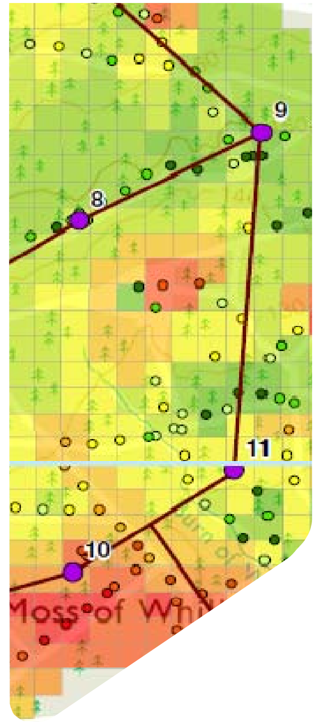


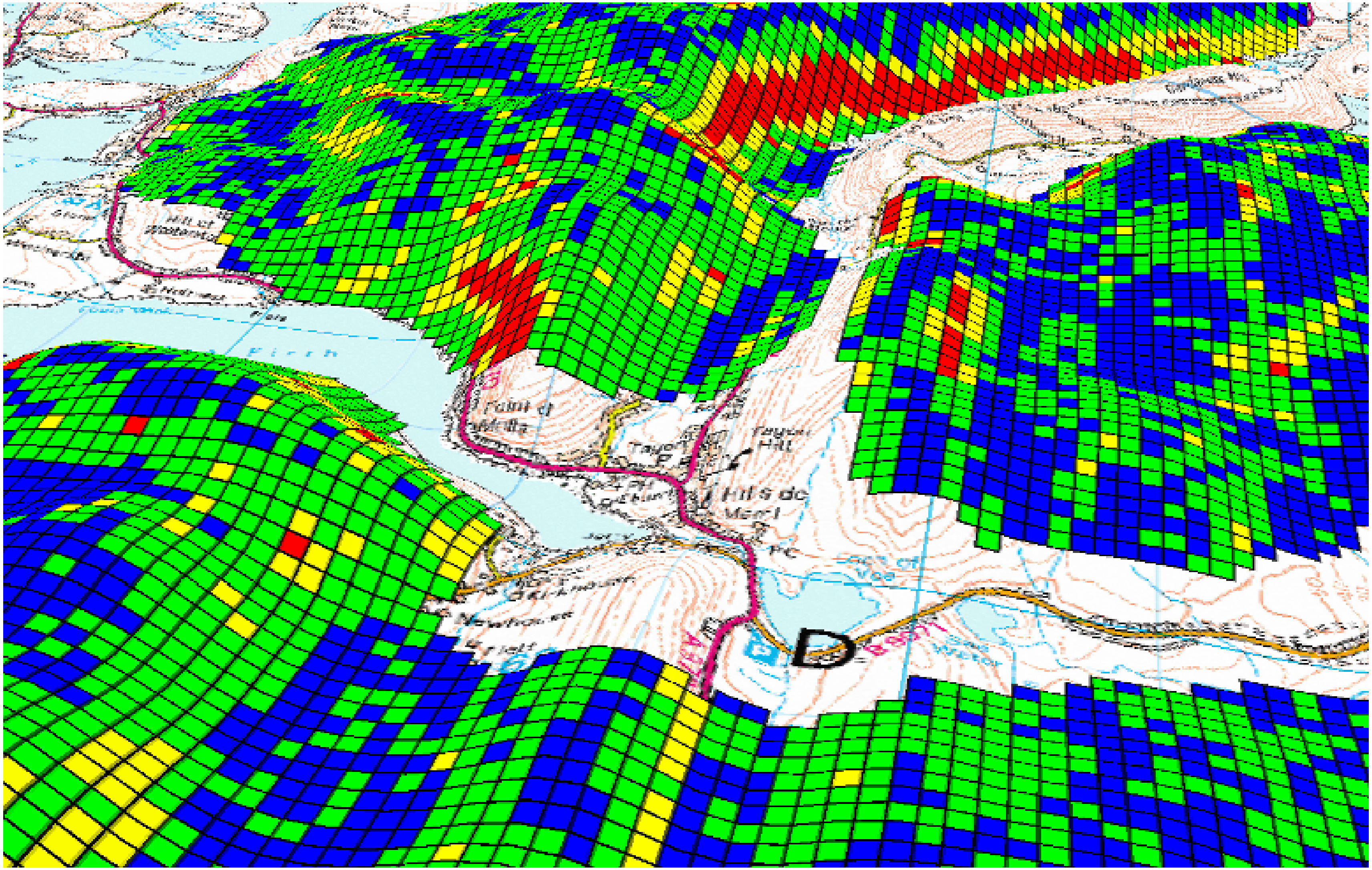
Peat Depth Mapping and Peatslide Susceptibility Assessment

Robert Bone

IGI Peat Stability Seminar, 7th October 2010

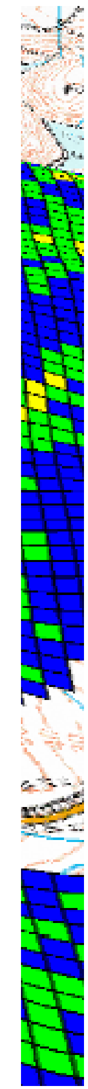
Geological Survey of Ireland, Dublin

End Product: A peatslide susceptibility map

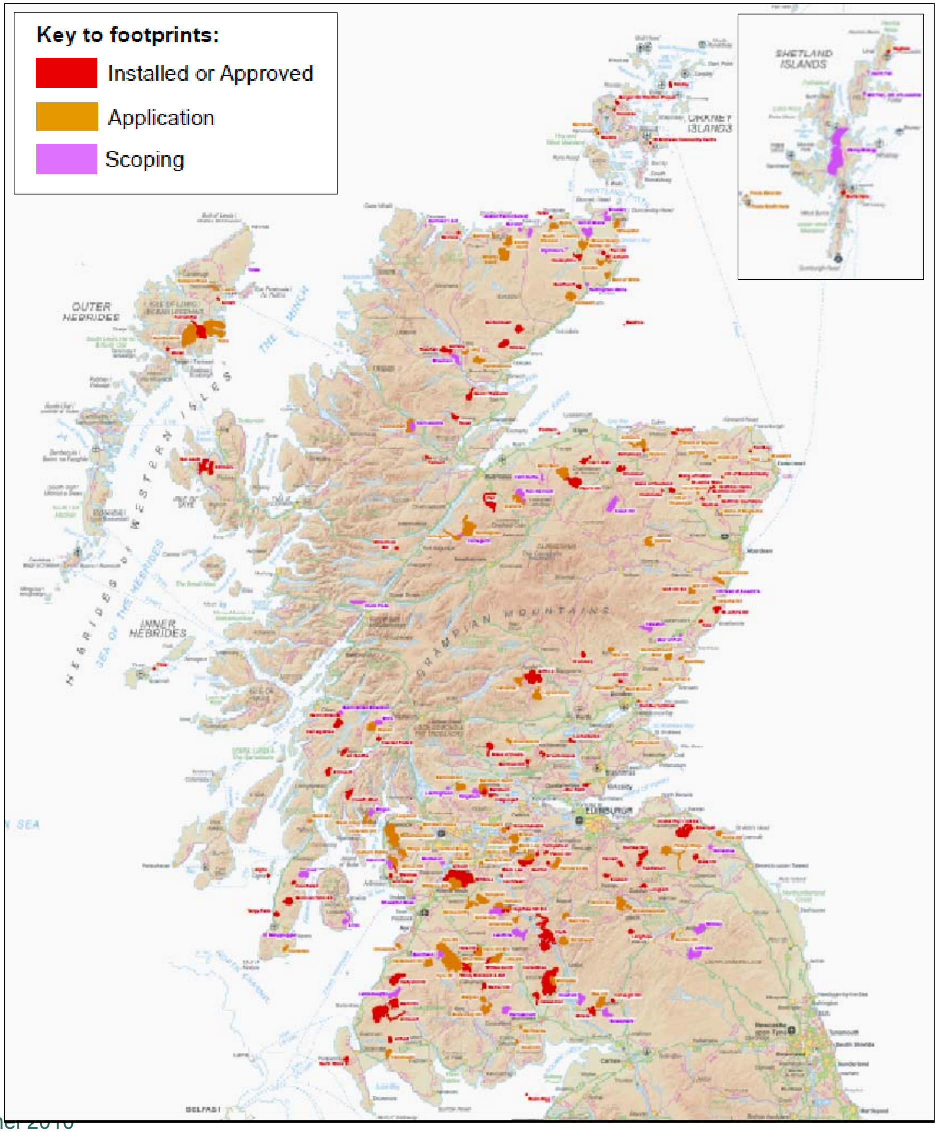


Presentation Outline

- **Background and Context**
  - Increasing scale and number of windfarms
  - Significant peatslide events
- **Developing Peat Depth Maps**
  - Why do we need these?
  - How do we prepare these?
- **Assessing Peatslide Susceptibility**
  - Types of analysis
  - Scottish Government Guidelines
  - Details of Mouchel's Approach

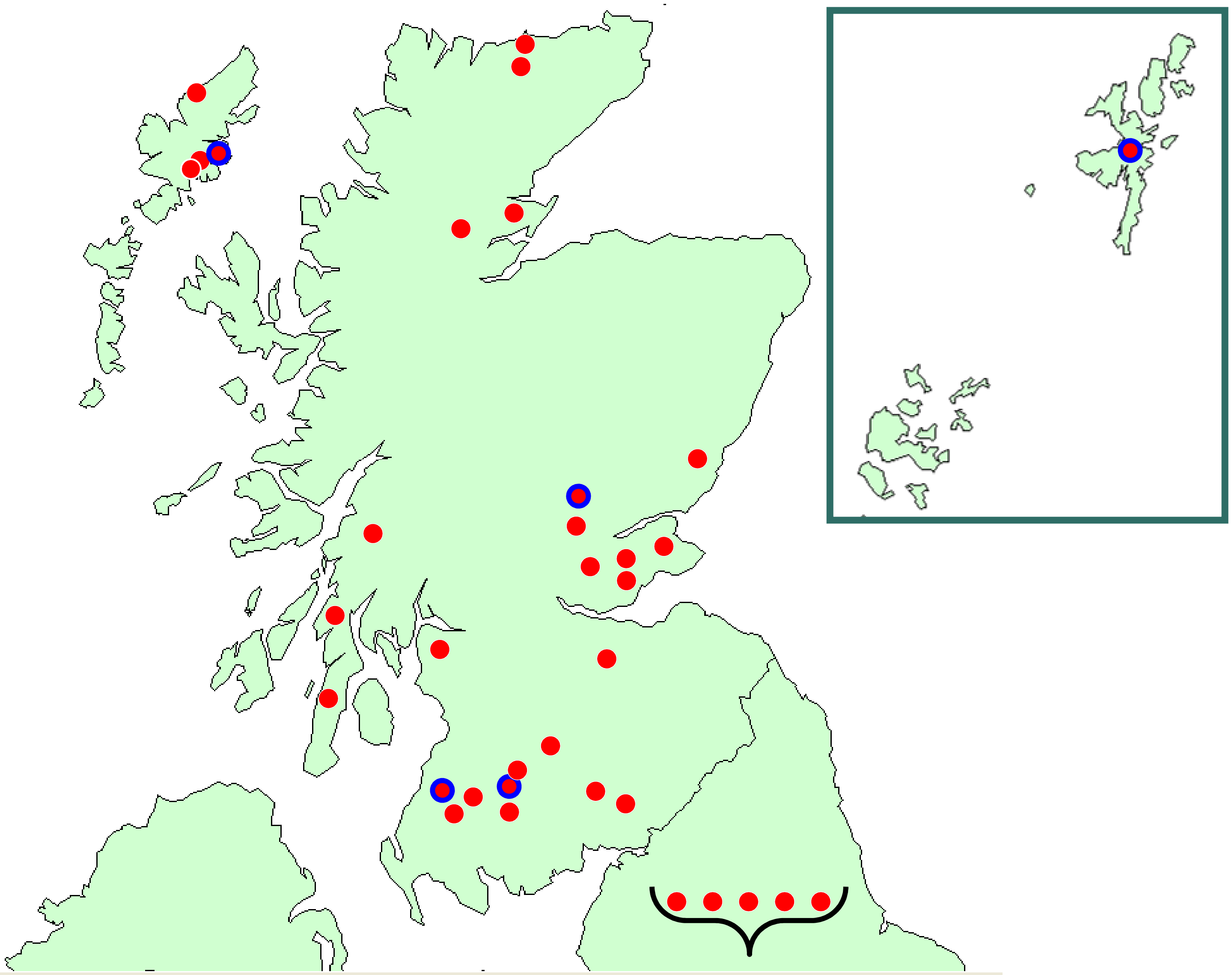


Background: Scale of windfarm development



	England	Scotland	Northern Ireland	Wales
Operational	105	96	27	34
Under Const'n	16	22	2	3
Consented	96	72	13	10
Planning	96	101	44	23
Grand Total	313	291	86	70

Mouchel's involvement…



Background: The historical context

- **Natural Events:**
  - **Peatslides / bog bursts**: Naturally occurring events and may range in magnitude from 10’s of m^3 to over a 1 million m^3 (Knocknageeha, Roscommon, Ireland, 1883).
  - **Channerwick**, Shetland Islands, Scotland (19 Sept 2003): Several peatslides were triggered by an intense rainstorm (c. 33mm/hr) which was part of a slow moving front which pushed south-eastwards across Scotland. Damage to roads and associated infrastructure.
  - **Pollatomish**, Co. Mayo, Ireland (19 Sept 2003): Multiple peat slides on the slopes of the Dooncarton and Barnachuille mountains. Damage to roads, bridges, cemetery, and evacuation of 40 families from homes.
- **Induced Event (Supposedly)**
  - **Derrybrien**, Co. Galway, Ireland (October 2003): 2.5km of land with a volume of about 450,000 m3 slipped during construction activities at a 71 turbine windfarm in Co. Galway, Ireland. Damage to forestry, farmland, water bodies and roads. Construction work delayed.

Peat Depth Mapping: Why?

- **Good Design**
  - Developers generally sensitive to risk issues
  - Constraints mapping to avoid construction difficulties
  - Cost effective layout (Turbine locations / Access routes)
  - Access track design (Floating vs Excavated roads)
  - Ecological impact minimisation

- **Planning / Consent Processes**
  - Carbon Balance Calculations (Carbon cost / benefit payback time)
  - Peatslide susceptibility assessment
    - *Scottish Executive (Section 36) consent requirement*
    - *Local Authority planning requirement*
  - Scottish Government Guidelines

  (Peat Landslide Hazard and Risk Assessment: Best Practice Guide for Proposed Electricity Generation Developments, January 2007.)

Peat Depth Mapping: How?

- **Desk Study**
  - Aerial photography
  - Soils maps
  - Digital terrain mapping
- **Fieldwork**
  - Survey route planning
  - Preparation (GPS / fieldwork maps / equipment / etc…)
  - Peat probing (lady with pole)
  - Observation (geomorph / risk factors etc)
  - Peat coring (von Post)
  - Shear vane testing
- **Data processing**
  - Indicative peat depth mapping (interpolation)
  - Peat stability assessment
  - Peatslide hazard assessment

Come to these later

Assessing Peatslide Susceptibility

- **Types of Assessment**

- **The Scottish Government's Guidelines: Making the method fit**
  - 'Likelihood' element: How do we assess this?

    The Guidelines cite one geotechnical model – the Infinite Slope.

    Mouchel has adopted that.
  - 'Exposure' element: How do we assess this?

    The Guidelines do not state how 'Exposure' is to be evaluated.

    Mouchel has set out our own definitions
  - Combining 'Likelihood' and 'Exposure'

- **An illustrated example**

Concluding Remarks

- **The commercial and legislative drivers for undertaking peat depth surveys**
- **The methods Mouchel uses to create peat depth maps**
- **The application of peat depth data to a variety of uses:**
  - Peatslide susceptibility assessment, but also
  - Constraint mapping for windfarm access track and turbine layout
  - Type of road construction (rock quantities)
  - Carbon balance calculations
- **How the methods developed 'fit' with the Scottish Government's Guidelines**

Questions ?

Hyperlink Slides Start Here

Ayrshire: Hill grazing, shallow soils, limited peat in hollows

Galloway: Coarse grasslands, extensive shallow peat

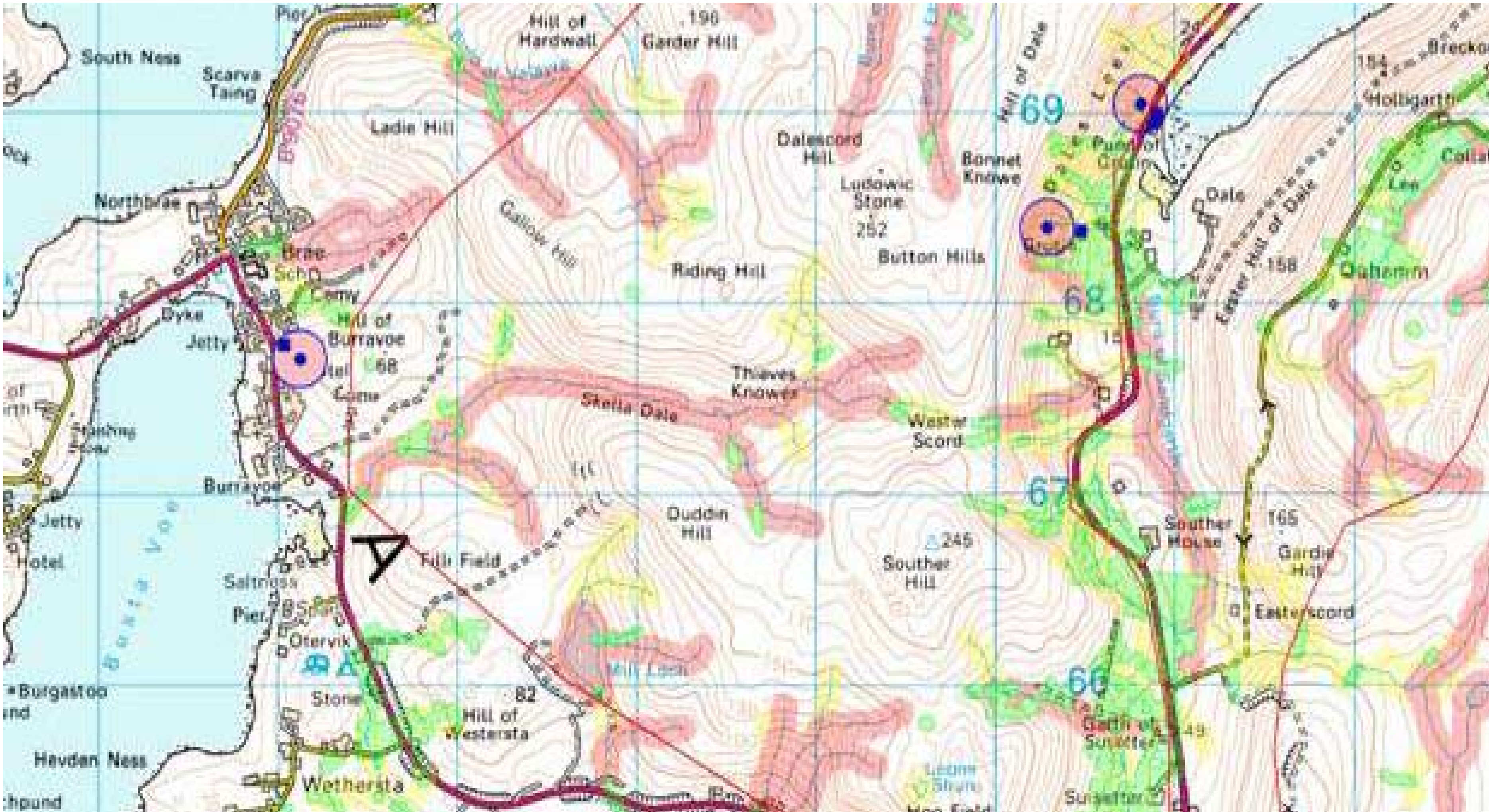
Perthshire: Forestry, traversed with roads, extensive peat

Shetland: Uniform blanket bog, deep generally, intact

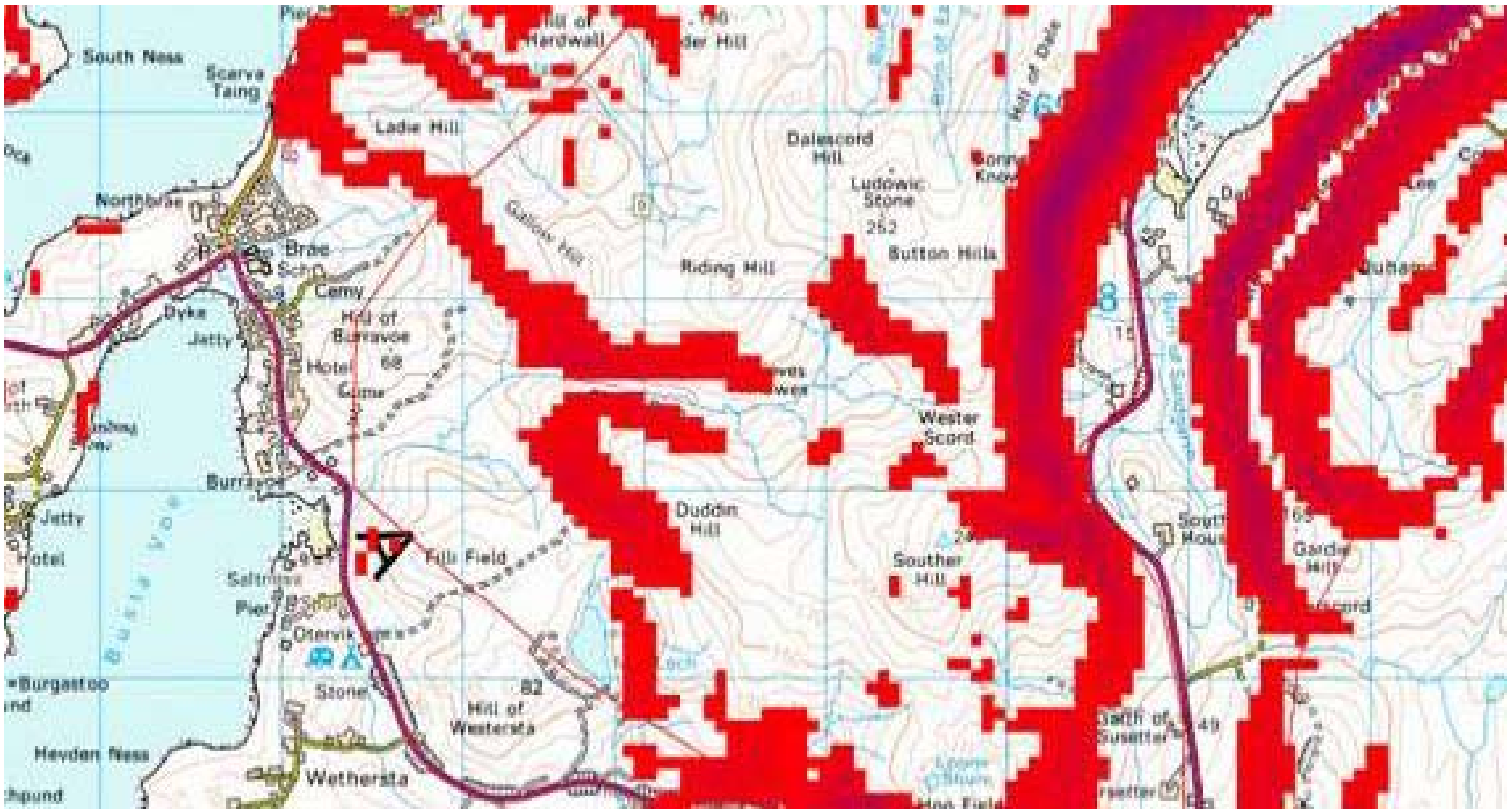
Hebrides: Lochans, rocky outcrops, areas of deep peat

Aerial Photography: Indicative signs of instability (2 at least !)

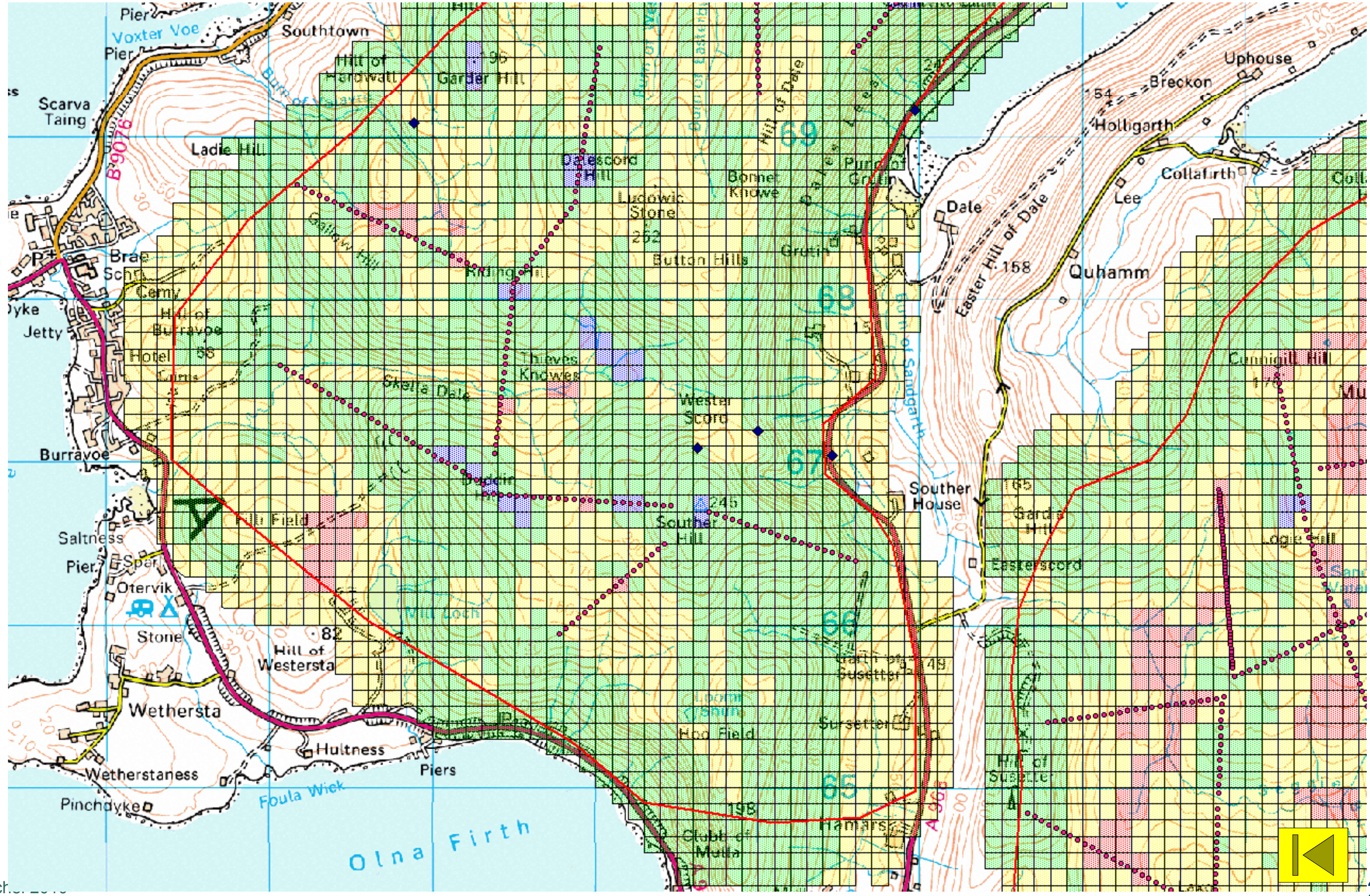
Constraint: Buffers round water features



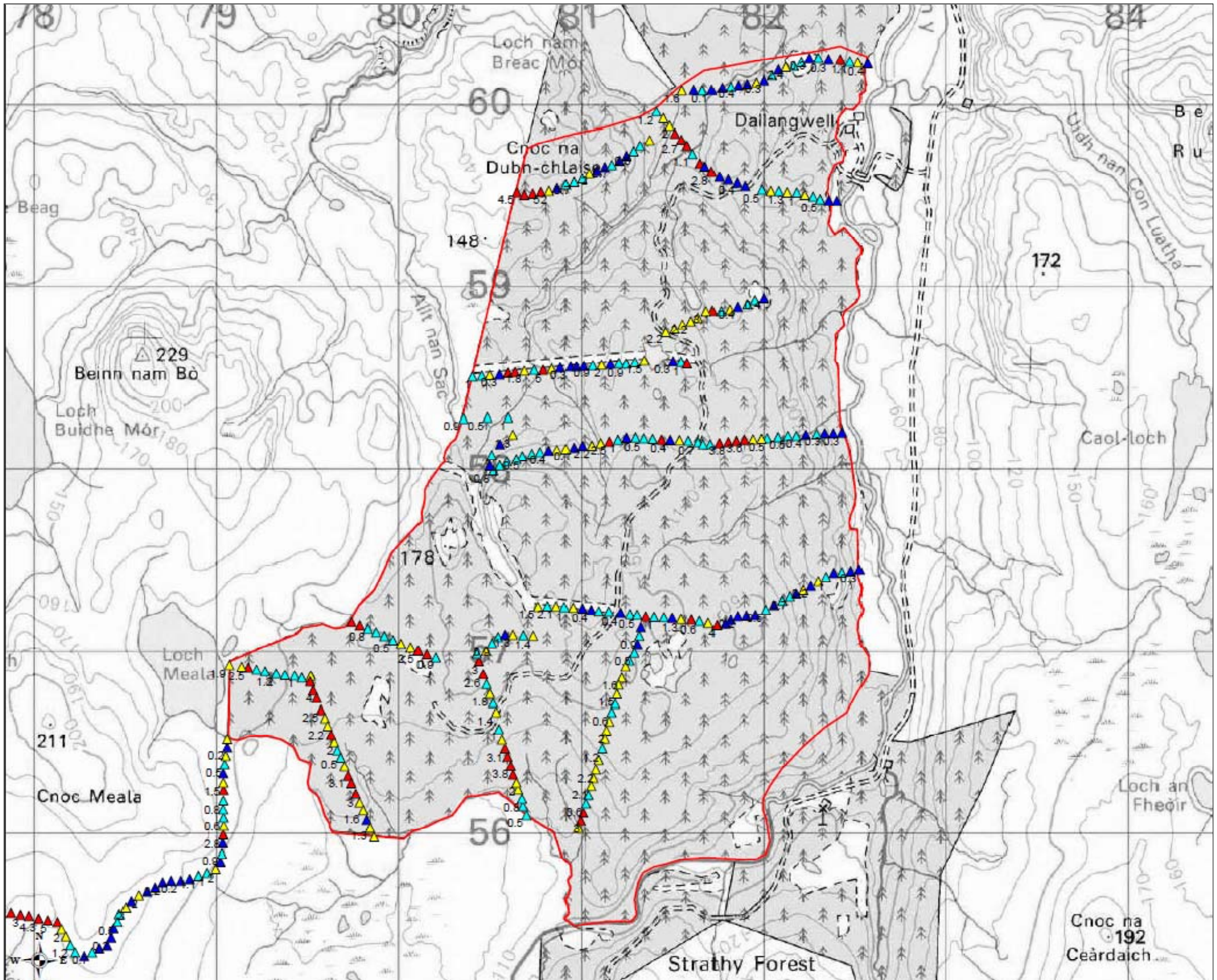
Constraint: Slopes > 10 Degrees



Constraint: Peat Depths



Peat depths: Survey results



Due to dense mature forestry on this site the preliminary peat probing survey work has been constrained mainly to rides.

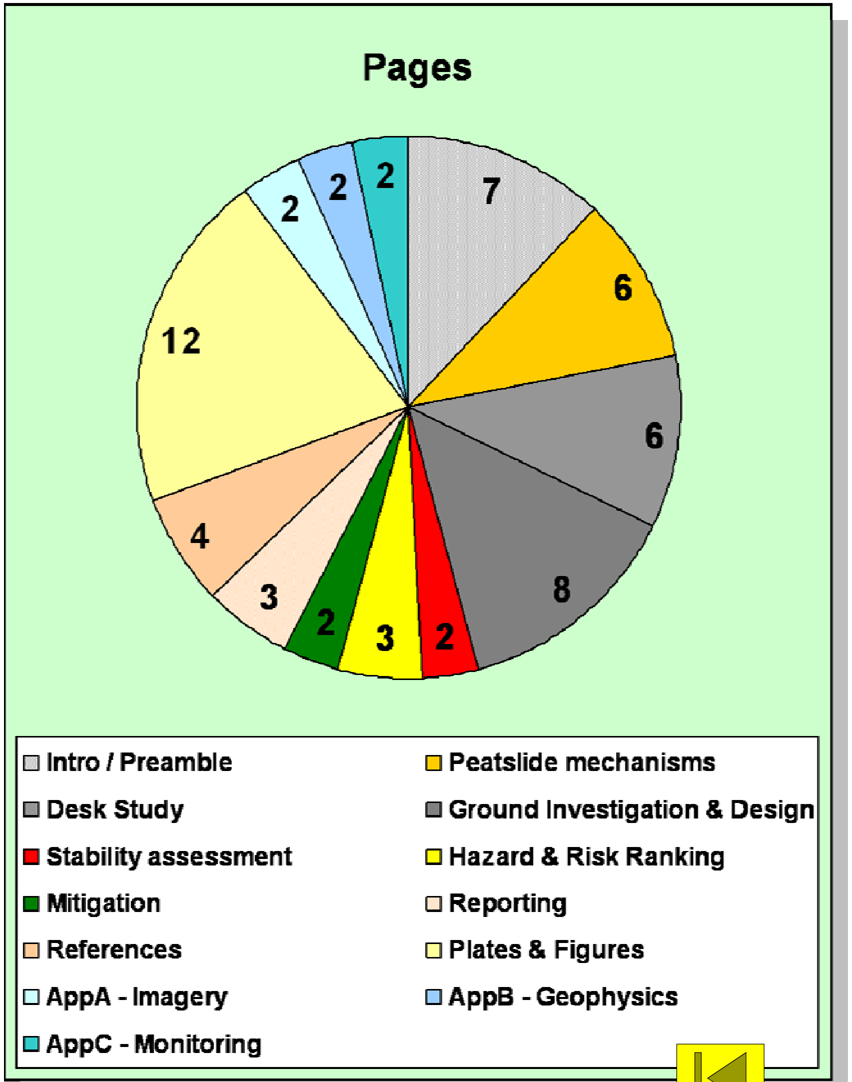
Anatomy of Scottish Government's "Peatslide Guidelines"

- **What do we expect of 'Guidelines'?**
- **Large proportion given over to descriptions:**
  - types of peatslide and illustrations
  - what a desk study may comprise
  - types of site / geophysical investigation
  - literature references

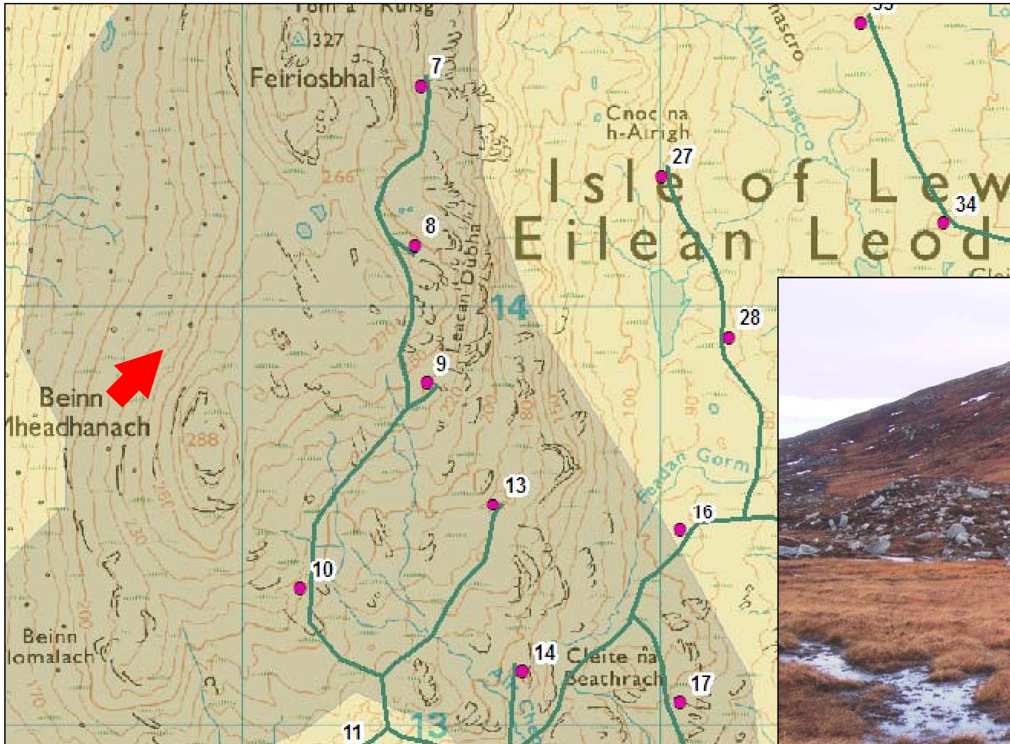
(all above textbook / academic in nature)

- **But very little on:**
  - stability assessment (Infinite Slope)
  - hazard / risk ranking (Matrix)
  - mitigation measures

(no examples of how these may be applied)

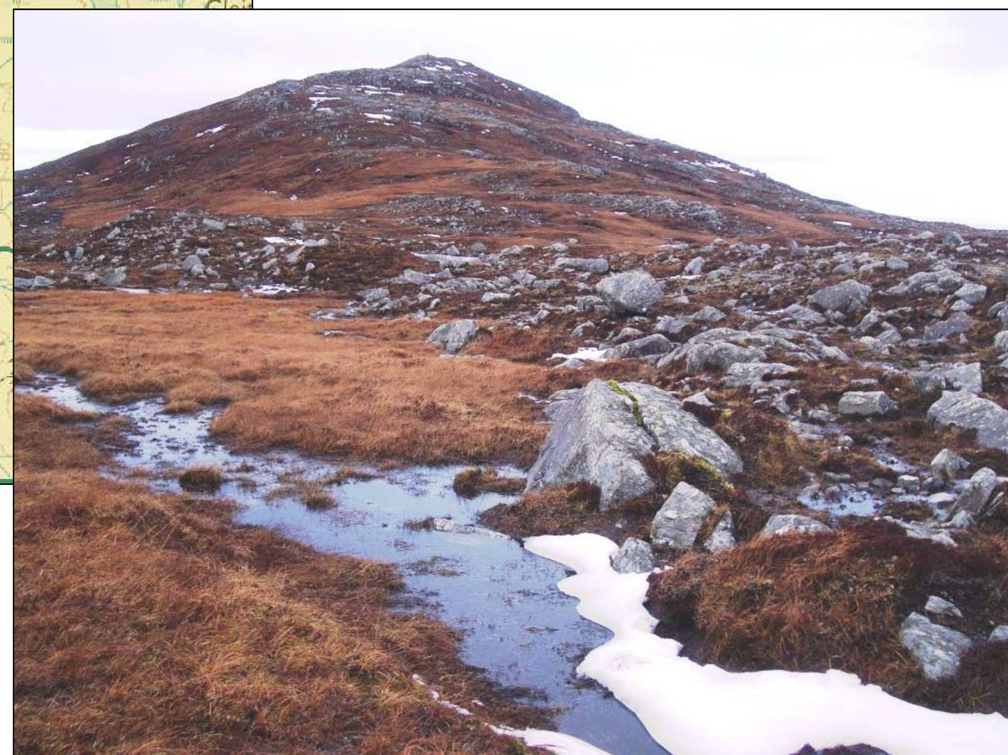


Soil Maps: Reality check



Described as Soil Type 394 – Peaty gleys, peat

Reality not a lot of soil and peat hard to find!



Fieldwork: Preparation / Equipment

- Overall site map with survey routes (poly-pocket)
- Detailed route maps with OS background (or aerial photo) (laminated)
- Garmin GPS pre-loaded with all survey points and other key locations (turbines / borrow pits etc)
- PDA and notebook just in case…
- Camera (but not with inbuilt GPS & Compass)

Observation: Tension cracks, Peatslides, Peat pipes, Erosion

Observation: Peat pipes

Observation: Erosion

mouchel

Peat (Russian) Corer: Interface / Decomposition (von Post), Bulk Density

In-situ Shear Vane Tests: Setting up the rig

Hand operated shear vane rig set up for a test.

Note adjacent probing rod to give initial indication of peat depth as sampling strategy depends on depth.

Tracked transport vehicle with extension rods etc behind.

In-situ Shear Vane Tests:

Close up of the head – which looks well used, but claims to be calibrated and the strain gauge looks new.

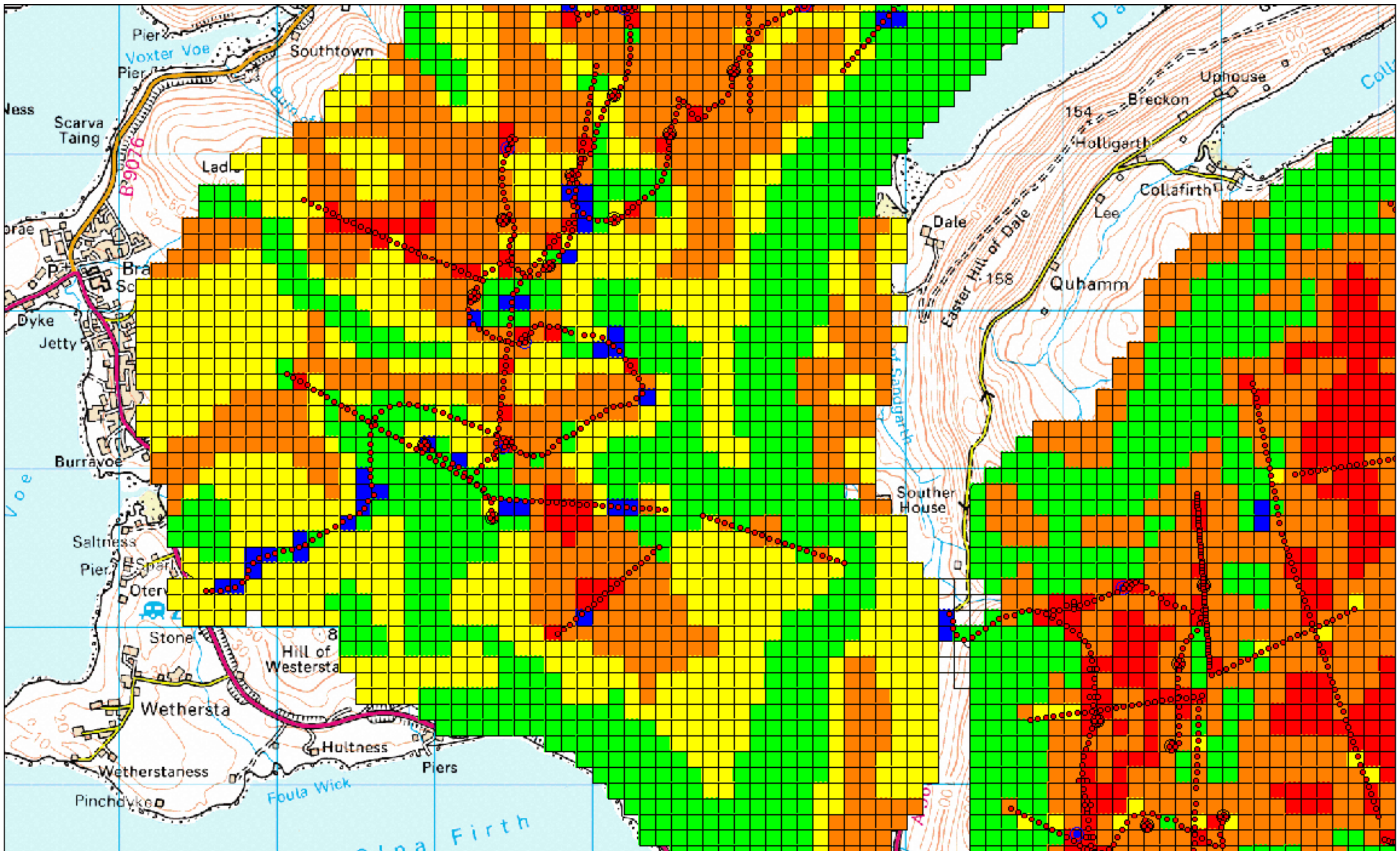
In-situ Shear Vane Tests: That sinking feeling…

The terrain can be deceptive and on a non-uniform surface the load may not be distributed evenly.

The track pressure of this Yanmar C30R is about the same as an average man standing on one foot.

But, a human can quickly redistribute weight between feet a vehicle is not quite so agile!

Indicative Peat Depth Maps (two passes)



Depth (m)	1	2
0.0 - 0.5		
0.5 - 1.0		
1.0 - 1.5		
1.5 - 2.5		
> 2.5		

Peat Depth Mapping: ‘Rules’ for indicative depths

- **GIS tools (linear / weighted / etc) interpolation not much good**
  - Current tools ignore topographic features eg slope / valleys / habitat
  - *(There is the potential for a post-graduate study here...)*
  - Okay for ‘guidance’ if combined with manual process below.

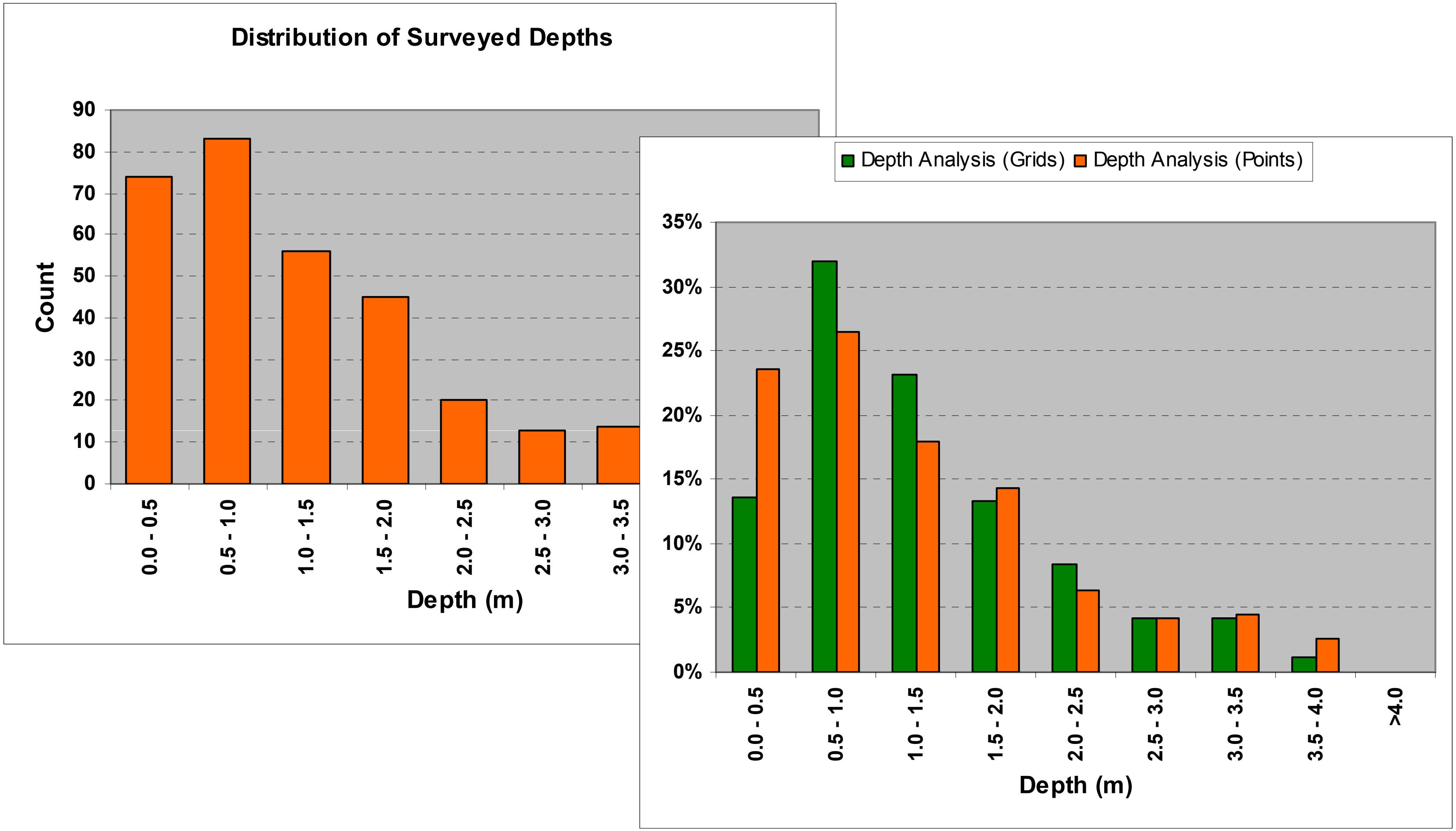
- **Manual cartographic approach**
  - Create a grid of suitable size (25m – 100m)
  - Define peat depth category intervals (typically 1.0m / 0.5m)
  - If grid has probing point(s) then assign max depth to cell
  - ‘Empty’ grid cells are assigned by moving outwards, trending towards next point but:

    if decreasing slope: marginal increase in depth

    if increasing slope: marginal decrease in depth

    but very steep slopes may have no peat
  - Use aerial photography to identify any likely step changes in habitat
  - Augment probing data with observation (cuttings / gulleys / road margins etc)

Peat Depth Mapping: Some checks



Methodologies

- **Geomorphological**
  - Mapping and field observation using expert opinion
- **Heuristic**
  - Subjective weighting and scoring of likely causative factors
  - Possible hybridisation of other methodologies
- **Physical**
  - Geotechnical Models (Infinite Slope Factor of Safety calculation)
- **Statistical**
  - Regression (of various types: numerical + categorical)
  - Sets (Unique Condition Units)
  - Neural Networks

Methodology Categorisation

	Geomorph-ological	Heuristic	Physical	Statistical
Quantitative		Attribute Scoring Schemes	Geo-technical Factor of Safety	Regressions Neural Networks
Qualitative	Mapping Observation	Logic lookup tables		

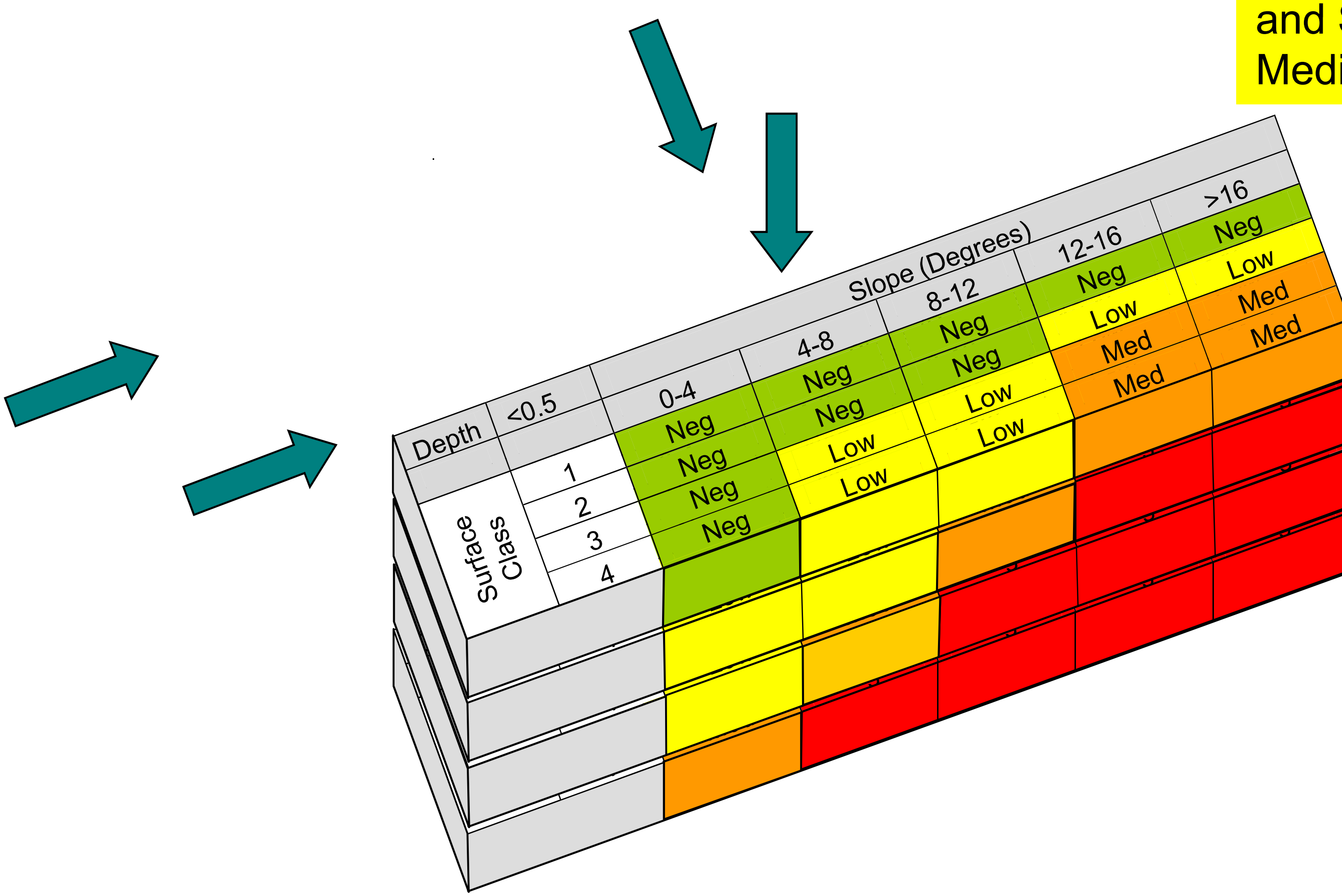
Attribute Scoring Schemes

Attribute	Values	Range
Peat Depth (first instance)	4	0 - 2
Relief	3	1 - 2
Exposure	4	1 - 3
Slope	5	0.05 - 2
Grade	4	1 - 2
Surface Loading	1	1
Peat strength	1	1
Peat stratification	1	1
Rainfall	1	1
Drainage	4	0.5 - 3
Subsurface hydrology	1	1
Peat Depth (second instance)	4	0 - 2
Evidence of instability	3	1 - 5

- 12 attributes or factors but 5 greyed out
- Greyed out factors recognised, but do nothing in assessment
- Each factor assigned a range of values
- Attributes combined through multiplication and 'score' can range from 0 – 288
- About 46,000 permutations, but hundreds give same score eg 6 = fn(240 permutations)
- Are all like scoring permutations really the same?

Simple Heuristic / Qualitative Three Factor Example

Example: If Depth 0.5-1.5 and Slope 8-12 degrees and Surface Class 3 then Medium Susceptibility



Surface Classification

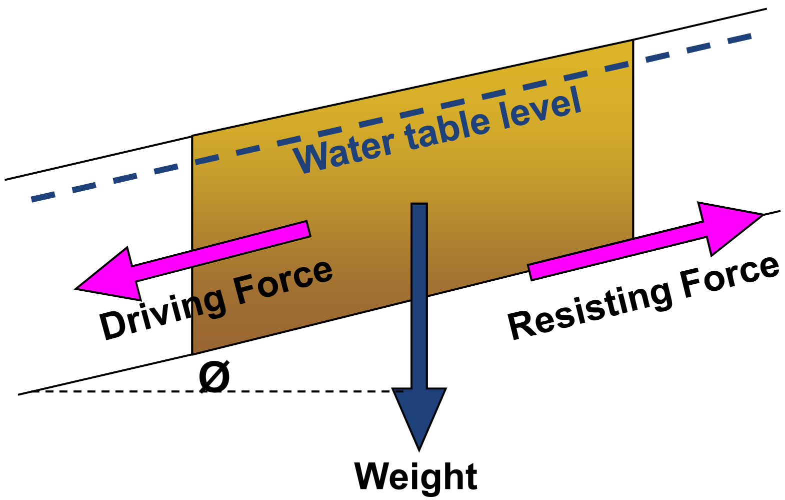
Class 1

Class 2

Class 3

Class 4

Quantitative Geotechnical Equation - Infinite Slope Model



Factor of Safety = Resisting Force / Driving Force

Resisting Force = (c' + (γ - mγw) z cos2β tanǿ)

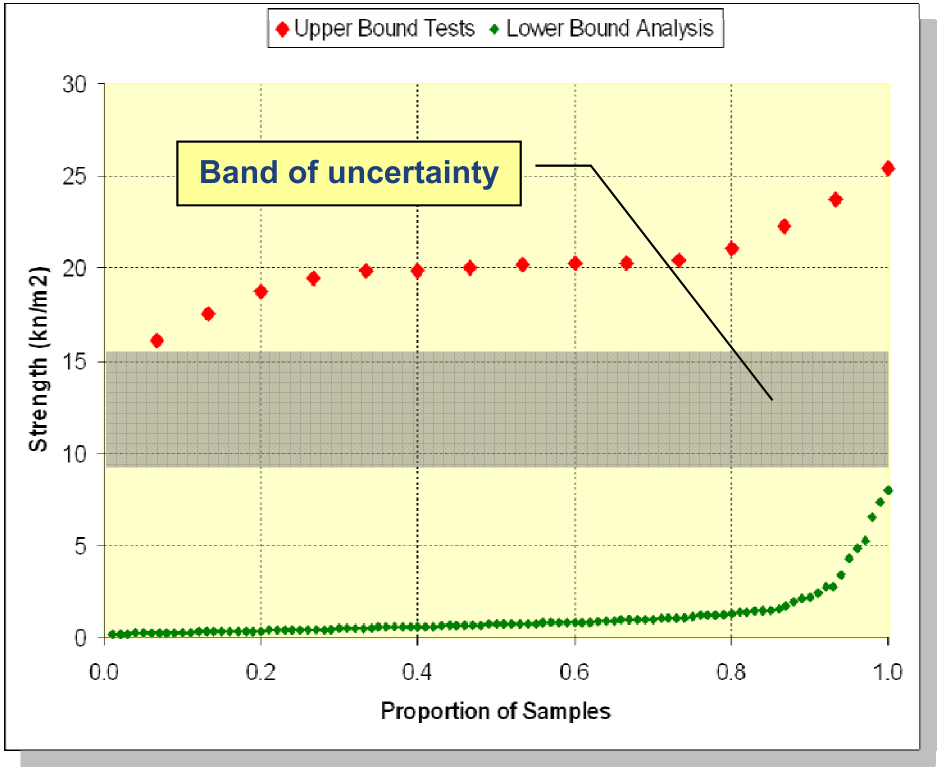
Driving Force = (γ z sinβ cosβ)

Where:

c'	(cohesive) shear strength [kN/m2]
γ	bulk density of peat [kg/m3]
γw	bulk density of water [kg/m3]
m	water table elevation as a ratio of peat depth [m]
z	peat depth perpendicular to slope [m]
β	slope angle [Degrees]
ǿ	angle of internal friction [Degrees]

Upper and Lower Bound Strength Estimates

- **Upper bound:**
  - results from Triaxial, Shear box or in-situ Vane test
  - strengths at failure and the results have a mean and normal distribution
  - additional samples extend max and min
  - ‘design’ value from lower tail of distribution
- **Lower bound:**
  - results from field observation of stable locations and back calculations
  - strength is minimum required to be stable at observed location
  - additional sample only increase max
  - ‘design’ value from upper tail of distribution



For all practical purposes it is reasonable to conclude that the maximum lower bound value will under-estimate the actual shear strength.

Scottish Government's 'Guideline' Method: The Process

Hazard over Lifetime		
Scale	Likelihood	Probability
5	**Almost certain**	**> 1:3**
4	**Probable**	**1:10 – 1:3**
3	**Likely**	**$1:10^2$ – 1:10**
2	**Unlikely**	**$1:10^7$ – $1:10^2$**
1	**Negligible**	**< $1:10^7$**

X

Exposure over Lifetime		
Scale	Exposure	Impact as % of project cost or time
5	**Extremely high impact**	**> 100% of project**
4	**Very high impact**	**10% - 100%**
3	**High impact**	**4% - 10%**
2	**Low impact**	**1% - 4%**
1	**Very low impact**	**< 1% of project**

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Insignificant				**Significant**						**Substantial**						**Serious**								

Hazard Ranking

‘Guideline’ Method: Conceptual Conundrums

- **Assessment process for ‘Hazard’ & ‘Exposure’ values not defined - left to ‘technically competent persons’**
- **Impact (as %) disadvantages smaller schemes**
- **Scoring scheme has numerical gaps – implications?**
- **Commutative arithmetic and equivalent scores**

<table>
<tr><th>Hazard</th><th>Exposure</th><th>H x E</th><th>Question</th></tr>
<tr><td>4 Probable</td><td>1 Very Low</td><td>4</td><td rowspan="3">Some ‘value’, but are these really all the same consequence or risk ?</td></tr>
<tr><td>1 Negligible</td><td>4 Very High</td><td>4</td></tr>
<tr><td>2 Unlikely</td><td>2 Low</td><td>4</td></tr>
</table>

‘Likelihood’ definition criteria (abbreviated)

	Regional Context	Local Context
Almost certain	–The wider region (if of similar condition units to study area) has several historic and recent past landslides –Study area has several historic and recent past landslides	**–FoS (from back calculation c’) <1.0** –FoS (from vane test c’) 1.0 to 1.3 **Ancillary considerations:** –Locally, indications of incipient instability such as tension cracks, bulges, misaligned fence lines or trees etc
Probable	–Study area has an historic or recent past landslide	**–FoS (from back calculation c’) is 1.0 to 1.3** –FoS (from vane test c’) is 1.3 to 2.0 **Ancillary considerations:** –Locally, indications of incipient instability such as tension cracks, bulges, misaligned fence lines or trees etc.
Likely	–Study area has an historic or recent past landslide	**–FoS (from back calculation c’) is 1.3 to 2.0** –FoS (from vane test c’) is 2.0 to 3.0 **Ancillary considerations:** –Locally, no adjacent indications of incipient instability but some on site
Unlikely	–Study area has no evidence of past landslides	**–FoS (from back calculation c’) is 2.0 to 3.0** –FoS (from vane test c’) is 3.0 to 4.0 **Ancillary considerations:** –Locally, no indications of incipient instability
Negligible	–Wider region (if of similar condition units to study area) has no historic and recent past landslides –Study area has no evidence of past landslides	**–FoS (from back calculation c’) is > 3.0** –FoS (from vane test c’) is > 4.0 **Ancillary considerations:** –Locally, no indications of incipient instability

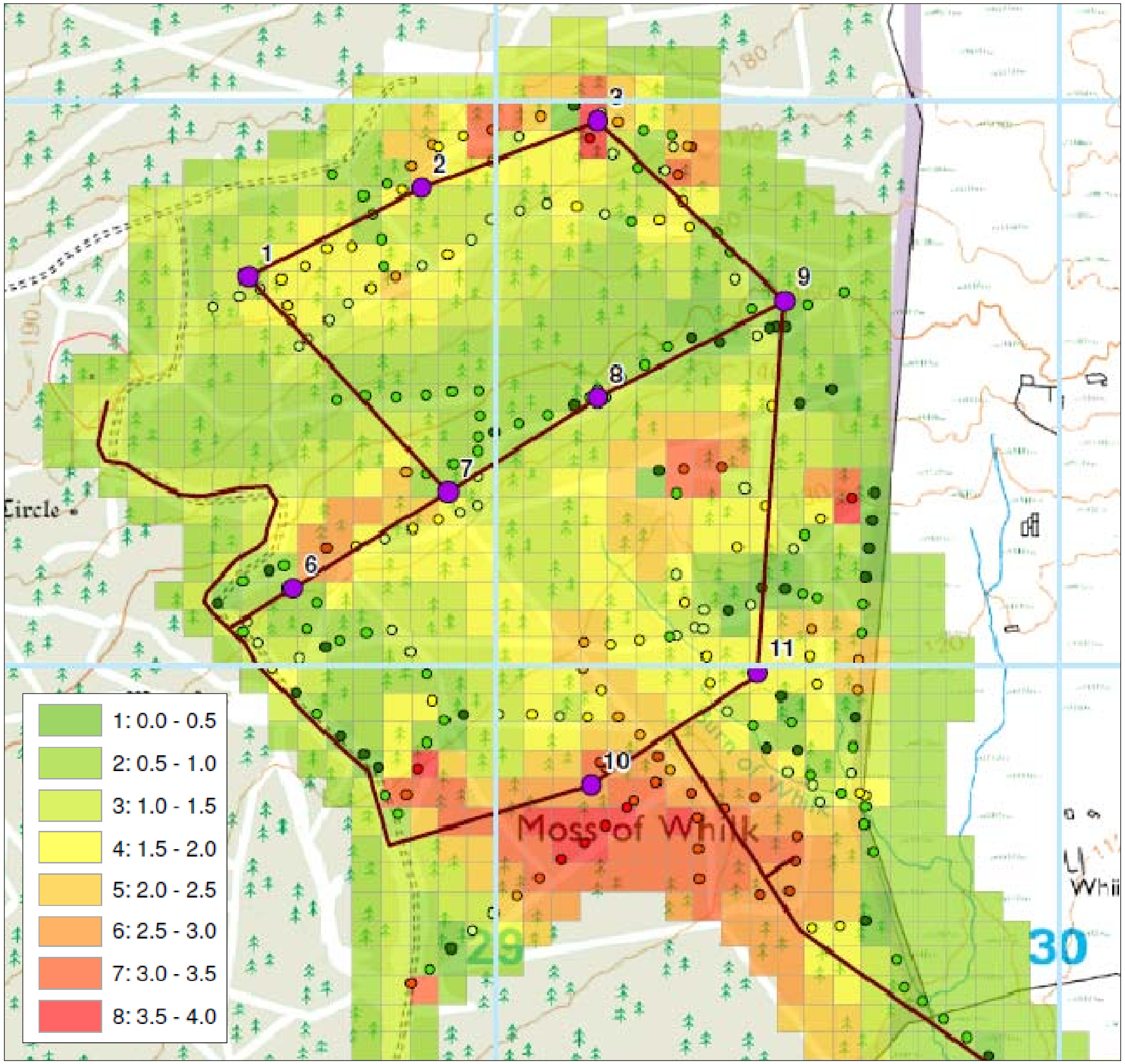
‘Exposure’ definition criteria (abbreviated)

	Habitat	Internal / Site Infrastructure	Public / Private Infrastructure
Extreme impact	– Large loss / damage to valued terrestrial and/or aquatic habitat	– Loss of operational substation and/or control building	– Impact on property: domestic public building or business. – Impact on public utilities (water, gas, electricity, telecoms, etc)
High impact	– Medium loss / damage to valued terrestrial and/or aquatic habitat – Large loss of commercial mono-culture	– Loss of operational turbine	– Impact on major (‘A’ / ‘M’) roads or bridges – Impact on private utilities (probably only water / wastewater)
Moderate impact	– Small loss / damage to valued terrestrial and / or aquatic habitat – Medium loss of commercial mono-culture – Large loss / damage to common terrestrial and / or aquatic habitat	– Loss / severance of a section of access track or bridge – Interruption to construction	– Impact on minor / rural roads or bridges.
Low impact	– Small loss of commercial mono-culture – Medium loss / damage to common terrestrial and / or aquatic habitat	– Blockage to section of access track	– Impact on open parkland / footpaths
Negligible impact	– Small loss / damage to common terrestrial and / or aquatic habitat	– No damage to assets	– No damage to assets

Likelihood & Exposure Combination

		Exposure Impact				
		Ext High	High	Moderate	Low	Very Low
Likelihood	Almost certain	Serious	Serious	Substantial	Significant	Insignificant
	Probable	Serious	Substantial	Substantial	Significant	Insignificant
	Likely	Substantial	Substantial	Significant	Insignificant	Insignificant
	Unlikely	Significant	Significant	Insignificant	Insignificant	Insignificant
	Negligible	Significant	Insignificant	Insignificant	Insignificant	Insignificant

Mouchel Peatslide Susceptibility Assessment: Steps 1 & 2



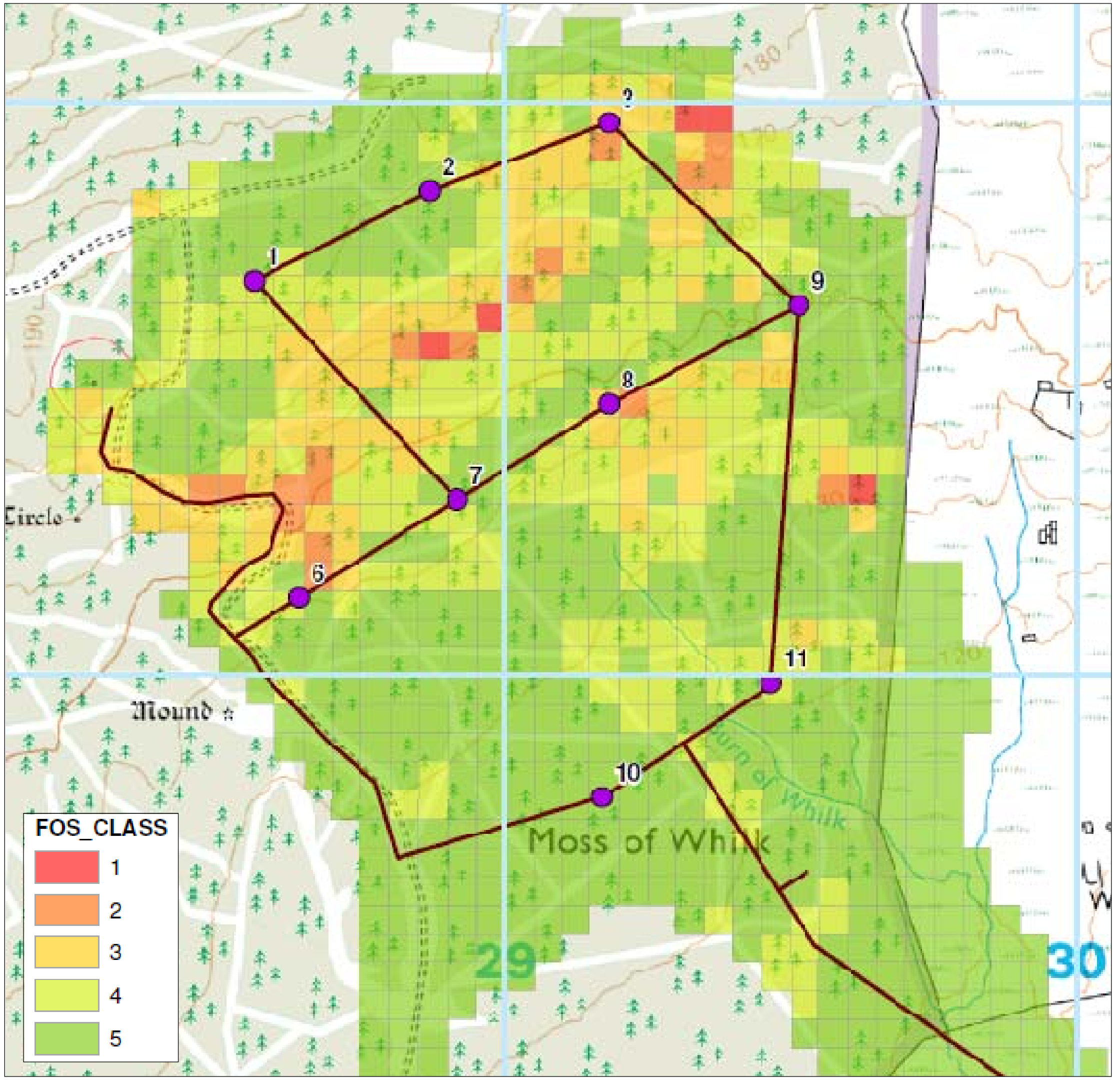
Step 1 (Depth Map)

From peat depth survey (points) develop an indicative peat depth map

Step 2 (Shear Strength)

From peat depth survey (points) and DTM back calculate lower bound shear strength for each location

Mouchel Peatslide Susceptibility Assessment: Steps 3 & 4



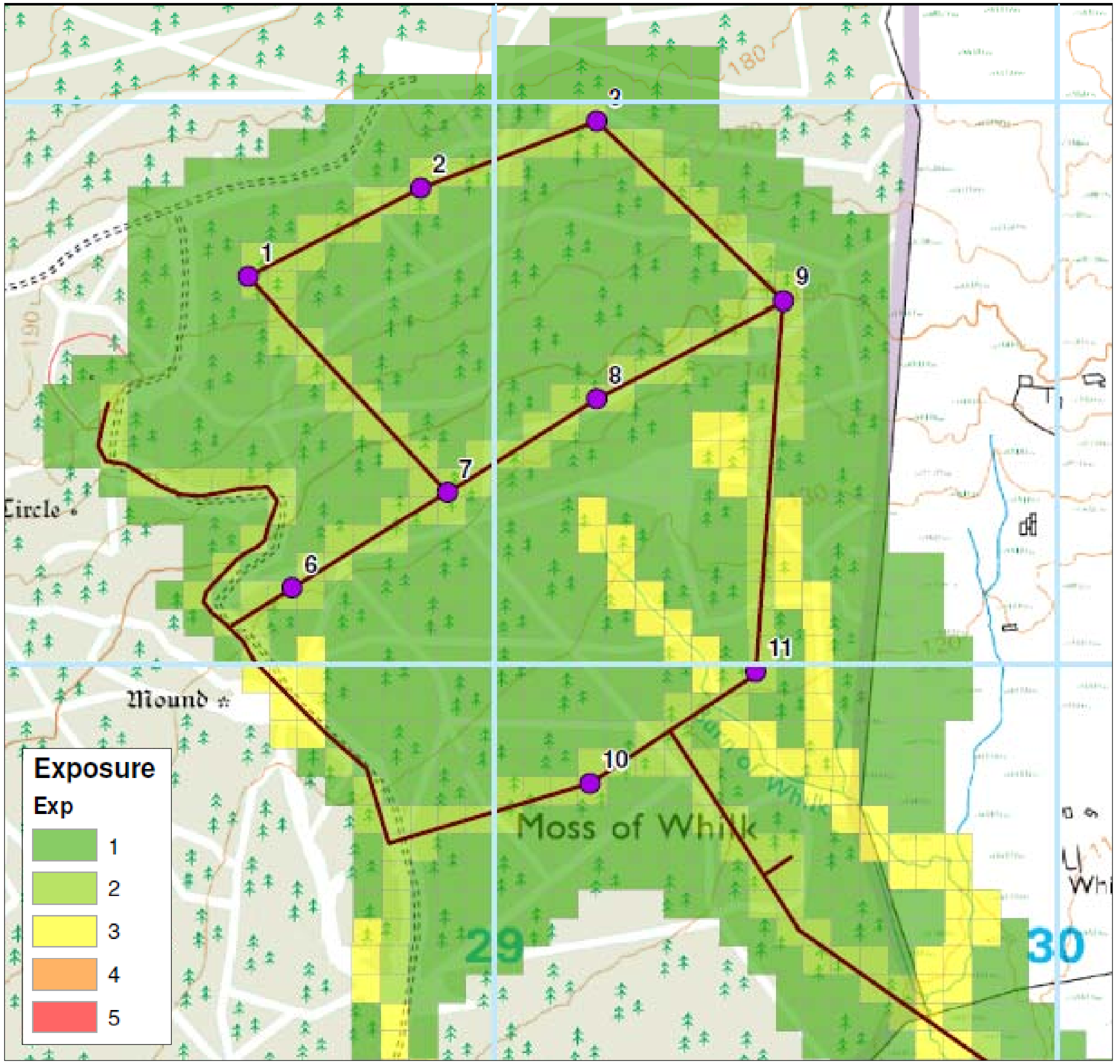
Step 3 (Factor of Safety)

For each grid cell calculate Factor of Safety (Infinite Slope Model). The main variables are DTM slope, peat depth, bulk density and shear strength.

Step 4 (FoS Classes / Likelihood)

Assign the FoS values to five FoS Classes which correspond to the five 'Guidelines' Likelihood levels of risk.

Mouchel Peatslide Susceptibility Assessment: Step 5



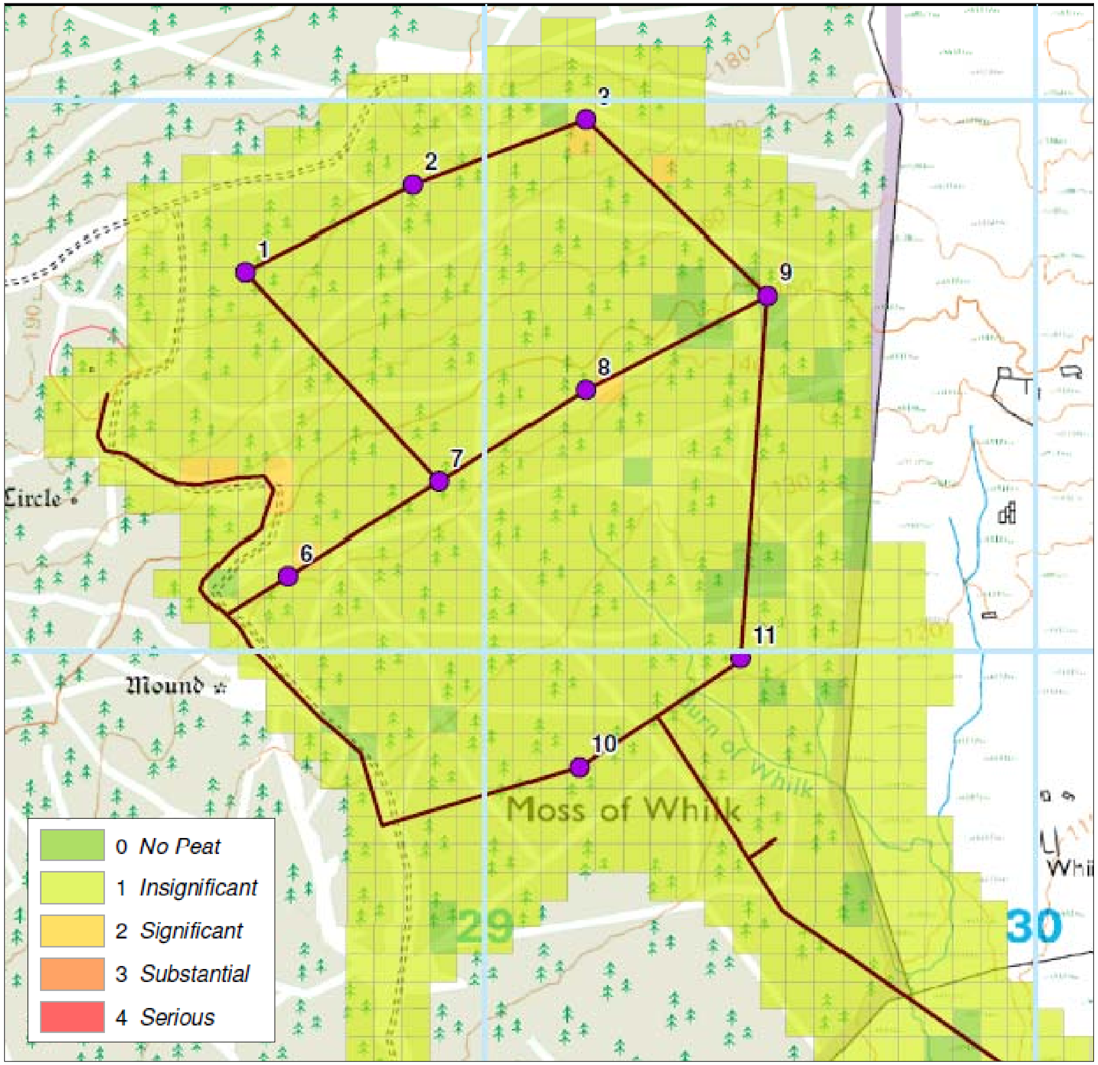
Step 5 (Exposure)

By buffering certain types of feature (eg access tracks, turbines, public roads, properties etc) identify grid cells that fall within these buffers.

Manually add / remove other cells as thought appropriate.

Assign five Exposure classes which correspond to the five levels in the ‘Guidelines’.

Mouchel Peatslide Susceptibility Assessment: Step 6



Step 6 (Hazard Rank)

For each grid cell combine the 'Likelihood' value and the 'Exposure' value to give the Hazard Rank.

Four levels: Insignificant - Significance.

<u>Note:</u>

In this example there are some cells with no peat (ie <0.5m) so are ignored.

Also, no Serious or Substantial conditions were identified. Had there been any a further more detailed assessment would be undertaken.

Miscellaneous Slides

Spare Slides

Final Steps: Exposure, EIA context, Risk Register

- **Combined Assessment Matrix has identified the areas of highest susceptibility**
- **Reject grid cells not relevant to windfarm footprint**
- **For candidate grid squares:**
  - estimate potential slide direction, volume, distance and receptor
  - possibly undertake further localised fieldwork
- **For each potential incident consider impact in 'EIA language':**

  not significant OR significant

- **For each potential incident consider mitigation measures and reassess impact post mitigation**
- **Tabulate details in the form of a Risk Register and summarise findings.**

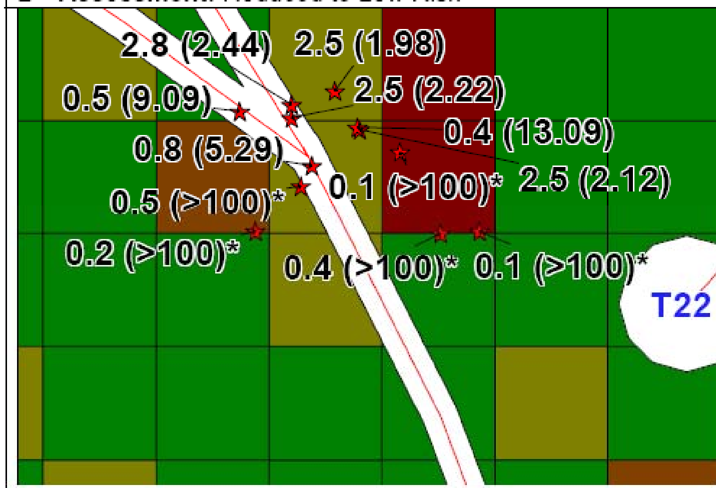
Detailed Assessment Area 2

See Drawing 5 for site location

Location: – near junction to TA21

1st **Assessment:** Combined Risk Assessment - Moderate

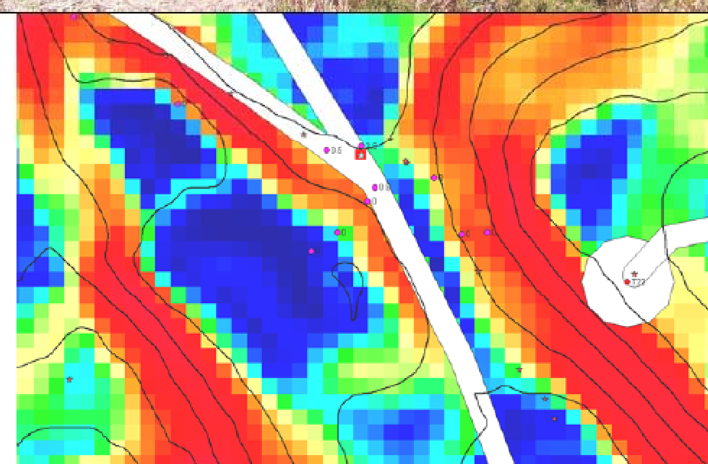
2nd **Assessment:** Reduced to Low Risk



The cells are coloured according to the 1st assessment of FoS, the numbers show peat depth and FoS from the 2nd assessment (in brackets)
** Calculations performed for soil, where peat depth is zero.*

Discussion:
This area lies towards the northwest end of a saddle between two hill tops about 450m apart. The high risk cells (above) are at the base of the northeast top where the hillside is steep (as illustrated in photo) and this strongly influences the mean slope for the grid cells used in the initial FoS calculations. However, at the deepest peat location (2.8m) the ground has little slope and on the slopes there is only shallow soil and no peat. In summary, the deeper peat is very fibrous, localised and constrained by topography. It is possible that short lengths of floating road may be used over the deeper peat. The FoS calculations do not suggest any risk of a peat slide developing.

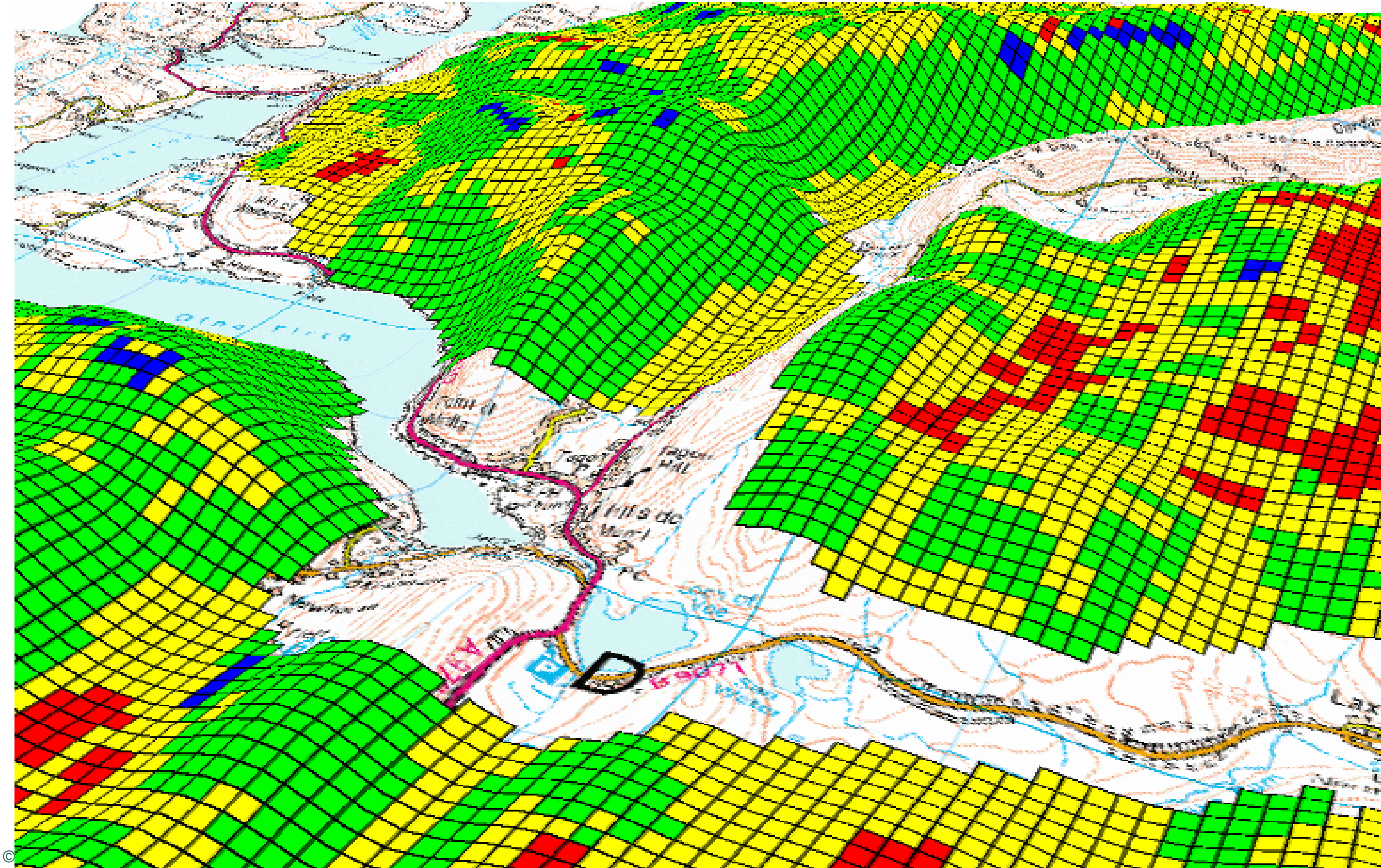
The steep slopes are indicated by red and the flat areas by blue. This is also shown by the 5m interval contour lines. The access track and junction to TA21 lies in a saddle. The steeper slopes have a cover of shallow soils about 0.2m deep.



Philosophy of Qualitative – Quantitative Assessment

	Qualitative	Quantitative
Area Covered	wide area - whole site	small area – localised feature
Techniques	causative factors in combination	mathematical formulae based model
Parameters	topography, hydrology, geology, photography, vegetation, judgement	material properties, problem geometry, loadings
Output	relative risks displayed in a spatial context	factor of safety for a specific cross-section
Applications	risk zone avoidance layout planning mitigation planning	embankment design excavation stability check road cutting stability check
	"JUDGEMENT"	"ENGINEERING"

Indicative Peat Depth



Qualitative Assessment – Pictorial Output