vegetation and nanotopes with more typical ‘classic’ blanket bog habitat. The H10b is restricted largely to the highest parts of the nanotope range. As such, the UEL-observed extent of H10b within Polygon 4188 probably thereby reflects the pattern of distribution and extent envisaged by Averis and Averis (2007), rather than the large extent recorded by the LWP HSA survey for this polygon.

The pattern of vegetation within gullies is also particularly significant, especially given the apparently widespread trend towards vegetation recovery within gully systems. Let us not forget, the LWP Erosion Classes describe all Erosion Classes except 5, 7 and 8 as either being un-eroded or showing significant levels of gully revegetation (“stable or might be revegetating”, in the words of LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, Table 11B.3). These Erosion Classes amount to 16,675 ha, or just over 77% of *all* the blanket bog habitat in the HSA. Specifically, “stable or perhaps revegetating” eroded bog represents just under 71% of all *eroded* bog in the HSA.

Over and above the fact that such a high figure points to a blanket mire landscape that is now undergoing a major period of apparently natural recovery (rather than the picture of an inexorably drying and degrading habitat painted by the LWP EIS documents), this figure also highlights the importance of the gully vegetation within the overall context of the blanket mire landscape. Essentially, if the bog *is* undergoing a period of vigorous recovery, it is doing so within the micro-environment – the nanotopes – of the gullies, *not* generally within the areas of upstanding, relatively dry hagg tops. That such vigorous recovery was taking place became fairly evident to the UEL Peatland Research Unit during field survey. This evidence ranged from the almost complete revegetation of the gully system in polygons such as Polygon 670 (though coded as dominant NVC type H10b, according to the LWP GIS dataset), to the extremely well-developed revegetation and re-ponding of the gully systems in Polygon 3499.

Two examples of typical revegetation and re-flooding of the erosion system can be seen in Figure 71. What is clear from these pictures is that a new set of nanotopes is re-emerging *within* the gully system, and that these newly-formed nanotopes (with their associated vegetation) are now growing up sufficiently to overwhelm the burnt and rather battered remnants of the hagg system. Thus a catalogue of the biodiversity within these recovering systems should make explicit reference to such new nanotope systems because these are what will return the bog to a form of natural condition. There is a danger that, because they lie within a gully system, they are regarded as somehow ‘inferior’ to areas of ‘original’ bog surface’. To think this would be a mistake because these actually represent the new, vigorous and natural bog surface (a natural surface that has developed without costly and labour-intensive restoration management progammes).

Unfortunately, one is left with a clear impression from the LWP EIS documents that this is precisely the LWP HSA survey perception of such features – secondary features of only limited significance – and thus the sampling tends to treat them as such. The approach *should* instead have been to identify these nanotopes and proceed to catalogue the vegetation within both the old and the new structures. Thus a generalised diagram of the nanotope systems that should have been sampled is shown in Figure 72.

Figure 71. Examples of vegetation recovery and re-wetting within erosion systems. Examples of gully systems becoming re-vegetated and re-flooded. Growth of fresh bog vegetation is creating nanotope zones which would have been largely lost during the active gullying stage. Thus there is re-development of good T1 low ridge, T2 high ridge, T3 hummock, and even A3 pools. The old T4 erosion haggs are now becoming increasingly paludified from below as the water table in the former gully rises with the accumulating active bog vegetation. Photos taken from the pool system at NB 486588, but similar scenes can be found within most of the Lewis peatlands erosion complexes.

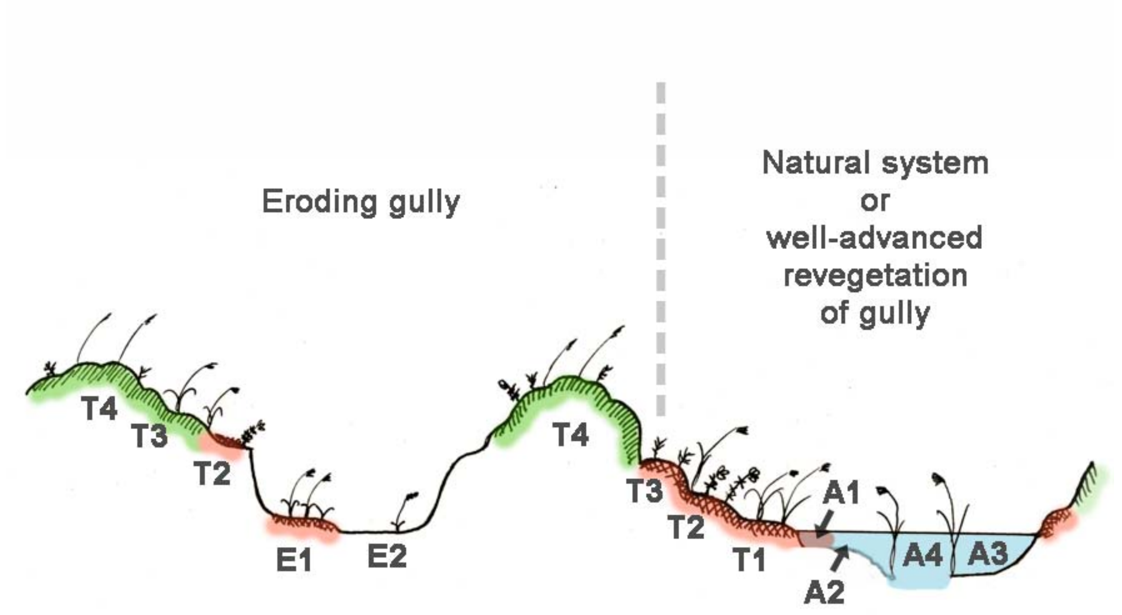


Figure 72. Summary diagram of nanotopes found on Lewis peatlands. Range of nanotope zones within examples of gully systems either actively eroding or becoming re-vegetated and re-flooded. Growth of fresh bog vegetation is creating nanotope zones which would have been largely lost during the active gullying stage. Green = *Racomitrium lanuginosum*; Red = *Sphagnum*; Blue = standing water. Thus there is re-development of good T1 low ridge, T2 high ridge, T3 hummock, and even A3 pools. The old T4 erosion haggs are now becoming increasingly paludified from below as the water table in the former gully rises with the accumulating active bog vegetation. Zone codes (other than E1 and E2, which are sub-catergories of TA2) are as described in JNCC (1994 – Table 3).

6.4.2.3 Results of the UEL vegetation survey

Within the time available on-site, it was not possible for the UEL Peatland Research Team to undertake a large amount of formal vegetation survey involving the accumulation of extensive quadrat datasets. However, using the principles of microtope and nanotope survey, it was possible to collect some usefully representative data for the range of microtopes and nanotopes examined. Despite the time-constraints, however, the 56 quadrats that were collected in the 10 days of fieldwork amount to almost twice the total collected by the LWP HSA survey team for the three most extensive vegetation types recorded within the LWP 2-year survey programme.

As already mentioned in the previous section, the raw data gathered by the UEL Peatland Research Team can be seen in Appendix 2, but a set of examples can be presented here to illustrate the way in which microtope/nanotope sampling makes it relatively simple to express the sometimes complex structural and vegetation patterns in an easily understandable form. The illustration uses three polygons identified by the LWP HSA and classified in the LWP EIS documents as having H10b as the dominant NVC type.

Figure 74 and Figure 75 present these three polygons as symbolic profiles based on Figure 72. The UEL quadrat data taken from these three polygons for each nanotope zone are displayed next to the appropriate zone in the stylised profile. The numerical information given for the vegetation in each nanotope zone represents the 'best fit' NVC assignment by TABLEFIT for the UEL quadrat data for that zone. The '2nd-best fit' is also provided (to give some sense of whether the vegetation is likely to be a good fit, or is transitional between NVC types).

The relative abundance of the individual nanotope zones is indicated by progressively darker borders to the NVC boxes (darkest = most abundant, lightest = rare). The proportion of NVC types recorded *by the LWP HSA survey* for the *whole* polygon is also indicated as a separate table in the illustration to show the vegetation mixture recorded for that polygon by the LWP HSA survey.

It can be seen from both Figure 74 and Figure 74 that the UEL data presented according to individual nanotope components often (though not always) differ significantly from the proportional assignment of NVC types to the polygon as a whole by the LWP HSA survey programme. In general, the occurrence of vegetation that can be described as 'normally peat forming' within the various nanotopes is found to be much more significant in the UEL data than is indicated by the overall LWP HSA polygon assignment.

It is not possible to talk about measured areas of these various nanotope zone types and their vegetation because such a complex mosaic does not lend itself to accurate calculation of areas. But then (as discussed above), despite the attempts of the LWP HSA survey to prove otherwise, that survey is also not able to provide meaningful area figures. Both the LWP HSA approach and the nanotope approach *are* able to provide estimates of *relative* abundance – in the sense of a DAFOR scale (dominant, abundant, frequent, occasional, rare).

It is even possible to use a reduced version of this without the vowels (DFR) and still obtain a valuable picture of the vegetation pattern.

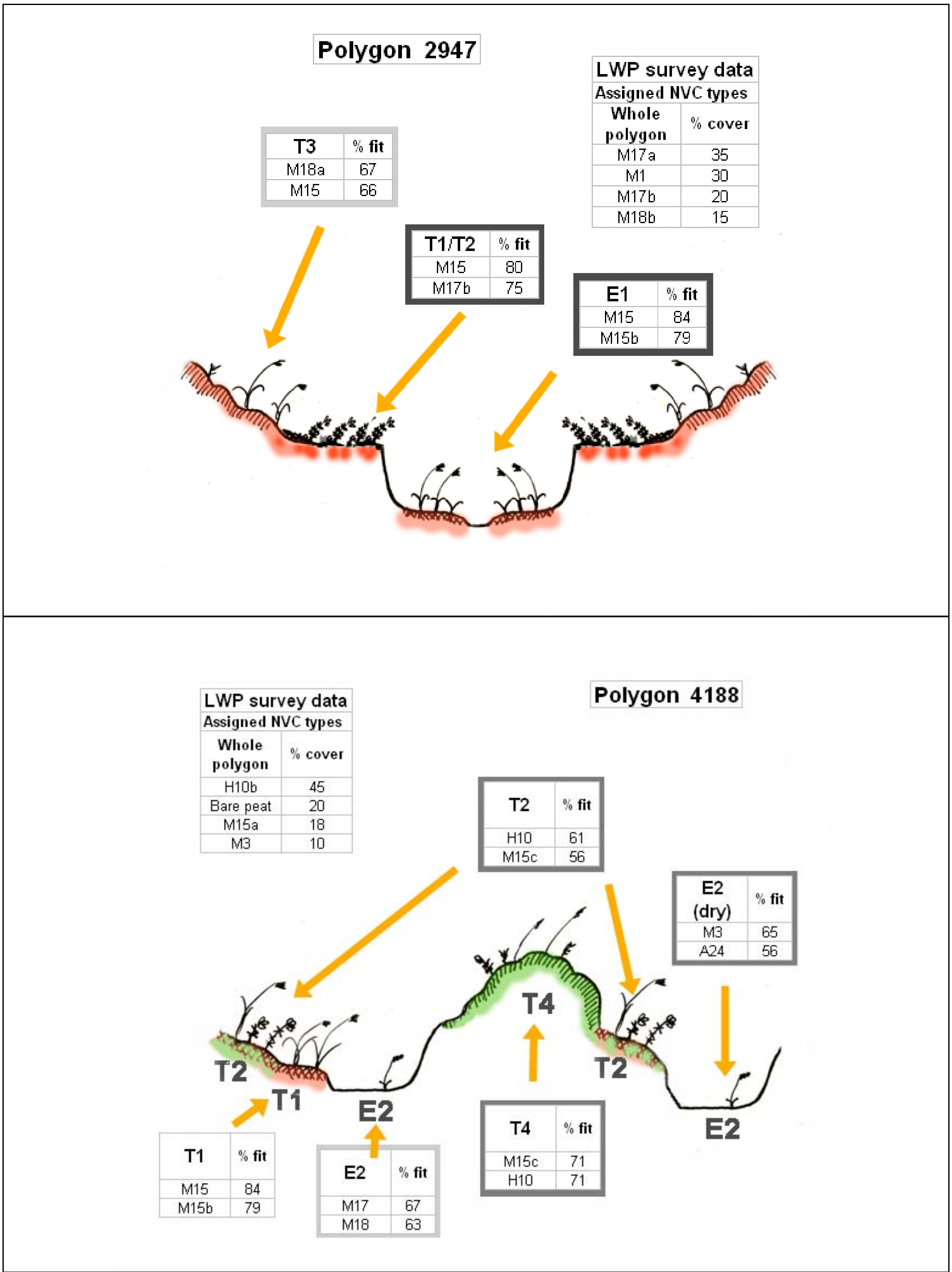


Figure 73. Summary nanotope diagrams for LWP HSA Polygons 2947 and 4188. Range of nanotope zones and NVC types recorded for two HSA polygons, the upper one (Polygon 2947) only moderately eroded, the lower one (Polygon 4188) heavily eroded. Green = *Racomitrium lanuginosum*; Red = *Sphagnum*; Blue = standing water. Proportion of NVC types recorded by LWP HSA survey for polygon as a whole is provided as a single table. Individual zone tables (with arrows) indicate best fit, and 2nd-best fit to NVC type according to TABLEFIT, for UEL quadrat data taken within each nanotope zone Abundance of zones is indicated by shaded borders according to DAFOR scale; darkest shading = Dominant, to no shading = Rare. Zone codes (E1 and E2 are sub-catergories of TA2) are as described in JNCC (1994 – Table 3). Complete data table for all UEL quadrats can be seen in Appendix 2.

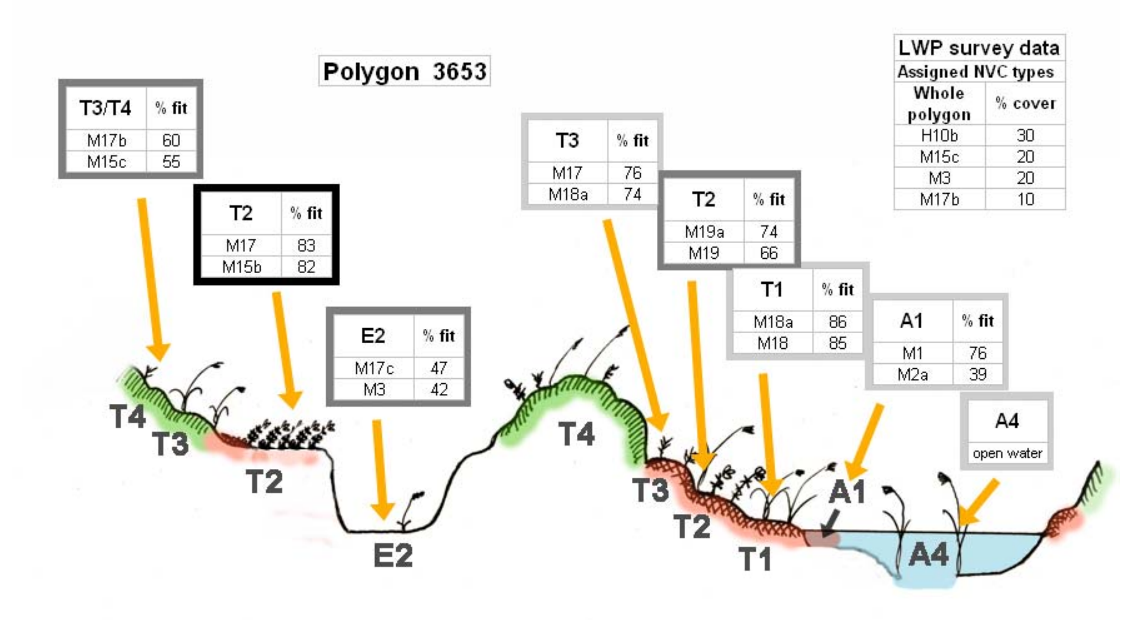


Figure 74. Summary nanotope diagrams for LWP HSA Polygon 3653.
Range of nanotope zones and NVC types recorded for an HSA polygon (Polygon 3653) showing a mixture of active erosion and vigorous vegetation recovery. Green = *Racomitrium lanuginosum*; Red = *Sphagnum*; Blue = standing water. Proportion of NVC types recorded by LWP HSA survey for polygon as a whole is provided as a single table. Individual zone tables (with arrows) indicate best fit, and 2nd-best fit to NVC type according to TABLEFIT, for UEL quadrat data taken within each nanotope zone Abundance of zones is indicated by shaded borders according to DAFOR scale: darkest shading = Dominant, to no shading = Rare. Zone codes (E1 and E2 are sub-catergories of TA2) are as described in JNCC (1994 – Table 3). Complete data table for all UEL quadrats can be seen in Appendix 2.

Using the nanotope zone approach, such apparently crude data are nevertheless capable of teasing-out the really essential information about the habitat which can be summarised thus:

- what are the main microtopes and nanotopes that characterise the mesotope?
- is the predominant microtope pattern a form of erosion?
- is the erosion intense, moderate or mild?
- are the predominant vegetation types 'normally peat forming'?
- are the 'normally peat forming' vegetation types restricted to erosion gullies?
- is the erosion system actively eroding, actively regenerating, or perhaps balanced between the two?

It is not at all clear that the LWP HSA survey results would be able to answer each of these questions adequately, or in some cases answer them at all. This is the essential weakness of the LWP HSA survey – though almost overloaded with data, it is quite simply the wrong sort of data to answer the basic questions of the EIS. One of the key questions, of course, is: how much 'active blanket bog' is there, and where is it? The LWP 2006 EIS document devotes a considerable amount of energy to this problem, but again the difficulty seems to be that this enormous amount of work has been focused on the wrong thing.

6.5 'Active blanket bog' within the development area

As referred to earlier in the present report, the EU Habitats Directive (92/43/EEC) has specified that blanket bog is a habitat of community concern requiring conservation action within the European Union, and that 'active blanket bog' requires priority action. Given that something between 80% and 90% of the proposed development area is blanket mire and associated habitats (such as freshwater lochs) of various types, the requirements of the Habitats Directive clearly have a direct bearing on what is proposed for the Lewis peatlands.

The LWP EIS documents adopt a particular position (or more strictly, particular positions) with regard to the definition of 'active blanket bog'. Consequently three key factors must be addressed within the present section:

- the definition of 'active blanket bog' provided by the official UK statutory agencies;
- the definition of 'active blanket bog' adopted by the LWP EIS documents;
- the identification of 'active blanket bog' by the UEL Peatland Research Unit within the proposed LWP development area.

6.5.1 The official statutory agency definition of 'active blanket bog'

Several sections of the present report have already referred to various issues concerning the definition provided by the statutory agencies in relation to the concept of 'active blanket bog'. The present section will simply review these and bring them together. However, as will become evident, there are significant implications in this for the way in which the LWP HSA survey has described the blanket mires of the proposed LWP development area.

6.5.1.1 The official definitions of 'active blanket mire'

The official definitions for the Annex 1 habitats listed in the EU Habitats Directive are reviewed by the EU Habitats Committee, endorsed by the Member States. In the UK the definitions are then overseen and promulgated by the Joint Nature Conservation Committee (JNCC). Consequently the definitions provided by the JNCC for particular Annex 1 habitats represent the official definitions endorsed by the UK Government, and in effect, by the Habitats Committee of the European Union.

The definition for 'active blanket bog' is as follows:

> *" 'Active' is defined as supporting a significant area of vegetation that is normally peat-forming. Typical species include the important*

peat-forming species, such as bog-mosses Sphagnum spp. and cottongrasses Eriophorum spp., or purple moor-grass Molinia caerulea in certain circumstances, together with heather Calluna vulgaris and other ericaceous species.

Thus sites, particularly those at higher altitude, characterised by extensive erosion features, may still be classed as 'active' if they otherwise support extensive areas of typical bog vegetation, and especially if the erosion gullies show signs of recolonisation."

JNCC website

It is important to highlight here the way in which the definition specifically recognises that peat may be formed through the waterlogged preservation of several species and species-groups, including the *Sphagnum* bog moss genus, but the definition explicitly acknowledges that genera such as the cotton grasses (*Eriophorum*) may also form peat. Even bogs with extensive gully erosion are specifically included within the definition, recognising amongst other things that an eroded bog showing evident signs of active regeneration is virtually by definition an 'active blanket bog'.

Ladder fens are also specifically identified as a type that occurs within the blanket mire landscape, and any site meeting the above definition would thus also qualify as 'active blanket mire'. The description of this type is important because it demonstrates a key aspect of the Annex 1 habitats definitions, both at the UK level and at the level of the EU Habitats Committee:

"Ladder fens form an integral part of some blanket bogs and have a characteristic surface patterning, with narrow pools and intervening low, narrow ridges parallel to the contours. Associated with this structure is a more species-rich flora than that of the surrounding mire expanse. This is due to local flushing of mineral nutrients through these fen areas, in contrast to the surrounding vegetation, which receives all its nutrients through precipitation, i.e. is ombrotrophic. Ladder fens may also be referable to 7140 Transition mires and quaking bogs."

JNCC website

The key element of the description given above is that it does not rely on an NVC type to define it. The critical factors are, in effect, the mesotope and microtope characteristics, with an additional key note that the vegetation is influenced by local flushing. Indeed even the first definition, that of 'pure' blanket bog, uses concepts over-and-above purely NVC types, such as re-vegetating eroding bog, and a vegetation 'that is normally peat forming'. The JNCC provides a number of NVC types as a guide to identification of blanket bog, but it is made clear that these are not exhaustive and should not be used solely and exclusively to define 'active bog'. For ladder fens, no example NVC types are given, and so the definition is left purely to the mesotope, microtope and general vegetation character.

The definition of 'active blanket bog' is thus fairly clear, and has been adopted and used throughout the UK. It can be summarised as:

- possessing a significant area of normally peat-forming vegetation that can be characterised broadly by NVC types M20, M19, M18, M17, M15, M3, M2, M1;

- if eroded, the general vegetation cover should still have a substantial element of normally peat-forming vegetation, and ideally evidence of re-vegetation in the gullies;
- ladder fens which possess a vegetation that can be described as normally peat forming can also be included.

6.5.1.2 Implications for the LWP HSA survey methodology

The problems highlighted in the discussion about nanotope sampling in the previous section, in particular about the simplistic dichotomous approach of the LWP HSA survey to vegetation sampling, means that there is a tendency within the LWP HSA survey data to consider only the extremes – the high haggs, and the deep gullies – rather than look at the finer scale of vegetation patterns within the general surface mosaic. The degree to which this is true is extremely difficult to determine without, in effect, repeating the whole LWP HSA survey and then comparing results. However, even this would not reveal a great deal because, as discussed above, the LWP HSA survey methodology would be extremely hard to repeat consistently anyway.

Thus we have some reasonably clear indications that the LWP HSA survey has tended, on at least some occasions, to generate vegetation descriptions that are significantly drier than a more appropriately-focused examination of these areas has subsequently revealed. If this has occurred consistently across the LWP HSA, it is quite likely that any attempt by LWP to assess the area of potential 'active blanket bog' will result in a significant under-estimate.

Currently the only practicable way of calculating the area of 'active blanket bog' using the LWP HSA data is to take the LWP HSA GIS polygons, identify those that contain NVC types that are considered to be 'normally peat forming' and sum those areas. But if the NVC assignments themselves are wrong, this becomes a meaningless task. Confidence in the original assignment of NVC types is the most fundamental requirement from such a dataset, but as we have seen, there are significant question marks over several aspects of the original NVC assignments.

6.5.2 The LWP approach to defining 'active blanket bog'

As already mentioned in the section above, the LWP 2006 EIS documents describe how a major programme of re-analysis was undertaken in order to provide a 'sound basis' for the identification of 'active blanket bog'. The LWP HSA survey data were re-examined by LWP, and on the basis of this, LWP decided that (LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11C, para 19):

- the division between active and non-active bog would be made using the area of *Sphagnum* bog moss recorded for each polygon by the LWP HSA survey;
- the threshold of *Sphagnum* cover separating active bog from non-active bog would be 10% cover.

Before considering the nature and validity of these two decisions, it is worth first looking at certain aspects of the methodology used to create the original information about *Sphagnum* cover.

6.5.2.1 Estimation of Sphagnum cover

It is stated in LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11C, para 19 that:

> *"Sphagnum was recorded in the field by **visual estimation of Sphagnum percent cover** for the **two largest NVC types** recorded per polygon."*
>
> *LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11C, para 19*

It should be noted that one of the commonest problems in vegetation field sampling occurs because two field surveyors looking at the same simple 2 x 2 m quadrat will often fail to agree on the % cover of many or most of the species present. As discussed in Section 6.4.2.1 above, the human mind is not good at combining scattered elements into a single composite area total. The problem of different observers seeing different things is termed 'observer bias' and is well known in field surveying.

If it is difficult enough to avoid 'observer bias' when using a simple square quadrat frame, how much more difficult – and thus approaching the meaningless or spurious – is it going to be to produce a figure of *Sphagnum* cover for two vegetation types that lie scattered within the already complex mosaics illustrated in Figure 70? The field surveyors involved in carrying out the LWP HSA survey were undoubtedly experienced and professional in their approach, but it is simply not possible to make a meaningful estimate of *Sphagnum* cover across such complex ground and within such complex polygon shapes. The figures generated must consequently be treated with the utmost caution.

6.5.2.2 Partial estimates of Sphagnum cover

The methodology used by the LWP HSA survey programme also recorded *Sphagnum* cover only from the two most extensive NVC types recorded within a polygon. It can be seen from the LWP (2004) values of NVC cover given in Appendix 3 of the present report, or from the original LWP HSA GIS dataset, that many polygons did not neatly and conveniently display a single high % cover for one NVC type. Instead the polygons often comprise several NVC types that have % cover values rather similar to each other. Thus Polygon 3653 has NVC cover-values of:

H10b	=	30%
M15c	=	20%
M3	=	20%
M17b	=	10%

In this case the measured *Sphagnum* cover would be based on *Sphagnum* cover for H10b, which generally has a relatively low % *Sphagnum* cover, and M15c, which has a variable *Sphagnum* cover. The unmeasured *Sphagnum* cover of M3 in the gullies, which will tend to have a higher % *Sphagnum* cover than the erosion haggs, would therefore not be included within the calculation because it does not fall within the 'top two' NVC cover-values, even though it scores the same cover value as M15c.

An adjustment is then made to the LWP HSA estimates of *Sphagnum* cover to compensate for the fact that a proportion of the ground lacks any measured value for *Sphagnum* cover (LWP 2006 EIS, Vol.5, Appendix 11C, para19). This adjustment is, however, still based on the values obtained from the field survey. The adjustment assumes that the remander of the polygon will have the same proportional cover of *Sphagnum* as was found in the two most extensive NVC types.

This is a questionable assumption because, as we have seen earlier, it seems that regenerating erosion gullies have been under-represented by the LWP HSA survey. These gullies generally have relatively high *Sphagnum* cover. It is therefore quite possible that areas for which there are no *Sphagnum* measurements in the LWP HSA dataset would have had higher *Sphagnum*-cover values than those areas for which measurements were obtained (essentially dry hagg tops and dry erosion gullies). In effect, the correction factor may well do the opposite of what it intends because it is based on figures from which the *Sphagnum*-rich elements have often already been filtered out.

6.5.2.3 The LWP measure of 'active blanket bog'

Notwithstanding the questions over 'measured' and 'corrected' values of *Sphagnum* cover, there are two more fundamental difficulties with the approach adopted by the LWP 2006 EIS towards identifying the extent of 'active blanket bog':

- *Sphagnum* is by no means the only vegetation that forms peat;
- the adopted approach is at variance with the official JNCC definition in several important ways.

Look at any stratigraphic diagram of a blanket mire peat core in the scientific literature and it will be found that significant sections of almost any peat column consist of plant remains other than *Sphagnum* (*e.g.* Boatman, Goode and Hulme, 1981; Tallis, 1985; Charman, 1995; Moores and Stevenson, undated). Indeed the standard symbol-set used for displaying stratigraphic remains (Troels-Smith, 1955) contains a great variety of symbols that have relatively little to do with *Sphagnum*.

It is therefore a rather singular decision to choose presence of *Sphagnum* alone – indeed a 10% presence - as the indicator of 'active blanket bog'. During phases when a bog has evidently accumulated peat in the past but this peat is almost entirely *Calluna-Eriophorum*, would this phase have been classed as 'non-active blanket bog'? Presumably so, according to the LWP definition, <u>despite</u> the evident accumulation of peat.

It is true that such *Sphagnum*-poor phases of peat accumulation may actually have had more *Sphagnum* as a component of the living vegetation than is suggested in the peat archive. However, the only evidence available is what is contained within the peat archive, so suggesting that there was once more *Sphagnum* is mere supposition. Furthermore, the structural material of *Sphagnum* is not readily broken down completely to the point where nothing remains, so such *Calluna-Eriophorum*-rich phases of peat accumulation may indeed represent periods when there was relatively little *Sphagnum* present in the living vegetation. The peat was instead created by the roots and leaf-bases of species such as *Eriophorum* cotton grasses.

There is also a difficulty with LWP's use of 10% *Sphagnum* cover as a threshold for the distinction between 'active' and 'non-active' bog. Such numbers imply that it is possible to calculate the area of a vegetation/habitat type to within an accuracy level of some 2-3% if a 10% threshold is to have any meaning. In practice, it would be a considerable achievement to obtain an accuracy level of 10% for the surveyed cover of *Sphagnum*, given the highly complex nature of the mapping units in terms of boundary complexity, physical microtopography and vegetation pattern. It is precisely for this reason that the definitions within the EU *Habitats Interpretation Manual* (European Commission, 2003) and the JNCC guidance give no quantitative threshold values.

At a more conceptual level, the difficulty with using *Sphagnum* alone as the indicator of 'active bog' is that, in many parts of the world, *Sphagnum* plays only a minor part in the picture, or it may be absent entirely. Thus in the 'cushion mires' of Tierra del Fuego, which tend to be found at moderate altitude and sometimes resemble a form of blanket mire, the entire system may be created by the cushion plants *Donatia fascicularis* and *Astelia pumila*. The definition adopted by LWP would conceptually exclude such systems, but the JNCC definition does not. The JNCC definition is thus a robust and universally applicable concept, whereas the LWP definition is not.

The other significant problem for the LWP definition of 'active blanket bog' is the way in which it does not correspond with various other aspects of the official JNCC definition. Thus there is little room within the LWP definition for aspects of the JNCC definition such as:

- eroded bogs, with or without re-vegetation in the gullies;
- bogs that are dominated by, for example, hare's-tail cotton grass (*Eriophorum vaginatum*) tussocks that are growing densely and vigorously in a tightly-packed mass and thus evidently adding to the peat store;
- areas such as ladder fen where there is a much greater proportion of the sedge family (Cyperaceae) within both the living vegetation and the peat archive, and yet as Charman (1994, 1995) shows there is undoubtedly accumulation of peat within such systems.

All in all, it is evident that the definition of 'active blanket bog' set out in LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11C, para 19 is neither appropriate in concept nor workable in practice. It also cuts across the official definition of 'active blanket bog' and tries to take the definition into conceptual areas that the official definition has deliberately sought to avoid precisely because such areas are inappropriate or unworkable.

Consequently, the whole body of work undertaken for the LWP 2006 EIS in relation to defining 'active blanket bog', then mapping areas accordingly and calculating possible impact totals, must unfortunately be viewed as largely irrelevant to the issue. In particular, this means that the major part of LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11D, Tables 11D.1 – 11D.9 are also irrelevant because the largest defined VERs – 'active blanket bog' and 'non-active blanket bog' have been calculated inappropriately.

This obviously represents a fairly major weakness in the evidence presented within the LWP 2006 EIS. If the basic Valued Ecological Receptor for the predominant habitat type in an EIS is incorrectly defined and mapped, it is almost inevitable that the EIS will fail to provide an adequate assessment of potential ecological impact.

6.5.2.4 UEL estimation of 'active blanket bog' in the LWP HSA

It will already be evident that there are grave concerns about a significant proportion of the data presented in support of the LWP EIS documents. As mentioned earlier, however, without undertaking a complete re-survey of the HSA there is little that can be done about this now. The UEL Peatland Research Unit survey has been able to highlight the *nature* of several such areas of concern, but within the time and resources available was unable to establish the total *extent* of the various problems.

Consequently any attempt to estimate the extent of 'active blanket bog' must perforce use the existing LWP HSA GIS data, but try to use it in such a way that minimises as many of the identified problems as possible. Given this, it is worth just briefly summarising these areas of concern:

- the identification of NVC vegetation classes appears to show an unwarranted tendency towards drier NVC types;
- in particular the extent of certain drier NVC types appears to have been estimated in an unduly (even 'surprisingly') generous way;
- the method employed to estimate the extent of NVC types within a polygon is extraordinarily difficult given the terrain involved, and is thus open to substantial 'observer bias';
- areas classed as particular Erosion Classes (and thus expected to fit the given definitions) have been found, in the field and through colour aerial photo analysis, not to correspond to the given definitions;
- the vegetation mapping appears to have adopted a somewhat 'dichotomous' approach where the two extremes of the vegetation pattern have been sampled, but much ground in between has not been sampled;
- certain very distinctive and generally 'active' mesotope types identified within the official JNCC guidance appear to have been completely overlooked;
- an undue emphasis within the LWP HSA approach on descriptive systems that focus on degree of damage has meant that relatively little relevant information is provided about those systems that are relatively free from significant erosion.

Within this context, it is possible to take the LWP HSA GIS dataset and carry out an analysis that highlights the total extent of areas that are *likely* to be 'active blanket bog'. There are many caveats to this exercise, but the selection steps involved in producing a somewhat conservative estimate would be as follows (with explanation):

- identify those polygons that contain any quantity of the following NVC types - M20, M19, M18, M17, M15, M3, M2, M1
- for each polygon, calculate the total area for **all** of the above NVC types listed (taken as 'active bog types');
- select those polygons in which the total area of 'active bog types' represents the **major** part of the vegetation cover (*i.e.* 50% or more);
- **ignore Erosion Class** (because this has been found in the field not to be a reliable indicator of 'active' conditions, and the above selection based on dominance of NVC 'active' types probably removes examples of heavy erosion from the total);

- select those polygons **that contain non-eroded ladder fens** (in fact all identified so far are selected by the above steps anyway).

The selection process above can only be used as an *indication* of total extent for 'active blanket bog' because there are concerns about the original raw data, and there are significant elements of description that are missing from those raw data. Nonetheless, the resulting total area, amounting to a little over 21,000 ha, paints the broad picture of where 'active blanket bog' is likely to be found within the LWP HSA boundary (see Figure 75).

This indicative area of 'active blanket bog' contains a variety of blanket mire conditions including much eroded bog. However, it fits comfortably within the definition of 'active blanket bog' provided by both the European Commission (2003) and the JNCC (JNCC website). It also embraces much blanket mire habitat that is of considerable value for the breeding wader populations, particularly golden plover (*Pluvialis apricaria*) because these birds seem not to be adversely affected by the presence of erosion – at least as long as there is some evidence of vegetation recovery. Furthermore, as discussed above, if the Lewis peatlands are indeed undergoing a period of vigorous recovery, as they seem to be, then these regenerating eroded areas are generally the sites of some of the most vigorous fresh growth to be found across the peatlands.

It is thus proposed that this indicative map of 'active blanket bog' should form the basis of all peatland habitat impact assessments in relation to the LWP windfarm development. The map generated by the LWP 2006 EIS based on % *Sphagnum* cover should *not* be used, because the scientific basis of the map is flawed, and the definition parameters cut across those specified in official definitions of 'active blanket bog'.

By analysing the overlap between the area of ground identified in Figure 75 as 'active blanket bog' and the ground directly taken up by the proposed LWP windfarm infrastructure, it is possible to calculate how much 'active blanket bog' would be lost beneath construction. This might seem like a straightforward mapping exercise but in fact it is not. Should the area of ground lost beneath construction include:

- the proposed batters alongside the road-line?
- the temporary compounds?
- the peripheral drains described for some elements of infrastructure?
- the hard-standing for sediment traps at water crossings?

Each of these items could be subject to much debate as to whether they constitute actual direct loss of 'active blanket bog'.

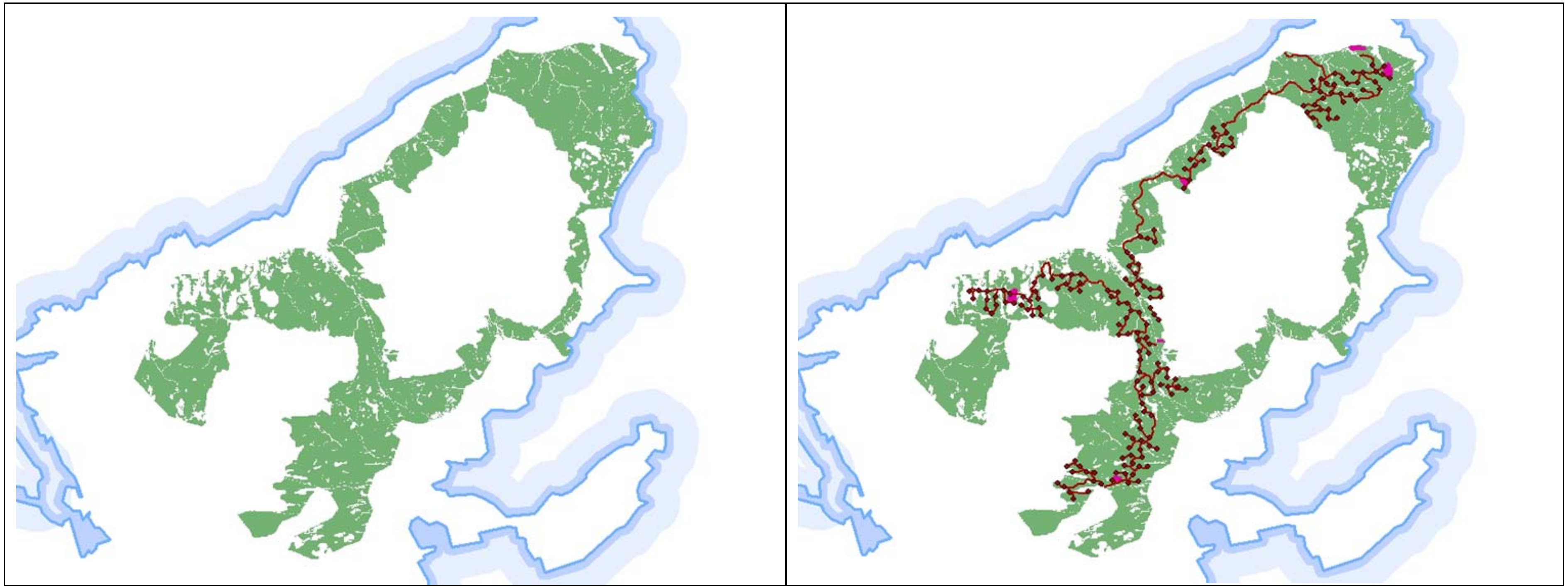


Figure 75. UEL estimate of ‘active blanket bog’ within the LWP HSA.
(Left): Area shaded in green represents a best approximation of total ‘active blanket bog’ within the LWP HSA boundary, given various uncertainties about the original raw survey data. The area amounts to a little more than 21,000 ha. (Right): The area of ‘active blanket bog’ shown in green as before, but with the proposed LWP road-line plus turbine locations (both shaded dark red), and rock sources (shaded cerise) displayed over the area of ‘active blanket bog’. Pale blue concentric lines represent the coastline of Lewis.

There is then the even more contentious question regarding the potential extent of indirect impacts caused by construction and ongoing presence of the windfarm infrastructure. These questions go to the heart of much that has already been discussed in relation to hydrology, drainage, construction methods, and many other issues.

Rather than be drawn into making a single observation at this stage about 'direct' losses – an observation that would probably confuse rather than illuminate at this stage, given the questions raised above – such calculations will be left to subsequent chapters. The present chapter will simply end by noting that Figure 75 identifies a total area of just over 21,000 ha that can be classed as 'active blanket bog' within the LWP HSA (compared with 7,703 ha calculated by LWP 2006 EIS, Vol.5, Appendix 11C, para 19), and that almost the whole of the proposed LWP development lies on this active bog.

Before considering the potential nature and scale of any indirect effects that might arise from the LWP development proposal, there is one additional factor that should be considered, not least because it has the potential to cause some of the most widespread indirect (and direct) effects of all. This factor is slope stability.

In effect, 'slope stability' is concerned with all aspects of movement within the mass of peat soil, but it is most generally associated with the largest and most dramatic of such movements – namely bog 'avalanches'. When such avalanche events occur in peat, they are more generally referred to as 'bog-slides' or 'peat-slides'. The next chapter of the present report considers the LWP development proposal in terms of its potential impact on slope stability within the Lewis peatlands.

7 PEATSLIDE RISK ASSESSMENT

Various issues involving soil instability have featured prominently as news items in recent years. These news items have highlighted several dramatic examples of sudden instability where there has been substantial loss of property or danger to life, but fortunately in Britain there has been no actual injury or loss of life in these recent events. There has been major coastal cliff erosion resulting in the loss of homes along the Norfolk coastline. There have been major landslips in Cornwall and in Scotland, including the double landslide in Scotland resulting in 57 trapped motorists on the A85 near Lochearnhead (see BBC website). Perhaps most dramatic and certainly the largest of all, there was the devastating bogslide at Derrybrien, Co. Galway in 2003 (see RTE website).

Given that some 80% - 90% of the proposed LWP windfarm development area is on peat, some of it as deep as 5 m, there are clearly questions of stability to be addressed. This is especially so, given not merely the Derrybrien bogslide and its association with windfarm construction, but the fact that another bogslide occurred within sight of Derrybrien, again as a direct result of windfarm construction (Lindsay and Bragg, 2004).

The Derrybrien collapse, combined with another major series of bogslides at Pollatomish, Co. Mayo, appears to have stimulated a variety of activity concerning issues of peat stability and possible construction impacts throughout Britain and Ireland. As part of this response the Scottish Executive has recently produced guidance on peatslide risk specifically for electricity generation schemes (Scottish Executive, 2006), and there is much valuable information provided within this document.

Two of the most in-depth and influential documents to have been published in the last three years, however, are the review by Warburton *et al*. (2004) of hydrological processes that influence peatslides, and the findings of the Irish Landslides Working Group (Creighton, 2006a). Both publications were available prior to completion of the most recent revision of the LWP proposals and publication of the associated LWP 2006 EIS. This body of literature, combined with the Scottish Executive's guidance on peatslide risk, provides a valuable context within which to asses the work on peatslide risk assessment presented in the LWP EIS documents.

Neither Warburton *et al.* (2004) nor Creighton (2006a) is cited by the LWP 2006 EIS. Indeed the LWP 2006 EIS provides only two references (additional to those of the LWP 2004 EIS) relating to peatslide risk. This is hardly a satisfactory approach to the issue, given the considerable amount of relevant literature that has been published since the LWP 2004 EIS, and specifically given the concerns about slope stability raised by Lindsay (2005) in relation to the LWP 2004 proposals. Much is made in LWP 2006 EIS, Vol.2, Sect.2, Chap.10, 10.1–10.4 of the consultation process undertaken after publication of the LWP 2004 EIS and prior to publication of the LWP 2006 EIS. There is little evidence to show that any of the comments made, suggestions offered, and issues raised, about peatslide risk during this consultation period were followed up and acted upon.

The present authors have not undertaken any fieldwork directly related to peatslide risk assessment, other than to check peat depths at various localities within the proposed LWP development area. However, many of the UEL Peatland Research

Unit findings from field survey and a remote-sensing overview do have considerable relevance to the issue.

In terms of the general principles of peatslide risk, the present chapter will thus rely largely on quotes from the main literature sources and from the LWP EIS documents, but in terms of identifying actual potential risk on site, the present chapter also draws on the UEL Peatland Research Unit findings.

7.1 The LWP EIS approach to peatslide risk assessment

The major part of the peatslide risk assessment within the LWP EIS documents is to be found in the LWP 2004 EIS. There is a section about peatslide risk in the LWP 2006 EIS, but this essentially summarises the effect of layout changes (between the 2004 and 2006 proposals) on specific at-risk localities identified in the 2004 assessment. It also gives a very brief account of management and monitoring proposals. Other than this, the main relevant information is contained in the chapters and associated appendices dealing with geology, hydrogeology and hydrology (Chapter 10 in both LWP EIS documents).

Consequently the main focus of the present review will be:

- the two key documents from the LWP 2004 EIS, namely LWP 2004 EIS, Vol.3, Chapter 17 – 'Peatslide Risk Assessment', and LWP 2004 EIS, Vol.6, Appendix 17A – 'Peatslide Susceptibility';
- the two maps LWP 2006 EIS, Vol.3, Chapter 17, Figs. 17.1 and 17.2, which update the maps from the LWP 2004 EIS;
- LWP 2004 EIS, Vol.3, Chapter 10 – Hydrology, Hydrogeology and Geology;
- LWP 2004 EIS, Vol.6, Appendix 10B – Methodology for Geological Baseline Field Studies;
- LWP 2004 EIS, Vol.6, Appendix 10D – Geological, Hydrogeological and Hydrological Impact Assessment – Baseline Studies;
- LWP 2006 EIS, Vol.2, Sect.2, Chapter 10 – Geological Hydrogeological and Hydrological Impact Assessment;
- LWP 2006 EIS, Vol.2, Sect.4, Part 3, Construction Outline Briefing Note 6 – Hydrology, Hydrogeology and Geology.

Of course one of the other critical datasets for peatslide risk assessment is the data for peat depth. The largely inaccessible nature of this dataset has already been discussed in Section 5.1.1, but the difficulties caused by this apply equally to the present chapter.

Unfortunately, the information provided in LWP 2006 EIS, Vol.3, Chapter 17, Fig.17.1 for "Peatslide Prone Locations", summarising the different forms of analysis undertaken, is equally obscure, with no explanation as to how the various coloured polygons and symbols came to be delineated as they are. Straight-edged squares and rectangles seem to be an oddly inappropriate (and thus one suspects not particularly sensitive) approach to defining 'Peatslide Susceptibility Mapping, Category Localities'. It is stated that such mapping was carried out using 'zones' (LWP 2004 EIS, Vol.4, Chapter 17, para 17), but such zones should be of sufficiently fine resolution to reflect the character of the landscape being analysed. The large rectangular blocks suggest otherwise in this case. The detailed methodology mentioned in LWP 2004 EIS, Vol.4, Chap.17, paras 16-18 then fails to explain the approach used in sufficient detail to make it clear how the methodology came to generate such simple shapes of susceptibility class. Consequently it is difficult to judge how effectively the stated method has been employed. The observable result from LWP 2006 EIS, Vol.3, Chapter 17, Fig.17.1, however, suggests that the approach has been unacceptably coarse-grained.

7.1.1 Peatslide risk - the LWP approaach

The LWP EIS documents set out a range of approaches designed to gather information relevant to the subjects of slope stability and potential engineering difficulties arising from the nature of the peat and sub-surface deposits. These approaches comprise:

- a literature review;
- identification of Hydrological Zones;
- creation of a peat-depth map along the proposed line of the windfarm roads;
- creation of a peatslide inventory;
- geomorphological mapping;
- peatslide susceptibility mapping;
- avalanche forecast mapping;
- slope-stability analysis;
- proposed experimental trial-pits in 'characteristic' ground;
- visits to other windfarm sites to see problems and solutions.

Two other sets of geotechnical data were gathered, but are not explicitly discussed in the Peatslide Risk Assessment. These are:

- Mexe-Probe California Bearing Ratio (CBR) measurements;
- limited hand augering.

It is worth noting that no additional engineering field data appear to have been gathered subsequent to the original 2003-4 fieldwork. Additional fieldwork might reasonably have been expected, to better inform LWP 2006 EIS approaches to peatslide risk, particularly as the proposed road layout is significantly different between LWP 2004 EIS and LWP 2006 EIS. This difference does not merely involve removal of sections. Whole new routes are suggested for certain road sections, but it appears that no geotechnical data have been gathered for these new sections. No explanation is given as to why such essential geotechnical data have not been gathered.

Of relevance here, and possibly explaining the absence of such information but at the same time raising an important general issue, is the following comment:

> *"The methodology for ground characterisation for this proposal* ***differs from typical engineering projects because of the large scale of the proposal*** *... the very large study area and the* ***short time-frame available to undertake site investigations*** *... Given the high degree of variability encountered over the very large site, the* ***information presented at this stage is therefore mainly reliant on professional interpretation of restricted site investigations*** *and from a geotechnical perspective, should be considered as preliminary."*
>
> *LWP 2004 EIS, Vol.6, Appendix 10B, para 1*

It is not explained why the project, simply because of its size, should be faced with a "short time-frame available to undertake site investigations", nor why, simply because of the scale of the project, a less detailed geotechnical submission than for typical engineering projects should be acceptable. Being aware of the size of the development from the start, LWP should have been fully aware that field investigations would need to be extensive and potentially carried out over an extended period of time. The approach here being proposed, and indeed adopted, is one suggesting that 'the larger the project proposal, the less information is needed prior to a planning decision'.

Of the work that has been carried out to date, the geotechnical methods adopt two broad approaches to peat stability and peatslide-risk analysis. The first of these involves 'slope stability analysis', while the second is described as 'peatslide hazard mapping' (LWP 2004 EIS, Vol.3, Chapter 17 [17.2.3]). However, before either of these is considered, it is worth just looking briefly at the other datasets described by LWP 2004 EIS, Vol.6, Appendix 10B as having been gathered to inform the geotechnical investigations.

7.1.2 Mexe-Probe California Bearing Ratio (CBR) measurements and hand augering

In somewhat similar vein to the peat depth measurements obtained by the LWP survey team, CBR measurements were taken at 100 m intervals all along the original proposed road network. Presumably the same limitations apply to the CBR measurements as have already been discussed in relation to the peat-depth measurements, except perhaps more so because the sampling interval was twice that of the peat depth sampling. Thus the CBR measurements presumably:

- do not provide a complete picture for the revised road layout;
- are not able to resolve changes in peat bearing-capacity over distances of less than 100 m.

CBR measurements are taken to gauge the load-bearing capacity of a substrate. Specifically, the test (originally developed by the California Highways Department – thus the name) compares the strength of the material under investigation against the strength of a standard fine-crushed rock. The value is expressed as a % of comparative performance, and the scale is logarithmic across the range of typical soils encountered. Thus crushed-rock base layers for pavements, for example, would be expected to have CBR values of at least 60%. Peat, in contrast, typically has CBR values of between 3% – 8%. In other words, peat is not a good sub-grade for roads (or pavements), as we have already seen in Section 4.1.2.1 of the present report:

> *"Subgrades of peat are* ***highly compressible and have very little bearing capacity****. Pavements constructed on them* ***can suffer from serious differential settlement****, so peat should usually be removed and replaced with a suitable fill ... in the long term the* ***performance of the pavement will be less certain; there may be localised failures and general loss of shape****."*
>
> *(Ministry of Defence, 1994)*

CBR values are concerned primarily with the process of road construction. As such, they give an insight into the potential difficulties of establishing a road-line with sufficient load-bearing capacity to support the types of vehicle movements that will occur during construction, maintenance and decommissioning of the windfarm. As no CBR *values* are ever presented, it is difficult to comment in any detail on the possible implications.

What *is* presented as a tangible output from the CBR and hand-auger work is LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8, which displays:

- catchments identified as potentially important for fisheries;
- public water supplies; and
- areas with some evidence of soft sub-peat strata (from CBR and hand-auger data collected spring 2004.

Clearly for the present we are interested in the final dataset listed here. There is some ambiguity in the description, because it is not entirely clear whether the measurements relate to the mineral ground *beneath* the peat, or to strata *within* the peat. LWP 2004 EIS, Vol.6, Appendix 10B, para 13 suggests that data were only obtained for sediment "at the base of the peat profile". However, in describing the hand-augering undertaken to support interpretation of the CBR data, LWP 2004 EIS, Vol.6, Appendix 10B, para 17 then talks of "being unable to retrieve a sample of the catotelm" (because, significantly, the peat is so liquid), and it is not clear why a 'sample' of the catotelm peat should be required unless it is to compare with CBR measurements of the peat itself.

Notwithstanding this small (but possibly important) area of ambiguity, the presence of markedly soft sediments in either the peat or the underlying mineral ground represents a major factor in terms of slope-stability. It is unfortunate, therefore, that the criteria used to define what is meant by "soft sub-peat strata" – specifically the CBR/hand-auger values that were used as a threshold – are neither presented nor explained. Nonetheless, the location of such ground is of considerable significance, and thus LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8 represents a key contribution to the peatslide risk-assessment process.

It is therefore a a curious thing to discover that this figure, in terms of its CBR/hand-auger data, is never referred to - not once in any of the LWP EIS documents. To have the Habitats Chapter of the LWP EIS make no reference to Hydrological Zones although they form the key descriptive units for other parts of the LWP EIS documents, is rather odd (see Section 5.2.6.2). For such a potentially important dataset as LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8 (CBR data) not to be referred to at all is most odd.

Even the way that the CBR measurements and hand-augering data are used leaves the LWP EIS reader un-enlightened. The data effectively vanish into what is presented as a 'black-box' process that is said to have determined the site layout. Normally with 'black-box' systems at least the inputs and outputs are known. In the case of the LWP process, however, even the inputs and outputs remain a mystery, other than in the form of the unexplained but nonetheless important 'soft-strata' locations mapped in LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8, and, presumably, the site layout which the reader is assured has been influenced, in some undefined way, by these and other data obtained:

> *"...this work was used to support the decision-making for the placement of access tracks and wind turbines. [However] more intensive probing will be required prior to construction to define final wind turbine and access track locations."*
>
> *LWP 2004 EIS, Vol.6, Appendix 10B, para 4*

The 37 locations identified in LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8 as having 'soft sub-peat strata' can be seen in Figure 76. What is immediately evident is that such soft strata appear to be remarkably widespread. Unlike many of the peat-related datasets, where the north-western arm of the proposed development often provides rather limited areas of interest, soft sub-peat ground is almost more common here than in any other part.

This is obviously not good news for LWP, because it raises issues of stability across an area that might otherwise have featured in only a rather limited way when considering peatslide risk. Now it seems that even shallow peat may be sitting on areas of potentially unstable sub-base and thus not be as robust in the face of disturbance as might first have been assumed.

The difficulty with the dataset, of course, is that it is not explained at all. Without a table of the CBR values obtained, or at least an indication of what threshold has been used to define 'soft strata', it is impossible to draw very much from the information as presented by LWP. It therefore sits there as something of a tantalising mystery, both in the nature of the data and in the way it has been used. Without further explanation from LWP, it is difficult to make much more headway.

In fact the only really tangible information about the state of the peat to be gleaned from the information associated with the peat coring, CBR and hand-augering work are the facts that:

> *"Augering was undertaken with a dedicated peat augur to cut through the acrotelm (fibrous peat/matted vegetation) and expose the softer catotelm (amorphous peat) beneath.* ***Due to the high water content, the peat augur is*** *[sic.]* ***unable to retrieve a sample of the catotelm****..."*
>
> *LWP 2004 EIS, Vol.6, Appendix 10B, para 17*

*"Further coring in the study area identified the catotelm layer to be composed of amorphous peat, **which liquefied when disturbed**, but otherwise was dense and solid."*

LWP 2004 EIS, Vol.6, Appendix 10D, para 47

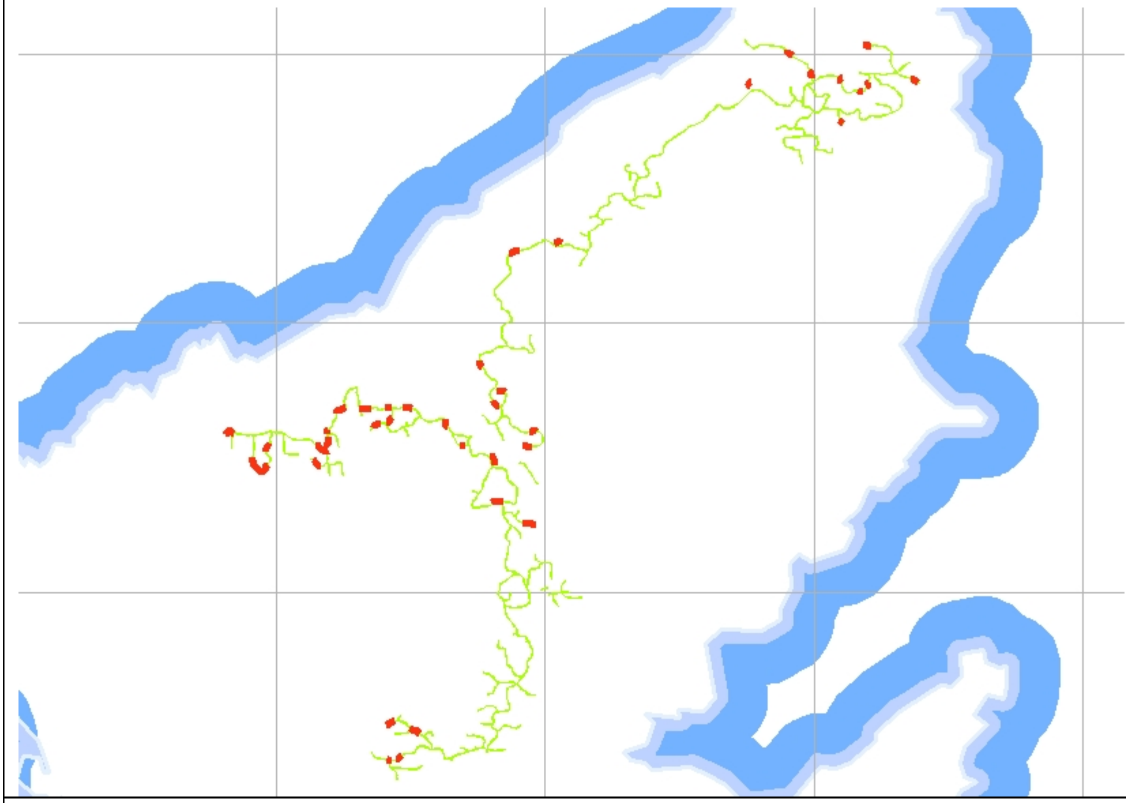


Figure 76. Sites identified by LWP as possibly having soft sub-peat strata.
Red shading indicates those areas identified as "showing some evidence of soft sub-peat strata", according to LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8. The proposed road-line for the LWp 2006 revised layout is shown in pale green. The coastline is displayed as concentric blue shading. The OS National Grid is shown in grey as 10 km squares.

In the light of these comments, it is worth also repeating here the observations made by the LWP EIS documents about the nature of the peat matrix:

*"Exposed faces in road cuttings reveal a **well-developed banded or laminated structure in the peat profile with marked variations in thicknesses of individual layers over short distances**. Typical moisture contents range from 90% to 100%, but in localised pockets of amorphous peat, the moisture content is considerably higher and frequently exceeds 1000% (Dr D. Nichols, pers. com.)."*

"Importantly, this means that on Lewis, the upper layer [acrotelm] has a textile-like fabric with relatively good engineering properties

but the middle and lower layers ***contain materials of very low strength*** *and with* ***large and erratic variations in fabric*** *ranging from fibrous and amorphous to that of jelly-like substances."*

"Most blanket bogs in Britain have an upper layer of textile-like fabric that is relatively continuous and uniform and which generally has relatively good engineering properties. ***In north Lewis, the fibrous peat layer not only varies in thickness but also more importantly, is highly disrupted by erosion****."*

LWP 2004 EIS, Vol.6, Appendix 10D, paras 26-28

The typically layered structure of the peat, with associated cracks and bands of differing composition, can also be seen in Figure 77.

Figure 77. Illustration of layering typically found in the Lewis peat profile. Distinct lamination within the Lewis blanket peat, visible in a cutting along the extended crofters' track at NB 433547. Note the very marked junction between the fine-grained brown layer and the darker, much cracked lower layer. In places another dark, cracked layer can be seen to lie above the brown layer. Note also that the cracks in the lower dark layer run vertically and horizontally. All of these lamination boundaries and various crack systems represent potential zones of weakness in the peat.

Thus although the CBR measurements represent the second-most extensive geotechnical dataset (after the peat-depth data) obtained during site investigations, these values are not discussed at all within LWP 2004 EIS, Vol.3, Chapter 17 –

Peatslide Risk Assessment. The extent to which these measurements could be used to inform the wider assessment of peatslide risk is a subject for debate which can only really progress if more information is provided by LWP. What *does* emerge from the work is the fact that the catotelm peat is often very soft, capable of liquefaction on disturbance, is highly variable, and is significantly disrupted by erosion. These are all points that have considerable relevance to the next two sections, which focus specifically on peatslide risk assessment.

7.1.3 Slope stability analysis

One of the key requirements for a planning application that potentially involves any aspect of slope stability is that there should be some form of stability analysis carried out on the area involved. Such an analysis should be undertaken within the context of the development proposal.

As mentioned at the start of the present chapter, the Scottish Executive has recently produced guidance about peatslide risk assessment (Scottish Executive, 2006). The guidance covers a range of issues to be addressed when undertaking such an assessment, including a number of topics that will be considered under the next section ('Peatslide Hazard Mapping').

For now, attention will focus on the parameters that are important in determining whether a peat slope can be considered 'stable' or 'at-risk of collapse'. Both the Scottish Executive (2006) guidance and the report of the Irish Landslides Working Group (Creighton, 2006a) explore the mathematical modelling of peat-slope stability, and both cite the widely-used 'infinite slope analysis' method as the 'standard' method of analysing slope stability in peat. This method is generally attributed to Skempton and DeLory (1957a, 1957b), though the first ideas concerning infinite slope analysis were in fact proposed by Haefli (1948) almost a decade before Skempton and DeLory's seminal papers. The Scottish Executive guidance cites only the more recent work by Warburton, Higgit and Mills (2004).

7.1.3.1 Infinite slope analysis – the Factor of Safety (FoS)

The basic principle of infinite slope analysis, as it relates to peat soils, is that the peat thickness is only a few metres deep but is draped across landforms that may extend for a kilometre of more. Thus, to all intents and purposes, the length of slope on which the peat sits is 'infinite' compared to the peat thickness which is being investigated. Consequently the analysis does not divide the peat slope into discrete lengths – it is assumed to be 'infinite'. The model also assumes that the failure is a slip that flows downslope parallel with the ground surface (translational planar slide), rather than being a rotational failure where material rotates as it slides (rather in the manner of ice-cream curling in a traditional ice-cream scoop). The model is based on a number of assumptions that involve simplifying real-life conditions. These assumptions are thus a potential source of error and will be discussed further below.

The slope analysis model is used to generate a value which is termed a 'Factor of Safety' (FoS or FS). The FoS for a peat slope is calculated by bringing together the key factors tending to make the peat move downslope under the effect of gravity, and balancing these factors against the factors that hold the peat in place on the slope. If the sliding factors ('shear stress') exceed the holding factors ('normal stress') then the FoS will be less than 1 and the peat will slide.

An excellent description of both the mechanisms involved, and methods used to calculate a Factor of Safety, is available from the Science Education Resource Centre at Carleton College, Minnesota (Moore, L. – SERC website). Farrell, Long, Gavin and Henry (2006) also explore the process of calculating a Factor of Safety. Both Moore (SERC website) and Farrell *et al*. (2006) draw out various key practical consequences arising from the model, highlighting the way in which certain parameters become particularly important under certain conditions.

It is worth noting that there are many versions of the basic formula for calculating FoS, not because they differ fundamentally from each other, but because they express the same key parameters in rather different ways or express the basic formula in different states of algebraic expansion or summary. Thus some authors express the weight of the peat as 'bulk unit weight', while others give 'density'. Stress may be expressed as 'effective stress parameters' or as 'total stress'. Slopes may be expressed in degrees, or in radians.

Farrell *et al.* (2006) present two versions of the model: one for total stress and one for effective stress. Thus for total stress, they give:

$$f(FOS) := \frac{Cu}{\gamma \cdot z \cdot \sin(\beta) \cdot \cos(\beta)}$$

For effective stress analysis, they give:

$$f(FOS) := \frac{c'}{\gamma \cdot z \cdot \cos(\beta) \cdot \sin(\beta)} + \frac{(\gamma - \gamma w \cdot m) \cdot \tan(\phi')}{\gamma \cdot \tan(\beta)}$$

Compare this with the formula given in the Scottish Executive guidance:

$$f(FOS) := \frac{c' + (\gamma - \gamma w) \cdot z \cdot (\cos(\beta) \cdot \cos(\beta)) \cdot \tan(\phi')}{\gamma \cdot z \cdot \sin(\beta) \cdot \cos(\beta)}$$

The formula given by the SERC website is expressed differently again, this time using material density rather than bulk unit weight and thus adding a term for acceleration due to gravity:

$$FS = \frac{c + (\rho g H \cos\theta - \rho_w g\ W) \tan\phi}{\rho g H \sin\theta}$$

Moore : SERC website

The purpose of demonstrating these various forms of essentially the same mathematical model is to emphasize that the critical factor is not so much the nature of the formula, but rather the nature of the parameters that feed into this formula.

7.1.3.2 Factor of Safety – essential parameters

Although the formulae displayed above can look fairly daunting, the key parts of the formulae can be summarised in fairly simple terms. The key terms are:

c_u	=	undrained shear strength of peat
γ	=	bulk unit weight of peat
γ_w	=	bulk unit weight of water
β	=	hillslope angle, or angle of slip surface
c’	=	cohesion of peat (‘strength’)
φ’	=	friction angle (effectively, angle needed to make material slide past itself)
m	=	thickness of water table (*i.e.* depth from sub-base to top of watertable)

These, and the FoS formula, are expressed in more readily understood visual form below in Figure 78.

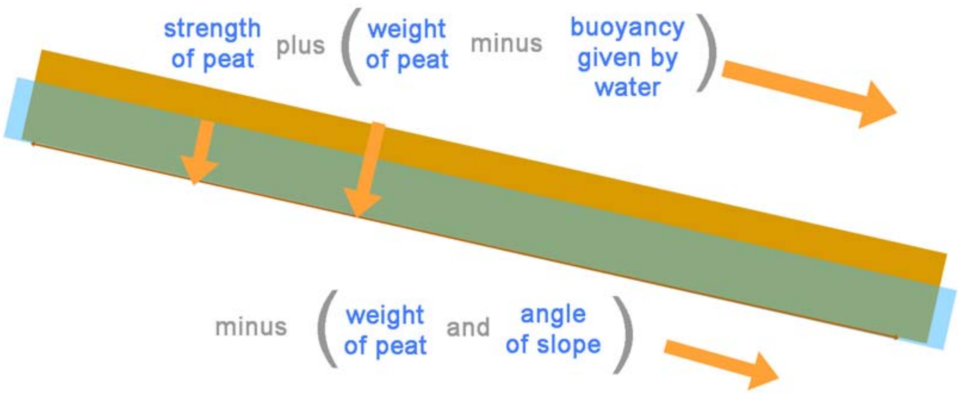


Figure 78. Illustration of parameters associated with slope stability.
Basic parameters considered in calculating Factor of Safety (FoS) for a peat-covered slope using the infinite slope analysis model of Skempton and DeLory (1957a, 1957b). The thickness of peat on the slope is shaded brown, and the thickness of the water table in the peat is indicated by the transparent blue shading. “Strength of peat” is used in a broad sense to include the concepts of ‘undrained shear strength’ (c_u), ‘effective cohesion’ (c’) and ‘effective friction angle’ (φ’). Note that the weight of peat acts in two directions: vertically downwards, (‘dead-weight’) pressing the peat firmly against the sub-soil, and downslope (‘downhill weight’), tending to drag the peat downhill. The steeper the slope, the more the downhill weight predominates and the less easily the dead-weight helps the peat ‘cling to the hillside’.

Various important features emerge from these parameters and the way that they are arranged in the formulae. The implications, as highlighted by Farrell *et al*. (2006) and Moore (SERC website) are that:

- FoS increases with increasing peat strength;
- FoS increases with increasing peat depth – *assuming* a uniform peat matrix;
- FoS decreases when unit weight and slope angle increase;
- changing overall cohesion of the peat has a relatively limited effect on FoS;
- changing the depth of water in the peat has a very considerable impact on FoS;
- when peat is saturated, the angle of friction may be so reduced as to play little part in stabilising the peat;
- where the FoS is close to 1, even small effects can have major implications for stability.

7.1.3.3 LWP slope stability analysis

The nature of the slope stability analysis undertaken for the windfarm area is discussed in LWP 2004 EIS, Vol.3, Chapter 17 [17.2.2]. There is some ambiguity in this section, because it begins with two paragraphs [paras 5 and 6] that describe a process of obtaining shear-vane values for:

> *"...twelve sites throughout northern Lewis in roadside cuttings and peat extraction areas. These were related to readings obtained in the literature and specifically to the recent Derrybrien incident."*
> *LWP 2004 EIS, Vol.3, Chapter 17 [17.2.2]*

Under the specific heading of slope stability analysis within this section (LWP 2004 EIS, Vol.3, Chapter 17 [17.2.2.1]), there is no *specific* mention of any field data being gathered for the analysis. The reader is left wondering whether the shear-vane results actually played any part in the assessment. At Derrybrien, specifically mentioned by LWP 2004 EIS, Vol.3, Chapter 17, para 5, AGEC carried out a slope stability analysis that involved a total of 250 shear vane tests at different depths across the 345 ha site. It appears that for Lewis, the slope stability analysis for an area of some 25,000 ha, may have involved just 12 shear-vane tests; or indeed there may have been none, because no mention is made of the shear-vane results in the discussion about the analysis itself. It is not clear whether the extensive Mexe Probe CBR dataset was used to inform this assessment in any way.

It may indeed be that no specific field tests (other than possibly the CBR measurements) were carried out for the slope-stability analysis. The whole exercise may have been carried out as a desk study. This is the impression gained from the information provided:

> *"While **a dedicated programme to establish geotechnical parameters for the peat in northern Lewis has yet to be carried out**, **geotechnical data**, based on historic information on*

peatslide events elsewhere ***was compiled for preliminary calculation purposes in the form of "book values"*** *and used in a computer programmes for analysing slope stability."*

LWP 2004 EIS, Vol.3, Chapter 17, para 7

LWP 2004 EIS, Vol.3, Chapter 17 [17.2.2.1] then reviews slope stability analysis as a concept, summarises the basis of 'Factor of Safety', and presents the results of a 'back analysis' on an area thought to be close to failure (Loch Bhatandip) within the LWP EIS study area. The back-analysis starts with an assumed FoS of 1 (*i.e.* near-failure, because the slope does seem close to failure) and gives values for a set of readily measurable parameters. It is not made clear whether these values, for parameters such as peat depth and slope-angle, were obtained from field survey or were estimated from existing maps.

These readily-measurable values are then used by LWP to calculate parameters that are less-readily measured – specifically, the 'peat strength' (undrained shear-strength c_u or cohesion c'). These derived parameters are then themselves used to perform a 'sensitivity analysis' of the model, meaning that the model is run with differing values for various parameters to see which parameters produce the most dramatic changes in FoS (LWP 2004 EIS, Vol.3, Chapter 17, para 10). In this way, the 'sensitive' parameters can be identified.

A key issue here is that by apparently relying on 'back analysis' to obtain values for the peat strength, it is only possible to derive a single value of shear strength/cohesion for the entire depth of peat. This is rather simplistic because, as LWP 2004 EIS, Vol.6, Appendix 10B, paras 26-28 describe, there is identifiable layering in the peat. Indeed LWP 2004 EIS, Vol.6, Appendix 10B, para 26 emphasises that in places the peat contains layers which are substantially wetter (and thus, by implication, weaker) than layers above or below. As demonstrated by the work of AGEC at Derrybrien, it is common when measuring shear-strength of a peat profile to take measurements at a range of depths down the peat profile precisely to cater for layering within the peat.

No mention is made of this in relation to the LWP FoS back analysis, and the reader is left to assume that a single value for shear strength must have been used in the subsequent LWP sensitivity analysis. If this is the case, then both the FoS analysis and sensitivity analysis must be viewed with some care, because they probably do not reflect the reality of the general peat profile, which is described in LWP 2004 EIS, Vol.6, Appendix 10B, para 26 as highly variable by LWP itself, and which has been illustrated in Figure 77 above.

The LWP FoS and sensitivity analyses are presented in the form of results obtained from the software package Oasys SLOPE, using Janbu's Method for parallel inclined inter-slice forces (because, as mentioned above, peatslides are sliding failures, not rotational failures). The resulting observations are illuminating:

"The results indicated, for example, that whereas variations in unit weight made little difference, ***changes in the depth of the water table were profound****. Raising the depth [thickness] of the water table from* ***1 m*** *[thick]* ***to 2 m*** *[thickness – i.e. up to the ground surface in the 2 m peat profile]* ***reduced the factor of safety from 1.826 to 0.742****."*

LWP 2004 EIS, Vol.3, Chapter 17, para 10

Two particular aspects of this observation give rise to a degree of concern.

Firstly, the LWP calculation indicates that raising the water table to the surface of the peat (*i.e.* a 2 m thickness of water table in a 2 m thickness of peat) gives rise to a FoS that is substantially lower than the failure threshold of FoS = 1, and is approximately half that of LWP's own target of a FoS = 1.4 for an acceptable degree of stability. Thus under conditions of very high water table, the sensitivity analysis suggests that the slope would fail. Even with a water thickness of only 1 m (*i.e.* the water table is 1 m below the surface of the 2 m peat thickness), the FoS is only 1.8.

This can be compared with FoS values obtained from the models created by AGEC for the Derrybrien windfarm site (AGEC, 2004). The model is based on the division of the site into 50 m cells. In the first model, the FoS values assume that there is no loading on the bog surface – the same assumption as used in the LWP FoS calculation for Loch Bhatandip. The second, more pessimistic AGEC model assumes that each cell is under a load of 10 kPa (equivalent to a 1 m thickness of peat loaded onto the existing bog surface).

Ignoring three very high FoS values from these two AGEC models (as they are assumed to be from cells containing little or no peat), the average FoS value for the 'unloaded' model was 3.7, while even the more pessimistic model gives an average FoS value 2.6. Both of these values are significantly higher than the maximum FoS value obtained by LWP for Loch Bhatandip. In other words, the values obtained for Loch Bhatandip even when the water table was drawn down 1 m into the peat suggest that the area is indeed significantly closer to slope failure than, for example, the peat at Derrybrien. As observed above in the previous section, where an area is close to the threshold of stability, minor changes in conditions can have major impacts on stability.

Secondly, the numbers used in the water-table sensitivity analysis are anomalous because the scales of water-table draw-down used to test the model are unrealistic. It is as though the LWP engineers have not spoken to the LWP ecologists at all. One of the central arguments of the LWP ecological work is that the water table in the peat is never drawn down very far into the catotelm even under the most intensive drainage pressures. The drawdown resulting from intense gullying within the worst erosion complexes is described as:

> *"resulting in the bog watertable perhaps falling by up to 30 – 40 cm."*
>
> *LWP 2006 EIS, Vol.5, Chapter 11, Appendix 11B, para 71*

Meanwhile the engineers, when carrying out their desk-based sensitivity analysis, use water-table figures that are very much deeper than this, stating that:

> *"...raising the depth of the water table from 1 m [that is, 1 m below ground level] to 2 m [the ground surface] reduced the factor of safety from 1.826 to 0.742."*
>
> *LWP 2004 EIS, Vol.3, Chapter 17, para 10*

As will hopefully now be obvious from all that has been said in Chapter 5 of the present report, the water table in a blanket bog normally lies within the acrotelm, and this acrotelm is actually extremely thin. Holden and Burt (2002) give a depth of around 10 cm for their studies in Pennine blanket mire, while Evans *et al*. (1999) suggest that it may be up to 40 cm thick in the same region of the Pennines.

Despite this, LWP 2004 EIS, Vol.3, Chapter 17, para 10 talks of modelling bog water tables that provide acceptable Factors of Safety when the water table has fallen 1 m below the bog surface. It additionally highlights the fact that when the water table is brought close to the surface the Factor of Safety falls considerably below the value of 1 required for a stable peatland.

Given that LWP 2004 EIS, Vol.3, Chapter 17, para 9 identifies a minimum FoS value of 1.4 as appropriate for design purposes, any modelled values of FoS falling well below 1 according to LWP's own calculations should have given considerable cause for alarm. At the very least, this sensitivity result should have stimulated much more integrated discussion within the documents between the ecohydrological findings and the (apparently rather limited) slope-stability work of the engineers.

To give an idea of the implications that these findings have for peat stability assessment within the proposed development area, it is possible to use the various parameters listed by LWP, and FoS values derived by LWP's modelling, to look in detail at the implications of changing water levels within a rather more meaningful acrotelm thickness than is discussed within LWP 2004, Vol.3, Chapter 17.

Indeed it is worth re-iterating here that LWP *may* have measured the water table at the Loch Bhatandip site and based the 1 m depth value on this, but if such measurements were taken the LWP EIS does not state that the water table was measured, nor does it give any details of how it was measured, nor indeed of the values obtained. The reader is thus left to assume that the water-table values used in the LWP sensitivity analysis are purely hypothetical values.

Had LWP provided the values for *all* the parameters it used in the FoS analysis, particularly that for shear strength/cohesion (c_u or c'), it would have been possible to repeat the whole LWP FoS analysis and provide detailed FoS figures for water-table depths that are likely to be more ecologically meaningful. However, given that only two quoted values for water depth and associated FoS values are given, it is nevertheless possible to plot these in terms of Factor of Safety and water-table depth. Assuming a straight-line relationship, it is then possible to look at FoS values based on water-table depths more typically associated with blanket mire acrotelms.

Thus Figure 79 illustrates the specific example used in LWP 2004 EIS, Vol.3 Chapter 17, para 10 for the incipient peatslide site at Loch Bhatandip. Using the water-table depths and FoS values given in the LWP account, a straight-line graph has been derived, based on varying the height of the water table within the 2 m thickness of peat. The values along the bottom (x) axis represent 'thickness of water table from the basal sediments'. Thus a value of 1.2 m means that the water table extends to a height of 1.2 m above the basal sediments and that it therefore lies within 80 cm of the bog surface. Equally, a value of 2 m means that the water table is at the bog surface.

Note also in Figure 79 that, because of the axis orientation, water-table fluctuations run left-right rather than up-and-down. Consequently a falling water table moves to the left, while a rising water table moves to the right. The zone where FoS is less than or equal to 1 has been shaded pale pink, while the zone that represents a typical acrotelm thickness has been shaded a darker pink.

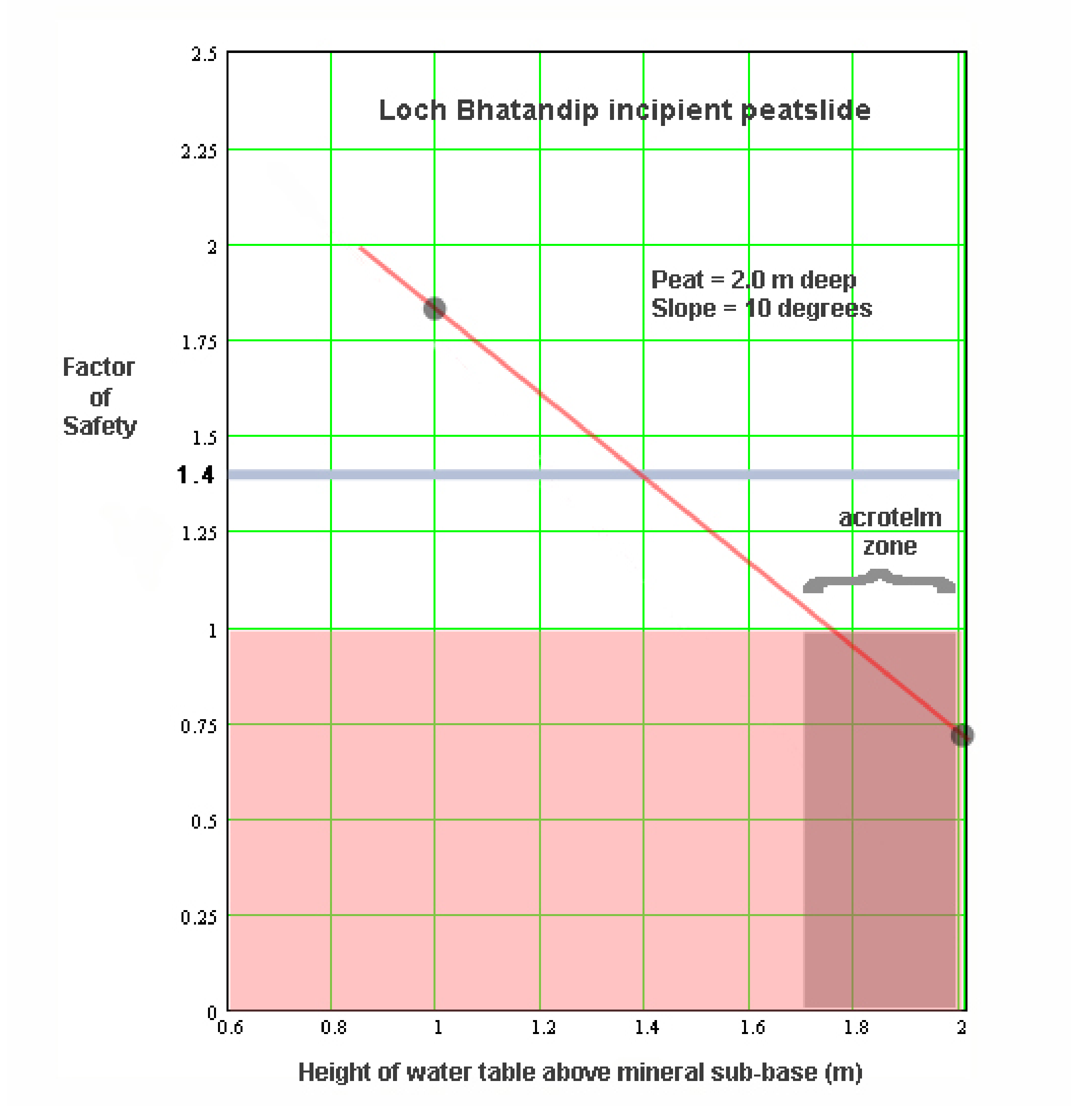


Figure 79. Factor of Safety for Loch Bhatandip.
Factor of Safety (FoS) sensitivity graph for the incipient peatslide at Loch Bhatandip, where the peat is assumed to be 2 m thick. Parameters are as defined in LWP 2004 EIS, Vol.3, Chapter 17, para 10. Ground slope is 10°, peat depth is 2 m. The graph shows the FoS that results from the LWP sensitivity analysis, based on the two values given for water table (1 m and 2 m) and the resulting Factors of Safety. These two values are displayed as dark-grey circles lying on a red line that joins these two sets of values in a straight-line relationship. As the water table in the 2 m thickness of peat is steadily raised from 1 m above the mineral sub-base up to the full thickness of peat at 2 m, the Factor of Safety steadily falls from 1.826 down to 0.742. The red diagonal line gives the relevant FoS values for each intermediate position of the water table. The blue-grey horizontal line represents a Factor of Safety of 1.4, which is the FoS value described as desirable by LWP. The pale pink-shaded region highlights the zone in which FoS values are less than 1 (*i.e.* the zone of slope failure). The darker pink region shows the peat-depth zone normally associated with the acrotelm, and thus the region within which the water table would normally be expected to fluctuate. Note that, because of the axis orientation, water-table fluctuations run left-right rather than up-and-down. Consequently a falling water table moves to the left, while a rising water table moves to the right. Note that for much of this acrotelm zone, the FoS is less than 1, while LWP's desired FoS of 1.4 requires the water table to lie at a depth of 60 cm below the bog surface (*i.e.* at a height of 1.4 m above the mineral sub-base).

In a typical bog, therefore, one would expect the water table to fluctuate left-to-right within the dark pink zone and *never* fall into the pale pink (catotelm) zone to the left. Looking at the FoS values on the left-hand axis, we can see that a water depth of 1 m gives an FoS of 1.75, which is the result obtained by the LWP sensitivity calculation using Oasys SLOPE.

Looking, however, at the position when the water table is at a more realistic position – perhaps close to the base of the acrotelm zone (water table at 1.7 m above the mineral sub-base – *i.e.* 30 cm below the bog surface) we find that the approximate value for the FoS = 1.05. This is not good. It means that the slope is close to failure. Raising the water table to the ground surface reduces the FoS even further to 0.74, which is potentially catastrophic in terms of slope stability.

As observed above, LWP is seeking to ensure that FoS values within the development remain at, or exceed, a value of 1.4. According to Figure 79 this is not achieved until the water table falls to around 60 cm below the bog surface (at 1.4 m). This is a depth even greater than the lowest draw-down described by the LWP EIS documents for drainage due to intense gullying. It is a draw-down figure that would only be expected within two or three metres of a drain or excavation. For the remainder of the bog surface, the FoS would appear to be less than the desired FoS threshold of 1.4. When the water table rises during rainstorms, the majority of the bog system would appear fairly rapidly to cross the critical stability threshold of FoS = 1.

Turning instead to Figure 80, which describes a typical example of blanket bog from the LWP development. It has 3 m of peat and a slope angle of 3°, and has a FoS greater than 1 until the water table rises to within about 8 cm of the bog surface. Once the water table enters this upper 8 cm of the bog, the FoS falls below the threshold for stability. Bragg (1982) and Evans *et al*. (1999) provide data for ‘residence curves’ of bog water tables, demonstrating that the bog water table in both a raised bog and a blanket mire spends almost 95% of the time within 5-6 cm of the bog surface. It thus seems quite probable that for such an area of bog the FoS could be close to or less than 1 for significant periods of time.

The desired FoS of 1.4 is only reached when the water table falls 20 cm into the peat (a value of ‘water-table thickness’ of 2.8 m). Holden and Burt (2002) indicate an acrotelm thickness of 20 cm in their Pennine study site, which would suggest that the water table of the model has to fall a considerable way through the acrotelm, possibly close to emptying the acrotelm altogether, before an acceptable level of slope stability can be achieved. Even with the water table at an extreme depth of 30 cm below the surface (2.7 m), the FoS is only 1.7, which is sufficiently close to the 1.4 threshold to be concerned that small factors may reduce stability to less than the target value.

These various figures serve to emphasize the fact that the standard models for slope-stability analysis appear to generate a series of FoS values that tend towards the low end of the stability threshold. Figures for FoS of 8, 9, or even 15 or 20, which are fairly common in other circumstances, do not emerge from the models used when realistic water levels are incorporated. Indeed the values obtained even when unrealistic water levels are used, fail to rise substantially above the hazard threshold.

In reality, however, the blanket bog slopes of the Lewis peatlands have *not* shown widespread peatslide behaviour. Although the LWP sensitivity analysis for Loch Bhatandip generated a larger FoS than the FoS derived from the simple SERC model, the LWP analysis, still gave an FoS value of 0.742 when the bog water-table was high. Consequently the slope should already have failed, because such high water tables will undoubtedly have occurred from time to time.

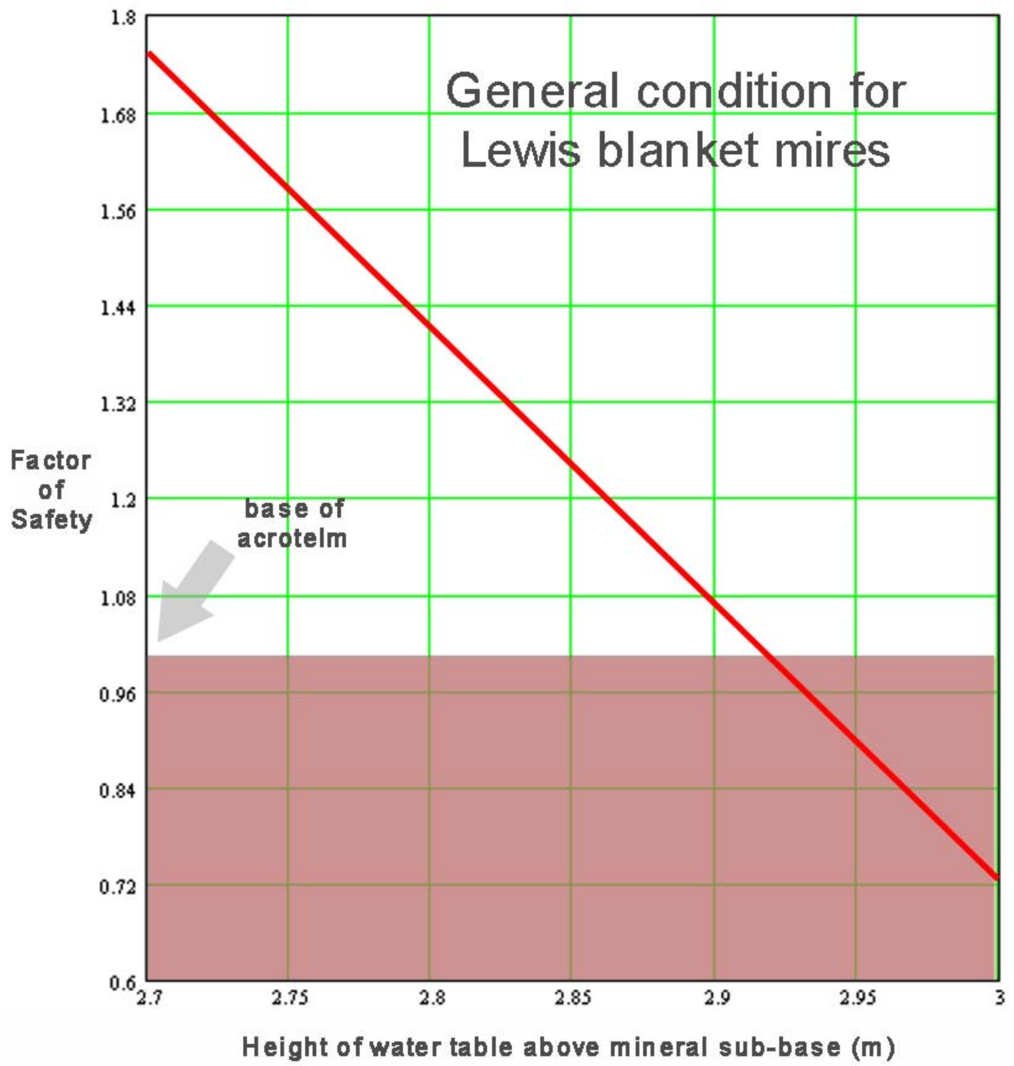


Figure 80. Generalised Factor of Safety for Lewis blanket mire, assuming 3 m peat depth.
Factor of Safety (FoS) sensitivity graph for conditions prevailing across the deeper Lewis peatlands (*i.e.* assuming a peat thickness of 3 m). Ground slope is assumed to be 3°, peat depth is 3 m, φ' is 30, c' is 8. The graph shows only the acrotelm zone. Thus the water table lies at 0.3 m below the bog surface at the *left*-hand side of the graph, but has risen to the bog surface at the extreme *right* of the graph. The red diagonal line gives the relevant FoS values for each position of the water table. The dark pink shaded region highlights the zone in which FoS values are less than 1.

This apparent paradox, in which the peat remains stable though the model indicates that it should have already collapsed, arises because of several different factors:

- Many of the parameters in the FoS equation are relatively easy to define with confidence – *e.g.* density of water, density of peat, slope angle, even instantaneous position of the water table. Some are much more difficult, and are still the subject of considerable research effort. If the values assigned to these parameters are not correct, then the FoS calculation will not reflect the true position on the ground.
- Even apparently readily-measurable parameters such as peat density can be difficult to describe accurately because there is often considerable variation in peat structure within the peat column.
- Water table position can be measured at any given moment in time, but it may be that there is a duration element in the stability process as well. In other words, the water table must remain at a given height for more than a few hours before the effect of the water table at that height is sufficient to alter the FoS of the peat.

Indeed many authors have questioned the reliability of FoS computations as a means of identifying the potential stability of peat soils. Thus Murphy (2006), in describing an investigation into peat failures in Co. Mayo, Ireland, concludes:

> *"...we believe that this computation delivers an underestimate of the strength of peat, because stability modelling did not account for the weathered layer* [a distinctive layer found within the peat]*."*
>
> *Murphy (2006)*

Casadei, Dietrich and Miller (2003) also conclude that slope stability modelling sometimes 'over-predicts' instability values, and they identify four problems associated with stability analysis:

- the coarseness of the rainfall record in terms of timescales, resolving rainfall data in days (or even weeks) rather than hourly;
- the coarseness of the rainfall record in terms of spatial resolution – *i.e.* the difficulty of obtaining rainfall data for specific localities (sometimes for several specific localities, if a large landscape area is to be analysed);
- the legacy of previous landslides can mean that in any given location the soil layer may not be as thick or as unstable as might otherwise have been expected, because much of the material has already been lost in previous landslide events and fresh material takes a significant period to re-develop;
- inaccurate data for topography and soil properties.

This last point is strongly echoed by Farrell *et al*. (2006), who observe:

> *"Of course the most significant (and so far unanswered) question is* ***does conventional soil mechanics apply to peat soils?*** *For example,* ***conventional methods for determining undrained shear strength, e.g. the field vane test, have been called into question when used in peat*** *(Landva, 1980) as different values of c_u are obtained with different sized vanes.* ***Determination of cu or c' in the laboratory is difficult*** *due to problems with sampling the*

peat, due to its near liquid state and due to its low strength which is at the limit of much of the current methods of strength determination."

Farrell et al. (2006)

Murphy (2006) and Casadei *et al*. (2003) demonstrate that standard slope-stability methods may *under*estimate the strength of peat. Farrell *et al*. (2006) in contrast highlight the fact that peat slides also occur on slopes as gentle as 2° although the standard models generally indicate that this is unlikely. Consequently Farrell *et al*. (2006) emphasize the uncertainty at *both* ends of the stability spectrum.

What can be drawn from the discussion above is that the blanket peat soils of the Lewis peatlands appear theoretically to have modelled Factors of Safety that are close to, or beyond, the threshold of instability. The fact that there are not more records of peatslides suggests that:

- the stability models are probably too simplistic (even using professional engineering software such as Oasys SLOPE); that
- the level of understanding currently available about peat soil processes in general and the collection of adequate field data from the Lewis peatland in particular, prevents a more realistic set of stability analyses from being undertaken at the present time.

Having examined a number of peat failures, particularly in the blanket peats of Ireland and northern England, Dykes (in press) reviews a number of key issues relating to the properties of peat, the incidence of peat failures and the calculation of safety factors. He identifies four principal difficulties currently troubling assessments of stability in blanket mires:

- the highly heterogeneous nature of peat soils, with values of saturated hydraulic conductivity ranging, in the catotelm, between 10^{-1} and 10^{-8} cm s^{-1}, this low conductivity in particular preventing effective dissipation of excess pore water and thus leading to potential instability, when such peats are subjected to loading;
- the almost complete lack of data describing the relationship between peat strength and other physical or botanical properties;
- the liquid limit of peat is difficult to determine because it varies depending on type of peat and degree of humification, which may vary significantly through a peat column, particularly in blanket peat;
- shear-strength measurements on blanket peat using standard techniques are highly suspect because the peat is almost always fully saturated.

In concluding, Dykes (in press) makes the following observations:

"Conventional stability analyses of blanket bog covered slopes may be appropriate, as has thus far been assumed, but there are as yet insufficient data to verify this or to permit the development of more reliable failure models for peat deposits. However, conventional

geotechnical analyses of this material are clearly inappropriate."

Dykes (in press)

Nonetheless, slope-stability analysis is widely used and has a fairly good record of success. It would be reasonable to suggest that the figures for slope stability in the Lewis peatlands may be broadly correct. If so, then the only calculated example presented by the LWP EIS documents suggest that the Lewis peatlands may have scales of Factor of Safety that are not very much greater than the LWP target threshold of 1.4, in which case other factors that could influence slope stability may take on particular significance. As Moore (SERC website) observes:

> *"**When FoS is close to 1, even small changes in FoS values can cause slope failure** ...* [thus, for example] *... **the removal of vegetation will decrease stability** because it will reduce cohesion, thus decreasing shear strength and **decreasing the numerator of the FoS**."*
>
> *Moore (SERC website)*

Given the levels of uncertainty associated with slope-stability analysis in blanket mire landscapes, how do the LWP EIS documents then use the results of this analysis? It seems that the results were used in some undefined way to inform the next stage in the peatslide risk assessment:

> *"The findings of the slope stability analysis were then **used as a guide to identify key regions** for the peatslide geomorphic and susceptibility mapping"*
>
> *LWP 2004 EIS, Vol.3, Chapter 17, para 11*

No further mention is made of the slope-stability analysis in LWP 2004 EIS, Vol.3, Chapter 17, either in the text or in the accompanying maps. It is therefore not at all transparent how the slope-stability work contributes to the EIA process.

7.1.4 Peatslide Hazard Mapping

The next stage in the LWP 2004 EIS peatslide risk assessment is described by LWP 2004 EIS, Vol.3, Chap.17, [17.2.3] as peatslide hazard mapping. Whereas the process of *slope-stability* analysis essentially consists of one assessment process, peatslide *hazard* mapping is an exercise where a variety of differing approaches can be brought together to highlight potential peatslide hazards. Those listed in LWP 2004 EIS, Vol.3, Chapter 17 [17.2.3] are considered here, along with one or two other topics which have a bearing on peatslide hazard issues. The first topic considered below is one of these additional aspects.

7.1.4.1 Identification of Hydrological Zones

The basis and utility of the LWP Hydrological Zones has already been discussed in Section 5.2.6. The one significant factor to emerge from this classification in relation to peat stability is the stated concern that Hydrological Zones 3 and 4 contain:

"..areas where the disposal of excess water into settling ponds has the ***potential to develop a downward pressure 'head' and result in 'bog bursts'*** *are likely to be limited to certain areas of the site. Such natural effects have been observed in the upper Watershed Mire mesotope, which is correlated with Hydrological Zone 4 (Perched Pool Network). In the absence of any information against this,* ***this area was considered to be of highest risk*** *of this effect occurring. In assessing this potential effect, consideration was given to the fact that approximately 42 % of the proposed area is contained within this hydrological zone. The assessment level of 'moderate' impact was therefore precautionary and* ***based on the uncertainty of the site conditions****. However the use of settlement ponds in this environment is unlikely to be practical and other sediment control would be applied, therefore mitigating this risk."*

LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 179, p.40

As noted earlier in the present report, the conclusion that settling ponds cannot be used in Hydrological Zone 4 (and potentially Zone 3) has fairly substantial implications. It means that siltbuster-style facilities will be required for all water-treatment localities, including water-crossings, throughout almost 50% of the development proposal area. This represents an enormous logistical, engineering and operational challenge. Examples have already been given of the potentially high densities of water crossings that might be required. Consequently it is difficult to see how the necessary infrastructure (hardstanding, *etc*.) could be supplied without adding significantly to the risk of instability.

7.1.4.2 The LWP peat-depth map

A considerable amount has already been said about the LWP peat-depth map. The only additional thing to say in relation to stability and peatslide issues is that peat depth is such a fundamental issue in relation to stability that it is difficult to see how a clear picture of peatslide risk can be achieved when almost 8% of the road-line for the development area, and virtually 100% of the overhead transmission-line route, have no peat-depth data.

Peat depth is a critical parameter in calculating a 'Factor of Safety' (Creighton, 2006a; Scottish Executive, 2006). Presumably no such calculations have been possible for the various sections of the LWP 2006 proposal that lack peat-depth information. However, this is neither mentioned nor addressed by the LWP 2006 EIS. Such un-mapped areas add substantially to the risks involved, precisely because they are un-mapped. As such, they should feature prominently in any overview of peatslide risk and potential hazard on the site. It seems that LWP does not subscribe to this view.

7.1.4.3 The peatslide inventory

Remarkably little information is provided about the peatslide inventory listed by LWP 2004 EIS, Vol.3, Chap.17, para 14 as part of the peatslide hazard mapping work. It is not mentioned at all in the LWP 2006 EIS documents, nor in LWP 2004 EIS, Vol.6, Appendix 10A – Data sources, desk-top studies and literature reviews, nor in LWP

2004 EIS, Vol.6, Appendix 10B – Methodology for geological baseline field studies. The account given in LWP 2004 EIS, Vol.3, Chapter 17, para 14 is so brief that it leaves most obvious questions un-answered:

- What area does the inventory cover – the LWP HSA, Lewis, the Outer Hebrides?
- How many peatslides were identified during the remote-sensing stage?
- What was the size range of the peatslides found?
- What was the distribution of identified peatslides?

It is noted in LWP 2004 EIS, Vol.3, Chapter 17, paras 24-28, however, that:

- the smallest landslide recorded was approx. 10 m diameter;
- smaller peatslides are certainly present in the area but were not recorded;
- very old, larger peatslides were also not recorded;
- not all peatslides identified by remote sensing were visited in the field. Only those with easy access or those deemed to pose a direct geotechnical threat were visited;
- the Western Isles have been described as recording one of the lowest densities of *landslides* in the UK, but it may simply be that many go un-recorded because many parts of the Western Isles are extremely remote and little-visited.

Without more information from the landslide inventory, it is difficult to comment on the findings or the value of this work. However, a similar exercise for the whole of Ireland (Creighton, 2006b), and a more detailed database analysis in Co. Mayo (Pellicer, 2006), have shed a great deal of light on various parameters associated with peatslide events

Creighton (2006b) notes that of 117 landslide events in Ireland, 66% (43 events) were in blanket bog. Even in upland blanket peats, bogslides occurred both on relatively flat plateau summits and on the surrounding slopes.

Pellicer's (2006) analysis highlights several important features of bogslides in Co. Mayo:

- Some peat slides were recorded as having occurred despite the absence of peat. This may sound bizarre but there is a simple explanation. If the peat was less than 1 m deep it was not recorded as 'peat'. In other words, bogslides occurred on both shallow peat and deep peat;
- The data show that 60% of all bogslides occur on slopes of less than 10°. Around 28% of bogslides occurred on slopes of between 10° and 20°. Consequently gentle slopes give rise to the majority of bogslides, and 88% of all bogslides occur on ground with gradients of 20° or less.
- There appears to be a slight tendency for bogslides to occur more frequently on slopes with a northerly or westerly aspect.

A similar analysis of the Lewis(?)/Outer Hebrides(?) peatslide inventory would have offered the possibility of making extremely informative comparisons between the parameters identified in Co. Mayo with those established for the Lewis peatlands. Unfortunately, this does not seem to be possible. Consequently all that can be done is to apply the lessons of Ireland in general, and Co. Mayo in particular, to the question of potential peatslide risk in the Lewis peatlands.

7.1.4.4 Geomorphological mapping

The geomorphological mapping described by LWP 2004 EIS, Vol.3, Chap.17, para 15 is a curious piece of analysis, and appears in part to be based on a mis-understanding of identified peatslide risk. Two landform-risk models are used. The first of these risk-scenarios consists of two waterbodies lying at different elevations, and separated by less than 1 km. The template for this model is cited as the large bogslide at Morsgail, described by Bowes (1962) and discussed earlier in the present report.

This first model may indeed represent a risk, provided the conditions that prevailed at Morsgail are repeated. This requires that the upper loch is held back by a peat dam, rather than the more usual condition where a loch sits in a basin formed in the underlying mineral soil. Lochs impounded by peat dams are more usually associated with true bog pools or dubh lochain systems (A3 or A4 pools – JNCC, 1994: Table 3), lying wholly within the peat and with no mineral base. This important distinction appears not to be recognised, especially when translated into concerns about particular localities, as will be discussed later. The sites highlighted by the LWP documents are all lochs lying in mineral basins, and thus are not truly relevant to the Morsgail model.

The other risk model is based on a landform consisting of roads and turbines constructed on a sidelong slope overlooking watercourses that lie at different levels and which (one must assume this refers to the watercourses, but it is ambiguous) are separated by more than 10 m elevation and a horizontal distance of less than 1 km.

The second model is described by LWP 2004 EIS, Vol.3, Chap.17, para 15 as being based on the conditions prevailing at the Derrybrien bogslide site, but this description bears little relationship to that site. The area of the Derrybrien bogslide is associated with a single line of seepage which eventually forms the headwaters of the Derrywee River. There is no second watercourse in the vicinity, nor any suggestion that a second watercourse played a part in the bogslide (AGEC, 2004; Lindsay and Bragg, 2004).

What *is* believed to have happened at Derrybrien is that the Factor of Safety was compromised because the site of the slope failure lay within an un-identified zone of slight water seepage (AGEC, 2004). This is not a model explored by the geomorphological mapping exercise, although it would have been easy to do. The failure to include such a model is surprising. It is precisely the combination of features that led to the 1966 tragedy at Aberfan, where a buried spring/seepage zone acted as a lubricant for the colliery spoil. Consequently it can hardly be described as an un-known and un-foreseeable risk. The absence of such a model from the LWP 2006 EIS is thus inexplicable, particularly as publication of the Derrybrien reports had clearly highlighted this significant area of risk.

The failure of the LWP hazard mapping to consider a risk model associated with seepage zones is most unfortunate, particularly given the proposed positioning of infrastructure in relation to such features as ladder fens, as highlighted in Section 5.2.7.4. This problem is considered further, below and in the next two chapters of the present report.

7.1.4.5 Peatslide Susceptibility Mapping

Peatslide susceptibility mapping is described in the LWP EIS documents as an approach "based on the method of Varnes (1984)", but modified because so few peat failures have been recorded. The method involved a desk study using various maps and aerial photographs, followed by field investigations that provide ground-truth data.

It is not clear whether these field investigations consisted of the various CBR measurements and hand augering listed in LWP 2004 EIS, Vol.6, Appendix 10B, paras 13-18, or whether additional field data were gathered for this work. If in fact other data were obtained, these data are never listed or explained.

Whatever the nature of the data obtained, the process is described thus:

> *"Based on professional engineering judgement the susceptibility of each facet was then estimated, taking into account not only* ***slope angle*** *and* ***slope morphology*** *but also the* ***relative relief, peat profile, lithology of rockhead, land use and land cover and natural drainage conditions****."*
>
> *LWP 2004 EIS, Vol.3, Chapter 17, para 18*

It is quite remarkable, then, given the very clear, detailed and well-illustrated guidance provided by Varnes (1984), and the impressive array of information considered both during the LWP desk study and subsequent fieldwork, that:

- the final maps produced as LWP 2006 EIS, Vol.3, Chapter 17, Figs. 17.1 and 17.2 indicating peatslide risk and peatslide susceptibility could be so starkly uninformative, compared to the types of highly informative maps presented and recommended by Varnes (1984) – see UNESCO website for these maps;
- and that ladder fens/eccentrc mires/percolation mires could have been completely missed, with road junctions and other infrastructure being proposed for the middle of such extremely wet seepage areas.

A preliminary exercise in peatslide suceptibility mapping has been carried out in Co. Mayo, Ireland, each using a somewhat different approach (Fealy, 2006; Pellicer, 2006). It is worth quoting the decision-making process that led to the identification of criteria that would then form the basis of both susceptibility-mapping exercises:

> *"A pragmatic approach to susceptibility mapping should therefore be guided by best available information. For the current case study and as a starting point for mapping susceptibility, the geotechnical sub-group of the Irish Landslides Working Group developed criteria which could form the basis of an initial susceptibility mapping exercise.*

After consideration, the sub-group proposed that there is the ***potential of an unacceptable risk of a landslide*** *which could give rise to a hazard where:*

- *peat is* ***in excess of 0.5 m****, or*
- *where the peat* ***slope angle is greater than 15°****."*

(Fealy, 2006)

Using these two criteria, it is possible to undertake a similar peatslide susceptibility analysis for the HSA area. It is possible because, though not recording any peat depths greater than 1 m, the HSA polygons do record detailed depths up to 1 m.

The resulting map (see Figure 81) is of considerable interest. It emphasizes the scale of potential peatslide risk within the proposed LWP development area, based on susceptibility criteria and the 'precautionary approach' adopted by the Irish Landslides Working Group. On this basis, the vast majority of ground in the LWP HSA has:

"...the potential of an unacceptable risk of a landslide which could give rise to a hazard..."

Fealy (2006)

The map in Figure 81 is based on two simple thresholds – slope and peat depth. Ground that crosses either of these thresholds is then simply classed as being 'at risk'. To obtain some feel for the *degree* of risk, and to limit consideration to areas that are clearly blanket mire, the criteria can be modified somewhat, thus:

- peat which is more than **1 m** deep, ***and***
- a map which is **graded according to slope** (in degrees).

This map is displayed as Figure 82. For any area with more than 1 m of peat, the slope-angle has been used to indicate a number of slope-angle classes. Thus green shading represents areas of moderate risk because they have a combination of moderate slope and 1 m+ peat depth, while red areas indicate the ground at most serious risk because here the slope-angle is large and combined with a 1 m+ peat depth. This now starts to resemble the types of hazard-map output illustrated by Vernes (1984), rather than what is offered by the LWP EIS documents in LWP 2006 EIS, Vol.3, Chapter 17, Fig.17.2.

It is obvious from Figure 82 that a number of specific areas within the proposed LWP development lie within high-risk areas of ground. It is also clear that 'at-risk' localities are distributed throughout the proposed development area. Closer examination of these 'at-risk' areas reveals that some have already been identified by LWP 2006 EIS, Vol.3, Chapter 17, Fig.17.2 as "peatslide prone" and certain actions have subsequently been taken, but there are many other road sections or turbine locations that continue to be 'at-risk' according to this analysis, despite the fact that the criteria used to define this map are distinctly more constrained than those used by the Irish Landslides Working Group.

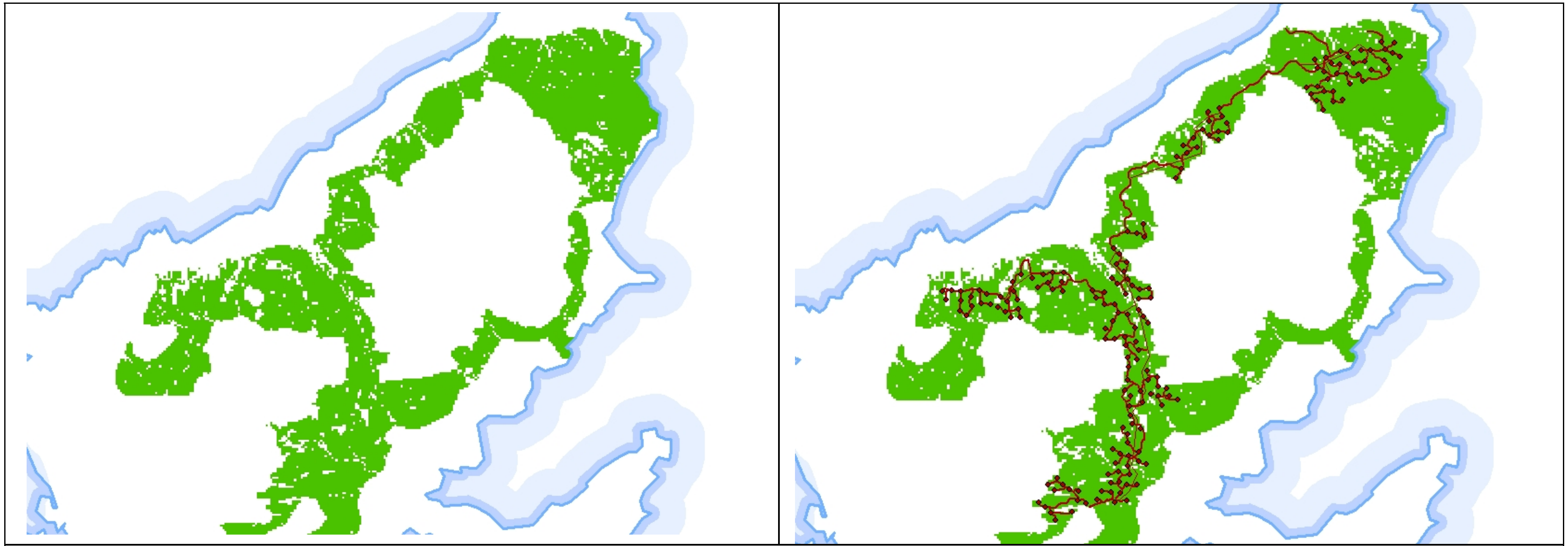
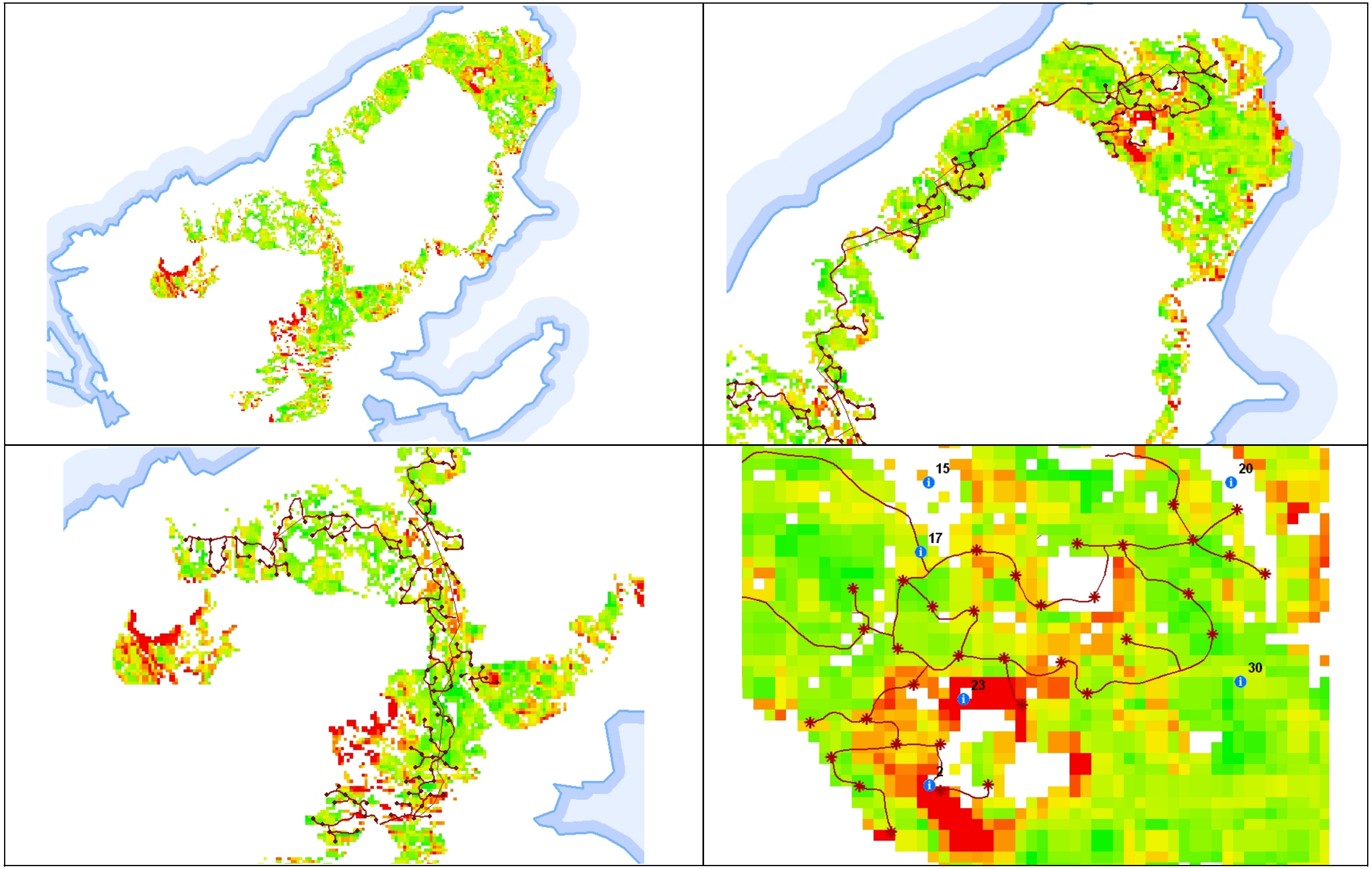


Figure 81. Distribution of blanket mire within the LWP HSA having potentially significant peatslide risk.
(Left): Area of ground within the LWP HSA which meets the criteria identified by Creighton (2006) for areas of peat with "potential for an unacceptable risk of a landslide which could give rise to a hazard" (green shading). The criteria used are that the peat is greater than 0.5 m deep whatever the angle of slope, or that it lies on a slope of 15° or more. **(Right)**: The same area, but with the LWP proposed windfarm road-lines, turbines and overhead transmission lines indicated in dark brown. The coastline is shown as concentric pale blue lines.



(Figure 82: Caption on next page)

Figure 82. Example of UEL-derived peatslide-hazard map.
Area of the LWP HSA identified as meeting rather stricter criteria than those identified by Creighton (2006a) for areas of peat with "potential for an unacceptable risk of a landslide which could give rise to a hazard" (shown in Figure 81). The criteria used here are instead that the peat is 1 m deep or more whatever the slope-angle, or that the peat lies on a slope of 15° or more. Areas have been graded according to slope-angle and thus (all other things being equal) areas of increasing risk of slope failure (decreased Factor of Safety) are highlighted. Red = areas most at risk; Orange = areas of high risk; Yellow = areas of moderately high risk; Green = areas of moderate risk.

(Top left): Total area of LWP HSA, with indicated degrees of risk, as described above. **(Top Right)**: The same map of 'at-risk' areas, but zoomed in to show the northern half of the LWP windfarm development. The LWP proposed windfarm road-lines, turbines and overhead transmission lines are also indicated in dark brown. **(Bottom left)**: The same information as shown top right, but this time for the southern half of the LWP windfarm development. **(Bottom right)**: The same information as shown top right, but zoomed in to display the northernmost assemblage of turbines and road-lines. From this it can be seen that a considerable proportion of the proposed infrastructure lies on fairly high risk ground. Areas already identified as being "at-risk" by LWP are indicated with a blue+white 'i' circle, together with the LWP reference number for that locality as used in LWP 2006 EIS, Vol.2, Sect.2, Chap.17.

The same picture is true for other sections throughout the development. Although some actions have been taken by LWP to reduce the peatslide risk (by, for example, re-routing the windfarm road-line), many more road sections, turbine bases or other infrastructure such as temporary compounds, lie within high-risk areas.

The approach modelled on that of the Irish Landslides Working Group contrasts markedly with the susceptibility mapping presented in LWP 2004 EIS, Vol.3, Chap.17 and elsewhere within the LWP EIS documents. It suggests that the areas of the proposed LWP development which are potentially 'at-risk' are much more extensive than has been indicated until now.

7.1.4.6 Avalanche corridor mapping

This is a puzzling inclusion in the hazard assessment, as discussed earlier in the present report. The puzzle is not because the approach is irrelevant – on the contrary, Lindsay and Bragg (2004) emphasize the benefits of using such an approach in peatslide assessments. What is curious about it is the way in which the topic is presented.

The fact that avalanche forecast mapping is widely and successfully used in snow-covered landscapes, and that there are many similarities between layered snow deposits and layered peat deposits, is made very clear. LWP 2004 EIS, Vol.3, Chapter 17, para 10 then states:

> *"The principals [sic] of snow avalanche forecasting involve not only evaluation of snow stability integrated with terrain and meteorological parameters but also an awareness of what might happen if the slope avalanches. The* ***principals*** *[sic]* ***of avalanche forecasting were applied to the peatland in the windfarm area****."*

No further information is given, other than four unexplained symbols on LWP 2006 EIS, Vol.3, Chapter 17, Figure 17.1 – Peatslide Prone Locations.

How have the principles of avalanche forecasting been applied? Where is the model of what might happen if there is a peat 'avalanche'? In the case of snow avalanches, the pattern of *couloirs* is used to model likely flow-paths for particular 'at-risk' avalanche slopes. There is no such mapping presented for the LWP EIS. This aspect, more than any other (what might happen if the peat avalanches, and where might it go?) is probably the single most common concern for all those involved in the consultation process. This is because, as seen at Derrybrien, Co. Galway, the consequences "of what might happen if the slope avalanches" can be very considerable indeed.

While the LWP EIS documents appear unable or unwilling to shed further light on this question, Chapter 9 of the present report highlights a number of localities identified by the UEL Peatland Research Unit as being 'at-risk' and considers the possible consequences of just such an event.

7.1.4.7 Visits to other sites

It is stated in LWP 2006 EIS, Vol.2, Sect.2, Chapter 10, para 16 that:

> *"...a number of **visits have also been made by LWP engineers** to various construction sites in order to **build a wider understanding of hydrological and hydroecological issues encountered within similar environments**. These visits have influenced the decisions made in regard to mitigation and management..."*

It seems reasonable to raise a number of questions about this statement:

- Were these visits to other sites made only by engineers?
- Were ecologists included in these visits?
- What were the specific findings of these visits in relation to what is proposed at the Lewis wind farm?
- Where and how have these findings influenced the revised LWP 2006 EIS?
- Why has the LWP 2006 EIS changed so little from the proposals set out in the LWP 2004 EIS on issues that are known problems on other sites?

7.2 Peatslide incidents – lessons from elsewhere

The two most widely-reported, and spectacular, peatslides in recent years have been the multiple slides at Pollatomish, Co. Mayo, and the single very large slide at Derrybrien, Co. Galway. These slides occurred within 5 weeks of each other during the autumn of 2003. The Pollatomish slides occurred on the night of 19th September. The Derrybrien slide happened during the afternoon of 19th October while windfarm workers were excavating a turbine base and (a little downslope) were also modifying some drainage arrangements.

Creighton (2006b) gives a summary of both peatslides. Lindsay and Bragg (2004) and AGEC (2004), on the other hand, give in-depth accounts of the Derrybrien peatslide. AGEC (2004) undertook a considerable programme of post-slide data-gathering in order to assess the danger of possible further peatslides. Lindsay and Bragg (2004) meanwhile considered the event itself, including possible contributory factors, and reviewed the findings of AGEC's (2004) geotechnical assessment. They also assessed the implications of this slide for other potential incidents of slope-failure within the Derrybrien wind-farm development.

Collins (2005 – and see The Woodland League website) provides a detailed account of post-peatslide events at Derrybrien, particularly in relation to the planning and legal consequences. Phillips (2005) and the Scottish Wind Assessment Project (2006) [see Scottish Wind Assessment Project website for this and Phillips (2005) reports] illustrate conditions prevailing on the ground two years after the peatslide. As commented earlier in the present report, both John Phillips and the Scottish Wind Assessment Project are widely seen as 'anti-windfarm'. Nonetheless their photographs illustrate actual conditions on the ground, and thus cannot be lightly dismissed.

7.2.1 The Pollatomish peatslides

The Pollatomish event consisted of more than 40 individual slides, most of them on the slopes of Dooncarton Mountain, Co. Mayo. Creighton's (2006b) description can be summarised thus:

- the peat thickness varied between 0.2 m and 1.2 m;
- the slides occurred on slopes that varied between 10° and 60°;
- the underlying mineral base consisted of weathered colluvial or head glacial deposits sometimes showing a downslope orientation of the mineral components;
- some 250 mm below the top of the weathered layer there was a hard, impermeable iron pan caused by leaching and re-deposition;
- rainfall on the night of the slides was intense, with up to 80 mm of rain falling in 2 hours;
- the summer months preceding this had been very dry;
- the peat is assumed by Creighton (2006b) to have developed fresh cracks, and old cracks to have re-opened, during these dry conditions;
- these cracks allowed the large rainfall volumes to percolate quickly through to the interface between peat and mineral, increasing pore-water pressures and causing the peat to become buoyant;
- once the peat became buoyant, frictional forces and 'dead-weight' were no longer able to hold the peat on the hillside and thus the second (downslope) part of the 'weight vector' prevailed and the peat moved downhill under the influence of gravity;
- the failure surface was thus generally at the peat-mineral interface.

7.2.2 The Derrybrien peatslide

The Derrybrien event consisted of a single peatslide that began in the afternoon of 19th October 2003, when a mass of peat some 45 m – 250 m wide and 1.75 km long broke away from the surrounding peat mantle and slid fairly slowly downhill, coming to rest 1.3 km further downslope. After some days showing only very slow creep-type movements, the slide was re-activated on the night of 28th October during heavy rains. The slide then began moving rapidly and entered the local river system. Volumes of material thence travelled up to 20 km (and possibly further) into Lough Cutra sufficient to cause an estimated 50% fish kill in the lough. This influx of material also had major implications for outline plans to turn Lough Cutra into the main water supply for the local town of Gort.

The essential characteristics and possible causative factors of the failure are discussed by AGEC (2004) and Lindsay and Bragg (2004), and can be summarised thus:

- the peat at the location of the slide varied between 2 m and 3.5 m thickness;
- the slope at the failure site varied between 2° and 8°;

- the underlying material consisted of glacial till;
- the weather had been remarkably dry for some weeks prior to the initial slide;
- the day of the slide was also dry and fine;
- two mechanical diggers were excavating a turbine base next to a floating road that crossed the slope parallel with the contours;
- a little way downslope, work was being carried out to drain water that had ponded behind another floating road that ran parallel with the 'digger' road described above;
- the upslope limit of the failure was marked by the upslope floating road and turbine-base excavation;
- the lower area of drainage works was swept away, so nothing can be said now about the nature of these works;
- the failure layer appears to have been *within* the peat, some 30 cm – 40 cm above the peat-mineral interface (see Lindsay and Bragg, 2004 – their Plates 20 and 22);
- the general site of the failure was found to lie in a zone of diffuse water collection and seepage (AGEC, 2004), forming the uppermost landform limit of a stream (not visible as a watercourse for a further 2 km) that eventually becomes the Derrywee River, which is the main inflow to Lough Cutra;
- the peat was found to be much weaker within this zone of diffuse seepage;
- the floating road and the accumulating pile of excavated peat represented a significant increase in natural load;
- the excavation was water-filled, and water pressure from the excavation may thus have forced its way downslope through the peat to make parts of the peat layer buoyant;
- the drainage works downslope may also have resulted in increased buoyancy as water was released from behind the ponded floating road onto and into the peat downslope;
- the area as a whole had been extensively afforested, and the peat was found to be deeply cracked along forestry drainage lines;
- the scale of failure appears to have resulted in part from 'unzipping' of peat along the cracks in the forestry drain lines running downslope.

Works recommended by AGEC (2004) to stabilise the site include:

- not placing excavated peat material onto the peat surface unless detailed geotechnical testing of the locality indicates that this is safe;
- avoidance of uncontrolled flow – all flowing water should be led into a suitably designed drainage system;
- avoidance of instability in excavation, thus ensuring that excavations are adequately supported, and that drains, if they show distortion and slumping, are piped or rock-filled to hold their shape;
- avoidance of steeper slopes (remember, FoS diminishes significantly with increasing slope angle);

- identification of construction localities that lie within possible natural drainage lines and seepage zones;
- detailed geotechnical investigations undertaken and extreme care to be exercised where construction may occur in a zone of seepage or a natural drainage zone;
- construction practice to recognise the potential for zones of weakness in the peat layers, and appropriate action to be taken.

The recommendations are particularly insistent on the issue of drainage:

> *"The* ***control of water from within the site is considered critical for long-term stability of the site. A robust drainage plan, monitoring and maintenance schedule for the proposed life-time of the site shall be produced and implemented****. The resulting drainage network should be in place to receive water during both temporary works and permanent works condition."*
>
> *AGEC (2004) Chapter 12, para 11*

7.2.3 Key relevant issues from Pollatomish and Derrybrien

A number of common issues, or issues that have a potentially direct relevance to the LWP proposal, can be drawn from the circumstances surrounding the two large peatslides at Pollatomish and Derrybrien:

- In the case of both the Pollatomish and Derrybrien peatslides, the underlying mineral deposit was variably weathered and worked glacial till. The same is true for most of the LWP development area;
- In the case of both the Pollatomish and Derrybrien peatslides, the period preceding the slides had been exceptionally dry. Extreme dry spells are a predicted feature of climate change, and thus the LWP development is likely to experience increasing numbers of such dry spells in the future;
- The peat at both Pollatomish and Derrybrien had suffered significant cracking as a result of drying effects – in the case of Derrybrien, additionally from forestry drainage. The LWP development will result in significant drainage of the peat, particularly in areas that currently have high water tables;
- Large volumes of uncontrolled surface-water flow may have initiated both Irish slides as cracks in the peat allowed this water to descend rapidly through the peat column to a weak layer. In the case of Pollatomish, this was the peat-mineral interface, whereas in the case of Derrybrien it appears to have been a weak layer within the peat. The peat within the LWP development has been acknowledged by LWP as being highly variable and containing weak layers;
- The large volumes of water associated with both slides came, in the case of Pollatomish, from intense rainfall, whereas there was no rain on the day of the Derrybrien slide but it seems that significant volumes of ponded water may have been released across the bog surface by site-drainage operations. There are many references within the proposed LWP hydrological management scheme where it is stated that excess water will be released 'to ground';

- The Derrybrien slope failure lay in a zone of diffuse seepage. Several parts of the LWP development lie in, or close to, regions of diffuse seepage;
- The Pollatomish slides occurred in peat that ranged from 0.2 m to 1.2 m in thickness, while the Derrybrien slide involved peat that was between 2 m to 3.5 m in thickness. In more than a few places within the LWP development, turbine excavation, road construction, or excavation for pylon bases, will be undertaken in peat that is more than 5 m deep;
- The Pollatomish slides occurred on slopes as low as 10°, while the Derrybrien slide occurred on an extremely gentle slope that varied between 2° and 8°. The vast majority of the LWP development will occur on slopes of between 2° and 15°.

There are clearly many common issues here, but none of these is addressed by the LWP 2006 EIS peatslide risk assessment. It is to some extent understandable that the LWP 2004 EIS should make little or no reference to these incidents as the causes were still being investigated when the 2004 EIS was being compiled. The LWP 2006 EIS has no such excuse. It was produced more than 3 years after the slides had occurred and more than 2 years after the main investigative reports had been published. Despite this, the LWP 2006 EIS Peatslide Risk Assessment makes no mention of these slides, or of the lessons that can be learned from them. It is almost as though these two massive peatslide events had never happened.

7.2.4 ECJ Prosecution : Derrybrien

It is worth noting that, after issuing the Irish Government with a 'Formal Letter of Notice' about the Derrybrien peatslide, the European Commission announced on 13th January 2005 that it would pursue infringement proceedings against the Irish Government. On 11th April 2005 the European Commission announced its decision to prosecute the Irish Government in the European Court of Justice because:

> *"..the **environmental impact assessments** (EIAs) undertaken for the windfarm development at Derrybrien appear to have been **manifestly deficient in failing to provide any or any adequate information on the geophysical risks associated with the project**. The developer's information **appears seriously lacking in this regard**, and no environmental authority made up for its deficiency".*
>
> *Letter of 20th July 2004 from European Commission to Mr Martin Collins, Derrybrien, Landslide Action Group*

7.2.5 Peatslide research

7.2.5.1 Review of peatslides : Derrybrien Report (Lindsay and Bragg, 2004)

In considering issues associated with the Derrybrien peatslide, Lindsay and Bragg (2004) review the range of evidence available for bogslide events elsewhere both in Ireland and from other parts of the globe. They include accounts or provide reference details for 30 peatslides in Britain and Ireland, including four from Scotland, eight from the Pennines of northern England, two from the North York Moors, as well as slides from14 counties of the Republic of Ireland and two from Northern Ireland. They also give details of slides that have occurred in Switzerland, Germany, British Columbia, Australia (Sydney), and the Falkland Islands. They conclude that peatslides are not rare events, but are both widely reported and occur wherever there is peat – even on sub-antarctic islands.

Lindsay and Bragg (2004) also review failure mechanisms, and observe that there is a recurring theme of:

- high rainfall after a dry period; and
- evidence of human disturbance (*e.g.* peat cuttings, drains, burning).

Clearly the Derrybrien peatslide did not completely fit this pattern because there was no rain, but there seems to have been the possibility that drainage works on the lower floating road released a considerable quantity of water over the bog surface, thereby simulating the effect of heavy rainfall. Otherwise, failure must be put down to the sudden loading of the bog surface by excavated peat, or possibly by release of water from the flooded excavation either by hydrostatic pressure or simply pumping (pumps are evident in photographs of the scene a day later, but it is not clear whether they were present and working at the time of the collapse).

7.2.5.2 Irish Landslides Working Group : Creighton (2006b)

The criteria used by the Irish Landslides Working Group for peatland that has a potentially unacceptable risk of peatslide has already been discussed above, namely:

- peat depth greater that 0.5 m, *or*
- peat on slopes greater than 15°

These precautionary criteria are used because the review of peatslides and peatslide risk in Ireland revealed that there were very substantial unknowns in terms of the triggers, mechanisms and factors pre-disposing blanket mires to a condition of instability. For example, in citing ongoing research work into the properties of peat and the conditions associated with slope failure, the following observations are offered:

> *"**There are very significant problems associated with work on peat strength** due to the high water content and compressibility of the material, the influence of the fibres, its inherent non-homogeneity and the very low in-situ stresses normally encountered. Although **most of the existing work on peat strength assumes that its behaviour follows laws of classical soil mechanics, this is far from clear**. Researchers around the world, particularly in Canada, have **expressed doubt on the application of existing techniques such as in-situ vane testing, cone penetration testing and laboratory triaxial testing of peat**"*
>
> *Noel Boylan and Michael Long, University College, Dublin*

> *“...**recent landslide events in peats have highlighted the difficulty in predicting the relevant shear strength parameters for such soils**. The permeability of peats is such that **it is questionable if undrained shear strength parameters are relevant** ... furthermore, different values of the effective stress parameters are obtained with different test methods.”*
>
> *Eric Farrell and Martin Carney, Trinity College, Dublin*

The report of the Irish Landslides Working Group concludes with some recommendations for further research into:

- peat strength and behaviour;
- strength and behaviour of Irish sub-soils, including glacial tills;
- multi-disciplinary studies into landslide phenomena;
- likely implications of climate change for landslide susceptibility.

7.2.5.3 Peatslide review : Warburton, Holden and Mills (2004)

The main focus of Warburton *et al*.’s (2004) work is a series of 18 peatslides that are recorded to have occurred within the north Pennines between 1870 and 1995. Warburton *et al*. (2004) examine the records of these slides for common patterns and possible causes. In the course of doing so, they also review a great deal else that is relevant to peatslides in blanket peat.

The authors begin by observing that peatslides appear to be a relatively frequent occurrence in the north Pennines, and that a review of all recorded British and Irish peatslides indicates a marked peak in June, July and August, with a smaller peak in October and November. They attribute this distribution to summer storms and prolonged late-autumn rainfall. The significance of this can be understood when considering their main findings:

- the Pennine slides occurred on a range of slope angles from 4° to 24°;
- peat depths were variable, and ranged from 0.6 m to 3 m;
- in some cases, failure appears to have involved detachment of the peat mass along the line of a moor-grip drain [somewhat akin to the ‘unzipping’ of peat rafts along forestry drains noted at Derrybrien];
- shear failure results when loads are applied to the peat surface sufficient to overcome the frictional resistance or the peat material;
- drying periods and drying effects [caused by, for example, drainage] produce a greater degree of shrinkage than the swelling associated with re-wetting, because a proportion of peat shrinkage is irreversible, and this shrinkage sets up stresses between the surface and lower layers of peat, leading to cracking;
- repeated wetting and drying can cause such cracks to become permanent lines of weakness;
- undrained bogs may have water contents of 1400% or more, while surface-drained bogs have 1000% and deep-drained bogs 700%;

- shrinkage is most dramatic in very wet 'quaking' peat (shrinkage can be as much as 2 cm – 4 cm/day);
- the cracks resulting from drying and shrinkage are then able to provide conduits through which surface water can rapidly reach deep into the peat (whereas seepage through the catotelm is normally very slow) and even reach the peat-mineral interface;
- cracks are more likely to develop after long dry spells of weather, and summer storms then provide large volumes of water which can be channelled rapidly to the peat-mineral interface, or to layers of weakness within the peat;
- failure is often associated with natural drainage lines and seepage zones, which do not generally dry out sufficiently to suffer cracking during dry periods – indeed they show little evidence of drying out at all during such periods – and so such areas may require some other form of trigger.

The review concludes with a summary of key issues, emphasising some points that are now coming to be recognised as important features of peat slides, but also emphasising the very large extent to which such processes are not yet understood and beyond our capacity to model accurately:

> *"Examination of peat mass movements in the north Pennines demonstrates several important hydrological characteristics: namely a* ***bias towards failures in summer months associated with summer thunderstorm activity*** *and the* ***concentration of failures along pre-existing drainage features****. It has* ***also highlighted the large gaps in our understanding of this type of shallow landslide instability*** *... The finite slope instability modelling used by Dykes and Kirk (2001) offers considerable promise for investigating peat slope failure mechanisms. However, as Dykes and Kirk (2001) acknowledge,* ***a better understanding of the basic hydrology of peat and peat slopes is required before realistic models can be developed****."*
>
> *Warburton et al. (2004)*

It is clear that, from an engineering perspective, much uncertainty still exists with respect to peat soils and slope stability. Some recognition of these issues could have been expected from both the LWP EIS documents, but particularly so for the LWP 2006 EIS given the recent spate of peatslide publications. It would also be reasonable to expect clear provision for such uncertainty in the assessment of peatslide risk. The lack of such recognition and operational provision highlights the fundamental weakness and general inadequacy of this important element within the LWP EIA process.

7.3 LWP Peatslide Risk Assessment

In assembling the various components of its peatslide risk assessment, the LWP EIS documents present a list of 36 locations which they consider to be 'at risk' because of one or more factors (LWP 2004 EIS, Vol.3, Chapter 17, Table 17.1). This list is then accompanied by more detailed accounts for 15 of the 36 localities (LWP 2004 EIS, Vol.6, Appendix 17A). These 15 were considered by LWP to be sufficiently close to the development line to warrant specific action.

What is particularly interesting about the 15 sites, and indeed the distribution of the remaining 21 localities identified by LWP as being in some way 'at-risk', is the very poor match between these and the places identified by LWP 2004 EIS, Vol.4, Chap.10, Fig.10.8 (and the subsequent LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8) as having evidence of "soft sub-peat strata". Of the 36 'at-risk' sites originally identified, only three are associated with areas also identified by LWP as having 'soft sub-peat strata'. Conversely, of the 37 locations identified by LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8 as having 'soft sub-peat strata' and still relevant to the revised 2006 development layout, only three are then identified by LWP as sites considered to be 'at-risk'.

It seems that low CBR values (at least, low values as suggested – though unexplained – by LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8) have played little part in the process of pin-pointing areas that might be 'at-risk' of slope-failure. It therefore becomes less and less clear how the CBR/hand auger data have been used in the EIA process.

Whatever the process behind the setting out and subsequent revision of the proposed development, the revised layout given in the LWP 2006 EIS involves the removal of some roads and turbines present in the original proposal. This means that five of the original 36 'at-risk' localities are no longer considered to be a problem because roads and turbines will no longer be built in their vicinity. LWP 2006 EIS, Vol.2, Sect.2, Chapter 17, Table 17.1 sets out the current position with regard to 'at risk' locations. For the ten locations still considered by LWP to be 'at risk', there are no new insights or guidance. The LWP 2006 EIS merely refers back to the original proposed mitigation for each, as set out in LWP 2004 EIS, Vol.6, Appendix 17A.

It is worth examining several of these locations, highlighting the proposed mitigation solutions and considering relevant issues of stability in the light of what has been discussed so far in the present chapter (and previous chapters).

7.3.1 Beinn Dhail locality

> *"Another area of concern involves the proposed road between wind turbine sites G49 and G50, on sidelong ground at the bottom of a slope, which is particularly steep in certain places.* ***Consideration should be given to an excavated road, built in short lifts and completely infilled with construction stone*** *to provide buttress support to the upslope ground.* ***Priority is medium****."*
>
> *LWP 2006 EIS, Vol6, Appendix 17A*

The ground conditions can be seen in Figure 83. From this, it is evident that the proposed excavated road will run along the margin of the large ladder fen shown in Figure 43. Peat depths along this stretch of road range from 2 m to 3 m, so this presents substantial engineering challenges anyway if the road is to be constructed by excavation, as suggested.

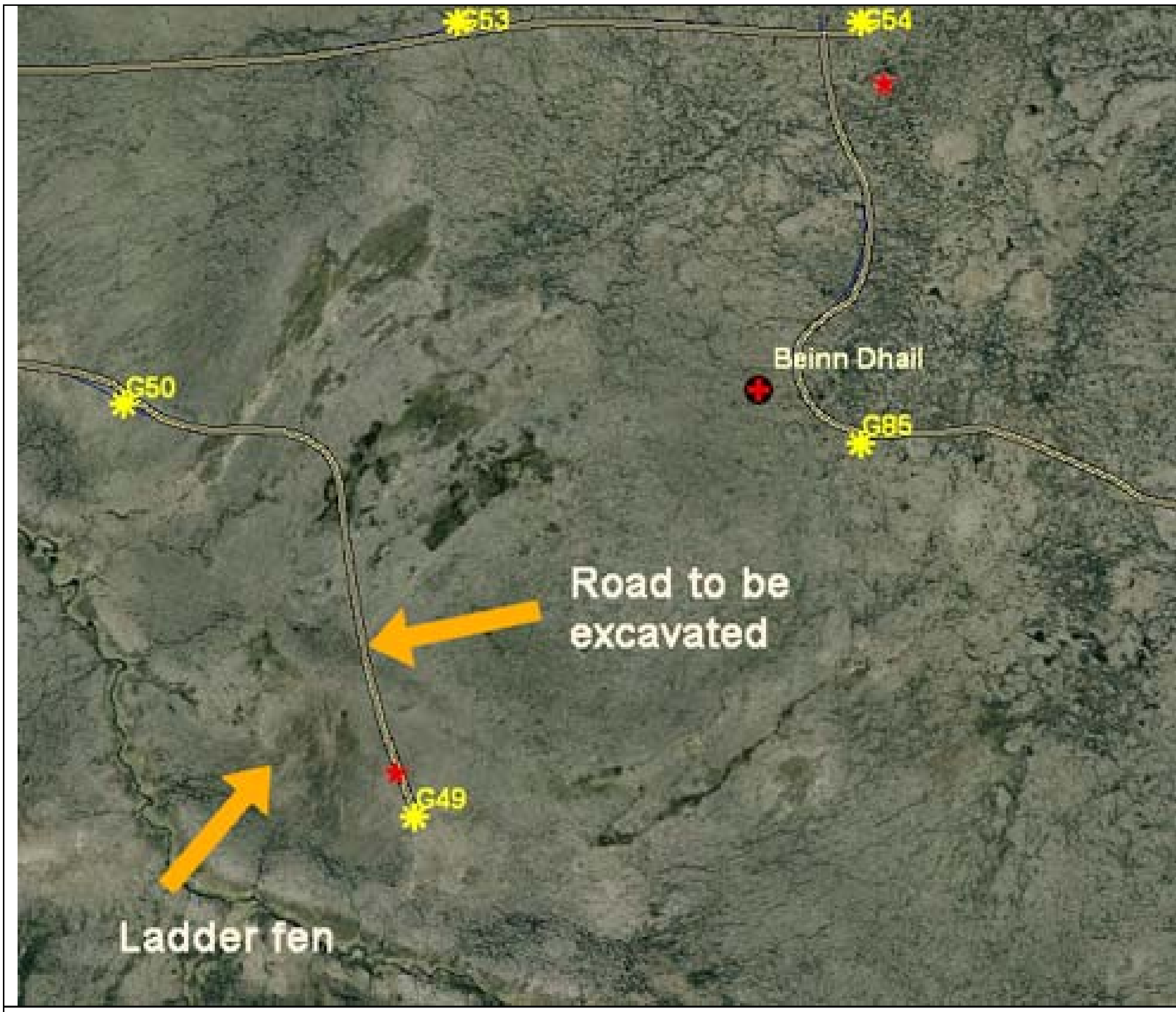


Figure 83. Peatslide issues at Beinn Dhail.
The area identified as 'Beinn Dhail locality' in LWP 2004 EIS, Vol.6, Appendix 17A. The proposed windfarm road-line is shown as a yellow-black line, while urbines are shown as yellow asterisks. The named LWP 'area of concern' is marked by a red and black cross. Red stars indicate areas of particular UEL concern, including the ladder fen (arrowed orange) which features elsewhere in the present report as Figure 43.

Aerial photograph © Getmapping.com 2006

However, this is likely to be made substantially more complicated by the fact that this ladder fen represents a major zone of seepage and thus the moisture content of the peat is likely to be extremely high. As we have seen with Derrybrien and with FoS calculations, such seepage zones are likely to be very much 'at-risk' in terms of slope stability. Furthermore, the excavation operations and presence of the road are almost certain to have a major impact on the hydrological functioning of this site, which is one of the finest examples of ladder fen within the LWP development area. The whole suggested LWP approach to this section of road appears to represent a substantial hazard to the interest, functioning and stability of the area.

7.3.2 West of Loch Bhatandip locality

"This locality occupies the downstream corridor immediately to the west of Loch Bhatandip and peatsliding would affect watercourses and waterbodies along the course of the Abhainn Ghrioda.

***Probability of peatsliding is medium** and likelihood of occurrence is low. However, in order to ameliorate the geotechnical risks, it is **recommended that no floating roads are built through this area**. Due to the potential for **significant consequences in this instance, a high priority applies**. Once this design change is implemented, **the residual risk is low to medium**,"*

LWP 2006 EIS, Vol6, Appendix 17A

The ground conditions can be seen in Figure 84.

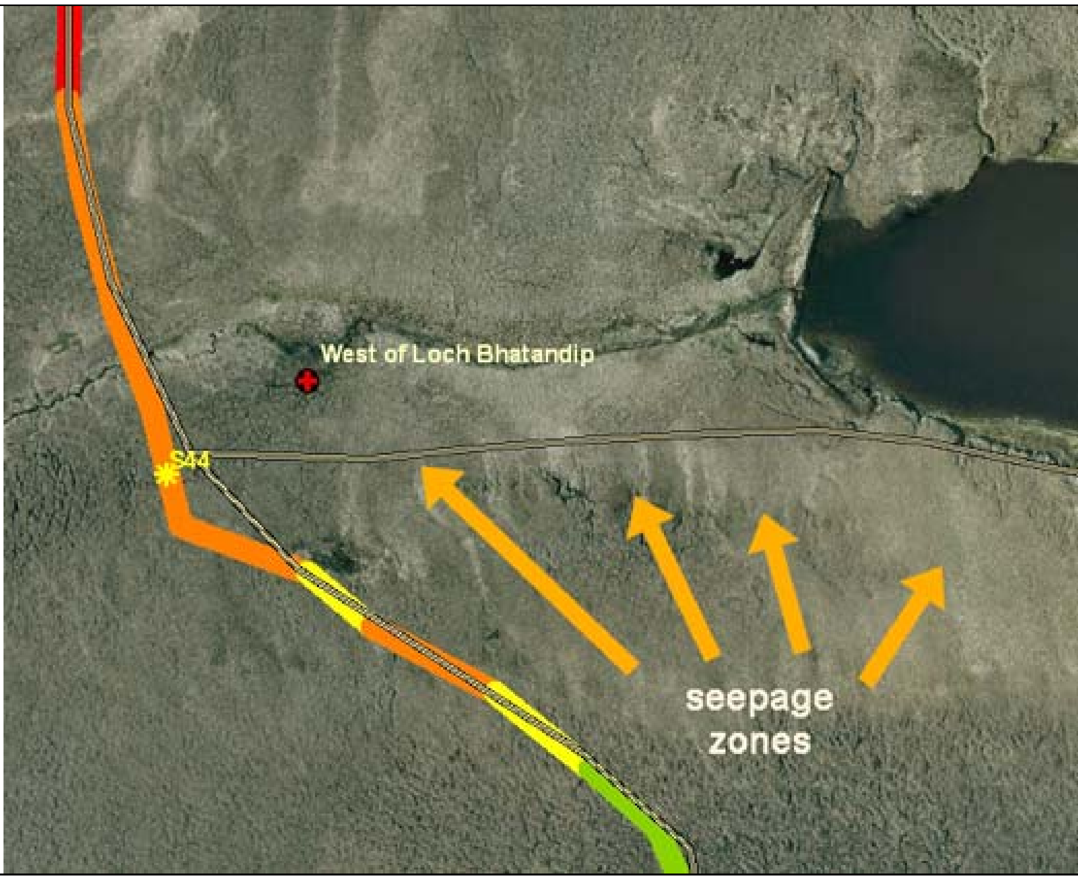


Figure 84. Peatslide issues at West Loch Bhatandip.
The area identified as 'West of Loch Bhatandip locality' in LWP 2004 EIS, Vol.6, Appendix 17A. The proposed windfarm road-line is shown as a yellow-black line, while urbines are shown as yellow asterisks. The named LWP 'area of concern' is marked by a red and black cross. Orange arrows point to a series of seepage lines that cross the windfarm road-line. The line of peat depths associated with the road is illustrated, with colours indicating depth-class: Green = 0.5 – 1.5 m; Yellow = 1.51 – 2.5 m; Orange = 2.51 – 3.5 m; Red = 3.5 – 5 m. Note that there are no peat depths available for the road as it runs towards and along Loch Bhatandip.

Once again, it is evident that there are serious issues in relation to seepage zones, and these would present considerable technical difficulties if an excavated road were to be built across the lines of seepage. There are no peat depth data for this section of road, but it is likely that depths are significant and possibly even considerable. The use of (presumably) excavated roads along this section would itself represent a major hazard, and thus the assessment and recommendations made by LWP for this section of road require much further elaboration than is provided in the LWP EIS documents. Without such elaboration, this area would have to be considered significantly ‘at risk’.

7.3.3 Abhainn Dhail locality

> *“**Sloping ground** along the banks of the river named Abhainn Dhail **may be prone to peatsliding**. Probability of peatsliding is low and **likelihood of occurrence is low to medium**. As a matter of high priority it is recommended that the proposed road and river crossing between turbine sites No’s G58 and G60 be deleted and an alternative access route be found to reach the position of wind turbine site No G60.”*
>
> *LWP 2006 EIS, Vol6, Appendix 17A*

The track between Turbines G58 and G60 has been removed for the LWP 2006 layout, and a new route to Turbine G60 has been drawn up. However, it can be seen (Figure 85) that the new route still crosses a substantial streamcourse.

The new route also crosses a significant slope as it rises to G60, and the peat at both the start and end of the new route is between 2.5 m and 3.5 m deep. Consequently it is difficult to see how this new route would be any less prone to peatsliding than the original route.

Furthermore, there are no peat depths for the new route itself, only depths at either end, so it may be that this new route is actually *less* stable than the original – it is impossible to say without further data. Without further information and elaboration from LWP, this new route appears to be as much ‘at risk’ as the original route.

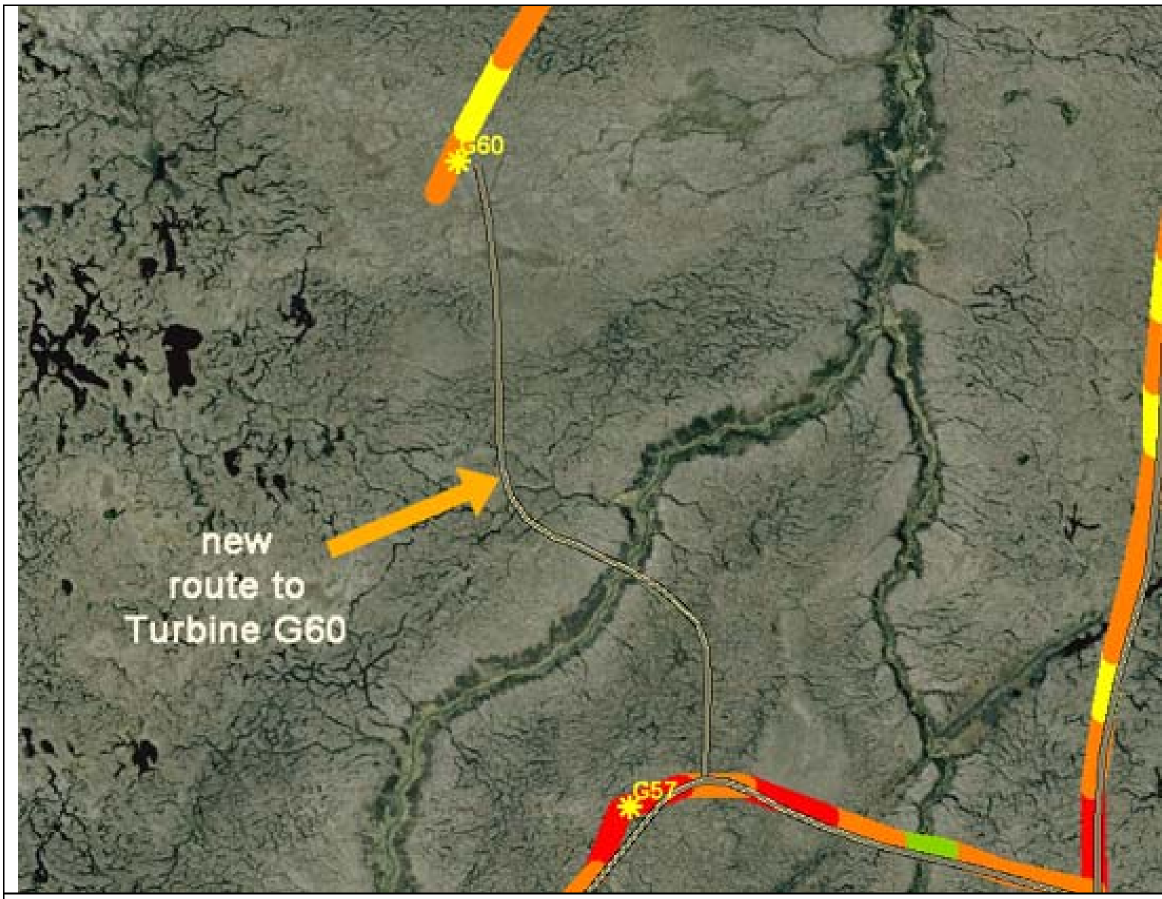


Figure 85. Peatslide issues at Abhainn Dhail.
The area identified as 'Abhainn Dhail locality' in LWP 2004 EIS, Vol.6, Appendix 17A. The proposed windfarm road-line is shown as a yellow-black line, while turbines are shown as yellow asterisks. The line of peat depths associated with the road is illustrated, with colours indicating depth-class: Green = 0.5 – 1.5 m; Yellow = 1.51 – 2.5 m; Orange = 2.51 – 3.5 m; Red = 3.5 – 5 m. Note that for the proposed road between Turbine G57 and G60 there are only depth data for the start and end of the road; no depths are available for the main section of this road linking the two turbines.

7.3.4 Spealltrabhat to Bhruthadail locality

> *"This locality involves a short stretch of the proposed road between wind turbine sites Nos B7 and B10 that passes through a narrow band of peatland separating Loch Spealltrabhat and Loch Bhruthadail. The* ***probability of peatsliding is low and the likelihood of occurrence is low to medium****. In order to ameliorate the geotechnical risk it is recommended that the* ***proposed road be built using the excavation method with total infill of construction stone to form a rockfill embankment*** *to a height of one metre above the existing ground level. Once this design change is implemented, the residual risk is low."*
>
> *LWP 2006 EIS, Vol6, Appendix 17A*

The peatslide risk model used in the Geomorphological Mapping exercise to identify "particular landforms associated with peatslides" (LWP 2004 EIS, Vol.3, Chapter 17, para 15) described LWP's 'Model 1' as:

> *"...a lochan at an upper level outfalling to another lochan at a lower level with a separation distance of less than one kilometre and a difference in elevation of greater than 10 m".*

Given that these two lochs are separated by only 160 m (see Figure 86), and that the difference in elevation between them is just over 10 m, these would seem to be very clear candidates for peatslide risk according to LWP's interpretation of the Morsgail peatslide. However, as has been discussed earlier, the Morsgail slide involved the breaching of a peat dam which was holding the water of the lochan in place, whereas the two lochs in this case both lie in the mineral sub-base. It is thus debatable whether there is a peatslide risk here of the type modelled by LWP.

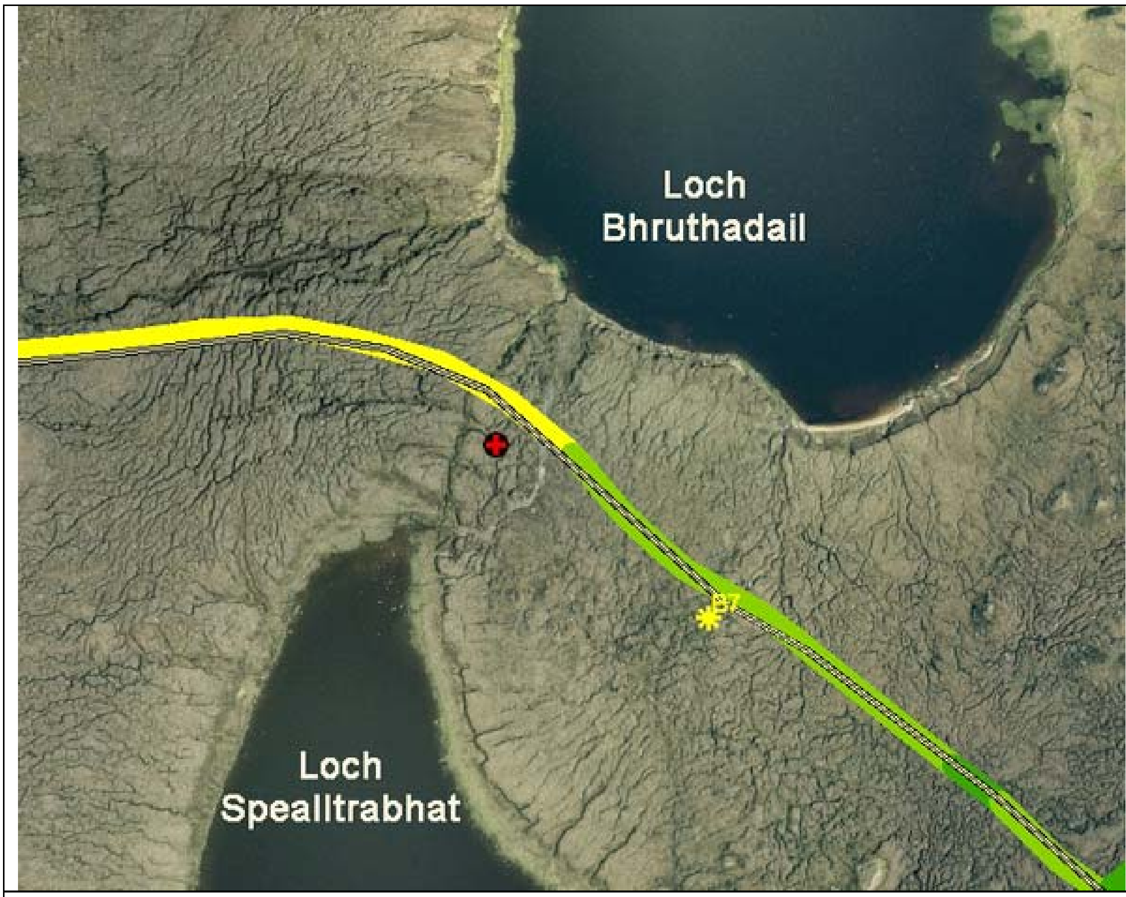


Figure 86. Peatslide issues at Spealltrabhat to Bruthadail.
The area identified as 'Spealltrabhat to Bruthadail locality ' in LWP 2004 EIS, Vol.6, Appendix 17A. The proposed windfarm road-line is shown as a double yellow line, turbines are shown as yellow-black line, while urbines are shown as yellow asterisks. The named LWP 'area of concern' is marked by a red and black cross. The line of peat depths associated with the road is illustrated, with colours indicating depth-class: Green = 0.5 – 1.5 m; Yellow = 1.51 – 2.5 m; Orange = 2.51 – 3.5 m; Red = 3.5 – 5 m. Note that the distance between the two lochs is approximately 165 m, and the lochs lie at different elevations, with slightly more than 10 m vertical separation between them.

That said, the peat depth runs consistently at 2 m to 2.5 m across much of the narrow neck of land lying between the lochs. While there seems little likelihood of the upper loch breaching its mineral basin and emptying into the lower loch, the potential for instability in the narrow ribbon of peat itself, where it lies between the lochs, does seem significant. The consequent impacts on the downslope loch should slope-failure occur within this ribbon of peat would seem to be considerable whether using floating roads or excavated roads. Excavation of the peat to construct the road is going to leave extremely narrow bands of deep peat either side of the roadline along this isthmus. Such an arrangement is unlikely to be stable in the medium to long term. It is difficult to see how such a locality could be identified with "low" risk under these circumstances, and it is equally difficult to see how the suggested engineering solution given by LWP would improve things.

7.3.5 North of Loch Bhatandip

> *"Relatively steeper slopes associated with the northern side of Loch Bhatandip present a **higher susceptibility to peatsliding**, particularly towards the western end of the loch. Probability of a peatslide incident is medium to low and the likelihood of occurrence is low. As a matter of medium priority it is **recommended that no floating roads are built** between wind turbine sites Nos S43 and S45."*
>
> *LWP 2006 EIS, Vol6, Appendix 17A*

As with the area identified to the west of Loch Bhatandip, the slopes to the north of the loch are dominated by substantial zones of seepage (see Figure 87). Consequently an excavated road cutting through these seepage lines would present considerable technical difficulties, and, given the wet nature of the peat, such road excavation would also present significant issues of stability on such slopes.

As floating roads are also acknowledged by LWP as presenting difficulties, it is not easy to identify a satisfactory solution here. The proposed solution from LWP of (presumably) excavated roads will present major engineering challenges but also pose a significant threat to the interest and hydrological functioning of these seepage zones.

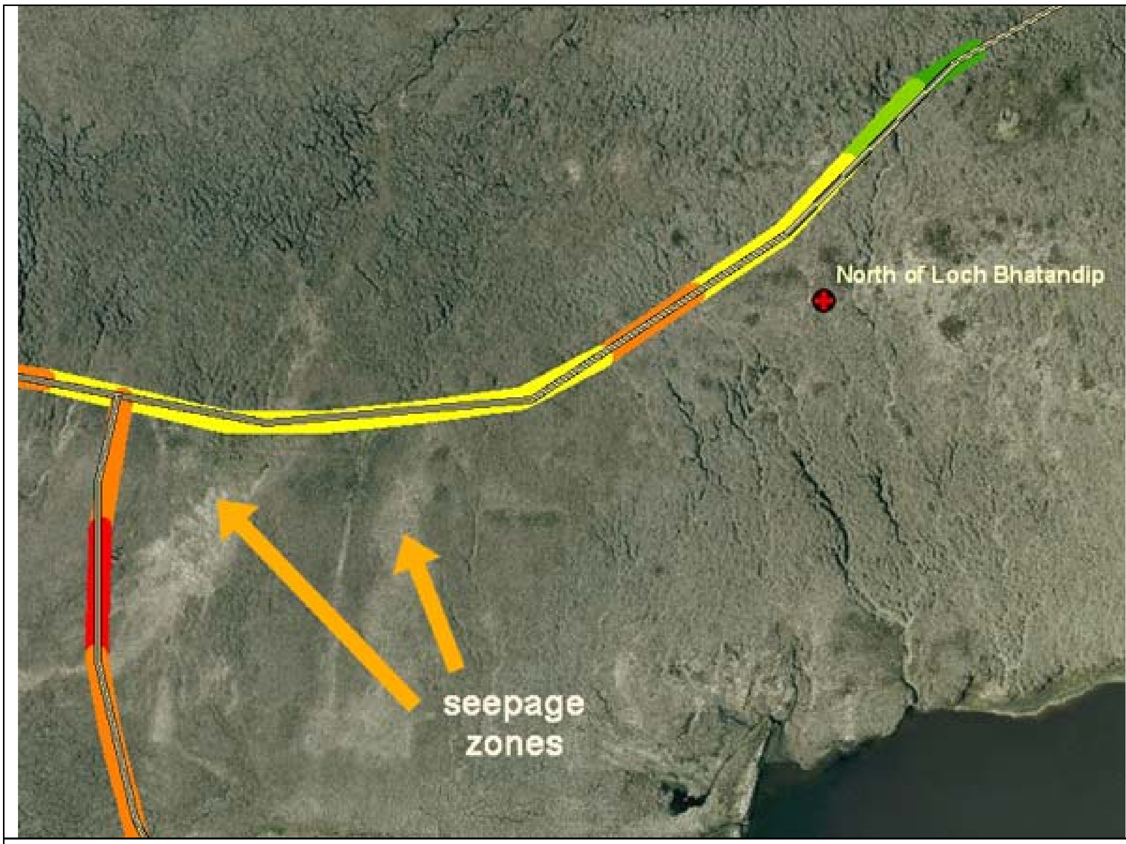


Figure 87. Peatslide issues at 'North of Loch Bhatandip'.
The area identified as 'North of Loch Bhatandip locality' in LWP 2004 EIS, Vol.6, Appendix 17A. The proposed windfarm road-line is shown as a yellow-black line. The named LWP 'area of concern' is marked by a red and black cross. Orange arrows point to a series of seepage lines that cross the windfarm road-line. The line of peat depths associated with the road is illustrated, with colours indicating depth-class: Green = 0.5 – 1.5 m; Yellow = 1.51 – 2.5 m; Orange = 2.51 – 3.5 m; Red = 3.5 – 5 m.

7.3.6 Allt Hogaraid locality

> *"Another well defined potential peatslide track runs from west to east along the valley of the Allt Hogaraid and presents **a medium probability for peatsliding**. The **likelihood of occurrence is difficult to estimate** but ... depends on the variability in moisture content of the peat throughout the upper reaches of the valley ... It is **recommended that surface drainage improvement works be carried out along the valley in advance of construction works**. The drainage improvement works entail the removal of obstructions from stream channels and the **hand-dug excavation of ancillary cross-drains through patches of wet ground**."*
>
> *LWP 2006 EIS, Vol6, Appendix 17A*

Firstly, it is questionable whether such proposed drainage of this wet valley would increase or decrease the stability of the system during the period of construction, given that there may be substantial shrinkage, subsidence and settlement for a considerable period after the drains have been installed.

Secondly, it is not clear that such drainage would provide the degree of stability sought for the road crossing of this valley, given that some areas have more than 5 m of extremely wet peat (see Figure 88).

Thirdly, this valley is clearly a major zone of seepage and percolation. As such, it should be regarded as an extremely high-risk area in terms of potential slope failure.

Finally, such a robust drainage programme would have a substantial effect on the ecological functioning and thus biological diversity over a considerable area of the seepage zone of the valley. Reduction in water content is, in effect, the whole purpose of the proposed drainage programme yet the existing peatland system has developed because of the presence of this particular water regime.

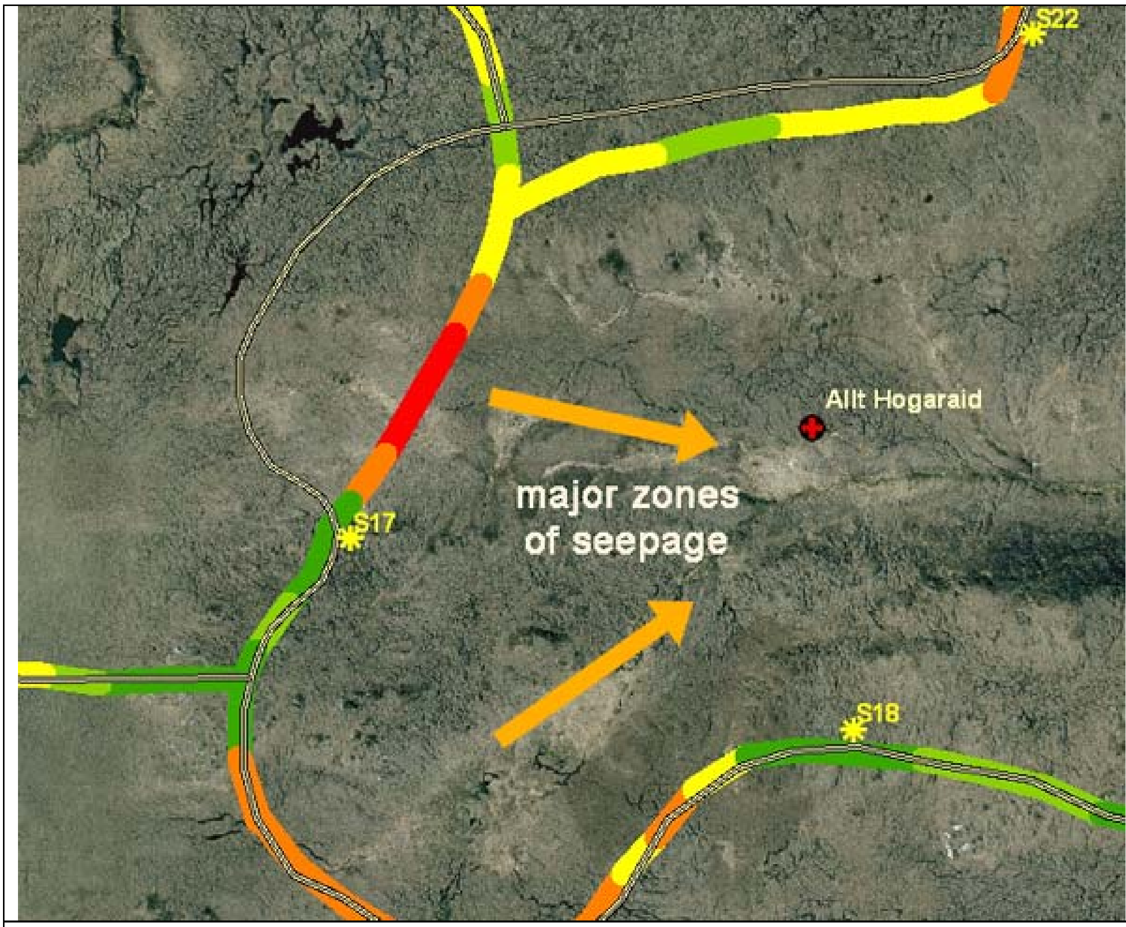


Figure 88. Peatslide issues at Allt Hogaraid.
The area identified as 'Allt Hogaraid' in LWP 2004 EIS, Vol.6, Appendix 17A. The proposed windfarm road-line is shown as a yellow-black line, while urbines are shown as yellow asterisks. The named LWP 'area of concern' is marked by a red and black cross. Orange arrows point to the major seepage lines of the Allt Hogaraid valley. The line of peat depths associated with the road is illustrated, with colours indicating depth-class: Green = 0.5 – 1.5 m; Yellow = 1.51 – 2.5 m; Orange = 2.51 – 3.5 m; Red = 3.5 – 5 m. Note that there are no peat depths available for the road along one section in the north-west of this illustration.

Indeed the proposed engineering solution from LWP raises some interesting internal conflicts with LWP's position with regard to drainage impacts. On the one hand, LWP argues that drainage has only an extremely localised effect on the eco-hydrology of peatland systems, yet the proposed engineering solution for Allt Hogaraid is that the wet ground should be drained using hand-dug ditches. According to LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 80 the actual effects of drainage should only be felt over distances of around 2 m. This would suggest that the drainage system at Allt Hogaraid will need to spaced at 4 – 5 m intervals throughout the valley if it is to have any marked effect.

Consequently it is difficult to see how the proposed 2.5 m zone (LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 80) of "actual likely average distance of change" associated with the development would apply in this case. The area impacted across Allt Hogaraid alone will amount to a substantial area of significant impact (if there is no impact, the engineering solution has by definition failed). To give a sense of scale, the distance from Turbine S22 to Turbine S18 (*i.e.* the valley-width) is 600 m, while the length of valley visible in Figure 88 is about 1 km. If the valley is substantially drained, the loss of existing peatland habitat in this one area alone could amount to 25% of the suggested "actual likely figure of 240 ha for all permanent loss" (LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 80), and this is without considering the potential area of damage should the road construction cause a peatslide along this valley.

7.3.7 Engineering solutions : summary of failings

It can thus be seen that, within the 15 localities identified as being 'at risk' as a result of the LWP peatslide risk assessment, the proposed engineering solutions fail to recognise:

- the presence of a major ladder fen;
- the presence of other substantial forms of seepage zone;
- that an alternative route to avoid deep peat and steep slopes also crosses deep peat and steep slopes – though the true picture about peat depth cannot be assessed because no depths are available;
- the potential dangers of excavating a road through deep peat on a narrow band of ground between lochs at substantially different elevations;
- the environmental impacts explicit and implicit in the extensive drainage of 'at risk' valley floors with substantial seepage.

7.4 Implications for peat stability at the LWP windfarm

A considerable number of points raised in the preceding parts of the present chapter clearly have direct relevance to the question of peat stability and peatslide risk assessment within the LWP EIS documents. The LWP EIS documents fail to take into account several major features that have significance for stability, and propose measures that are frequently inappropriate for the conditions on the ground.

However, these considerations have so far been of a generic nature. The Factor of Safety calculations have been undertaken using, in effect, generic values for many of the key parameters, rather than being based on detailed measurements taken from throughout the development area. Similarly, the Irish Landslides Working Group approach is based on two criteria that are then applied uniformly throughout the area of Irish landscape assessed for peatslide risk.

It is, however, possible to tailor such an assessment more closely to the actual ground involved by looking at specific local conditions. Thus Figure 82 has already demonstrated one way of refining such generic criteria to produce a range of risk values across the LWP HSA, although these are then applied generically without any consideration of other factors. By combining local factors with this broad range of risk, it then becomes possible to start identifying specific localities that have particular elements of risk. This process is explored further below.

7.4.1 UEL assessment of peatslide risk

Combining the criteria used in LWP 2004 EIS, Vol.6, Appendix 17A to identify specific areas of concern with information gathered during the UEL Peatland Research Unit's survey of the Lewis windfarm development, it emerges that there may be a considerably larger number of 'at-risk' locations than the 15 (or 36) sites listed in LWP 2004 EIS, Vol.3, Chapter 17, Table 17.1. This section of the present report looks at what emerges when all available site-specific information is used to assess peatslide risk.

7.4.1.1 Sub-selection of potentially 'high-risk' sites : LWP/UEL combined selection criteria

The original 36 sites identified by LWP 2004 EIS, Vol.3, Chap.17 as being a potential peatslide hazard were identified on the basis of site-specific features that apparently emerged from the LWP Peatslide Risk Assessment, though not in any transparent way. What *is* transparent are the various site-specific details identified by LWP 2004 EIS, Vol.6, Appendix 17A as reasons for particular concern. The information provided by the individual site descriptions, together with LWP's recommended operational changes, shed some light on the features that LWP regards as indicative of potential peatslide risk.

Such insight, coupled with a more general review of conditions evident at each of the identified localities, means that a set of parameters can be drawn up, based on LWP's own criteria. The UEL Peatland Research Unit used this approach, combined with analysis of a digital terrain model of the area and of colour aerial photographs, to identify what appear to be the key criteria used by LWP in selecting sites deemed at risk from slope failure were the development to go ahead. These criteria were identified as:

- sloping (<10°) peat-covered ground above river banks or loch shores;
- sloping (<10°) peat-covered ground along valley flanks;
- sloping (<10°) peat-covered ground lying between more level areas of deep peat;

- areas where the road-line will cut across a slope (parallel to the contours) above which there is a marked (<12°) peat-covered slope;
- areas where deep peat occurs on a narrow isthmus between lochs;
- wet, percolating mire systems lying along valley bottoms or in zones of water collection.

Adoption of these criteria across the whole of the development area would mean that a very large proportion of the development would emerge as 'at-risk'. Consequently two further criteria were added by the UEL Peatland Research Unit in order to focus on those sites most seriously 'at-risk':

- the ground should have a peat thickness of 2 m or greater; *or*
- areas where a water feature is retained by the peat thickness (as at Morsgail).

The criteria outlined above were then applied to available GIS data for the development area. These data consisted of:

- a map of slope angles created from a digital terrain model for the area;
- 1:25,000-scale OS maps;
- high-resolution colour aerial photographs;
- the LWP/UEL-derived map of peat depths along the proposed roadline;
- all the infrastructure proposed for the development (roads, transmission lines, turbine bases, temporary compounds, etc.);
- the locations identified as 'at-risk' by LWP (for ready comparison).

Locations which met the selection criteria given above, and which lay in close proximity to any part of the development infrastructure, were highlighted using the datasets listed above. These locations were then examined in detail using the high-resolution aerial photographs and compared with UEL field-survey notes where available.

7.4.1.2 Identification of 'high-risk' sites by UEL selection process

The result of the sub-selection process described above nonetheless continued to highlight a surprisingly large number of potentially significant 'at-risk' sites where, according to LWP's own parameters, there is a risk of sufficient magnitude to warrant concern and possible action. Rather than the 36 sites originally identified as being potentially at risk by LWP, a total of 97 areas emerged from the UEL selection process described above. Thses sites are regarded as having a moderate, high or very high risk. Their distribution is illustrated in Figure 89.

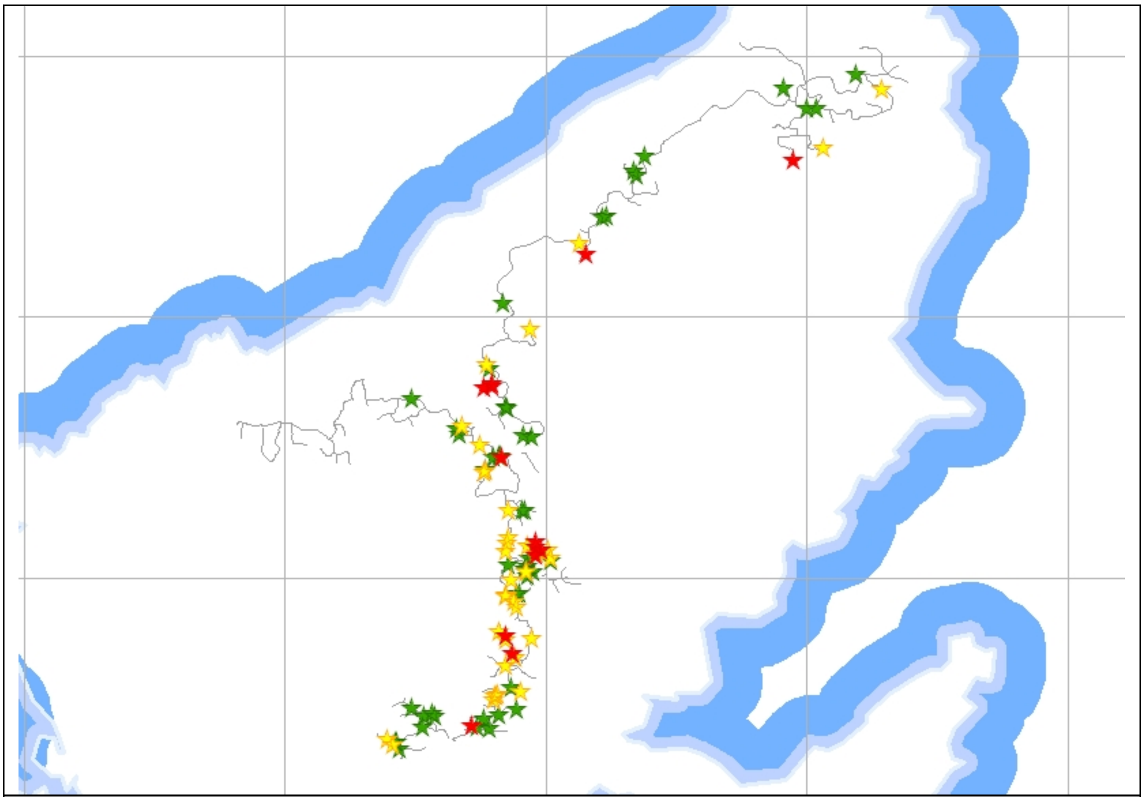


Figure 89. Localities identified by UEL as potentially 'at risk' of slope failure.
Map of 97 areas identified by the UEL Peatland Research Unit as being significantly 'at risk' in terms of peatslide stability. Green stars = 'moderate stability risk'; Yellow stars = 'high risk'; Red stars = 'Very high risk'. The proposed LWP windfarm road-line is shown as a dark grey line. Also displayed is the coastline of Lewis, in concentric pale blue shading. The OS National Grid is shown in light grey as 10 km squares.

The number of sites identified in this way is, frankly, surprising because the number of sites is so large, despite using many of the same selection criteria as LWP, when compared with the 15 such localities finally selected by LWP as being at significant risk. Specifically, the UEL Peatland Research Unit identifies more than *six times* the number of 'significantly at risk' areas than were identified by LWP.

It can be seen from Figure 89 that the majority of the UEL 'at-risk' sites are located in the central and southern sections of the development. Significant numbers are also found scattered across the northern section, however. Only the north-western arm of the development appears to be largely free from such risk using these criteria, other than a single locality not far from LWP's own area of concern at Tom Aister.

The scale of difference between the UEL and the LWP dataset is sufficiently large to warrant a serious appraisal of the whole LWP peatslide risk assessment. It has already been demonstrated earlier that there are concerns about the way in which Factor of Safety values have been calculated in relation to unrealistic water tables. FoS calculations using more typical water-table values suggest that much of the peat may not be far above the critical safety threshold. Some of these calculations were performed by LWP itself. It has also been demonstrated that applying criteria used in Ireland to assess peatslide risk within the proposed LWP development area identify a considerable proportion of this area as being 'at-risk'. Now, finally, a site-by-site review using many of LWP's own criteria has identified a very large number of specific localities which appear to be significantly 'at-risk', or at least to warrant much closer investigation.

On this basis, the comment in LWP 2004 EIS, Vol.3, Chapter 17, para 40 seems rather inappropriate:

> *"As discussed in Section 17.4, peatslide prone areas have been identified and avoided where possible,* ***resulting in only 15 areas which have any potential vulnerability****."*

It cannot seriously be argued that only 15 localities "have any potential vulnerability", especially given the literature available about the levels of uncertainty that currently prevail when trying to assess stability issues in peat. Indeed elsewhere in the LWP EIS (LWP 2006 EIS, Vol.2, OBN12 (Construction) – peat management, para 16), it is observed that:

> *"****In general, areas of peatslide risk have been avoided****. However a management plan is still required as* ***this area is still not well understood at present****. Chapter 17, Volume 2, LWP (2006) identifies the risk areas and outlines the control and monitoring measures required.* ***This area is rapidly developing*** *and these developments will be monitored and incorporated into plans."*
>
> *LWP 2006 EIS, Vol.2, OBN12 (Construction)*
> *peat management, para 16*

The LWP EIS documents do not therefore, as claimed, provide a development proposal where, "in general, areas of peatslide risk have been avoided". Figure 49 (Section 5.2.7.4) alone shows this not to be the case. The scale of the peatslide issue is substantially greater than is suggested by the LWP EIS documents. Questions have already been raised about the implications of LWP's own findings in assessing Factor of Safety models. Furthermore, an assessment of peatslide risk using an approach adopted by the Irish Landslides Working Group (ILWG) has been shown to generate a much larger area that could be considered 'at-risk' than the LWP EIS documents appear to show.

In summary, it is probably fair to say that the LWP Peatslide Risk Assessment does not reflect the relevant data available for the site, nor the current state of understanding about peatslide risk. As such, it gives a misleading and unduly positive view of the possible slope-stability risks associated with the LWP development.

To conclude this section of the present report, it is worth taking a step back to look at engineering processes in general, and the lessons to be learned about using construction methods that are still in the early stages of development and use.

7.5 Engineering and real-world construction

Engineers use theoretical design principles and the known behaviour of materials to turn designs on paper into tangible real-world objects. When Utzon was asked how the elegant overlapping shells of his design for the Sydney Opera House would actually be constructed, the architect reportedly replied “I really have no idea,” to the understandable consternation of the NSW Government. Thus it fell to Ove Arup engineering to help Utzon turn his iconic design into reality.

Much engineering involves well-established design and construction processes. The structures are of a standard design which have been tried and tested. The conditions under which they are constructed are either carefully controlled or are well-understood and can be allowed for within the design scheme. Millions of homes are constructed each year with nothing worse than a few minor creaks or leaks – new homes rarely collapse.

7.5.1 Failure at the limits of knowledge

The success (and safety) record of projects changes dramatically, however, when engineering pushes at the boundaries of established principles and practice. This is when the unexpected happens. Indeed it could be said that engineering progress is largely founded upon the process of pushing beyond what is known and safe, observing the (sometimes catastrophic) consequences, and learning from them. To quote Steve Denton, of Parsons Brinckerhoff engineering consultancy, commenting after the 2007 Minneapolis bridge collapse:

> *“In engineering it is disasters that move us forward. The construction of the great European cathedrals led to collapses that changed the way we do things. It’s the same with these bridges.”*
>
> *Harlow and Leake (2007)*

One of the most famous example of a project that suffered the consequences of pushing beyond known engineering limits was the Tacoma Narrows Bridge in Washington State. The bridge became known as ‘Galloping Gertie’ because under certain wind conditions the bridge-span would start rising and falling like a gentle trampoline, giving those driving across it a most interesting experience. Then four months after the bridge had been completed, on 7th November 1940, a moderate but steady wind caused the oscillations to reach an intensity not previously seen. The roadway started to incorporate a violent twisting motion into its familiar oscillations. Fortunately all drivers caught on the bridge were able to escape, with a Mr Leonard Coatsworth being the last to escape on foot before the whole span collapsed (for video footage of the event, see: Tacoma Narrows Bridge - Wikkipedia website).

The cause of the failure is subject to ongoing debate even today. At one time, failure was attributed to the shedding of ‘Karman vortices’ but this theory has since been questioned. Tom Irvine (Wright State University website) illustrates and analyses the collapse, provides an in-depth review of recent thinking, and suggests that the cause may instead have been aedrodynamic instability.

The Tacoma Narrows Bridge was based on a design that was both novel and relatively untested. Suspension bridges were a new technology and there was much still much to learn about their strengths and limitations. These limitations are still being discovered today. The same *Sunday Times* article by Harlow and Leake (2007) cited above highlights the fact that completely unforeseen corrosion of the cables has been discovered in the Severn and Forth Road Bridges, and similar corrosion of cables is suspected in the Humber Bridge. This has resulted in traffic limits being imposed on the Severn Bridge. There are even suggestions that the bridge may eventually have to be closed to traffic after little more than 50 years in service, although it was constructed with a design life of 100 years.

Indeed even examples of what, on the face of it, appear relatively straightforward engineering projects have suffered catastrophic failure because of unforeseen factors, whether they be structural, ground conditions, or just human failure. Thus on 30th June 2005, construction of a new Tesco superstore at Gerrards Cross, Buckinghamshire, resulted in collapse of the Chilterns Railway tunnel beneath the construction site. The cause is still under investigation by the Office of Rail Regulation on behalf of the Health and Safety Executive because the case may result in prosecution. The point is that construction of a superstore is hardly a cutting-edge engineering project, yet even here a set of unforeseen circumstances has led to completely unexpected and catastrophic results.

In other words, judgement on the success or failure of a new engineering design should be reserved until the design has been successfully built *and then proven itself* over its designed working life. A structure with a design life of 25 years cannot be regarded as having been successful if it results in collapse, or has serious structural problems, after only 17 years.

The style of floating road now being used on windfarms, and proposed for the LWP development, has only been in use for some 10 years, though the majority of established examples are much younger. Furthermore, only a small proportion of these have been constructed on deeply-gullied peat. The record so far for such roads is perhaps best described as mixed, ranging from the catastrophic bogslide at Derrybrien, Co. Galway (and an adjacent slide at Sonnach Old), to evidence of significant settlement into the peat (with consequent ponding and flooding) on sections of most sites, and to the continued release of sediment loads into water-courses even after the main construction phase has been completed.

7.5.2 Assessment of engineering proposals

Given the above, a critical part of looking at a proposed engineering project therefore involves consideration of the degree to which the proposed engineering approaches are novel, and have been tried-and-tested. Where the proposed methods are relatively novel, and have not been extensively tested over meaningful time-periods, it is particularly important to ensure that all available evidence relevant to the method is brought together and considered within the context of the proposal. It is also vital to ensure that an openly precautionary approach is adopted.

Where, during testing and use elsewhere, there have been observed failures, such failures should play a transparently central part in shaping the methods to be used in the proposed development. As observed already (Harlow and Leake, 2007), “In engineering it is disasters that move us forward.” If appropriate use is not made of such disasters, then there is a real danger that the same failures will be repeated.

The preceding parts of the present chapter have repeatedly emphasised the uncertain nature of the ground on which the LWP infrastructure is to be built. The present and preceding chapters have also highlighted the failure of LWP to identify a very large number of features and localities having direct relevance to questions of stability, and which raise serious doubts about LWP's whole approach to the issue. The technique of 'floating roads' remains relatively novel, with virtually no scientific literature available to give guidance on questions of long-term stability and operational performance, peat stability, hydrological changes, or ecological impacts, Given all the above, it would seem that the LWP EIS documents have failed to provide any adequate assessment of the likely possible stability issues resulting from:

- floating road construction;
- rockfill road construction;
- overhead powerline construction;
- excavation for infrastructure.

As such, it is difficult to see how the competent authorities can form a meaningful opinion about the likely impact of these proposed construction methods. The information provided by the LWP EIS documents is simply not adequate to make such a judgement.

8 DIRECT AND INDIRECT IMPACT ASSESSMENT

> *"...[one cannot]...predict* ***future events exactly*** *if one* ***cannot even measure the present state*** *of the universe precisely." (Prof. Stephen Hawking, Lucasian Professor of Mathematics, University of Cambridge)*
>
> *(Hawking, 1988).*

LWP, on the other hand, appear rather confident and specific in their predictions:

> *"In the case of indirect change, literature review on blanket bog response to ditching, together with dipwell studies at Farr Wind Farm and modelled comparison of the Farr and North Lewis sites, suggest that* ***most impact will occur within 2 m*** *of the edge of disturbed ground. Allowing for a small amount of effect beyond this limit,* ***setting 2.5 m as the actual likely average distance of change*** *... [means that] ... permanent loss due to habitat change could therefore be considered to be zero."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 80*

Given Hawking's wholly justified stricture about measurement in relation to prediction, the exact nature and the small scale of predicted impact-distances offered here by LWP look somewhat inappropriate. The highly variable nature of the ground within the Lewis peatlands, the acknowledged variability within the fabric of the peat soil itself, and the uncertainties about what actual infrastructure will be required (*e.g.* will there be road-side drains, will there be siltbuster-style units at all gully crossings?), combine together to make both measurement and consequent prediction extremely difficult.

If measurement is difficult, whether it be at 'test sites' such as the Farr Wind Farm (see Appendix 1) or on the ground at the LWP development site, such difficulties render virtually meaningless the predicted distances of 2-3 metres for 'likely distance of change' given above.

For example, along any 10 m length of the infrastructure boundary it is quite possible to find a combination of a low peat hagg growing on a zone of weak peat, a bare-peat gully, a high peat hagg, and an infilling gully choked with *Sphagnum* which is ponding a certain amount of water. Measurement, predictions and actual impacts will be very different for each of these features.

To give an actual example of the way in which the reality on the ground makes a mockery of the 2.5 m zone predicted by LWP, Figure 90 illustrates a typical stretch of proposed roadline displayed over a high-resolution photograph of the area. It can be seen that the roadline itself crosses a great many erosion gullies in only this short length. Even more strikingly, it also cuts across two substantial pool structures. Many of the gullies, and both pools, extend for 50 m+ beyond the roadline and associated batters.

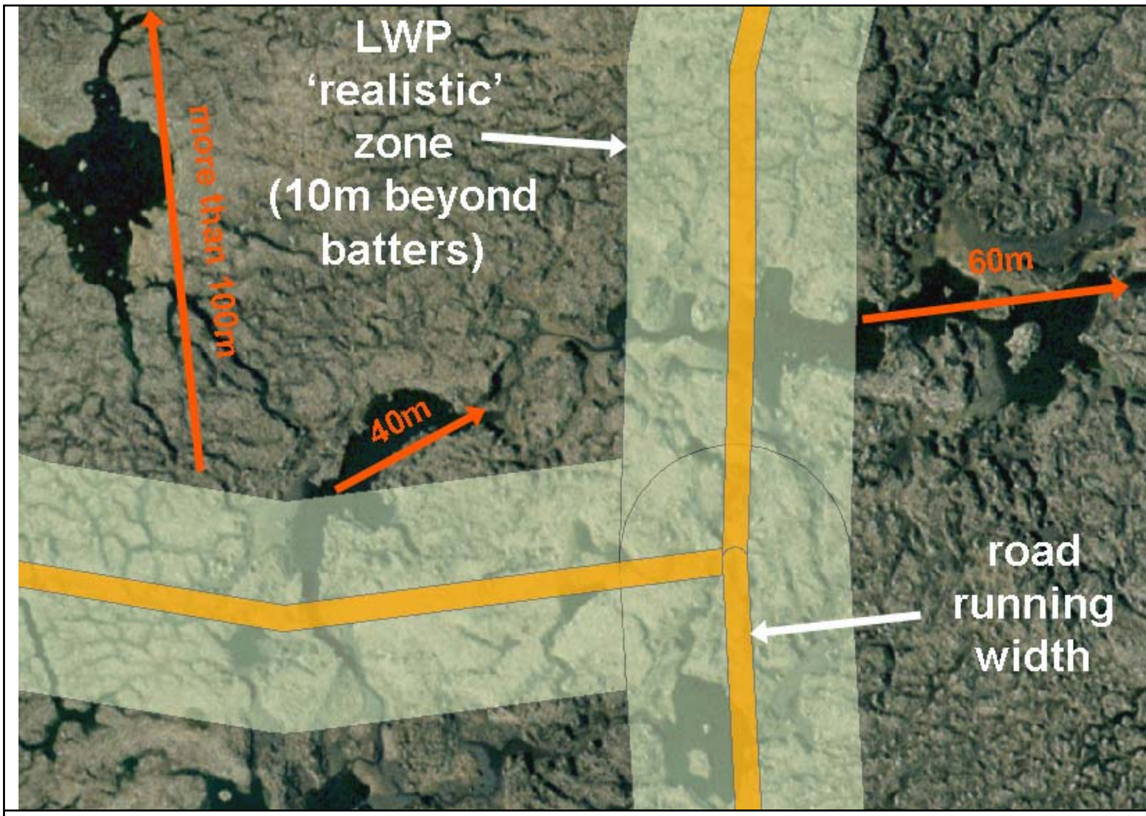


Figure 90. Example of ground conditions assicated with proposed roadline.
Example of proposed windfarm roadline, crossing area with large pool structures (black features). The road running width (5 m) is shown in orange. The zone encompassing batters (10 m each) either side of the road, and then a further 10 m width representing the LWP 2006 EIS 'realistic' impact zone, is shown in semi-transparent blue/grey.

There are sufficient numbers of these hydrologically-sensitive features along the road-line, and each type is sufficiently extensive, to mean that putting together an estimate of even the *average* impact-distance is clearly going to be a complex process, but a process which is nonetheless likely to result in distances well in excess of 2.5 m.

The LWP view suggests that the pools and gullies will only experience change over distances sufficiently small to result in an *average* impact distance of only 2.5 m overall. Such an average figure suggests that some parts of the infrastructure will have no impact at all, but the predicted average also suggests that even relatively substantial impacts cannot exceed 10 m or so if the average impact-distance is to remain so low.

This leads to the slightly absurd suggestion that only $1/6^{th}$ of the water in a pool 60 m long will actually be affected. Similarly, it suggests that the portion of a gully downslope from the roadline will only experience a change in water regime for a distance of somewhere between 2.5 m and 10 m; beyond that, the hydrological regime is in some way restored to its former condition. Given that some gullies will be used as outflow points for cross-drains, while others will be permanently cut off from their upslope lengths, this does not seem either likely or realistic.

The dimensions of features on the ground simply do not permit such a narrow zone of impact to be defined in the way adopted by the LWP EIS documents. Impact zones must reflect the scale of features likely to be impacted. To illustrate the point, imagine a playing-field completely covered with small glass disks, 2.5 m in diameter. If a bulldozer is then driven across this field, it would be reasonable to expect that a zone of broken glass would extend to around 2.5 m beyond the actual track of the bulldozer because only those disks crushed by the bulldozer will be broken. Now replace the 2.5 m disks with disks that are 60 m in diameter and repeat the exercise. Obviously the zone of broken disks will now extend to some 60 m either side of the bulldozer track because the individual features damaged are so much larger. The same principle applies to bog pools and erosion gullies that extend for 60 m or 100 m, but this concept does not seem to have been recognised by the LWP impact assessment.

Indeed the 2.5 m impact zone proposed by LWP becomes even less justifiable (and Hawking's stricture even more relevant) when it is understood, firstly, the extent to which the LWP EIA has failed to measure the appropriate things, and secondly, the degree to which those things that LWP has measured have not been measured appropriately. The previous chapter of the present report, for example, repeatedly points to areas of considerable uncertainty in relation to peat-soil stability, and emphasises that these uncertainties are specifically highlighted by authorities on the subject. Chapters 5 and 6 both detail ways in which the LWP EIA has failed to identify key features of significance for ecology, hydrology and even construction, and has measured other features inappropriately.

The over-arching approach to potential impact assessment, as emphasised in Articles 3 and Articles 5 (as amended) of EU Directive 97/11/EC), must be that each part of a proposed development is assessed in terms of its potential for impact, and that the scale of impact is assessed appropriately for each of these parts. Thus, given the acknowledged and demonstrably variable nature of the peat in terms of depth, state of humification, water content, vegetation cover, state of erosion and slope-angle, the LWP EIA could have taken each individual road section and considered:

> *"What would be the potential area of impact if this particular section should fail in some way?"*

Clearly it would not be possible within the timescale and resources available for the EIA to measure each road section in detail, but this does not mean that a tailored approach is impossible. On the contrary, ample information exists within the data already gathered by LWP, or in the form of readily-available data, for at least some form of tailored picture to be assembled, as already demonstrated in the previous chapter of the present report.

The LWP EIA does not recognise this possibility (or if it did recognise the possibility, it did not then act on it). Instead the LWP EIA assessment of direct and indirect impacts is based on a single, uniformly-applied prediction that:

- takes no account of obviously variable local conditions;
- makes no use of available data that describe this local variability;
- is based on a combination of site-studies that are of debatable value;
- does not draw fully on published research findings.

Most importantly, the predicted impact zone is based on, and applied to, a fundamentally-flawed account of the proposed development area in which, for example, substantial parts of the development have no information about peat depths. Consequently both the underlying site description and the subsequent prediction of impact represent significant failures of the EIA process.

8.1 Failures of the LWP EIA

Previous chapters of the present report have made clear that serious questions exist about the LWP EIA approach to the measurement of a great many critical factors and the application of those measurements to potential impact assessment. Such concerns embrace:

- methodological weaknesses in the Farr windfarm studies;
- the lack of any peat data for 8% of the road system;
- the lack of *any* peat data for the overhead transmission route;
- the failure to examine the scale and consequences of road subsidence;
- the failure to address the unresolved issue of fine-sediment release;
- the inappropriate and thus un-informative nature of the main classification system used in impact assessment (hydrological zones);
- the lack of any information from the most appropriate descriptive scale for the blanket bog habitat (mesotopes);
- the consequent failure to identify key peatland mesotopes of high sensitivity;
- the consistent focus on catotelm rather than acrotelm response when discussing drainage effects;
- the failure to acknowledge and respond to the potential impact-sensitivities of conditions on the ground, where pools, gullies or other features may themselves extend for 100 m or more;
- the belief, not supported by any presented evidence, that erosion of the Lewis blanket bogs is wholly a process of natural hydrological collapse, apparently thus leading the LWP team to overlook more obvious evidence – in particular...
- the failure to catalogue widely-recognised effects of burning across the habitat;
- the failure to recognise in its own data the evidence of widespread vegetation recovery and thus the widespread presence of 'active' blanket bog;
- creation of an inappropriate definition for 'active' blanket bog which cuts across the official definition, and calculation of impact figures on this basis, despite being previously guided to the official definitions;
- the failure to embrace major uncertainties that are clearly enunciated in the peat-landslide literature; and
- the failure to consistent and appropriate criteria to conditions on the ground when undertaking the peatslide risk assessment.

Given these major areas of concern about the various measurements presented in the LWP EIS documents (and more areas of concern to do with slope stability are raised in the next chapter), it is simply not possible to proceed on the basis of the impact evaluations set out in the LWP EIS documents. They are so far removed from the essential reality of the issues/areas involved that they shed relatively little meaningful light on the issue.

This presents a difficulty in terms of generating an alternative, more appropriate scenario. Had the LWP EIA merely interpreted its own data inappropriately, it would be possible simply to take the original data and carry out a more appropriate interpretation. In this case, however, the raw data themselves are suspect or of debatable value. Consequently it is difficult to undertake any meaningful re-analysis based solely on the data presented in the LWP EIS documents. The only real solution would be to repeat the work in a more appropriate way and gather a new set of peatland data. This is clearly not feasible.

8.2 UEL impact assessment : an alternative to the LWP EIA

Fortunately, a significant proportion of the method used by the official conservation agencies (though not used by LWP) for describing and classifying peatland ecosystems, can be undertaken using remote-sensing and cartographic techniques, particularly when integrated in digital form in a GIS. Furthermore, certain key LWP datasets have been found either to be reasonably reliable or to be amenable to re-interpretation. Thus, for example, the peat-depth data for the roadline have been checked in the field by the UEL Peatland Research Unit and proved to be mostly accurate, while the GIS mapping of 'Erosion Class' rather fortuitously provides a moderately good breakdown of peatland sites at the microtope scale. Added to this information are data obtained during field survey by the UEL Peatland Research Unit. This can be used as 'ground-truth' data in evaluating the information available from the UEL Peatland Research Unit's archive of Getmapping.com high-resolution colour aerial photographs for the whole development area.

In combining these various information-sets together into an integrated GIS dataset, and then underpinning this with information and understanding from the existing scientific literature, it becomes possible to undertake a constrained EIA evaluation. It is not the complete evaluation that would be possible if informed by comprehensive and appropriate ground-survey of the development area, but is nonetheless a usefully indicative guide to potential impacts.

8.2.1 Limitations to an alternative EIA

It is important to understand the implications of using the type of constrained dataset employed by the UEL Peatland Research Unit:

- Geotechnical information about the peat matrix across the development site (weak layers in the peat; rates of hydraulic conductivity, etc.) are not available;

- Ground conditions at every potential water-crossing and silt-management system have not been assessed, nor indeed has the total *number* of possible water-crossings and associated silt-management systems been estimated;
- The vegetation is *known* from only those localities visited by the UEL Peatland Research Unit;
- For the remainder of localities (HSA polygons), the only vegetation data available come from two sources subject to considerable debate:
- firstly there are the LWP quadrat data, which may or may not fairly reflect the vegetation of the area, but certainly do not provide information about the distribution of these quadrat data within the nanotope patterns;
- secondly, there is the NVC mapping of polygons; but
- there are serious concerns about the way in which NVC classes have been assigned to polygons for which there are no quadrat data – and even more concerns about the area estimates provided for each NVC type within each polygon.

Adding a further layer of uncertainty to the estimation of possible impacts (though this uncertainty would be present even if a full LWP or UEL field survey had been completed) is the present underlying degree of scientific uncertainty about how peatland systems react under particular conditions. This reflects the current (rather limited) level of scientific knowledge about peatland ecosystems and their behaviour under various forms of stress.

Based on the information and approach summarised above, and taking into account the constraints also listed above, the UEL Peatland Research Unit has undertaken a constrained EIA of the development area. This EIA attempts to provide at least an indicative estimate of potential development impact based on actual site conditions as far as they can be judged using the information available.

8.2.2 UEL (constrained) EIA : information used

The development infrastructure has been integrated with data for altitude, slope and aspect, peat depth, UEL macrotope boundaries, example UEL mesotope boundaries, LWP Erosion Class, pool systems, erosion gully systems and percolation/ladder fen systems evident from aerial photographs, LWP quadrat data, UEL quadrat data, UEL field-survey notes and photographs. This was supported by information from existing scientific literature.

8.2.3 UEL (constrained) EIA : general comments

The areas where significant scales of impact may arise have already been discussed in earlier chapters of the present report. Thus the presence of sizeable ladder fens, and their associated seepage zones on deep peat, represent one type of feature that could result in an impact zone of considerable size. Micrositing might solve some of these problems, but there are many areas where the proposed micrositing corridor of 100 m would not be sufficient to accommodate the scale of infrastructure-displacement required.

Impact assessment obviously involves a review of ground conditions along the road-line, transmission line and around the other major elements of infrastructure. In order to do so, it is first necessary to establish as precisely as possible the size and location of these elements of infrastructure.

8.2.4 Impact zone : complete LWP infrastructure

The LWP infrastructure comprises:

- the road system, which will consist of a 5 m running width plus 10 m batters constructed either side of the road;
- the turbines and hard standing, which are described as 45 m x 50 m and totalling 36.2 ha (LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 53);
- permanent compounds, which are described only as "totalling 5.1 ha" (LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 53);
- temporary compounds, which are described as 50 m x 50 m (LWP 2004 EIS, Chap.7, Fig.7.19), but totalling approx. 3 ha (LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 53);
- four batching plants, which are described as 50 m x 60 m (LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 53);
- the control building, which is given as 1 ha;
- the 'temporary' road for the overhead power lines; this road will be approx. 5 m wide (and may need to be semi-excavated for much of its length).

Adding these together generates the map shown in Figure 91. It creates a total development 'footprint' of 555 ha at this stage in the analysis. However, two factors should be borne in mind at this stage.

Firstly, the proposed roadline is merely indicative, in the sense that micrositing and the resulting sinuosity of the roadline may result in a longer total road length. This is also true, probably even more so, for the route of the overhead power-lines.

Secondly, we have still to consider the indirect effects associated with the bulk of the development infrastructure. The question of micrositing is examined in the next section, because it raises important questions about what ground should be looked at in terms of both direct and indirect impacts.

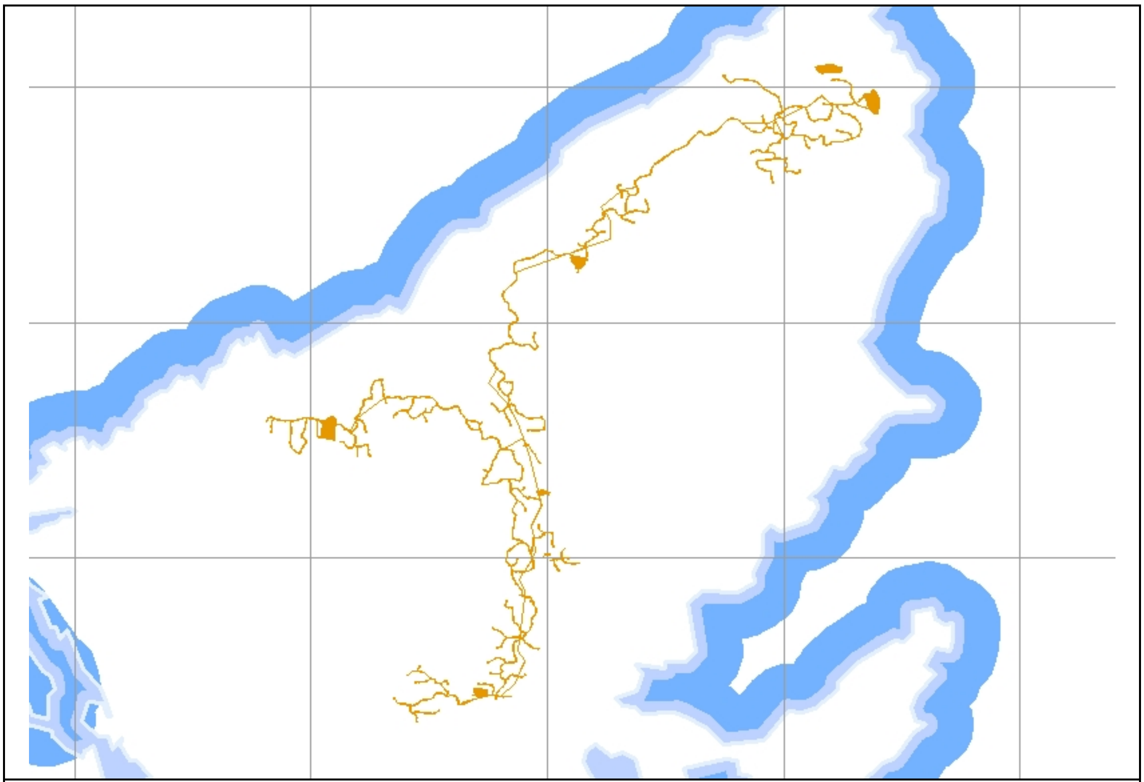


Figure 91. Map showing ground directly affected by proposed LWP infrastructure. Extent of proposed LWP infrastructure (shaded dark orange). This consists of the site roads with a 5 m running width and 10 m side batters, a straight track for the overhead pylons with a 5 m running width, turbines and hard-standing, four batching plants, the temporary compounds, the sub-stations, the rock sources and the control building. Dimensions are as listed by, or calculated from, LWP 2006 EIS, Vol.2, Section 2, Chapter 11, 11.6.1.1, para 53 or LWP 2006 EIS, Vol.5, Appendix 11b. The National Grid is shown (in grey) as 10 km squares. The coastline is shown as concentric blue shading.

8.2.5 Micrositing

As discussed in Section 3.1 of the present report, the issue of micrositing adds significant complications to the picture of possible direct and indirect impacts from a development because:

- micrositing involves an additional zone of uncertainty amounting to 100 m on *either* side of the proposed roadline and overhead powerline, and 100 m around any other feature;
- though in theory able to *reduce* the environmental impact of the development, micrositing may be constrained and overly-influenced by micrositing imperatives arising from engineering constraints, with the result that a final decision based on engineering grounds may represent greater harm to environmental factors;
- the sinuous nature of roadlines resulting from micrositing (particularly for the overhead power-lines), and the possible need for extra road sections if turbine bases are re-sited further from the original roadline, can increase the total required road-length significantly.

As emphasised in Section 3.1, micrositing does not necessarily result in an increased area of impact, although there is considerable potential for it to do so. Micrositing may simply lead to a re-positioning of the existing zone of actual and potential impact. Indeed, in a best-case scenario, it may even *slightly* reduce the total area of direct impact if all micrositing decisions involve maintaining as straight a roadline as possible and bringing the turbines even closer to the road where feasible. However, the effect would be slight as the indicative roadlines and powerline routes are already fairly straight, and many turbines are already placed adjacent to the road.

Nonetheless, it has also already been pointed out in Section 3.1.2.2, and above, that micrositing does have the very real potential to *increase* the development footprint. There is an inevitable increase in the development footprint whenever a turbine is moved up to 100 m further from its originally-mapped location. In a worst-case scenario, the roadline could thus be increased by 20 km to cater for re-positioning of turbines and other infrastructure features.

There is also the possibility that increased sinuosity will add to the length of the site roads and the power-line trackways. Thus a roadline with, say, a 2-curve sinuosity and a roadway for the overhead powerlines with somewhere between a 3- and 4-curve sinuosity can add 12 km to the formal roadline and 8 km to the 'temporary' powerline road, respectively.

Given these possibilities, it is therefore necessary to look at all features that might find themselves lying within the zone affected by such micrositing decisions. Where the direct or indirect zone of impact then embraces features of concern, these need to be highlighted as part of a worst-case possibility. This is necessary if only to ensure that such a worst-case possibility is avoided, bearing in mind that not all micrositing decisions will necessarily have environmental considerations as their over-riding priority.

Consequently the total more-or-less 'permanent' roadline damage caused by direct construction for turbines *and* powerlines could be as much as 173 km for the formal roadline (LWP predict 141 km) and up to 40 km for the powerline trackway (LWP predict no impact). This gives a total worst-case length for potential permanent roadway impact of 213 km, which is 33% greater than the claimed permanent roadway impact total of only 141 km.

It is important to emphasise that although this is a worst-case scenario, it is based on a logical and realistic set of worst-case conditions, and should therefore have featured at some point in the LWP EIS.

It is absolutely certain, therefore, that the introduction of micrositing gives rise to an increased area that must be *assessed* for potential risk and damage. It is also more likely that micrositing will result in an increased footprint on the ground. Whether this increased footprint will nevertheless give rise to a smaller environmental impact (because sensitive areas are actively avoided) is a question that cannot be assessed at this stage.

This is because LWP 2006 EIS, Vol.2, Sect.4, Part 2, OBN1, para 1, clearly acknowledges unforeseen ground conditions as one of the major factors triggering micrositing decisions. Given that the infrastructure must go somewhere, there is no way of knowing at present how often engineering constraints will have to prevail simply because of the surrounding ground conditions. Consequently it is necessary for the purposes of the potential impact assessment to assume the worst - that micrositing will be largely determined by the constraints imposed by the needs of engineering and construction.

It must also be borne in mind that the final position of the infrastructure might lie at the outer edge of the micrositing boundary. Any indirect effects would then extend beyond that boundary. An extra zone is therefore required around the micrositing corridor in order to embrace ground that might be affected by such indirect effects.

For the purposes of the present UEL assessment, the original LWP 'potential zone of impact (PZI) of 50 m was accordingly added to the area of the micrositing corridor, because this was the impact assessment distance originally agreed between LWP and SNH.

Thus Figure 92 represents a composite search area consisting of:

- all infrastructure;
- a 100 m micrositing radius placed around the centre-point of all infrastructure;
- with LWP's original 50 m 'potential zone of influence' (PZI), starting at the edge of the micrositing boundary.

It must be emphasised that while all features lying within the pink-shaded area displayed in Figure 92 are *potentially* at risk, the total area indicated by that zone does not represent the development's direct and indirect footprint.

Instead it provides an 'Area of Search' for features that would give rise to concern if development were planned in their general vicinity as a result of the planned layout, or following changes to this layout because of micrositing decisions.

As such, there is little to be gained by calculating the area of this composite 'area of search'. Indeed there is much to be lost – in the sense that it will be mistakenly understood to represent a measurable area of direct or indirect impact. Those figures will come in the next few sections of the present report.

For the moment, it is worth noting that this 'area of search' embraces a number of significant localities and features which would give rise to concern if development were to occur within their vicinity. The identification of these localities is discussed next.

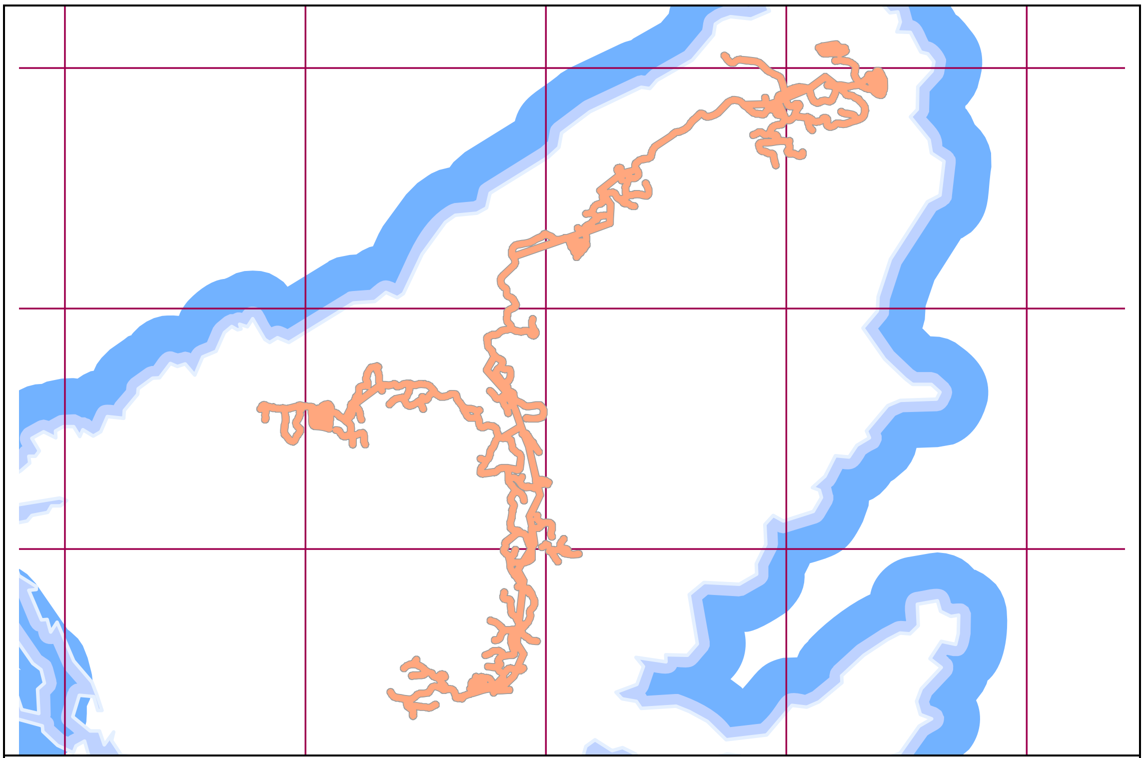


Figure 92. 'Area of Search' for potentially sensitve areas given LWP requirements for micrositing.
The 'Area of Search' (shaded pink) for features at risk from obvious direct or indirect impact from the LWP development. This Area of Search (AoS), has been constructed by combining the actual footprint of the development infrastructure (including the overhead pylon routes), then adding a 100 m micrositing buffer around this, and finally adding LWP's original 50 m 'potential zone of impact' (PZI) around this. The National Grid is shown (in dark red) as 10 km squares. The coastline is shown as concentric blue shading.

8.2.6 Sites of hydrological concern

Hydrology is the over-riding factor influencing peatland character and function, and it is possible to identify specific features on the ground that are almost certain to suffer direct hydrological impact during construction and maintenance of the proposed LWP infrastructure. These features would seem to be a good place to start in terms of assembling a realistic picture of the impacts that may arise from the LWP development.

The characteristics of such localities can be fairly readily summarised as follows:

- ladder fens/eccentric mires;
- seepage zones/percolation mires;
- bog pool systems;
- substantial gully systems, expecially re-vegetating gullies;
- evident peat pipes;
- very deep peat;

- construction in areas already hydrologically disrupted by forestry of peat-cutting drainage.

Based on the micrositing ‘Area of Search’ as before, and using the range of available information described in Section 8.2.2, the UEL Peatland Research Unit has identified 199 localities where there are specific issues of hydrological concern. These are localities where there is clear potential for hydrological disruption to the peatland system as a result of the proposed LWP development. It is worth pointing out that such types of hydrological disruption also have a direct bearing on the question of slope stability.

Consequently all 97 localities identified in the previous chapter of the present report as being ‘at-risk’ of slope failure also feature within this list as sites liable to suffer hydrological disruption from the development. Some sites within the total list of 199 locations are thus identified as being at risk of hydrological disrruption alone, while others are identified as being at risk from both hydrological disruption and potential slope failure.

The distribution of all 199 localities so identified is shown in Figure 93. It is clear that the distribution of sites in Figure 93 shows marked clustering, but to some extent this may be an artefact arising from the absence of peat-depth data for significant stretches of the northern part of the development.

Nonetheless, it is clear that the highest density of potential ‘problem’ areas lies in the central-southern parts of the proposed development, while the north-western arm of the development has few evident ‘at-risk’ locations in terms of the peat-based criteria used to select such locations.

8.2.7 UEL (constrained) EIA : Zones of Concern (ZoCs)

The 199 individual sites of hydrological concern identified above were then examined in more detail using:

- high-resolution colour aerial photographs;
- UEL Peatland Research Unit field survey of some areas;
- LWP peat-depth data;
- LWP HSA survey data
- digital topographic data;
- LWP’s peatslide-risk criteria;
- published Irish Peatslide Working Group criteria;
- factors identified by Warburton et al. (2004) in relation to slope stability.

However, determining an accurate potential area of impact for every one of these 199 sites of hydrological concern is beyond the scope of the work required for the present report. In effect, it would require a fairly detailed field examination of each identified locality. For the moment such areas can only be identified as fairly generalised 'zones of concern' (ZoCs).

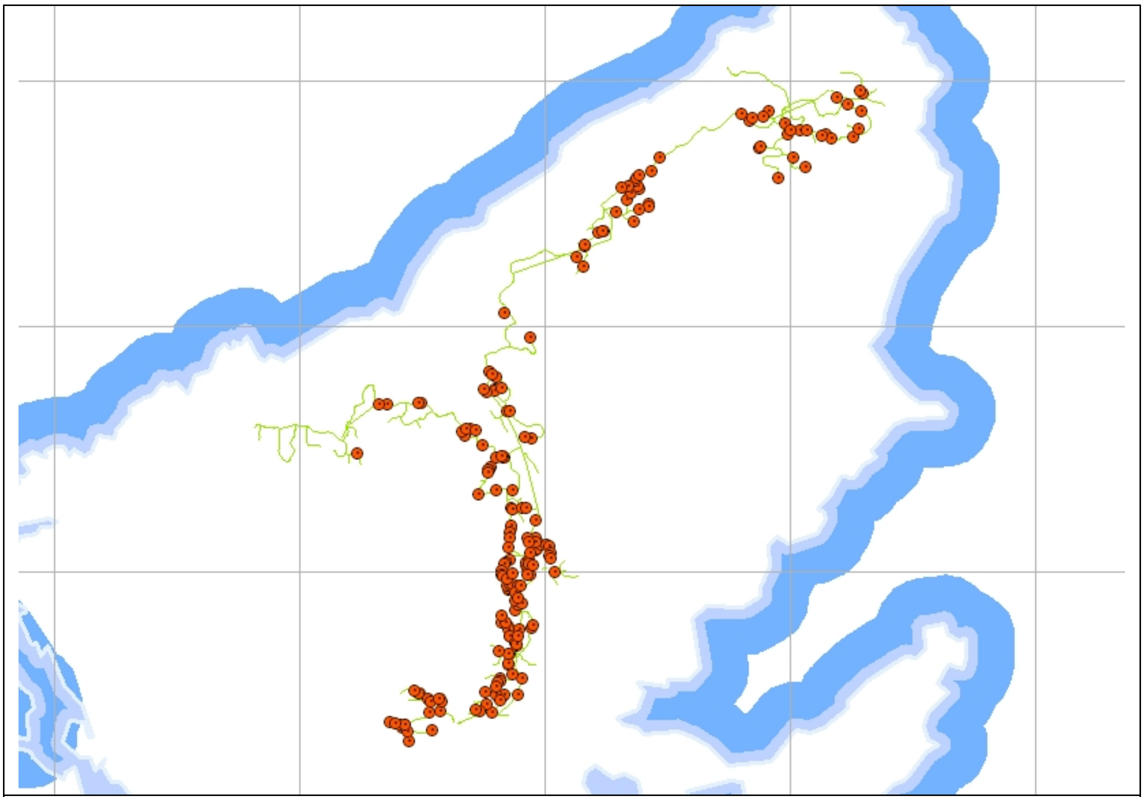


Figure 93. Distribution of areas identified by UEL as being of hydrological concern. The distribution of 199 localities (dark orange dots) identified by the UEL Peatland Research Unit as being of hydrological concern – i.e. areas where the LWP development appears likely to have a significant hydrological impact on a particular feature or collection of features. The proposed LWP road-line and overhead powerlines are shown in pale green. The coastline is displayed as concentric blue shading. The OS National Grid is shown in grey as 10 km squares. Details for these sites are given in Appendix 3.

The extent of each ZoC identified was defined on the basis of the feature itself together with ground in the immediate vicinity that has the potential to suffer direct impact as a result of the proposed development. Some of these features are quite large, and incorporate other ZoCs. In other cases, an assemblage of quite small ZoCs overlap and combine to create a single larger ZoC. This process of successive amalgamation resulted ultimately in the creation of 76 ZoCs.

These ZoCs are displayed in Figure 94. The total area of ZoCs is 1,532 ha, although, as indicated above, this should not be taken as anything more than an indicative total of the possible impact area associated with these features.

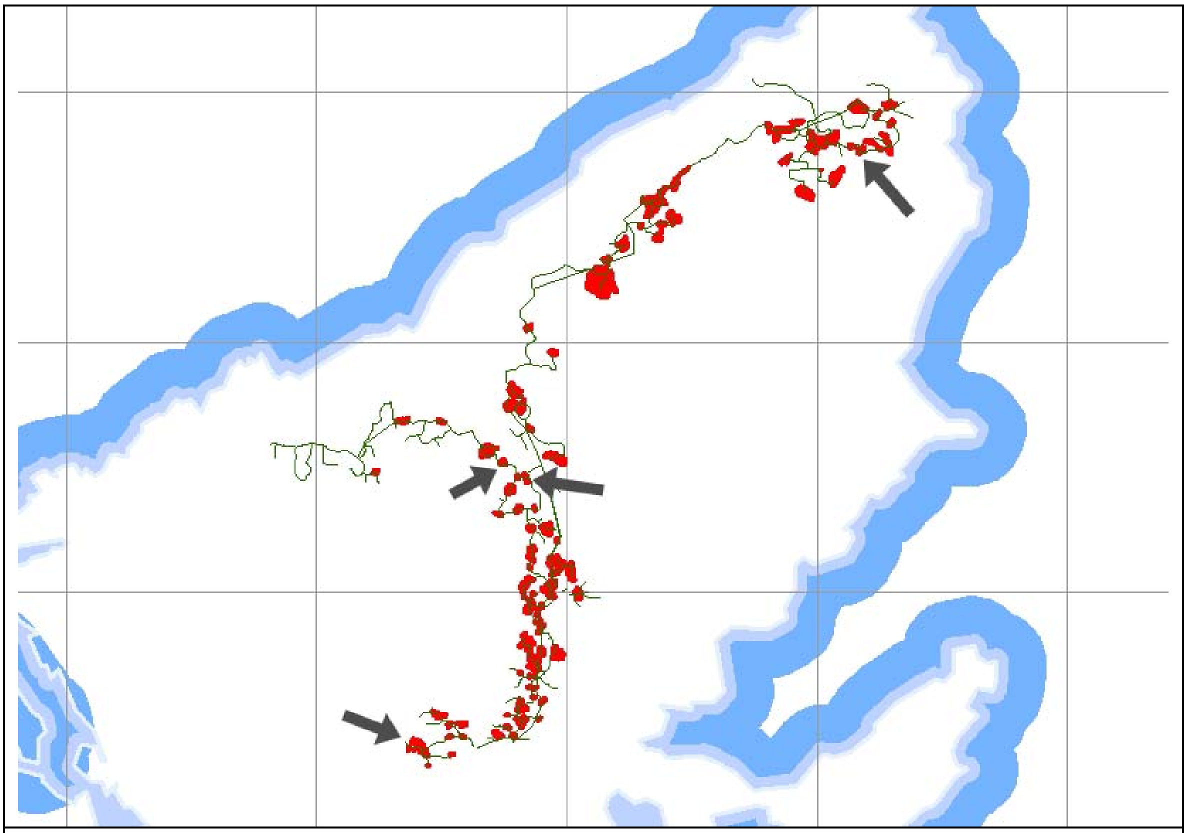


Figure 94. Distribution of UEL 'Zones of Concern'.
Map of 'Zones of Concern' (ZoCs), with 50 m PZI (LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 67) buffer added. ZoCs are features or areas where, on the basis of available information, there are concerns that there may be significant impact resulting from construction of the LWP windfarm infrastructure. A boundary is drawn around the feature of concern and then the LWP PZI of 50 m is applied to that boundary to create the ZoC. The resulting ZoCs are shown in red. Grey arrows indicate examples given in the four figures below.Also shown in dark green are the road-lines and the overhead transmission lines. The OS National Grid is shown (in grey) as 10 km squares. The coastline is shown as concentric blue shading.

It is worth pointing out here the role of micrositing in this exercise. Initially, it was simply to highlight those features of concern which either currently find themselves in the path of the LWP development or which have the potential to do so. Although the micrositing corridor itself has not added to the fundamental measured footprint of the development *per se*, it has nonetheless identified areas that do add to the potential development footprint.

It is not feasible within the constraints of the present report to provide detailed maps and aerial photo images for every ZoC to illustrate the nature of each identified problem. However, listings of all 199 identified sites of hydrological concern, and for all 76 ZoCs, are provided in Appendix 3 and Appendix 4 respectively within the present report. In addition, some examples illustrating the kinds of problems identified are provided below as Figure 95, Figure 96, Figure 97 and Figure 98.

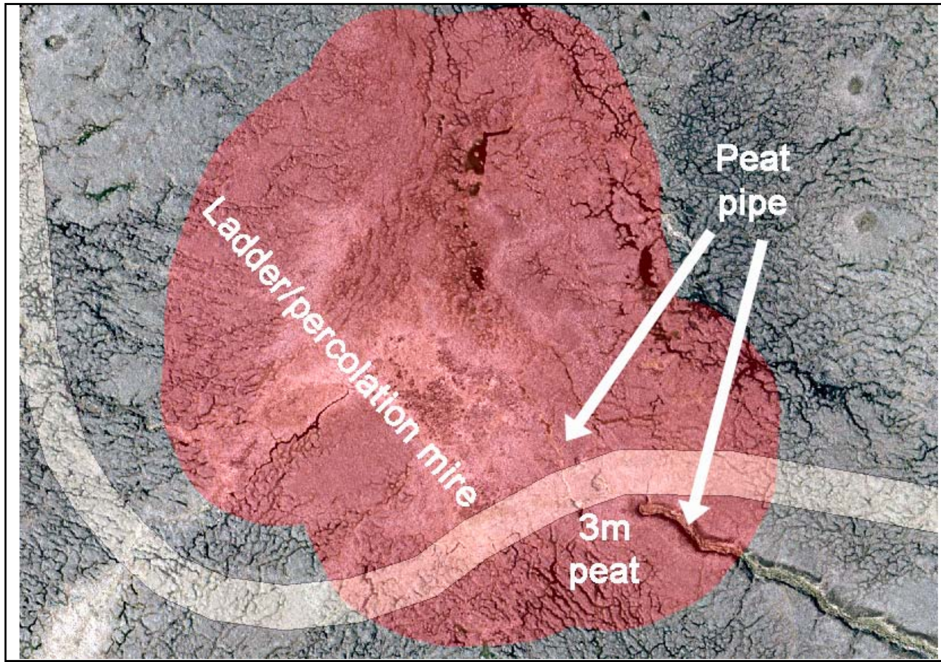


Figure 95. Zone of Concern – Example 1.
'Zone of Concern' (ZoC) . NB 374452. A mixed ladder fen/percolation mire cut across at the foot, in 3 m or peat, by the road-line, just where the fen complex enters a peat pipe system. Red shading = ZoC. Road-line shown as transparent white. Width of road-line (5 m running width plus two 10 m batters) = 25 m.

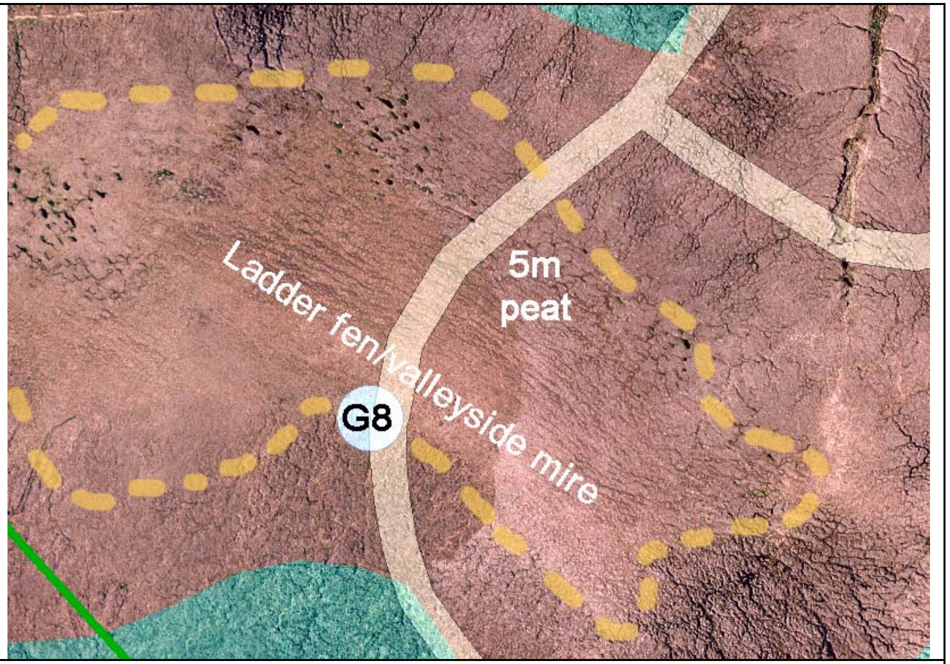


Figure 96. Zone of Concern – Example 2.
'Zone of Concern' (ZoC) .NB 380474. A large mixed ladder fen and valleyside mire (bounded by yellow dotted line), lying on up to 5 m peat depth, bisected by the road-line and with turbine G8 to be constructed on the downslope toe of the mire complex. Pink shading = ZoC. Road-line shown as transparent white. Width of road-line (5 m running width plus two 10 m batters) = 25 m.

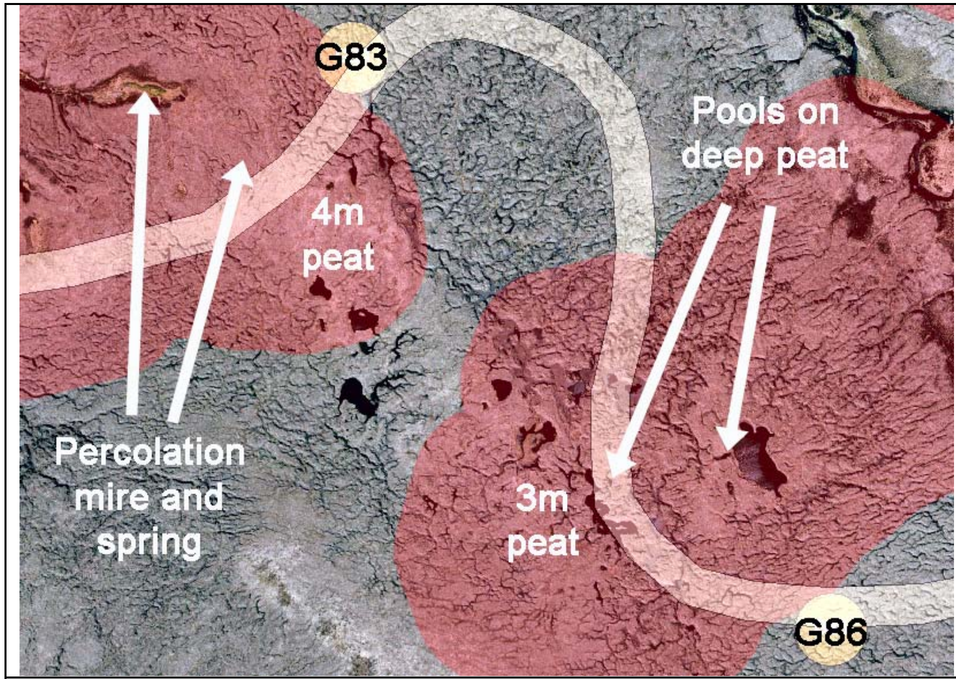


Figure 97. Zone of Concern – Example 3.
'Zone of Concern' (ZoC) . NB 515577. A percolation mire and spring (green colour), lying on up to 4 m peat depth, bisected by the road-line and with turbine G83 to be constructed on the margin of the mire complex. Also a pool system on 3 m peat depth, with pools bisected or covered by the road-line. Turbine G86 will be constructed on the edge of this deep peat. Pink shading = ZoC. Road-line shown as transparent white. Width of road-line (5 m running width plus two 10 m batters) = 25 m.

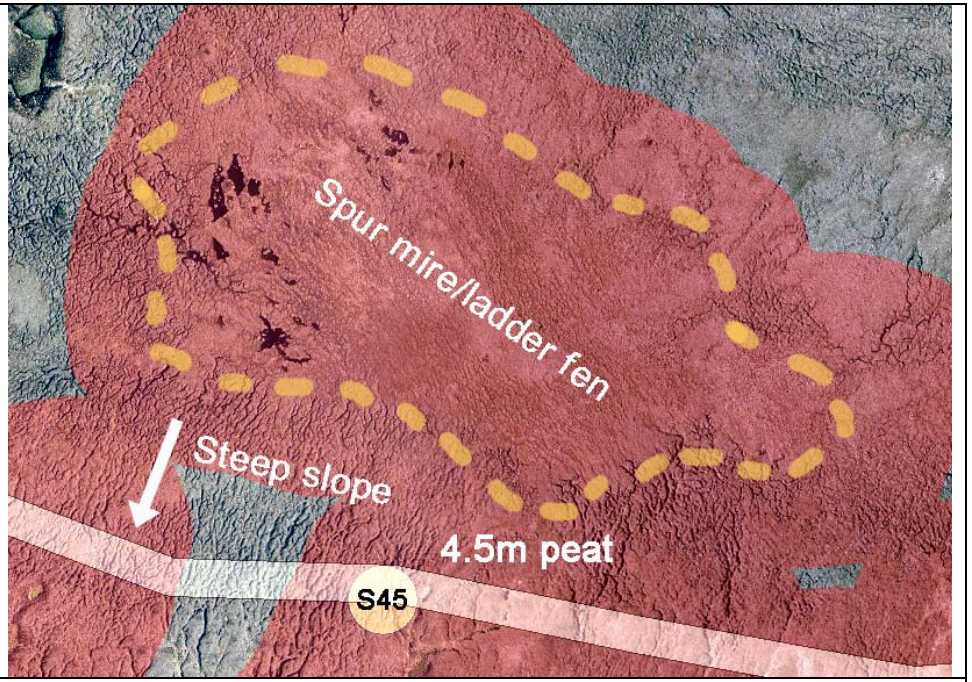


Figure 98. Zone of Concern – Example 4.
'Zone of Concern' (ZoC) . NB 339340. A large mixed ladder fen and spur mire (bounded by yellow dotted line). The road-line and turbine S45 are to be constructed on the 7° slopes just beneath this mire complex, cutting though peat up to 4.5 m depth. Pink shading = ZoC. Road-line shown as transparent white. Width of road-line (5 m running width plus two 10 m batters) = 25 m.

It is additionally worth noting that at least some of the ZoCs correspond to areas identified by LWP as being:

> *"Areas with some evidence of **soft sub-peat strata** from CBR and hand auger data collected spring 2004."*
>
> *LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8*

Whether such soft sub-peat strata could render the overlying peatland even more prone to disturbance is not clear. The LWP EIS documents are not particularly illuminating about this dataset. The only feature of note that can be highlighted with any certainty from the LWP information regarding this dataset is that a surprising number of such localities are indicated in LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8 as lying in the north-western part of the development.

Such a distribution is interesting because this part of the LWP development area is generally dominated by thinner peat and tends to have relatively few areas identified as being of concern by the UEL assessment process (see, for example, Figure 94). If, instead, these areas of soft sub-peat strata do have significant implications for potential impacts, then even this north-western sector may be of concern. Unfortunately the LWP EIS documents do not appear to explore the possible implications of this dataset, so it is difficult to say more at this stage.

8.2.8 Impact zone and surface hydrology (vegetation and nanotopes)

The infrastructure set out in Sections 8.2.4 and 8.2.7 above represents the approximate area over which there will be direct construction impact, or for which there are clearly-identified areas of concern. However, added to these identified localities must be the impact associated more generally with *every* part of the windfarm infrastructure. This is actually what LWP's 2.5 m impact zone attempts to define – although not very convincingly.

8.2.8.1 Indirect impacts : LWP hydrology review

The conclusion drawn by LWP from the work undertaken at Farr Wind Farm (LWP 2006 EIS, Vol.5, Appendix 11E) is that there is likely to be an extremely narrow zone of general indirect impact associated with the proposed LWP development. However, there is ample evidence in LWP's own comments, and from published literature, that in general this zone of influence may be substantially wider than LWP's chosen width of somewhere between 2..5 m – 10 m.

Thus, for example:

> *"We **cannot underemphasize the importance of blanket bog surface** upon the likely extent of wind farm impacts, particularly from roads. In particular, **we make no claim that the above zones and distances also apply to very wet blanket mires,***

with a patterned surface of pools, low ridges, lawns and low hummocks. We suspect that the ***very gentle slopes, high water level and high hydraulic conductivity of the acrotelm in very wet peat vegetation*** *would enable deep excavation and road-induced* ***changes in surface and acrotelm flow to occur over much longer distances and for longer periods*** *than in microbroken or gullied ground."*

LWP 2006, Volume 5, Appendix 11e, para 37

Despite the remarkably confusing triple-negative involved in 'not under-emphasizing the fact that no claims are being made', it is clear that the figures of 2.5 m quoted confidently at the start of the present chapter relate only to those conditions where roads are constructed "on relatively dry peat surfaces which are microbroken and/or gullied". Where the ground is wetter, gently sloping, with a conductive surface layer (acrotelm), changes may well occur "over much longer distances and for longer periods." Such comments argue very clearly that for significant areas of the development, including all pool systems, ladder fens, percolation mires and re-vegetating gullies, the impact zone should be drawn more widely than is suggested by the LWP EIS documents.

Indeed Section 5.2.5.2 has earlier identified the fact that LWP's mapping of Erosion Classes does not give a true picture of either the state of re-vegetation in erosion gullies, nor of the total ground occupied by un-eroded blanket bog. Extensive areas of un-eroded bog are enclosed within the mapped boundaries of those Erosion Classes characterised by intense gullying. Significant areas of this smooth blanket bog have a relatively bryophyte-rich surface layer.

Consequently an examination of the development infrastructure using aerial photographs reveals that a surprising proportion of the development area could in fact consist of ground where LWP itself would acknowledge the likelihood that development impacts would be felt "over much longer distances and for longer periods."

One of the difficulties with the LWP EIS documents is that one section readily acknowledges significant uncertainties and that actual local variation may have a substantial effect on the size of any impact zone, but this degree of uncertainty is not then carried through in other critical sections. In particular, such uncertainty does not feature in the final calculations of predicted impact and loss. Acknowledgement of uncertainties, and associated caveats, may appear in the texts, but they then fail to play as prominent a role as they should in the final assessment of possible impact.

Thus we find early in the main LWP Habitats Chapter that there is recognition of possible impacts over distances of 50 m or more:

"There are other peatland studies, generally from fens and raised bog habitats e.g. work in southern Scotland at Blacklaw by Nicholson et al., (1989), which show ***measurable drawdown over longer distances****. Boelter (1964), working in the USA on fen and swamp habitats considered that a short-distance drawdown* ***(5 m) was the norm for peats with low hydraulic conductivity and a <u>watertable at depth</u>*** *within that type of peat. However, certain conditions (a deep (1.25 m), wide (2 m) and long (135 m) single ditch, a watertable at or close to the surface, high hydraulic conductivity in the upper peat layer) were shown to* ***increase a***

> ***measurable drawdown distance to the limit of measurement (50 m) and probably further*** *in the lake-filled bog used."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 39*

Later in the same section of the LWP EIS, this impact distance is reduced to 10 m:

> *"Lewis Peatland conditions, away from very wet areas (principally Erosion Class 1 ground),* ***probably fit the 10 m precautionary zone*** *above. There is therefore likely to be very limited drawdown around a ditch or other excavation if the peat has low hydraulic conductivity and a watertable at depth (10 cm or more below the surface) in the blanket peat."*
>
> *LWP2006 EIS, Vol.2, Sect.2, Chap.11, para 42*

It would thus be reasonable to question what possible *long-term* drawdown distances might be relevant to blanket mire with high- to moderately-high hydraulic conductivity and water tables that are not "at depth". In spite of the failure of this LWP comment to acknowledge, or make reference to, the likely longer-term effects of any draw-down (such as subsidence, slumping and oxidative wastage of the exposed peat over time), even this more expansive observation is then dismissed as less likely than the 2.5 m zone of impact cited at the start of the present chapter.

Yet there is explicit acknowledgement by LWP that the possibility exists for hydrological impacts to be felt over several hundred metres. Thus in describing the process of refining the layout of the LWP development proposal, the following explanation is provided:

> *"For the original proposal (LWP 2004) ... one wind turbine position was moved a short distance in the centre of the layout to place it on a slope draining away from the nearby SAC, to* ***avoid any risk of impact on SAC hydrology extending over a few hundred metres****. Two sections of road were* ***also moved*** *to take these on to slopes draining away from the SAC,* ***despite their original routes being more than 50 m from the SAC boundary****."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 50*

Such a comment looks very odd when put alongside LWP's prediction that:

> *"...****most impact will occur within 2 m*** *of the edge of disturbed ground. Allowing for a small amount of effect beyond this limit,* ***setting 2.5 m as the actual likely average distance of change*** *... [means that] ... permanent loss due to habitat change could therefore be considered to be <u>zero</u>."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chapter 11, para 80*

The LWP position seems to be predicated on the idea that virtually the whole of the development will be constructed on highly-dissected, deeply-oxidised (humified) peat with very low hydraulic conductivities. Chapter 5 of the present report has already discussed the reason for acknowledging that hydrological effects may be felt over considerable distances, particularly where at least parts of the ground support vigorously-growing bog vegetation.

As described at the start of this chapter, the proposed LWP development area is actually highly variable with much fresh peat forming in gullies to create an intimate mosaic with dry hagg tops and re-wetting hagg ridges. The question of how such a mosaic of conditions may behave in the face of development impact is thus clearly an important issue, and is explored in the next section.

8.2.8.2 Indirect impacts : hydraulic conductivity

Eggelsmann (1975) demonstrates the dramatic change in hydraulic conductivity of *Sphagnum* peat (see Figure 99) as the peat becomes less decomposed (expressed as moisture content). From this it is evident that acrotelm peat with a von Post value of just less than 2 (almost un-decomposed peat) has a hydraulic conductivity some 30x greater than peat with a von Post value of 5 (moderately decomposed).

This difference translates into flow rates of 2.5 m/day rather than 0.1 m/day Clearly it is of the utmost value that some clear picture be obtained concerning the relative extents of ground within the LWP development area that have a von Post value of around 2, and those areas with values closer to 5.

Unfortunately such information is not directly available from the data provided by LWP, but the UEL Peatland Research Unit field survey has established that such *Sphagnum*-rich conditions with low rates of decomposition are found at least in a high proportion of erosion gullies, and even on many low-lying erosion haggs. In addition, much smooth ground has also been found to support a significant proportion of such low-decomposition peat-forming vegetation. Both issues have already been explored in Chapter 5 of the present report.

The position would thus seem to be that a significant density of highly-conductive linear features (erosion gullies) will be disrupted by the development infrastructure, as will areas of erosion hagg that either continue to support active bog vegetation or on which active bog is now regenerating as the gullies re-vegetate. Many areas of un-gullied ground will also have highly-conductive vegetation, ranging from ladder fens, percolation mires and pool systems to areas of simple, smooth, *Sphagnum*-rich blanket mire.

In terms of the impact, and more specifically the distance and nature of this impact, resulting from construction of the proposed LWP infrastructure, Holden and Burt (2003) emphasise that one of the key differences between the surface hydrology of blanket bogs compared with raised bogs is that there is generally a relatively significant gradient associated with blanket mire systems. Consequently the pattern of surface hydrology may vary significantly with slope and with the presence of features giving rise to preferential water flows.

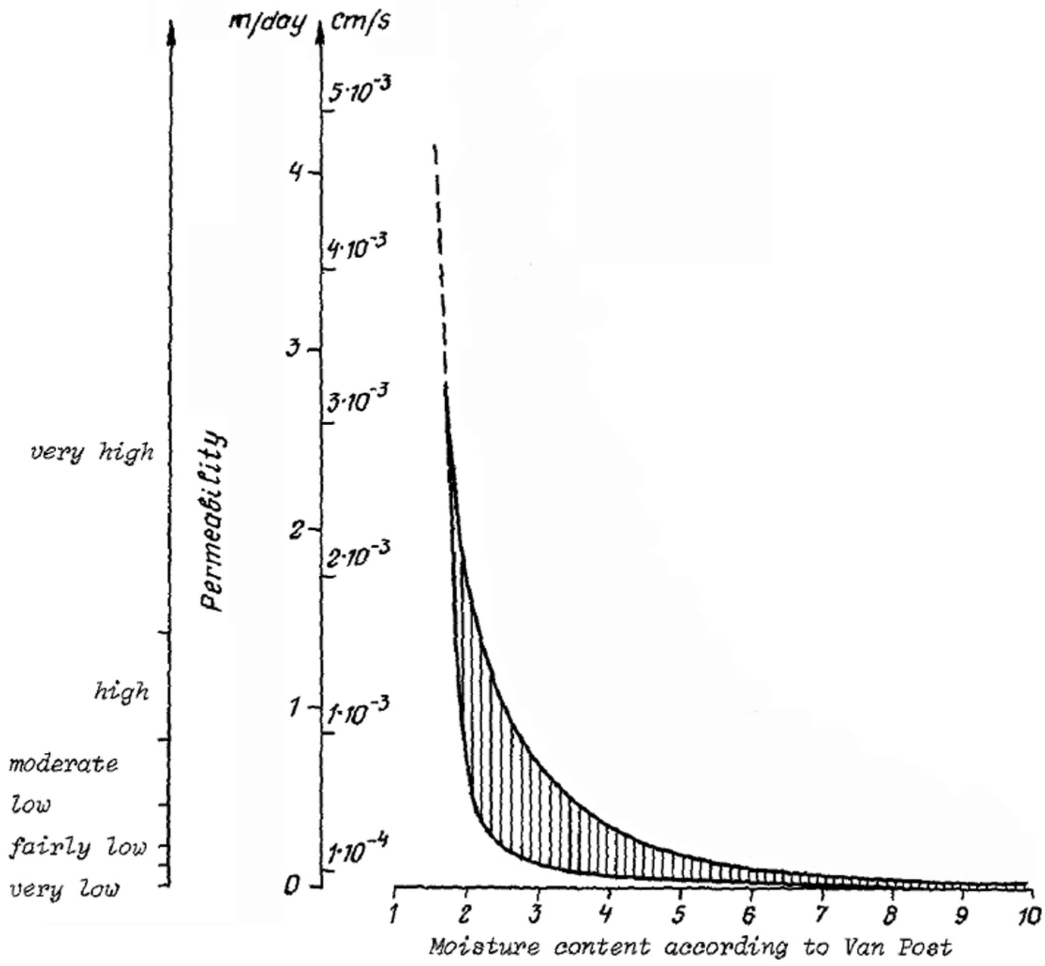


Figure 99. Relationship between humification and permeability in peat.
Diagram modified from Eggelsmann (1975) showing the relationship between Von Post moisture content (degree of decomposition or 'humification') of *Sphagnum* peat and the hydraulic conductivity of that peat. Clearly all highly-humified peats have fairly or very low hydraulic conductivities, but at around Von Post scale 3 this changes dramatically by more than an order of magnitude. Thus while peat of Von Post 5 may display a permeability of 0.1 m per day, peat of Von Post 2 may show permeability rates of 2 m per day.

8.2.8.3 Indirect impacts : topography, slope and 'flow lines'

As Holden, Evans, Burt and Horton (2006) observe, in blanket mires the usually-cited model of symmetrical water-table drawdown associated with a drain is inappropriate. For most moorland drains there is a highly asymmetrical pattern of impact, with the downslope regions experiencing the major part of the impact. This pattern is very clearly seen in the drawdown maps shown by Holden *et al*. (2006), where the most marked changes in water-table behaviour are obviously on the downslope side of each drain. Furthermore, Holden *et al*. (2006) illustrate the changes in water-table behaviour (drawdown, water-table range, occurrence of overland flow) between un-drained and drained plots. From these maps it is strikingly apparent that the behaviour of the drained slopes is entirely different from that of the un-drained slopes, and that these effects extend for 20 m at least. The change in overland-flow patterns in particular suggest that the effects would be felt over a considerable distance – many tens of metres, certainly.

Obviously this effect depends in part on the orientation of the drains in relation to the slope. A drain that runs directly down a slope will have less effect on surface and sub-surface flow than a drain that cuts almost at right-angles across the slope, thus also cutting across the direction of water seepage. One of the indirect but extremely practical benefits of drawing up 'flow lines' during the process of mesotope identification is that these flow lines can then be used to make assessments about the likely effects of, in particular, linear structures and the way in which they may cut across natural drainage lines. Thus the flow-line mapping, if undertaken for the whole of the LWP development area, would give some extremely valuable insights in relation to the question of 'downslope' impacts resulting from, for example, road positioning.

A refinement of this approach is set out in detail in Holden (2005) and Holden *et al*. (2005) from something of a reverse perspective – the method has been devised to identify the best erosion gully systems to *block* in order to gain maximum restoration benefit in terms of a stabilised hydrology. The approach is based on the calculation of a 'topographic index' map for the area, and as Holden (2005) and Holden *et al*. (2006) observe, the topography plays a major part in controlling hydrological behaviour in blanket mires. Thus the topographic index can be used in the same way as flow lines to determine areas likely to be affected by the hydrological disjunctions caused by drain or road lines, but Holden's (2005) and Holden *et al*'s (2005) approach has the advantage of being a quantitative method that can give some indication of impact distances. Indeed Holden (2005) demonstrates that calculations of estimated impact-distance can result in hydrological disruption over very considerable distances depending on the topographic index values involved.

It is beyond the scope of the present report to undertake such an analysis for the whole of the LWP development area. Indeed the complete mapping of flow lines and mesotopes for the whole of the LWP development area is also a task beyond the remit of the UEL Peatland Research Unit project. Both tasks could have been undertaken as part of the process in gathering together the major datasets necessary to inform production of the LWP 2006 EIA.

It is to be regretted that so much energy appears to have been diverted to the work at Farr Wind Farm when it could, with much less effort, have been devoted to the production of information such as flow lines, topographic indices, microtopes, mesotopes and macrotopes which, by their very nature, would generate an integrated hydrological picture of the proposed development. The Farr Wind Farm data, in contrast, sit in isolation and contribute remarkably little to the understanding of likely possible effects on Lewis (see Appendix 1).

In the absence of such flow-line mapping or topographic index analysis from LWP, it has been necessary to treat all infrastructure as though it will to some extent cut across slopes rather than run perpendicularly downslope. In general, this is probably a fair assumption in any case, as most linear elements of the infrastructure appear to cut across slopes rather than run straight down them. It is just worth bearing in mind that further refinement of the impact assessment described below would be possible using the various methods described above.

8.2.8.4 General zone of indirect hydrological impact (GPZI)

Site-specific determination of potential impact distances depends upon having site-specific information. For much of the proposed LWP development there is sufficient information to make at least informed judgements about possible impacts, but for some sections of the development the absence of key datasets means that such judgements cannot easily be made.

For example, long sections of the overhead power-lines have no peat-depth data. Neither are there any field data from the UEL Peatland Research Unit survey, because the power-line corridors were not examined in detail during that survey. This is unfortunate because significant sections of the power-lines cross Erosion Classes 5,7 or 8.

Such classes are defined as moribund by the LWP EIS documents but appear from UEL field data and remote-sensing survey to show significant signs of regeneration. However, without further detailed field survey it is not possible to be sure of the extent to which these particular polygons may be showing recovery along the full length of the poweline route.

For those parts of the proposed LWP development that lack such key data, it is necessary to apply a generalised zone of potential disturbance. It is an unsatisfactory measure. The reasons have been discussed in previous sections. Nonetheless it is better to establish a justifiable, generalised zone of potential impact than to have no zone at all.

Given the review of potential hydrological impacts presented above, it seems reasonable to adopt a semi-precautionary approach – indeed the same approach recommended by SNH – to define a generalised zone of indirect impact around the LWP development infrastructure. Thus this generalised zone of potential impact would consist of a 50 m band surrounding all parts of the proposed LWP infrastructure.

Such a zone is in fact similar to LWP's most precautionary boundary, although it is not identical. In the case of LWP's boundary for the site roads, the 50 m PZI is measured from the road centre-line. For present purposes, this generalised zone is instead measured from the outer edge of the 10 m batters proposed by LWP for either side of the road. This is because almost certainly drains will need to be installed alongside floating roads, despite LWP's claim that this will not be the case (the arguments concerning the eventual need for drains have been stated in Section 4.1.5.1 and will not be repeated here).

Such drains will probably be installed towards the outer edge of the batters, and so for present purposes the 50 m impact zone begins at the outer margin of this drainage structure.

At the scale of the whole development proposal, the map of infrastructure plus the 50 m zone of generalised potential zone of impact (GPZI) looks little different from the map shown in Figure 91 (at the scale displayed), and thus little would be gained by showing a second map. The area-totals obtained from the two maps do, however, differ significantly as can be seen in Table 15 below. It is also worth pointing out that some of this GPZI ground overlaps with ground already identified in Section 8.2.7 as lying within a ZoC. The relevant resulting totals can be seen in Table 15.

Table 15: Area totals for infrastructure, GPZI and ZoCs
Area of ground occupied by LWP infrastructure and by overlapping potential impact zones.

Total area of infrastructure, including 10 m batter either side of road, and a 5 m-width semi-excavated road along the pylon routes	555 ha
Infrastructure area as above, but with UEL's 50 m zone of general potential impact (GPZI) applied uniformly around this	2,265 ha
UEL GPZI, combined with the area of ZoCs identified above in Section 8.2.7	3,154 ha

So far, discussion has either focused on specific localities with evident issues of impact, or on the general pattern of water-table behaviour and vegetation response in relation to disturbance. In effect, this latter process hinges on the response of the bog system at the vegetation and nanotope level of descriptive hierarchy. Impacts can also occur at the level of overall surface pattern, or microtope. It is the potential response at this higher level of ecosystem functioning that will be explored next.

8.2.9 Impact zone and microtope changes : microtope-mesotope zone of concern (MZoC)

In the natural, undisturbed state, a microtope pattern across a small ladder fen may consist of a repeated series of T2 high ridge, T1 low ridge, A1 *Sphagnum* hollows and A2 mud-bottom hollows. Equally, an area of 'smooth' blanket mire may typically consist of a slightly undulating surface of T2 high ridge, T3 hummocks and T1 low ridge (*sensu* NCC 1989). Under the influence of drainage effects, such microtope patterns can, and have, broken down to form erosion complexes consisting of haggs and gullies.

That such erosion complexes can then 'eat back' into one or more microtope pattern within the body of the mesotope has been recognised since at least the time of Osvald (1949), and was illustrated by Lindsay (2005) with reference to the LWP 2004 EIS development proposals. The example from Butterburn Flow, Cumbria, given in Lindsay (2005), can be seen in Figure 100, which shows how substantial erosion complexes ranging from at least 150 m to almost 1 km in extent have been caused at Butterburn Flow by single drain systems. The extent of changes to the vegetation canot be determined from these images, nor can the extent of micro-erosion. Consequently these images, and associated distances, represent the minimum extent of impact.

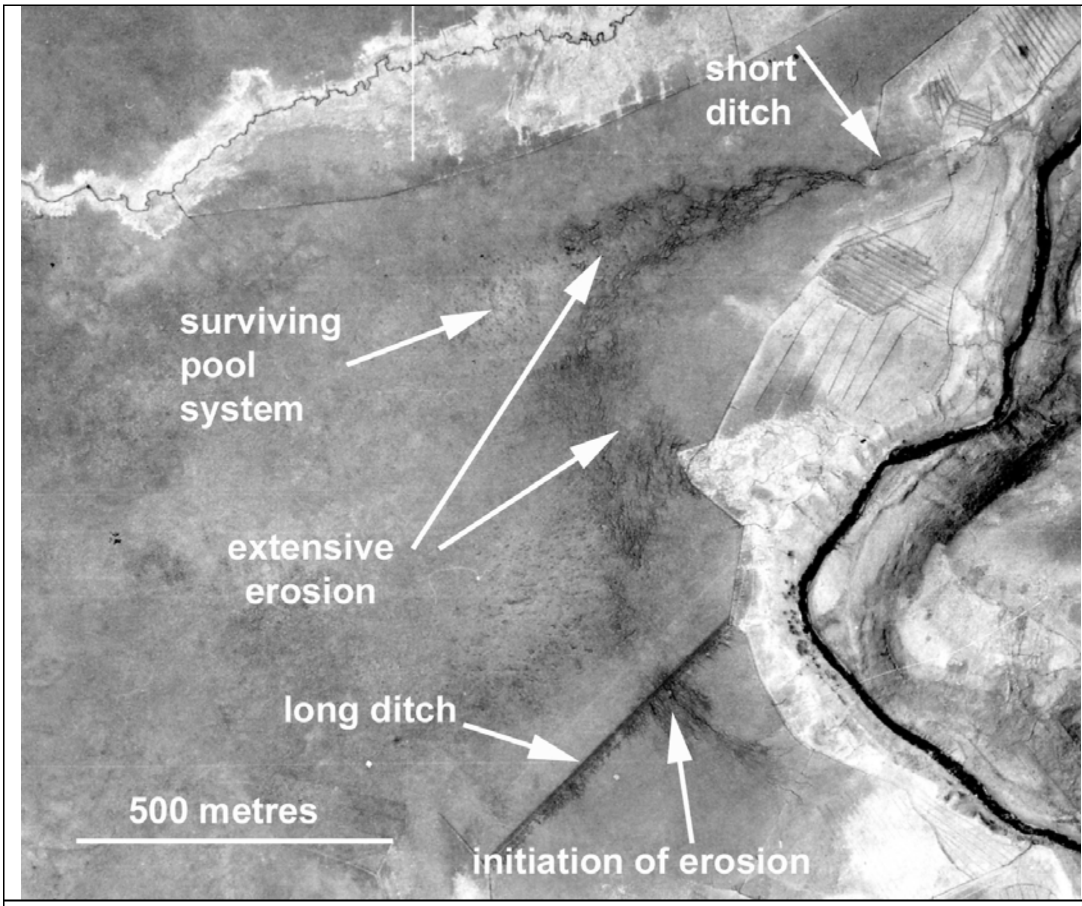


Figure 100. Erosion at Butterburn Flow, Cumbria, northern England.
Vertical aerial photograph of Butterburn Flow, Cumbria, NW England. Two clear ditches are indicated by arrows – one a short ditch, the other much longer. Both are associated with a dark network of erosion channels, although the shorter ditch at the north-eastern corner of the site (top right) is associated with the more extensive pattern of erosion. This larger area of erosion extends into a microtope pattern of A1 *Sphagnum* hollows (*sensu* Lindsay *et al*., 1985)

In general, in blanket mires it is the deepest areas of bog that have the highest water tables. Furthermore the most intensely patterned areas on a bog also tend to be the areas of deepest peat. These regions thus tend to be most at risk from impacts that can lead to breakdown of the microtope surface pattern. In the case of fens, particularly areas of seepage and percolation within the blanket mire complex, these may have shallower peat but nevertheless still have high water tables and also display marked surface patterning. This patterning too is sensitive to disruption.

Highly patterned areas, though representing mechanisms for providing stability under natural conditions, are also somewhat pre-disposed to erosional collapse if artificially disrupted. This is because the closely-spaced series of hollows or pools can quickly become an interconnected network of water channels – as described by Osvald (1949) and stressed repeatedly by the LWP EIS documents.

This extensive breakdown of surface features by drainage is clearly illustrated in Figure 100 above, and emphasises the scale of the distances that can be involved in such events. The markedly patterned bog areas being eaten into by erosion are also the deepest parts of the site. However, it must be emphasised that *all* parts of a blanket mire system display some form of microtope pattern, even if this pattern consists of just a single extensive nanotope of T2 high ridge with a few scattered T3 hummocks. Furthermore, as long as there is a peat deposit, there is the potential for any microtope system to break down into an erosion complex. The deeper the peat, the more likely it is that there will be a microtope pattern of some complexity. This, in turn, makes it more likely that the erosion pattern will become both deep and extensive.

The critical factor for microtope sensitivity in bog peat is thus the depth of the peat. Fortunately information about peat depth is available for rather more than 90% of the proposed LWP permanent road-line and turbine locations at least. It is thus possible to use this dataset to provide a more location-specific, and to some extent microtope-sensitive, zone of potential impact around the the majority of the proposed LWP development.

The stability of the microtope is also closely linked to broader stability issues within the mesotope. Breakdown, drying and cracking of the microtope can lead to conditions that pre-dispose parts of the mesotope to failure. The breakdown of surface cohesion by erosion, the channelling of water deep into the peat body via drying and tension cracks, the possible ponding of water along the road-line, the disturbance of deep peat on sloping ground by construction, all combine to highlight the relationship that exists between peat depth, ground conditions, construction, and ecosystem stability at the microtope/mesotope scale.

A tailored zone of potential impact can thus be derived from the peat-depth data, attuned appropriately to the scale of microtope and mesotope units. In creating this potential microtope-mesotope impact zone, it has therefore been assumed that:

- if erosion is stimulated, it has the potential to extend throughout the whole of one or more microtope patterns within a mesotope;
- disruption of microtope flow patterns by construction can lead to onset of erosion, or rejuvenation of erosion in recovering erosion microtopes;
- deep, un-decomposed (un-humified) peat will undergo more rapid shrinkage and cracking as a result of drainage or reduced water inputs than would be the case with shallower more humified peats, and thus provide more routes for excess water to enter the peat and exploit weak layers;
- onset, or rejuvenation, of erosion can also lead to slumping and cracking of wet, deep peat, which provides routes for surface water to enter weak zones within the peat body, thereby rendering the microtope, or even the mesotope, less stable;
- although basic slope-stability calculations suggest that deeper peat is more stable than shallow peat because of its greater ‘dead’ weight (see Section 7.1.3.2), deep peat may in fact be more at risk of sub-surface slope failure than shallower peats because:
- deep peat has a greater thickness within which layers of weakness can develop;
- LWP itself acknowledges that the deep peat of Hydrological Zones 3 and 4 have a significant risk of failure under certain circumstances (LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 73);
- if deep peat does suffer slope failure, the area of failure is likely to be greater than if a section of shallow peat should fail;

- if deep peat does suffer slope failure, the area impacted by the failure is likely to be more extensive than would be the case if shallow peat were to fail.

On the basis of the above assumptions, the series of peat depths gathered by LWP along the development road-line has been used to form a template for a tailored zone of potential microtope-mesotope impact centred on the line of available peat depths. It must be recognised that this line is not entirely the same as the line of the current development proposal; there are sections of the 2006 proposal for which no peat – depth data exist. The microtope-mesotope zone of concern (MZoC) thus provides a tailored solution for around 90% of the development proposal based on peat depth.

The MZoC has been calculated such that:

- it provides an exponential increase in possible impact-area as the depth of peat increases (to reflect the fact that construction/stability issues in peat of 5 m depth are very much greater than those in peat depths of 1 m or 2 m);
- the impact area is scaled to that of microtope patterns, or whole mesotope units in the case of relatively small mire mesotopes.

The formula used is:

$$\text{MZoC} = (\text{peat depth})^2 \times 20$$

These parameters have been used not only because they generate values that are appropriate to the mesotope scale, but also because they result in zone sizes that appear to reflect the scales of impact seen on other sites. Thus on Butterburn Flow, the extent of evident erosion across the deeper peat dominated by A1 hollows seen in Figure 100 extends for at at least 500 m, while the area of erosion associated with the longer drain to the south is on shallower peat and displays erosion extending for some 150 m or so. LWP itself has been quoted above as tacitly recognising the possibility of impacts being felt across “several hundred metres”. At Derrybrien, Co. Galway, the demonstrable impact of the peatslide on the blanket peat habitat (rather than on the freshwater system) extended for some 2.5 km before moving onto more mineral ground and entering the local river system.

A maximum width of 500 m from the roadline, associated with a maximum peat depth of 5 m, could be considered conservative, given that a 2 km block of peat slid from the hillside at Derrybrien. Equally, many microtope patterns extend for 500 m, and some for as much as a kilometre. Meanwhile mesotopes are often a kilometre or more in extent. These are the typical scales of such features – and thus the scales of potential impact – that are being addressed by the MZoC system.

The map of these MZoCs can be seen in Figure 101, and an example of the way in which these MZoCs sit within the overall microtope and mesotope pattern can be seen in detail in Figure 102 (the location of this is arrowed in Figure 101).

Clearly it is not possible to see from Figure 101 precisely where each MZoC circle sits on the development site, nor is it feasible to provide detailed images as shown in Figure 102 for every part of the development. There is thus a danger that the present report might be accused, with some justification, of also producing a peat-based map that is as difficult to interpret as the peat depth map provided by LWP 2004 EIS, Vol.4, Chap.10, Fig.10.3. The difference in this case, however, is that Appendix 5 of the present report lists the centroid of each peat-depth line length, the length of that line, and the peat depth and MZoC value for the line.

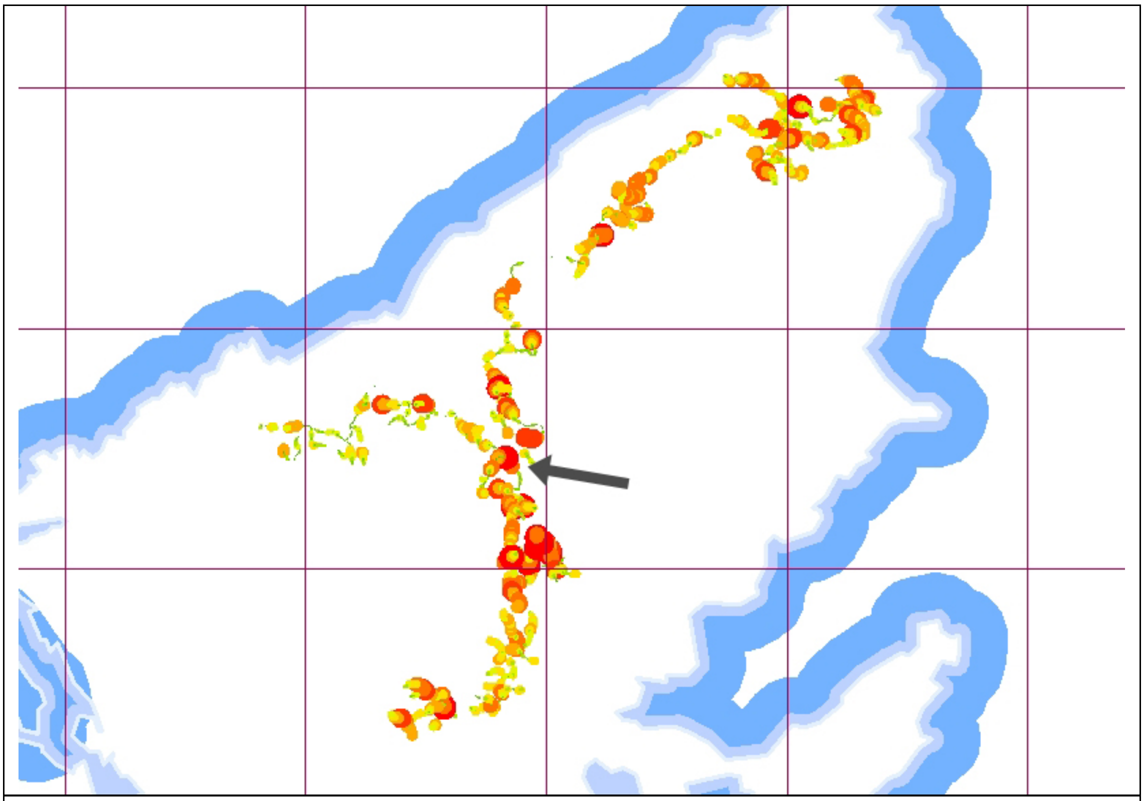


Figure 101. Distribution of UEL Mesotope-microtope Zones of Concern.
Map displaying the distribution and extent of mesotope-microtope zones of concern (MZoCs). These are derived from the LWP peat-depth data, as described in Section 8.2.9. Shallow peat is given a relatively narrow MZoC (green), while the deep 5 m peats have the largest MZoC (red). Other depths between these are shaded yellow through to orange with increasing peat depth. The grey arrow shows the location of a more detailed view given in Figure 102. The coastline is displayed as concentric blue shading. The OS National Grid is shown in grey as 10 km squares.

In fact the dataset in Appendix 5 will not, of itself, enable the reader to construct an exact version of the MZoC dataset shown in Figure 101 because often the centroid is not for a circle but instead for a circle elongated along the roadline (thus strictly a 'stadium', or 2-dimensional capsule-shape). This is because of the way the data were assembled while creating the derived version of the LWP peat-depth dataset.

However, should LWP ever decide to release the original peat-depth data, it would then be an easy task for anyone with GIS to create the complete map of MZoCs – more complete than even the map shown in Figure 101 - by creating a buffer (calculated using the formula given above) around each 50 m section of road.

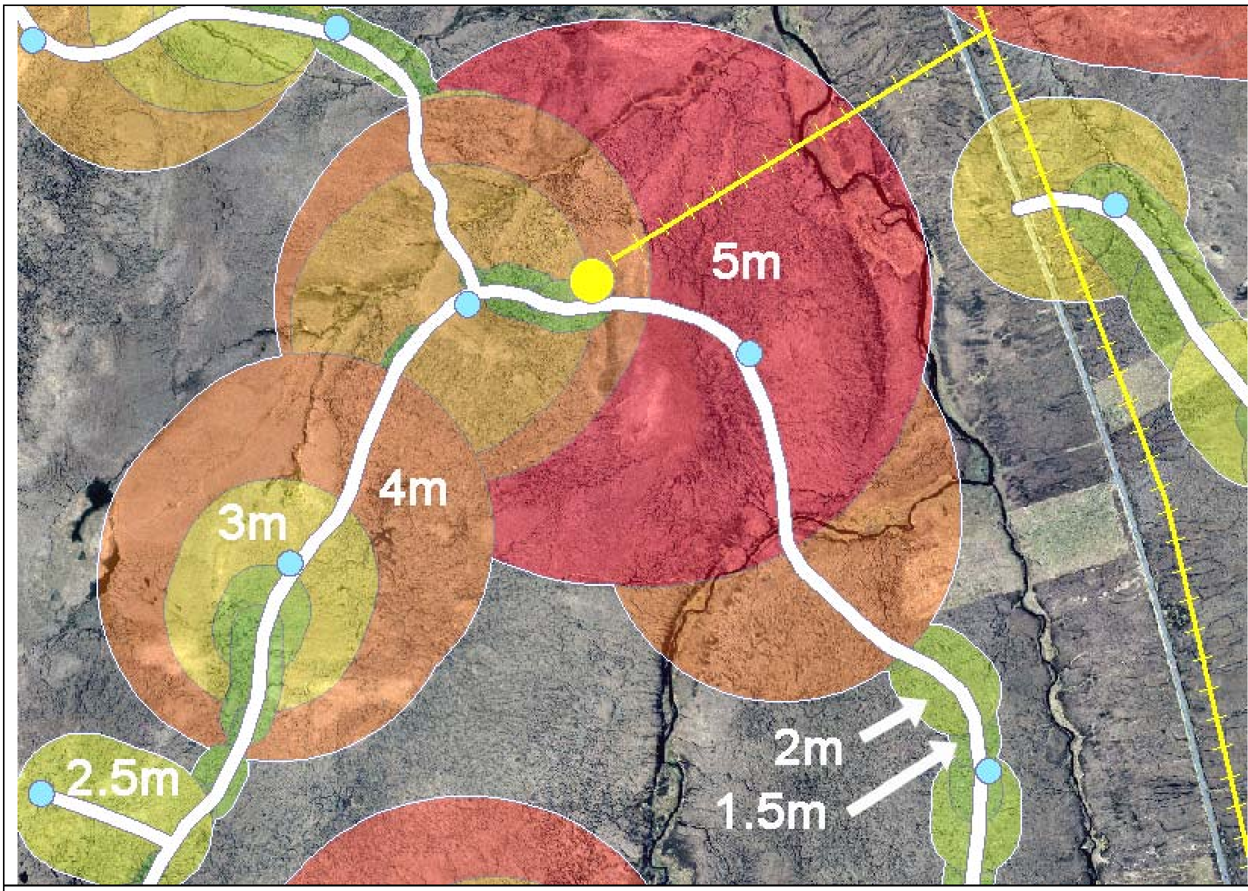


Figure 102. Detailed view of an example Mesotpe-microtope Zone of Concern.
Detailed example of the mesotope-microtope zone of concern (MZoC) at NB 383445, displayed over a vertical aerial photograph. The MZoC is derived from the LWP peat-depth data, as described in Section 8.2.9 of the present report. Shallow peat tends to have a relatively narrow MZoC (green), while the deep 5 m peats generally have the largest MZoC (red). Other depths between these are shaded yellow through to orange with increasing peat depth. The proposed LWP road-line is shown as a cream line, while turbines are shown as turquoise circles. The yellow barred line represents a section of proposed overhead pylon line.

8.2.10 UEL (constrained) Potential Zone of Impact (UEL PZI) : direct and indirect effects

Assembling together the range of information discussed above about possible impact distances, it is possible then to assemble a map that embraces all these issues into a composite zone of potential direct and indirect effects.

Thus Figure 103 represents the composite area of potential direct and indirect impact. It consists of:

- all infrastructure;

- a 50 m zone of potential indirect effects, starting at the outer edge of all infrastructure;
- all identified ZoCs (including the 97 areas considered to be potentially at-risk of slope failure), together with their 50 m boundary;
- variable zones of microtope-mesotope sensitivity (MZoCs), based on peat depth and measured from the road centre-line.

The shading in Figure 103 has been used to distinguish the extent to which the MZoC factor dominates in a number of key areas, while in others the MZoCs contribute little to the zone of impact. This does not necessarily mean that peat depth is unimportant here. It may simply represent areas where depth data have not yet been collected. This is particularly the case in the north and east of the development. To the west, peat depth genuinely plays a much smaller role in determining possible impacts.

The same information but shaded uniformly so as not to distinguish between areas derived from one criterion or another, is shown in Figure 104. Table 16 provides a summary of:

- areas derived solely by site-specific factors (ZoCs);
- areas derived solely by locally-tailored, though generalised, factors (MZoCs);
- areas derived solely by universally-applied criteria (LWP's 50 m PZI);
- the total area within which impact may occur during construction, during the life of the windfarm, or after decommissioning, based on the criteria described above.

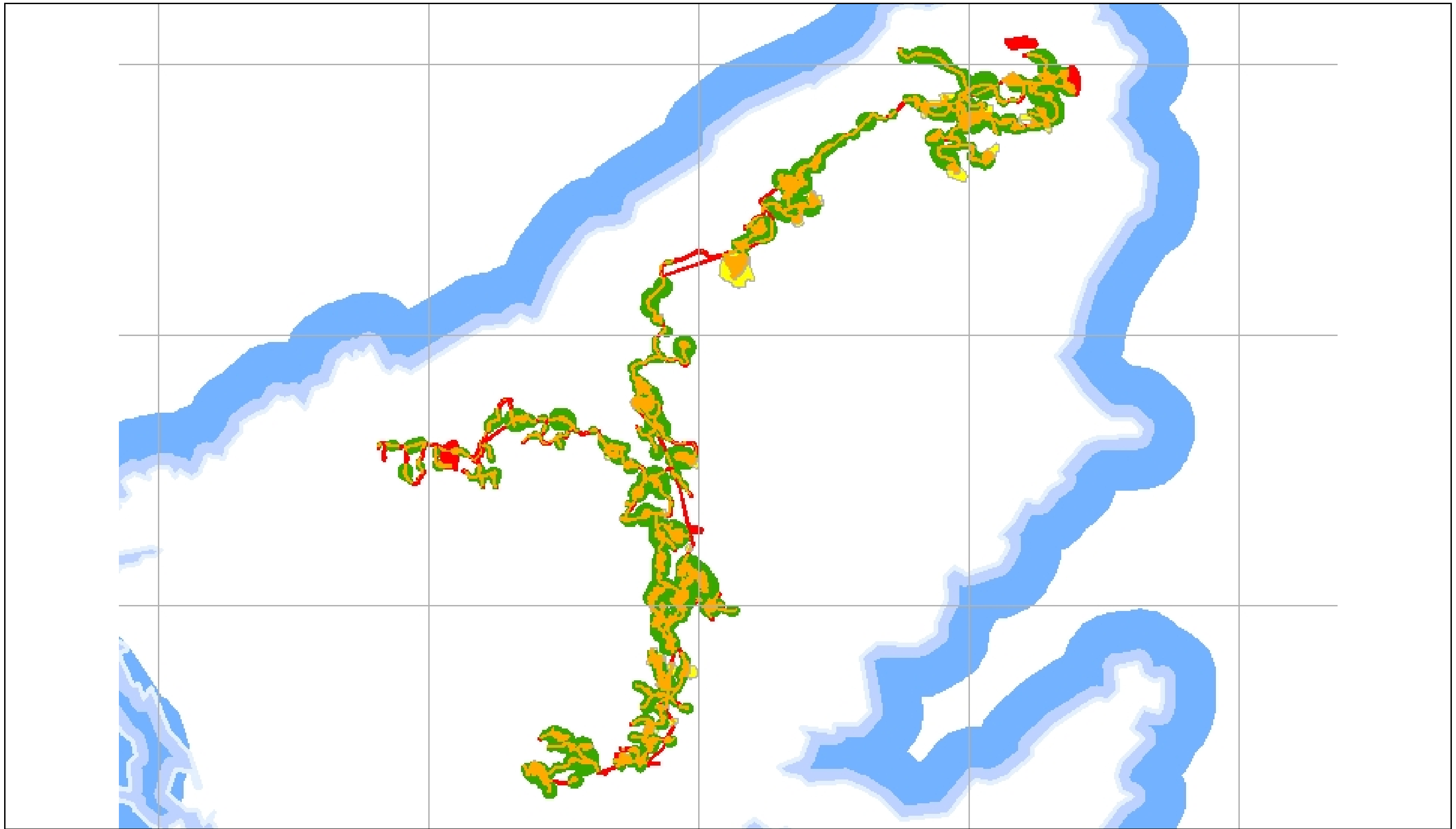


Figure 103. Distribution of factors contributing uniquely to sections of the UEL 'Potential Zone of Impact' (PZI).
A map of combined potential direct and indirect impacts for the LWP development proposal. Yellow shading = ground identified solely as a general PZI; Red shading = ground identified solely as a ZoC; Green shading = ground identified solely as an MZoC; Orange shading = ground identified by two or more of these categories. The coastline is displayed as concentric blue shading. The OS National Grid is shown in grey as 10 km squares.

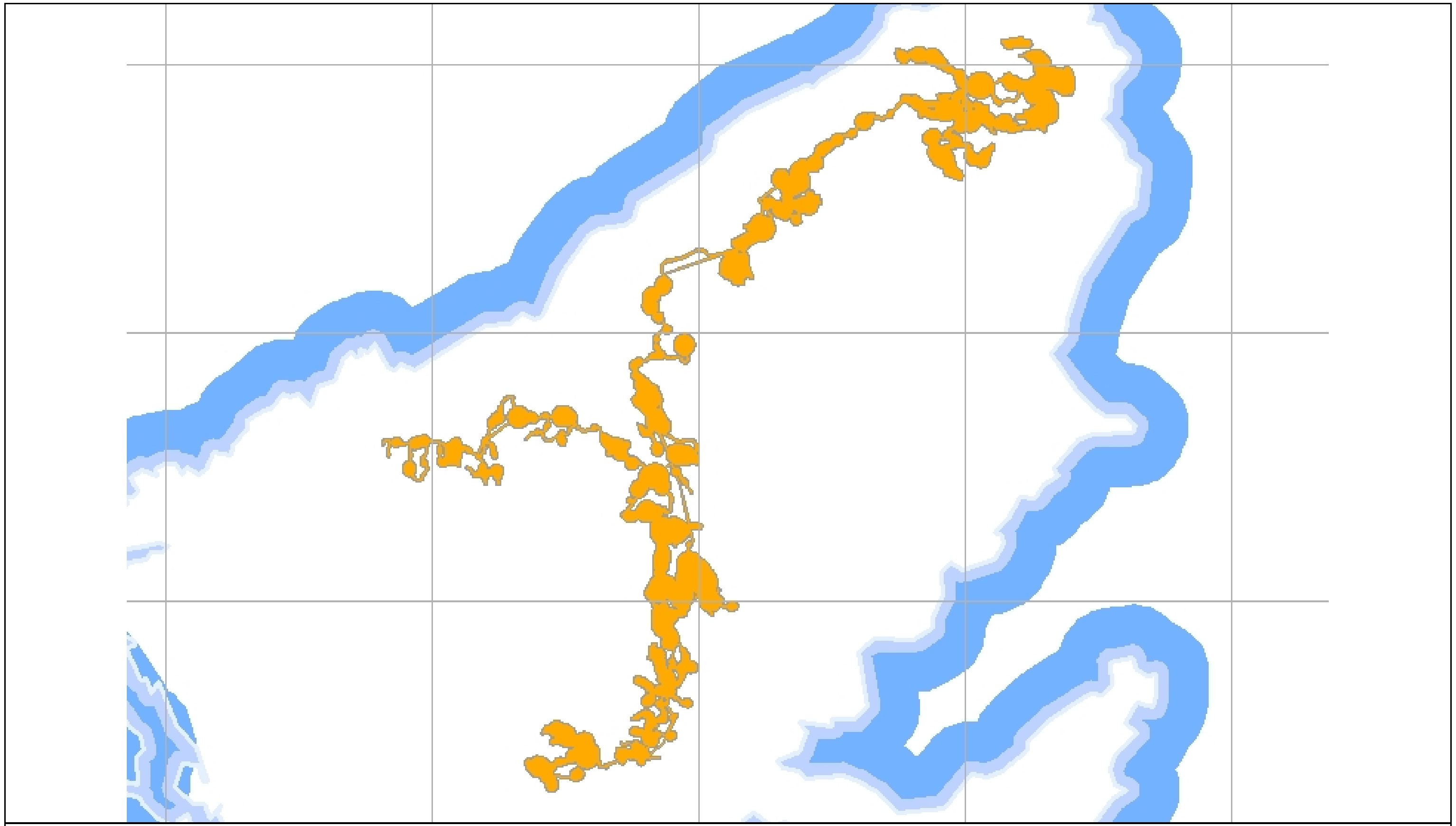


Figure 104. Extent of UEL Potential Zone of Imact (UEL PZI).
A map of combined potential direct and indirect impacts for the LWP development proposal. Orange shading represents ground identified as general PZI, or as a ZoC, or as an MZoC, or any combination of these. The coastline is displayed as concentric blue shading. The OS National Grid is shown in gray as 10 km squares

Table 16: Area totals for UEL Potential Zone of Impact (UEL PZI)
Areas of ground covered by the various types of UEL potential zone of impact. Area values are given for ground unique to each impact-zone type (*i.e.* locations where only one criterion applies), then combined figures embracing all criteria are presented .

Area unique to LWP's PZI (50 m from infrastructure)	450 ha
Area unique to Zones of Concern (ZoCs) plus 50 m buffer	227 ha
Area unique to microtope-mesotope zone of concern (MZoCs)	2,416 ha
Area where two or more of the above are combined	2,477 ha
Total UEL Potential Zone of Impact	5,569 ha

This gives a total area of 5,569 ha for potential loss or disturbance. At six times the scale of what LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 79 describes as a 'realistic scenario' (901 ha), and nearly 3½ times larger than LWP's 'worst-case' Potential Zone of Impact (LWP 2006 EIS, Vol.2, Sect.2, Chap.11, para 76), this UEL PZI clearly embraces a considerably larger amount of ground than is indicated in any of the LWP EIS documents.

Once again, it is worth emphasising that not every part of Figure 104 is predicted to show some form of impact, direct or indirect. Rather, it is a map of the ground within which it is possible that impacts may be felt, given what is known about the likely construction and maintenance of the infrastructure, the nature of the ground, and our current understanding of peatland ecology, hydrology and slope-stability.

Thus, for any given section of roadline, or other part of the proposed development, it is possible to identify the various factors that conspire together at this particular locality. From this, it is possible to judge the potential extent of likely possible impact, as indicated by the boundary given for that location in Figure 104.

To take a specific example, Figure 105 provides a detailed look at the area of the ladder fen/valleyside flow already shown in Figure 96 above. It distinguishes areas identified as PZI, ZoC, MZoC, or a combination of these. In addition, the infrastructure proposed for the area is displayed to make clear the type of disturbance giving rise to these zones. Figure 105 is also helpful in demonstrating why it is not meaningful to give a listing of the various components of the UEL PZI, as has been done for the 199 sites of hydrological concern, the ZoCs and the MZoCs. There is so much overlap that everything merges together, and in fact the UEL PZI actually forms one single large polygon. Consequently it is only meaningful to talk of a total area for this final dataset.

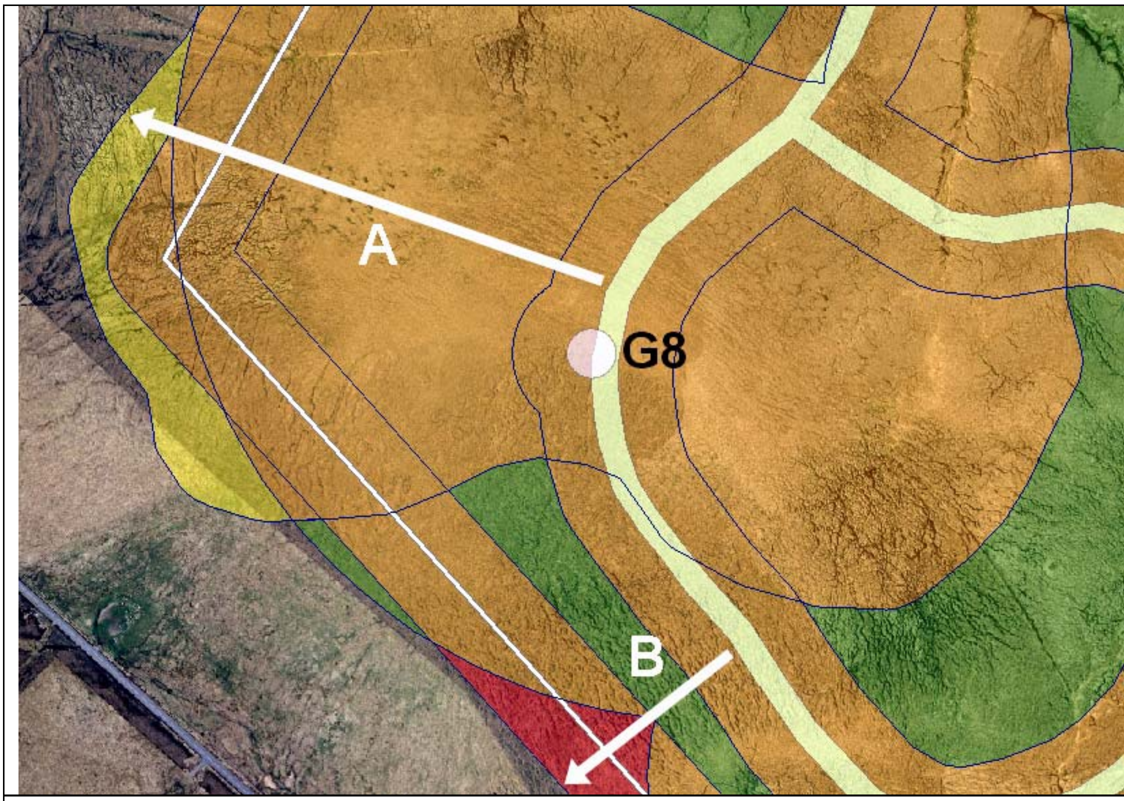


Figure 105. Example of contribution made by differing factors to the UEL PZI.
The LWP development proposal at Turbine G8. The road-line plus its 10 m batters is shown as a pale green corridor. Turbine G8 itself is shown as a mauve circle. An overhead powerline is shown as a narrow pale-blue line that changes direction abruptly. Beneath this infrastructure there is an aerial photograph showing a large ladder fen. There is also coloured shading reflecting the various types of impact zone. Red = ground unique to the powerline PZI; Green = ground unique to an MZoC; Yellow = ground unique to a ZoC; Orange-brown = ground which is embraced by two or more of these impact-zone types. The white arrows, A and B, are discussed in the text. Line A = 450 m; Line B = 200 m.

Close examination of Figure 105 at any given location reveals the various factors that influence the possible scale of impact. Thus along Line A, the factors consist of a 50 m PZI, together with a ZoC represented by the ladder fen/valleyside mire, and a zone of deep peat MZoC. For the middle section of Line A, the factors consist of the main body of the ladder fen/valleyside mire ZoC and an MZoC, then there is yet another PZI around the road-line, before Line A (and the total zone) ends with a small zone devoted purely to the ladder fen/valleyside mire ZoC. For the much shorter Line B, there is the general 50 m zone of a PZI, then a narrow green zone of an MZoC, ending finally in a region where the sole factor is a PZI associated with the power-lines. It is worth just mentioning that none of the potential zones of impact displayed here is as large as some of the actual impacts shown in Figure 100 earlier in the present chapter for Butterburn Flow (Line A is 450 m long, and Line B is 200 m).

In this way, each individual section of infrastructure has a composite zone of potential impact, and while it is not suggested that every part of this will undergo change, it is perfectly reasonable to say that, “If this particular locality experiences an impact, it is quite possible that the impact would be felt over this defined distance, given the prevailing ground conditions and our current understanding of peatland processes." Equally, it is also reasonable to observe that it is currently impossible to predict which locality may *actually* suffer such impacts and which will not. Consequently all that can reasonably be done at this time is to identify a zone of potential impact for the development site as a whole. However, at least this zone has been constructed on the basis of as much available site-specific information as possible – unlike the 2.5 m or 10 m 'realistic' zone of potential impact proposed by the LWP EIS documents.

8.3 Impact on 'active' blanket bog

The question of what information to use for the identification of 'active' blanket mire, and the resulting distribution of this habitat type, has already been discussed at length in Section 6.5. What remains to be determined is the extent of active blanket mire that might be affected by the LWP development proposal.

Taking the map of active blanket mire shown in Figure 75, Section 6.5.2.4, and clipping from that only the area of potential impact shown in Figure 104 above, produces the map shown in Figure 106, while the north-easternmost part of the development is shown in detail in Figure 107.

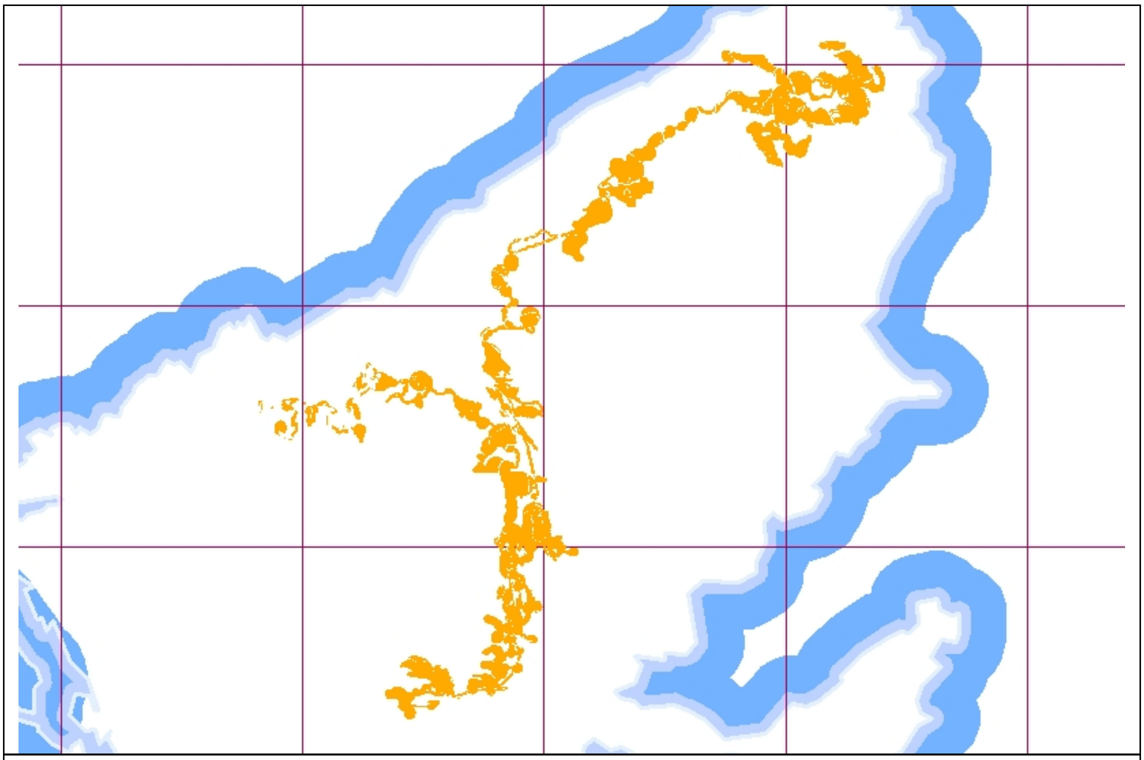


Figure 106. 'Active blanket bog' within the UEL PZI.
Map of 'active blanket bog' potentially affected by the combined effects of direct and indirect impacts arising from the LWP development proposal. Orange shading represents ground identified as areas of the UEL PZI containing vegetation that can be classified as 'active blanket bog' according to the criteria set out in Section 6.5.2.4 of the present report. The coastline is displayed as concentric blue shading. The OS National Grid is shown in grey as 10 km squares.

The total area of active blanket bog within the potential impact zone, as shown in Figure 106, amounts to 4,808 ha. This is in stark contrast to LWP's estimate of 201 ha, based on their highly restrictive interpretation of 'active' blanket bog and their extremely limited assessment of impact distance.

The detailed view of potential impacts shown in Figure 107, as well as showing the areas of active blanket mire that lie within the potential impact zone, also reveals in mid-blue shading the scatter of areas and features that are not classed as active blanket mire. Most of these represent stream-courses or small areas of thin organic or even mineral soil. However, the large blank (mid-blue) area to the south-west of the image represents the SAC, which was of course not surveyed by the LWP survey team. It will be noted that the suggested zone of potential impact extends into the SAC at this point (represented by the mid-blue shading that intrudes into the otherwise-blank SAC dominating the bottom-left of the diagram).

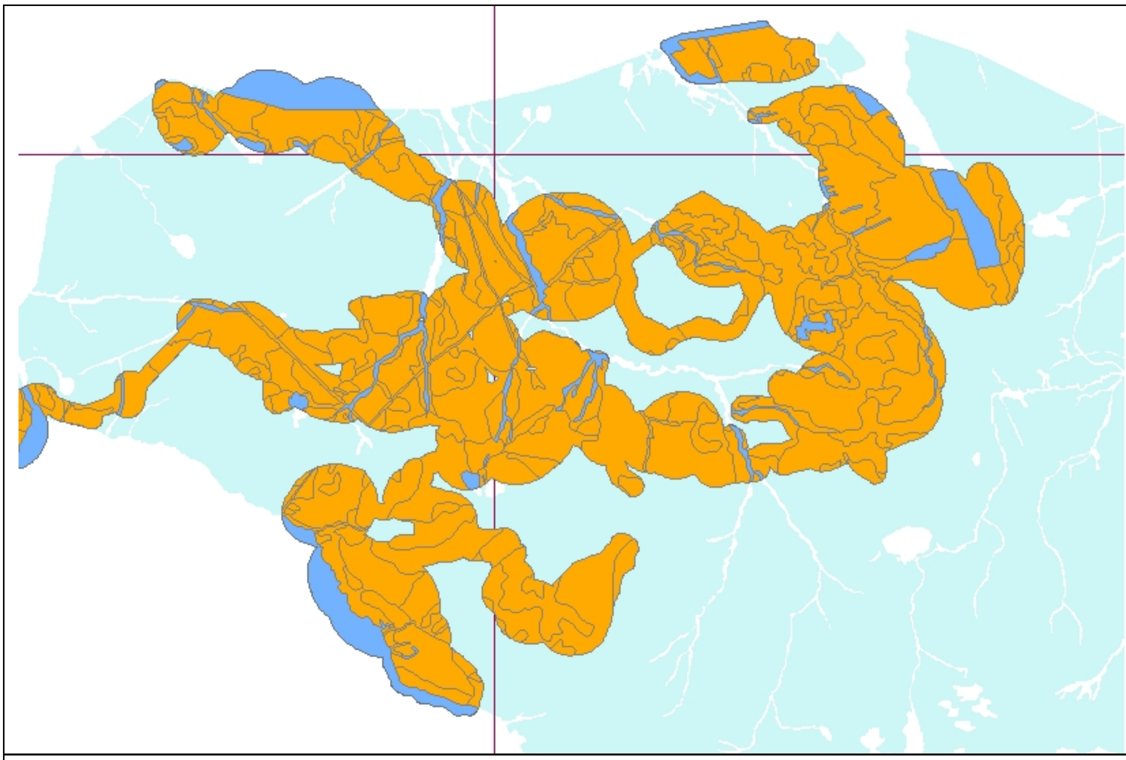


Figure 107. Map of UEL PZI on 'active blanket bog' in the northern part of the proposed LWP development.
Detail based on the map of 'active blanket bog' potentially affected by the combined effects of direct and indirect impacts arising from the LWP development proposal (Figure 106). Orange shading represents parts of the UEL PZI that can be classified as 'active blanket bog' according to the criteria set out in Section 6.5.2.4 of the present report. Mid-blue shading represents ground that falls within the UEL PZI, but which does not support 'active blanket bog', or ground that lies outside the LWP HSA boundary. 'Active blanket bog' within the LWP HSA boundary but lying outside the identified potential impact zone is shaded pale blue. The OS National Grid is shown in grey as 10 km squares.

Closer examination of the area of potential impact extending into the SAC reveals (see Figure 108) that the boundary between the SAC and the HSA area (and thus also the SPA) is a stream-course. It might seem unlikely that any hydrological impact could extend across this water feature, but it should also be noted that the peat just within the LWP development area is of the deepest kind. It lies on a slope which in places is as steep as 11°, and it is thus worth recalling that the Irish Landslides Working Group (Creighton, 2006a) identified a slope of 15° or more as having a significant risk of instability simply on the basis of slope-angle alone.

The behaviour of the Derrybrien bogslide (Lindsay and Bragg, 2005), which occurred in peat that was substantially thinner and on a gentler slope than the area highlighted in Figure 108, suggests that if a serious bogslide were to occur at this location, the volumes of peat involved, and the speed of the flow, could completely overwhelm the relatively minor stream-course separating the LWP development area from the Lewis Peatlands SAC.

A large liquid body of peat sliding suddenly down what is a relatively marked slope would undoubtedly have sufficient power to spill some way across onto the relatively gently-sloping SAC ground lying on the opposite bank. Above this, further into the SAC, is a pool system.

There is no way of judging whether a massive bogslide on one slope could trigger a slide on the opposite slope within the SAC, because there are no peat-depth data for the SAC in this area. However, the fact that very deep peat has formed on the development side of the valley, and the gradient is gentler on the SAC side, suggests that substantial depths of peat may exist on both sides of this stream.

Catastrophic damage to, and possible removal of, the toe of peat on such peat-covered slopes wtithin the SAC (which, as already noted, support a pool system upslope) as a result of a large bogslide, would create precisely the conditions that LWP has explicitly identified as a having a significant peatslide risk, and has therefore undertake specific action to avoid elsewhere.

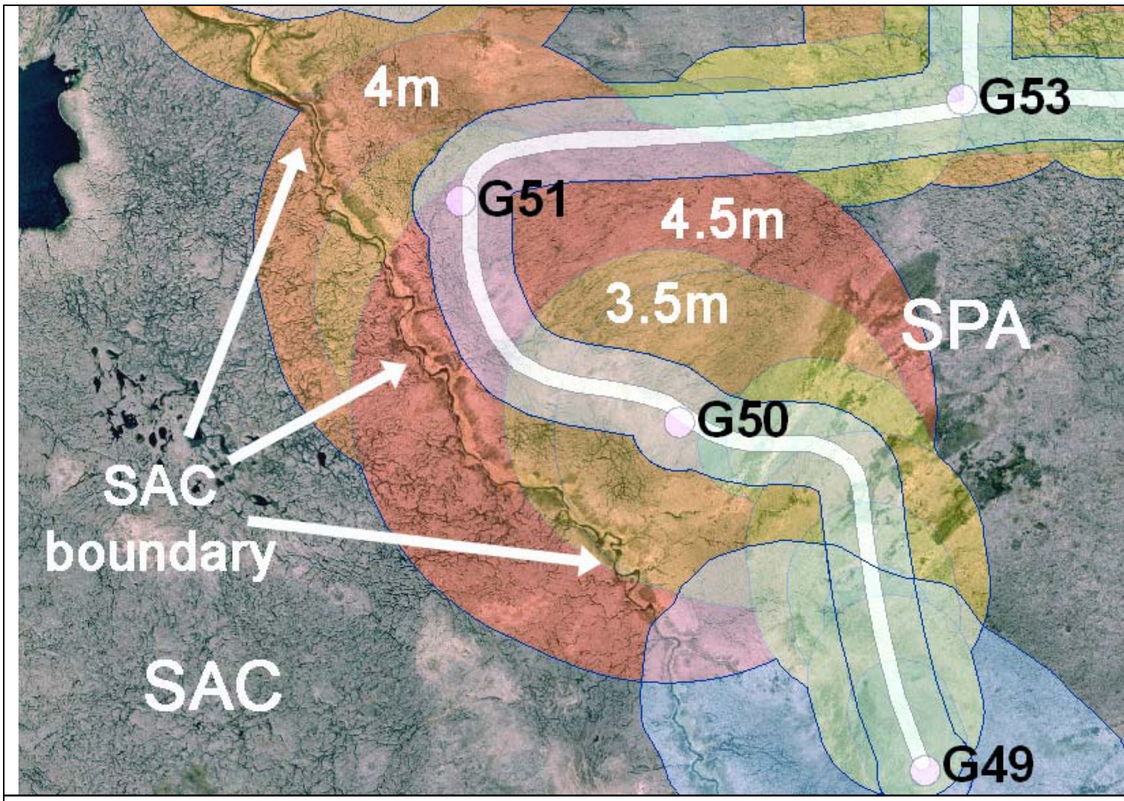


Figure 108. Example of ground where the UEL PZI extends into the SAC.
Detail taken from the map of the UEL PZI shown in Figure 107, at the border between the SAC boundary and the SPA boundary. The map displays peat depth colour-shading where peat depth is the dominant impact criterion for this particular section of the UEL PZI. Peat depths associated with particular depth-shading are indicated by white numbers. The contribution to the UEL PZI of the general PZI associated with the proposed LWP road-line and turbines is also shown as a pale line bordered by pale blue-green shading. Turbine numbers are provided in black type. ZoCs contributing to the UEL PZI are shaded pale blue. The stream-course forming the boundary between the SAC and the SPA is arrowed in white (strictly, the land marked 'SAC' is also SPA, as the two designations are coincident over the area of the SAC; the land on the left, marked 'SPA' lies outside the SAC, and is thus uniquely SPA). Note how the potential impact associated with the deepest peats extends across the stream-line into the SAC.

This is not the only location where such conditions combine to pose a potential threat to the SAC. There are several places along the boundaries of both the northern and the southern parts of the Lewis Peatlands SAC where deep peat associated with the line of the proposed LWP development lies close to the dividing line between the combined SAC/SPA and the SPA ground only. These sections of boundary are potentially at risk from impacts that encroach from the adjacent SPA ground into the SAC in the manner shown in Figure 108 above. Furthermore, Lindsay (2005) has commented that there are certain parts of the SAC boundary that are perhaps not as hydrologically secure as they might be. In some cases these somewhat 'weaker' sections occur in the same general area as the identified areas of potential encroachment, while in other parts there is no coincidence between the two.

The distribution of these two types of boundary issue can be seen in Figure 109, from which it will be evident that the majority of cases occur along the boundary of the northern part of the Lewis Peatlands SAC. However, on the few occasions where the boundary of the southern part of the SAC is involved, the peat is still quite deep and the distances involved are quite small.

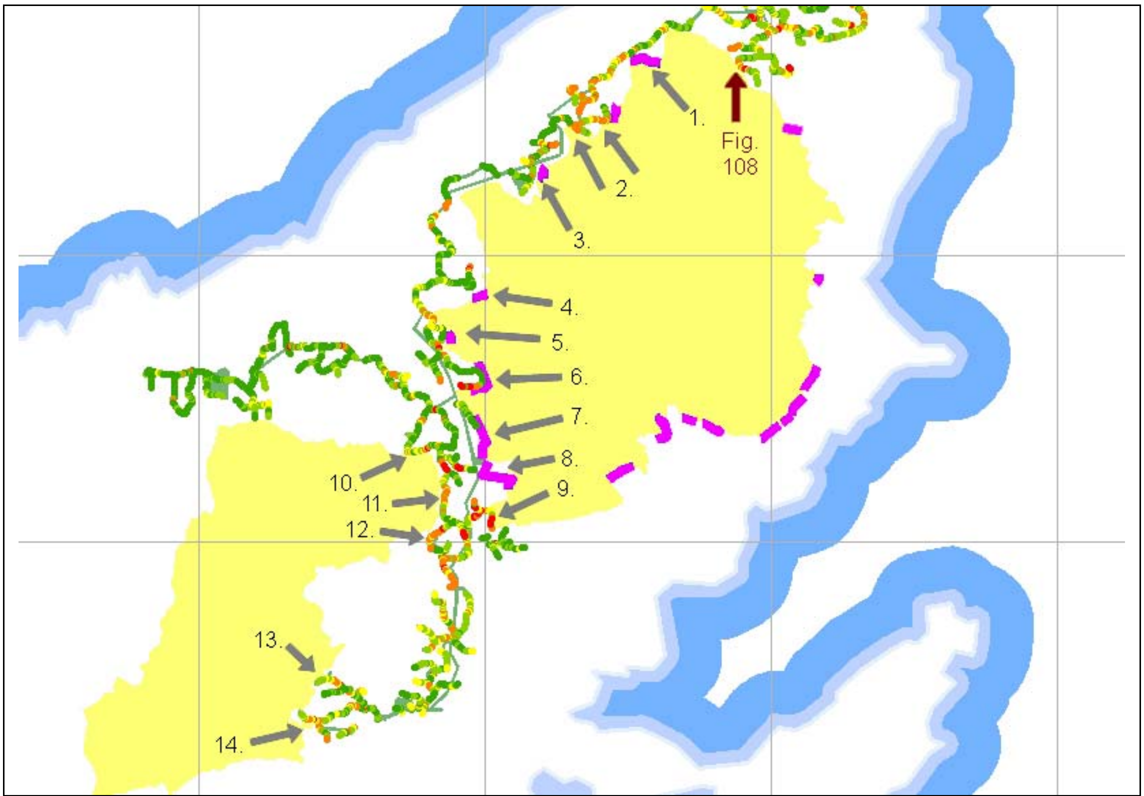


Figure 109. Distribution of potential boundary issues for the SAC.
The extent of the Lewis Peatlands SAC, consisting of a northern and a southern component (shaded pale orange/cream). Sections of the boundary around the northern component which are not as hydrologically secure as they might be are indicated with a thick purple line. The peat-depth map associated with the road-line of the proposed LWP development is also shown. It is displayed as a colour-gradient linked to differing peat depths; thus mid-green is the shallowest peat, yellow is peat between 1.0 m and 2.0 m, then orange and red are deep peats, with red symbolising peat depths of 5 m or more. Areas of particular concern along the SAC boundaries are indicated with grey arrows, and numbered. The numbers refer to the detailed views of these areas provided in Appendix 6. The area illustrated in Figure 108 is arrowed in brown. The route of the overhead power lines is also shown, distinctive in its blue-green straight sections. There are no peat-depth values for the powerline route. The coastline is shown as concentric blue shading. The OS National Grid is displayed as pale grey lines indicating 10 km squares.

At the scale necessary to show all parts of the proposed LWP development in relation to the SAC boundaries, it is impossible to see the necessary detail of peat depth and SAC boundary in Figure 109. Consequently Appendix 6 provides detailed views of each boundary section of the SAC identified either as hydrologically weak, or as potentially at risk from impact encroachment, or as both.

In considering specific examples that embrace all the various impact factors discussed above, and the possibility that such impacts may extend further than expected, it is also worth highlighting the fact that concerns have already been raised by Scottish Water about possible pollution, security of the ecosystem and stability of the peat in the vicinity of Loch Mor an Star. Indeed LWP 2006 EIS, Vol.2, Sect.2, Chap.10 (10.10.5) addresses a number of the issues raised by Scottish Water. These will be considered in the next section below.

8.4 Loch Mor an Starr

8.4.1 A 'window' into the surrounding bog water-table?

LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 118 acknowledges that Loch Mor an Starr (NB 396386) is:

- a public water supply;
- highly sensitive to pollution;
- highly sensitive to changes in water flows.

LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 124 then states:

> *"The Loch most likely represents* ***a window in the high water table typical of peat bog environments****, with loch levels corresponding to the height of the water table. During rainfall events the water table would rise and loch recharge would occur mainly from surface water run off. Some recharge from peat pipes may be possible, and small amounts of recharge from sub-peat groundwater may also occur."*

In fact this is unlikely to be the case. The LWP EIS is confusing Loch Mor an Starr with a classic 'bog lake', which is indeed something of a window into the water table of the bog (Ivanov, 1981; 'A4 pool' *sensu* NCC, 1989). In fact Loch Mor an Starr is a body of water that has to some extent been created and maintained artificially by the dam forming its easternmost extremity. As such, it would be a mistake to assume the loch is a 'window in the high water table typical of [the surrounding] peat bog, with water levels corresponding to the height of the water table.' On the contrary, the water levels in Loch Mor an Starr are much more likely to correspond to the height of the sluice on the dam at the outflow from the loch. There are many reasons to believe that Loch Mor an Starr should not be considered hydrologically-equivalent to a bog lake.

Firstly, in Britain, lochs the size of Loch Mor an Starr are never true bog lakes. This is because bog lakes are part of the microtope/nanotope pattern, being derived from development through peat growth and accumulation of formerly quite small-scale structures (Goode, 1970). Lindsay *et al*. (1988) have characterised the nature of this pattern in Britain, and make the distinction between 'A4 permanent pools' and mineral-based lochs – as indeed do red-throated and black-throated divers, the former generally using A4 bog pools while the latter generally use mineral-based lochs.

Secondly, there is evidence that the present shore-line of the loch is not natural. The most striking evidence of this comprises the series of 'breakwaters' that have been constructed along the eastern bank of the loch. Behind these breakwaters the eastern shoreline can be seen to have collapsed in several places, the areas of collapse taking the form of 'bites' out of the shore-line, with concentric slumping lines around these in the immediate hinterland (see Figure 110). These are most unusual features.

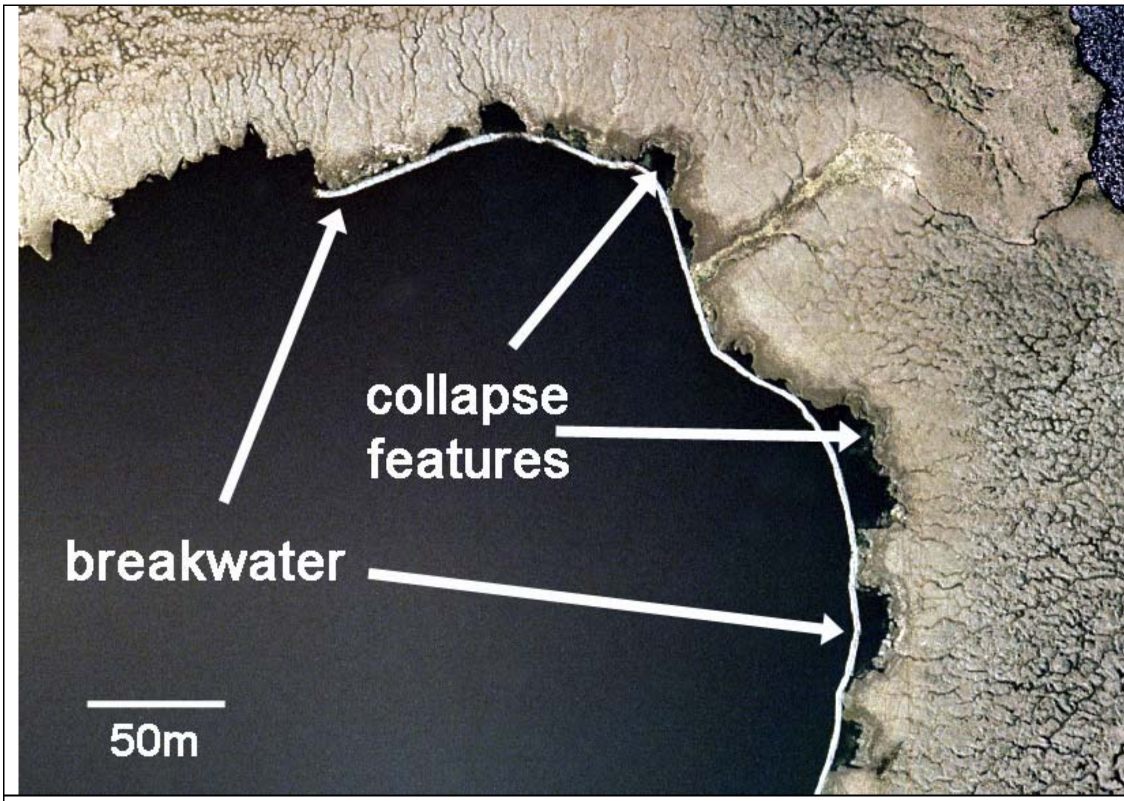


Figure 110. Breakwater and collapse features at Loch Mor an Starr.
North-western corner of Loch Mor an Starr. The 'bite-shaped' collapse features along the loch bank can be clearly seen, as can the thin meandering line of a breakwater constructed to prevent further erosion of the shoreline.

Aerial photograph © Getmapping.com 2006

Notwithstanding Osvald's (1948) vision of wave-action steadily eating away at the lee-shores of bog-pools, most lochs within blanket mire landscapes have quite smooth shorelines, whether these shorelines are lee-shores or not. For lochs the size of Loch Mor an Starr this is because they are generally lochs formed on mineral soil and have a sandy shore-line that resists wave action. For those (typically much smaller) lochans that are genuine bog pools, these too generally have relatively smooth lee shore-lines, despite Osvald's (1948) description of wave-action . Thus the various lochs found within the windswept blanket mires of Yell, Shetland, have quite smooth shore-lines whether they have a mineral shore-line or one consisting of peat. The same can be said for large bog 'lakes' (*dubh lochs* – *dubh lochan* being the even smaller bog pool) in the blanket mires near Cape Wrath, or the larger *dubh lochs* of Caithness (Shielton SSSI), or of Islay (Duich Moss NNR), or indeed the majority of *dubh lochs* within the blanket mires of Lewis.

The strangely irregular margin of Loch Mor an Starr, almost as though someone has been taking regular small, and occasionally large, bites from the shore-line, suggests three things:

- firstly, that the loch water table has been artificially manipulated (this is not entirely a leap of intuition, given the presence of a dam);
- secondly, that artificial changes in the loch water level are likely to be the cause of this evident shore-line collapse, particularly where there is added erosion energy from wind-blown waves with a relatively long 'fetch' (the worst of the erosion has a potential fetch of some ½ km);
- that water levels in Loch Mor an Starr are most unlikely to reflect the position of the water table in the surrounding bog; loch levels are far more likely to reflect the relationship between inflows from the surrounding bog and the height of the sluice at the dam.

This last point is based on the fact that examples of *dubh lochs* in other blanket mire regions with strong winds (even in the eroded bogs of Shetland) show only minor evidence of shore-line collapse, if indeed they show any such signs at all. Instead the transition from *dubh loch* to bog surface in these water bodies usually consists of a loch margin generally raised only slightly above the level of the loch and offering few opportunities for the substantial collapse features evident at Loch Mor an Starr. For the shore-line to collapse on the scale seen here, the water table in the loch must at times be substantially lower than the water table in the surrounding bog.

It therefore seems that LWP begins its consideration of Loch Mor an Starr with a false premise. This is then compounded by a series of assumptions that are at best questionable. There is also a series of significant omissions. Taken together, these render the LWP 2006 EIS incapable of making an adequate assessment of the possible implications for Loch Mor an Starr of the proposed LWP development.

The section headings used below are those used by LWP 2006 EIS, Vol.2, Sect.2, Chap.10 (10.10.5).

8.4.2 Location of wind turbines

It is certainly true that the 11 turbines proposed for the catchment containing Loch Mor an Starr all lie a considerable distance from the loch itself. LWP 2006 EIS, Vol.2, Sect.2, Chap.10, Table 10.11 demonstrates that the nearest two turbines (S60 and S64) will both sit approximately 200 m from the loch shore. Others will be anything up to 2 km from the loch.

Rather surprisingly, however, no mention is made of the fact that the overhead power-line, its pylons, and its construction road, not only involves crossing the head of the loch in two places, but the power-line lies within 10 m – 30 m of the loch for almost 300 m of its length (see Figure 111). Indeed at least two pylons will be constructed within 25 m of the loch shore, while a major corner tower will be constructed some 50 m from the shore-line. Although LWP may consider that construction of the power-line will have almost no environmental effect, Section 4.3.2.3 of the present report makes clear that there is considerable potential for impact, some of which is likely to be long term. The ground that the power-line route will cross is fairly eroded, and there are thus several distinct water-courses to be crossed.

Clearly the construction traffic is not going to cross the loch itself. Consequently it must be assumed that quite a roundabout route will be needed for the power-line construction phase. This will add significantly to the area of ground occupied by, and indeed modified by, the power-line construction route. Furthermore, the fact that pylon bases will need to be constructed in such close proximity to the loch raises significant concerns about sedimentation and – potentially – stability issues (see below).

In addition, although the site-roads that service the turbines are generally set some 200 m back from the loch, in two locations these roads lie within 75 m – 85 m of the loch shore. The road-lines also have several significant hydrological issues that are not mentioned by the LWP EIS documents. For example, although LWP 2004 EIS, Vol.4, Chap.7, Fig.7.15a shows four planned water-crossing points for the immediate vicinity of Loch Mor an Starr, these crossing points only address four of the most obvious water crossings. The many other substantial erosion gullies which would be cut by either the road-line or the power-line route are not mentioned or provided for in the LWP EIS documents. Neither is it acknowledged that the road-lines will cut through two ladder fens and one substantial percolation fen, all of which feed down into the loch (see below).

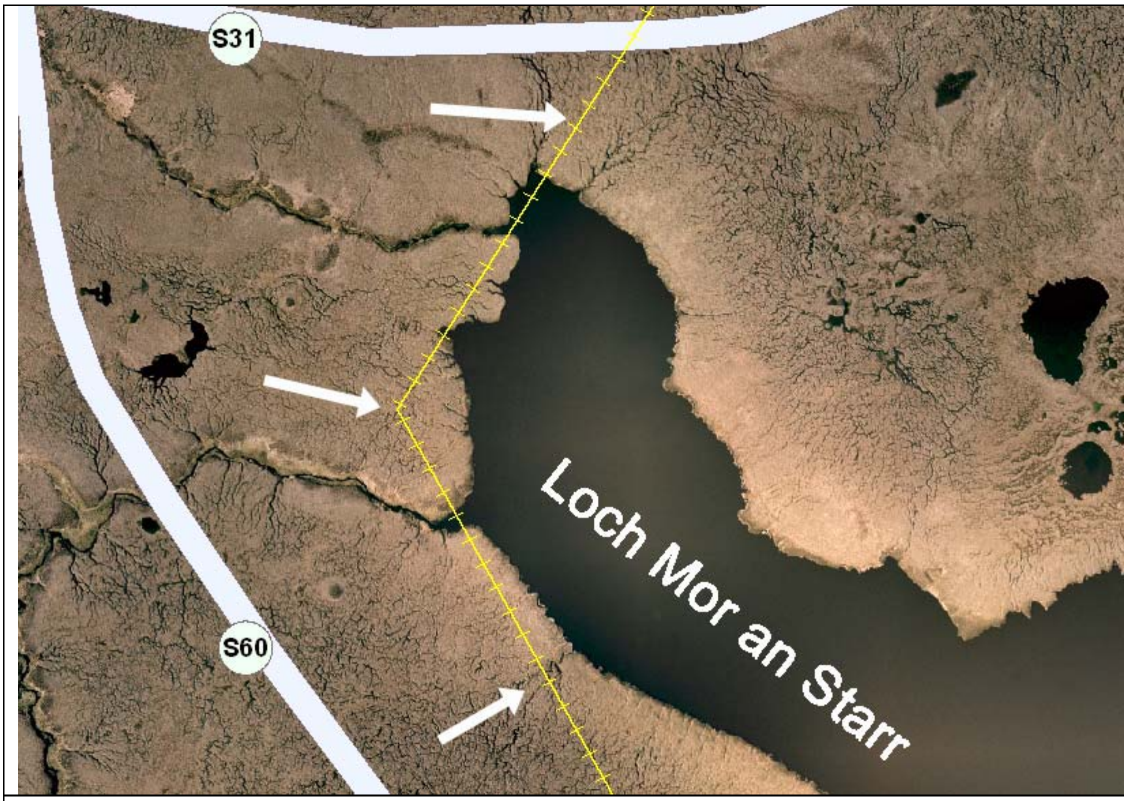


Figure 111. Route of overhead powerlines., northern Loch Mor and Starr.
The norther arm of Loch Mor an Starr, with the intended route of the overhead powerlines, and the proposed position of roads (pale blue corridor) and turbines (Turbines S31 and S60). It can be seen that the powerlines will actually cross the loch. There will be a single deviation tower where the powerline route changes direction, and given that LWP has stated that pylon towers should be around 250 m apart, then two more pylon towers will need to be constructed close to the loch edge. The deviation tower is approximately 60 m from the loch shore. White arrows point to probable pylon locations.

Thus Figure 112 summarises the number of water-features (including ladder fens and percolation mires) that must be crossed by either the road-lines or the power-line trackway, and highlights the four locations identified by LWP as the only water crossings requiring action. The number of distinct water features identified in Figure 112 (detailed in Figure 113 to Figure 115) and the very much smaller number of channels highlighted for action by LWP as formal 'water crossings', is quite striking. It suggests that LWP does not recognise the number of features that, unless specific provision is made for them, are likely to create significant hydrological problems for construction and maintenance along the west shore of Loch Mor an Starr.

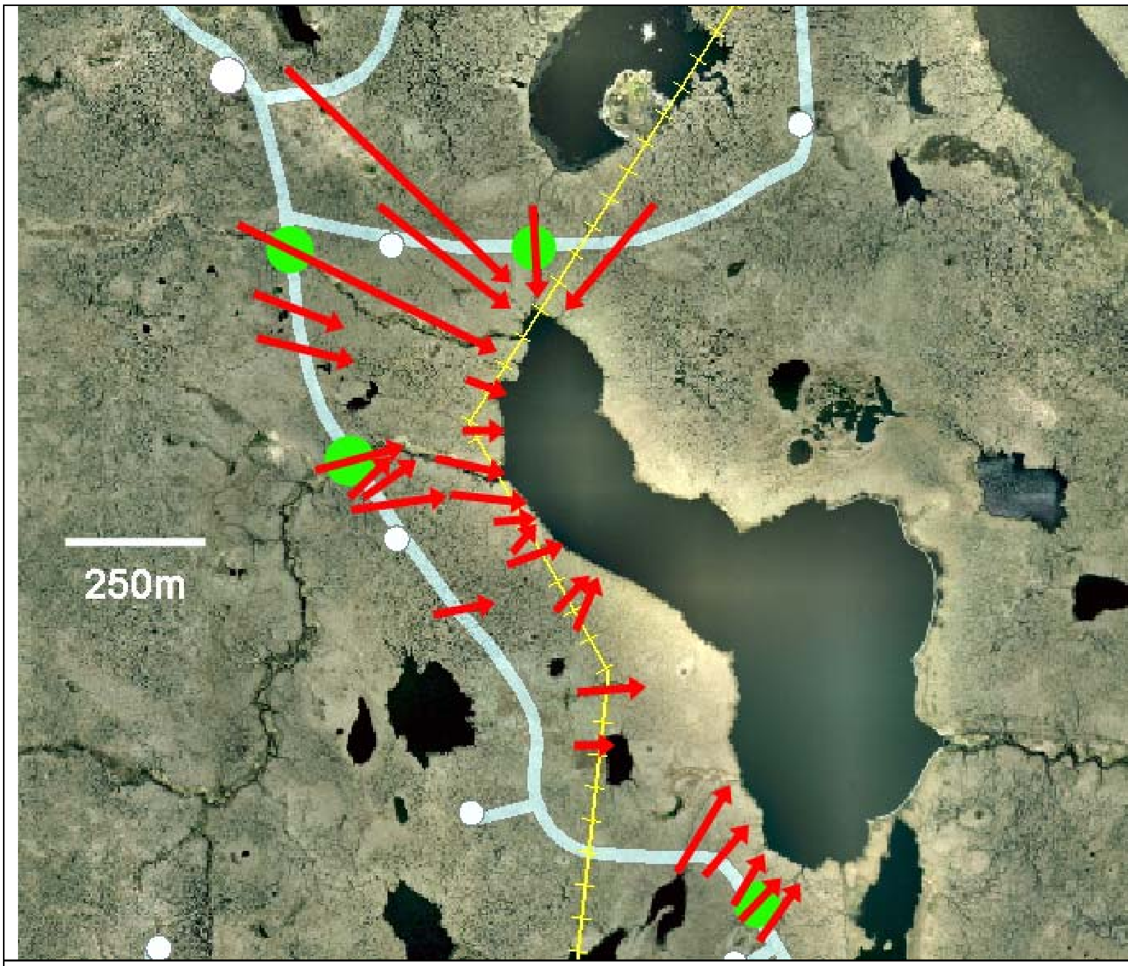


Figure 112. Potentially-affected watercourses entering Loch Mor an Starr.
Water channels and LWP proposed 'water crossings' at Loch Mor an Starr. Red arrows indicate position of watercourses that flow towards Loch Mor an Starr, and potentially affected by the LWP development. Green circles indicate the location of LWP's 'official' water-crossing sites. Also shown are the proposed overhead powerline (yellow line), road corridor (pale blue) and turbine locations (white circles).

Aerial photograph © Getmapping.com 2006

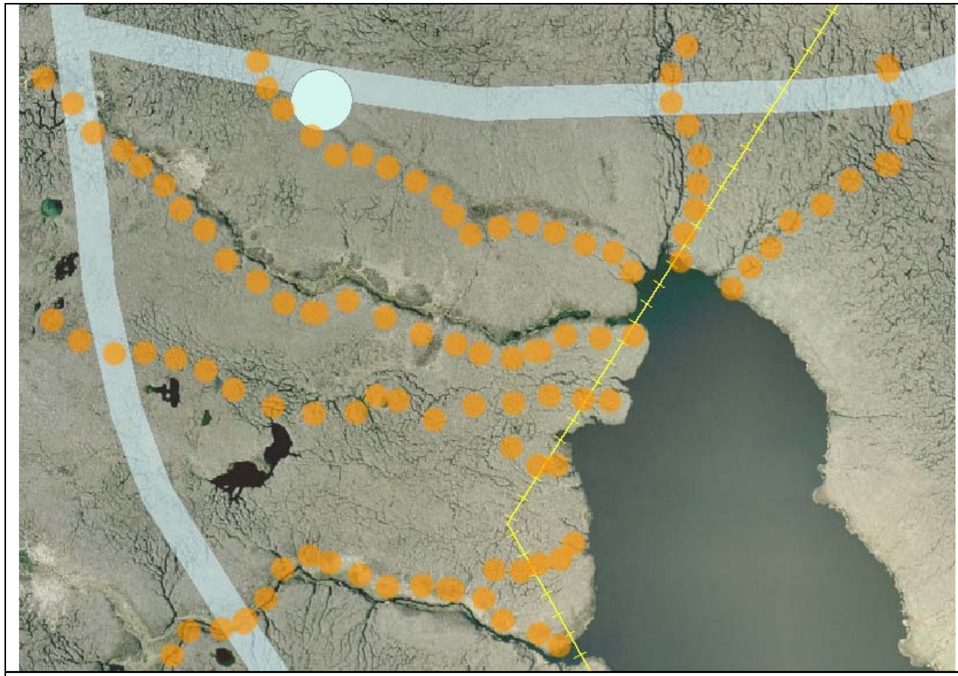


Figure 113. Detailed view of issues, north Loch Mor an Starr.
Detailed view of water channels in the northern part of Loch Mor an Starr, indicated by red arrows in Figure 112. Channels here indicated by dotted orange lines, turbines by pale plue circles.

Figure 114. Detailed view of issues, central Loch Mor an Starr.
Detailed view of water channels along the western-central shore of Loch Mor an Starr, indicated by red arrows in Figure 112. Channels here indicated by dotted orange lines. Overhead powerline is shown in yellow, road corridor is shown in pale blue, and turbine shown in pale turquoise. The road corridor is 25 m wide.

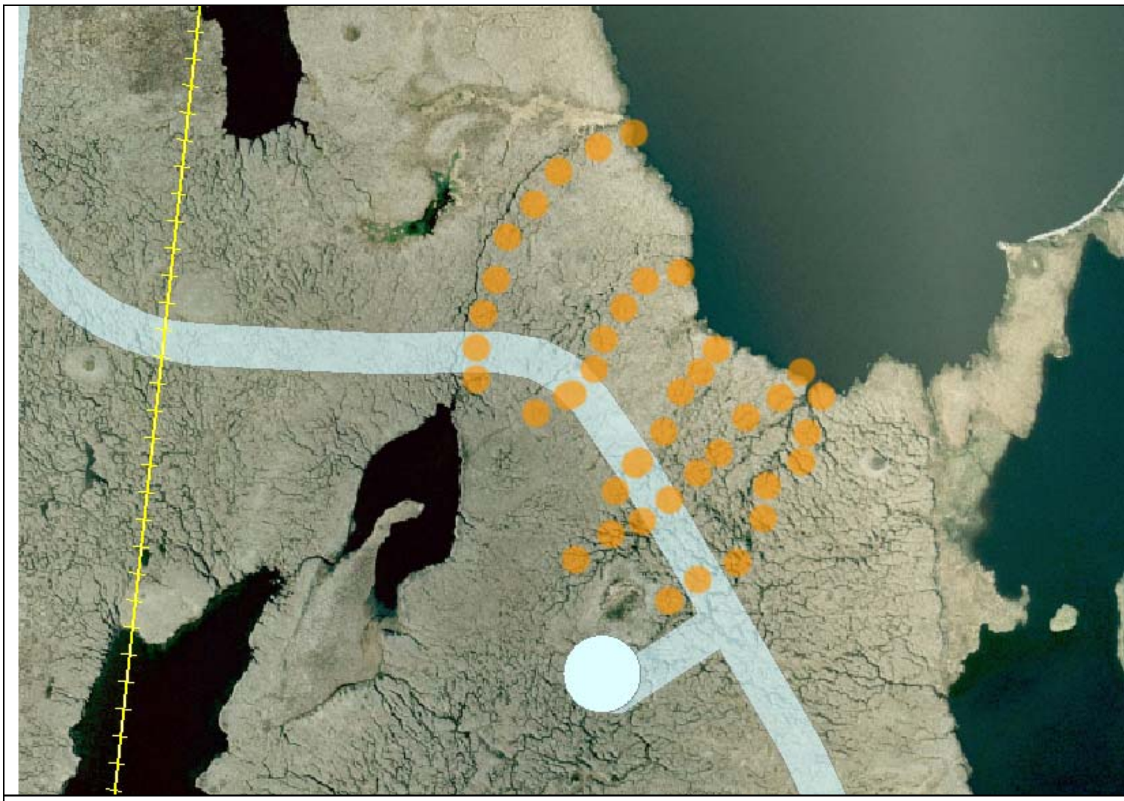


Figure 115. Detailed view of issues, south Loch Mor an Starr.
Detailed view of water channels along the south-western shore of Loch Mor an Starr, indicated by red arrows in Figure 112. Channels here indicated by dotted orange lines. Overhead powerline is shown in yellow, road corridor is shown in pale blue, and turbine shown in pale turquoise. The road corridor is 25 m wide.

8.4.3 Contamination of Loch Mor an Starr

Several of the additional water-features identified in Figure 112 feed directly downslope towards the loch from the constructed road-line or from the power-line route. Consequently there is a clear need for sediment control. The need for this would be most acute during the construction phase, but there is likely to be a continuing need during the life of the windfarm.

This need for sediment control itself gives rise to further issues. Thus it is particularly worth highlighting the fact that the whole western side of the Loch Mor an Starr catchment is identified by LWP as belonging to Hydrological Zone 4, while the remainder is designated as Hydrological Zone 3. As discussed earlier in the present report, both of these hydrological zones are described by LWP as:

> *"...areas where the disposal of excess water into settling ponds* ***has the potential to develop a downward pressure 'head' and result in 'bog bursts'****."*
>
> *LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 73*

Consequently it is LWP's intention that for the treatment of sedimentation in such areas:

> *"...a proprietary system such as a siltbuster will be used. This system could be located on a hardstanding at wind turbine excavations or other suitable bearing surface."*
> *LWP 2006 EIS, Vol.2, Sect.4, Part 3, OCMS1, para 20*

This raises two questions. Firstly, Section 4.2.3.4 of the present report has already highlighted the fact that siltbuster-type technology can only remove fine silt if accompanied by treatment with flocculants. The significance of using such flocculants in relation to a public water supply is not discussed by the LWP EIS documents.

Secondly, there is the question of where exactly any such treatment systems would sit. The various water crossings identified in Figure 112 are not generally associated with turbine hardstandings. Will each identified crossing be supplied with a treatment unit, as stated by LWP? If so, does this mean that there will need to be a significant increase in the amount of construction along these sections of road-line (and power-line route?) to provide additional hardstandings for such units? What does it mean for the potential volumes of flocculant? As the LWP EIS documents do not acknowledge the presence of these additional water crossings, they also do not address the issues of sediment control for such crossings.

What LWP 2006 EIS, Vol.2, Sect.2, Chap.10, paras 125 and 126 do consider, however, is the potential for general flow of contaminants into Loch Mor an Starr. Firstly it is acknowledged (para 125) that the majority of water movement occurs as streamflow or surface-water flow. Indeed it is even stated that:

> *"Flow of water or contaminants through intact peat profiles would **mainly be limited to the surface layer** due to the low hydraulic conductivity of the lower layer or catotelm (Holden and Burt 2001)."*
> *LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 126*

Inexplicably, therefore, the rates of flow that are then used to demonstrate the slow rate of contaminant movement through peat are the rates given by Holden and Burt (2002) for the catotelm – the very layer through which it has been acknowledged that the contaminants will *not* flow. Holden and Burt (2002) quote rates 100x faster for the acrotelm, as is acknowledged in LWP 2004 EIS, Vol.6, Appendix 10D, para 46. Furthermore, the use of the phrase 'intact peat profiles' obscures the fact that a significant amount of the Lewis blanket peat is eroded, and thus much rapid water (and pollutant) movement will occur along erosion gullies rather than seeping through any acrotelm layer that might be present. It is thus obviously wholly unjustified for LWP to present rates of 15 m per year as a realistic scenario (as LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 126 does), and to conclude that:

> *"...any pollutants derived from the construction of a wind turbine or road do not pose a risk [to Loch Mor an Starr] due to the low hydraulic conductivity of peat."*

Pollutants moving through unvegetated erosion gullies will move very fast indeed, while those pollutants carried by overland flow or the highest acrotelm flows in revegetating gullies are capable of moving at speeds of more than 800 metres per day, based on hydraulic conductivities cited by Holden and Burt (2002) for Pennine blanket mire.

8.4.4 Draining of Loch Mor an Starr

8.4.4.1 Catastrophic collapse of Loch Mor an Starr

LWP begins by addressing the fear that Loch Mor an Starr could be drained if a peat pipe or fissure were to be cut, or that downward pressure by the water in the loch could cause the loch to empty if its margins were breached. LWP provides assurance that such a scenario is unlikely because turbines and roads sit at a higher elevation than the loch itself (LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 133).

While this may be so, it is worth highlighting the fact that Loch Mor an Starr is almost certainly exerting some downward pressure on any areas of peat lying level with, or lower than, the loch because the water level of the loch is maintained at an artificially high level. Instability along the loch margins has already been commented on above. The scenario leading to potential collapse of the loch, as described by LWP 2006 EIS, Vol.2, Sect.2, Chap 10, para 133, may therefore not be so far removed from the present position, and Scottish Water might thus have real grounds for concern over possible breaches to this stability. The fact that the LWP EIS documents regard the loch as a natural ‘bog lake’ suggest that they fail to appreciate the very particular problems of an artificially-elevated water body established within a blanket mire system.

8.4.4.2 Catastrophic collapse into Loch Mor an Starr

It is suggested by LWP 2006 EIS, Vol.2, Sect.2, Chap.10, para 135 that a more likely scenario is that of slope-failure in the peat lying above Loch Mor an Starr, leading to a ‘bog burst’ that flows into the loch. Such slope-failure is recognised as possible should a hydraulic ‘head’ be allowed to develop, as might occur if settling ponds were used to de-water turbine excavations.

The proposed solution to this potential problem (LWP 2006 EIS, Vol.2, Sect.4, Annex 1, OCMS1, para 20) is the use of siltbuster-style technology, placed on hardstandings, with final outflows either being fed into local gullies or being released ‘to ground’. While this may or may not provide a safe means of turbine dewatering (as discussed in various earlier parts of the present report), it does nothing to address other serious issues of stability raised by the proposed construction route through this catchment.

In particular, there must be grave concerns about the presence of two ladder fens and a percolation mire, combined with the very great depth of peat along the proposed construction route. In the case of the two ladder fens, the road will cut across the downslope toe of these extremely wet, percolating systems and both lie on extremely deep peat (see Figure 116 and Figure 117).

It has already been emphasised several times in the present report that published authorities consistently highlight the dangers of disrupting or loading areas of peat where there is water seepage. Precisely this set of conditions is believed to have pre-disposed the peat in the vicinity of the Derrybrien bog-slide to failure (AGEC 2004). All that was needed was the necessary trigger. In the case of Loch Mor an Starr, there are two such distinct zones of seepage feeding towards the same section of road, and their confluence lies no more than 250 m from the nearest stream-course if following the most likely collapse route (see Figure 116). This stream-course then empties directly into Loch Mor an Starr.

The extreme thickness of peat associated with these ladder fens (almost 2 m greater than that which collapsed at Derrybrien) must also be a very considerable cause for concern. Where there is seepage through the peat this can substantially reduce the 'dead-weight' component of the slope-stability analysis (*i.e.* that which gives the peat its resistance to movement) and significantly increase the gravitational tendency for the peat to slide downslope because such movement is lubricated by layers of water seepage.

Management of drainage along this section of road is likely to be critical to any immediate tendency to instability. A lack of cross-drains will mean that substantial volumes of seepage water will collect on the upslope side of the road, raising precisely the same fears that have been expressed by LWP about using settling ponds in this area.

In the case of the percolation fen, one road cuts across the northern margin of the fen, while a road to the south cuts across what is obviously a peat pipe that leads to the lochan lying towards the southern part of the percolation mire. Given the depth of peat here, the evident sub-surface flow associated with the peat pipe, and the probable extremely wet nature of the fen itself, any construction is likely to be in a region of peat with considerable susceptibility to slope-failure.

The downward 'head' in this case would be caused not so much by the weight of any ponded water (although this would also be a significant issue), but would probably come largely from the weight of the floating road itself. The foot of the percolation mire is located only 350 m from Loch Mor an Starr.

In addition, it can be seen from Figure 117 that the peat thickness beneath the proposed road-line all along the western side of Loch Mor an Starr is consistently very deep, as well as markedly dissected by surface erosion and, in some places, what appear to be springs or peat pipes. There is consequently much heterogeneity in the peat, and it is not therefore reasonable to assume that the uniform peat matrix used by the basic slope-failure model is relevant in this case. Furthermore, the un-named loch at NB 387386 lies at least 5 m above the level of Loch Mor an Starr and yet is only 300 m distant from it.

One of the LWP Peatslide Hazard Mapping criteria was based on a landform model in which one loch, separated from another by less than 1 km, lay at least 10 m above the second loch (LWP 2004 EIS, Vol.3, Chap.17, para 15). On this basis, LWP has already made special arrangements for modified construction in such cases - though the wisdom and likely success of these arrangements has been questioned by the present report. In the case of Loch Mor an Starr and the un-named loch, the horizontal distance between them is very much less than 1 km, and the difference in elevation is likely to be close to 10 m. As such, there would seem to be strong reason for concern based on LWP's peatslide risk-assessment criteria alone.

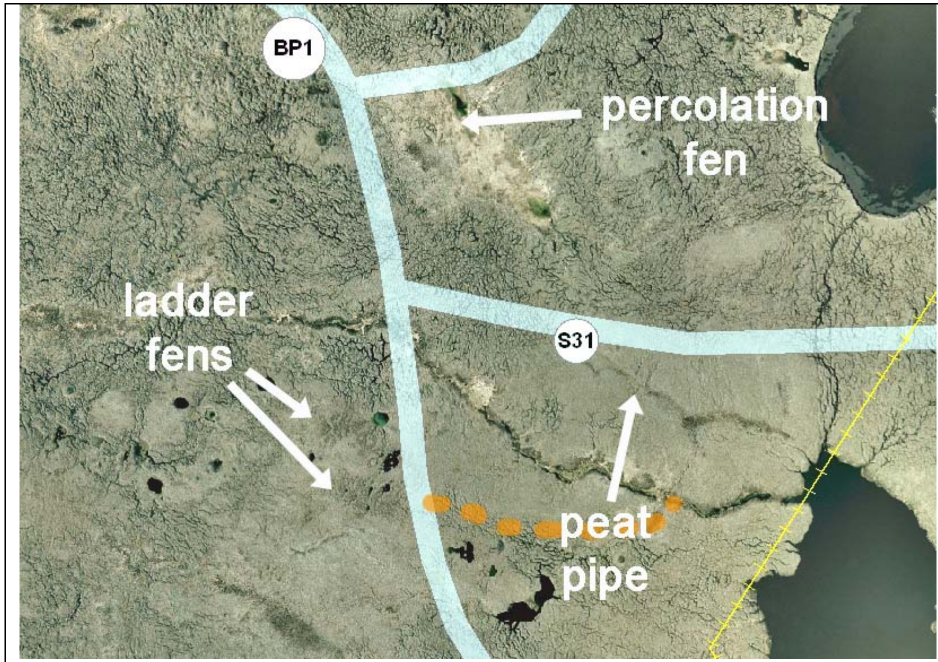


Figure 116. Ladder/percolation fen, north Loch Mor an Starr.
Detailed view of ladder/percolation fens and peat pipe feeding into Loch Mor an Starr (the loch is the dark area in the bottom-right of the picture. Direction of possible flow of materials from ladder fens. here indicated by dotted orange lines. Overhead powerline is shown in yellow, road corridor is shown in pale blue, and turbine shown in pale turquoise. The road corridor is 25 m wide.

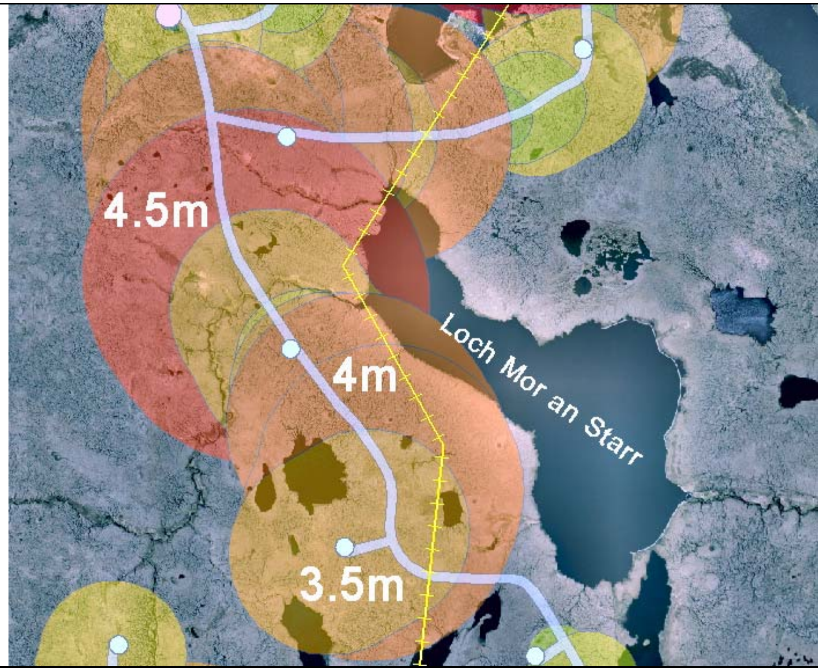


Figure 117. MZoCs and Loch Mor an Starr.
View of Loch Mor an Starr with mesotope-microtope zones of concern (MZoCs) indicated, along with the proposed road corridor (pale blue), the overhead powerline route (yellow line), and the locations of several turbines (pale blue circles). MZoC shading reflects peat depth, with depths indicated for the most relevant colours. Note the prevalance of deep (4 m+) peat along the western shore of Loch Mor an Starr.

8.4.5 Loch Mor an Starr : summary

Overall, then, it would seem that the picture regarding the potential impact of the LWP development on Loch Mor an Starr does not reflect the remarkably sanguine description provided by LWP 2006 EIS, Vol.2, Sect.2, Chap.10 (10.10.5). In particular:

- the use of catotelm conductivity rates rather than surface-flow rates presents an unrealistic picture of the likely speed at which sediments and contaminants would pass towards the loch;
- the very close proximity of the overhead power-line and pylons (and their attendant construction track) to the loch is not considered at all;
- the implications of providing sediment/pollution technology (probably involving flocculants), rather than simple settling ponds, are neither discussed nor assessed;
- the potential scale of the requirement for sediment/pollution technology within the catchment of the loch is apparently not recognised;
- the stability issues raised by cutting across ladder/percolation fens with the road-line, particularly on very deep peat, are addressed by LWP only in terms of a generic need for sediment-control technology, not in terms of slope-stability;
- the general question of slope-stability on such deep peat is not addressed either, despite the obvious presence of peat piping and other signs of preferential water flow *within* the peat body.

If the loch were to suffer from any of the above impacts, this would represent not just a substantial area of impact; it would also represent a major hazard in social terms. Thus it is all the more surprising to find such a sanguine view of the issue in LWP's presentation of the case.

9 CUMULATIVE EFFECTS and IMPACT INTERACTIONS

European Commission guidance (European Commission 1999) for the process of scoping the geographical extent of an EIA states that:

> *"**Indirect and cumulative impacts and impact interactions may well extend beyond the geographical site boundaries of the project**. ... Additional data may need to be gathered to cover wider spatial boundaries, taking into account the potential for impacts to affect areas further away from the site than if just direct impacts were considered. **Consideration should also be given to the distance that an impact can travel**, and any interaction networks."*
>
> *European Commission, 1999*

For the peatland environment on Lewis, there are many activities in relation to LWP's proposed development that are likely to influence the geographical boundaries of the EIA, particularly arising from cumulative effects and impact interactions. However, undoubtedly one of the most spatially significant impacts of all would be if a sizeable peatslide were to occur. There is a strong possibility that material from any such peatslide would enter the local stream-courses either immediately, or following subsequent rain, and result in extensive impacts along these freshwater systems. The examples of the peatslides at Derrybrien, Co. Galway, and Pollatomish, Co. Mayo, vividly illustrate just how extensive and significant such impacts can be (Lindsay and Bragg, 2004; Creighton, 2006b).

Peat-slides, even quite small ones, can have a significant effect on landform, local drainage, vegetation, birds, fish populations, stream ecology and even, potentially, public water supplies. As such, they embrace issues not merely of geographical extent, but also of direct and indirect impacts, cumulative effects and impact interactions. Given the nature of the data gathered by LWP in relation to peatslide risk, it is reasonable to expect that the LWP EIS documents would go on to consider not only the localities for which there appeared to be a potential risk, but also the potential geographical, ecological and social consequences of slope-failure should it occur.

Surprisingly, the LWP EIS documents do not do this. Despite the identification in LWP 2006 EIS, Vol.3, Chap.10, Fig.10.8 of many areas where there is evidence of sub-surface weakness, and the identification of several localities which LWP itself highlights as being at 'moderate' risk even after LWP's own mitigation measures have been implemented, there is no consideration of possible scenarios actually involving peatslide events. This evident gap in the LWP EIA process is precisely the sort of failure that the EU guidance, quoted at the start of this chapter, is attempting to help developers avoid.

The issue, and potential impact, of landslide risk assessment offers a good case-study for the way in which the LWP EIS documents generally tend to draw the boundaries of their considerations extremely conservatively and with a narrow remit. This approach inevitably then offers very little room for consideration of issues highlighted by the EU guidance cited above.

9.1 Landslide risk assessment : a case-study

Fealy (2006) explores the concept of 'landslide risk assessment', and explains the distinction between 'hazard' and 'risk'. Both concepts form part of the assessment process, but each explores different aspects of this overall process.

9.1.1 Landslide 'hazard'

Fealy (2006), in considering landslide risk assessment in Ireland, defines 'hazard' as a landslide:

> *"with the potential to impact on humans";*

He then notes, however, that:

> *"There is very little land area in Ireland that is not owned or utilised by humans. As such,* ***any event will have a human impact and therefore can be considered a hazard****."*
>
> *Fealy (2006)*

It could, indeed it must, be argued, in the case of a site protected for its wildlife interest by an EU Directive, that Fealy's definition of 'hazard' must be broadened to include the potential to impact on the defined wildlife interest of the site. Conceptually, because nature conservation is a construct of human society, it can be argued that a negative impact on the wildlife of such a site (and thereby a breach of these human-constructed laws) is also by definition an 'impact on humans'. Thus, in order to avoid ambiguity over this issue, it is explicitly assumed in the present document that 'hazard' is indeed acknowledged as additionally embracing threats to the recognised wildlife interest of the area.

9.1.2 Landslide 'risk'

Fealy (2006) defines 'risk' as:

> *"...the probability of a landslide occurring in combination with* ***a full estimation of all possible outcomes****...These* ***outcomes will generally be expressed in cost terms*** *such as damage costs or the loss of life or injury.*
>
> *Fealy (2006)*

Fealy (2006) additionally notes that:

> *"Landslide events with a* ***perceived*** *low frequency should be considered as posing significant risk if their potential cost is high."*

He explains the reasons for this in the following terms:

> *"Low to medium magnitude events will often attract less attention than high magnitude events, and the probability of occurrence of all*

magnitude events is often not well understood. Put another way, ***just because we have no record of damaging landslides in an area does not mean that they cannot occur****."*

Fealy (2006)

9.1.2.1 Landslide risk assessment : quantitative or qualitative?

Fealy (2006) discusses the fact that risk assessments can be either 'qualitative' or 'quantitative'. He acknowledges that a quantitative approach would seem the more desirable option, but then points out that the present level of knowledge about landslide processes, particularly in peat-dominated landscapes, coupled with the limited array of data available, means that such a numerical approach is not a realistic option.

One advantage of the qualitative approach, as Fealy (2006) points out, is that it is often simpler to express and thus is generally easier for a wider audience to understand. The obvious drawback, however, is that it can be accused of over-simplifying the picture, but the simple fact remains – if adequate data and understanding are quite simply not available, there is little to be gained by attempting to quantify the probability of slope-failure. Indeed such an attempt has the potential to be actively dangerous if it gives a spurious appearance of stability and safety in areas which are actually in danger of slope failure.

Fealy (2006) cites Aleotti and Chowdbury (1999) and their pragmatic recognition that:

"...of the challenges posed by the probabilistic component of hazard assessment, coupled with assessing both vulnerability and the uncertainties associated with both of these aspects, frequently the best thing that can be achieved is an assessment of susceptibility. They define susceptibility as the ***possibility*** *that a landslide will occur in a particular area on the basis of the local environmental conditions."*

Fealy (2006)

9.1.2.2 Landslide risk assessment : the semi-quantitative approach

Given the constraints that exist regarding data availability and scientific understanding of environmental processes, Fealy (2006) suggests that the most pragmatic way forward for the present is a combination of approaches:

- for the assessment of likelihood, a largely qualitative approach must be adopted because a meaningful quantitative approach is not yet possible;
- an estimate of likely consequences can be expressed numerically in terms of likely costs and losses resulting from a peat-slide and any attendant clean-up/recovery programme.

With such approach, a number of scenarios would be assessed on the basis of a peat-slide event occurring at those localities that have at least been identified in terms of peat-slide risk as being 'susceptible' (*sensu* Allioti and Chowdbury, 1999). These scenarios would embrace all parts of the landscape likely to suffer some impact should such an event occur. A quantitative assessment would then be assembled of the environmental or social costs likely to arise from such impacts.

The areas likely to be involved can be highlighted using available slope-stability information and other relevant data, combined with the likely route(s) of any flow from identified areas of possible slope-failure. These flow-routes will almost invariably end in water bodies of some description, be they lochs, stream-courses, rivers or the sea, and precisely which water bodies might be affected can be assessed by examining the local landform.

The steps outlined here are relatively straightforward, given the existing level of environmental information about the proposed LWP development site, the landforms involved, and the calculable costs associated with likely losses and restoration actions It is therefore difficult to explain why such a review is not included within the LWP EIS documents.

9.1.3 The LWP approach : 'likelihood' and 'consequences'

It is made clear above by both the EU (1999) guidance and by Fealy (2006), that peatslide risk assessment is more than just a mechanistic process of investigating slope stability. The risk assessment should include consideration both of the engineering issues surrounding probability of slope-failure *and* the consequences of such failure should it occur. Section 7.1 of the present report has already looked at the data gathered and techniques applied by the LWP EIA to the question of peatslide risk assessment and the *likelihood* of a peatslide event occurring. It is thus important (and instructive) to look at the approach adopted by the LWP EIS documents to the question of 'consequences'.

9.1.3.1 'Catchment sensitivities'

A 'sensitivity' analysis is presented in LWP 2006 EIS, Vol.2, Sect.2, Chap.10 on a catchment basis, and the Hydrological Zones are evaluated in terms of their sensitivity. However, in the case of catchments it has already been explained in Section 5.2.1.2 of the present report that catchments make poor analysis units in peat-dominated landscapes. This is because catchment boundaries by their very nature tend to cut right through the main units of peatland. It is like trying to undertake a sensitivity analysis of one half of a lake, and approaching it as though the other half would be unaffected by what occurs in the waters adjacent to it. The nature, relevance, and utility, of Hydrological Zones has been explored at length in Section 5.2.6.2 and will not be considered again here. Suffice it to say that they offer nothing, and nothing is offered, in terms of a peatslide risk-assessment as described above.

The LWP catchment-sensitivity analysis focuses purely on the density and footprint of infrastructure planned for each catchment. This gives a broad-brush approach to the issue, but gives little real information about the specific areas of ground that might be at risk. LWP 2006 EIS, Vol.2, Sect.2, Chap.10, Table 10.13 and paras 185 and 192 represent almost the only occasions when individual water bodies are considered in terms of their sensitivity to impacts arising from instability and mobility of materials. In all three of these occasions, attention focuses purely on levels of sedimentation arising from construction activities (rather than more catastrophic slope-failure). The cumulative impacts are considered to be 'low' in all cases.

9.1.3.2 Risks to specific water features

Within the LWP EIS chapters devoted specifically to peatslide risk – particularly LWP 2004 EIS, Vol.6, Appendix 17 – it is true that individual rivers or water bodies are sometimes named, but there is no description of, or deliberation about, the possible consequences should one of these localities actually experience a peatslide event. The lack of any real review of possible impacts arising from a peatslide event is all the more puzzling when one considers that in many cases, LWP 2004 EIS, Vol.6, Appendix 17 recognises that the peatslide risk, even after design changes, remains somewhere between 'medium' and 'low'. It should be noted that the lowest risk category is 'very low', which suggests that there is a recognised degree of risk even in 'low-risk' cases.

Thus in describing the peatslide risk assessment at West of Loch Bhatandip locality', it is stated that:

> *"Due to the potential for **significant consequences** in this instance, a high priority applies. Once this [high priority] design change is implemented, the residual risk is **low to medium**."*
> *LWP 2004 EIS, Vol.6, Appendix 17A (17A.1.5)*

The locality is thus still recognised as being at potentially 'medium risk' but the 'significant consequences' that would ensue should this risk become reality are never explored, at least not explored in any explicit way. The regions of risk vaguely indicated in LWP 2006 EIS, Vol.3, Chap.17, Fig.17.01 have already been discussed, as have the 'avalanche forecast mapping' claimed by LWP 2004 EIS, Vol.4, Chap.17. Indeed it is worth re-iterating the LWP statement about such avalanche prediction work:

> *"The principals* (sic) *of snow avalanche forecasting involve not only evaluation of snow stability integrated with terrain and meteorological parameters but **also an awareness of what might happen if the slope avalanches**."*
> *LWP 2004 EIS, Vol.4, Chap.17 (17.2.3.4)*

If there is any awareness of 'what might happen if the slope avalanches' on one or more of the Lewis sites, the LWP EIS documents do not to share the details of this awareness with their readers.

9.1.4 UEL Peatslide Susceptibility Mapping and Consequences

In the absence of anything meaningful from the LWP EIS documents about areas and features actually at risk from peatslide events, the UEL Peatland Research Unit has combined the information from its own assessment of peatslide risk (as described in Section 7.4.1 of the present report) with the type of information outlined in Section 9.1.2 above.

9.1.4.1 UEL mapping of 'likelihood' and 'geographical consequences'

As made clear above by Aleotti and Chowdbury (1999) and Fealy (2006), it is not yet realistic to attempt a deterministic, quantitative assessment of peatslide 'likelihood'.

However, some degree of ‘susceptibility’ can be assigned to localities on the basis of recognised predisposing features. The UEL Peatland Research Unit approach to this has been detailed in Section 7.4.1.2 of the present report.

For the purposes of mapping ‘likelihood’ and ‘geographical consequences’, only those locations regarded by the UEL Peatland Research Unit as having ‘moderate’, ‘high’, or ‘very high’ risk of slope-failure have been used to produce . Employing the principles of avalanche mapping, landform data have been used to identify likely routes of peatslide flow should these identified sites of potential initiation suffer slope-failure. The resulting ‘peatslide corridors’ (see Figure 118) consist of:

- ground that would be directly or indirectly impacted by any peatslide itself;
- those water bodies/water-courses with the potential to be affected by mass movement of peat down the water channel, as occurred at Derrybrien, Co. Galway; and
- those water bodies/water-courses with the potential to be affected by increased sedimentation of peat and sub-soil resulting from erosion by rain of displaced peatslide material, subsequent to the peatslide itself.

Several features are immediately evident from Figure 118, according to the criteria described above:

- firstly, a high proportion of the main river systems within the proposed development area would be subject to peatslide risk;
- only one section of the proposed development – the north-western arm - is free from peatslide risk;
- all other parts of the proposed development contain two or more major river systems potentially at risk;
- there is a large concentration of potential ‘initiator’ sites in the centre of the development;
- every river system or water body that could be affected by more than one potential initiator site is at a greater degree of risk, and the risk increases with the number of potential initiator sites involved; thus the Abhainn Bharabhais is of particular concern, so too is Loch Mor an Starr, but these are not the only such examples.

The mapping of these geographical consequences is a relatively straightforward process, given existing information about peat depth, landform and at least some information about ground conditions. Indeed to some extent even the mapping of ‘likelihood’, in terms of identifying potential initiator sites, is fairly self-evident. It is not therefore clear why the data gathered to produce LWP 2006 EIS, Vol.3, Chap.17, Fig.17.01 have been used to display only ‘Peatslide Prone Locations’ rather than more extensive areas susceptible to peatslide impact. While LWP 2006 EIS, Vol.3, Chap.17, Fig.17.01 does show stretches of ground, sometimes along sections of river systems, that have been identified by LWP’s peatslide hazard mapping procedures, these areas are evidently highly constrained and cannot be regarded as realistic indications of the geographical extent of impact should slope-failure occur. Even more constrained, almost to the point of being meaningless, is the subsequent map given in LWP 2006 EIS, Vol.3, Chap.17, Fig.17.02, which reduces 'Peatslide Risk Areas' to mere dots. While these may be the sites of potential *initiation* (according to LWP's analysis), they offer no clue about the likely geographical extent of impacts in the event of slope-failure.

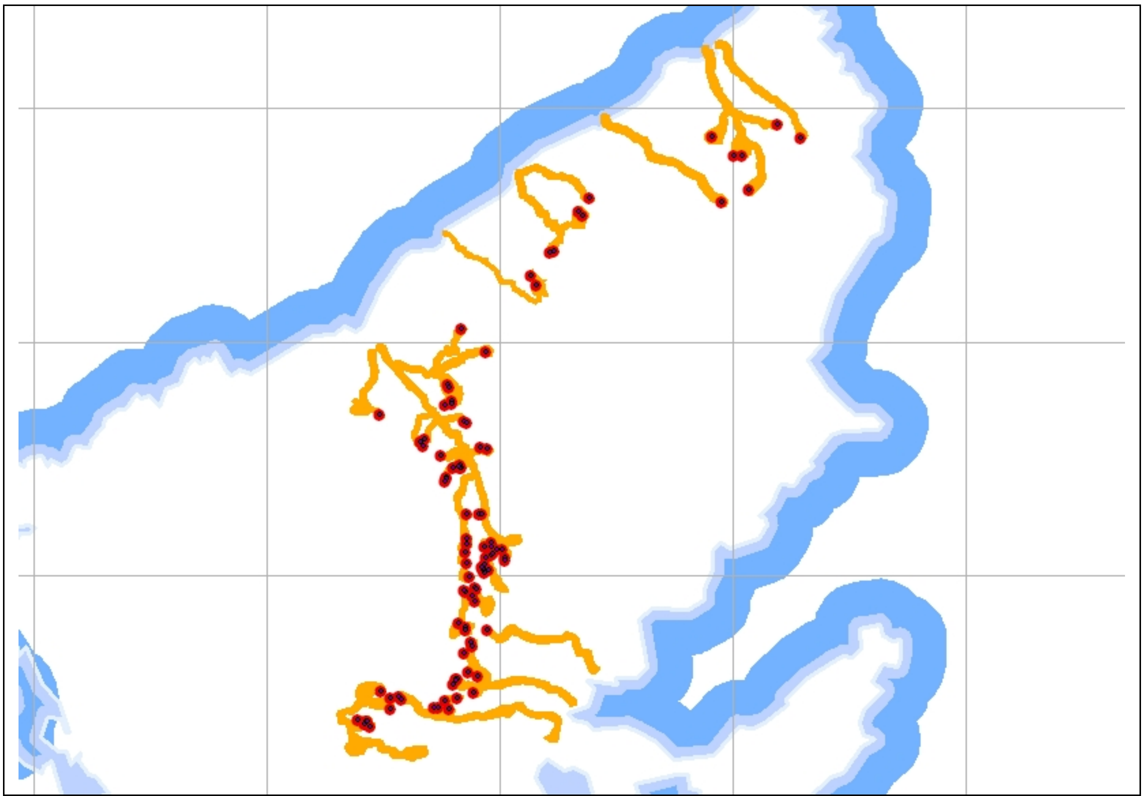


Figure 118. Potential peatslide corridors.
Peatslide corridors associated with the LWP development proposal. Corridors have been constructed on the basis of identified sites of possible/potential initiation – i.e. sites considered to have a moderate, high or very high peatslide risk (red dots – and see Figure 89). Using landform data, the probable route of any peatslide, or of material washed out from a peatslide, has been mapped by following main likely routes of water flow. In this way, the main river systems potentially at risk from peatslide events have been identified. The coastline is shown as concentric blue shading, while the OS National grid is shown as pale grey lines representing 10 km squares.

9.1.4.2 UEL assessment of 'cost consequences'

There are significant features of interest that lie within the boundaries of the peatslide corridors shown in Figure 118, but clearly the majority of these corridors will consist of the water bodies themselves, namely the lochs and stream-courses into which material may flow, rather than the adjaqcent blanket mire environment. The task of assessing the potential impacts (environmental, financial and social) on these freshwater systems lies beyond the scope of the UEL project. So too do the various environmental costs associated with bird habitat, and social costs relating to loss of agricultural capacity on any affected ground.

In general, the peatland ground that is at risk from such slope failure has already been incorporated into the boundaries of the Zones of Concern (ZoCs) discussed in Section 8.2.7 of the present report. Consequently there is little to add here in terms of potential environmental 'cost consequences' for features such as 'active blanket bog'.

However, such cost consequences – environmental, financial and social - would have been relatively straightforward for LWP to pull together for these (largely) freshwater systems, even if only indicatively. The potential financial cost consequences are likely to be substantial, but this is all the more reason for such an exercise to be undertaken and to form a key part of the EIA. That LWP chose not to do so represents yet another major failing of the LWP EIA approach.

10 CONCLUSION

As stated at the start of the present report, the purpose of the report is to review the nature of the evidence presented in the LWP EIS documents, and examine critically the scope, treatment and interpretation of the evidence in those documents. It is not the purpose of the present report to act as an advocate for the conservation (or otherwise) of the Lewis Peatlands.

That said, it is difficult to spend so much time investigating the Lewis Peatlands, their nature, diversity and functioning, while at the same time considering the potential impact of the LWP development on that environment, without coming to the conclusion that this is a development wholly out of keeping with the nature and sustainable maintenance of this internationally-important landscape.

Indeed Dr Tom Dargie, ecological consultant to Lewis Wind Power, has emphasised that he has:

> *"...from the outset of involvement in 2001, advised Lewis Wind Power to abandon the Lewis proposal due to the international conservation status of most of the site..."*
>
> *Dargie (2007c)*

In this, the authors of the present report cannot help but find themselves in complete agreement with Dr Dargie.

11 REFERENCES

AGEC (2004) *Reports on Derrybrien Windfarm – Final Report on Landslide of October 2003 – Final Report on Post-Landslide Site Appraisal*. Applied Ground Engineering Consultants Ltd. for Electricity Supply Board International, 04 February 2004. Bagenalstown, Co. Carlow, Ireland : AGEC Ltd.

Alleotti, P. and Chowdhury, R. (1999) Landslide Hazard Assessment: summary review and new perspectives. *Bulletin of Engineering Geology and Environment*, 58, 21-44.

Attohokine, B. (1992) Investigation of post-construction failure of a lightly trafficked road in Ghana. *Proceedings of the Institution of Civil Engineers-Municipal Engineer,* 93(1), 51-55.

Averis, A.G.B & Averis, A.M. (1995) The vegetation of upland areas around Loch Seaforth, North Harris, Outer Hebrides, Scotland. Scottish Natural Heritage contract report NW/S/044/94.

Averis, B and Averis, A. (2007) *An assessment of the occurrence of H10b and M15c heath vegetation in northern Scottish peatlands*. Report commissioned by Dr Tom Dargie, Boreas Ecology, Sutherland.

Barber, K.E. (1981) Peat Stratigraphy and Climate Change : A palaeoecological test of the theory of cyclic peat bog regeneration. Rotterdam : A.A. Balkema.

Belyea , L. and Clymo , R.S. (1998). Do hollows control the rate of peat growth? In: V. Standen, J.H. Tallis and R. Meade (Eds.) *Patterned Mires and Mire Pools. Origin and Development; flora and fauna. (Proceedings of the Mires Research Group Conference, University of Durham, 6-7 April 1998.)* London : British Ecological Society.

Birks, H.J.B. (1973) *Past and Present Vegetation of the Island of Skye*. Cambridge : Cambridge University Press.

Birse, E.L. (1980) *Plant Communities of Scotland : A Preliminary Phytocoenonia*. Soil Survey of Scotland, Bulletin No.4. Craigiebuckler, Aberdeen : The Macaulay Institute for Soil Research.

Boatman, D.J. (1983) The Silver Flowe National Nature Reserve, Galloway, Scotland. *Journal of Biogeography*, 10, 163-274.

Boatman, D.J., Goode, D.A. and Hulme, P.D. (1981) The Silver Flowe – III Pattern development on Long Lock and Craigeazle mires. *Journal of Ecology*, 69, 897-918.

Boelter, D.H. (1965) Hydraulic properties of peats. *Soil Science*, 100, 227-231.

Boelter, D.H. (1972) Water table drawdown round an open ditch in organic soils. *Journal of Hydrology*, 15, 329-340.

Bogie, R., Hunter, R.F. and Knight, A.H. (1958) Studies in the root development of plants in the field using radioactive tracers. *Journal of Ecology*, 46, 621-639.

Bord na Mońa (2001) *Milled Peat Production*. Newbridge, Co. Kildare : Bord na Mońa.

Bostock, J.L. (1980) The History of the Vegetation of the Berwyn Mountains, North Wales, with emphasis on the development of blanket mire. Unpublished PhD thesis, University of Manchester.

Bower, M.M. (1962) The cause of erosion in blanket peat bogs: a review of recent work in the southern Pennines. *Scottish Geographical Magazine*, 78, 33-43.

Bowes, D.R. (1960) A bog burst on the Isle of Lewis. *Scottish Geographical Magazine*, 76, 21-23.

Bragg, O.M. (1982) *The acrotelm of Dun Moss*. Unpublished PhD thesis. University of Dundee.

Bragg, O.M., Hulme, P.D., Ingram, H.A.P., Johnston, J.P. and Wilson, A.I.A. (1994) A maximum-minimum recorder for shallow water tables, developed for ecohydrological studies on mires. *Journal of Applied Ecology*, 31(3), 589-592.

Bragg, O.M. and Tallis, J.H. (2001) The sensitivity of peat-covered upland landscapes. *Catena*, 42, 345-360.

Braun-Blanquet, J. (1932) *Plant Sociology : The Study of Plant Communities*. [English transl. edn. by G.D. Fuller and H.S. Conard]. New York : McGraw-Hill.

Bryson, B. (2003) *A Short History of Nearly Everything*. London : Doubleday.

Casadei, M., Dietrich, W.E. and Miller, N.L. (2003) Testing a model for predicting the timing and location of shallow landslide initiation in soil-mantled landscapes. *Earth Surface Processes and Landforms*, 28, 925-950.

Chapman, T. and Green, G. (2004) Observational Method looks set to cut city building costs. *Civil Engineering*, 157, August 2004, Paper 13416, pp. 125–133.

Charman, D.J. (1993) Patterned fens in Scotland: evidence from vegetation and water chemistry. *Journal of Vegetation Science*, 4, 543-552.

Charman, D.J. (1994) Patterned fen development in northern Scotland: developing a hypothesis from palaeoecological data. *Journal of Quaternary Science*, 9(3), 285-297.

Charman, D.J. (1995) Patterned fen development in northern Scotland: hypothesis testing and comparison with ombrotrophic blanket peats. *Journal of Quaternary Science*, 10(4), 327-342.

Carlson, R.E. (1972) The Liverpool and Manchester Railway Project, 1821-1831. Newton Abbot : David and Charles.

Clymo, R.S. and Hayward, P.M. (1982) The ecology of *Sphagnum*. In: A.J.E. Smith (Ed.) *Bryophyte Ecology*. pp.229-291. Newton Abbot : David and Charles.

Clymo, R.S. and Duckett, J.G. (1986) Regeneration of *Sphagnum*. *New Phytologist*, 102, 589-614.

Collins, M. (2005) Derrybrien: *The struggle of a small rural community to have its voice heard*. Unpublished research project for Diploma in Community Development Practice – Derrybrien, Loughrea, Co. Galway. (See: The Woodland League website)

Conway, V.M. (1954) Stratiography and pollen analysis of southern Pennine blanket peats. *Journal of Ecology*, 42, 117-147.

Coupar, A., Immirzi, P. and Reid, E. (1997) The nature and extent of degradation in Scottish blanket mires. In: J.H. Tallis, R. Meade and P.D. Hulme (Eds.) *Blanket Mire Degradation – Causes, Consequences and Challenges*. Proceedings of a British Ecological Society symposium held at the University of Manchester, 9-11 April 1997. pp. 90-100. Aberdeen : Macaulay Land Use Research Institute.

Couwenberg, J. and Joosten, H. (2005) Self-organization in raised bog patterning: the origin of microtope zonation and mesotope diversity. *Journal of Ecology*, 93(6), 1238-1248.

Crampton, C.B. (1911) *The Vegetation of Caithness Considered in Relation to the Geology*. Committee for the survey and study of British vegetation.

Crawford, R.M.M. (1997) Oceanicity and the Ecological Disadvantages of Warm Winters. *Botanical Journal of Scotland*, 49(2), 205-221.

Creighton, R. (Ed.) (2006a) *Landslides in Ireland*. Dublin : Geological Survey of Ireland.

Creighton, R. (2006b) *The Irish Landslide Database*. In: R. Creighton (Ed.) *Landslides in Ireland*. pp.9-22. Dublin : Geological Survey of Ireland.

Crowe, S. K. (2007) The Natural Revegetation of Eroded Blanket Peat: Implications for Blanket Bog Restoration. Unpublished PhD thesis, The University of Manchester.

Darby, H.C. (1956) *The Draining of the Fens*. Cambridge : Cambridge University Press.

Dargie, T. (2007a) *Lewis Wind Farm: Rebuttal of the 2005 and 2007 Lindsay Observations on Habitats and Ecological Assessment – Technical Rebuttal Report to Lewis Wind Power*. Dornoch : Boreas Ecology.

Dargie, T. (2007b) *Lewis Wind Farm: Rebuttal of the 2005 and 2007 Lindsay Observations on Habitats and Ecological Assessment – Summary Rebuttal Report to Lewis Wind Power*. Dornoch : Boreas Ecology.

Dargie, T. (2007c) Predicting the impact of windfarm developments on blanket bog habitat: approach and professional standards in the case of the conntroversial proposed Lewis Windfarm. *IMCG Newsletter*, Issue 2007/4, 9-14.

Dayton, N. (2003). *NVC survey and habitat condition assessment of Lewis Peatlands candidate Special Area for Conservation.* Unpublished report to Scottish Natural Heritage by the Quadrat Consultancy. SNH Contract No. BAT/LC06/01/02/99. Battleby, Scottish Natural Heritage.

Dykes, A.P. (in press) Properties of peat relating to instability of blanket bogs. *Proceedings of the 10th International Symposium on Landslides and Engineered Slopes*. Rotterdam : A.A. Balkema.

Edil, T.B. (1997) Construction over peats and organic soils. Conference on Recent Advances in Soft Soil Engineering, 5-7 March, 1997, Kuching, Sarawak, pp.85-108.

EEC Council of Ministers (1997) Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment. Official Journal NO. L 073, 14/03/1997 P. 0005

Eurola, S., Hicks, S., and Kaakinen, E. 1984. Key to Finnish mire types. In: P.D. Moore (Ed.) European Mires. pp. 11-118. London : Academic Press.

Eggelsmann, R. (1975) Physical effects of drainage in peat soils of the temperate zone and their forecasting. In: *Hydrology of Marsh-Ridden Areas : Proceedings of a symposium held at Minsk, 1972*. pp. 69-76. Co-edition IAHS/UNESCO *UNESCO Studies and reports in hydrology 19, Publication 105*. Paris : The UNESCO Press. Available from: http://www.cig.ensmp.fr/~iahs/redbooks/105.htm

Essex Planning Officers' Association (1994) *The Essex Guide to Environmental Assessment*. (revised edn.) Chelmsford : Essex County Council.

European Commission (1999) *Guidelines for the Assessment of Indirect and Cumulative Impacts as well as Impact Interactions*. Luxembourg : Office for Official Publications of the European Communities.

European Commission (2001) *Guidance on EIA : Scoping*. Luxembourg : Office for Official Publications of the European Communities.

European Commission (2003) *Interpretation Manual of European Union Habitats – EUR 25*. Brussels : European Commission, DG Environment.

Evans, M.G., Burt, T.P., Holden, J. and Adamson, J.K. (1999) Runoff generation and water table fluctuations in blanket peat: evidence from UK data spanning the dry summer of 1995. *Journal of Hydrology, 221*, 141–160

Evans, M., Allott, T., Holden, J., Flitcroft, C. and Bonn, A. (Eds.) (2005) Understanding Gully Blocking in Deep Peat. Moors for the Future Report No.4. Castleton : Moors for the Future. (see also Moors for the Future website below)

Everingham, F. and Mayer, P. (1991) *A Peatland Survey of Lewis (1987-89) : Introduction, Methods and Discussion*. NCC Contract Survey Report No. 132. Peterborough : Nature Conservancy Council.

Farrell, E.R., Long, M., Gavin, K and Henry, T. (2006) Geotechnics of Landslides. *In*: R. Creighton (Ed.) *Landslides in Ireland*. Dublin : Geological Survey of Ireland.

Fealy, R. (2006) Landslide Susceptibility Mapping. In: R. Creighton (Ed.) *Landslides in Ireland*, pp. 32-46. Dublin : Geological Survey of Ireland.

Finno, R.J. and Calvello, M. (2005) Supported Excavations: the Observational Method and Inverse Modeling. *Journal of Geotechnical and Geoenvironmental Engineering, ASCE,* 131(7), pp. 826-836.

Foster, A.P. and Procter, D.A. (1995) The Occurrence of Some Scarce East Anglian Fen Invertebrates in Relation to Vegetation Management. In: B.D. Wheeler, S.C. Shaw, W.J. Fojt, R.A. Robertson (Eds.) *Restoration of Temperate Wetlands*. pp. 223-240. Chichester : John Wiley and Sons.

Gilman, K. (1994) *Hydrology and Wetland Conservation.* Chichester : John Wiley and Sons.

Gimmingham, C.H. (1997) Opening Address: 'Burnett, 1964' and After. Botanical Journal of Scotland, 49(2), 117-126. Scottish Vegetation: Plant Ecology in Scotland – Special Issue of Papers from the Botanical Society of Scotland Symposium, University of Stirling, 6-8 September, 1996, ed. by J. Proctor.

Glaser, P.H. (1992) Ecological development of patterned peatlands. In: H.E. Wright, B.A. Coffin and N.E. Aaseng (Eds.) *The Patterned Peatlands of Minnesota*. pp. 27-42. Minneapolis : University of Minnesota Press.

Godwin, H. and Conway, V.M. (1939) The ecology of a raised bog near Tregaron, Cardiganshire. *Journal of Ecology*, 27, 315-359.

Goode, D.A. (1970) *Ecological Studies on the Silver Flowe Nature Reserve*. Unpublished PhD thesis, University of Hull.

Goode, D.A. (1972) Criteria for selection of peatland nature reserves in Britain. *Proceedings of the 4th International Peat Congress, I-IV, Helsinki*, 167-177.

Goode , D.A. (1973). The significance of physical hydrology in the morphological classification of mires. In: *Proceedings of the International Peat Society Symposium, Glasgow, 1973.* Classification of Peat and Peatlands, Paper 3.

Goode, D.A. (1974) The flora and vegetation of Shetland. In: R. Goodier (Ed.) *The Natural Environment of Shetland*. Edinburgh : Nature Conservancy Council.

Goode, D.A. and Lindsay, R.A. (1979) The peatland vegetation of Lewis. *Proceedings of the Royal Society of Edinburgh*, 77B, 279-293.

Göransson, C., Hellman, K., Löfroth, M., Månsson, M., Ots, T., Forslund, M. and Rundlöf, S. (1983) Våtmarksinventering i sydvästra Sverige [Mire inventory of south-west Sweden] – Katalog över särskilt värdefulla objekt. Rapport snv pm 1681. Solna : Statens naturvärdsverk Biblioteket.

Gould, R, Bedell, P.R. and Muckle, J.G. (2002) Construction over organic soils in an urban environment: four case histories. *Canadian Geotechnical Journal,* 39(2), 345-356.

Hanrahan, E.T. (1964) A road failure on peat. *Geotechnique,* 14, 185-202.

Harlow, J and Leake, J. (2007) Could it happen here? *The Sunday Times, Aug 5th 2007, Focus*, p.13.

Hawking, S. (1988) A Brief History of Time : from the Big Bang to black holes. London : Bantam Press.

Haefli, R. (1948) The stability of slopes acted on by parallel seepages. Proceedings of the 2nd International Conference on Soil Mechanics and Foundation Engineering, Rotterdam, 1, pp.134-148.

Hobbs, N.B. (1986) Mire morphology and the properties and behaviour of some British and Foreign peats. *Quarterly Journal of Engineering Geology*, 19, 7-80.

Holden, J. (2005) Peatland hydrology and carbon release: why small-scale process matters. *Philosophical Transactions of the Royal Society, A,* 363, 2891-2913. doi:10.1098/rsta.2005.1671

Holden, J and Burt, T.P. (2002) Piping and pipeflow in a deep peat catchment. *Catena,* 48, 163-199.

Holden, J., Burt, T.P. and Vilas, M. (2002) Application of ground-penetrating radar to the identification of subsurface piping in blanket peat. *Earth Surface Processes and Landforms,* 27, 235-249.

Holden, J and Burt, T. (2003) Runoff production in blanket peat covered catchments. *Water Resources Research*, 39(7), 1191,doi:10.1029/2003WR002067.

Holden, J., Hobson, G., Irvine, B., Maxfield, E., James, T. and Brookes, C. (2005) Strategic locations for gully blocking in deep peat. In: M. Evans, T. Allott, J. Holden, C. Flitcroft and A. Bonn (Eds.) *Understanding Gully Blocking in Deep Peat. Moors for the Future Report No.4*. pp. 77-95. Castleton : Moors for the Future. (see also Moors for the Future website below)

Holden, J., Evans, M.G., Burt, T.P. and Horton, M. (2006) Impact of Land Drainage on Peatland Hydrology. *Journal of Environmental Quality*, 35, 1764-1778.

Hulme, P.D. (1985) The peatland vegetation of the Isle of Lewis and Harris and the Shetland Islands, Scotland. *Aquilo, Seria Botanica*, 21, 81-88.

Hulme, P.D. and Blyth, A.W. (1984) A classification of the peatland vegetation of the Isle of lewis and Harris, Scotland. *Proceedings of the 7th International Peat Congress, Dublin 1984*, 188-204.

Hunter, R.F. and Grant, S.A. (1971) The Effect of Altitude on Grass Growth in East Scotland. *Journal of Applied Ecology*, 8(1), 1-19.

Ingram, H.A.P. (1982) Size and shape in raised mire ecosystems: a geophysical model. *Nature*, 297, 300 - 303 (27 May 1982).

Ivanov, K.E. (1981) *Water Movement in Mirelands*. [Engish transl. edn. by A. Thompson and H.A.P. Ingram]. London : Academic Press.

Jefferies, T.A. (1915) Ecology of the Purple Heath Grass (Molinia Caerulea) [sic.]. *Journal of Ecology*, 3(2), 93-109.

Joint Nature Conservation Committee (JNCC) (1994) Guidelines for selection of biological SSSIs : bogs. Supplement to Guidelines for selection of biological SSSIs (Nature Conservancy Council, 1989). Peterborough : JNCC.

Jones, D.B., Maddison, J.D. and Beasley, D.H. (1995) Long-term performance of clay and peat treated by surcharge. *Proceedings of the Institution of Civil Engineers-Geotechnical Engineering,* 113(1), 31-37.

Joosten, H. and Clarke, D. (2002) *Wise Use of Mires and Peatlands – background and principles including a framework for decision-making*. Totness, Devon : International Mire Conservation Group and International Peat Society.

Karofeld, E. (1999) *Formation and development of microtopography on Estonian raised bogs.* Tallinn Pedagogical University University Dissertations on Natural Sciences 2. Tallinn : TPÜ Kirjastus.

Konovalov, P.A. and Zekhniev, F.F. (2005) Experimental multi-layered water-saturated soils consolidation with the help of vertical drains. *16th International Conference on Soil Mechanics and Geotechnical Engineering*, *12-16 Sept. 2005, Osaka, Japan*, pp.1211-1213.

Laitinen, J., Rehell, S. and Huttunen, A. (2005) Vegetation-related hydrotopographic and hydrologic classification for aapa mires (Hirvisuo, Finland). *Annales Botanici Fennici*, 42, 107-121.

Landva, A.O. (1980) Vane testing in peat. *Canadian Geotechnical Journal*, 17(1), 1-19.

Lindsay, R.A. (1995) Bogs: The Ecology, Classification and Conservation of Ombrotrophic Mires. Battleby, Perth : Scottish Natural Heritage.

Lindsay, R.A. (2005) Lewis Wind Farm Proposals : observations on the official Environmental Impact Statement. Commissioned Research Report for the RSPB. London : University of East London.

Lindsay, R.A. (2007) *Comments on (LWP 2006) Addendum to the Environmental Statement*. Unpublished report for the Royal Society for the Protection of Birds (RSPB). Available from RSPB website.

Lindsay, R.A., Riggall, J. and Burd, F. (1985) The use of small-scale surface patterns in the classification of British peatlands. *Aquilo, Seria Botanica*, 21, 69-79.

Lindsay, R.A., Charman, D.J., Everingham, F., O'Reilly, R.M., Palmer, M.A., Rowell, T.A. and Stroud, D.A. (1988) *The Flow Country : The Peatlands of Caithness and Sutherland*. Peterborough : Nature Conservancy Council.

Lindsay, R.A. and Ross, S.Y. (1994) Monitoring of peat bog systems. pp.73-92. In: *Monitoring of Ecological Change in Wetlands of Middle Europe. Proc. International Workshop, Linz, Austria, 1993.* Stapfia 31, Linz, Austria, and IWRB Publication No. 30, Slimbridge, UK.

Lindsay, R.A., Steer, J.M., Everingham, F., Bragg, O.M., Brown, A and Freeman, J. (2003) *Munsary Peatlands Monitoring Project – Establishment of Monitoring ('Surveillance') Baseline*. Salisbury : Plantlife International.

Lindsay, R.A. and Bragg, O.M. (2004) Windfarms and Blanket Mires : The Bog Slide of 16th October 2003 at Derrybrien, Co. Galway, Ireland. London : University of East London.

MacDonald, A., Stevens, P., Armstrong, H. Immirzi, P and Reynolds, P. (1998) *A guide to upland habitats: surveying land management impacts* (2 vols.). Battleby : Scottish Natural Heritage.

Mackay, A.N. and Tallis, J.A. (1996) Summit-type blanket mire erosion in the Forest of Bowland, Lancashire, UK: Predisposing factors and implications for conservation. *Biological Conservation*, 76, 31-44.

Maltby, E., Legg, C.J. and Proctor, M.C.F. (1990) The ecology of severe moorland fire on the North York moors: effect of the 1976 fires and subsequent surface and vegetation development. *Journal of Ecology*, 78, 490-518.

Masing, V. (1982) The plant cover of Estonian bogs: a structural analysis. *In*: V. Masing (Ed.) *Peatland Ecosystems*. pp. 50-92. Tallinn : Valgus.

McManus, K., Hassan, R. and Sukkar, F. (1997) Founding embankments on peat and organic soils. *Conference on Recent Advances in Soft Soil Engineering, 5-7 March, 1997, Kuchung, Sarawak,* pp.351-366.

McVean, D.N. and Ratcliffe, D.A. (1962) Plant Communities of the Scottish Highlands. Monographs of the Nature Conservancy, No.1. London : HMSO.

Meade, R. (1997) Introduction. *In*: J.H. Tallis, R. Meade and P.D. Hulme (Eds.) *Blanket Mire Degradation – Causes, Consequences and Challenges*. Proceedings of a British Ecological Society symposium held at the University of Manchester, 9-11 April 1997. pp. 1-2. Aberdeen : Macaulay Land Use Research Institute.

Ministry of Defence (1994) Geotechnical Investigations for Design and Construction of Airfield Pavements. Defence Works Functional Standards 09. London : HMSO.

Moen, A. (1985) Classification of mires for conservation purposes in Norway. *Aquilo, Seria Botanica*, 21, 95–100.

Moen, A. (1990) The plant cover of the boreal uplands of central Norway. I. Vegetation ecology of Sølendet nature reserve; haymaking fens and birch woodlands. *Gunneria*, 63: 1–451.

Moen, A. (1999) *National Atlas of Norway – Vegetation*. Hønefoss : Norwegian Mapping Authority.

Moores, A.J. and Stevenson, A.C. (undated) A preliminary investigation into the significance of climate and land management history on the prevalence of Racomitrium lanuginosum on the blanket bogs of Lewis. Unpublished report to SNH by Department of Geography, University of Newcastle-upon-Tyne. SNH Contract No. BAT/97/98/53. Stornoway : Scottish Natural Heritage.

Müller-Dombois, D. and Ellenberg, H. (1974) *Aims and methods of vegetation ecology*. New York : John Wiley and Sons.

Murphy, S. (2006) A geophysical investigation into the peat failures on Dooncarton Mountain, County Mayo, Ireland. *Geophysical Research Abstracts*, 8, 07216, 2006 SRef-ID: 1607-7962/gra/EGU06-A-07216

National Wetland Working Group (NWWG) (1988) *Wetlands of Canada.* Environment Canada, Ecological Land Classification Series 24. Montreal : Polyscience Publishers.

Nature Conservancy Council (NCC) (1989) *Guidelines for selection of biological SSSIs*. Peterborough : Nature Conservancy Council.

New Civil Engineer (2007) Failure at Seafield pumping station : news item. 26 April 2007.

Nichol, D. (1998) Construction over peat in Greater Vancouver, British Columbia. *Proceedings of the Institution of Civil Engineers-Municipal Engineer,* 127(3), 109-119.

Nichol, D. and Farmer, I.W. (1998) Settlement over peat on the A5 at Pant Dedwydd near Cerrigydrudion, North Wales. *Engineering Geology,* 50(3-4), 299-307.

O'Mahony, M.J., Ueberschaer, A., Owende, P.M.O. and Ward, S.M. (2000) Bearing capacity of forest access roads built on peat soils. *Journal of Terramechanics*, 37, 127-138.

Osvald, H. (1923) Die Vegetation des Hochnmoores Komosse, Kap. 5 [The vegetation of the raised bog Komosse, Chapter 5]. *Svenska Växtsociologiska Sällskapets Handlingar*, I, 265-310.

Osvald, H. (1925) Zur Vegetation der ozeanishen Hochmoore in Norwegen [The vegetaton of oceanic raised bogs in Norway.] *Svenska Växtsociologiska Sällskapets Handlingar,* VII, 1-106.

Osvald, H. (1949) Notes on the vegetation of British and Irish Mosses. *Acta Phytogeographica Suecica*, 26, 1-62.

Pearsall, W.H. (1956) Two blanket-bogs in Sutherland. *Journal of Ecology*, 44, 493-516.

Pellicer, X. (2006) Bréifne Area Landslides Susceptibility Mapping. *In*: R. Creighton (Ed.) *Landslides in Ireland*. pp. 47-64. Dublin : Geological Survey of Ireland.

Phillips, J. (2005) Windfarm Developments of Blanket Bog: A cautionary tale from Derrybrien, Co. Galway, and pointers for safeguards needed when similar developments are proposed for the United Kingdom. Unpublished report for the Scottish Wind Assessment Project (www.swap.org.uk).

Ratcliffe, D.A. (Ed) (1977) *A Nature Conservation Review*. Cambridge : Cambridge University Press.

Rahadian, H., Satriyo, B. and Peryoga, T. (2003) 2nd International Conference on Advances in Soft Soil Engineering and Technology, 2-4 July, 2003, Putrajaya, Malaysia, pp.387-397.

Rodwell, J.S. (Ed.) (1991) *British Plant Communities Vol.2: Mires and Heaths*. Cambridge : Cambridge University Press.

Ruuhijärvi, R. (1960) Über die regionale Einteilung der nordfinnischen Moore. [Regional variation in north Finnish mires.] — *Annales Botanici Societatis Zoologicae Botanicae Fennicae Vanamo*, 31, 1–360.

Sakurai, S., Akutagawa, S., Takeuchi, K., Shinji, M. and Shimiju, N. (2003) Back analysis for tunnel engineering as a modern observational method. *Tunnelling and Underground Space Technology*, 18, 185-196

Saorgus Energy Ltd. (2000) *Environmental Assessment : Derrybrien Wind Farm Extension*. Tralee, Ireland : Saorgus Energy Ltd.

Scottish Executive (2006) Peat Landslide Hazard and Risk Assessments **:** Best Practice Guide for Proposed Electricity Generation Developments. Edinburgh : Scottish Executive.

Scottish Wind Assessement Project (2006) *The Politics of Peat : Lessons from the Derrybrien landslide*. Unpublished report by SWAP. See SWAP website (www.swap.org.uk).

Seppällä, M. (1999) Geomorphological aspects of road construction in a cold environment, Finland. *Geomorphology*, 31, 65–91.

Shotbolt, L., Anderson, A.R. and Townend, J. (1998) Changes to a blanket bog adjoining forest plots at Bad a' Cheo, Rumster Forest, Caithness. *Forestry*, 71 (4), 311-324.

Sjörs, H. 1948. Myrvegetation i Bergslagen [Mire vegetation in Bersglagen, Sweden]. *Acta Phytogeographica Suecica*, 21, 1-299 [English summary: 277-299].

Skempton, A.W. and DeLory, F.A. (1957a) Stability of natural slopes in London Clay. Proceedings of the 4th International Conference on Soil Mechanics and Foundation Engineering, Rotterdam, 2, pp.72-78.

Skempton, A.W. and DeLory, F.A. (1957b) Stability of natural slopes in London Clay. *American Society of Civil Engineers (ASCE) Journal*, 2, 378-381.

Spence, D. (1979) Shetland's Living Landscape : A Study in Island Plant Ecology. Lerwick : The Thule Press.

Standen, V., Tallis, J.H. and Meade, R. (Eds.) (1998) *Patterned Mires and Mire Pools : Origin and Development; flora and fauna*. Proceedings of a British Ecological Society Mires research group Conference at the University of Durham, 6-7 April, 1998. London : British Ecological Society.

Standen, V and Owen, M.J. (1999) An evaluation of the use of translocated blanket bog vegetation for heathland restoration. *Applied Vegetation Science*, 2, 181-188

Steiner, G.M. (1992) *Österreichischer Moorschutzkatalog. [Austrian Mire Conservation Catalogue.]* Wein : Bundesministerium für Umwelt, Jungend und Familie.

Steiner, G.M. (2005) *Moortypen. [Mire classification]* (with English abstract). In: G.M. Steiner (Ed.), *Moore von Sibirien bis Feuerland. [Mires from Siberia to Tierra del Fuego.]* pp. 5 – 26. Linz : Land Oberösterreich, Biologiezentrum / Oberösterreichische Landesmuseen.

Stevenson, A.C., Jones, V.J. and Battarbee, R.W. (1990) The cause of peat erosion : a palaeolimnological approach. *New Phytologist*, 114, 727-735.

Stewart, A.J.A. and Lance, A.N. (1983) Moor draining: a review of impacts on land use. *Journal of Environmental Management*, 17, 81-99.

Stewart, A.J.A. and Lance, A.N. (1991) Effects of moor-draining on the hydrology and vegetation of northern Pennine blanket bog. *Journal of Applied Ecology*, 28, 1105-17.

Stoneman, R. and Brooks, S. (Eds.) (1997) *Conserving bogs: the management handbook*. Edinburgh : The Stationery Office.

Tallis, J.H. (1981) Uncontrolled fires. *Moorland Erosion Study, Phase 1 Report* (Ed. by J. Phillips, D. Yalden, and J. Tallis), 176-182. Bakewell, Derbyshire : Peak Park Joint Planning Board.

Tallis, J.H. (1985) Mass movement and erosion of a southern Pennine blanket peat. *Journal of Ecology*, 73, 283-315.

Tallis, J.A. (1995) Climate and erosion signals in British blanket peats: the significance of *Racomitrium lanuginosum* remains. *Journal of Ecology*, 83(6), 1021-1030.

Tallis, J.H. and Livett, E.A. (1994) Pool-and-hummock patterning in a southern Pennine blanket mire: I. Stratigraphic profiles for the last 2800 years. *Journal of Ecology*, 82, 775-788.

Tansley, A.G. (1935) The use and abuse of vegetational concepts and terms. *Ecology*, 16, No. 3, 284-307.

Tansley, A.G. (1939) *The British Islands and their Vegetation*. Cambridge : Cambridge University Press.

Thomas, R.H.G. (1980) *The Liverpool and Manchester Railway*. London : Batsford.

Townend, J., Shotbolt, L and Anderson, R. (1997) Hydrological effects of forest plantations on blanket peat at Rumster Forest, Caithness. In: J.H. Tallis, R. Meade and P.D. Hulme (Eds.) *Blanket Mire Degradation – Causes, Consequences and Challenges*. Proceedings of a British Ecological Society symposium held at the University of Manchester, 9-11 April 1997. pp. 85-86. Aberdeen : Macaulay Land Use Research Institute.

Troels-Smith, J. (1955) Karakterisering af lose jordater [Characterisation of unconsolidated sediments.] *Danmarks Geologiske Undersøgelse* IV series, 3(10), 1-73.

van Baars, S. and Vrijling, J.K. (2005) Geotechnical applications and conditions of the observational method. *HERON,* 50(3), 155-172.

van der Molen, W.H. (1975) Subsidence of peat soils after drainage. In: Hydrology of Marsh-Ridden Areas : Proceedings of a symposium held at Minsk, 1972. pp. 183-186. Co-edition IAHS/UNESCO UNESCO Studies and reports in hydrology 19, Publication 105. Paris : The UNESCO Press. Available from: http://www.cig.ensmp.fr/~iahs/redbooks/105.htm

Varnes, D.J. (1984) Hazard Zonation: Landslide Hazard Zonation : review of principles and practice: Natural Hazards No.3. Paris, UNESCO, International Association of Engineering Geologists, Commission on Landslides and Other Mass Movements on Slopes.

Walter, H. (2002) *Walter's Vegetation of the Earth - The Ecological Systems of the Geo-Biosphere* (4th Edition). Ed. by S.-W. Breckle. New York : Springer Verlag.

Warburton, J., Holden, J., Mills, A.J. (2004) Hydrological controls of surficial mass movements in peat. *Earth-Science Reviews,* 67*,* 139-156.

Warburton, J., Higgit, D. and Mills, A.J. (2004) Anatomy of a Pennine peat slide, Northern England. *Earth Surface Processes and Landforms*, 28, 457-473

Weber, C.A. (1902) Über die Vegetation und Entstehung des Hochmoors von Augstumal im Memldelta [The Vegetation and Development of the Aukštumala Raised Bog in the Memel Delta]. Berlin : Paul Parey.

Wells, D.E. and Zoltai, S. (1985) Canadian system of wetland classification and its application to circumboreal wetlands. *Aquilo, Seria Botanica*, 21, 45-52.

Wheeler, B.D. and Shaw, S.C. (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*. pp. 49-72. Chichester : John Wiley and Sons.

Yang, J and Dykes, A.P. (2006) The liquid limit of peat and its application to the understanding of Irish blanket bog failures. *Landslides*, 3, 205-216.
DOI 10.1007/s10346-006-0038-z

Zoltai, S.C., and Pollett, F.C. 1983. Wetlands in Canada: their classification, distribution and use. In: A.J.P. Gore (Ed.) Mires: Swamp, Bog, Fen and Moor. Regional Studies, 245--268. Amsterdam : Elsevier Scientific (Ecosystems of the World 4B).

Websites

BBC website : Scottish landslide
http://news.bbc.co.uk/1/hi/scotland/3579034.stm

Bord na Mona website : peat milling
http://www.bnm.ie/files/20061124040627_milled_peat_production.pdf

Canadian Sphagnum Peat Moss Association web site : drainage of peat
http://peatmoss.com/pm-harvest.php

Eng-Tips Forum : pre-loading and piling :
http://www.eng-tips.com/viewthread.cfm?qid=136167&page=9

European Commission : guidance on EIA scoping
http://ec.europa.eu/environment/eia/eia-guidelines/g-scoping-full-text.pdf

Forestry Civil Engineering road design:
http://www.forestry.gov.uk/pdf/forestroadsspec.pdf/$FILE/forestroadsspec.pdf

Highway maintenace :
http://www.highwaysmaintenance.com/drainage.htm

Imperial College portal website
http://www3.imperial.ac.uk/portal/pls/portallive/docs/1/587933.PDF

Irvine – Tacoma Narrows Bridge : Wright State University
http://www.cs.wright.edu/~jslater/SDTCOutreachWebsite/tacoma_bridge_failure.pdf

JNCC website : active blanket bog
http://www.jncc.gov.uk/ProtectedSites/SACselection/habitat.asp?FeatureIntCode=H7130

Moore, L. – SERC website : Calculating Factors of Safety
http://serc.carleton.edu/quantskills/workshop05activities/moore.html

Moors for the Future website : Holden *et al*. (2005) gully blocking
http://www.moorsforthefuture.org.uk/mftf/downloads/publications/MFF_Report_No4.pdf

Moors for the Future website : Evans *et al*. (2006) erosion recovery
http://www.moorsforthefuture.org.uk/mftf/main/Home.htm
www.moorsforthefuture.org.uk/mftf/downloads/conferences/2006Conference/2006_conference/MFF_2006Evans.pdf

Peatland Strategy, Caithness and Sutherland:
http://www.snh.org.uk/pdfs/scottish/nhighland/PeatlandsStrategy.pdf

RSPB website : R A Lindsay (2006) report on LWP (2004) EIS
http://www.rspb.org.uk/supporting/campaigns/lewis/index.asp
Lewis Wind Farm Peatland Report

RSPB website : R A Lindsay (2007) report on LWP 2006 Addendum
http://www.rspb.org.uk/supporting/campaigns/lewis/index.asp

RSPB Appendix 1, peatland impacts, comments on LWP addendum

RTE website : Derrybrien bogslide video news item
http://www.rte.ie/news/2003/1029/landslide.html

SERC website : Calculating Factors of Safety
see Moore, L. website reference above

Scottish Wind Assessment Project website : Report by Mr J. Phillips, and Report by Scottish Wind Assessment Project, on Derrybrien peatslide
http://www.swap.org.uk/
http://www.swap.org.uk/Windfarms%20on%20blanket%20peat.pdf

Siltbuster website : products and services
http://www.siltbuster.co.uk/index.html

Siltbuster website : "Know your particle size"
http://www.siltbuster.co.uk/process.html

Tacoma Narrows Bridge : video of collapse, Wikkipedia
http://en.wikipedia.org/wiki/Tacoma_Narrows_Bridge#Collapse

Times Online : Cobra Swamp :
http://www.timesonline.co.uk/tol/news/world/asia/article1299182.ece

UNESCO website : Varnes, D.J. (1984) paper illustrating landslide hazard maps
http://unesdoc.unesco.org/images/0006/000630/063038eb.pdf

UN FAO website : subsidence :
http://www.fao.org/docrep/x5872e/x5872e09.htm

Woodland League website : Report on Derrybrien peatslide by Mr Martin Collins
http://www.woodlandleague.org/communities/derrybrien/

Wright State University website – see Irvine website reference above.

.

12 Appendix 1 Appraisal of Appendix 11E of the Lewis Wind Farm Proposal: Farr Dipwell Studies

Olivia Bragg
School of Social Sciences (Geography), University of Dundee, DD1 4HN, UK

Qualifications and experience

My undergraduate training was in Natural Sciences at Cambridge University, where I combined courses in biological and physical sciences before specialising in Environmental Biology and Biological Resources (B.A. 1975, M.A. 1979). I then joined the University of Dundee as a NERC research student under the supervision of Dr Hugh Ingram. Soon afterwards, Ingram established in peer-reviewed literature that the hydrological basis of mire function is impeded seepage rather than ‘capillary forces’ (published in *Nature*, 1982) combined with their diplotelmic soil structure, and created the English terms ‘acrotelm’ and ‘catotelm’ (published in the *Journal of Soil Science*, 1978). These ideas form the conceptual framework (paradigm) for modern peatland ecology.

My doctoral thesis (1983), based on fieldwork at an upland mire in Perthshire, provided the first account of the hydrological attributes of the acrotelm. I remained in Dundee as a Senior Demonstrator and Research Assistant in Biological Sciences, then as a Research Fellow set up and ran a small research group from Hugh Ingram’s laboratory, for whose activities I created the term ‘mire ecohydrology’. After 7 years in that role I spent a further 7 years as a private consultant, completing numerous assignments providing advice on peatland management and analysing hydrological data (including results of long-term dipwell studies), mostly for nature conservation agencies, whilst retaining my connection with the university first as an Honorary Lecturer in Biological Sciences and then as an Honorary Research Fellow in Geography. In 1998 I returned to University employment as part of a departmental team developing techniques for implementation of the Water Framework Directive in Scotland, which I have since carried out in tandem with peatland work in Europe, Canada, Indonesia and Russia. I am a member of the British Ecological Society, the British Hydrological Society, the International Mire Conservation Group (Main Board member) and the International Peat Society. I have published 15 peer-reviewed papers on peatland ecohydrology, edited or co-edited 3 books on peatlands and written around 60 consultancy reports for various sponsors. Since 2004 I have been Editor of the internet journal *Mires and Peat*. I visited the Derrybrien Wind Farm in 2003 and have examined several wind farm sites on peat in Scotland and Wales.

Remit and approach

The aim of this assignment is to provide a critical appraisal of the account of hydrological investigations carried out by Lewis Wind Power (LWP) in support of their application to develop the Lewis Wind Farm. The investigations were carried out at Farr Wind Farm in Inverness-shire, starting during the construction phase. Farr Wind Farm is sited on blanket peatland that is considered to resemble that on Lewis. The resulting document is 96 pages long and describes the first year’s data from a substantial series of field studies in a format that often separates the methods, results and conclusions for individual studies. Within the two days allocated for production of this appraisal, it has been possible to compile detailed comments on only some parts of the work, although the whole document has been studied and has provided general background.

The stated aim of the work is to investigate the effect of wind farm infrastructure upon the water table and hydraulic conductivity of adjacent blanket mire, and in particular to establish the distance over which any effects operate. There is also an intention to investigate timescales and to classify changes as 'temporary–insignificant' or 'permanent–significant'. Measurements began at various times between 29 September 2005 and 24 February 2006, and data up to the beginning of October 2006 are presented (i.e. 7–12 month runs of data). Some of the conclusions include assessments of 'long term effects' on this basis.

Dipwell studies

There are nine dipwell studies altogether, counting two controls. Five have been selected to form the core of this commentary.

Study	Date installed	No. dipwells	Peat depth	Vegetation*	Relevant sections of report
Control: intact	08 Feb '06	5	Not stated	M17a	Paras. 48 (bullet 1), 57–62; Figs. A11E.1, 2, 3, 12, 13, 14; Plates A11E.8–13; pages 19, 26–27, 36–40, 47–49
Control: microbroken	08 Feb '06	5	Not stated	M17b	
T36 Ditch	01 Feb '06	10	Not stated	M17b	Para. 48 (bullet 8), 100–107 ; Plates A11E29–30; pages 21–22, 72, 75–76
Uisge Dubh	24 Feb '06	12	Zero to >1 m	17 m transect across sequence U5-H12-M15	Para. 48 (bullet 7), 91–99; Figs. A11E.9, 30; Plates A11E.25–28; Pages 21, 31, 71–74, 81
T4	18 Nov '05	18	Not stated	M17b	Para. 48 (bullet 6),81–90; Figs. A11E.26–29; Plates A11E.14–24; Pages 21, 61–70, 77–80

* Key to NVC communities recorded at study locations:
H10 Calluna vulgaris – Erica cinerea dry heath
H12 Calluna vulgaris - Vaccinium myrtillus dry heath
M15 Trichophorum cespitosum (Scirpus cespitosus) – Erica tetralix wet heath
M17a Scirpus cespitosus - Eriophorum vaginatum blanket mire, Drosera rotundifolia - Sphagnum sub-community
M17b Scirpus cespitosus - Eriophorum vaginatum blanket mire, Cladonia sub-community
U5 Nardus stricta - Galium saxatile acidic grassland

Control Studies (NH724292)

Two clusters of 5 dipwells were installed within areas measuring less than 5 m x 5 m, in ‘nearby’ locations at least 25 metres upslope of a floating road. Depth to water table was measured to an accuracy of ±5 mm on *ca*. 30 occasions (i.e. *ca*. weekly) over a period of 8 months (February to early October).

The means of all ‘depth to water table’ readings for intact and microbroken mire differ by 1.5 cm. However, LWP then discard the data from one ‘microbroken’ dipwell located in the floor of a rill (hollow) because they regard it as atypically high (above the surface in wet weather), to make the difference between means 4 cm. Whichever is closer to the true value, the difference is probably statistically insignificant, although the statistics presented do not actually test this.

The data are then used to define, for each control surface type and site visit, an envelope or depth zone within which the water table is located. The envelope chosen is bounded by ‘depth to water table’ values of (mean plus one standard deviation) to (mean minus one standard deviation) (explained most clearly in Para. 52). Once the dipwells have filled up, the envelope for the intact surface type appears from Figures 12 and 13 to range in thickness from 5 cm to around 12 cm (i.e. standard deviation 2.5–6 cm), whereas for microbroken surface the envelope is 16–32 cm thick (standard deviation 8–16 cm).The ‘average single deviation either side of the mean ranges’ given in Para. 61 almost eluded me, but I think these are the average depths below the mire surface of the upper and lower envelope boundaries.

For the ‘microbroken’ site, some of the data lie outside the envelope (Fig. A11E.13). This is not surprising because only 68% (i.e. 3 or 4) of the 5 observations should lie within one standard deviation of the mean (assuming normal distribution). LWP appear not to know this, however, and take steps to bring the rogue traces within the calculated envelope. They do this by ‘adjusting for microtopography’; i.e. they subtract 5–9 cm from the observed values to raise three of the traces closer to the surface. The statistics should already have taken into account all variation in the data, including the effect of microtopography; and moreover the unadjusted data were used to derive the envelope limits in the first place. Thus, the subsequent application of ‘corrections for microtopography’ to make the data fit the statistics is invalid. If an envelope containing most of the observations is required, it would be more appropriate to place its limits two standard deviations (95% of observations) or even three standard deviations (99.7% of observations) from the mean (Empirical Rule).

Indeed, these considerations make all of the ‘corrections for microtopography’ detailed in Table A11E.2 highly questionable. They are not supported by data, and amount to double correction given the nature and use of the control. Thus, in addition to Table A11E.2, Figures 14, 16, 18, 21, 23, 25, 27, 29 and 32 should be discarded. However, before doing this it is worth noting that the adjustment applied for the U5m dipwell in the T38-30 study is designed to remove the ‘significant’ influence of a wind farm ‘road ditch’ (Table A11E.2). Therefore it is possibly unsurprising that this dipwell “shows no signs of significant drying due to that drainage feature” and “no major road effects are detectable in the trends present” (Paragraph 65, page 41). In fact the adjustment amounts to only 1 cm. Such an adjustment seems hardly justifiable when water levels were measured to “0.5 cm accuracy” (Para. 47) and replicate control readings can differ by decimetres (see below); but the fact that it is made at all is worrying since it could be construed as an attempt to mask the effect of one of the features whose impact is under examination.

The ‘microbroken’ control is used to provide the reference condition for all of the experimental studies. This is a degraded condition, presumably resulting from management for grazing that involves drainage and muirburn. By using it as the reference condition, LWP define maintenance of this degraded condition as the 'best possible' outcome for the habitat. In the context of the proposed Lewis development, this does not seem totally consistent with the requirement of the European Birds Directive (Article 3) to repair damaged habitat within SPA areas since, if the intensity of grazing and associated management were reduced, the habitat could be expected to recover towards the 'intact' condition. Thus, there would appear to be a case for making some use of the 'intact' control condition, either in place of or in addition to the 'microbroken' condition, as the reference against which the impact of wind farm development is gauged.

Moving to another attribute of the results for the control sites, the variability of the data is problematic. The statistical analysis indicates that the envelope containing 95% of 'depth to water table' measurements for microbroken surface that is not influenced by wind farm operations is 32–64 cm thick (two standard deviations either side of the mean). Thus, on some days, a water table measurement in microbroken surface elsewhere would have to differ from the mean value for the control plot by more than 16 centimetres before it would be classed as significantly altered; on other days, 32 cm drawdown of the water table would be unremarkable. Such an insensitive technique seems inadequate for flagging up ecologically significant changes in water table position for a habitat where changes in plant species occur if the mean water table level changes by a few millimetres or centimetres. It would still be unacceptably insensitive if the full thickness of the 'natural readings' envelope were only 16–32 cm as claimed, given that a difference of 1.5–4 cm in mean water table between the 'intact' and 'microbroken' control plots is associated already with a change in NVC sub-community.

A large part of the insensitivity probably arises from the choice of datum level. This is effectively set at a different absolute altitude for each dipwell. From characteristics of the traces in Figure A11E.13, I would guess that Dipwells 2 and 4 are located on hummocks, Dipwells 1 and 5 at lawn level and Dipwell 3 in a hollow (we are told that it is actually in a rill); and I would estimate the altitude of the mire surface around Dipwells 1, 5, and 2, relative to the edge of the rill, to be 3, 10, and 20 cm respectively. Plate A11E.11 provides some support for these suggestions. The important point here is that the most of the variability in the control data – and thus most of the insensitivity of the technique – can be associated with the unevenness (microtopography) of the mire surface. Much of this variability could have been avoided by referring the water table measurements to a single recognisable level within the microtopography, such as 'lawn' or 'hollow-edge' level, or the lower limit of *Calluna vulgaris*, following research-based approaches that were already being used 20 years ago in mire ecohydrological research in Sweden and the UK. In order to allow access to hydraulic gradients and comparison of the data with the predictions of models (see later), it would be even better to relate both water and mire surface levels to a stable datum of known absolute altitude.

Another potential source of variability is the unpredictable response times of the instruments. The effect is not noted in LWP's account of the control studies but may underlie the atypical shape of the trace for Dipwell 4 in Figure A11E.13 – e.g. the water table here moves in the opposite direction from that in all the other dipwells during the second half of June and changes little after the beginning of September (note there is probably a transcription error in the reading for Dipwell 2 immediately following 12/09/06). 'Unresponsive' dipwells crop up throughout the other studies, and for some instruments it is difficult to decide to what degree the observed deviations of water table behaviour from that of the controls might reflect instrument lag rather than real hydrological effects. This is probably an instrument design issue, explored in the next paragraph.

In order for the water level in a dipwell to reflect faithfully a change of water table in its surroundings, water must be able to move into or out of the dipwell rapidly enough for equilibration with the pore water in the surrounding soil to occur within a time interval that is short relative to the rate of water table movement. The dominant factor in determining the rate of water exchange between the dipwell and its surroundings is the permeability of the saturated soil material surrounding its walls, and the volume of water that must be transferred per unit change in water table height is proportional to the area of cross-section of the dipwell. The structure of the mire soil profile introduces singular considerations for dipwell design because saturated hydraulic conductivity (permeability) typically declines by one or more orders of magnitude between the surface and a depth of a decimetre or so, and thus the required water exchanges are increasingly impeded as the water table falls below the surface. In raised mire peat, which tends to be more permeable than blanket mire peat, dipwells of diameter *ca*. 1 cm with wall perforations spaced at 1 cm centres are sufficiently responsive for many purposes; but even with this design a time lag can be demonstrated when the water table is low.

These issues are covered in one of the references cited by LWP (Gilman 1994, page 30). Nonetheless, the dipwells used in this study are 3 cm in diameter (Para. 47), and thus require the exchange of nine times the volume of water that would be required for re-equilibration of a dipwell of diameter 1 cm following the same change in water table. Moreover, the perforations in their walls are at vertical intervals of 15 cm, so that the uppermost orifice that is available for water exchange could be as much as 15 cm below the surface and thus in low-permeability peat. These design features are likely to result in undesirably (and unnecessarily) long response times which are amply demonstrated by the time required for a number of the instruments to fill up after installation, and the failure of several of them ever to contain water. Moreover, although Para. 47 states only that “all piezometers had a cap”, none of the dipwells in the Plates is without one. It seems conceivable that some of the dipwells may inadvertently have been made airtight through the combination of widely spaced perforations, low-permeability peat and cap; air trapped inside the dipwell would be compressed as the water level rose, and so would increasingly impede the process of equilibration. There is some evidence of stepping in these ‘slow-response’ traces (e.g. the T38-30 study, Figures A11E.17, 18) that may correspond to release of pressure at the times of readings.

Effect of a ditch: T36 Drainage Ditch Study (NH21288)

In this study, 10 dipwells were placed in typical microbroken blanket bog at spacings of 2 m (0–10 m) and 5 m (10–30 m) on a transect running perpendicular to and downslope from a 0.8 m deep roadside ditch; the effect is thus the combined result of a floating road and a ditch.

The circumstances described on Page 21 are of interest, in that wind farm ES work usually presents floating roads as installations that require no drainage; and yet once construction begins, roadside ditches are added as necessary. The justification for creating this particular ditch appears to have been ecological (to divert road wash away from bog pools), but the specification (depth 0.3 m with a ‘chick-friendly’ cross-section) was substituted - at the discretion of the machine operator - by the 0.8 m excavation shown in Plate A11E.29.

The ditch was excavated on 27 January 2006 and the dipwells were installed 5 days later so that there are no baseline or 'early impact' data. However, the run of data coincides almost exactly with that for the microbroken control study, and comparison of the water level traces for ditch and control (Figs. A11E.13 and A11E.31) is informative.

As we might expect, the water table adjacent to the ditch (0m) oscillates in the range 50–80 cm below surface and the traces for all dipwells up to 10 m away are sufficiently outside the 'control envelope' to be noted as significant (Para. 104).

LWP comment that the water level indicated by the 20m dipwell is also low – initially similar to that of the 4 m dipwell – and suggest that the data from this instrument should be 'corrected for microtopography' (Para. 103). Figure A11E.10 shows that the 20 m dipwell is located on the edge of a pool that is intercepted by the ditch after it bends away from the road. Thus it seems probable that the pool would be drained by the ditch, and thus transmit the impact of the ditch directly to the 20 m dipwell, short-circuiting the resistance to seepage provided by the intervening peat. In other words, impact on hydrology can arise through more than one mechanism in this type of terrain. The proposal that a correction should be applied to remove the effect suggests, perhaps, a rather blinkered approach on the part of LWP.

A striking feature of all of the water level records shown in Fig. A11E.31 is that they fluctuate over greater ranges than any of the control records. For example, the 15 m trace moves from the lower to the upper margin of the 'control envelope' during the reading interval immediately before 08/08/06; none of the control traces (Fig. A11E.13) exhibits such high-amplitude fluctuations. Where seepage has been intercepted by a ditch upslope, additional drawdown of the water table during drought (and thus enhanced amplitude of water table fluctuations) is likely to arise due to the lack of a seepage supply to partly replace water lost by evapotranspiration. Thus there is some evidence in the data to suggest altered hydrology due to the presence of the ditch that is not highlighted by LWP.

An expected consequence of the permanent drawdown observed adjacent to the ditch, as well as any enhanced dry-weather drawdown downslope, is shrinkage of the peat. We know little about quantities and timescales, and this study may offer an opportunity to discover more. Demonstration of any immediate effect would have required baseline data, or at least the presence of dipwells before excavation of the ditch. However, the fact that the dipwells penetrate to the base of the peat may mean that they could yield information on whether or not there is any continued shrinkage under the new water table regime. Indeed, this information may already be accessible.

Data are presented as 'depth to water table' from the mire surface. I assume this means, in practice, that the observer measured the distance from the rim of the dipwell to the water surface inside it, then a number representing the distance from the rim of the dipwell to the mire surface was subtracted. Thus the altitude datum for each dipwell is, temporarily during reading, its rim; and in this study the altitude of the rim relative to the surface of the mineral material beneath the peat may be sufficiently stable through time to provide a datum for study of temporal changes not only in the position of the water table but also in the position of the mire surface. If the dipwell is stable and the rim-to-surface distance is measured at each site visit, that record will provide a direct record of any vertical movements of the mire surface during the period of observations. If, on the other hand, a rim-to-surface distance measured at installation has been used to relate all subsequent readings to the level of the mire surface, re-measurement of this distance in equivalent weather conditions now will give an indication of how much the surface has moved in the interim. Either type of information would be an informative addition to the data presented, giving some insights into the longer-term effects that are included in LWP's experimental objectives.

Uisge Dubh Trench Study

Insights into possible longer-term effects of introducing a new drainage channel are provided by the Uisge Dubh Trench Study which is, in effect, another type of control. It investigates 'depth to water table' on a transect running perpendicular to the line of a stream that is cut into the mineral substratum between two more or less discrete peat bodies or mesotopes. The feature is described by LWP as a 'natural over-sized drainage ditch'.

I know of no definitive account of how these features form, and I suspect they can arise by more than one mechanism. However, I have followed streams that appear to be cutting back into blanket peat, for example at Blar nam Faoileag in Caithness, and have seen evidence of essentially similar processes in peatlands that are otherwise less similar to those in Inverness-shire and Lewis. The attributes of the Uisge Dubh seem consistent with such a secondary origin, in which the stream has effectively sliced through a mire/peat blanket that originally continued across the 'trench', although this may have happened at an earlier stage of development.

Whatever its origin, LWP have imaginatively taken advantage of this feature's presence to study the longer-term outcome of introducing a new drainage channel into the peat blanket. Comparison of Figures A11E.13, 30 and 31 illustrates the eventual outcome for the water table.

On the mire expanse (Dipwells 7–11, accepting that Dipwell 12 behaves anomalously), the water table is restricted to the upper part of the 'control envelope'. This is attributed by LWP to the smoothness of (lack of hummocks on) the mire surface, which is typical of microtopes that have to transmit the most intense seepage fluxes due to location near the edges of mesotopes (i.e. large catchment area) and/or steeper slope (hydraulic gradient).

In the M15–H12 transition zone (*ca*. 5–8 m from the edge of the peat blanket), Dipwells 5 and 6 show water table behaviour similar to that of the 2m, 6m and 8 m dipwells in the T36 Ditch study. Closer to the stream, we move into a *ca*. 5 m wide zone of dry, slumped and eroding peat with H12 dry heath vegetation (Plate A11E.27) where the dipwells never contain water. This is typical for exposed peat edges; the peat responds by losing water and shrinking towards a condition in which it cannot be re-wet (Hobbs 1986). This in turn reduces its hydraulic conductivity, tending to stem water loss by seepage. It also requires some alteration of the mire profile upslope, probably through shrinkage that decreases in intensity with distance from the edge and so steepens the surface (and hydraulic) gradient.

The correspondence of widths of zones exhibiting the different types of water table behaviour in Figures A11E.30 and 31 is striking, and further supports LWP's implied suggestion that the situation that may ultimately arise at the T36 Ditch is illustrated by the Uisge Dubh. In other words, moving away from the ditch line, there will eventually be a *ca*. 7 m zone of dry heath and transition vegetation before a mire expanse community appears.

Another point that seems worthy of note is that the edge of the peat adjacent to the Uisge Dubhe now lies some 10 m back from the drainage line, introducing the possibility that this ‘mineral corridor’ could have widened by around 20 m since formation. Two possible mechanisms for retreat can be postulated. Firstly, the dry peat edge is prone to oxidation at least during dry weather; and secondly Para. 91 describes flooding after rainfall that may be a factor in promoting erosion such as that illustrated in Plate A11E.28. Erosion also appears to be associated with old ditches at Farr (e.g. Para. 77). If the demonstrated effect on water table at the T36 ditch is indeed an early phase of development of a new feature resembling the Uisge Dubhe, we have the prospect that any ditches that are needed to keep wind farm roads passable throughout their lives may ultimately form retreating peat edges similar to those bounding this ‘natural over-sized drainage ditch’ or mesotope divide.

Our understanding of the hydrological function of the mire mesotope indicates that microtopes (with their associated plant communities) are naturally arranged in a consistent catenary sequence along each flowline running from the centre to the edge of the mesotope. The change of NVC community from M15 to M17 between the peripheral location adjacent to the Uisge Dubh and the vicinity of Turbine 4 some hundred metres closer to the centre of the mesotope is consistent with this principle of mesotope structure. Thus a further potential impact of introducing a new/artificial mire edge to the system is that a belt of ‘mire-periphery’ vegetation, perhaps tens of metres wide, will ultimately develop in a former ‘mire-centre’ location and displace mire-centre microtopes such as pool systems.

T4 Study

Dipwells were arranged on a transect that ran upslope and downslope from the T4 turbine site, observations beginning (just) before and continuing during and after installation. The effects of creating, overpumping and backfilling the base excavation; opening and closing ditches to meet construction and permanent drainage requirements; and road re-routing; all carried out during a period of wintry weather with frost, snow necessitating closure of the site and a thaw; are described in some detail.

The downslope section of the transect received water from overpumping and from a temporary ditch that was required to drain ponded water from behind a peat stockpile (Plate A11E.24). After backfilling, permanent drainage was required for the hard standing which was apparently below the general level of the peatland surface, and this was achieved by digging a ditch that again discharged towards the dipwell transect downslope. In consequence, downslope water levels were high throughout the period of observations (Fig. A11E.28).

The water discharged below the excavation presumably originated from its upslope side. ‘Strong alteration’ of the edges of excavations, involving shrinkage and drying, is reported (Para. 28). Figure A11E.26 shows the 0 m dipwell filling rather slowly initially, and the slope of the trace becoming shallower when excavation began on 12th December but beginning to behave ‘normally’ after the Christmas holiday period when pumping was interrupted. Thereafter, no evidence for water table drawdown is apparent in the record as it is presented. Let us suppose, however, that the dipwell initially had a long response time (possibly as a result of compression by the excavator that began work within days of dipwell installation) and its water level was rising gradually towards equilibium with the water table in its surroundings. Creation and pumping of the excavation then caused a rapid fall in water table downslope, reducing the hydraulic head difference that was driving dipwell equilibration so that its filling rate declined as observed; but the associated peat shrinkage caused subsidence of the mire surface, altering the absolute altitude of the datum to which the water level observations were referred. In this scenario, a 'normal' dipwell trace might subsequently be recorded even though the absolute altitude of the water table, the amount of water stored in the peat and the hydraulic gradient promoting seepage towards the turbine base had all been altered.

As suggested for the T36 Drainage Ditch Study above, the data may already contain sufficient information to yield insights into the intensity of any such effects, depending upon how the mire surface datum was related to the level of the dipwell rim. From Plate A11E.14, there appears to be rather more of Dipwell 1 than of Dipwell 2 above ground level; however trimming to 10 cm above ground at installation is reported only for the control studies (Para 48, bullet 1) and it is unclear whether or not this was also done at T4. Whatever the experimental details, the degree of peat shrinkage and any consequent change in surface profiles that have occurred since installation of the dipwell should be determined before the effect of deep excavation on peatland hydrology can be dismissed as 'only temporary' (Para. 88, bullet 3) on the basis of the data collected.

The data from the 3 m dipwell are also consistent with the scenario described above. It filled rapidly after installation, but once excavation began, the water level started to fall gradually but smoothly and continued to do so throughout the nine months of records, suggesting an ongoing effect of installation of the turbine base that requires further investigation/elucidation.

Interpretation of the water level records in Figure A11E.26 is hampered first by the small vertical scale, multiplicity of traces and similarity of the colours used; and secondly by the fact that there was another influence operating upslope. The 6 m and 9 m traces should be examined in conjunction with any available datum measurements in the context of both the downslope and the upslope influences, upon which insufficient information is provided by LWP to make any meaningful comment possible here.

The consequence of installing the road passing between the 20 m and 30 m dipwells illustrates dramatically the unpredictable results of installing 'floating roads' in this type of terrain. This road apparently crossed a section of wet mire that was efficiently retaining water despite LWP's contention that "water volume is not present" (Para. 136). The floating road very obviously sank, displacing a 'large peat mass 1.3 m high' and necessitating the unplanned installation of a drainage ditch upslope and a rock toe downslope whose potential impacts, once again, were presumably not assessed in the ES.

Transient and permanent effects on water table depth at the locations of the 15 m and 20 m dipwells are described. However, the way in which the data are analysed again provides only partial insights into the resulting ecohydrological changes. The dramatic elevation and drainage of the 20 m dipwell clearly illustrates the potential instability of the mire surface due to peat elasticity/plasticity, and again underlines the need for re-analysis of the data referring surface and water levels to stable and preferably common datum levels so that they can be related to one another in space and time.

Contrary to LWP's interpretation, I can see possible indications in the responses of the three dipwells upslope of the new road that there is an effect here; for example, the 'drying for the period immediately following displacement' (Para. 89, bullet 5) may be sharper at the 30 m and 40 m locations than at the 50 m location (although it is not easy to identify some of the traces due to similarity of colours), and in addition to the summer drying effect noted by LWP I wonder if the 50 m record in particular shows a downward trend; this could be tested statistically.

Other dipwell studies

For the remaining four dipwell studies, it appears that no measures were taken to prevent vertical movements of the dipwells and thus of their reference datum levels. This is unfortunate insofar as these are presumably the studies that were conducted on deep peat, where we would expect to find the most pronounced elastic responses of peat to drainage; but also where it would be most difficult to anchor the instruments to the substratum. The dipwells were apparently simply pushed into the mire surface so that their lower ends were located somewhere within the peat profile. It is to be hoped that they remained in fixed positions relative to the mire surface throughout the experimental period; previous experience of analysing data from such dipwells indicates that it is all too easy for individual instruments to be displaced either by animals or accidentally by the observer. The results must be interpreted not only with the potential for instability of dipwells relative to the mire surface in mind, but also taking into account that any expansion or contraction of peat associated with changes in water content cannot be directly registered in data from dipwells installed in this way. Specifically, the fluctuations of the time series plots of dipwell readings do not necessarily reflect the fluctuations of the water table in terms of absolute altitude. Thus a rising dipwell water level may reflect a rising water table, a falling mire surface, or a combination of both; and if constant water table relative to the mire surface is indicated by an individual dipwell, both may be either rising or falling relative to the levels of other instruments in the transect in a situation where hydraulic gradients are undergoing change. Although results that are consistent with this anticipated effect are demonstrated, the experimental technique that was employed precludes any meaningful analysis.

Details of the four studies are summarised below.

Study	Date installed	Peat depth	vegetation	No. dipwells	Piezometer nests	Relationship to wind farm infrastructure
T38-30	**29 Sep 2005**	Not stated	M17b	8	8	Upslope and downslope of floating road (constructed July) without cable trench, with upslope drain
T36-37	**29 Sep 2005**	Not stated	M17b	4 (3)	4 (3)	Across slope below a T-junction with stem running downhill
T33	**30 Sep 2005**	Not stated	M17b	8	8	Deep excavation early Sept; combination of road, excavation and buried cables
T40	**29 Sep 2005**	4.8 m	M17b – H10 mosaic	4	4	downslope of 7.07 m base excavation (July) into fine silty sand

Of these studies, two investigated the effects of roads and two the effects of turbine base excavations.

There are a number of apparently unresponsive dipwells in the road studies, especially at T38-30; and at T36-37 some instruments were destroyed during unplanned widening of cable trenches and reading of the remaining dipwells was suspended for around 3 months in order to avoid disturbance to nesting golden plover. Thus, few data are actually available. Given the problems experienced at T38-30 and LWP's apparent uncertainty about whether the effects they observed were real or due to instrument problems, the phrasing of the conclusions gives an inappropriately optimistic impression. For example, at the end of Para. 66:

> *"no major longer-term road effects are probably detectable in the trends present in downslope dipwells but results are uncertain ….."*

actually means that no useful information was obtained.

Near the two turbine bases, water level fluctuations appear to have been 'suspended' for *ca*. 9 months after excavation commenced (September to June for T33, July to April/May for T40) but the long response times of some instruments again make it difficult to completely separate real effects from those attributable to bad instrument design. Although described, slightly misleadingly, as 'hysteresis effects', these may reflect elastic effects, for example the re-wetting and rebound of peat after compression during drainage of the workings. The pertinent question here is how the surface profile and the associated hydraulic gradient after turbine installation differed from the original configurations. Unless the transects were levelled beforehand, the opportunity to discover this may well have been missed.

The thickness of the 'control envelope' also makes it difficult to assess how successfully the water table returned to the correct position after this 'temporary suspension'; without knowing the microtopographical situation of each dipwell, it is impossible to work out whether the water table fluctuations are 'normal' for the particular microform sampled. However, this is an omission that could presumably be corrected in hindsight.

At T40, the turbine base was installed in a particularly deep excavation which would warrant more detailed ongoing monitoring. The information on page 20 (Para. 48, bullet 5) describes the final arrangement as a plug of stone backfill straddling the interface between peat and a sandy substratum, with at least the lowermost 0.4 m of peat (and probably its whole profile given that the edges of the concrete pad are unlikely to be sealed into peat) in close hydraulic contact through the backfill with what may be a 2.9 m thick sandy aquifer beneath the peat. This would seem to provide an opportunity for vertical leakage of water that bypasses the natural sealing effect of the peat blanket, and could be particularly disruptive to the ecosystem's hydrology. The unexplained anomalies noted in the water table record from the 5 m dipwell should perhaps be considered in this context.

Hydraulic conductivity

The intention seems to have been to measure hydraulic conductivity at a range of depths in each location using nested piezometers, installed with their bases at different depths. I think that piezometers used in this way would need to be some distance apart in order to prevent the tests from interfering with one another, but as neither LWP nor the paper they refer to (probably Holden and Burt 2003b rather than 2003a as cited in Para. 109) deal with the issue it is impossible to judge the validity of the proposed method.

LWP had difficulty with these measurements because their piezometers never attained equilibrium. One causative factor could be that the caps made them airtight (see above); also LWP did themselves no favours by designing and installing their instruments so that water could enter only through their bases (i.e. with zero cavity length); equilibration would be more rapid if water were admitted also through defined sections of the walls.

In the end, the wait for equilibration was abandoned and LWP used the rate of rise of the water level "to approximate hydraulic conductivity". Hydraulic conductivity is a precise physical quantity, defined as the rate of flow of water through unit cross section of soil under unit hydraulic gradient. In order to calculate it from measurements in 'piezometers' ('seepage tubes' is the preferred term; piezometers strictly measure only pressure head) using rigid soil theory, one needs to measure the hydraulic gradient and allow for the radial flow geometry, and alternative analyses based on compressible soil theory are now gaining favour for peat (e.g. Holden and Burt 2003b). I have found no explanation of the calculation method that was used by LWP. Thus it is impossible to work out what the data given in Table A2.3 actually mean in terms of the hydraulic conductivity of the peat. If, as seems possible, these data simply indicate the rate of rise of the water level in each tube towards an undetermined equilibrium position, it is highly misleading to equate these values to hydraulic conductivity.

Hydrological modelling

A re-arrangement of the 'drain spacing formula' based on Darcy's Law and the Dupuit-Forchheimer approximation is used to model the theoretical drawdown distance associated with a ditch so that results from Farr (central Highlands) can be translocated to the rather different climate of Lewis. It is slightly puzzling that, having interpreted their observations at Farr to indicate drawdown distances such as 8 m (Para. 107, page 72) and 10–12 m (Para. 90, page 64), and argued (Para. 128) that the drier summer conditions on Lewis mean that the drawdown distance here is likely to be double that at Farr, LWP are satisfied with a maximum modelled drawdown distance of 4.08 m for Farr (Table A2.4, page 96), which means that the equivalent value for Lewis is 8.12 m (Para. 129, page 91), i.e. less than or similar to the drawdown distance actually observed at Farr.

However, there is a plausible explanation for the anomaly. The 'model' given in Para. 125 is taken from a consultancy report commissioned by English Nature in 2004 (Morgan-Jones *et al*. 2005). What does not emerge clearly from that report is the fact that the quoted simplification of the drain-spacing equation applies to a ditch that penetrates to the base of the conducting layer or aquifer, in this case the peat layer. Even if the ditch is shallower than the peat layer, the hydraulic gradient created by drawdown will cause water to move towards the ditch through the full thickness of the peat aquifer, which is assumed to have uniform permeability. Depending upon the situation at the ditch, the deeper flow lines may rise into the ditch floor or pass beneath it (see e.g. Figure 5 of Heathwaite 1995). Obviously, for a set ditch depth h_b, the relative importance of seepage through peat below the level of the ditch floor will depend upon the total thickness of peat. A closer representation of this situation is available using the 'drain spacing formula' with a fully penetrating ditch of depth equal to the thickness of the peat layer T in which the water level is maintained at depth h_b below the surface. The full analytical solution for this situation, expressed in terms of T and h_b, is[4]:

$$X_b = \sqrt{h_b(2T - h_b)}\left(\frac{k}{P}\right)^{0.5}$$

Note that this reduces to the model quoted in Para. 125 when $T = h_b$.

The diagram shows (in black with hollow symbols) the effect on predicted drawdown distance for the four cases given in Table A2.4 for Lewis in June. The left-hand value in each series is the one given in Table A2.4, and the remainder of the curve shows how drawdown distance increases with peat thickness up to 5 m (peat thickness figures that I have noticed in the Farr report are 1 m and 4.8 m). For a ditch 1 m deep in peat with k = 0.006 m/day on Lewis, the predicted drawdown distance is just over 8 m in peat 1 m thick but increases to >24 m in peat 5 m thick; and if k = 0.0001 m/day (note that this is mis-typed as 0.00001 m/day on more than on occasion, e.g. in Para. 132 and Table A2.4), drawdown distances increase from 0.5–1 m in shallow peat to 2–3 m in 5 m deep peat. Interestingly, if we apply the June effective rainfall figure for Farr to the case of a 1 m deep ditch with k = 0.006 m/day, the predicted drawdown distance ranges from 4.08 m (T = 1 m) to 12.25 m (T = 5 m), which more or less encompasses the range observed on the site and places the results for Farr in the expected (Para. 128) relationship with those for Lewis. The four curves for Farr corresponding to the four plotted for Lewis are shown (in pink with solid symbols) in the Figure for comparison. [Note that h_b is denoted "h(b)" in the diagram due to font limitations in Excel].

There are, however, some major caveats attached to over-reliance on this model:
It is a 'broad-brush' analytical solution of the ombrogenous mire flow problem, and the same equation as that used by Ingram (1982) to provide a simple quantitative expression of the 'groundwater mound' concept. Whilst this has been used effectively in appraisals of mires at 'whole system' level, e.g. to guide management in cases where few site-specific data are available, it cannot be relied upon to give accurate quantitative predictions of the position of the water table, especially at sub-mesotope scale. It models only seepage through a uniform catotelm, and so fails to take into account other routes for water movement as well as the spatial variability of peat hydraulic properties and slope that are particularly characteristic of blanket mire; see, for example, Holden and Burt (2003a). Indeed, the LWP data already indicate one route by which ditch drainage can bypass the seepage route that is represented by the model (see appraisal of T36 Drainage Ditch study above).

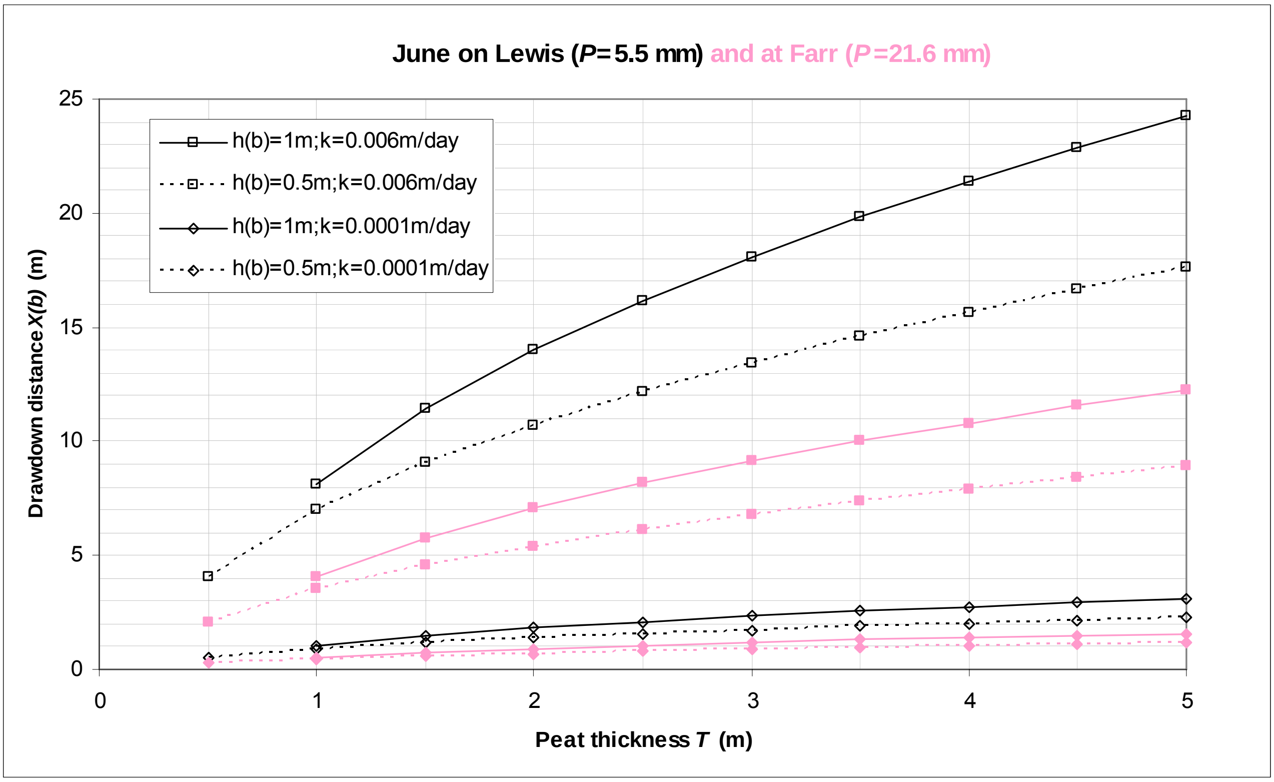
The model assumes that the peat aquifer overlies an impermeable substratum. The demonstrated presence of sand beneath at least some of the peat at Farr (Para. 48 bullet 5) suggests that it may not be universally applicable there; we have no information on the material underlying the peat on Lewis.

The use of this model for defining hydrological protection zones as proposed by Morgan-Jones *et al*. (2005) is, in any case, questionable. The results it will yield are not necessarily precautionary estimates because the model assumes that there is always a supply of rainfall. I would consider a mire buffer zone to be effective only if it were designed to ensure survival of the mire through the longest typical period of drought (i.e. no incident rainfall).

---

[4] Derived, for example, by substituting in Equation 1.5 of the Morgan-Jones derivation $h_b = T$ and $h_d = (T - h_b)$, which gives correspondence with the treatment of Childs (1969).

The Morgan-Jones *et al*. (2005) model is a first attempt to develop a general equation for definition of hydrological buffer zones that is applicable for all the soil types found at the perimeters of designated raised bog areas in England. It is based on rigid soil theory, and attention is drawn (on page 31 of the web version) to its shortcomings for cases where the soil outside the SSSI boundary is peat. In these cases, shrinkage of peat to a stable new profile is anticipated on the upslope side of the ditch defining the outer edge of the buffer zone so long as the ditch itself forms a temporally stable hydrological boundary. The prevention of shrinkage of any peat on the downslope side of the boundary ditch is considered to be beyond the scope of the work that was carried out; if shrinkage were to occur here it would be progressive so that the ditch would not provide the required stable boundary. In this context, the model that LWP have selected seems much less appropriate for modelling the effect of a single ditch crossing blanket mire than is suggested in Paras. 123–124.



LWP conclusions

The field investigations that were carried out are described in Sections A11E.5–7 (pages 15–85) of the LWP report, and so far I have focused on these sections for their content of new information on hydrological impacts of wind farm development. I have many further queries and notes arising from the introductory and concluding material presented, but as there is insufficient time to discuss the remaining sections of the report in detail, I shall deal only with Section A11E.11, which contains the conclusions that LWP draw from the work. For some paragraphs and passages, I have suggested alternative wordings which I consider convey more accurately the scientific outcome of the work on the basis of the results presented. Again, I refer to some other sections of the report where relevant.

Para. 134
"Peatland which is microbroken is shown to have a water table which is usually much lower than very wet peatlands" is not a valid conclusion of the work reported, since equivalent measurements were not made in what I think LWP mean by the latter type of habitat. This conclusion should present the content of Para. 60, which states that "there is not a large difference in the average water levels over the recording period" between intact (17.6 cm) and microbroken (19.1 cm) peatland, and that the water table depth for intact ground with *Sphagnum* is about 18 cm and for microbroken ground excluding rills 22 cm. An indication of the statistical significance of the difference between the two means would also be helpful.

Para. 135
Since it was not possible to calculate any hydraulic conductivity values for the peat at Farr due to poor instrument design and performance, a conclusion that states what "results on hydraulic conductivity show" is invalid.

Para. 136
Since the "above two results" are invalid, it is obviously invalid to draw a further conclusion from them. Some conclusions that might be drawn here on the basis of the experimental results reported are as follows:

> *The results, site observations and available literature suggest that microbroken surfaces differ from very wet peatland areas in the way that the (fixed) supply of water (determined by the net flux of rainfall arriving at the mire surface) is stored and transmitted. The changes are complex and vary spatially, indicating a need for caution and the application of a micro-site approach in anticipating interactions with wind farm development. One effect that was demonstrated in this study is that it is difficult to install drainage ditches without intercepting one or more of the sinuous surface pools that are characteristic of microbroken peatland, and that these can act as routes for drainage that short-circuit seepage through peat. An effect reported in literature for peatland in this stressed/degraded 'microbroken' condition is increased flashiness, i.e. increased intensity of storm runoff and thus in erosive forces. Observations at Farr suggest that some ditches can act as nuclei for erosion.*

Para. 137
Following the discussion of the Uisge Dubhe study above, I would re-word this conclusion as follows:

> *Examination of the sides of a natural drainage trench suggests that it is widening through oxidation and erosion of peat, being currently around 20 m wide. A study of water levels on a transect perpendicular to one side of this trench and over adjacent blanket bog show that 'mire-periphery' vegetation can be supported within 2–3 m of the upper edge of the trench, the mire edge being effectively bunded by a 7 m wide belt of peat that has dried and shrunk to maximum bulk density and supports dry heath vegetation. Thus the total width of the zone associated with the drainage line that lacks mire vegetation is around 34 metres, and this is flanked*

by belts of peatland where a 'mire periphery' community (M15) replaces the 'mire centre' (M17) NVC community. Water table behaviour adjacent to a new wind farm ditch is similar to that in the transition zone at the upper edge of the trench, whilst some old estate ditches on the site are now eroding. These observations reinforce the impression that the natural drainage trench provides the best available indication of the eventual outcome of introducing a new drainage line within the peat blanket.

Para. 138

The impact of this conclusion could be changed completely simply by transposing its first and second parts, and adding a small amount of information on the T4 study, as follows:

One study of a dipwell transect beside a floating road showed severe change to hydrology when the road failed to float on installation and a large peat mass 1.3 m high was thrust upwards on the lower side of the road. After installation of upslope drainage and a rock toe downslope, water levels measured relative to the mire surface showed a persistent drying effect for 8–12 m downslope. There was a possible smaller drying effect that stretched for only 5 m upslope. Other studies of dipwells beside roads and away from deep excavations for wind turbine bases, for distances of up to 50 m, show no evidence of permanent long-term change in depth to water table beyond the immediate vicinity of wind farm infrastructure within the sensitivity (± >16 cm) and terms of reference of the studies. For turbine base excavations, temporary effects, usually showing increased wetness including the results of overpumping onto the mire surface, are identified but full recovery of depth to water table is shown to occur over periods of up to 9 months after the start of deep excavation. However, we do not know if there were any accompanying temporary and permanent changes in other ecologically significant attributes such as peat volume, water content or hydraulic gradient because assessment of these variables was not within the scope of the work carried out.

Para. 139

Again, the discussion of the T36 Drainage Ditch study above leads to a suggested expansion of this conclusion, as follows:

A transect study of an accidentally over-deepened wind farm ditch (0.8 m depth) on a moderate slope shows that water levels downhill are dropped greatly close to the ditch but that drawdown of the water table relative to the mire surface due to enhanced seepage towards the ditch is not detectable beyond 8–10 m downslope. Again, any shrinkage of the peat was not measured, however. The results of this study also appear to demonstrate a second mechanism of water table drawdown caused by the ditch that short-circuits the seepage route, in that the downhill route of the ditch intercepts and drains the end of a linear surface pool that connects with the line of the transect some 20 m downslope from the ditch under study, resulting in lowered water table at this point on the transect.

Para. 140
For the first part of this conclusion, the following wording would more appropriately express the re-interpretations of the data presented above:

> *The above results are consistent with our understanding that the hydraulic and elastic properties of peat combine to provide a strong feedback response to drainage that tends to maintain the close relationship between water table and surface that is necessary for the maintenance of mire vegetation. They also reveal that ditching of areas with complex microtopography, especially those with long, sinuous pools of open water, can hardly avoid introducing additional drainage that bypasses the feedback response of the peat and reaches across the full length of any pool intercepted.*

The literature review of Section A11E.9 could be summarised more helpfully as follows:

> *A brief review of the scientific literature reveals that most previous studies have focused on the ability of drains to relieve surface saturation, and thus to make peatland more productive for grazing or cultivation, rather than on issues of ecosystem integrity and long-term maintenance of the peat blanket and its inherent environmental and biodiversity functions. Gilman (1994) points out that ditching fails to improve drainage outwith a narrow zone alongside the ditch due to a peat wastage feedback tending to maintain favourable water table conditions for mire plants, but leading ultimately to disappearance of the peat blanket through oxidation (as has occurred in the English fens). One study (Stewart and Lance 1991) has demonstrated the elimination of Sphagnum as far away from a drain as midway to the next drain downslope, whilst another (Wilkie and Thompson 1998) indicates that ditches show a wide variety of behaviour depending upon their locations and describes vegetation changes, deepening and slumping effects that appear to be related to slope.*

Para. 141
This is related to Para. 140, and a suggested re-wording is as follows:

> *Our study was restricted to surveillance monitoring of the distance between the mire surface and the water table, which provides a convenient index of ecosystem function without affording any insights into mechanisms underlying any departure from 'normality'. An impediment to this approach is that there is no standard definition for 'normality' and our control data were such that the method was unsatisfactorily insensitive. Our interpretation of the data obtained is that water table drawdown at Farr is likely to lead initially to vegetation change over a zone which extends for up to 10 m beyond the outermost location of any disturbed ground or wind farm infrastructure. This is in keeping with published British information relating to the management of blanket peatland for agricultural purposes, but importantly does not preclude consequent shrinkage and wastage of peat over a much wider area. Such*

mesotope-level effects lead to changes in surface slope and hydraulic gradient with more far-reaching implications for the extent and catenary arrangement of vegetation communities and surface patterning types (microtopes), as well as for the water and carbon storage and runoff generation characteristics of the peatland; and they could lead ultimately to loss of the entire peat blanket. Some of our experiments - but probably only those on shallow peat - are designed in such a way that, with a few further field measurements, they may be capable of giving insights into the intensity of such effects at Farr. However, we lacked the resources to investigate such implications and (possibly specialist) re-analysis of our data to shed light on these longer-term issues is recommended.

Paras.142, 143
These two conclusions are not outcomes of the experimental work, they provide little extra information and some conjecture, and seem unnecessary.

Para. 144
Again, this should be re-worded in the light of the discussion above:

We have attempted to extend the results from Farr to indicate those likely to occur around a wind farm development in North Lewis by use of a one-dimensional model of water level drawdown by a ditch which incorporates climatic data for the two areas. The model suggests that under conditions of high blanket bog hydraulic conductivity and use of a deep (1m) ditch there will be a maximum drawdown width of 8–25 m in peat ranging from 1–5 m depth, compared to a 4–13 m drawdown width for Farr. This difference is due to markedly drier summer conditions in Lewis. The result is not necessarily, however, a precautionary extreme because the model assumes that there is always a supply of rainfall. The precautionary estimate should be constructed on the basis of the longest likely period of drought. Actual drawdown width may differ from the predicted value in many instances due to spatial and temporal variation in hydraulic gradient, peat permeability and other flow processes. However we have no water table measurements that are directly relevant to the use of a model of this type because the model describes the profile of the water table relative to a stable common datum level, and such datum levels have not been established for any of our transects. An inherent limitation of this model is that it can indicate only a transient outcome since it does not take into account the progressive shrinkage/wastage of peat downslope of the ditch that the author of the model anticipates will occur in this application.

Conclusions

This study may well be the first quantitative investigation of the hydrological effects of wind farm construction on peat. The nine study locations have been selected to explore a wide range of situations where wind farm development and peatland ecohydrology may interact, and data collection has been assiduous. The outcome, however, is equivocal; and given the resources that are apparently available for the wind farm ES process, it is disappointing that so little useful information has resulted.

A fundamental problem with this investigation is that, although "the work seeks to establish the distance away from wind farm infrastructure that (ecohydrological) effects extend, the only starting premis is that "depth to watertable is assumed to be a key factor determining the type of vegetation on a blanket bog surface" (Summary, Paras. 2, 3). Thus, all other aspects of peatland function that influence the distribution of vegetation, maintain the pool systems that are important features for birds, and indeed prevent the peat blanket from disappearing completely due to oxidation, are dismissed within the first 12 lines of the report. Of course, effects on these other aspects of peatland function will not be identified if they are not investigated in the first place.

The reason for basing the work exclusively on manual dipwell readings is unclear. Whilst the technique can be helpful in situations where hydrology is relatively stable; where expertise, technical and financial resources are limited; and where information about a large number of locations is required; there are severe penalties in terms of data yield. The first problem is that significant response lags can arise when dipwells are used in peat, a second is the restriction of data to the times of site visits so that the extreme positions (i.e. maximum and minimum) of the water table are seldom recorded, and a third is that dipwells yield only patchy information on the temporal duration of different water table conditions. The use of modern instrumentation would have gone a long way towards overcoming problems encountered by LWP in carrying out the work, and it is almost incredible that this appears not to have been considered for an investigation of effects arising from sudden and potentially drastic engineering changes to the ecosystem.

Whatever constraints applied to the choice of instrumentation, the way that the instruments were installed was critical to their utility in recording the full hydrological effects of wind farm construction. LWP's contention that gullied peat deposits with microbroken surfaces contain little water is misleading and contradicted by their own observations of shallow water table (and thus saturated peat) at the Farr transect locations. However, peat undergoes significant volume changes when water is removed, so that very subtle changes in 'depth to water table' may be recorded in conjunction with substantial changes in pore structure, water storage and hydraulic gradient resulting from new drainage, and these changes in turn have far-reaching implications for vegetation as well as for other aspects of peatland ecology. LWP appear not to have made this connection; despite their observation of "shrinkage and drying" at the edges of deep excavations (Para. 28) they state in Para. 113 that "deep excavation would not directly lead to consolidation". This is despite the fact that at least three of their cited references mention peat shrinkage phenomena, and at least one discusses the implications in some detail (see e.g. Hobbs 1986, Gilman 1994 and Morgan-Jones *et al*. 2005). Considering the content of these references, failure at least to systematically record peat thickness and level the transects of dipwells at the time of installation are glaring omissions from the experimental procedure that should not have occurred in a competently researched investigation by experienced practitioners.

Indeed, LWP appear to have invested in this work only rather limited expertise in hydrology and blanket mire ecohydrology. The persistent use of the term 'flux' (which has a precise hydrological meaning) when 'fluctuation' is meant is disconcerting; then the choice and application of methodology, limited experimental objectives, invalid application of statistical methods, poor fit of data precision to experimental accuracy, failure to recognise the implications of some features of the data collected, unfamiliarity with cited literature, and the incorrect application of a simple analytical flow solution all contribute further to this impression. In a situation where a new impact with poorly understood but potentially profound effects on ecohydrology is being considered for such an important area as the Lewis SAC, it would seem desirable to focus adequate resources, including appropriate specialist input, on the issues.

The way that the report is organised is not user-friendly. Information on individual studies is scattered and interspersed by literature review and discussion sections so that previous knowledge, new findings and LWP opinions are not clearly separated and so not readily distinguishable without close study. There are also many mistakes, together with some self-contradiction and examples of difficult English. All this makes reading less than straightforward, and the document would benefit from re-drafting to a more standard scientific format.

Para. 18 explains that the original LWP ES predicted no significant indirect loss of blanket mire habitat arising from hydrological change beyond directly altered areas, but that LWP's position on this has now changed. Various statements in the report's introductory sections convey an impression that LWP commitment to the new view is not wholehearted, however; for example

"We are convinced that the zone of subtle indirect changes to vegetation beyond successions created by habitat disturbance is narrow (ca. 5 m) and very slight" (Para. 14)

".. succession on disturbed ground and very little change in areas of habitat change will, within 5 to 25 years, form ground which differs little from types already present .." (Para. 18)

One is left with a slightly uncomfortable feeling that the work is being approached from a position of bias that might hamper the rigorous application of scientific method; and this feeling is not alleviated on reading some of the bold-type conclusions in Section A11E.6 in conjunction with the supposedly supporting data, especially when one finds that data have been overtly altered.

Nonetheless, this work constitutes a promising start to elucidating some of the interactions that theory and previous experience lead us to anticipate between wind farm construction and peatland ecohydrology. As the study is ongoing, it is to be hoped that LWP will be able to allocate appropriate resources to making good the correctable omissions from the existing experimental procedure, and to extending the work to build on the experience of this first exploratory investigation.

References

Childs, E.C. (1969) An Introduction to the Physical Basis of Soil Water Phenomena. Wiley, London, 493 pp.

Gilman, K. (1994) *Hydrology and Wetland Conservation*. Wiley, Chichester, 101 pp.

Heathwaite, L. (1995) Problems in the hydrological management of cut-over raised mires, with special reference to Thorne Moors, South Yorkshire. In: Wheeler, B.D., Shaw, S.C., Fojt, W.J. and Robertson, R.A. (eds.) *Restoration of Temperate Wetlands*. John Wiley and Sons Ltd., Chichester, 315–329.

Hobbs, N.B. (1986) Mire morphology and the properties and behaviour of some British and foreign peats. *Quarterly Journal of Engineering Geology*, 19, 7–80.

Holden, J. and Burt, T.P. (2003a) Hydrological studies on blanket peat: the significance of the acrotelm-catotelm model. *Journal of Ecology*, 91, 86–102.

Holden, J. and Burt, T.P. (2003b) Hydraulic conductivity in upland blanket peat: measurement and variability. *Hydrological Processes*, 17, 1227–1237.

Ingram, H.A.P. (1978). Soil layers in mires: function and terminology. *Journal of Soil Science*, 29, 224–227.

Ingram, H.A.P. (1982). Size and shape in raised mire ecosystems: a geophysical model. *Nature*, 297, No. 5864, 300–303.

Morgan-Jones, W., Poole, J.S. and Goodall, R. (2005) Characterisation of Hydrological Protection Zones at the Margins of Designated Lowland Raised Peat Bog Sites. JNCC Report No. 365. Available online at http://jncc.gov.uk/pdf/jncc365_web.pdf.

Stewart, A.J.A. and Lance, A.N. (1991) Effects of moor-draining on the hydrology and vegetation of northern Pennine blanket bog. *Journal of Applied Ecology*, 28, 1105–1117.

Wilkie, N.M. and Thompson, P.S. (1998) Identification and restoration of damaged blanket bog: a guide to restoring drained and afforested peatland. RSPB LIFE Peatlands Project, Inverness.

13 Appendix 2 Quadrat data obtained by UEL

Target no. 1

Somewhat degraded almost micro-erosion area, visually dominated by *Trichophorum cespitosum*. Clear evidence of past fire damage in species composition. Gentle T1-A1 undulating, but A1 is terrestrial now (E1) and T1 was probably T2 originally. Some T3 hummocks still present.

Date	Altitude (m)	Peat depth (m)		Dargie (2004)	
October 11, 2006					
National Grid Reference	Aspect	3.65	T1/A1	GISPoly#	2947
NB 43895 55024				FieldPoly#	
Recorder	Slope			NVC	Area of possible burning
Richard Lindsay & Jamie Freeman					

Species	T3	T1/T2	E1
Carex panicea	2		1
Calluna vulgaris	3	3	2
Campylopus introflexus		2	
Cladonia impexa	2	2	
Cladonia uncialis	1		
Drosera rotundifolia	1	1	1
Erica tetralix	2	2	2
Eriophorum angustifolium	4	3	4
Eriophorum vaginatum	1		
Hypnum jutlandicum		2	1
Molinia caerulea	1	2	2
Narthecium ossifragum	1		1
Odontoschisma sphagni			1
Potentilla erecta	2	2	2
Racomitrium lanuginosum		3	1
Sphagnum capillifolium	5		1
Sphagnum subnitens			2
Sphagnum tenellum			3
Trichophorum cespitosum		4	3

Target no. 3

Date	Altitude (m)	Peat depth (m)	Dargie (2004)	
October 11, 2006				
National Grid Reference	Aspect		GISPoly#	2654
NB 44100 55136 (2m)			FieldPoly#	
Recorder	Slope		NVC	M17b
Richard Lindsay & Jamie Freeman				

Species	T3/T4	E1	E2
Bare peat			5
Carex panicea	1	1	1
Calluna vulgaris	3	2	
Cladonia arbuscula	2		
Cladonia impexa	3	2	
Cladonia uncialis	2		
Erica cinerea	2		
Erica tetralix		2	
Eriophorum angustifolium	4	5	2
Molinia caerulea	3		
Pleurozia purpurea		1	
Potentilla erecta	1	1	
Racomitrium lanuginosum	5		
Sphagnum capillifolium		2	
Sphagnum cuspidatum		4	
Sphagnum tenellum		2	
Trichophorum cespitosum	2	3	

Target no. 19

Area of micro-erosion within a pool system. Very close to drain and drove road which cuts across the drain. Gullies re-vegetatiing with mainly Eriophorum angustifolium and Carex panicea and smaller amounts of Sphagnum cuspidatum. T1 is present at the edge of some A4 pools and very occassionally gullies.

Date	Altitude (m)	Peat depth (m)		Dargie (2004)	
October 12, 2006					
National Grid Reference	Aspect	3.60	T2	GISPoly#	954
NB 45429 57083 (?)				FieldPoly#	
Recorder	Slope			NVC	M15c
Jamie Freeman & Richard Lindsay					

Species	T3/T4	T2	T1	E1/E2	A4
Bare peat				3	
Carex panicea		3		4	
Calluna vulgaris	4	3	4		
Cladonia impexa	3	3	2	1	
Cladonia uncialis	2	1		2	
Drosera rotundifolia		1			
Erica cinerea	2	1			
Erica tetralix	2	3	2	2	
Eriophorum angustifolium	4	3	4	4	
Molinia caerulea	3	2	4	3	
Narthecium ossifragum		2	2		
Pleurozia purpurea		2			
Potentilla erecta	1	2			
Racomitrium lanuginosum	5	4			
Sphagnum capillifolium			5		
Sphagnum cuspidatum			2		
Sphagnum papillosum			2		
Sphagnum subnitens			1		
Trichophorum cespitosum		3	3		

Target no. 25

An area of micro-erosion with some moderate gullies all showing signs of vigorous re-vegetation. Some gullies have standing water which is well colonised by *Sphagnum cuspidatum*. T3/T4 is dominated by *Eriophorum angustifolium*, *Racomitrium lanuginosum* and *Cladonia impexa* as well as short, grazed *Calluna vulgaris*.

Date	Altitude (m)	Peat depth (m)		Dargie (2004)	
October 12, 2006					
National Grid Reference	Aspect	3.55	T3/T4	GISPoly#	93
NB 44535 56741 (3m)				FieldPoly#	
Recorder	Slope			NVC	M17b
Richard Lindsay & Jamie Freeman					

Species	T3/T4	T2	T1	E1	E2
Bare peat					5
Carex panicea		1	2		2
Calluna vulgaris	4	3			
Cladonia arbuscula	2		2		
Cladonia impexa	3	4	3		
Cladonia uncialis	2	2			
Drosera anglica				2	
Drosera intermedia				1	
Drosera rotundifolia			1		
Erica cinerea	2				
Erica tetralix	2	3	2		
Eriophorum angustifolium	3	4		2	3
Hypnum jutlandicum	1		1		
Molinia caerulea	3	2	3	1	
Odontoschisma sphagni			2		
Pleurozia purpurea		3			
Polygala serpyllifolia	1				
Potentilla erecta		2			
Racomitrium lanuginosum	4	3	1		
Scapania sp.	1				
Sphagnum capillifolium			5		
Sphagnum cuspidatum				5	1
Sphagnum subsecundum				2	
Sphagnum tenellum			3		
Trichophorum cespitosum	2	3	2	1	2

Target no. 30

South facing erosion complex showing vigorous re-generation within the erosion gullies. Hagg-top vegetation typical of western oceanic blanket mire hagg-tops.

Date	Altitude (m)	Peat depth (m)		Dargie (2004)	
October 9, 2006	113				
National Grid Reference	Aspect			GISPoly#	670
NB 35282 34172				FieldPoly#	
Recorder	Slope			NVC	H10b
Richard Lindsay & Jamie Freeman					

Species	T4	T3	T1	E1	E2
Bare peat					5
Calluna vulgaris	3	3	2		
Cladonia coccifera	1				
Cladonia impexa	2	1			
Cladonia uncialis	1				
Erica cinerea	2	2			
Erica tetralix	1	1	2	2	
Eriophorum angustifolium		3	3	3	4
Eriophorum vaginatum	2	1		3	
Hypnum jutlandicum	2	3			
Molinia caerulea	1	2	3	2	
Polygala serpyllifolia			2	2	
Potentilla erecta	1	2	2		
Racomitrium lanuginosum	2		2	1	
Sphagnum capillifolium		2	5		
Sphagnum cuspidatum			1	5	
Sphagnum subnitens			2	2	
Sphagnum tenellum			1		
Trichophorum cespitosum	3	3	4	3	

Target no. 48

Date	Altitude (m)	Peat depth (m)		Dargie (2004)	
October 10, 2006					
National Grid Reference	Aspect	1.73	hag-top	GISPoly#	3612
NB 40719 53271 (3m)				FieldPoly#	
Recorder	Slope	0.66	gully	NVC	M17b
Richard Lindsay & Jamie Freeman					

Species	T4	E1	E2
Bare peat			5
Calluna vulgaris	4	2	
Cladonia impexa	3		
Cladonia uncialis	1		
Erica cinerea	3		
Erica tetralix	2	1	
Eriophorum angustifolium	4	5	3
Molinia caerulea	3		
Polygala serpyllifolia	1		
Potentilla erecta	2		
Racomitrium lanuginosum	4		
Sphagnum cuspidatum		4	
Sphagnum magellanicum		2	
Sphagnum papillosum		1	
Sphagnum subnitens		1	
Sphagnum subsecundum		2	
Trichophorum cespitosum	3		

Target no. 62

T3/T4 *Racomitrium langinosum* hummocks with moderate E2 erosion gullies which are re-vegetating with *Eriophorum angustifolium* and *Carex panicea*. A4 pools with T1 at edges. *Trichophorum cespitosum* is visually dominant. Around pools re-vegetation is by terrestrialisation with a relatively natural micro-topography which forms different vegetation types within the polygon.

Date	Altitude (m)	Peat depth (m)	Dargie (2004)	
October 14, 2006				
National Grid Reference	Aspect	4.75	GISPoly#	3653
NB 48281 58325 (2m)			FieldPoly#	
Recorder	Slope		NVC	H10b
Jamie Freeman & Richard Lindsay			Erosion Class	6.7

Species	T3/T4	T2	E2	T3	T2	T1	A1	A4
Bare peat			5					
Carex panicea		2	2					
Calluna vulgaris		3		4	3	1		
Campylopus atrovirens		1						
Cladonia arbuscula	1			3				
Cladonia impexa	4	4		2	3			
Cladonia uncialis	2			1	2			
Drosera anglica						1	1	
Drosera rotundifolia				2				
Eleocharis multicaulis						1	3	
Erica cinerea	3	1						
Erica tetralix	3	3		3	2	2		
Eriophorum angustifolium	3	3	3	5	3	3	2	
Eriophorum vaginatum	3	2			2	3		
Hypnum jutlandicum				3	3			
Molinia caerulea	2	3		2				
Narthecium ossifragum		2	2	2		3	2	
Pleurozia purpurea	2	3						
Potentilla erecta	1	2						
Racomitrium lanuginosum	4	3		1	2			
Sphagnum capillifolium		1		4	4	2		
Sphagnum cuspidatum						1	4	
Sphagnum magellanicum						4	2	
Sphagnum papillosum				2		3		
Sphagnum subsecundum							2	
Sphagnum tenellum						2		
Trichophorum cespitosum	2	3	3			3		

Target no. 64

A mixture of *Trichophorum cespitosum* dominated bog and tussocky *Eriophorum vaginatum*. Mainly T3 hummocks with *Calluna vulgaris*, *Cladonia impexa* and *Cladonia arbuscula*. Smooth area of peat on gentle slope. Some *Sphagnum,* predominantly *Sphagnum capillifolium* and *Sphagnum papillosum*. Mosaic of two different T3 and T2 types. Drier, smaller hummocks dominated by *Racomitrium lanuginosum*. Larger areas of T2 are dominated by *Trichophorum cespitosum* (possible burning) with smaller areas of *Eriophorum angustifolium*. Where T2 (*Eriophorum angustifolium*) is wetter, *Sphagnum papillosum* and *Narthecium ossifragum* appear.

Date	**Altitude (m)**	**Peat depth (m)**		**Dargie (2004)**	
October 14, 2006					
National Grid Reference	**Aspect**	2.3		GISPoly#	1163
NB 49102 58779 (2m)				FieldPoly#	
Recorder	**Slope**			NVC	M17b
Richard Lindsay & Jamie Freeman					

Species	T3 (*C.vulg & E.vag*)	T3 (*R.lang & E.vag*)	T2 (*T.caesp*)	T2 (*E.ang*)	
Calluna vulgaris	5	3	4	4	
Cladonia arbuscula	1	2			
Cladonia impexa	3	4	5		
Cladonia uncialis	1	2	2		
Drosera rotundifolia				1	
Empetrum nigrum	4	4		3	
Erica tetralix	3	2	3	3	
Eriophorum angustifolium	2		2	5	
Eriophorum vaginatum	5	5	1	4	
Hypnum jutlandicum	2		2	2	
Molinia caerulea	3		2	2	
Narthecium ossifragum			1	1	
Odontoschisma sphagni	2				
Pleurozia purpurea			3		
Pleurozium schreberi	2	3		4	
Potentilla erecta	2	3	2	2	
Racomitrium lanuginosum	2	5	2		
Rhytidiadelphus loreus	2			3	
Sphagnum capillifolium	3		2	3	
Sphagnum papillosum				1	
Sphagnum tenellum			3		
Trichophorum cespitosum			3		

Target no. 68

Air-photo shows a smoother area and a more eroded area, though both are coded as being H10b. Visually dominated by *Trichophorum cespitosum* suggesting fire damage.

Date	Altitude (m)	Peat depth (m)		Dargie (2004)	
October 14, 2006					
National Grid Reference	**Aspect**	3.72	T3/T4	GISPoly#	2343
NB 48609 58383 (2m)				FieldPoly#	
Recorder	**Slope**			NVC	H10b
Richard Lindsay & Jamie Freeman					

Species	T3/T4	T2	E1	E2
Bare peat		1		5
Carex panicea		1	3	3
Calluna vulgaris	4	3	1	
Cladonia arbuscula	2			
Cladonia impexa	3	4	1	
Cladonia uncialis	2	1		
Drosera anglica			1	
Drosera rotundifolia			1	
Erica tetralix	3	3		
Eriophorum angustifolium	5	3	3	3
Eriophorum vaginatum	2			
Molinia caerulea	4	3	1	
Narthecium ossifragum			2	
Pleurozia purpurea	3	2		
Polygala serpyllifolia		2		
Potentilla erecta	2	2	1	
Racomitrium lanuginosum	5	3		
Sphagnum capillifolium		2		
Sphagnum compactum			3	
Sphagnum cuspidatum			4	2
Sphagnum papillosum		1		
Sphagnum subnitens				2
Sphagnum subsecundum			3	
Sphagnum tenellum		1	2	
Trichophorum cespitosum	3	5	2	

Target no. 70

Severely eroded, relatively thin peat often eroded down to the mineral sub-base. *Calluna vulgaris* dominate the hag-tops with *Eriophorum angustifolium* on the flats. Extensive bare peat forming the gullies suggesting it is still actively eroding and may still be heavily grazed. However there are still some signs of re-generation.

Date	Altitude (m)	Peat depth (m)		Dargie (2004)	
October 13, 2006					
National Grid Reference	**Aspect**	1.2	hag-top	GISPoly#	4188
NB 29183 45561 (4m)				FieldPoly#	
Recorder	**Slope**	0.55	gully	NVC	H10b
Jamie Freeman & Richard Lindsay					

Species	T4	T2	T1	E2	E2 (dry)
Bare peat				5	4
Carex echinata		1			
Carex panicea					2
Calluna vulgaris	4	4	3		2
Campylopus introflexus	1	1			2
Cladonia arbuscula		1			
Cladonia impexa	3	2	3		
Cladonia uncialis	2	1	2		
Dicranum scoparium		1			
Erica cinerea	3	2			
Erica tetralix	2	2	2		
Eriophorum angustifolium	3	4	5	3	1
Hypnum jutlandicum	3	2			
Juncus bulbosus				2	3
Juncus effusus					2
Molinia caerulea	1	1			
Nardus stricta		1			3
Potentilla erecta	2	2	1		
Racomitrium lanuginosum	2	2			
Rhytidiadelphus squarrosus		2			
Sphagnum auriculatum		1			
Sphagnum capillifolium		1	3		
Sphagnum subnitens			1		
Sphagnum subsecundum				1	
Sphagnum tenellum		1	3		
Trichophorum cespitosum	1		3		
Unidentified hepatic	1				
Poaceae (unidentified grass)					2

Target no. 71

Close to A-road. Pool system showing signs of micro-erosion. Visually dominated by a mixture of *Eriophorum angustifolium*, *Trichophorum cespitosum* and smaller amounts of *Molinia caerulea*. All gullies showing signs of re-generation with colonisation by *Eriophorum angustifolium*, *Trichophorum cespitosum* and *Carex panicea*. Occasional *Racomitrium lanuginosum* hummocks, T1 by pools and very occasional at gully edges. Also some A3 pools present.

Date	Altitude (m)	Peat depth (m)	Dargie (2004)	
October 13, 2006				
National Grid Reference	Aspect	2.00	GISPoly#	1546
NB 39767 40503 (3m)			FieldPoly#	
Recorder	Slope		NVC	M15c
Jamie Freeman & Richard Lindsay				

Species	T3/T4	T2	T1	E1	A2	A3
Bare peat				3		
Carex panicea	2	2	2	2		
Calluna vulgaris	3	3	4			
Cladonia impexa	4	3	3			
Cladonia uncialis	2	2	1			
Drosera intermedia					2	
Eleocharis multicaulis					3	3
Erica cinerea	2					
Erica tetralix	2	3				
Eriophorum angustifolium	3	3	3	4	2	
Molinia caerulea	4	3	3			
Narthecium ossifragum				3		
Pleurozia purpurea		3	2			
Polygala serpyllifolia		1				
Potentilla erecta	2	2	2			
Racomitrium lanuginosum	5	4	3			
Sphagnum capillifolium			5			
Sphagnum cuspidatum				4	5	3
Sphagnum papillosum			3			
Sphagnum recurvum			2			
Sphagnum tenellum			3			
Trichophorum cespitosum	3	4	5	4	2	
Utricularia minor						3

Target no. 99

Feels like a very broad percolation mire. Very natural system with few signs of erosion if any although there is some evidence of burning such as small pockets of bare peat. A2 pools are degraded through burning. Linear T3 hummocks: percolation mire or former ladder fen? Some of the least patterned bog yet some of the deepest wettest peat. *Molinia caerulea* very visually dominating which separates this area out from other vegetation types.

Date	Altitude (m)	Peat depth (m)		Dargie (2004)	
October 14, 2006					
National Grid Reference	Aspect	4.5	T1	GISPoly#	3653
NB 48398 58325 (3m)				FieldPoly#	
Recorder	Slope			NVC	H10b
Richard Lindsay & Jamie Freeman				Erosion Class	6.7

Species	T3	T2	T1	A1	A2
Calluna vulgaris	4	4	3		
Cladonia arbuscula			2		
Cladonia impexa	2	4	2		
Cladonia uncialis	2	1	1		
Drosera anglica				1	2
Drosera rotundifolia	1			1	
Erica tetralix	2	2	3	2	1
Eriophorum angustifolium	4	3	5	4	4
Molinia caerulea	3	3	3	3	2
Narthecium ossifragum	3	2	2		3
Pedicularis sylvatica	1				
Pleurozia purpurea		1		1	2
Polygala serpyllifolia	1				
Potentilla erecta	2	1	2		
Racomitrium lanuginosum		3			
Sphagnum capillifolium	4	2	3		
Sphagnum cuspidatum				5	2
Sphagnum magellanicum			1	2	3
Sphagnum papillosum	3	1	3		
Sphagnum subnitens	3		3		
Sphagnum tenellum		2	2		
Trichophorum cespitosum	3		3		3

14 Appendix 3 : Sites of Hydrological Concern

Listing for Areas of Hydrological Concern

x/y coordinates are for the centroid of each buffered record of peat depth

Note that the '1' and the '9' at start of the x/y coordinates represent the 'NB' of an OS 6-figure National Grid reference

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
1	138524	937776	Gully/pool crossing	Fairly wide gully system, apparently bare peat, extending for 130m+; peat 2.5m deep	Very high
2	138528	937660	Percolation mire	Extensive area of smooth fen next to loch shore; peat 3m deep	High
3	138567	937390	Gully/pool crossing	Road crosses long erosion gully, apparently revegetated; peat 2.5m deep	
4	138576	937350	Gully/pool crossing	Road crosses wide bare-peat gully/pool, with surrounding erosion revegetating; peat 3m deep	
5	138787	937105	Ladder fen	Road runs along top edge of good, big ladder fen; peat 3.5m deep	Very high
6	139502	937674	Ladder fen	Road runs 50m above head of excellent ladder fen; peat 3m deep	High
7	138560	936173	Peat pipe	Road cuts across possible peat pipe; no peat depths available	
8	138194	935661	Gully/pool crossing	Road cuts through extensive erosion complex, some bare peat, some revegetated; peat 2.5m deep	
9	138170	934862	Percolation : peat pipe	Road cuts across long stream/spring line, with possible peat pipe	
10	138328	934901	Gully/pool crossing	Road cuts across long erosion gully, 150m long; peat 3m deep	
11	138373	934977	Gully/pool crossing	Road cuts across a fairly long gully; peat 3m deep	

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
12	138042	934957	Gully/pool crossing	Road cuts across very marked gully or peat crack; peat 3.5m	
13	137610	935114	Erosion complex	Turbine @ road end sits on 3.5m peat, within marked erosion complex	
14	138144	935522	Gully/pool crossing	Road cuts wide bare-peat gully from complex erosion upslope; no peat depths available	High
15	138176	935537	Gully/pool crossing	Road cuts across gully from large pool within upslope erosion complex; peat depths not available	High
16	137868	934245	Deep bog : smooth	Road cuts across area of relatively undamaged deep bog; peat 3.5m deep	Moderate
17	135401	933534	Erosion complex	Road and turbine (S71) end in anastomosing erosion complex; much regeneration; peat 3.5m deep	
18	134470	933087	Erosion complex	Road and turbine (S70) end in anastomosing erosion complex; widspread regen.; peat 3.5m deep	
19	134195	933624	Percolation mire	Road crosses what may be a percolation mire associated with peat pipe; peat 4m deep	High
20	134431	933479	Percolation mire	Road crosses several percolation mires; no peat depths available	Moderate
21	133719	933840	Percolation mire	Road cuts across above spring emergence (25m distant); peat 3.5m deep	
22	134148	933772	Percolation mire	Road crosses gully containing percolation mire; peat 3.5m deep	
23	135311	934274	Erosion complex	Road crosses recovering erosion complex; peat 3.5m deep	Moderate
24	135782	934294	Percolation : peat pipe	Crosses long seepage zone/percolation mire; spring emergence; possible peat pipe; peat 5m deep	
25	137653	934597	Forestry drains	Road cuts through fairly deep peat extensively ploughed for forestry; peat 3m deep	Moderate
26	135736	934784	Gully/pool crossing	Road runs beside very long gully feeding from regenerating erosion complex; peat 3-4m deep	

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
27	134913	935016	Erosion : percolation	Road and turbine (S4) cut through foot of regen. erosion, head of percolation fen; 4.5m deep	Moderate
28	134874	935051	Erosion : peat pipe	Road cuts through foot of regen. erosion; possible peat pipe; peat 4.5m deep	
29	134723	935150	Deep bog : slight erosion	Road cuts across slope of deep peat with slight erosion; peat 4m deep	
30	135301	934757	Percolation : erosion	Road and turbine (S5) lie in deep, eroded, regen. saddle mire with springs; peat 3.5m deep	
31	135282	934791	Percolation mire	Crosses deep peat with several possible springs; peat 3.5m deep	
32	135345	934704	Forestry drains	Crosses band of forestry drains that run straight downslope; peat 1-3 m	Moderate
33	138901	934953	Percolation mire	Road crosses percolation mire leading to long gully/stream structures; peat 3m deep	Moderate
34	138555	936242	Seepage crossing	Crosses possible narrow line of seepage; no peat depths available; 4x4 tracks	
35	138602	936645	Deep bog : smooth	Road and turbine S25 cut through undamaged bog; peat 3.5m deep	
36	138512	936634	Ladder : percolation mire	Road cuts across foot of v.small ladder fen and associated percolation mire; peat 3m deep	High
37	138852	936970	Ladder fen	Road and powerline cut across percolation zone at eastern edge of ladder fen; peat 3.5m deep	High
38	138121	936769	Erosion complex	Road and turbine (S28) lie on intense, gullied, regen. erosion complex; peat 3m deep	
39	138255	937941	Percolation mire	Road cuts across complex fen seepage zone	High
40	138424	937917	Erosion : ladder fen	Road crosses several extensive gullies feeding into ladder fen 50m to N ; peat 3.5m deep	
41	138258	938189	Erosion : percolation	Road end, and turbine (S61), lie on eroded peat within 25m of seepage zone to river; peat 3m deep	

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
42	139519	937793	Ladder fen	Road cuts across erosion at head of excellent ladder fen; peat 2.5-3m deep	
43	138839	938428	Deep bog : eroded	Turbine base in eroded deep peat	
44	138919	938637	Deep bog	Road cuts acorss wide area of deep peat; peat 4m deep	
45	138790	938809	Deep bog : eroded	Road crosses extensive erosion complex on deep peat: peat 3.5m deep	
46	138521	939282	Ladder fen	Road crosses small ladder fen; peat 4m deep	High
47	138510	939333	Ladder fen	Road crosses foot of small ladder fen; peat 4m deep	High
48	138503	939447	Peat pipe	Road crossed stream/peat pipe system; peat 4m deep	
49	138585	939468	Erosion complex	Road crosses deep erosion complex; peat 4m deep	
50	138685	939451	Peat pipe	Road and turbine lie on possible peat pipe; peat 2.5-4m deep	
51	138927	939436	Gully/pool crossing	Road cuts across v. long gully/stream linking lochs; peat 3m deep	Moderate
52	139408	939841	Gully/pool crossing	Road cuts across long erosion gully/pool; peat 3.5m deep	
53	139338	940112	Percolation mire	Road crosses head of long seepage line; peat 3.5m deep	Moderate
54	139298	940233	Ladder fen	Road and turbine (S34) lie within complex ladder fen system; peat 4-5m deep	High
55	139279	940272	Peat pipe	Road lies in deep peat at head of peat pipe system; peat 5m deep	Moderate
56	139243	940344	Peat pipe	Road cuts across deep peat at head of peat pipe system; peat 4-4.5m deep	Moderate
57	139356	940462	Percolation mire	Road cuts through zone of seepage, possibly linked to peat pipe; peat 2-3m deep	Moderate
58	139346	940366	Peat pipe	Road cuts across head of peat pipe system; peat 4m deep	
59	139351	940335	Peat pipe	Road cuts across head of peat pipe system; peat 2m deep	
60	139637	940876	Percolation mire	Road cuts through deep percolation mire; peat 5m deep	Very high
61	139719	940899	Deep bog : smooth	Road and turbine (S35) cut across patch of smooth deep bog; peat 3.5-5m deep	High
62	139871	941071	Ladder fen	Road junction and temp compnd (TC2) to be constructed on ladder fen; peat 5m deep	Very high

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
63	140112	941104	Ladder fen	Road cuts across foot of small ladder fen on deep peat; peat 4m deep	High
64	140214	941052	Peat pipe	Road and turbine (S39) lie along peat pipe system; peat 3m deep	
65	140232	940760	Ladder fen	Road runs through small area of complex ladder fen; peat 4.5m deep	High
66	140208	940640	Deep bog : drained	Area of deep peat subject to sausage peat extraction; peat 5m deep	Moderate
67	140239	940522	Erosion complex	Road end, and turbine (S38), lie on deep-peat erosion complex showing regeneration; peat 4m deep	
68	139638	941382	Erosion complex	Road and turbine (S36) lie in erosion complex on deep peat; peat 4m deep; downslope from 5m peat	Very high
69	139656	941208	Deep bog : smooth	Road cuts edge of smooth bog area; peat 5m deep; downslope from ladder fen	Very high
70	138588	940487	Percolation mire	Road crosses percolation mire on deep peat; peat 5m deep	Moderate
71	138437	940392	Peat pipe	Road crosses peat pipe on deep peat; peat 4m deep	
72	138376	940330	Peat pipe	Road and turbine (S33) lie on peat pipe beneath deep peat; peat 4m deep	
73	138285	940045	Peat pipe	Road crosses head of peat pipe; no peat depth data	
74	138274	939870	Gully/pool crossing	Road crosses long gully/pool; no peat depth data	
75	138316	939829	Erosion complex	Road crosses erosion complex with wide bare-peat gullies; no peat depth data	
76	138505	939702	Percolation mire	Road crosses edge of complex fen area, possibly percolation; peat 3m deep	
77	138717	939935	Ladder fen	Road and turbine (S32) lie at head of small ladder fen; peat at least 2.5m deep	High
78	140440	939959	Percolation mire	Road crosses head of complex percolation mire; peat 4.5m deep	
79	138641	941734	Peat pipe	Road cuts across major peat pipe; peat 3.5-4m deep	

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
80	138645	941882	Deep bog : smooth	Road cuts across patch of rel. uneroded bog on deep peat; peat 3.5m deep	
81	138623	942605	Percolation mire	Road crosses zone of percolation on deep peat; peat 4.5m deep	High
82	138682	942519	Peat pipe	Road crosses line of possible peat pipe, on deep peat; peat 3.5m deep	
83	139106	942598	Deep peat : drained	Road and turbine (D31) lie on deep peat drained by sauasage cutting; peat 4.5m deep; 4 deg slope	Moderate
84	138705	943326	Gully/pool crossing	Road crosses v.v. long gully feeding from eroded pool complex; peat 1.5m deep	
85	138360	944619	Ladder fen : bog?	Road cuts across foot of good, if small, ladder fen (mixed with bog?); peat 5m deep	Very high
86	138286	944621	Deep peat : percolation	Road crosses deep peat linked to patterned bog/ladder fen; peat 5m deep	Moderate
87	138023	944626	Deep bog : smooth	Road and turbine (B40) lie on patch of smooth deep peat; peat 4m deep	Moderate
88	137802	944237	Erosion complex	Road cuts across regenerating erosion complex on deep peat; peat 3.5m deep	
89	137744	944165	Percolation : peat pipe	Road and turbine (B39) cut across complex percolation zone, linked to pools; peat 4m deep	Moderate
90	137719	944129	Ladder fen	Road cuts across foot of small ladder fen; peat 3.5m deep	High
91	137680	944040	Ladder fen	Road cuts western side of small ladder fen; peat 2-3m deep	High
92	137297	943170	Gully/pool crossing	Road and turbine (B37) cross very two long gullies; peat 3-3.5m deep	
93	138042	943328	Deep bog	Road crosses zone of mildly eroded bog; peat 4.5m deep	
94	137505	945127	Ladder fen : percolation : pipe	Road crosses head of peat pipe, and foot of ladder fen seepage; peat 3.5m deep	High
95	136969	945814	Deep bog : smooth	Road cuts across extensive area of relatively smooth bog; peat 3.5m deep	

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
96	136736	945536	Ladder fen	Road runs along edge of small ladder fen; peat 2m deep	Moderate
97	134962	946850	Deep bog : smooth	Road cuts across extensive area of deep, rel. uneroded bog; peat 3-4m deep	
98	137970	947447	Ladder fen	Road cuts through excellent ladder fen; peat 4m deep	Very high
99	137982	947361	Ladder fen	Turbine (G8) lies at head of excellent ladder fen; note burning; peat 2.5m deep	Very high
100	139444	949549	Deep bog : smooth	Road end and turbine (G11) on very deep peat with light erosion; peat 4.5m deep	High
101	141627	953269	Pool system : eroded	Road T-junction crosses system of large eroded pools; peat 3.5m deep	
102	141629	953314	Gully/pool crossing	Road cuts across large pool (re Garadh Dhub?)in erosion complex; peat 3.5m deep	
103	144245	955001	Gully/pool crossing	Road crosses long gully leading to eroding pool\ system; peat 2m deep	
104	144274	954869	Gully/pool crossing	Road crosses long gully leading upslope to eroding pool system; peat 2m deep	
105	143876	954759	Gully/pool crossing	Road crosses edge of long-ish pools; peat 4m deep	
106	133583	946836	Ladder : percolation mire	Road cuts across head of wide percolation mire; peat 2.5m deep	
107	132391	944815	Erosion complex	Road and turbine (B2) lie on somewhat eroded deep peat; peat 3.5m deep	
108	133234	946838	Deep bog : smooth	Road cuts across pocket of deep, rel. uneroded bog; peat 4.5m deep	
109	136635	945702	Ladder fen	Road cuts across edge of small ladder fen; peat 2.5m deep	Moderate
110	136811	945836	Ladder fen	Road cuts across foot of small ladder fen on deep peat: peat 3.5m deep	High
111	137221	945778	Gully/pool crossing	Road and turbine (B44) cross long gully on deep peat; peat 3m deep	
112	138252	947485	Peat pipe	Road crosses head of peat pipe; peat 1.5-3m deep	

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
113	139493	945424	Deep bog : smooth	Road crosses expanse of very deep, rel. smooth peat; peat 4-4.5m deep	Moderate
114	138491	946556	Percolation mire	Road cuts across complex seepage area; peat 3.5m deep	Moderate
115	138046	947908	Deep bog : smooth	Road and turbine (G9) lie on relatively uneroded peat; peat 3.5m deep	
116	137780	948162	Ladder fen	Road crosses margin of small ladder fen; peat 3m deep	High
117	138394	950554	Gully/pool crossing	Road crosses foot of many gullies leading up to pools; peat 3m deep	Moderate
118	142183	953837	Percolation : peat pipe	Road crosses deep seepage line with possible peat pipe; peat 4m deep	Moderate
119	142424	953872	Erosion complex	Road end and turbine (G34) lie on deep peat of regen. erosion; peat 4m deep	
120	142949	954643	Deep bog : smooth	Road crosses area of rel. uneroded bog; peat between 3-4m deep	
121	143642	954263	Peat pipe	Road end, and turbine (G97), lie on possible line of peat pipe; peat 3m deep	
122	143353	955144	Deep bog : smooth	Road crosses significant area of rel. uneroded bog; peat 3.5m deep	
123	143391	955567	Peat pipe	Road cuts across line of peat pipe(s); peat 3.5m deep	Moderate
124	143539	955414	Gully/pool crossing	Road cuts across pool/gully on deep peat; peat 4m deep; edge of 4 deg slope	Moderate
125	143846	955588	Gully/pool crossing	Road cuts v. long gully, turbine (G41) on deep peat; peat 4m deep	
126	143814	955720	TN1222 - seepage	Road cuts across set of large pools adjacent to seepage? Peat 4m deep	
127	143711	955910	Gully/pool crossing	Cuts through two pools, asociated with much regen; peat 3-4m deep	
128	144352	956310	Pool system : eroded	Road cuts right through large pool complex, eroded but much regen; peat 4m deep	

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
129	144719	956861	Deep bog : smooth	Area of relatively lightly eroded and smooth bog; peat 3.5m deep	
130	148060	958624	Percolation : peat pipe	Road crosses percolation zone, also possible peat pipe; peat 3.5m deep	
131	148385	958349	Percolation mire	Road cuts across large, wide percolation mire linked to ladder fen; peat 3m deep	
132	149126	958766	Percolation mire	Road end, and turbine (G60), lie within wide percolation mire feeding main river	Moderate
133	150409	957997	Percolation mire	Road, and nearby turbine (G81), cross major seepage line and possible peat pipe; peat 3.5m deep	Moderate
134	150681	957962	Peat pipe	Road cuts across possible head of peat pipe; peat 3m deep	
135	151456	957824	Percolation : peat pipe	Crosses area of smooth seepage with possible associated peat pipe; peat 4m deep	
136	151696	957627	Pool : peat pipe	Road passes large pool, possibly at head of peat pipe; peat 3m deep	
137	152568	957730	Percolation : peat pipe	At head of fen seepage zone with peat pipe downhill; may not be fen; 3m peat depth	
138	152793	958047	Peat pipe	Road actually runs along it, and crosses it at junction	
139	152930	958743	Percolation : peat pipe	Wide fen seepage zone, with peat pipe to west (crossed); peat 4m deep; turbine site!	High
140	152360	959048	Gully/pool crossing	Long, narrow gully on 3.5m peat; appears revegetated	
141	148736	957266	Erosion : ladder fen	Road crosses deep erosion complex, perhaps once part of ladder fen; peat 4m deep	
142	149536	956018	Ladder fen	Road cuts across head of ladder fen; peat 2.5m deep	Very high
143	150667	956486	Erosion complex	Road end, and turbine (G94), on deep eroded peat at head of seepage; peat 3.5-5m deep	High
144	151324	957781	Peat pipe	Road cuts across head of peat pipe system; peat 3.5m deep	
145	152979	959455	Peat pipe	Cuts across mid-point of pipe	

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
146	152882	959608	Peat pipe	Cuts across head of visible pipe	
147	149921	957827	Ladder fen : degraded	Road cuts through small area of possible\ former ladder fen, now eroded; peat 3.5m deep	
148	148836	957329	Ladder fen : degraded	Road cuts through what was probably a ladder fen, now eroded; peat 3.5m deep	
149	137658	947313	Ladder fen	Pylon line passes within 100m of foot of excellent ladder fen; no peat depths	Very high
150	138886	937022	Ladder fen	Pylon cuts across top of ladder fen, within 50m; no specific peat depths, but possibly 3.5m	
151	138110	935497	Erosion complex	Road runs along foot of complicated watershed erosion complex; no peat depths available	High
152	134288	933747	Percolation mire	Road cuts across possible spring outflow, plus possible peat pipe; peat 2.5m deep	Moderate
153	134332	933747	Percolation mire	Road cuts across head of spring mire and possible peat pipe; peat 2.5m deep	Moderate
154	135797	934693	Ladder : percolation mire	Road end, and turbine (S7), sit in deep v. wet percolation/ladder fen - no depths - Wingecarribee	Moderate
155	148479	958486	Percolation mire	Powerline crosses seepage line leading to peat pipe; no peat depths available	
156	149798	958277	Gully/pool crossing	Powerline crosses large eroded pool complex with regen.; no peat depths available: nearest 4m	
157	143437	955695	Pool system : peat pipes	Pylon line cuts across large pool system and head of pipe system; no peat depths	
158	143164	955633	Pool system	Pylon angle tower in semi-eroded pool system; peat 3.5m deep	
159	137536	947451	Ladder : percolation mire	Pylon corner lies in eroded bog 70m from good ladder fen; no peat depth data	
160	138301	944695	Deep bog : percolation	Pylon terminates on deep peat, possibly with percolation; peat 4m deep	Moderate

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
161	138254	944680	Deep peat : percolation	Sub-station lies on deep peat, with possible percolation; peat 3.5m deep	Moderate
162	139664	942063	Pool system	Pylon line crosses close to excellent little pool system; no peat depth data	
163	139321	941355	Erosion complex	Pylon corner sits in erosion complex close to ladder fen, possibly deep; no peat depth data	
164	139523	940230	Ladder : percolation mire	Pylon corner lies within percolation mire associated with small ladder fen; no peat depth data	Moderate
165	139308	939889	Gully/pool crossing	Pylon line crosses v large pool at edge of loch; no peat depth data	
166	139068	938682	Gully/pool crossing	Pylon corner next to long spring (?) line; no peat depth data	
167	138955	937663	Pool system	Pylon line runs through large pool system; no peat depth data	
168	138926	937386	Pool system	Pylon line runs right through large pool system; no peat depth data	
169	139071	935638	Percolation mire	Pylon line crosses, corner on, wide percolation mire; no peat depth data, but probably deep	High
170	148905	958542	Pool system	Pylon line crosses edge of extensive high-quality pool system; no peat depths	
171	143731	956031	Erosion complex	Road and turbine (G96) on deep mildly eroded bog; peat 4m deep	
172	142353	953864	Gully/pool crossing	Road crosses extremely long stream, cuts deep into peat; peat 5m deep	Moderate
173	137870	948045	Deep bog : pylon	Start of pylon line sits in deep peat; peat 4m deep	Moderate
174	138576	946525	Deep peat : turbine	Road and turbine (G5) cut through deep peat at head of complex seepage; peat 3.5-4m	Moderate
175	139240	942615	Deep bog : compound	Temporary compound (TC3) on deep peat drained by sausage extraction; peat 3-3.5m deep; 6 deg slope	Moderate

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
176	139637	941382	Deep bog : eroded	Road and turbine (S36) lie on very deep peat; peat 5m deep	
177	133949	933811	Deep peat : turbine	Very deep peat just next to turbine S45; LWP express concern about stability	High
178	138015	935330	Percolation mire - large valley	Wide valley of percolation/valley fen; LWP says 'peatslide track', and must therefore drain	High
179	137388	934296	Deep peat on slope	Sub-station to be built on deep (3m) peat with significant (6 deg) slope: forestry drainage	Moderate
180	150055	957992	Source Abhainn Dhaill	Headwaters : Feadan Hiortagro with sub-station, pylon, roads on deep peat, all on slopes	Moderate
181	151899	959313	Deep peat - compounds	Much infrastructure (t.c., sub-stn, pylon-end, road) on peat with deep (3.5m) peat down 6 deg slope	Moderate
182	150155	956896	Peat mound	Large peat mound - possible archaeological significance, 70m from road-line	
183	143851	956143	Stream crossing	Stream crossing on deep (4m) peat	Moderate
184	139175	945457	Deep peat : turbine	Road end and turbine (B48) on very deep peat on riparian slope; peat 4.5m deep	Moderate
185	134883	946869	Stream crossing	Stream crossing with 4.5m peat on one bank; peat 4.5m deep	Moderate
186	139351	941223	Ladder fen : large	Pylon route crosses moderately large ladder fen	High
187	138589	941567	Deep peat : slopes	Deep peat lying at foot of steep slope	High
188	138573	941342	Deep peat : slopes	Deep peat lying a foot of steep slope	High
189	138518	941004	Deep peat : slopes	Deep peat crossing relatively steep slope	High
190	139397	940764	Deep peat : slopes	Moderately deep peat lying just below relatively steep slope	Moderate
191	138688	935821	Deep peat : slopes	Moderately deep peat crosses relatively steep slope	Moderate
192	138221	934740	Deep peat : slopes	Moderately deep peat on steep slope	Moderate
193	135692	934795	Deep peat : slope	Deep peat on moderately steep slope	Moderate
194	137189	934344	Deep peat : slope	Deep peat on steep slope, to be quarried for Rock Source RS1; peat 3m deep	Very high
195	141327	952826	Pool system	Quarry (RS4) right next to (within 20m) of pool	High

Id	x_coord	y_coord	Type_	Observns	Peatslide risk
196	141575	952420	Loch Ceartabhat	Quarry (RS4) right next to loch on deep peat; peat 3m deep	Very high
197	138819	939123	Loch Mor an Starr	Corner pylon within 50m	High
198	138945	938900	Loch Mor an Starr	Pylon tower within 30m of loch, on gully	High
199	139010	939424	Loch Mor an Starr	Pylon tower on eroded peat within 75m of loch	Moderate

15 Appendix 4: Listing of ZoCs

x/y coordinates are for the centroid of each buffered record of peat depth

Note that the '1' and the '9' at start of the x/y coordinates represent the 'NB' of an OS 6-figure National Grid reference

Id	x_coord	y_coord	Area (ha)
1	134463	933096	2
2	135389	933534	5
3	134223	933819	0
4	134063	933822	40
5	135313	934240	6
6	135859	934245	5
7	137890	934263	7
8	137244	934343	14
9	137624	934620	7
10	135306	934728	7
11	135819	934748	12
12	138886	934955	4
13	138195	934862	21
14	137616	935116	4
15	134890	935115	17
16	138174	935458	23
17	139033	935666	8
18	138674	935827	5
19	138625	936210	10
20	138582	936662	7
21	138136	936793	4
22	138829	937282	38
23	139630	937567	28
24	138476	937803	39
25	138282	938281	6
30	138503	939836	63
31	138531	941007	5
32	139782	941006	72
33	138589	941570	23
34	139616	942092	6
35	138565	942573	11
36	139203	942552	25
37	137269	943154	8
38	138712	943365	5
39	138043	943336	11
40	137743	944123	19
41	138031	944641	5
42	138353	944573	12
43	132370	944816	7
44	137463	945214	9
45	139571	945384	34
46	137206	945789	3
47	136786	945656	26
48	138522	946566	8
49	134975	946848	7
50	133438	946877	14
51	137946	947455	44
52	137911	948071	29
53	139468	949599	11
54	138481	950589	10

26	138893	938772	23	55	141369	952414	124
27	138660	939958	5	56	141590	953280	13
28	140446	939944	17	57	142260	953930	23
29	139331	940155	38	58	142960	954663	4

Id	x_coord	y_coord	Area (ha)
59	143716	954428	28
60	144269	954986	27
61	149517	955978	35
62	150156	956899	2
63	143774	955864	95
64	150771	956642	30
65	148750	957299	16
66	151758	957692	11
67	151380	957843	8
68	152270	957918	17
69	152795	957968	27
70	150163	958031	77
71	148064	958589	10
72	148769	958528	47
73	152974	958783	9
74	152404	959095	9
75	151641	959394	32
76	152880	959509	18

16 Appendix 5: Listing of MZoCs

x/y coordinates are for the centroid of each buffered record of peat depth

Note that the '1' and the '9' at start of the x/y coordinates represent the 'NB' of an OS 6-figure National Grid reference

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1	134461	933134	3.50	246
2	134477	933187	2.50	126
3	134483	933234	2.00	80
4	134468	933282	1.50	46
5	134443	933318	1.00	20
6	134407	933348	2.00	80
7	134358	933380	3.50	246
8	134316	933407	2.00	80
9	135301	933421	2.50	126
10	134274	933429	3.00	180
11	135354	933479	3.00	180
12	135416	933532	3.50	246
13	134224	933515	3.50	246
14	134198	933610	3.00	180
15	134196	933662	4.00	320
16	134312	933750	2.50	126
17	134202	933727	3.00	180
18	134235	933753	2.00	80
19	134385	933756	2.00	80
20	134188	933764	2.00	80
21	134137	933774	3.50	246
22	134429	933770	2.50	126
23	134060	933788	3.00	180
24	133982	933804	4.50	406
25	134472	933797	3.00	180
26	133908	933815	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
29	133693	933857	3.00	180
30	136250	933850	0.50	6
31	134556	933861	2.00	80
32	133657	933883	2.50	126
33	134589	933897	1.50	46
34	134621	933925	0.50	6
35	133623	933921	3.00	180
36	136237	933927	2.00	80
37	133594	933962	2.50	126
38	134754	933986	3.00	180
39	134832	933998	1.00	20
40	134906	934003	2.00	80
41	134961	934007	2.50	126
42	135008	934015	1.00	20
43	135057	934024	2.00	80
44	135122	934057	1.00	20
45	137821	934065	3.00	180
46	136179	934076	1.50	46
47	135172	934109	2.50	126
48	137081	934107	3.00	180
49	135775	934153	2.00	80
50	135753	934159	2.00	80
51	135831	934158	1.00	20
52	136117	934147	1.00	20
53	135194	934150	3.00	180

27	134518	933828	2.50	126
28	133789	933830	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
56	135708	934172	1.50	46
57	136051	934176	1.50	46
58	135926	934177	2.00	80
59	136001	934183	2.50	126
60	137008	934181	1.50	46
61	135661	934190	0.50	6
62	136959	934196	2.50	126
63	136904	934206	1.50	46
64	135223	934192	3.50	246
65	135772	934189	2.00	80
66	135619	934213	1.00	20
67	137417	934205	2.00	80
68	137688	934213	0.50	6
69	137857	934201	3.00	180
70	135574	934235	0.50	6
71	135254	934234	3.00	180
72	135532	934251	1.00	20
73	137691	934251	2.00	80
74	135781	934253	5.00	500
75	137402	934256	3.00	180
76	135308	934273	3.50	246
77	135377	934289	3.00	180
78	135456	934276	3.50	246
79	137874	934262	3.50	246
80	137699	934299	3.00	180
81	137896	934315	2.50	126
82	135780	934311	4.00	320
83	135762	934353	2.00	80

54	137047	934157	2.00	80
55	137837	934142	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
90	135641	934469	2.00	80
91	138050	934496	1.50	46
92	137719	934495	2.00	80
93	138106	934548	1.00	20
94	137678	934576	2.50	126
95	138162	934599	1.00	20
96	137638	934608	3.00	180
97	135569	934575	1.00	20
98	137591	934631	1.50	46
99	137495	934626	2.00	80
100	137548	934638	1.50	46
101	135509	934636	1.50	46
102	137248	934644	1.00	20
103	138190	934641	0.50	6
104	135466	934656	2.50	126
105	137205	934667	1.50	46
106	135411	934680	2.00	80
107	135364	934698	1.00	20
108	138211	934687	1.00	20
109	137142	934698	1.00	20
110	134429	934714	1.50	46
111	134487	934729	1.50	46
112	134537	934740	2.50	126
113	134588	934745	1.50	46
114	134637	934750	2.50	126
115	135538	934700	1.50	46
116	134712	934756	1.50	46
117	134783	934759	1.00	20

84	137921	934353	2.00	80
85	137716	934353	4.00	320
86	135730	934385	1.00	20
87	137729	934402	1.00	20
88	135692	934415	1.50	46
89	137982	934424	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
124	134882	934779	2.00	80
125	138216	934788	2.00	80
126	138205	934813	3.00	180
127	134973	934819	1.00	20
128	135266	934800	3.50	246
129	138193	934831	3.00	180
130	135248	934845	2.00	80
131	135198	934855	1.00	20
132	135008	934850	0.50	6
133	135147	934866	2.00	80
134	138164	934862	4.00	320
135	135101	934878	1.00	20
136	135042	934885	1.50	46
137	135069	934893	1.50	46
138	135062	934909	1.50	46
139	138271	934873	3.00	180
140	135031	934922	4.00	320
141	138350	934946	2.00	80
142	138853	934958	2.50	126
143	138801	934967	1.50	46
144	138754	934976	0.50	6
145	138032	934978	3.00	180
146	138085	934930	3.50	246
147	138925	934967	3.00	180

118	135301	934734	3.00	180
119	138223	934741	2.50	126
120	135603	934772	2.00	80
121	135747	934777	3.00	180
122	135644	934793	2.50	126
123	135697	934795	4.00	320

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
158	137960	935092	0.50	6
159	138018	935060	0.50	6
160	137827	935096	2.00	80
161	137876	935093	1.00	20
162	137777	935096	3.00	180
163	137727	935099	2.00	80
164	134837	935086	3.00	180
165	137674	935106	2.50	126
166	138025	935105	0.50	6
167	137604	935118	3.00	180
168	138043	935136	1.00	20
169	134199	935131	2.00	80
170	134268	935169	2.50	126
171	134313	935191	2.00	80
172	134717	935158	4.00	320
173	134384	935211	3.00	180
174	134481	935223	2.50	126
175	134576	935214	3.00	180
176	138119	935254	3.00	180
177	138240	935507	2.00	80
178	138301	935515	2.50	126
179	138338	935525	2.00	80
180	138383	935536	1.50	46
181	138430	935547	1.00	20

148	138379	934981	3.00	180
149	138711	934991	1.00	20
150	138993	934996	2.00	80
151	138662	935009	1.50	46
152	134957	934983	4.50	406
153	138612	935021	1.00	20
154	138023	935004	3.00	180
155	138417	935014	2.00	80
156	138513	935030	0.50	6
157	134890	935045	4.00	320

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
192	138111	935734	3.00	180
193	138065	935758	2.50	126
194	137783	935735	2.50	126
195	137972	935772	3.00	180
196	137871	935771	2.00	80
197	137917	935772	1.00	20
198	138677	935751	2.50	126
199	138615	936090	2.00	80
200	138537	936133	3.00	180
201	139537	936181	3.00	180
202	139434	936194	2.50	126
203	139338	936210	2.00	80
204	139283	936222	1.50	46
205	137982	936232	2.50	126
206	138028	936244	3.00	180
207	138089	936285	3.50	246
208	138142	936344	3.00	180
209	139091	936364	2.00	80
210	139021	936440	1.50	46
211	138950	936537	2.00	80

182	138485	935555	2.50	126
183	138579	935568	2.00	80
184	138234	935555	1.50	46
185	137556	935628	1.00	20
186	138654	935613	3.00	180
187	137606	935645	2.00	80
188	137656	935661	2.50	126
189	138200	935643	2.50	126
190	137700	935684	2.00	80
191	138153	935703	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
226	139002	936686	2.00	80
227	139086	936781	1.50	46
228	138117	936774	3.00	180
229	139124	936831	2.00	80
230	139133	936861	2.50	126
231	139156	936870	2.50	126
232	139048	936869	1.00	20
233	138029	936860	2.50	126
234	139184	936895	2.00	80
235	138915	936919	2.50	126
236	137926	936935	3.00	180
237	139235	936951	2.50	126
238	137809	936984	2.50	126
239	138845	936985	3.50	246
240	137717	937012	3.00	180
241	139276	937014	2.00	80
242	138819	937031	4.00	320
243	138798	937076	3.50	246
244	138778	937126	4.00	320
245	138754	937171	2.50	126

212	138900	936589	2.50	126
213	138918	936585	2.50	126
214	138225	936556	2.50	126
215	138898	936602	2.50	126
216	138921	936605	2.50	126
217	138199	936610	2.00	80
218	138440	936606	2.50	126
219	138519	936640	3.00	180
220	138595	936649	3.50	246
221	138771	936655	4.00	320
222	138843	936632	3.50	246
223	138670	936654	3.00	180
224	138717	936655	3.50	246
225	138166	936678	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
260	139455	937599	2.50	126
261	138537	937594	3.00	180
262	139475	937642	3.00	180
263	138525	937676	3.50	246
264	138521	937728	3.00	180
265	138521	937774	2.50	126
266	139477	937766	2.50	126
267	138528	937830	3.00	180
268	138513	937879	2.50	126
269	138472	937905	3.00	180
270	138372	937916	1.50	46
271	138421	937916	3.50	246
272	139472	937866	3.00	180
273	138327	937918	2.00	80
274	139464	937942	2.00	80
275	139453	937992	2.50	126

246	138728	937201	2.00	80
247	138688	937232	1.50	46
248	138645	937257	1.50	46
249	139325	937153	2.50	126
250	138611	937285	2.00	80
251	138585	937331	3.00	180
252	138558	937379	2.50	126
253	139333	937340	2.00	80
254	138550	937423	3.00	180
255	139336	937434	3.00	180
256	139361	937482	3.50	246
257	138554	937478	3.50	246
258	138549	937526	2.50	126
259	139410	937543	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
294	138508	939398	3.50	246
295	138858	939440	4.00	320
296	138936	939440	3.00	180
297	138984	939442	2.50	126
298	138776	939444	3.50	246
299	138728	939450	2.50	126
300	139106	939457	2.00	80
301	138502	939460	4.00	320
302	138585	939473	4.00	320
303	139223	939488	1.00	20
304	139266	939508	2.50	126
305	138494	939517	3.50	246
306	140470	939514	1.00	20
307	139335	939546	3.00	180
308	140429	939561	1.00	20
309	139396	939589	2.50	126

276	138257	937970	2.50	126
277	139438	938039	2.00	80
278	139423	938083	2.50	126
279	138232	938077	2.00	80
280	139385	938142	2.00	80
281	138252	938152	3.00	180
282	138835	938451	3.50	246
283	138911	938544	4.00	320
284	138920	938634	3.50	246
285	138884	938697	4.00	320
286	138822	938776	3.50	246
287	138762	938850	3.00	180
288	138688	938950	3.50	246
289	138634	939031	3.00	180
290	138607	939073	4.50	406
291	138559	939165	3.50	246
292	138522	939284	4.00	320
293	138512	939354	3.00	180

310	140401	939603	1.50	46
311	138475	939582	1.00	20
312	138457	939648	1.50	46
313	138447	939685	3.00	180
314	138429	939700	3.00	180
315	138400	939703	0.50	6
316	138482	939705	3.00	180
317	140360	939668	2.00	80
318	139410	939696	2.00	80
319	138437	939712	3.00	180
320	138567	939720	2.00	80
321	140319	939729	2.50	126
322	139405	939737	2.00	80
323	138627	939750	1.00	20
324	141096	939778	1.00	20
325	141147	939780	1.50	46
326	141049	939782	1.50	46
327	141001	939789	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
328	141228	939789	3.00	180
329	140952	939796	1.50	46
330	140297	939777	3.00	180
331	140878	939807	2.00	80
332	138659	939792	3.00	180
333	140782	939830	1.50	46
334	140282	939830	2.50	126
335	139400	939808	3.50	246
336	140714	939863	2.50	126
337	140277	939870	1.50	46
338	140674	939895	1.50	46
339	138688	939865	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
362	140603	940054	2.00	80
363	139336	940118	3.50	246
364	139935	940135	1.50	46
365	139984	940155	1.00	20
366	140032	940165	1.00	20
367	140078	940169	0.50	6
368	139317	940164	4.00	320
369	139291	940211	5.00	500
370	139290	940250	5.00	500
371	139268	940259	5.00	500
372	138267	940281	4.00	320
373	138290	940290	3.00	180

340	140280	939902	2.00	80
341	140290	939915	2.00	80
342	139394	939889	3.00	180
343	140265	939918	2.00	80
344	140177	939919	1.00	20
345	140227	939923	1.50	46
346	140325	939935	3.50	246
347	139392	939936	2.50	126
348	140372	939961	4.00	320
349	140425	939968	4.50	406
350	140471	939970	2.00	80
351	140517	939980	3.00	180
352	140569	939988	2.50	126
353	140606	939991	2.00	80
354	140637	939952	2.50	126
355	140631	939994	2.00	80
356	140671	940001	3.00	180
357	140616	940001	2.00	80
358	139385	939984	3.00	180
359	140771	940010	2.00	80
360	139370	940038	2.50	126
361	139353	940079	2.00	80

374	139324	940288	4.00	320
375	138327	940307	3.50	246
376	139252	940309	4.50	406
377	139341	940330	2.00	80
378	138373	940334	4.00	320
379	139231	940359	4.00	320
380	138414	940368	3.50	246
381	139339	940381	4.00	320
382	140644	940269	1.50	46
383	139215	940406	3.00	180
384	139341	940438	3.00	180
385	139204	940451	2.00	80
386	138491	940429	4.00	320
387	139354	940479	2.00	80
388	138576	940493	5.00	500
389	138622	940527	3.50	246
390	138657	940551	2.00	80
391	139179	940520	3.00	180
392	139383	940542	2.50	126
393	138696	940579	3.00	180
394	139143	940585	1.50	46
395	138737	940611	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
396	140223	940559	4.00	320
397	139403	940610	1.50	46
398	138775	940637	2.00	80
399	139086	940627	2.00	80
400	138842	940663	1.50	46
401	138821	940656	1.00	20
402	138851	940664	1.50	46
403	138888	940665	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
430	139972	941106	3.50	246
431	140138	941103	3.50	246
432	140036	941113	3.00	180
433	140086	941113	4.00	320
434	139833	941104	5.00	500
435	138515	941087	2.50	126
436	139783	941132	3.50	246
437	138522	941158	2.00	80

404	138981	940660	1.50	46
405	140196	940656	5.00	500
406	139407	940662	3.00	180
407	139403	940712	2.00	80
408	138909	940699	1.50	46
409	138870	940752	3.00	180
410	138827	940774	1.00	20
411	138753	940785	1.50	46
412	138679	940798	1.00	20
413	139408	940780	2.50	126
414	140217	940760	4.50	406
415	138612	940821	2.00	80
416	139439	940845	2.00	80
417	139573	940879	3.00	180
418	140237	940857	3.50	246
419	139481	940871	2.50	126
420	139651	940895	5.00	500
421	139723	940924	3.50	246
422	139752	940952	3.00	180
423	140238	940926	2.50	126
424	138523	940957	2.50	126
425	139771	940991	4.00	320
426	138517	941009	3.50	246
427	139819	941050	5.00	500
428	140202	941034	3.00	180
429	139896	941093	5.00	500

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
464	138695	942399	3.50	246
465	138793	942419	2.50	126
466	138720	942442	3.50	246
467	138754	942448	3.50	246

438	139725	941165	3.00	180
439	138537	941205	2.50	126
440	138552	941253	3.00	180
441	138566	941296	3.50	246
442	139652	941271	5.00	500
443	138572	941345	4.00	320
444	139629	941408	4.00	320
445	138579	941427	3.50	246
446	138589	941502	2.50	126
447	138586	941562	4.00	320
448	138590	941631	3.50	246
449	138613	941695	4.00	320
450	138636	941747	3.50	246
451	138652	941790	3.00	180
452	138641	941859	3.50	246
453	138606	941919	2.50	126
454	138562	941975	3.00	180
455	138536	942042	2.50	126
456	138540	942095	3.00	180
457	138576	942209	2.50	126
458	139041	942184	2.00	80
459	138617	942271	3.00	180
460	138643	942315	3.50	246
461	138669	942358	3.00	180
462	138933	942317	1.50	46
463	138832	942391	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
498	138535	942953	3.00	180
499	138653	942971	2.50	126
500	138435	942976	2.50	126
501	138435	943069	2.00	80

468	138716	942483	4.00	320
469	138683	942515	3.50	246
470	139602	942529	1.00	20
471	139535	942533	1.50	46
472	139177	942571	4.00	320
473	139439	942562	3.00	180
474	139223	942574	3.50	246
475	138651	942557	5.00	500
476	139270	942585	3.00	180
477	139339	942584	2.00	80
478	139127	942586	4.50	406
479	139067	942614	5.00	500
480	139023	942638	3.50	246
481	138604	942624	4.50	406
482	138993	942665	2.50	126
483	138559	942683	3.50	246
484	138531	942716	3.00	180
485	138493	942760	4.00	320
486	138919	942757	1.50	46
487	138853	942841	2.00	80
488	138830	942864	2.00	80
489	138880	942876	3.00	180
490	138800	942894	2.00	80
491	138436	942917	2.50	126
492	138440	942895	1.50	46
493	138935	942913	2.00	80
494	138435	942927	2.50	126
495	138446	942935	2.50	126
496	138764	942925	2.50	126
497	138719	942953	3.00	180
Id	x_coord	y_coord	Depth_m	buffer_x20 (m)

502	137361	943143	3.00	180
503	137416	943145	3.50	246
504	137315	943147	2.50	126
505	137470	943152	3.00	180
506	137284	943153	3.00	180
507	137517	943161	2.50	126
508	138432	943144	1.50	46
509	137561	943171	1.50	46
510	137610	943178	2.50	126
511	137709	943194	3.00	180
512	137808	943208	2.50	126
513	137273	943187	3.00	180
514	138429	943193	2.00	80
515	137905	943228	3.00	180
516	137275	943238	2.50	126
517	138413	943242	2.50	126
518	137950	943259	3.50	246
519	138799	943296	1.00	20
520	137986	943290	3.00	180
521	137280	943285	2.00	80
522	138730	943316	1.50	46
523	138658	943337	1.00	20
524	138402	943307	3.50	246
525	138020	943326	4.50	406
526	138609	943348	1.50	46
527	137291	943334	1.50	46
528	138560	943357	1.00	20
529	138514	943362	2.00	80
530	138067	943357	3.50	246
531	138112	943369	2.00	80
Id	x_coord	y_coord	Depth_m	buffer_x20 (m)

532	138392	943374	3.00	180
533	138404	943360	3.00	180
534	138447	943370	3.00	180
535	138356	943376	2.50	126
536	138156	943376	1.00	20
537	138211	943379	2.50	126
538	138286	943378	1.50	46
539	137326	943400	2.00	80
540	138881	943362	1.50	46
541	138909	943476	1.00	20
542	137389	943472	1.00	20
543	138916	943525	1.50	46
544	137433	943530	1.50	46
545	138925	943574	1.00	20
546	137469	943595	1.00	20
547	137502	943652	1.50	46
548	138936	943647	1.50	46
549	137488	943686	1.50	46
550	137531	943696	1.50	46
551	137413	943721	2.50	126
552	138944	943724	2.00	80
553	137567	943740	1.00	20
554	138944	943774	1.50	46
555	137596	943778	1.50	46
556	137630	943845	1.00	20
557	138928	943896	1.50	46
558	138889	943959	2.00	80
559	138828	943999	0.50	6
560	137663	943968	1.50	46
561	138767	944036	1.50	46
562	137677	944064	2.00	80
563	138727	944070	2.00	80
566	137694	944109	3.00	180
567	138639	944157	2.00	80
568	139604	944173	1.50	46
569	137735	944177	4.00	320
570	138602	944219	1.50	46
571	137787	944235	3.50	246
572	139561	944237	1.00	20
573	138597	944268	4.00	320
574	137815	944275	2.50	126
575	139538	944278	1.50	46
576	137832	944319	1.50	46
577	139512	944322	2.00	80
578	138584	944343	1.00	20
579	132443	944392	2.00	80
580	139473	944385	1.50	46
581	138568	944418	1.50	46
582	131956	944396	1.50	46
583	139431	944448	2.50	126
584	139398	944490	2.00	80
585	138542	944488	2.00	80
586	129467	944501	0.50	6
587	139370	944527	1.50	46
588	132431	944482	1.50	46
589	137886	944458	1.00	20
590	129340	944544	1.00	20
591	137960	944578	0.50	6
592	131955	944520	2.00	80
593	138475	944582	2.00	80
594	132426	944580	2.50	126
595	138429	944606	2.50	126
596	138226	944622	1.50	46
597	138386	944619	3.00	180

564	138689	944102	0.50	6
565	139672	944085	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
600	137997	944608	3.50	246
601	129574	944581	1.00	20
602	139325	944589	2.00	80
603	138182	944628	1.00	20
604	132431	944625	2.00	80
605	138137	944643	1.50	46
606	129270	944619	2.00	80
607	138033	944649	4.00	320
608	138080	944661	1.00	20
609	129601	944652	0.50	6
610	139284	944654	1.50	46
611	129221	944678	1.00	20
612	131950	944645	2.50	126
613	131564	944706	1.00	20
614	138047	944696	2.00	80
615	129621	944698	1.00	20
616	129192	944717	1.50	46
617	131526	944734	0.50	6
618	132043	944751	2.50	126
619	131953	944727	3.00	180
620	131976	944755	3.00	180
621	132114	944758	0.50	6
622	138044	944744	2.50	126
623	132157	944776	2.00	80
624	139229	944735	2.00	80
625	129668	944756	0.50	6
626	139062	944807	1.00	20
627	139111	944809	3.00	180

598	138274	944625	3.50	246
599	138333	944625	5.00	500

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
634	132312	944833	3.00	180
635	132385	944838	3.50	246
636	132423	944742	3.00	180
637	138031	944838	2.50	126
638	129115	944842	1.00	20
639	131437	944858	1.50	46
640	129741	944857	1.50	46
641	131855	944863	2.50	126
642	131389	944917	1.00	20
643	131879	944936	3.00	180
644	129110	944918	3.50	246
645	129766	944935	1.00	20
646	131883	944989	2.50	126
647	129115	944998	2.50	126
648	137951	945021	1.00	20
649	129734	945040	2.00	80
650	131884	945037	1.50	46
651	137351	945071	2.50	126
652	137401	945074	1.00	20
653	137302	945077	2.00	80
654	129706	945074	1.50	46
655	137872	945069	1.50	46
656	137440	945092	1.50	46
657	131883	945084	1.00	20
658	129124	945066	1.00	20
659	130653	945131	1.50	46
660	130736	945126	2.00	80
661	137486	945119	3.50	246

628	131720	944740	2.50	126
629	131896	944787	3.00	180
630	138037	944795	3.00	180
631	132222	944809	2.50	126
632	129711	944815	1.00	20
633	131478	944793	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
668	130367	945142	3.00	180
669	137532	945138	2.00	80
670	137579	945144	3.00	180
671	137634	945140	2.50	126
672	129635	945147	1.50	46
673	131877	945135	1.50	46
674	129133	945142	1.50	46
675	137236	945155	1.00	20
676	130325	945162	2.50	126
677	131864	945178	0.50	6
678	129133	945192	0.50	6
679	130290	945209	2.50	126
680	129139	945238	1.00	20
681	131818	945231	1.00	20
682	129611	945213	2.00	80
683	137219	945226	1.50	46
684	130274	945261	1.50	46
685	129609	945287	1.50	46
686	137211	945300	2.00	80
687	130267	945308	1.00	20
688	131725	945298	1.00	20
689	129629	945333	2.00	80
690	137201	945349	2.50	126
691	131704	945359	0.50	6

662	129669	945113	2.50	126
663	137708	945128	1.00	20
664	130507	945139	1.50	46
665	130581	945136	2.00	80
666	130405	945141	2.00	80
667	130453	945140	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
702	131559	945429	1.00	20
703	139654	945442	3.50	246
704	136882	945458	2.00	80
705	136952	945462	2.50	126
706	139177	945456	4.50	406
707	137009	945465	3.50	246
708	139731	945461	2.50	126
709	137059	945469	1.50	46
710	139774	945473	2.00	80
711	137100	945477	1.00	20
712	137136	945487	2.50	126
713	137165	945457	2.50	126
714	129696	945447	1.00	20
715	131499	945478	1.50	46
716	136762	945496	2.00	80
717	137146	945506	2.50	126
718	130271	945482	1.00	20
719	131436	945522	1.50	46
720	132294	945467	2.50	126
721	136732	945538	1.50	46
722	131840	945493	1.00	20
723	131395	945552	1.00	20
724	130271	945554	2.00	80
725	131360	945587	1.50	46

692	131641	945360	1.00	20
693	129655	945378	1.50	46
694	131595	945401	0.50	6
695	131751	945404	1.50	46
696	139479	945423	3.50	246
697	137187	945398	3.00	180
698	139550	945426	4.00	320
699	130263	945382	1.50	46
700	139379	945431	4.50	406
701	139266	945441	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
736	130943	945665	1.50	46
737	137125	945639	3.00	180
738	131016	945672	2.50	126
739	130256	945657	1.50	46
740	130769	945674	1.50	46
741	131091	945681	2.00	80
742	131141	945685	2.50	126
743	131236	945666	2.00	80
744	138425	945655	3.50	246
745	130692	945686	1.00	20
746	130645	945694	1.00	20
747	139896	945670	1.50	46
748	131944	945682	1.00	20
749	130600	945703	1.00	20
750	137140	945697	2.50	126
751	136646	945684	2.50	126
752	130549	945719	2.00	80
753	130252	945705	2.00	80
754	137150	945731	2.50	126
755	137169	945731	2.50	126

726	137132	945565	2.00	80
727	131917	945590	1.50	46
728	130264	945606	2.50	126
729	131323	945624	2.50	126
730	139872	945573	1.00	20
731	136697	945600	1.00	20
732	132266	945600	2.00	80
733	131931	945637	0.50	6
734	130893	945662	2.00	80
735	130842	945664	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
770	138397	945792	2.00	80
771	131914	945797	1.00	20
772	136726	945847	2.00	80
773	136880	945826	3.50	246
774	128850	945854	0.50	6
775	129267	945846	2.50	126
776	136684	945853	1.50	46
777	129092	945855	0.50	6
778	128800	945860	1.00	20
779	136636	945866	3.00	180
780	129345	945866	3.50	246
781	132127	945873	1.50	46
782	129397	945879	2.50	126
783	128139	945869	1.50	46
784	132081	945883	2.00	80
785	132029	945885	1.50	46
786	131887	945868	0.50	6
787	128603	945889	3.00	180
788	131943	945890	1.00	20
789	136570	945856	3.00	180

756	138413	945714	2.50	126
757	131947	945728	0.50	6
758	130500	945744	1.50	46
759	137116	945751	3.00	180
760	136602	945750	3.00	180
761	130254	945754	1.00	20
762	130462	945769	1.00	20
763	132238	945721	2.50	126
764	137050	945781	2.00	80
765	137225	945774	3.00	180
766	136577	945796	2.50	126
767	130422	945800	1.50	46
768	132206	945807	1.50	46
769	130254	945804	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
804	131880	945916	0.50	6
805	130090	945941	1.00	20
806	139267	945944	1.50	46
807	129989	945941	0.50	6
808	129633	945939	3.50	246
809	128435	945936	1.00	20
810	139341	945947	1.00	20
811	134857	945911	2.50	126
812	128185	945949	1.00	20
813	129683	945959	1.00	20
814	139441	945963	1.50	46
815	139167	945959	1.00	20
816	136515	945961	2.50	126
817	129724	945976	0.50	6
818	139750	945906	1.00	20
819	128226	945982	0.50	6

790	129443	945891	1.50	46
791	129487	945900	0.50	6
792	128553	945899	2.00	80
793	130345	945865	0.50	6
794	128653	945899	3.00	180
795	128723	945880	2.50	126
796	129536	945910	2.00	80
797	130252	945877	1.00	20
798	128508	945915	0.50	6
799	129583	945924	1.50	46
800	130219	945925	1.00	20
801	128160	945908	2.00	80
802	130165	945932	0.50	6
803	136550	945918	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
838	138222	946120	2.00	80
839	134157	946103	1.00	20
840	134598	946085	1.50	46
841	134718	946147	0.50	6
842	136365	946152	1.50	46
843	132002	946117	1.00	20
844	138202	946168	1.50	46
845	134748	946176	1.50	46
846	134120	946170	2.00	80
847	134807	946195	1.00	20
848	134858	946201	1.00	20
849	134910	946204	0.50	6
850	136332	946190	2.00	80
851	134982	946208	1.00	20
852	138760	946186	1.50	46
853	133594	946129	1.50	46

820	138332	945923	1.50	46
821	139079	945990	0.50	6
822	134415	945988	1.00	20
823	134824	945988	3.00	180
824	136485	945998	1.50	46
825	131890	945991	1.00	20
826	134800	946031	2.00	80
827	138264	946027	2.00	80
828	136458	946037	2.00	80
829	134234	946011	1.50	46
830	131926	946054	0.50	6
831	138999	946050	1.00	20
832	134772	946072	2.50	126
833	138242	946076	1.50	46
834	136428	946079	3.00	180
835	134741	946115	2.00	80
836	136396	946118	2.00	80
837	138892	946113	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
872	138165	946316	0.50	6
873	137918	946296	2.50	126
874	135100	946317	2.00	80
875	138675	946301	2.50	126
876	132108	946338	0.50	6
877	138202	946350	1.00	20
878	135123	946363	1.00	20
879	132134	946375	0.50	6
880	138657	946372	2.00	80
881	138238	946381	0.50	6
882	137861	946376	2.00	80
883	135148	946400	0.50	6

854	134090	946217	1.50	46
855	134832	946225	2.50	126
856	138704	946235	2.00	80
857	137980	946261	3.00	180
858	132061	946220	0.50	6
859	138028	946266	2.50	126
860	134067	946257	2.00	80
861	133796	946252	2.00	80
862	138079	946275	3.00	180
863	133917	946281	2.50	126
864	133964	946286	2.00	80
865	135063	946252	1.50	46
866	138128	946292	1.50	46
867	138168	946246	0.50	6
868	136299	946259	1.50	46
869	134111	946303	1.00	20
870	132084	946291	1.50	46
871	134155	946319	0.50	6

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
906	135312	946519	1.00	20
907	137744	946513	0.50	6
908	135371	946515	1.00	20
909	138423	946536	1.50	46
910	138563	946530	3.50	246
911	138522	946550	3.00	180
912	134284	946529	2.50	126
913	138470	946551	3.50	246
914	132227	946546	2.50	126
915	135349	946560	2.00	80
916	137699	946557	1.00	20
917	138391	946564	1.50	46

884	135901	946385	1.00	20
885	138274	946415	1.00	20
886	132166	946415	1.00	20
887	138651	946421	3.00	180
888	136011	946442	1.50	46
889	136061	946453	2.50	126
890	136252	946394	1.00	20
891	135184	946437	1.00	20
892	136141	946455	1.50	46
893	137818	946437	2.50	126
894	135450	946459	2.00	80
895	132195	946454	0.50	6
896	135225	946467	0.50	6
897	137782	946477	1.50	46
898	135405	946480	1.00	20
899	138640	946473	3.50	246
900	138326	946469	0.50	6
901	134224	946414	1.00	20
902	135267	946494	1.50	46
903	138606	946507	4.00	320
904	132219	946494	2.00	80
905	138383	946514	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
940	132438	946803	3.50	246
941	133405	946815	2.00	80
942	135120	946808	1.00	20
943	133360	946822	1.00	20
944	134531	946826	0.50	6
945	133507	946819	1.50	46
946	133124	946823	1.50	46
947	132483	946824	2.00	80

918	135326	946602	0.50	6
919	138373	946640	3.50	246
920	138375	946620	2.50	126
921	135297	946644	1.00	20
922	132223	946626	3.00	180
923	138376	946663	3.50	246
924	135267	946681	0.50	6
925	132230	946699	2.50	126
926	135232	946716	1.00	20
927	138384	946715	4.50	406
928	132256	946735	2.00	80
929	134307	946654	1.00	20
930	135197	946753	0.50	6
931	132297	946762	0.50	6
932	133805	946776	0.50	6
933	132341	946780	1.00	20
934	132388	946789	1.50	46
935	134319	946775	0.50	6
936	135160	946782	1.00	20
937	138384	946771	3.50	246
938	138377	946797	3.00	180
939	133457	946812	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
974	134209	946885	2.50	126
975	134299	946883	1.00	20
976	138349	946866	3.50	246
977	132568	946891	1.00	20
978	138294	946942	2.00	80
979	138181	946957	3.00	180
980	138142	946994	1.50	46
981	138425	947002	3.00	180

948	133160	946832	0.50	6
949	133769	946809	3.00	180
950	138369	946817	3.00	180
951	133316	946831	2.00	80
952	134577	946831	1.00	20
953	135071	946829	4.00	320
954	133212	946837	4.50	406
955	133269	946837	3.50	246
956	134480	946834	1.00	20
957	135021	946844	2.50	126
958	134625	946844	1.50	46
959	134430	946849	0.50	6
960	134678	946858	2.50	126
961	133738	946850	2.50	126
962	132535	946853	1.00	20
963	132577	946815	0.50	6
964	133602	946850	2.50	126
965	133699	946869	3.00	180
966	134751	946869	2.00	80
967	134819	946870	2.50	126
968	134881	946870	4.50	406
969	134959	946861	3.50	246
970	133973	946822	1.00	20
971	134328	946839	1.00	20
972	134372	946871	0.50	6
973	134134	946883	0.50	6

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1008	138186	947750	4.00	320
1009	138186	947803	3.50	246
1010	138172	947843	3.00	180
1011	138134	947873	3.50	246

982	132542	947020	1.50	46
983	138472	947062	2.50	126
984	138099	947050	0.50	6
985	138489	947105	2.00	80
986	138061	947114	1.00	20
987	132526	947091	2.50	126
988	132537	947163	2.00	80
989	138046	947175	0.50	6
990	138514	947228	1.50	46
991	137975	947338	1.50	46
992	132564	947280	0.50	6
993	137943	947392	2.50	126
994	137956	947433	3.00	180
995	138500	947414	1.00	20
996	138260	947486	1.50	46
997	138362	947481	3.00	180
998	138217	947508	3.00	180
999	138003	947489	4.00	320
1000	138175	947536	2.50	126
1001	138063	947542	5.00	500
1002	138098	947574	3.50	246
1003	138135	947568	3.00	180
1004	138117	947593	3.50	246
1005	132930	947338	0.50	6
1006	138144	947635	3.00	180
1007	138176	947697	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1042	139572	949025	2.00	80
1043	139290	949051	1.50	46
1044	138852	949060	1.00	20
1045	139244	949072	1.00	20

1012	138099	947896	3.00	180
1013	138054	947914	3.50	246
1014	138002	947933	2.00	80
1015	137965	947955	3.00	180
1016	137923	947985	3.50	246
1017	137881	948027	4.00	320
1018	137834	948085	2.50	126
1019	137784	948166	3.00	180
1020	137728	948280	2.50	126
1021	137662	948353	3.00	180
1022	137595	948428	2.50	126
1023	137581	948475	2.00	80
1024	137574	948523	1.00	20
1025	137572	948573	1.50	46
1026	137573	948624	1.00	20
1027	137562	948696	2.50	126
1028	137588	948801	3.00	180
1029	137656	948859	2.50	126
1030	137699	948884	3.00	180
1031	137747	948905	2.50	126
1032	137789	948913	2.00	80
1033	139418	948905	1.00	20
1034	137932	948937	1.50	46
1035	139543	948938	1.50	46
1036	139366	948955	1.50	46
1037	138062	949007	2.00	80
1038	139327	949018	2.00	80
1039	138951	949045	1.50	46
1040	139001	949050	2.00	80
1041	138101	949040	1.50	46
Id	x_coord	y_coord	Depth_m	buffer_x20 (m)

1046	139156	949079	1.50	46
1047	138756	949082	2.00	80
1048	139553	949074	1.50	46
1049	138165	949077	2.00	80
1050	138709	949097	1.50	46
1051	138235	949105	2.50	126
1052	138283	949117	2.00	80
1053	138664	949119	2.00	80
1054	138378	949133	2.50	126
1055	138625	949144	1.50	46
1056	138502	949157	3.00	180
1057	139501	949153	1.00	20
1058	139446	949264	1.50	46
1059	139422	949336	1.00	20
1060	139417	949382	3.00	180
1061	138425	949411	1.00	20
1062	139420	949432	3.50	246
1063	138394	949457	2.50	126
1064	139423	949482	4.00	320
1065	138380	949512	1.50	46
1066	139433	949528	4.50	406
1067	138373	949553	1.00	20
1068	139447	949576	4.00	320
1069	138379	949660	1.50	46
1070	138389	949703	2.00	80
1071	138384	949755	2.50	126
1072	138375	949806	2.00	80
1073	138370	949850	1.00	20
1074	138376	949898	1.50	46
1075	138385	949931	1.00	20
Id	x_coord	y_coord	Depth_m	buffer_x20 (m)

1076	138607	950049	1.50	46
1077	138662	950055	0.50	6
1078	138707	950066	1.50	46
1079	138755	950086	2.00	80
1080	138786	950104	3.00	180
1081	138521	950519	1.50	46
1082	138432	950546	3.00	180
1083	138370	950614	2.00	80
1084	138363	950711	1.00	20
1085	138347	950806	1.50	46
1086	138299	950861	0.50	6
1087	138238	950897	3.00	180
1088	138197	950929	3.50	246
1089	138166	950974	4.00	320
1090	138137	951040	2.50	126
1091	138116	951113	3.00	180
1092	138111	951166	1.50	46
1093	138114	951209	2.00	80
1094	138130	951260	3.00	180
1095	138152	951305	1.50	46
1096	138203	951360	4.00	320
1097	138260	951414	3.00	180
1098	138648	951749	4.00	320
1099	138675	951817	3.50	246
1100	138700	951857	2.50	126
1101	138707	951923	1.50	46
1102	138693	952021	1.00	20
1103	138668	952088	0.50	6
1104	138645	952130	1.00	20
1105	138618	952175	1.50	46
1106	141307	952197	2.50	126
1107	141347	952264	2.00	80
1110	141460	952425	2.00	80
1111	141509	952481	3.00	180
1112	138600	952463	1.50	46
1113	141537	952526	2.50	126
1114	141553	952572	2.00	80
1115	138654	952572	0.50	6
1116	138731	952631	1.00	20
1117	138802	952659	1.50	46
1118	138876	952676	2.00	80
1119	141552	952642	2.50	126
1120	138947	952692	1.00	20
1121	138995	952704	1.50	46
1122	141477	952702	1.50	46
1123	139045	952723	1.00	20
1124	141571	952716	3.50	246
1125	141610	952760	2.50	126
1126	141287	952761	1.00	20
1127	141649	952818	2.00	80
1128	141672	952886	2.50	126
1129	141011	952862	2.00	80
1130	140908	952932	1.00	20
1131	141669	952961	2.00	80
1132	140331	952927	0.50	6
1133	141657	953035	1.50	46
1134	140135	953073	0.50	6
1135	141647	953079	0.50	6
1136	141632	953156	2.50	126
1137	141623	953228	2.00	80
1138	141569	953266	2.00	80
1139	141521	953269	3.50	246
1140	141472	953281	2.50	126
1141	141622	953275	3.50	246

1108	138584	952290	1.00	20
1109	141396	952351	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1144	141669	953433	1.00	20
1145	141733	953468	1.50	46
1146	141779	953489	1.00	20
1147	141820	953508	2.00	80
1148	141867	953540	3.50	246
1149	141938	953614	2.00	80
1150	141975	953641	2.50	126
1151	142044	953673	2.00	80
1152	142113	953705	1.50	46
1153	142133	953743	2.00	80
1154	142124	953791	3.00	180
1155	142137	953822	3.00	180
1156	142185	953834	4.00	320
1157	142099	953833	3.00	180
1158	142253	953853	3.00	180
1159	142326	953868	5.00	500
1160	142389	953878	4.00	320
1161	142450	953886	4.00	320
1162	142043	953877	3.50	246
1163	141980	953927	3.00	180
1164	141790	953965	0.50	6
1165	141941	953963	1.00	20
1166	143603	954270	3.00	180
1167	143553	954285	2.50	126
1168	143508	954313	2.00	80
1169	143468	954340	1.50	46
1170	143403	954367	2.00	80
1171	143303	954385	2.50	126

1142	141404	953314	3.00	180
1143	141630	953372	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1178	143162	954561	3.50	246
1179	143216	954573	2.50	126
1180	143038	954572	4.00	320
1181	142367	954566	0.50	6
1182	142987	954601	3.00	180
1183	143285	954606	3.50	246
1184	142358	954616	1.50	46
1185	142951	954643	3.50	246
1186	142357	954669	1.00	20
1187	144164	954701	3.00	180
1188	142925	954686	1.00	20
1189	144094	954707	4.00	320
1190	143422	954686	2.50	126
1191	143529	954728	1.00	20
1192	144000	954729	3.50	246
1193	142902	954727	1.50	46
1194	143600	954739	3.00	180
1195	143824	954759	3.00	180
1196	143901	954752	4.00	320
1197	143727	954756	3.50	246
1198	142426	954735	0.50	6
1199	144227	954738	3.50	246
1200	142512	954778	1.50	46
1201	142555	954795	3.00	180
1202	142858	954790	1.00	20
1203	142606	954814	3.50	246
1204	142657	954824	2.50	126
1205	142703	954825	1.50	46

1172	143237	954399	0.50	6
1173	142107	954268	0.50	6
1174	142371	954518	1.50	46
1175	143106	954554	3.50	246
1176	143169	954479	3.50	246
1177	143079	954557	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1212	144162	955179	1.50	46
1213	143335	955126	3.50	246
1214	143376	955246	2.50	126
1215	143402	955312	3.50	246
1216	143442	955379	4.00	320
1217	143538	955412	4.00	320
1218	143658	955433	3.00	180
1219	143451	955437	4.00	320
1220	143753	955471	3.50	246
1221	143808	955510	1.00	20
1222	143430	955499	3.50	246
1223	143141	955426	2.50	126
1224	143411	955542	2.50	126
1225	143332	955579	3.50	246
1226	143232	955594	4.00	320
1227	143155	955566	3.00	180
1228	143183	955599	2.50	126
1229	143836	955563	4.00	320
1230	143134	955608	3.50	246
1231	143847	955615	3.00	180
1232	143089	955626	2.00	80
1233	143839	955644	3.00	180
1234	143051	955654	4.00	320
1235	143012	955689	3.00	180

1206	144268	954832	2.50	126
1207	144267	954905	2.00	80
1208	144259	954951	1.50	46
1209	144244	954998	2.50	126
1210	144214	955066	2.00	80
1211	144182	955134	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1246	143819	956122	0.50	6
1247	143853	956148	4.00	320
1248	143901	956178	3.00	180
1249	149497	956146	2.00	80
1250	143946	956196	3.50	246
1251	143995	956210	3.00	180
1252	144045	956219	2.50	126
1253	144094	956228	2.00	80
1254	144140	956234	2.50	126
1255	149482	956215	2.50	126
1256	144215	956249	3.00	180
1257	144283	956271	2.50	126
1258	149473	956265	3.00	180
1259	144324	956299	4.00	320
1260	144358	956340	3.00	180
1261	150610	956363	3.50	246
1262	144375	956388	3.50	246
1263	150487	956385	3.00	180
1264	150654	956403	3.00	180
1265	150351	956435	2.50	126
1266	144382	956435	2.00	80
1267	149315	956454	2.00	80
1268	150205	956450	2.50	126
1269	149360	956456	1.50	46

1236	143810	955719	4.00	320
1237	143775	955786	2.00	80
1238	142987	955781	3.50	246
1239	143010	955858	3.00	180
1240	143080	955855	3.50	246
1241	143734	955843	2.50	126
1242	143705	955908	3.00	180
1243	149533	956023	2.00	80
1244	149515	956074	2.50	126
1245	143751	956027	4.00	320

1270	149438	956382	2.50	126
1271	150279	956454	3.50	246
1272	149272	956459	3.50	246
1273	150670	956458	3.50	246
1274	149227	956472	3.00	180
1275	150084	956468	1.50	46
1276	149190	956488	3.50	246
1277	149136	956516	4.50	406
1278	149076	956536	4.00	320
1279	150672	956509	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1280	144396	956502	2.50	126
1281	149031	956545	3.00	180
1282	148985	956558	3.50	246
1283	150053	956525	2.00	80
1284	144420	956572	3.00	180
1285	148944	956586	3.00	180
1286	150064	956587	2.50	126
1287	144443	956615	2.50	126
1288	148906	956645	3.50	246
1289	150108	956648	3.00	180
1290	150130	956718	2.50	126
1291	148877	956720	4.00	320
1292	144500	956697	3.00	180
1293	144566	956773	3.50	246
1294	148866	956772	2.50	126
1295	144604	956802	3.00	180
1296	150118	956787	2.00	80
1297	148879	956862	2.50	126
1298	148919	956890	2.00	80
1299	148989	956907	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1314	144902	956991	3.00	180
1315	149625	957020	2.00	80
1316	145117	957074	1.50	46
1317	149622	957064	2.50	126
1318	145126	957101	2.00	80
1319	149621	957115	3.50	246
1320	145147	957141	3.00	180
1321	145185	957178	3.50	246
1322	145232	957207	2.50	126
1323	149398	957232	1.00	20
1324	149471	957236	2.00	80
1325	149575	957196	3.00	180
1326	149348	957236	2.00	80
1327	145275	957232	1.50	46
1328	149150	957239	1.00	20
1329	149224	957252	1.50	46
1330	148651	957241	3.50	246
1331	149078	957250	1.50	46
1332	149305	957252	1.50	46
1333	148734	957271	4.00	320

1300	149114	956916	2.00	80
1301	149211	956920	1.50	46
1302	149260	956923	2.00	80
1303	149338	956927	2.50	126
1304	149413	956933	2.00	80
1305	144708	956878	3.50	246
1306	149463	956940	2.50	126
1307	144816	956949	3.00	180
1308	149998	956964	2.50	126
1309	149912	956972	1.50	46
1310	149662	956964	2.00	80
1311	149861	956975	2.50	126
1312	150086	956904	2.50	126
1313	144857	956973	2.50	126

1334	149037	957274	1.00	20
1335	145333	957277	2.00	80
1336	148800	957308	3.50	246
1337	149301	957319	2.50	126
1338	148915	957343	2.00	80
1339	148980	957316	1.50	46
1340	145469	957325	1.50	46
1341	148865	957339	3.00	180
1342	145591	957350	2.00	80
1343	149325	957365	3.00	180
1344	145658	957377	2.50	126
1345	145725	957412	3.00	180
1346	149354	957435	2.00	80
1347	145788	957458	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1348	151028	957467	2.00	80
1349	149386	957500	2.50	126
1350	145845	957507	2.00	80
1351	150969	957524	1.50	46
1352	145878	957540	1.50	46
1353	151836	957574	2.50	126
1354	151885	957578	2.00	80
1355	151788	957579	2.50	126
1356	151935	957583	1.50	46
1357	149435	957553	2.00	80
1358	150951	957567	2.00	80
1359	151988	957589	2.50	126
1360	145911	957575	2.00	80
1361	152026	957595	2.00	80
1362	151741	957593	2.00	80
1363	149490	957596	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1382	151690	957763	1.00	20
1383	151263	957782	3.50	246
1384	152693	957774	2.50	126
1385	149877	957776	3.00	180
1386	152763	957795	2.00	80
1387	151364	957797	3.00	180
1388	152809	957808	2.50	126
1389	150892	957807	3.00	180
1390	146070	957792	3.00	180
1391	152855	957824	2.00	80
1392	149907	957816	3.50	246
1393	152884	957836	3.00	180
1394	151694	957812	2.00	80
1395	151436	957826	4.00	320
1396	150106	957844	3.50	246
1397	152911	957843	3.00	180

1364	149536	957616	2.00	80
1365	149585	957629	1.50	46
1366	149634	957636	2.00	80
1367	150937	957617	1.50	46
1368	149686	957644	1.50	46
1369	149747	957648	2.00	80
1370	152326	957664	2.50	126
1371	151699	957646	3.00	180
1372	152451	957698	2.00	80
1373	145971	957657	1.50	46
1374	152520	957717	2.50	126
1375	150920	957689	2.00	80
1376	151684	957716	2.50	126
1377	146025	957736	1.00	20
1378	149823	957702	3.50	246
1379	152592	957741	3.00	180
1380	150900	957759	2.50	126
1381	151190	957781	1.00	20

1398	150149	957848	3.00	180
1399	150057	957849	2.50	126
1400	152951	957854	2.50	126
1401	146126	957848	3.50	246
1402	151477	957854	2.50	126
1403	149943	957852	2.00	80
1404	146181	957866	4.00	320
1405	151108	957826	2.00	80
1406	150015	957867	2.00	80
1407	152883	957859	3.00	180
1408	152996	957871	3.00	180
1409	151690	957863	1.50	46
1410	150884	957860	3.50	246
1411	149971	957879	3.50	246
1412	149987	957885	3.00	180
1413	146230	957883	3.00	180
1414	153041	957892	2.50	126
1415	151505	957889	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1416	149966	957903	3.00	180
1417	151672	957906	1.50	46
1418	153087	957913	3.00	180
1419	150210	957890	4.50	406
1420	146261	957914	2.50	126
1421	151009	957904	1.50	46
1422	150874	957912	2.50	126
1423	151537	957927	2.50	126
1424	151583	957943	1.00	20
1425	151631	957933	1.50	46
1426	150946	957940	1.00	20
1427	150901	957951	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1450	152768	958061	3.50	246
1451	149628	958069	2.50	126
1452	153219	958052	3.50	246
1453	149012	958079	2.50	126
1454	152718	958080	4.50	406
1455	146348	958076	0.50	6
1456	148961	958083	1.00	20
1457	152668	958090	3.50	246
1458	146541	958083	1.00	20
1459	146393	958092	1.00	20
1460	146446	958097	2.50	126
1461	146500	958096	1.50	46

1428	150273	957945	4.00	320
1429	146856	957960	2.00	80
1430	152861	957927	2.50	126
1431	150782	957969	3.50	246
1432	150861	957965	1.50	46
1433	146812	957972	1.50	46
1434	149916	957949	2.50	126
1435	146281	957959	3.00	180
1436	150601	957978	3.00	180
1437	150452	957995	3.50	246
1438	150311	957983	3.50	246
1439	150396	958002	3.00	180
1440	149862	958002	3.50	246
1441	153161	957973	2.50	126
1442	146290	958008	1.50	46
1443	146693	958005	2.00	80
1444	149796	958035	3.00	180
1445	152819	958012	3.00	180
1446	150342	958029	2.50	126
1447	149701	958053	2.50	126
1448	146309	958047	1.00	20
1449	146581	958054	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1484	150392	958181	1.50	46
1485	152275	958191	2.50	126
1486	149575	958190	3.50	246
1487	149161	958199	2.00	80
1488	153259	958198	2.50	126
1489	149574	958228	4.00	320
1490	150409	958222	1.50	46
1491	149192	958235	3.00	180

1462	148911	958095	2.50	126
1463	148864	958102	2.00	80
1464	149058	958094	2.00	80
1465	147154	958098	2.50	126
1466	152595	958103	3.00	180
1467	150360	958084	3.00	180
1468	152523	958115	2.50	126
1469	152474	958121	3.00	180
1470	148765	958114	3.00	180
1471	152422	958128	2.50	126
1472	153238	958105	3.00	180
1473	148667	958133	2.50	126
1474	149096	958124	2.50	126
1475	152373	958140	2.00	80
1476	147164	958131	2.00	80
1477	150375	958137	2.50	126
1478	149588	958121	2.50	126
1479	153251	958154	2.00	80
1480	152325	958162	2.00	80
1481	149131	958162	1.50	46
1482	148602	958168	3.00	180
1483	147170	958176	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1518	150537	958482	2.00	80
1519	150358	958492	2.50	126
1520	150048	958493	2.50	126
1521	150424	958518	2.00	80
1522	148208	958516	3.50	246
1523	150026	958535	3.00	180
1524	149610	958516	3.00	180
1525	151325	958570	2.00	80

1492	149542	958248	3.50	246
1493	149488	958263	3.00	180
1494	149448	958274	1.00	20
1495	149404	958286	3.50	246
1496	149219	958278	4.50	406
1497	149573	958279	4.00	320
1498	149349	958306	4.50	406
1499	149251	958309	4.50	406
1500	149296	958318	3.50	246
1501	148484	958262	2.50	126
1502	150443	958294	2.50	126
1503	148391	958345	3.00	180
1504	153259	958336	3.50	246
1505	149577	958344	3.50	246
1506	148356	958378	2.50	126
1507	150496	958378	2.00	80
1508	149585	958393	2.50	126
1509	150174	958426	1.50	46
1510	150123	958433	2.50	126
1511	153238	958411	3.00	180
1512	150537	958435	2.50	126
1513	149595	958441	3.50	246
1514	150079	958455	3.00	180
1515	150268	958445	2.00	80
1516	148286	958445	3.00	180
1517	153202	958477	3.50	246
1526	150010	958571	3.00	180
1527	148150	958564	3.00	180
1528	151371	958585	1.50	46
1529	153135	958555	2.50	126
1530	149618	958589	2.50	126
1531	151204	958594	2.50	126
1532	148091	958606	3.50	246
1533	151417	958612	1.00	20
1534	151754	958630	1.00	20
1535	153066	958623	1.00	20
1536	151706	958640	1.50	46
1537	151140	958634	1.50	46
1538	148026	958637	3.00	180
1539	151822	958637	1.50	46
1540	151510	958645	1.50	46
1541	151633	958656	2.00	80
1542	149621	958638	3.00	180
1543	147954	958660	2.50	126
1544	147904	958671	1.50	46
1545	149963	958644	2.00	80
1546	147859	958679	2.50	126
1547	151112	958670	1.00	20
1548	153034	958665	3.00	180
1549	147772	958695	3.00	180
1550	149625	958687	2.50	126
1551	149911	958697	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1552	152956	958729	4.00	320
1553	149641	958759	3.00	180
1554	152848	958787	3.50	246
1555	149839	958766	2.00	80
1586	152040	959068	2.50	126
1587	150160	959117	1.00	20
1588	153540	959123	2.50	126
1589	152298	959109	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1556	151931	958772	1.00	20
1557	152785	958830	2.50	126
1558	149764	958833	2.50	126
1559	149667	958832	2.50	126
1560	152746	958855	1.00	20
1561	152703	958869	2.50	126
1562	152602	958880	4.50	406
1563	152656	958877	3.50	246
1564	149744	958892	2.50	126
1565	149888	958906	2.00	80
1566	149815	958904	3.00	180
1567	152526	958894	4.00	320
1568	151048	958801	2.00	80
1569	151989	958877	1.50	46
1570	149931	958925	2.50	126
1571	152016	958948	2.00	80
1572	149967	958960	2.00	80
1573	152456	958950	3.00	180
1574	153837	958968	2.00	80
1575	150986	958994	2.00	80
1576	152028	958994	1.50	46
1577	153744	959022	3.00	180
1578	152393	959024	3.50	246
1579	153678	959061	3.50	246
1580	150040	959028	2.50	126
1581	149945	959031	2.50	126
1582	152335	959073	3.00	180
1583	153630	959086	3.00	180
1584	150118	959092	2.00	80
1585	153584	959107	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1590	153506	959138	1.50	46
1591	153430	959145	1.50	46
1592	153469	959146	3.00	180
1593	150206	959140	1.50	46
1594	153389	959149	3.00	180
1595	150254	959158	1.00	20
1596	152272	959150	2.50	126
1597	153338	959163	1.50	46
1598	150296	959168	0.50	6
1599	153294	959178	1.00	20
1600	150911	959111	2.50	126
1601	150348	959182	3.50	246
1602	150772	959194	2.00	80
1603	150400	959197	2.00	80
1604	150700	959200	3.00	180
1605	152040	959164	2.00	80
1606	150462	959206	2.50	126
1607	150541	959210	5.00	500
1608	150625	959206	3.50	246
1609	153249	959198	1.50	46
1610	153204	959220	2.00	80
1611	152562	959242	3.00	180
1612	152614	959245	4.00	320
1613	153161	959240	2.50	126
1614	152517	959249	2.50	126
1615	152020	959232	2.50	126
1616	152671	959257	3.50	246
1617	152470	959262	3.00	180
1618	152254	959220	3.00	180
1619	152720	959269	2.50	126

1620	151928	959274	2.50	126
1621	151979	959275	2.00	80
1622	153119	959265	3.00	180
1623	151873	959277	3.50	246
1624	152763	959279	2.00	80
1625	151821	959283	3.00	180
1626	152811	959287	1.00	20
1627	152103	959285	1.50	46
1628	151778	959290	3.50	246
1629	152224	959292	1.50	46
1630	152246	959282	1.50	46
1631	152271	959293	2.00	80
1632	152370	959282	2.50	126
1633	152863	959293	2.50	126
1634	151733	959296	4.00	320
1635	152913	959301	3.00	180
1636	152961	959309	2.50	126
1637	149882	959197	2.00	80
1638	153082	959298	3.50	246
1639	153006	959320	3.00	180
1640	149840	959337	1.50	46
1641	153102	959351	3.50	246
1642	153139	959380	3.50	246
1643	153025	959383	4.00	320
1644	149825	959390	3.50	246
1645	153173	959417	4.00	320
1646	149810	959441	2.00	80
1647	149797	959484	3.00	180
1648	153227	959474	4.50	406
1649	152971	959467	3.00	180
1650	153285	959523	4.00	320
1651	149780	959534	3.50	246

1654	153369	959575	3.50	246
1655	149759	959581	3.00	180
1656	153411	959598	3.00	180
1657	149732	959620	2.50	126
1658	153455	959625	3.50	246
1659	149698	959651	2.00	80
1660	153500	959655	2.00	80
1661	149655	959676	2.50	126
1662	149607	959698	0.50	6
1663	149563	959719	2.00	80
1664	149518	959739	2.50	126
1665	149472	959761	2.00	80
1666	152856	959687	3.00	180
1667	149409	959797	2.50	126
1668	149343	959834	3.00	180
1669	152834	959828	3.50	246
1670	149300	959859	2.00	80
1671	149261	959883	2.50	126
1672	152844	959882	4.00	320
1673	152854	959929	3.00	180
1674	149197	959925	3.00	180
1675	152864	959975	3.50	246
1676	149121	959993	2.50	126
1677	152869	960026	4.00	320
1678	149073	960042	1.50	46
1679	152860	960076	3.50	246
1680	149037	960078	3.50	246
1681	152837	960115	3.00	180
1682	148981	960135	3.00	180
1683	148927	960190	3.50	246
1684	152761	960178	4.00	320
1685	147741	960227	2.00	80

1652	153325	959549	3.50	246
1653	152917	959550	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1688	147790	960236	2.50	126
1689	148863	960230	2.50	126
1690	152634	960253	3.00	180
1691	148801	960256	2.00	80
1692	147835	960262	1.50	46
1693	147648	960261	3.50	246
1694	148753	960273	4.00	320
1695	152562	960275	3.50	246
1696	148675	960293	2.50	126
1697	147873	960290	2.00	80
1698	148578	960305	2.50	126
1699	152440	960301	3.00	180
1700	147609	960295	3.00	180
1701	148503	960311	3.00	180
1702	152082	960316	1.00	20
1703	148451	960318	3.50	246
1704	148401	960323	2.50	126
1705	148354	960327	3.00	180
1706	147915	960317	2.50	126
1707	152343	960322	2.50	126
1708	148303	960332	2.50	126
1709	147576	960326	2.50	126
1710	148251	960338	4.00	320
1711	152157	960329	0.50	6
1712	147957	960339	2.00	80
1713	148202	960345	2.50	126
1714	148153	960351	3.50	246
1715	148050	960353	3.00	180

1686	147693	960236	2.50	126
1687	152678	960235	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1722	153455	959625	3.50	246
1723	153411	959598	3.00	180
1724	153369	959575	3.50	246
1725	153325	959549	3.50	246
1726	153285	959523	4.00	320
1727	153227	959474	4.50	406
1728	153173	959417	4.00	320
1729	153139	959380	3.50	246
1730	153102	959351	3.50	246
1731	152263	960348	2.00	80
1732	152343	960322	2.50	126
1733	152440	960301	3.00	180
1734	152562	960275	3.50	246
1735	152634	960253	3.00	180
1736	152678	960235	2.50	126
1737	152761	960178	4.00	320
1738	152837	960115	3.00	180
1739	152860	960076	3.50	246
1740	152869	960026	4.00	320
1741	152864	959975	3.50	246
1742	152854	959929	3.00	180
1743	152844	959882	4.00	320
1744	152834	959828	3.50	246
1745	152856	959687	3.00	180
1746	152917	959550	3.50	246
1747	152971	959467	3.00	180
1748	153025	959383	4.00	320
1749	153082	959298	3.50	246

1716	152263	960348	2.00	80
1717	147540	960363	3.00	180
1718	147504	960405	2.50	126
1719	147459	960464	1.50	46
1720	147421	960517	1.00	20
1721	153500	959655	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1756	153161	959240	2.50	126
1757	153204	959220	2.00	80
1758	153249	959198	1.50	46
1759	153294	959178	1.00	20
1760	153338	959163	1.50	46
1761	153389	959149	3.00	180
1762	153430	959145	1.50	46
1763	153469	959146	3.00	180
1764	153506	959138	1.50	46
1765	153540	959123	2.50	126
1766	153630	959086	3.00	180
1767	153678	959061	3.50	246
1768	153584	959107	2.00	80
1769	153744	959022	3.00	180
1770	153837	958968	2.00	80
1771	152763	959279	2.00	80
1772	152720	959269	2.50	126
1773	152671	959257	3.50	246
1774	152614	959245	4.00	320
1775	152562	959242	3.00	180
1776	152517	959249	2.50	126
1777	152470	959262	3.00	180
1778	152370	959282	2.50	126
1779	152271	959293	2.00	80

1750	153006	959320	3.00	180
1751	152961	959309	2.50	126
1752	152913	959301	3.00	180
1753	152863	959293	2.50	126
1754	152811	959287	1.00	20
1755	153119	959265	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1790	152746	958855	1.00	20
1791	152785	958830	2.50	126
1792	152848	958787	3.50	246
1793	152956	958729	4.00	320
1794	153034	958665	3.00	180
1795	153066	958623	1.00	20
1796	153135	958555	2.50	126
1797	153202	958477	3.50	246
1798	153238	958411	3.00	180
1799	153259	958336	3.50	246
1800	153259	958198	2.50	126
1801	153251	958154	2.00	80
1802	153238	958105	3.00	180
1803	153219	958052	3.50	246
1804	153161	957973	2.50	126
1805	153087	957913	3.00	180
1806	153041	957892	2.50	126
1807	152996	957871	3.00	180
1808	152951	957854	2.50	126
1809	152902	957840	3.00	180
1810	152883	957859	3.00	180
1811	152861	957927	2.50	126
1812	152819	958012	3.00	180
1813	152768	958061	3.50	246

1780	152254	959220	3.00	180
1781	152272	959150	2.50	126
1782	152298	959109	3.50	246
1783	152335	959073	3.00	180
1784	152393	959024	3.50	246
1785	152456	958950	3.00	180
1786	152526	958894	4.00	320
1787	152602	958880	4.50	406
1788	152656	958877	3.50	246
1789	152703	958869	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1824	152809	957808	2.50	126
1825	152763	957795	2.00	80
1826	152693	957774	2.50	126
1827	152592	957741	3.00	180
1828	152520	957717	2.50	126
1829	152451	957698	2.00	80
1830	152326	957664	2.50	126
1831	152026	957595	2.00	80
1832	151988	957589	2.50	126
1833	151935	957583	1.50	46
1834	151885	957578	2.00	80
1835	151836	957574	2.50	126
1836	151788	957579	2.50	126
1837	151741	957593	2.00	80
1838	151699	957646	3.00	180
1839	151684	957716	2.50	126
1840	151690	957763	1.00	20
1841	151694	957812	2.00	80
1842	151690	957863	1.50	46
1843	151672	957906	1.50	46

1814	152718	958080	4.50	406
1815	152668	958090	3.50	246
1816	152595	958103	3.00	180
1817	152523	958115	2.50	126
1818	152474	958121	3.00	180
1819	152422	958128	2.50	126
1820	152373	958140	2.00	80
1821	152325	958162	2.00	80
1822	152275	958191	2.50	126
1823	152855	957824	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1858	150782	957969	3.50	246
1859	150601	957978	3.00	180
1860	150452	957995	3.50	246
1861	150396	958002	3.00	180
1862	150342	958029	2.50	126
1863	150360	958084	3.00	180
1864	150375	958137	2.50	126
1865	150392	958181	1.50	46
1866	150409	958222	1.50	46
1867	150443	958294	2.50	126
1868	150496	958378	2.00	80
1869	150537	958435	2.50	126
1870	150537	958482	2.00	80
1871	150424	958518	2.00	80
1872	150358	958492	2.50	126
1873	150268	958445	2.00	80
1874	150174	958426	1.50	46
1875	150123	958433	2.50	126
1876	150079	958455	3.00	180
1877	150048	958493	2.50	126

1844	151631	957933	1.50	46
1845	151583	957943	1.00	20
1846	151537	957927	2.50	126
1847	151505	957889	3.00	180
1848	151477	957854	2.50	126
1849	151436	957826	4.00	320
1850	151364	957797	3.00	180
1851	151263	957782	3.50	246
1852	151190	957781	1.00	20
1853	151108	957826	2.00	80
1854	151009	957904	1.50	46
1855	150946	957940	1.00	20
1856	150901	957951	1.50	46
1857	150861	957965	1.50	46

1878	150026	958535	3.00	180
1879	150010	958571	3.00	180
1880	149963	958644	2.00	80
1881	149911	958697	1.50	46
1882	149839	958766	2.00	80
1883	149764	958833	2.50	126
1884	150874	957912	2.50	126
1885	150884	957860	3.50	246
1886	150892	957807	3.00	180
1887	150900	957759	2.50	126
1888	150920	957689	2.00	80
1889	150937	957617	1.50	46
1890	150951	957567	2.00	80
1891	150969	957524	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1892	151028	957467	2.00	80
1893	150311	957983	3.50	246
1894	150273	957945	4.00	320
1895	150210	957890	4.50	406
1896	150149	957848	3.00	180
1897	150106	957844	3.50	246
1898	150057	957849	2.50	126
1899	150015	957867	2.00	80
1900	149972	957898	3.00	180
1901	149916	957949	2.50	126
1902	149862	958002	3.50	246
1903	149796	958035	3.00	180
1904	149701	958053	2.50	126
1905	149588	958121	2.50	126
1906	149575	958190	3.50	246
1907	149574	958265	4.00	320

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1926	150254	959158	1.00	20
1927	150296	959168	0.50	6
1928	150348	959182	3.50	246
1929	150400	959197	2.00	80
1930	150462	959206	2.50	126
1931	150541	959210	5.00	500
1932	150625	959206	3.50	246
1933	150700	959200	3.00	180
1934	150772	959194	2.00	80
1935	150911	959111	2.50	126
1936	150986	958994	2.00	80
1937	151048	958801	2.00	80
1938	151112	958670	1.00	20
1939	151140	958634	1.50	46
1940	151204	958594	2.50	126
1941	151325	958570	2.00	80

1908	149577	958344	3.50	246
1909	149585	958393	2.50	126
1910	149595	958441	3.50	246
1911	149610	958516	3.00	180
1912	149618	958589	2.50	126
1913	149621	958638	3.00	180
1914	149625	958687	2.50	126
1915	149641	958759	3.00	180
1916	149667	958832	2.50	126
1917	149744	958892	2.50	126
1918	149815	958904	3.00	180
1919	149888	958906	2.00	80
1920	149931	958925	2.50	126
1921	149967	958960	2.00	80
1922	150040	959028	2.50	126
1923	150118	959092	2.00	80
1924	150160	959117	1.00	20
1925	150206	959140	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1960	151821	959283	3.00	180
1961	151778	959290	3.50	246
1962	151733	959296	4.00	320
1963	149945	959031	2.50	126
1964	149882	959197	2.00	80
1965	149840	959337	1.50	46
1966	149825	959390	3.50	246
1967	149810	959441	2.00	80
1968	149797	959484	3.00	180
1969	149780	959534	3.50	246
1970	149759	959581	3.00	180
1971	149732	959620	2.50	126

1942	151371	958585	1.50	46
1943	151417	958612	1.00	20
1944	151510	958645	1.50	46
1945	151633	958656	2.00	80
1946	151706	958640	1.50	46
1947	151754	958630	1.00	20
1948	151822	958637	1.50	46
1949	151931	958772	1.00	20
1950	151989	958877	1.50	46
1951	152016	958948	2.00	80
1952	152028	958994	1.50	46
1953	152040	959068	2.50	126
1954	152040	959164	2.00	80
1955	152020	959232	2.50	126
1956	152103	959285	1.50	46
1957	151979	959275	2.00	80
1958	151928	959274	2.50	126
1959	151873	959277	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
1994	149448	958274	1.00	20
1995	149404	958286	3.50	246
1996	149349	958306	4.50	406
1997	149296	958318	3.50	246
1998	149219	958278	4.50	406
1999	149192	958235	3.00	180
2000	149251	958309	4.50	406
2001	149161	958199	2.00	80
2002	149131	958162	1.50	46
2003	149096	958124	2.50	126
2004	149058	958094	2.00	80
2005	149012	958079	2.50	126

1972	149698	959651	2.00	80
1973	149655	959676	2.50	126
1974	149607	959698	0.50	6
1975	149563	959719	2.00	80
1976	149518	959739	2.50	126
1977	149472	959761	2.00	80
1978	149409	959797	2.50	126
1979	149343	959834	3.00	180
1980	149300	959859	2.00	80
1981	149261	959883	2.50	126
1982	149197	959925	3.00	180
1983	149121	959993	2.50	126
1984	149073	960042	1.50	46
1985	149037	960078	3.50	246
1986	148981	960135	3.00	180
1987	148927	960190	3.50	246
1988	148863	960230	2.50	126
1989	148801	960256	2.00	80
1990	148753	960273	4.00	320
1991	148675	960293	2.50	126
1992	149542	958248	3.50	246
1993	149488	958263	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2028	149301	957319	2.50	126
2029	149224	957252	1.50	46
2030	149150	957239	1.00	20
2031	149078	957250	1.50	46
2032	149037	957274	1.00	20
2033	148980	957316	1.50	46
2034	148915	957343	2.00	80
2035	148865	957339	3.00	180

2006	148961	958083	1.00	20
2007	148911	958095	2.50	126
2008	148864	958102	2.00	80
2009	148765	958114	3.00	180
2010	148667	958133	2.50	126
2011	148602	958168	3.00	180
2012	148484	958262	2.50	126
2013	149971	957879	3.50	246
2014	149943	957852	2.00	80
2015	149907	957816	3.50	246
2016	149877	957776	3.00	180
2017	149823	957702	3.50	246
2018	149747	957648	2.00	80
2019	149686	957644	1.50	46
2020	149634	957636	2.00	80
2021	149585	957629	1.50	46
2022	149536	957616	2.00	80
2023	149490	957596	1.50	46
2024	149435	957553	2.00	80
2025	149386	957500	2.50	126
2026	149354	957435	2.00	80
2027	149325	957365	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2062	149998	956964	2.50	126
2063	149912	956972	1.50	46
2064	149861	956975	2.50	126
2065	149662	956964	2.00	80
2066	149463	956940	2.50	126
2067	149413	956933	2.00	80
2068	149338	956927	2.50	126
2069	149260	956923	2.00	80

2036	148800	957308	3.50	246
2037	148734	957271	4.00	320
2038	148651	957241	3.50	246
2039	149305	957252	1.50	46
2040	149348	957236	2.00	80
2041	149398	957232	1.00	20
2042	149471	957236	2.00	80
2043	149575	957196	3.00	180
2044	149621	957115	3.50	246
2045	149622	957064	2.50	126
2046	149625	957020	2.00	80
2047	150672	956509	3.50	246
2048	150670	956458	3.50	246
2049	150654	956403	3.00	180
2050	150610	956363	3.50	246
2051	150487	956385	3.00	180
2052	150351	956435	2.50	126
2053	150279	956454	3.50	246
2054	150205	956450	2.50	126
2055	150084	956468	1.50	46
2056	150053	956525	2.00	80
2057	150064	956587	2.50	126
2058	150108	956648	3.00	180
2059	150130	956718	2.50	126
2060	150118	956787	2.00	80
2061	150086	956904	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2096	148451	960318	3.50	246
2097	148401	960323	2.50	126
2098	148354	960327	3.00	180
2099	148303	960332	2.50	126

2070	149211	956920	1.50	46
2071	149114	956916	2.00	80
2072	148989	956907	1.50	46
2073	148919	956890	2.00	80
2074	148879	956862	2.50	126
2075	148866	956772	2.50	126
2076	148877	956720	4.00	320
2077	148906	956645	3.50	246
2078	148944	956586	3.00	180
2079	148985	956558	3.50	246
2080	149031	956545	3.00	180
2081	149076	956536	4.00	320
2082	149136	956516	4.50	406
2083	149190	956488	3.50	246
2084	149227	956472	3.00	180
2085	149272	956459	3.50	246
2086	149315	956454	2.00	80
2087	149360	956456	1.50	46
2088	149438	956382	2.50	126
2089	149473	956265	3.00	180
2090	149482	956215	2.50	126
2091	149497	956146	2.00	80
2092	149515	956074	2.50	126
2093	149533	956023	2.00	80
2094	148578	960305	2.50	126
2095	148503	960311	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2130	147164	958131	2.00	80
2131	147154	958098	2.50	126
2132	146856	957960	2.00	80
2133	146812	957972	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2100	148251	960338	4.00	320
2101	148202	960345	2.50	126
2102	148153	960351	3.50	246
2103	148050	960353	3.00	180
2104	147957	960339	2.00	80
2105	147915	960317	2.50	126
2106	147873	960290	2.00	80
2107	147835	960262	1.50	46
2108	147790	960236	2.50	126
2109	147741	960227	2.00	80
2110	147693	960236	2.50	126
2111	147648	960261	3.50	246
2112	147609	960295	3.00	180
2113	147576	960326	2.50	126
2114	147540	960363	3.00	180
2115	147504	960405	2.50	126
2116	147459	960464	1.50	46
2117	147421	960517	1.00	20
2118	148391	958345	3.00	180
2119	148356	958378	2.50	126
2120	148286	958445	3.00	180
2121	148208	958516	3.50	246
2122	148150	958564	3.00	180
2123	148091	958606	3.50	246
2124	148026	958637	3.00	180
2125	147954	958660	2.50	126
2126	147904	958671	1.50	46
2127	147859	958679	2.50	126
2128	147772	958695	3.00	180
2129	147170	958176	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2134	146693	958005	2.00	80
2135	146581	958054	1.50	46
2136	146541	958083	1.00	20
2137	146500	958096	1.50	46
2138	146446	958097	2.50	126
2139	146393	958092	1.00	20
2140	146348	958076	0.50	6
2141	146309	958047	1.00	20
2142	146290	958008	1.50	46
2143	146281	957959	3.00	180
2144	146261	957914	2.50	126
2145	146230	957883	3.00	180
2146	146181	957866	4.00	320
2147	146126	957848	3.50	246
2148	146070	957792	3.00	180
2149	146025	957736	1.00	20
2150	145971	957657	1.50	46
2151	145911	957575	2.00	80
2152	145878	957540	1.50	46
2153	145845	957507	2.00	80
2154	145788	957458	2.50	126
2155	145725	957412	3.00	180
2156	145658	957377	2.50	126
2157	145591	957350	2.00	80
2158	145469	957325	1.50	46
2159	145333	957277	2.00	80
2160	145275	957232	1.50	46
2161	145232	957207	2.50	126
2162	145185	957178	3.50	246
2163	145147	957141	3.00	180

2164	145126	957101	2.00	80
2165	145117	957074	1.50	46
2166	144902	956991	3.00	180
2167	144857	956973	2.50	126
2168	144816	956949	3.00	180
2169	144708	956878	3.50	246
2170	144604	956802	3.00	180
2171	144566	956773	3.50	246
2172	144500	956697	3.00	180
2173	144443	956615	2.50	126
2174	144420	956572	3.00	180
2175	144396	956502	2.50	126
2176	144382	956435	2.00	80
2177	144375	956388	3.50	246
2178	144358	956340	3.00	180
2179	144324	956299	4.00	320
2180	144283	956271	2.50	126
2181	144215	956249	3.00	180
2182	144140	956234	2.50	126
2183	144094	956228	2.00	80
2184	144045	956219	2.50	126
2185	143995	956210	3.00	180
2186	143946	956196	3.50	246
2187	143901	956178	3.00	180
2188	143853	956148	4.00	320
2189	143819	956122	0.50	6
2190	143751	956027	4.00	320
2191	143705	955908	3.00	180
2192	143734	955843	2.50	126
2193	143775	955786	2.00	80
2194	143810	955719	4.00	320
2195	143839	955644	3.00	180
2198	143808	955510	1.00	20
2199	143753	955471	3.50	246
2200	143658	955433	3.00	180
2201	143513	955395	4.00	320
2202	143402	955312	3.50	246
2203	143376	955246	2.50	126
2204	143335	955126	3.50	246
2205	143451	955437	4.00	320
2206	143430	955499	3.50	246
2207	143411	955542	2.50	126
2208	143332	955579	3.50	246
2209	143232	955594	4.00	320
2210	143183	955599	2.50	126
2211	143134	955608	3.50	246
2212	143089	955626	2.00	80
2213	143051	955654	4.00	320
2214	143012	955689	3.00	180
2215	143155	955566	3.00	180
2216	143141	955426	2.50	126
2217	142987	955781	3.50	246
2218	143010	955858	3.00	180
2219	143080	955855	3.50	246
2220	144162	955179	1.50	46
2221	144182	955134	1.50	46
2222	144214	955066	2.00	80
2223	144244	954998	2.50	126
2224	144259	954951	1.50	46
2225	144267	954905	2.00	80
2226	144268	954832	2.50	126
2227	144227	954738	3.50	246
2228	144164	954701	3.00	180
2229	144094	954707	4.00	320

2196	143847	955615	3.00	180
2197	143836	955563	4.00	320

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2232	143824	954759	3.00	180
2233	143727	954756	3.50	246
2234	143600	954739	3.00	180
2235	143529	954728	1.00	20
2236	143422	954686	2.50	126
2237	143285	954606	3.50	246
2238	143216	954573	2.50	126
2239	143147	954560	3.50	246
2240	143079	954557	1.00	20
2241	143038	954572	4.00	320
2242	142987	954601	3.00	180
2243	143603	954270	3.00	180
2244	143553	954285	2.50	126
2245	143508	954313	2.00	80
2246	143468	954340	1.50	46
2247	143403	954367	2.00	80
2248	143303	954385	2.50	126
2249	143237	954399	0.50	6
2250	143169	954479	3.50	246
2251	142951	954643	3.50	246
2252	142925	954686	1.00	20
2253	142902	954727	1.50	46
2254	142858	954790	1.00	20
2255	142703	954825	1.50	46
2256	142657	954824	2.50	126
2257	142606	954814	3.50	246
2258	142555	954795	3.00	180
2259	142512	954778	1.50	46

2230	144000	954729	3.50	246
2231	143901	954752	4.00	320

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2266	141941	953963	1.00	20
2267	141980	953927	3.00	180
2268	142043	953877	3.50	246
2269	142110	953806	3.00	180
2270	142137	953822	3.00	180
2271	142185	953834	4.00	320
2272	142253	953853	3.00	180
2273	142450	953886	4.00	320
2274	142133	953743	2.00	80
2275	142113	953705	1.50	46
2276	142044	953673	2.00	80
2277	141975	953641	2.50	126
2278	141938	953614	2.00	80
2279	141867	953540	3.50	246
2280	141820	953508	2.00	80
2281	141779	953489	1.00	20
2282	141733	953468	1.50	46
2283	141669	953433	1.00	20
2284	141630	953372	3.50	246
2285	141622	953275	3.50	246
2286	141623	953228	2.00	80
2287	141632	953156	2.50	126
2288	141647	953079	0.50	6
2289	141657	953035	1.50	46
2290	141569	953266	2.00	80
2291	141521	953269	3.50	246
2292	141472	953281	2.50	126
2293	141404	953314	3.00	180

2260	142426	954735	0.50	6
2261	142357	954669	1.00	20
2262	142358	954616	1.50	46
2263	142367	954566	0.50	6
2264	142371	954518	1.50	46
2265	142021	954187	0.50	6

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2300	141553	952572	2.00	80
2301	141537	952526	2.50	126
2302	141509	952481	3.00	180
2303	141460	952425	2.00	80
2304	141396	952351	3.00	180
2305	141347	952264	2.00	80
2306	141307	952197	2.50	126
2307	141477	952702	1.50	46
2308	141287	952761	1.00	20
2309	141011	952862	2.00	80
2310	140908	952932	1.00	20
2311	140295	952954	0.50	6
2312	139045	952723	1.00	20
2313	138995	952704	1.50	46
2314	138947	952692	1.00	20
2315	138876	952676	2.00	80
2316	138802	952659	1.50	46
2317	138731	952631	1.00	20
2318	138654	952572	0.50	6
2319	138600	952463	1.50	46
2320	138584	952290	1.00	20
2321	138618	952175	1.50	46
2322	138645	952130	1.00	20
2323	138668	952088	0.50	6

2294	141669	952961	2.00	80
2295	141672	952886	2.50	126
2296	141649	952818	2.00	80
2297	141610	952760	2.50	126
2298	141571	952716	3.50	246
2299	141552	952642	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2334	138111	951166	1.50	46
2335	138116	951113	3.00	180
2336	138137	951040	2.50	126
2337	138166	950974	4.00	320
2338	138197	950929	3.50	246
2339	138238	950897	3.00	180
2340	138299	950861	0.50	6
2341	138347	950806	1.50	46
2342	138363	950711	1.00	20
2343	138370	950614	2.00	80
2344	138432	950546	3.00	180
2345	138521	950519	1.50	46
2346	138786	950104	3.00	180
2347	138755	950086	2.00	80
2348	138707	950066	1.50	46
2349	138662	950055	0.50	6
2350	138607	950049	1.50	46
2351	138385	949931	1.00	20
2352	138376	949898	1.50	46
2353	138370	949850	1.00	20
2354	138375	949806	2.00	80
2355	138384	949755	2.50	126
2356	138389	949703	2.00	80
2357	138379	949660	1.50	46

2324	138693	952021	1.00	20
2325	138707	951923	1.50	46
2326	138700	951857	2.50	126
2327	138675	951817	3.50	246
2328	138648	951749	4.00	320
2329	138260	951414	3.00	180
2330	138203	951360	4.00	320
2331	138152	951305	1.50	46
2332	138130	951260	3.00	180
2333	138114	951209	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2368	139446	949264	1.50	46
2369	139501	949153	1.00	20
2370	139553	949074	1.50	46
2371	139572	949025	2.00	80
2372	139543	948938	1.50	46
2373	139418	948905	1.00	20
2374	139366	948955	1.50	46
2375	139327	949018	2.00	80
2376	139290	949051	1.50	46
2377	139244	949072	1.00	20
2378	139156	949079	1.50	46
2379	139001	949050	2.00	80
2380	138951	949045	1.50	46
2381	138852	949060	1.00	20
2382	138756	949082	2.00	80
2383	138709	949097	1.50	46
2384	138664	949119	2.00	80
2385	138625	949144	1.50	46
2386	138502	949157	3.00	180
2387	138378	949133	2.50	126

2358	138373	949553	1.00	20
2359	138380	949512	1.50	46
2360	138394	949457	2.50	126
2361	138425	949411	1.00	20
2362	139447	949576	4.00	320
2363	139433	949528	4.50	406
2364	139423	949482	4.00	320
2365	139420	949432	3.50	246
2366	139417	949382	3.00	180
2367	139422	949336	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2402	137574	948523	1.00	20
2403	137581	948475	2.00	80
2404	137595	948428	2.50	126
2405	137662	948353	3.00	180
2406	137728	948280	2.50	126
2407	137784	948166	3.00	180
2408	137834	948085	2.50	126
2409	137881	948027	4.00	320
2410	137923	947985	3.50	246
2411	137965	947955	3.00	180
2412	138002	947933	2.00	80
2413	138054	947914	3.50	246
2414	138099	947896	3.00	180
2415	138134	947873	3.50	246
2416	138172	947843	3.00	180
2417	138186	947803	3.50	246
2418	138186	947750	4.00	320
2419	138176	947697	3.50	246
2420	138144	947635	3.00	180
2421	138102	947578	3.50	246

2388	138283	949117	2.00	80
2389	138235	949105	2.50	126
2390	138165	949077	2.00	80
2391	138101	949040	1.50	46
2392	138062	949007	2.00	80
2393	137932	948937	1.50	46
2394	137789	948913	2.00	80
2395	137747	948905	2.50	126
2396	137699	948884	3.00	180
2397	137656	948859	2.50	126
2398	137588	948801	3.00	180
2399	137562	948696	2.50	126
2400	137573	948624	1.00	20
2401	137572	948573	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2436	138514	947228	1.50	46
2437	138500	947414	1.00	20
2438	138362	947481	3.00	180
2439	138260	947486	1.50	46
2440	138217	947508	3.00	180
2441	138175	947536	2.50	126
2442	138135	947568	3.00	180
2443	138349	946866	3.50	246
2444	138370	946816	3.00	180
2445	138384	946771	3.50	246
2446	138384	946715	4.50	406
2447	138376	946662	3.50	246
2448	138375	946620	2.50	126
2449	138391	946564	1.50	46
2450	138423	946536	1.50	46
2451	138470	946551	3.50	246

2422	138063	947542	5.00	500
2423	138003	947489	4.00	320
2424	137956	947433	3.00	180
2425	137943	947392	2.50	126
2426	137975	947338	1.50	46
2427	138046	947175	0.50	6
2428	138061	947114	1.00	20
2429	138099	947050	0.50	6
2430	138142	946994	1.50	46
2431	138181	946957	3.00	180
2432	138294	946942	2.00	80
2433	138425	947002	3.00	180
2434	138472	947062	2.50	126
2435	138489	947105	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2470	139872	945573	1.00	20
2471	139774	945473	2.00	80
2472	139731	945461	2.50	126
2473	139654	945442	3.50	246
2474	139550	945426	4.00	320
2475	139479	945423	3.50	246
2476	139379	945431	4.50	406
2477	139266	945441	3.50	246
2478	139177	945456	4.50	406
2479	138383	946514	1.50	46
2480	138326	946469	0.50	6
2481	138274	946415	1.00	20
2482	138238	946381	0.50	6
2483	138202	946350	1.00	20
2484	138165	946316	0.50	6
2485	138128	946292	1.50	46

2452	138522	946550	3.00	180
2453	138563	946530	3.50	246
2454	138606	946507	4.00	320
2455	138640	946473	3.50	246
2456	138651	946421	3.00	180
2457	138657	946372	2.00	80
2458	138675	946301	2.50	126
2459	138704	946235	2.00	80
2460	138760	946186	1.50	46
2461	138892	946113	2.00	80
2462	138999	946050	1.00	20
2463	139079	945990	0.50	6
2464	139167	945959	1.00	20
2465	139267	945944	1.50	46
2466	139341	945947	1.00	20
2467	139441	945963	1.50	46
2468	139750	945906	1.00	20
2469	139896	945670	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2504	139062	944807	1.00	20
2505	139111	944809	3.00	180
2506	139229	944735	2.00	80
2507	139284	944654	1.50	46
2508	139325	944589	2.00	80
2509	139370	944527	1.50	46
2510	139398	944490	2.00	80
2511	139431	944448	2.50	126
2512	139473	944385	1.50	46
2513	139512	944322	2.00	80
2514	139538	944278	1.50	46
2515	139561	944237	1.00	20

2486	138079	946275	3.00	180
2487	138028	946266	2.50	126
2488	137980	946261	3.00	180
2489	137918	946296	2.50	126
2490	137861	946376	2.00	80
2491	137818	946437	2.50	126
2492	137782	946477	1.50	46
2493	137744	946513	0.50	6
2494	137699	946557	1.00	20
2495	138168	946246	0.50	6
2496	138202	946168	1.50	46
2497	138222	946120	2.00	80
2498	138242	946076	1.50	46
2499	138264	946027	2.00	80
2500	138332	945923	1.50	46
2501	138397	945792	2.00	80
2502	138413	945714	2.50	126
2503	138425	945655	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2538	129192	944717	1.50	46
2539	129221	944678	1.00	20
2540	129270	944619	2.00	80
2541	129340	944544	1.00	20
2542	129467	944501	0.50	6
2543	129574	944581	1.00	20
2544	129601	944652	0.50	6
2545	129621	944698	1.00	20
2546	129668	944756	0.50	6
2547	129711	944815	1.00	20
2548	129741	944857	1.50	46
2549	129766	944935	1.00	20

2516	139604	944173	1.50	46
2517	139672	944085	1.00	20
2518	128139	945869	1.50	46
2519	128160	945908	2.00	80
2520	128185	945949	1.00	20
2521	128226	945982	0.50	6
2522	128435	945936	1.00	20
2523	128508	945915	0.50	6
2524	128553	945899	2.00	80
2525	128603	945889	3.00	180
2526	128653	945899	3.00	180
2527	128723	945880	2.50	126
2528	128800	945860	1.00	20
2529	128850	945854	0.50	6
2530	129092	945855	0.50	6
2531	129139	945238	1.00	20
2532	129133	945192	0.50	6
2533	129133	945142	1.50	46
2534	129124	945066	1.00	20
2535	129115	944998	2.50	126
2536	129110	944918	3.50	246
2537	129115	944842	1.00	20

2550	129734	945040	2.00	80
2551	129706	945074	1.50	46
2552	129669	945113	2.50	126
2553	129635	945147	1.50	46
2554	129611	945213	2.00	80
2555	129609	945287	1.50	46
2556	129629	945333	2.00	80
2557	129655	945378	1.50	46
2558	129696	945447	1.00	20
2559	129989	945941	0.50	6
2560	130090	945941	1.00	20
2561	130165	945932	0.50	6
2562	130345	945865	0.50	6
2563	130422	945800	1.50	46
2564	130462	945769	1.00	20
2565	130500	945744	1.50	46
2566	130549	945719	2.00	80
2567	130600	945703	1.00	20
2568	130645	945694	1.00	20
2569	130692	945686	1.00	20
2570	130769	945674	1.50	46
2571	130842	945664	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2572	130893	945662	2.00	80
2573	130943	945665	1.50	46
2574	131016	945672	2.50	126
2575	131091	945681	2.00	80
2576	131141	945685	2.50	126
2577	131236	945666	2.00	80
2578	131323	945624	2.50	126
2579	131360	945587	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2606	132431	944625	2.00	80
2607	132426	944580	2.50	126
2608	132431	944482	1.50	46
2609	132443	944392	2.00	80
2610	131953	944727	3.00	180
2611	131950	944645	2.50	126
2612	131955	944520	2.00	80
2613	131956	944396	1.50	46

2580	131395	945552	1.00	20
2581	131499	945478	1.50	46
2582	131559	945429	1.00	20
2583	131595	945401	0.50	6
2584	131691	945324	1.00	20
2585	131818	945231	1.00	20
2586	131864	945178	0.50	6
2587	131877	945135	1.50	46
2588	131883	945084	1.00	20
2589	131884	945037	1.50	46
2590	131883	944989	2.50	126
2591	131879	944936	3.00	180
2592	131748	944774	2.50	126
2593	131564	944706	1.00	20
2594	131526	944734	0.50	6
2595	131478	944793	2.00	80
2596	131437	944858	1.50	46
2597	131389	944917	1.00	20
2598	131914	944783	3.00	180
2599	132043	944751	2.50	126
2600	132114	944758	0.50	6
2601	132157	944776	2.00	80
2602	132222	944809	2.50	126
2603	132312	944833	3.00	180
2604	132385	944838	3.50	246
2605	132423	944742	3.00	180

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2640	129443	945891	1.50	46
2641	129397	945879	2.50	126
2642	129345	945866	3.50	246
2643	129267	945846	2.50	126

2614	130252	945877	1.00	20
2615	130254	945804	1.50	46
2616	130254	945754	1.00	20
2617	130252	945705	2.00	80
2618	130256	945657	1.50	46
2619	130264	945606	2.50	126
2620	130271	945554	2.00	80
2621	130271	945482	1.00	20
2622	130263	945382	1.50	46
2623	130267	945308	1.00	20
2624	130274	945261	1.50	46
2625	130290	945209	2.50	126
2626	130325	945162	2.50	126
2627	130367	945142	3.00	180
2628	130405	945141	2.00	80
2629	130453	945140	1.00	20
2630	130507	945139	1.50	46
2631	130581	945136	2.00	80
2632	130653	945131	1.50	46
2633	130736	945126	2.00	80
2634	129724	945976	0.50	6
2635	129683	945959	1.00	20
2636	129633	945939	3.50	246
2637	129583	945924	1.50	46
2638	129536	945910	2.00	80
2639	129487	945900	0.50	6

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2674	132537	947163	2.00	80
2675	132564	947280	0.50	6
2676	132577	946815	0.50	6
2677	131943	945890	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2644	131704	945359	0.50	6
2645	131751	945404	1.50	46
2646	131840	945493	1.00	20
2647	131917	945590	1.50	46
2648	131931	945637	0.50	6
2649	131944	945682	1.00	20
2650	131947	945728	0.50	6
2651	131914	945797	1.00	20
2652	131884	945894	0.50	6
2653	131890	945991	1.00	20
2654	131926	946054	0.50	6
2655	132002	946117	1.00	20
2656	132061	946220	0.50	6
2657	132084	946291	1.50	46
2658	132134	946375	0.50	6
2659	132166	946415	1.00	20
2660	132195	946454	0.50	6
2661	132219	946494	2.00	80
2662	132227	946546	2.50	126
2663	132223	946626	3.00	180
2664	132230	946699	2.50	126
2665	132256	946735	2.00	80
2666	132297	946762	0.50	6
2667	132341	946780	1.00	20
2668	132388	946789	1.50	46
2669	132438	946803	3.50	246
2670	132483	946824	2.00	80
2671	132545	946869	1.00	20
2672	132542	947020	1.50	46
2673	132526	947091	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2678	132029	945885	1.50	46
2679	132081	945883	2.00	80
2680	132127	945873	1.50	46
2681	132206	945807	1.50	46
2682	132238	945721	2.50	126
2683	132266	945600	2.00	80
2684	132294	945467	2.50	126
2685	132930	947338	0.50	6
2686	133124	946823	1.50	46
2687	133160	946832	0.50	6
2688	133212	946837	4.50	406
2689	133269	946837	3.50	246
2690	133316	946831	2.00	80
2691	133360	946822	1.00	20
2692	133405	946815	2.00	80
2693	133457	946812	3.50	246
2694	133507	946819	1.50	46
2695	133602	946850	2.50	126
2696	133699	946869	3.00	180
2697	133738	946850	2.50	126
2698	133769	946809	3.00	180
2699	133973	946822	1.00	20
2700	134134	946883	0.50	6
2701	134209	946885	2.50	126
2702	134311	946856	1.00	20
2703	134319	946775	0.50	6
2704	134307	946654	1.00	20
2705	134284	946529	2.50	126
2706	134224	946414	1.00	20
2707	134155	946319	0.50	6

2708	134111	946303	1.00	20	2742	135232	946716	1.00	20
2709	133964	946286	2.00	80	2743	135197	946753	0.50	6
2710	133917	946281	2.50	126	2744	135160	946782	1.00	20
2711	133796	946252	2.00	80	2745	135120	946808	1.00	20
2712	133594	946129	1.50	46	2746	135071	946829	4.00	320
2713	134067	946257	2.00	80	2747	135021	946844	2.50	126
2714	134090	946217	1.50	46	2748	134959	946861	3.50	246
2715	134120	946170	2.00	80	2749	134881	946870	4.50	406
2716	134157	946103	1.00	20	2750	134819	946870	2.50	126
2717	134234	946011	1.50	46	2751	134751	946869	2.00	80
2718	134415	945988	1.00	20	2752	134678	946858	2.50	126
2719	134635	946106	1.50	46	2753	134625	946844	1.50	46
2720	134838	946199	1.00	20	2754	134577	946831	1.00	20
2721	134910	946204	0.50	6	2755	134531	946826	0.50	6
2722	134982	946208	1.00	20	2756	134480	946834	1.00	20
2723	134832	946225	2.50	126	2757	134430	946849	0.50	6
2724	134718	946147	0.50	6	2758	134372	946871	0.50	6
2725	134741	946115	2.00	80	2759	135371	946515	1.00	20
2726	134772	946072	2.50	126	2760	135405	946480	1.00	20
2727	134800	946031	2.00	80	2761	135450	946459	2.00	80
2728	134824	945988	3.00	180	2762	135901	946385	1.00	20
2729	134857	945911	2.50	126	2763	136011	946442	1.50	46
2730	135063	946252	1.50	46	2764	136061	946453	2.50	126
2731	135100	946317	2.00	80	2765	136141	946455	1.50	46
2732	135123	946363	1.00	20	2766	136252	946394	1.00	20
2733	135148	946400	0.50	6	2767	136299	946259	1.50	46
2734	135184	946437	1.00	20	2768	136332	946190	2.00	80
2735	135225	946467	0.50	6	2769	136365	946152	1.50	46
2736	135267	946494	1.50	46	2770	136396	946118	2.00	80
2737	135312	946519	1.00	20	2771	136428	946079	3.00	180
2738	135349	946560	2.00	80	2772	136458	946037	2.00	80
2739	135326	946602	0.50	6	2773	136485	945998	1.50	46

2740	135297	946644	1.00	20
2741	135267	946681	0.50	6

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2776	136570	945856	3.00	180
2777	136577	945796	2.50	126
2778	136602	945750	3.00	180
2779	136646	945684	2.50	126
2780	136697	945600	1.00	20
2781	136732	945538	1.50	46
2782	136762	945496	2.00	80
2783	136882	945458	2.00	80
2784	136952	945462	2.50	126
2785	137009	945465	3.50	246
2786	137059	945469	1.50	46
2787	137100	945477	1.00	20
2788	137136	945487	2.50	126
2789	136636	945866	3.00	180
2790	136684	945853	1.50	46
2791	136726	945847	2.00	80
2792	136880	945826	3.50	246
2793	137050	945781	2.00	80
2794	137116	945751	3.00	180
2795	137150	945731	2.50	126
2796	137140	945697	2.50	126
2797	137125	945639	3.00	180
2798	137132	945565	2.00	80
2799	137146	945506	2.50	126
2800	137169	945731	2.50	126
2801	137225	945774	3.00	180
2802	137165	945457	2.50	126
2803	137187	945398	3.00	180

2774	136515	945961	2.50	126
2775	136550	945918	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2810	137401	945074	1.00	20
2811	137440	945092	1.50	46
2812	137486	945119	3.50	246
2813	137532	945138	2.00	80
2814	137579	945144	3.00	180
2815	137634	945140	2.50	126
2816	137708	945128	1.00	20
2817	137872	945069	1.50	46
2818	137951	945021	1.00	20
2819	138031	944838	2.50	126
2820	138037	944795	3.00	180
2821	138044	944744	2.50	126
2822	138047	944696	2.00	80
2823	138033	944649	4.00	320
2824	137997	944608	3.50	246
2825	137960	944578	0.50	6
2826	137886	944458	1.00	20
2827	138080	944661	1.00	20
2828	138137	944643	1.50	46
2829	138182	944628	1.00	20
2830	138226	944622	1.50	46
2831	137832	944319	1.50	46
2832	137815	944275	2.50	126
2833	137787	944235	3.50	246
2834	137735	944177	4.00	320
2835	137694	944109	3.00	180
2836	137677	944064	2.00	80
2837	137663	943968	1.50	46

2804	137201	945349	2.50	126
2805	137211	945300	2.00	80
2806	137219	945226	1.50	46
2807	137236	945155	1.00	20
2808	137302	945077	2.00	80
2809	137351	945071	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2844	137469	943595	1.00	20
2845	137433	943530	1.50	46
2846	137389	943472	1.00	20
2847	137326	943400	2.00	80
2848	137291	943334	1.50	46
2849	137280	943285	2.00	80
2850	137275	943238	2.50	126
2851	137273	943187	3.00	180
2852	137284	943153	3.00	180
2853	137315	943147	2.50	126
2854	137361	943143	3.00	180
2855	137416	943145	3.50	246
2856	137470	943152	3.00	180
2857	137517	943161	2.50	126
2858	137561	943171	1.50	46
2859	137610	943178	2.50	126
2860	137709	943194	3.00	180
2861	137808	943208	2.50	126
2862	137905	943228	3.00	180
2863	137950	943259	3.50	246
2864	137986	943290	3.00	180
2865	138020	943326	4.50	406
2866	138067	943357	3.50	246
2867	138112	943369	2.00	80

2838	137630	943845	1.00	20
2839	137596	943778	1.50	46
2840	137567	943740	1.00	20
2841	137521	943680	1.50	46
2842	137488	943686	1.50	46
2843	137413	943721	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2878	138432	943144	1.50	46
2879	138435	943069	2.00	80
2880	138436	942966	2.50	126
2881	138446	942935	2.50	126
2882	138535	942953	3.00	180
2883	138653	942971	2.50	126
2884	138719	942953	3.00	180
2885	138764	942925	2.50	126
2886	138800	942894	2.00	80
2887	138840	942854	2.00	80
2888	138919	942757	1.50	46
2889	138880	942876	3.00	180
2890	138935	942913	2.00	80
2891	138440	942895	1.50	46
2892	138493	942760	4.00	320
2893	138531	942716	3.00	180
2894	138559	942683	3.50	246
2895	138683	942515	3.50	246
2896	138716	942483	4.00	320
2897	138993	942665	2.50	126
2898	139023	942638	3.50	246
2899	139177	942571	4.00	320
2900	139223	942574	3.50	246
2901	139270	942585	3.00	180

2868	138156	943376	1.00	20
2869	138211	943379	2.50	126
2870	138286	943378	1.50	46
2871	138356	943376	2.50	126
2872	138436	943370	3.00	180
2873	138514	943362	2.00	80
2874	138404	943360	3.00	180
2875	138402	943307	3.50	246
2876	138413	943242	2.50	126
2877	138429	943193	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2912	138754	942448	3.50	246
2913	138793	942419	2.50	126
2914	138832	942391	2.00	80
2915	138933	942317	1.50	46
2916	139041	942184	2.00	80
2917	138540	942095	3.00	180
2918	138536	942042	2.50	126
2919	138562	941975	3.00	180
2920	138606	941919	2.50	126
2921	138641	941859	3.50	246
2922	138652	941790	3.00	180
2923	138636	941747	3.50	246
2924	138613	941695	4.00	320
2925	138590	941631	3.50	246
2926	138586	941562	4.00	320
2927	138589	941502	2.50	126
2928	138579	941427	3.50	246
2929	138572	941345	4.00	320
2930	138566	941296	3.50	246
2931	138552	941253	3.00	180

2902	139339	942584	2.00	80
2903	139439	942562	3.00	180
2904	139535	942533	1.50	46
2905	139602	942529	1.00	20
2906	138720	942442	3.50	246
2907	138695	942399	3.50	246
2908	138669	942358	3.00	180
2909	138643	942315	3.50	246
2910	138617	942271	3.00	180
2911	138576	942209	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2946	139179	940520	3.00	180
2947	139204	940451	2.00	80
2948	139215	940406	3.00	180
2949	139231	940359	4.00	320
2950	139317	940164	4.00	320
2951	139336	940118	3.50	246
2952	139353	940079	2.00	80
2953	139370	940038	2.50	126
2954	139385	939984	3.00	180
2955	139392	939936	2.50	126
2956	139394	939889	3.00	180
2957	139400	939808	3.50	246
2958	139405	939737	2.00	80
2959	139410	939696	2.00	80
2960	139290	940250	5.00	500
2961	139324	940288	4.00	320
2962	139341	940330	2.00	80
2963	139339	940381	4.00	320
2964	139341	940438	3.00	180
2965	139354	940479	2.00	80

2932	138537	941205	2.50	126
2933	138522	941158	2.00	80
2934	138515	941087	2.50	126
2935	138517	941009	3.50	246
2936	138523	940957	2.50	126
2937	138612	940821	2.00	80
2938	138679	940798	1.00	20
2939	138753	940785	1.50	46
2940	138827	940774	1.00	20
2941	138870	940752	3.00	180
2942	138885	940686	1.50	46
2943	138981	940660	1.50	46
2944	139086	940627	2.00	80
2945	139143	940585	1.50	46

2966	139383	940542	2.50	126
2967	139403	940610	1.50	46
2968	139407	940662	3.00	180
2969	139403	940712	2.00	80
2970	139408	940780	2.50	126
2971	139439	940845	2.00	80
2972	139481	940871	2.50	126
2973	139573	940879	3.00	180
2974	139651	940895	5.00	500
2975	139723	940924	3.50	246
2976	139752	940952	3.00	180
2977	139771	940991	4.00	320
2978	139852	941061	5.00	500
2979	139972	941106	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
2980	140036	941113	3.00	180
2981	140086	941113	4.00	320
2982	140138	941103	3.50	246
2983	140202	941034	3.00	180
2984	140238	940926	2.50	126
2985	140237	940857	3.50	246
2986	140223	940559	4.00	320
2987	139833	941104	5.00	500
2988	139783	941132	3.50	246
2989	139725	941165	3.00	180
2990	139652	941271	5.00	500
2991	139629	941408	4.00	320
2992	140078	940169	0.50	6
2993	140032	940165	1.00	20
2994	139984	940155	1.00	20
2995	139935	940135	1.50	46

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
3014	140782	939830	1.50	46
3015	140878	939807	2.00	80
3016	140952	939796	1.50	46
3017	141001	939789	2.00	80
3018	141049	939782	1.50	46
3019	141096	939778	1.00	20
3020	141147	939780	1.50	46
3021	141228	939789	3.00	180
3022	140280	939902	2.00	80
3023	140277	939870	1.50	46
3024	140282	939830	2.50	126
3025	140297	939777	3.00	180
3026	140319	939729	2.50	126
3027	140360	939668	2.00	80
3028	140401	939603	1.50	46
3029	140429	939561	1.00	20

2996	140177	939919	1.00	20
2997	140227	939923	1.50	46
2998	140274	939917	2.00	80
2999	140325	939935	3.50	246
3000	140372	939961	4.00	320
3001	140425	939968	4.50	406
3002	140471	939970	2.00	80
3003	140517	939980	3.00	180
3004	140569	939988	2.50	126
3005	140616	939992	2.00	80
3006	140616	940001	2.00	80
3007	140603	940054	2.00	80
3008	140644	940269	1.50	46
3009	140671	940001	3.00	180
3010	140771	940010	2.00	80
3011	140637	939952	2.50	126
3012	140674	939895	1.50	46
3013	140714	939863	2.50	126

3030	139396	939589	2.50	126
3031	139335	939546	3.00	180
3032	139266	939508	2.50	126
3033	139223	939488	1.00	20
3034	139106	939457	2.00	80
3035	138984	939442	2.50	126
3036	138936	939440	3.00	180
3037	138858	939440	4.00	320
3038	138776	939444	3.50	246
3039	138728	939450	2.50	126
3040	138585	939473	4.00	320
3041	138502	939460	4.00	320
3042	138494	939517	3.50	246
3043	138475	939582	1.00	20
3044	138457	939648	1.50	46
3045	138442	939698	3.00	180
3046	138482	939705	3.00	180
3047	138567	939720	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
3048	138627	939750	1.00	20
3049	138659	939792	3.00	180
3050	138688	939865	2.50	126
3051	138429	939700	3.00	180
3052	138400	939703	0.50	6
3053	138267	940281	4.00	320
3054	138290	940290	3.00	180
3055	138327	940307	3.50	246
3056	138373	940334	4.00	320
3057	138414	940368	3.50	246
3058	138491	940429	4.00	320
3059	138576	940493	5.00	500

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
3082	139453	937992	2.50	126
3083	139464	937942	2.00	80
3084	139472	937866	3.00	180
3085	139477	937766	2.50	126
3086	139475	937642	3.00	180
3087	139455	937599	2.50	126
3088	139410	937543	3.00	180
3089	139361	937482	3.50	246
3090	139336	937434	3.00	180
3091	139333	937340	2.00	80
3092	139325	937153	2.50	126
3093	139276	937014	2.00	80

3060	138622	940527	3.50	246
3061	138657	940551	2.00	80
3062	138696	940579	3.00	180
3063	138737	940611	2.50	126
3064	138775	940637	2.00	80
3065	138821	940656	1.00	20
3066	138508	939398	3.50	246
3067	138512	939354	3.00	180
3068	138522	939284	4.00	320
3069	138559	939165	3.50	246
3070	138607	939073	4.50	406
3071	138634	939031	3.00	180
3072	138688	938950	3.50	246
3073	138762	938850	3.00	180
3074	138822	938776	3.50	246
3075	138884	938697	4.00	320
3076	138920	938634	3.50	246
3077	138911	938544	4.00	320
3078	138835	938451	3.50	246
3079	139385	938142	2.00	80
3080	139423	938083	2.50	126
3081	139438	938039	2.00	80

3094	139235	936951	2.50	126
3095	139184	936895	2.00	80
3096	139156	936870	2.50	126
3097	139133	936861	2.50	126
3098	139048	936869	1.00	20
3099	138915	936919	2.50	126
3100	138845	936985	3.50	246
3101	138819	937031	4.00	320
3102	138798	937076	3.50	246
3103	138778	937126	4.00	320
3104	138754	937171	2.50	126
3105	138728	937201	2.00	80
3106	138688	937232	1.50	46
3107	138645	937257	1.50	46
3108	138611	937285	2.00	80
3109	138585	937331	3.00	180
3110	138558	937379	2.50	126
3111	138550	937423	3.00	180
3112	138554	937478	3.50	246
3113	138549	937526	2.50	126
3114	138537	937594	3.00	180
3115	138525	937676	3.50	246

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
3116	138521	937728	3.00	180
3117	138521	937774	2.50	126
3118	138528	937830	3.00	180
3119	138513	937879	2.50	126
3120	138472	937905	3.00	180
3121	138421	937916	3.50	246
3122	138372	937916	1.50	46
3123	138327	937918	2.00	80

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
3150	138430	935547	1.00	20
3151	138383	935536	1.50	46
3152	138338	935525	2.00	80
3153	138301	935515	2.50	126
3154	138119	935254	3.00	180
3155	138043	935136	1.00	20
3156	138020	935072	0.50	6
3157	137960	935092	0.50	6

3124	138257	937970	2.50	126
3125	138232	938077	2.00	80
3126	138252	938152	3.00	180
3127	139124	936831	2.00	80
3128	139086	936781	1.50	46
3129	139002	936686	2.00	80
3130	138911	936598	2.50	126
3131	138898	936602	2.50	126
3132	138843	936632	3.50	246
3133	138771	936655	4.00	320
3134	138717	936655	3.50	246
3135	138670	936654	3.00	180
3136	138595	936649	3.50	246
3137	138918	936585	2.50	126
3138	138950	936537	2.00	80
3139	139021	936440	1.50	46
3140	139091	936364	2.00	80
3141	139283	936222	1.50	46
3142	139338	936210	2.00	80
3143	139434	936194	2.50	126
3144	139537	936181	3.00	180
3145	138537	936133	3.00	180
3146	138615	936090	2.00	80
3147	138677	935751	2.50	126
3148	138579	935568	2.00	80
3149	138485	935555	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
3184	138190	934641	0.50	6
3185	138162	934599	1.00	20
3186	138050	934496	1.50	46
3187	137982	934424	1.00	20

3158	137876	935093	1.00	20
3159	137827	935096	2.00	80
3160	137777	935096	3.00	180
3161	137727	935099	2.00	80
3162	137674	935106	2.50	126
3163	137604	935118	3.00	180
3164	138024	935001	3.00	180
3165	138085	934930	3.50	246
3166	138164	934862	4.00	320
3167	138196	934825	3.00	180
3168	138271	934873	3.00	180
3169	138350	934946	2.00	80
3170	138379	934981	3.00	180
3171	138417	935014	2.00	80
3172	138513	935030	0.50	6
3173	138612	935021	1.00	20
3174	138662	935009	1.50	46
3175	138711	934991	1.00	20
3176	138754	934976	0.50	6
3177	138801	934967	1.50	46
3178	138853	934958	2.50	126
3179	138925	934967	3.00	180
3180	138993	934996	2.00	80
3181	138216	934788	2.00	80
3182	138223	934741	2.50	126
3183	138211	934687	1.00	20

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
3218	136117	934147	1.00	20
3219	136051	934176	1.50	46
3220	136001	934183	2.50	126
3221	135926	934177	2.00	80

3188	137921	934353	2.00	80
3189	137896	934315	2.50	126
3190	137874	934262	3.50	246
3191	137857	934201	3.00	180
3192	137837	934142	2.00	80
3193	137821	934065	3.00	180
3194	137417	934205	2.00	80
3195	137402	934256	3.00	180
3196	137688	934213	0.50	6
3197	137691	934251	2.00	80
3198	137699	934299	3.00	180
3199	137716	934353	4.00	320
3200	137729	934402	1.00	20
3201	137719	934495	2.00	80
3202	137678	934576	2.50	126
3203	137638	934608	3.00	180
3204	137591	934631	1.50	46
3205	137548	934638	1.50	46
3206	137495	934626	2.00	80
3207	137248	934644	1.00	20
3208	137205	934667	1.50	46
3209	137142	934698	1.00	20
3210	137081	934107	3.00	180
3211	137047	934157	2.00	80
3212	137008	934181	1.50	46
3213	136959	934196	2.50	126
3214	136904	934206	1.50	46
3215	136250	933850	0.50	6
3216	136237	933927	2.00	80
3217	136179	934076	1.50	46
Id	x_coord	y_coord	Depth_m	buffer_x20 (m)

3222	135831	934158	1.00	20
3223	135762	934156	2.00	80
3224	135708	934172	1.50	46
3225	135772	934189	2.00	80
3226	135781	934253	5.00	500
3227	135780	934311	4.00	320
3228	135762	934353	2.00	80
3229	135730	934385	1.00	20
3230	135692	934415	1.50	46
3231	135641	934469	2.00	80
3232	135569	934575	1.00	20
3233	135539	934694	1.50	46
3234	135603	934772	2.00	80
3235	135644	934793	2.50	126
3236	135697	934795	4.00	320
3237	135747	934777	3.00	180
3238	135466	934656	2.50	126
3239	135411	934680	2.00	80
3240	135364	934698	1.00	20
3241	135301	934734	3.00	180
3242	135266	934800	3.50	246
3243	135248	934845	2.00	80
3244	135198	934855	1.00	20
3245	135147	934866	2.00	80
3246	135101	934878	1.00	20
3247	135046	934891	1.50	46
3248	135008	934850	0.50	6
3249	134973	934819	1.00	20
3250	134882	934779	2.00	80
3251	135031	934922	4.00	320
Id	x_coord	y_coord	Depth_m	buffer_x20 (m)

3252	134957	934983	4.50	406
3253	134890	935045	4.00	320
3254	134837	935086	3.00	180
3255	134717	935158	4.00	320
3256	134576	935214	3.00	180
3257	134481	935223	2.50	126
3258	134384	935211	3.00	180
3259	134313	935191	2.00	80
3260	134268	935169	2.50	126
3261	134199	935131	2.00	80
3262	134783	934759	1.00	20
3263	134712	934756	1.50	46
3264	134637	934750	2.50	126
3265	134588	934745	1.50	46
3266	134537	934740	2.50	126
3267	134487	934729	1.50	46
3268	134429	934714	1.50	46
3269	135661	934190	0.50	6
3270	135619	934213	1.00	20
3271	135574	934235	0.50	6
3272	135532	934251	1.00	20
3273	135456	934276	3.50	246
3274	135377	934289	3.00	180
3275	135308	934273	3.50	246
3276	135254	934234	3.00	180
3277	135223	934192	3.50	246
3278	135194	934150	3.00	180
3279	135172	934109	2.50	126
3280	135122	934057	1.00	20
3281	135057	934024	2.00	80
3282	135008	934015	1.00	20
3283	134961	934007	2.50	126

3286	134754	933986	3.00	180
3287	134621	933925	0.50	6
3288	134589	933897	1.50	46
3289	134556	933861	2.00	80
3290	134518	933828	2.50	126
3291	134472	933797	3.00	180
3292	134429	933770	2.50	126
3293	134385	933756	2.00	80
3294	134312	933750	2.50	126
3295	134216	933758	2.00	80
3296	134202	933727	3.00	180
3297	134196	933662	4.00	320
3298	134198	933610	3.00	180
3299	134224	933515	3.50	246
3300	134274	933429	3.00	180
3301	134316	933407	2.00	80
3302	134358	933380	3.50	246
3303	134407	933348	2.00	80
3304	134443	933318	1.00	20
3305	134468	933282	1.50	46
3306	134483	933234	2.00	80
3307	134477	933187	2.50	126
3308	134461	933134	3.50	246
3309	134137	933774	3.50	246
3310	134060	933788	3.00	180
3311	133982	933804	4.50	406
3312	133908	933815	3.00	180
3313	133789	933830	3.50	246
3314	133693	933857	3.00	180
3315	133657	933883	2.50	126
3316	133623	933921	3.00	180
3317	133594	933962	2.50	126

3284	134906	934003	2.00	80	3318	138234	935555	1.50	46
3285	134832	933998	1.00	20	3319	138200	935643	2.50	126

Id	x_coord	y_coord	Depth_m	buffer_x20 (m)
3320	138153	935703	2.00	80
3321	138111	935734	3.00	180
3322	138065	935758	2.50	126
3323	137972	935772	3.00	180
3324	137917	935772	1.00	20
3325	137871	935771	2.00	80
3326	137783	935735	2.50	126
3327	137700	935684	2.00	80
3328	137656	935661	2.50	126
3329	137606	935645	2.00	80
3330	137556	935628	1.00	20
3331	135416	933532	3.50	246
3332	135354	933479	3.00	180
3333	135301	933421	2.50	126
3334	152157	960329	0.50	6
3335	152082	960316	1.00	20

17 Appendix 6: Detailed views of possible SAC boundary threats

Section 8.3 of the present report identifies that there are certain stretches of the SAC boundary that could, potentially, be affected by the LWP development proposal, while in other parts of the SAC the boundary is simply not as hydrologically robust as it might be. Although the details of such potential dangers have been spelled out in relation to a single location in the northern part of the development (Figure 108), the remaining locations have only been considered so far in terms of the general map of the development and the SAC, and repeated here as Figure xxxx. The remaining areas of boundary concern are therefore illustrated below in detail, to give some sense of what the issues are with each of these identified boundary lengths.

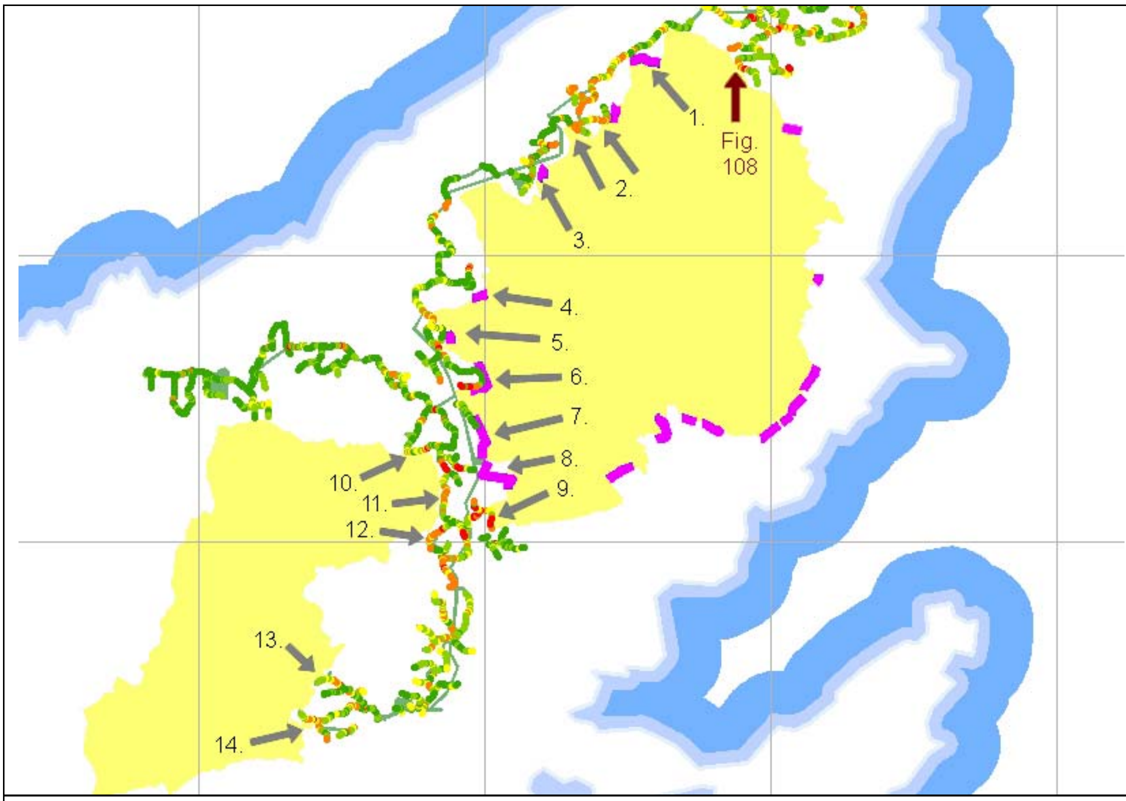


Figure 119: SAC boundary issues – overview map
The extent of the Lewis Peatlands SAC, consisting of a northern and a southern component (shaded pale orange/cream). Sections of the boundary around the northern component which are not as hydrologically secure as they might be are indicated with a thick purple line. The peat-depth map associated with the road-line of the proposed LWP development is also shown. It is displayed as a colour-gradient linked to differing peat depths; thus mid-green is the shallowest peat, yellow is peat between 1.0 m and 2.0 m, then orange and red are deep peats, with red symbolising peat depths of 5 m or more. Areas of particular concern along the SAC boundaries are indicated with grey arrows, and numbered. The numbers refer to the detailed views of these areas provided in Appendix 6. The area illustrated in Figure 108 is arrowed in brown. The route of the overhead power lines is also shown, distinctive in its blue-green straight sections. There are no peat-depth values for the powerline route. The coastline is shown as concentric blue shading. The OS National Grid is displayed as pale grey lines indicating 10 km squares.

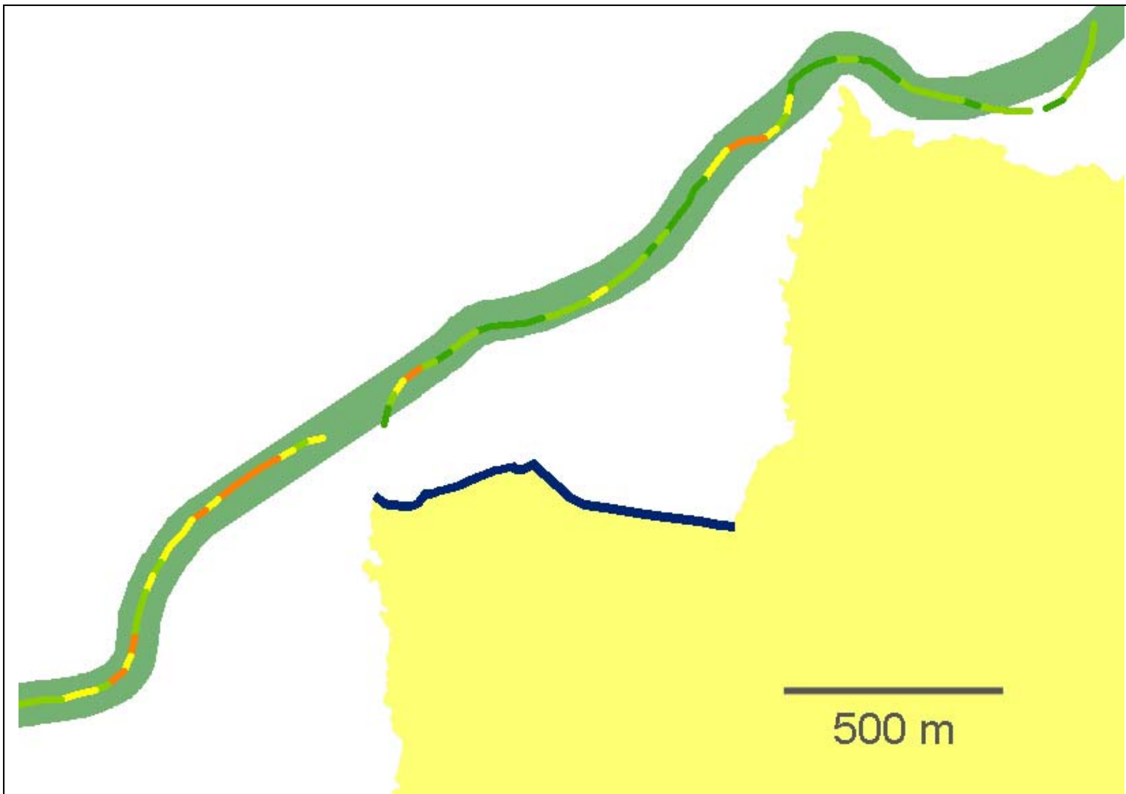


Figure 120. SAC boundary issues – Area 1.
An area of LWP development on shallow peat runs close to the SAC boundary in the north, but probably to little effect. A less-robust section of the SAC boundary is shown in dark blue, but this is some way from the LWP development.

Figure 121. SAC boundary issues – Area 2.
A less-than-robust section of SAC boundary is shown in dark blue. It lies within 150 m or so of the proposed development, and at least one section of this is on comparatively deep peat. There is also an obvious projection of the SAC into the heart of the LWP development, bordered on one side by the roadline constructed on comparatively deep peat, and on the other by the route of the overhead powerlines, for which there is no peat-depth information. Both of these parts of the development lie about 100 m fron the SAC boundary.

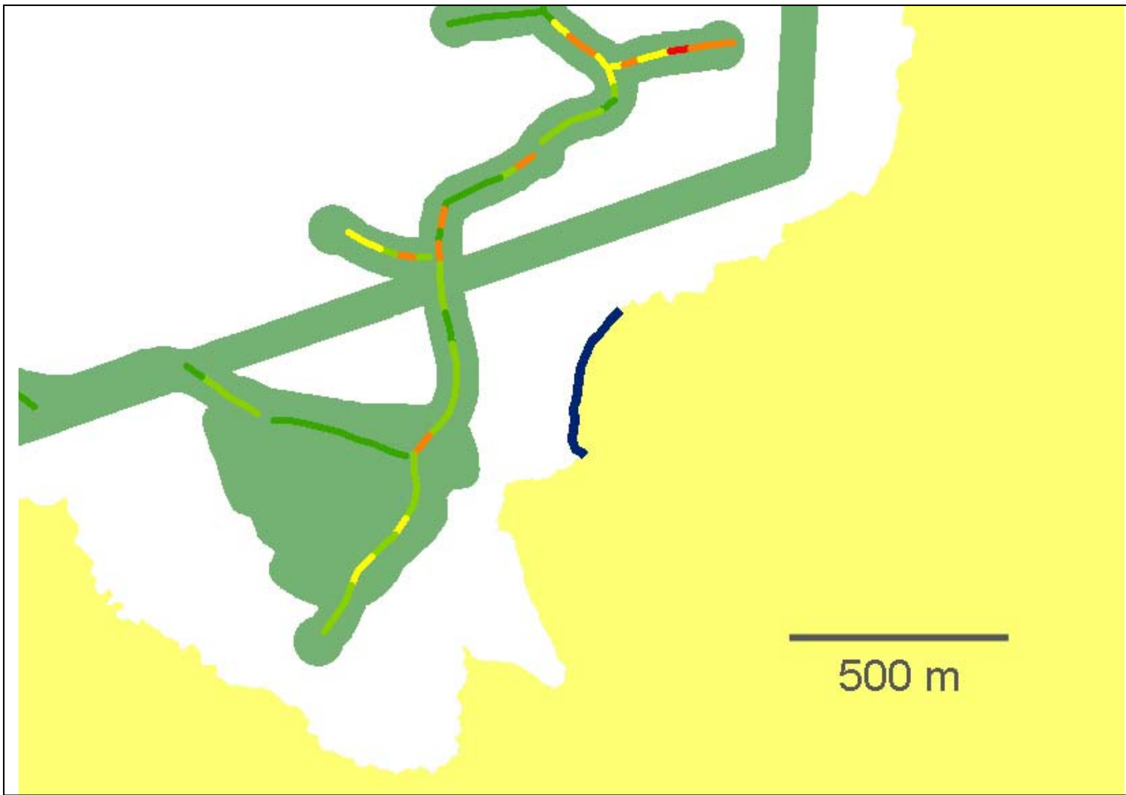


Figure 122. SAC boundary issues – Area 3.
A less-than-robust section of SAC boundary is shown in dark blue. It lies some distance from the proposed development, though an adjacent part of the SAC boundary lies within 100 m or so of the overhead powerline route – for which there are no peat-depth data. Just to the south of the blue-section boundary, an area representing a ZoC approaches within 100 m or so of the SAC boundary, and some of the peat here may be comparatively deep.

Figure 123 SAC boundary issues – Area 4.
A less-than-robust section of SAC boundary is shown in dark blue. It lies some distance from the proposed development, and even then the development lies on quite thin peat. At the end of the roadline there is obviously a turbine, and this lies in very deep peat. However, this is located some 250 m from the SAC boundary.

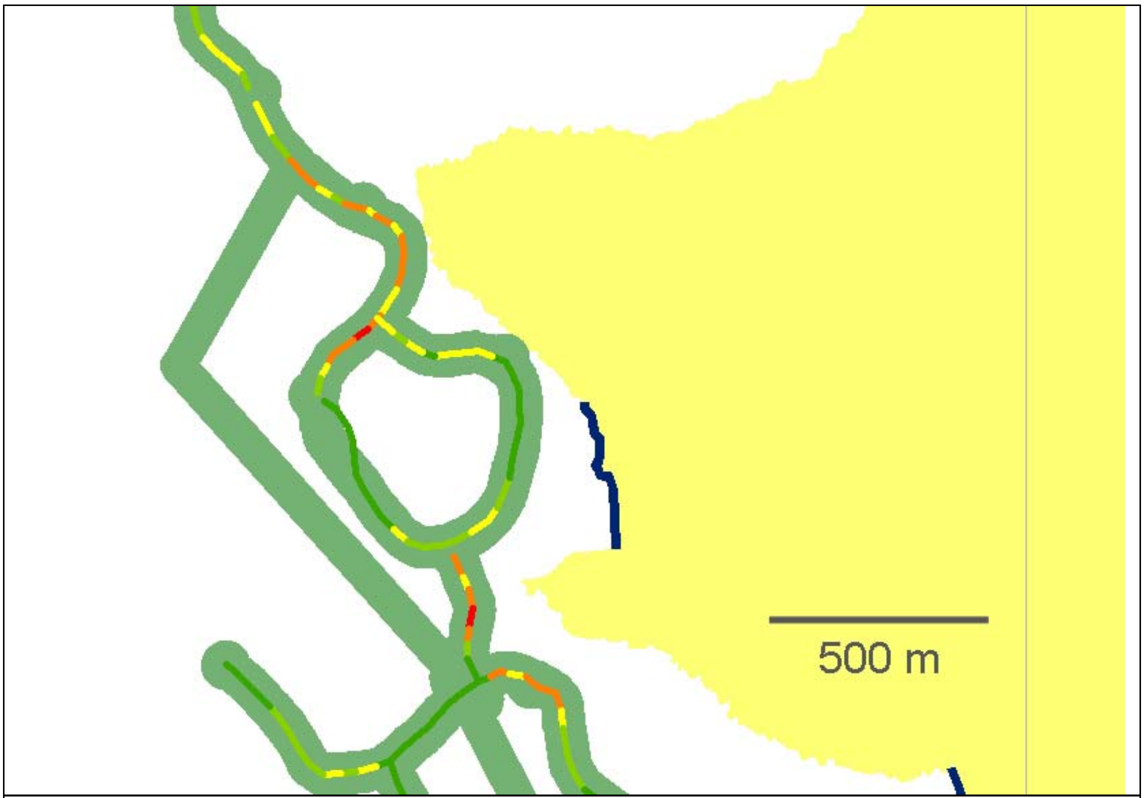


Figure 124 SAC boundary issues – Area 5.
A less-than-robust section of SAC boundary is shown in dark blue. It lies within 100 m or so of the proposed development, while two adjacent parts of the SAC boundary lies right next to the line of development, and one of these sections is dominated by comparativelt deep peat. Just to the south of the blue-section boundary, another section of the development approaches within 100 m or so of the SAC boundary, and some of the peat here is very deep.

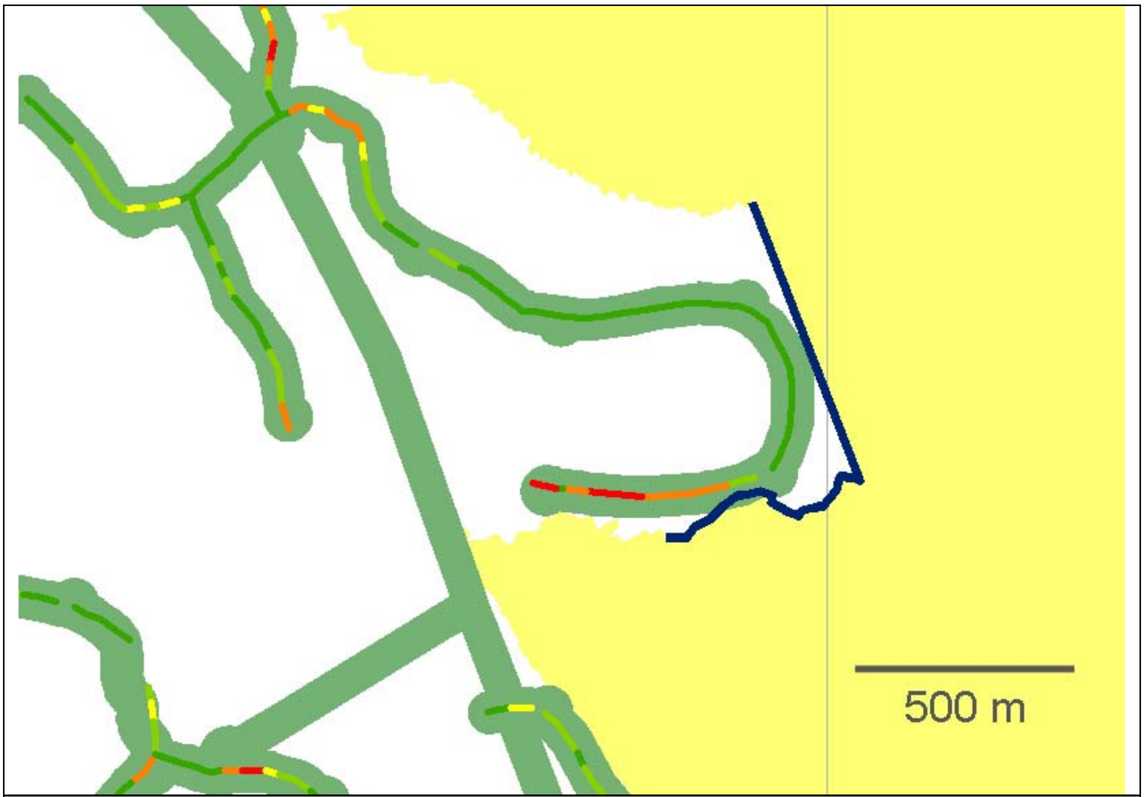


Figure 125 SAC boundary issues – Area 6.
A less-than-robust section of SAC boundary is shown in dark blue. It lies right next to the line of the proposed development, though for most of this length the peat is quite shallow. However, towards the souther n extremity of this boundary, and extending further west, the development continues to lie next to the SAC boundary, and some of the peat here is very deep. This deep peat is associated with both the roadline and a turbine.

Figure 126 SAC boundary issues – Area 7.
A less-than-robust section of SAC boundary is shown in dark blue. It lies right next to a section of the proposed development, though most of the peat here is comparatively shallow. Just to the south of the blue-section boundary, an area representing a ZoC abuts the SAC boundary, but because it is related to the overhead powerlines, there are no peat-depth data for this section.

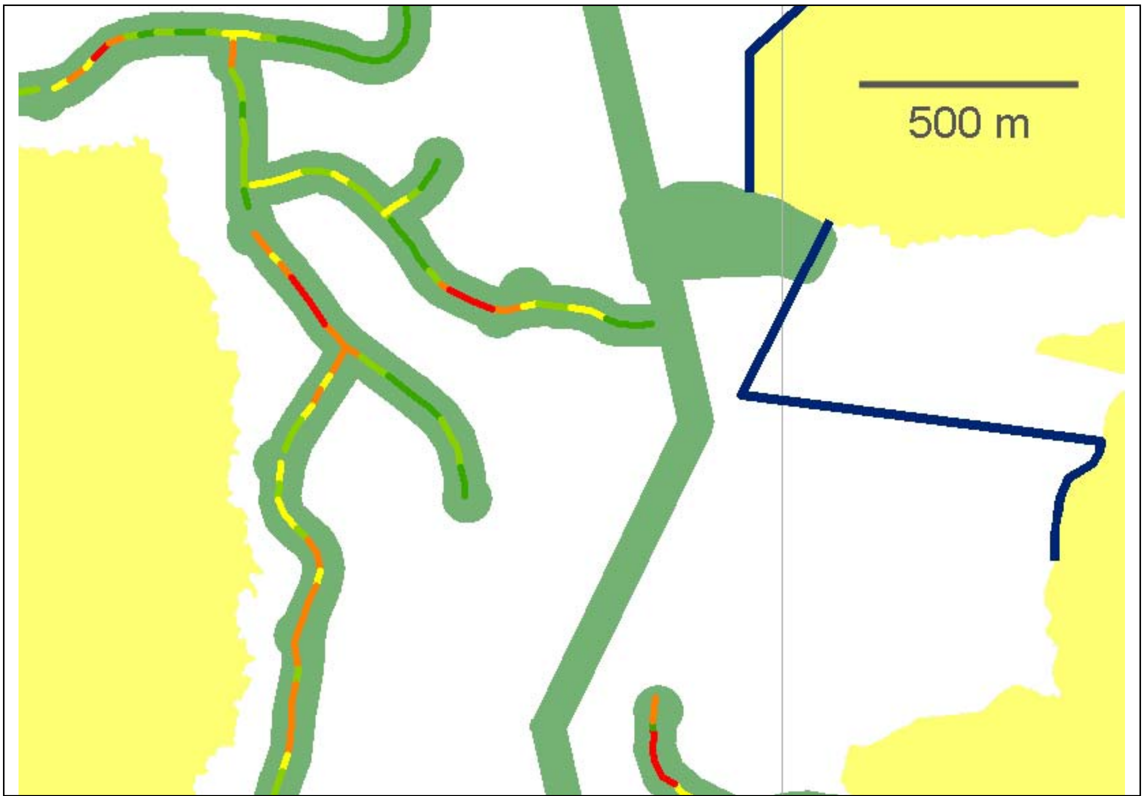


Figure 127 SAC boundary issues – Area 8.
A less-than-robust section of SAC boundary is shown in dark blue. It abuts an area representing a ZoC, but because the ZoC relates to an area of the overhead power lines, there are no peat-depth data for this section.

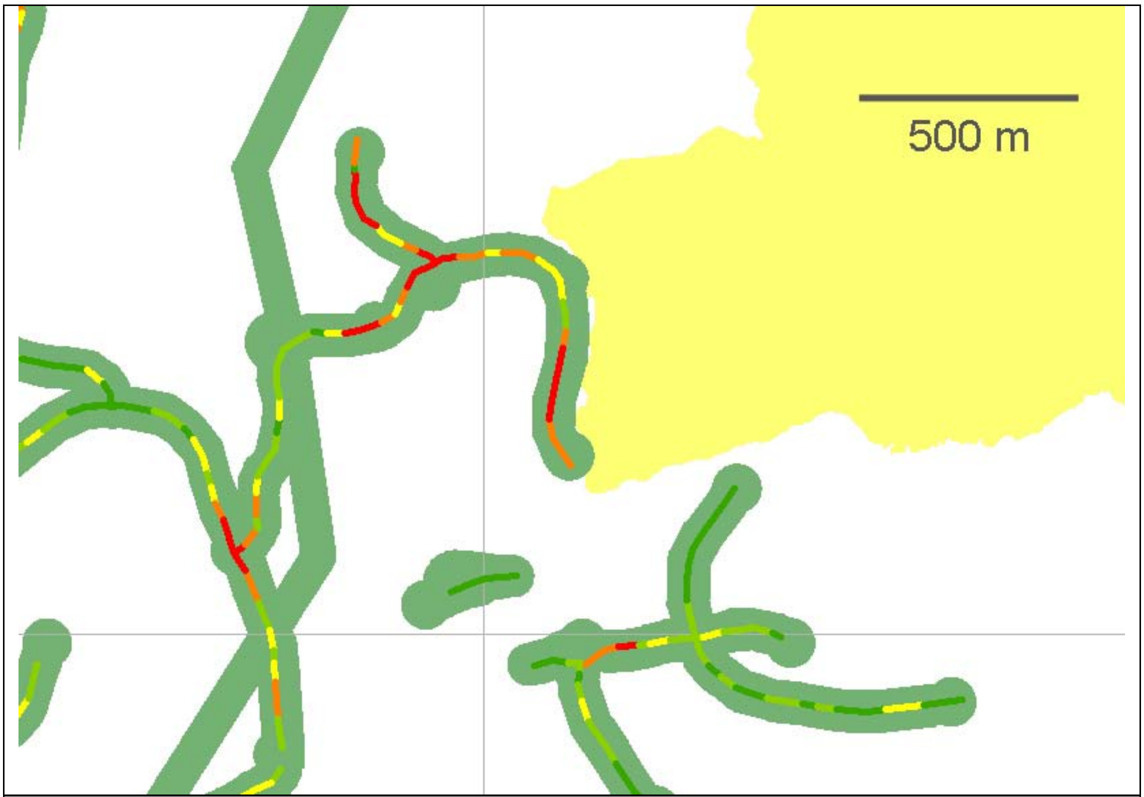


Figure 128 SAC boundary issues – Area 9.
The proposed roadline abuts the SAC boundary for more than 500 m here. There are also two turbine bases here. The development infrastructure is associated with extensive areas of the deepest peat.

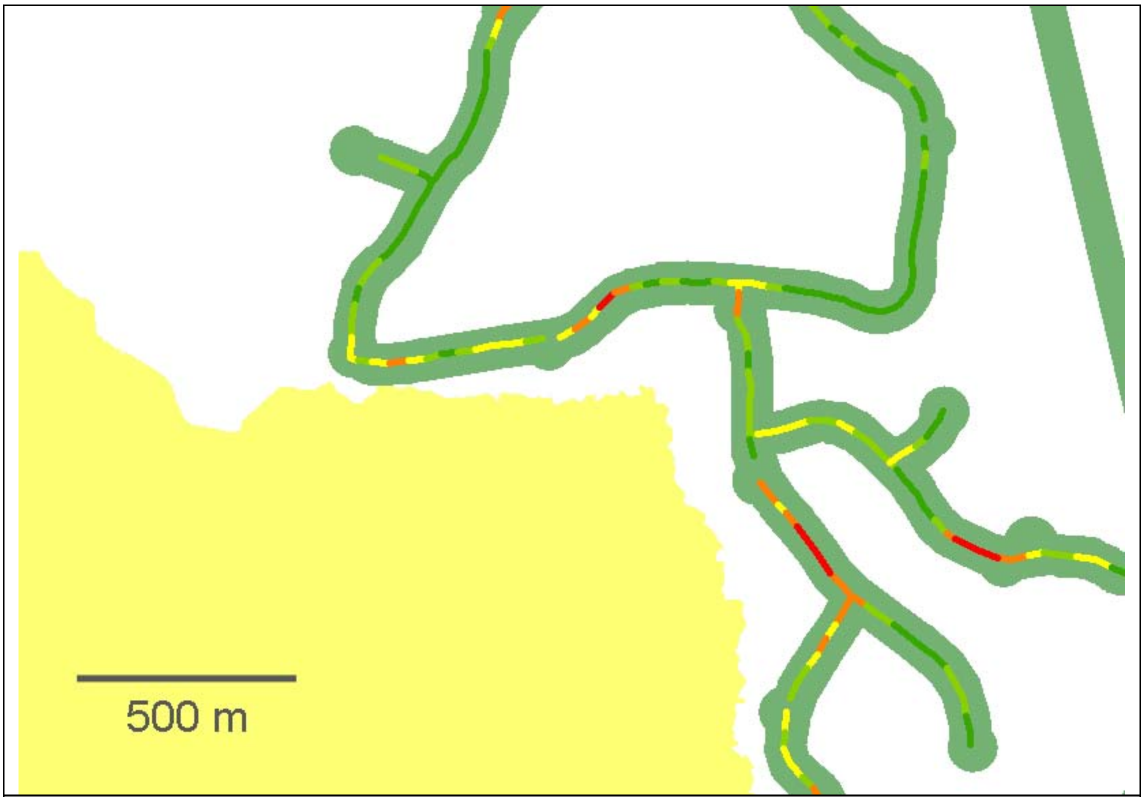


Figure 129 SAC boundary issues – Area 10.
The proposed roadline lies within 100 m or so of the SAC boundary for more than 500 m here. There are also two turbine bases here. The development infrastructure is associated with extensive areas of moderately deep peat. To the south, the line of development lies at distances of between 50 m and 150 m from the SAC boundary. The roadline and turbines are here associated with peat depths ranging from very deep to comparatively shallow.

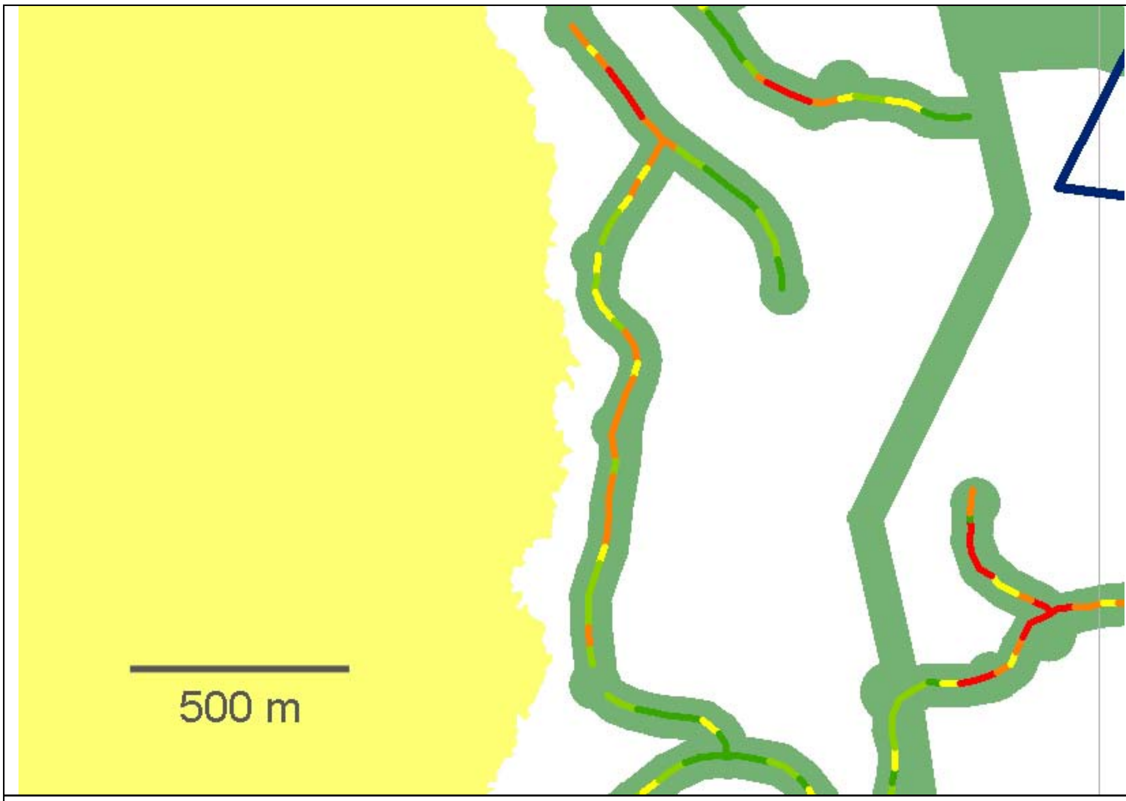


Figure 130 SAC boundary issues – Area 11.
The proposed roadline lies close to the SAC boundary for almost 1.5 km here. The development infrastructure is associated with stretches of comparatively deep peat, as well as sections on comparatively shallow peat.

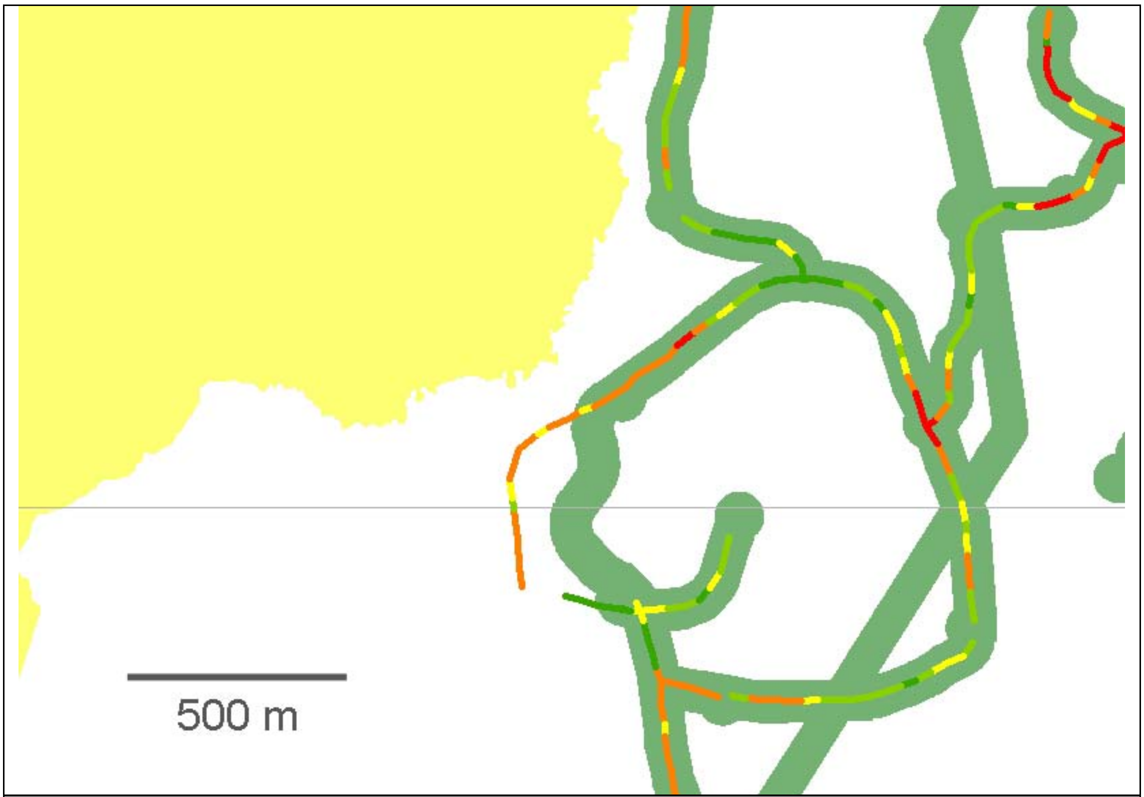


Figure 131 SAC boundary issues – Area 12.
The proposed roadline lies within 100 m or so of the SAC boundary for parts of this section, and most of this section is associated with comparatively or very deep peat. There is a new section of road here for which there are no peat-depth data, but the new section runs away from the SAC rather than towards it.

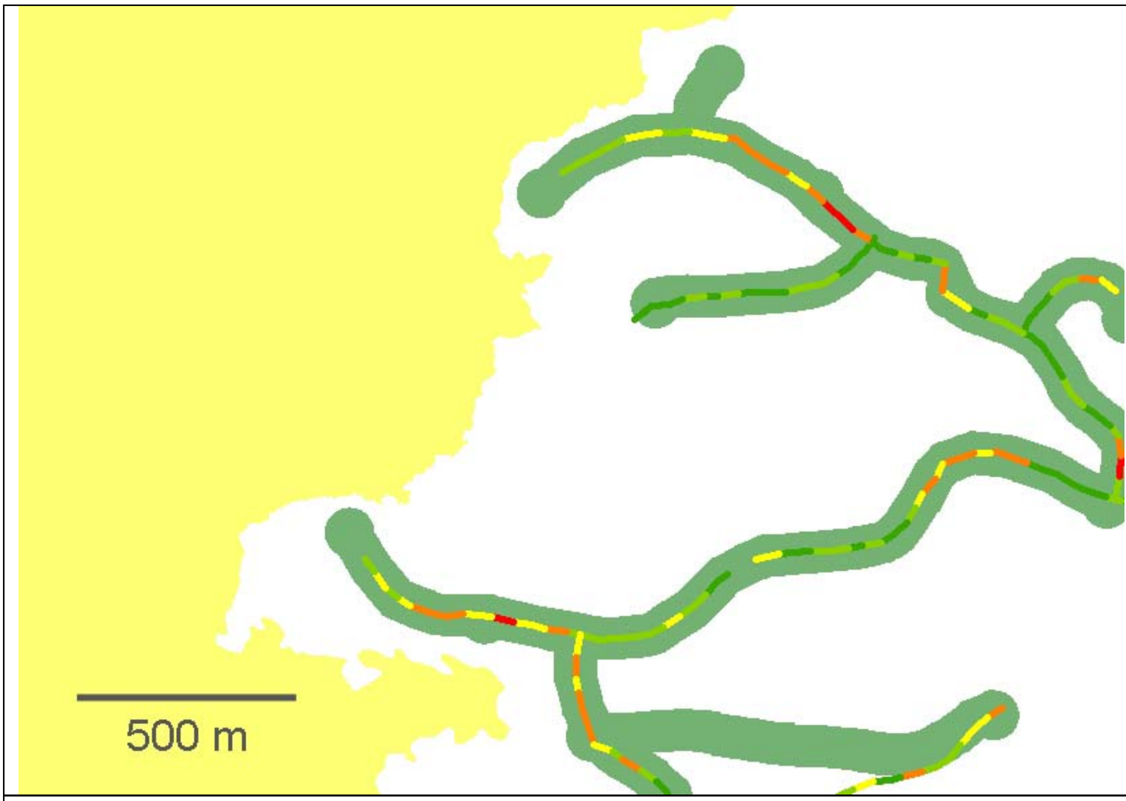


Figure 132 SAC boundary issues – Areas 13 and 14.
The proposed roadline lies very close to the SAC boundary in several places here, and the closest approach es are associated with two turbine bases. The peat is relativel shaloow here, however, although the finger of SAC to the south lies within 100 m of a road section and turbine base associated with very deep peat.

Peatland Research Unit
School of Health & Bioscience
University of East London