DR VANESSA BANKS FOR BGS LANDSLIDE RESEARCH COLLEAGUES

Landslide susceptibility modelling in a changing climate

British Geological Survey

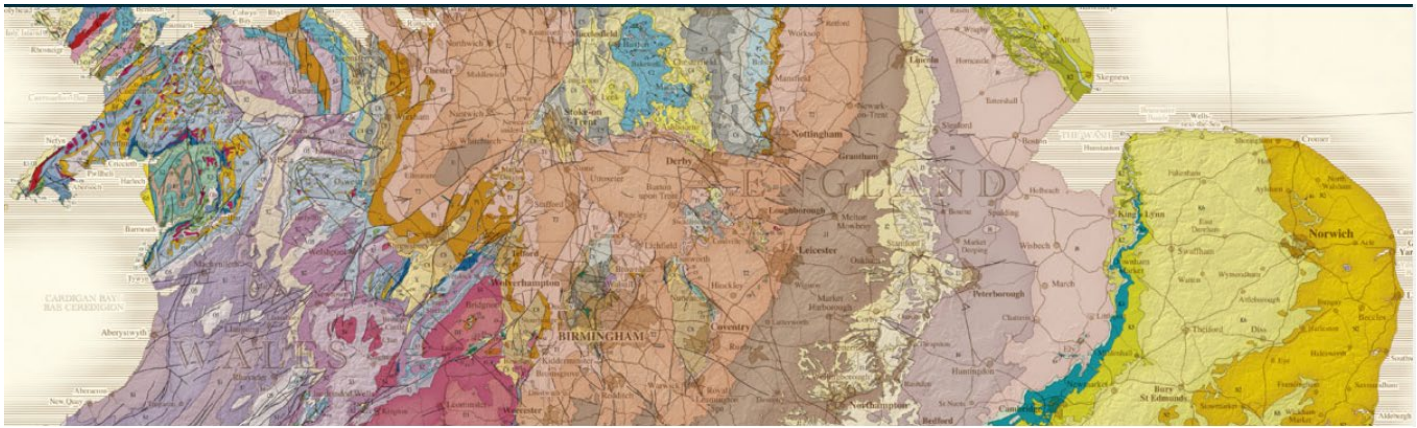
Presentation content

- Introduction to BGS and the GeoSure product
- Heuristic, deterministic and statistical approaches
- Soil and rock responses to climate change
- BGS clay shrink-swell potential and GeoClimate
- Landslide processes and susceptibility modelling
- Climate change induced triggering processes
- Climate change induced landslide processes
- Climate change and reactivation of landslides
- Anthropogenic change and the feedback to climate change
- Geoclimate data and model validation

SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

Introduction to BGS and the GeoSure product

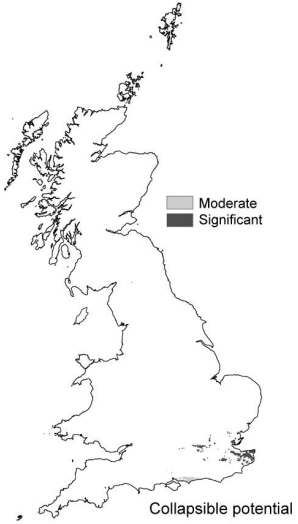
Introduction to BGS

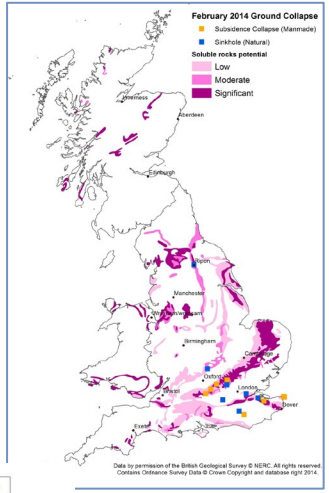


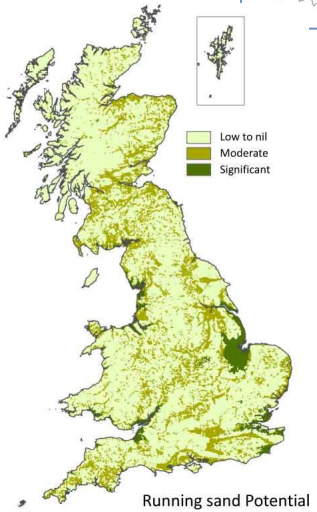
- World-leading geological survey & global geoscience organisation, focused on public-good science for government and research to understand earth and environmental processes.
- We are the UK's premier provider of objective and authoritative geoscientific data, information and knowledge to help society to use its natural resources responsibly, manage environmental change and be resilient to environmental hazards.

GeoSure

- The BGS GeoSure national datasets provide geological information about potential ground movement or subsidence that can help planning decisions.
- Largely heuristic
- Insurance –driven
- 1:50 000 to national scale
- Subject to climate change updating







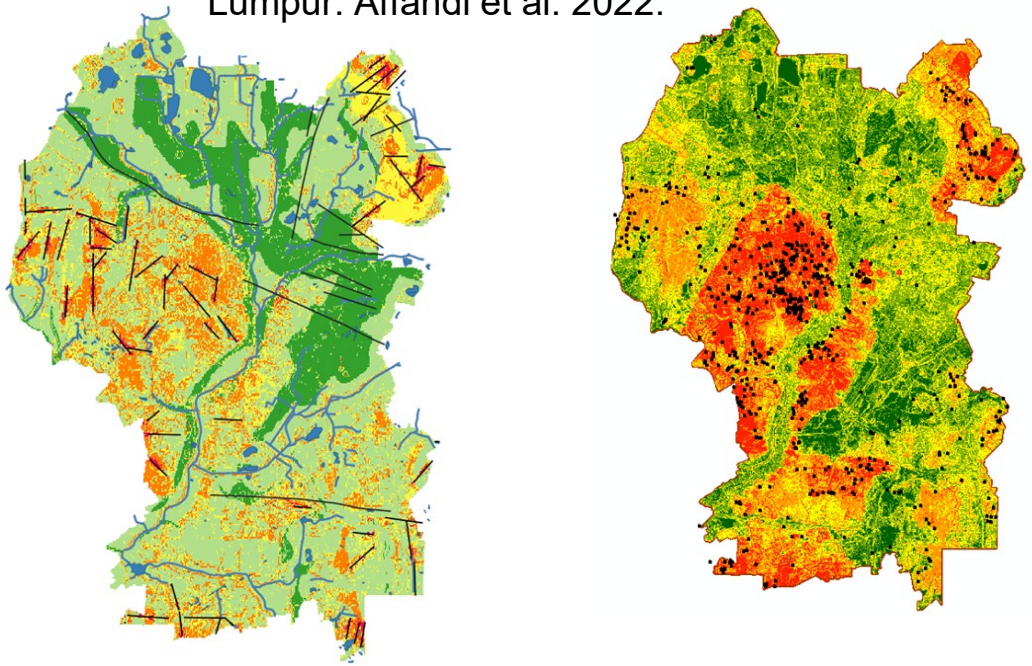
SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

Heuristic, deterministic and statistical approaches

Susceptibility modelling

- Heuristic
- Data driven statistical (bivariate, multivariate or machine learning)
- Deterministic

Heuristic and statistical approaches to landslide susceptibility for Kuala Lumpur. Affandi et al. 2022.



Base data with knowledge left and data right

Landslide susceptibility modelling approaches

- A review of statistically based approaches (**Reichenbach et al., 2018**. Earth-Science Reviews); data developed under the Lampre project
- GIS and earth observation hosted approaches, e.g. **Domazetovic et al. (2019**; J of Physical Geography) applied to gully erosion and comparable with the approach taken by **Bee et al. (2019**; Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2019-54) and described later in the presentation.
- Bivariate statistics **van Westen et al., 2006**) adopted by **Daniel et al. (2021)** in conjunction with heuristic approaches for Canada Hill, Sarawak, Malaysia
- AI approaches: A review of AI approaches (**Merghadi et al. 2020**; Earth-Science Review) applied to a case study from Algeria favoured tree-based ensemble algorithms and as for **Pham et al. (2018**; Civil Engineering and Environmental Systems) Random Forest tree algorithms were found to be most reliable, in the case applied to landslides in the Luc Yen district of Northern Vietnam.
- The reliability of deterministic methods is very scale dependent.

SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

Soil and rock responses to climate change

CC impacts on mass movement processes in soil & rock

- Precipitation (amount and intensity)
- Temperature
- Wind
- Extremes
- Energy and coastal surge
- Barometric pressure

- Erosion
- Subrosion, e.g. piping
- Changes to soil water content
- Soil smearing and changes to recharge
- Changes to groundwater conditions more extremes
- Soil swelling and shrinkage
- Changes in the unsaturated zone, e.g. capillary rise, reorganisation of grains
- Desiccation and shrinkage
- Thermal expansion and contraction
- Crack development and fatigue
- Accelerated coastal tension and undercutting; including due to flooding

Translation to geotechnical property changes

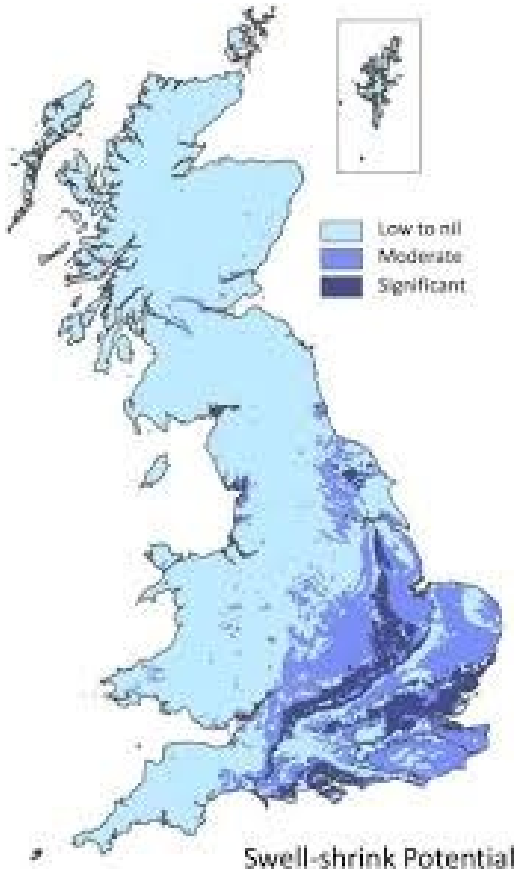
- Soil water content
- Grain-size
- Cohesion
- Friction angle
- Soil suction
- Swelling pressures

SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

Clay shrink-swell potential

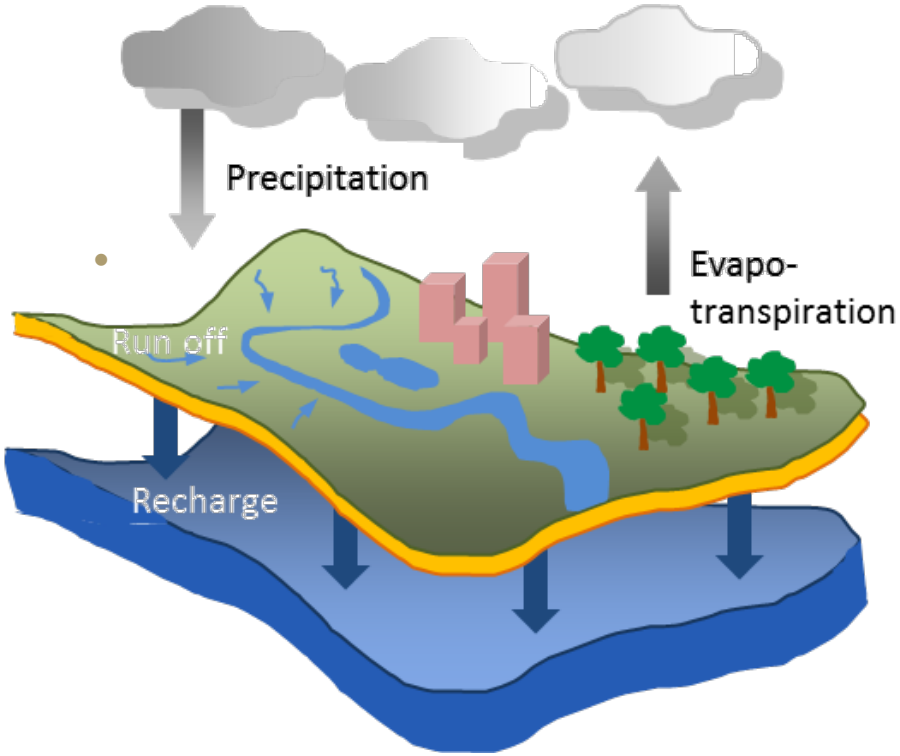
Clay shrink-swell potential

- Heuristic with deterministic component
- Atterberg limits
- Shrinkage potential
- Volume change potential



Relating shrink-swell to climate

- Soil Moisture Deficit (**SMD**) is used to assess how wet or dry the ground is
- Apply the ***BGS ZOODRM*** groundwater recharge model to assess the potential SMD over a 2 km grid
- Input variables for SMD:
  - Estimated rainfall
  - Potential evapo-transpiration
  - Soil type
  - Land cover
  - Terrain
  - Surface runoff potential



Combine Days in drought with GeoSure

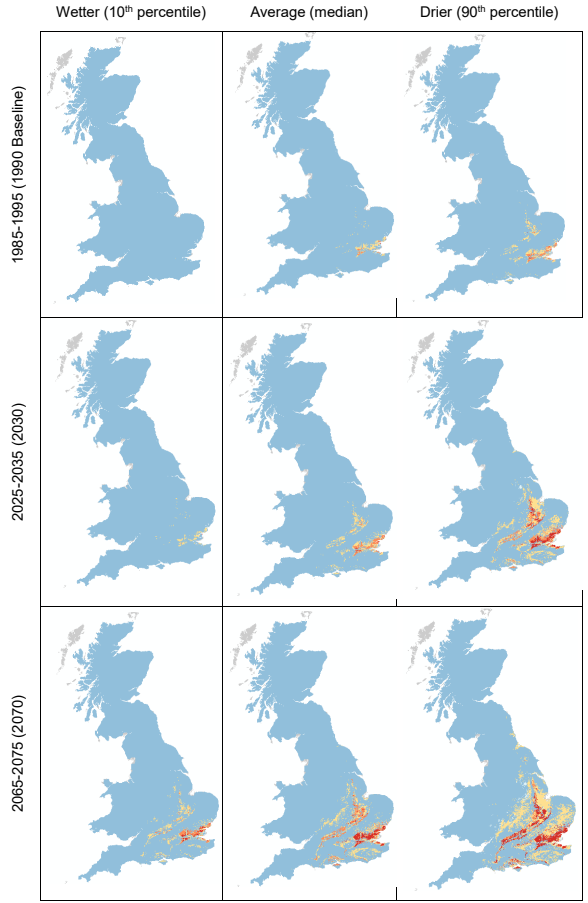
		GeoSure IP' Value				
		<10	10-20	20-40	40-60	>60
		A	B	C	D	E
Days in Drought Score	1	A1	B1	C1	D1	E1
	2	A2	B2	C2	D2	E2
	3	A3	B3	C3	D3	E3
	4	A4	B4	C4	D4	E4
	5	A5	B5	C5	D5	E5

Product outputs

Colour (used in legend)	Susceptibility description
Blue	It is 'highly unlikely' that foundations will be affected by increased clay shrink-swell due to climate change.
Light Blue	It is 'unlikely' that foundations will be affected by increased clay shrink-swell due to climate change.
Yellow	It is 'likely' that foundations will be affected by increased clay shrink-swell due to climate change.
Orange	It is 'highly likely' that foundations will be affected by increased clay shrink-swell due to climate change.
Red	It is 'extremely likely' that foundations will be affected by increased clay shrink-swell due to climate change.
Grey	Input datasets are unavailable.

Wetter – Median – Drier

Projection period 10 years around 2070, 2030, 1990



SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

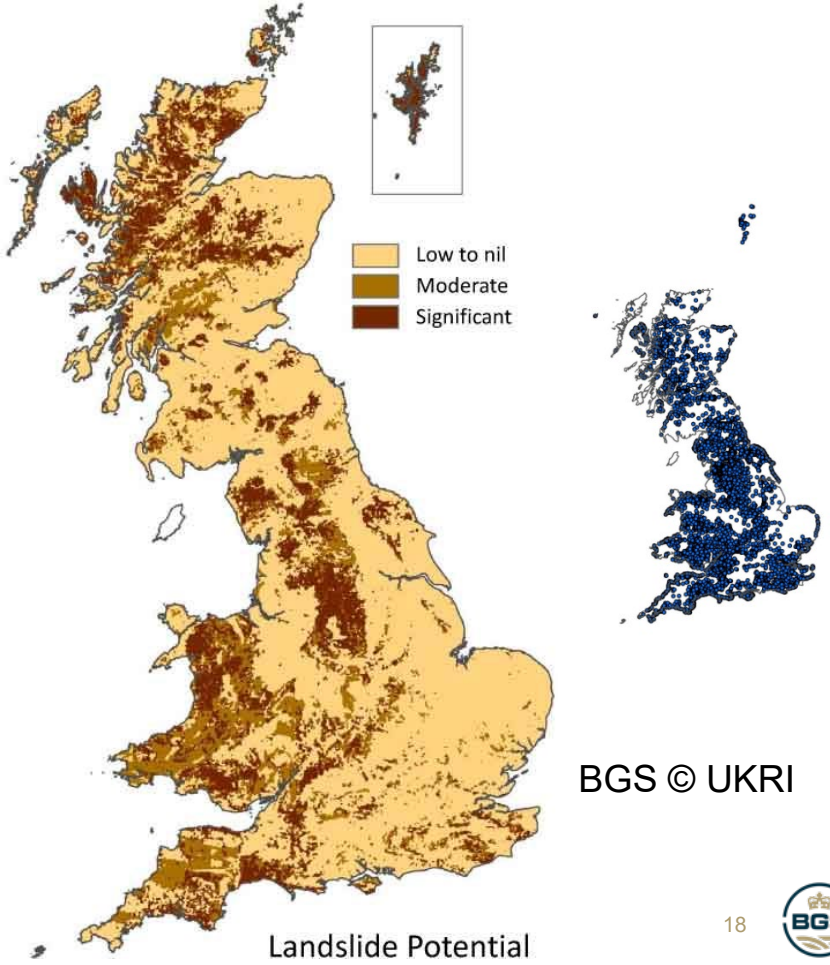
Landslide processes and susceptibility modelling

GeoSure modelling - landslide

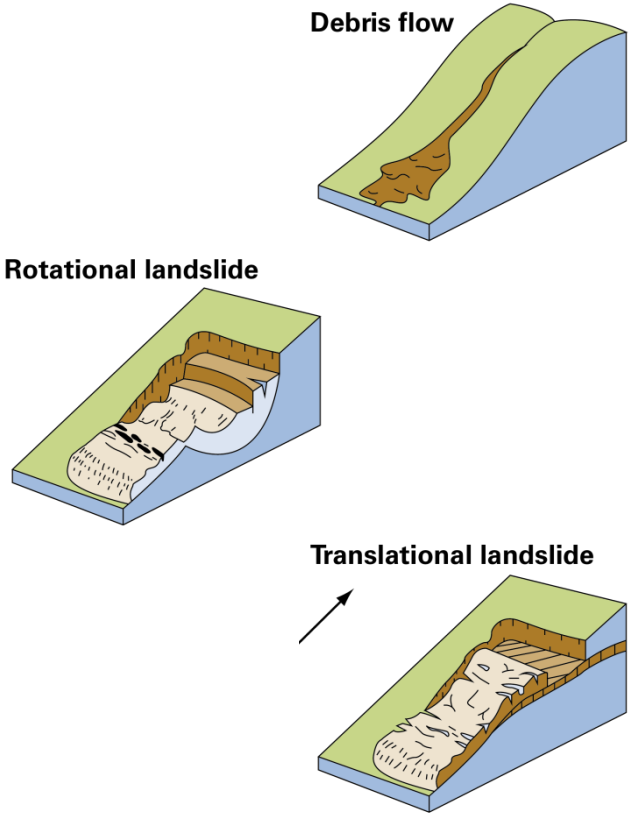
GeoSure Product

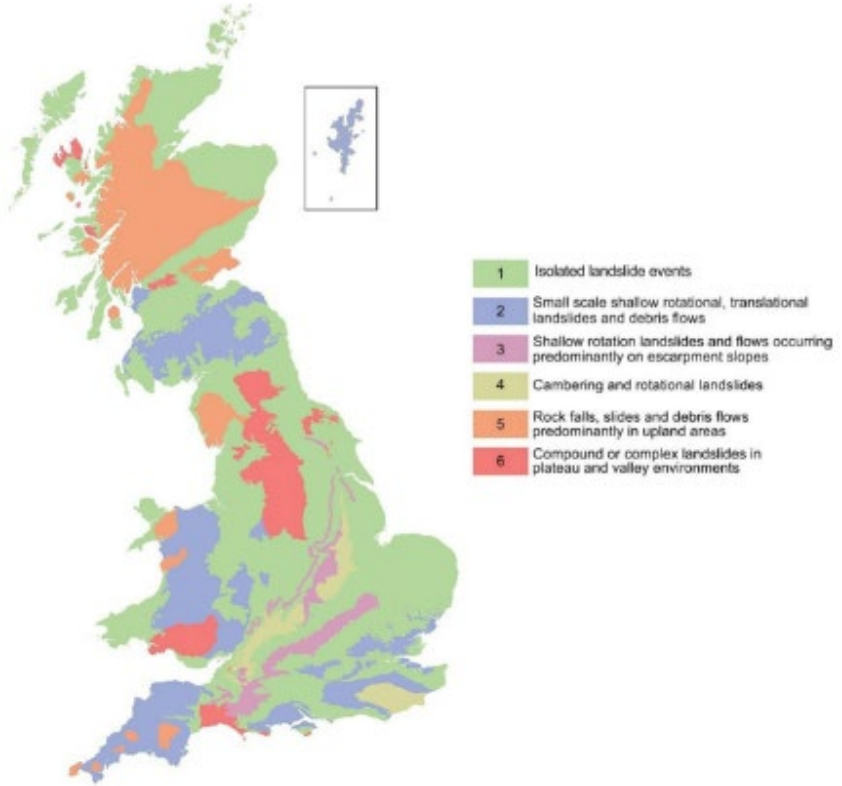
- Topography
- Geology and lithology
- Geomorphology
- National geotechnical database
- Expert knowledge – heuristic approach with much underpinning knowledge from the National Landslide Database (NLD)

Accessible via Open Access and Licence reflected in resolution



Landslide susceptibility - by landslide type and or domain





Debris flow modelling example

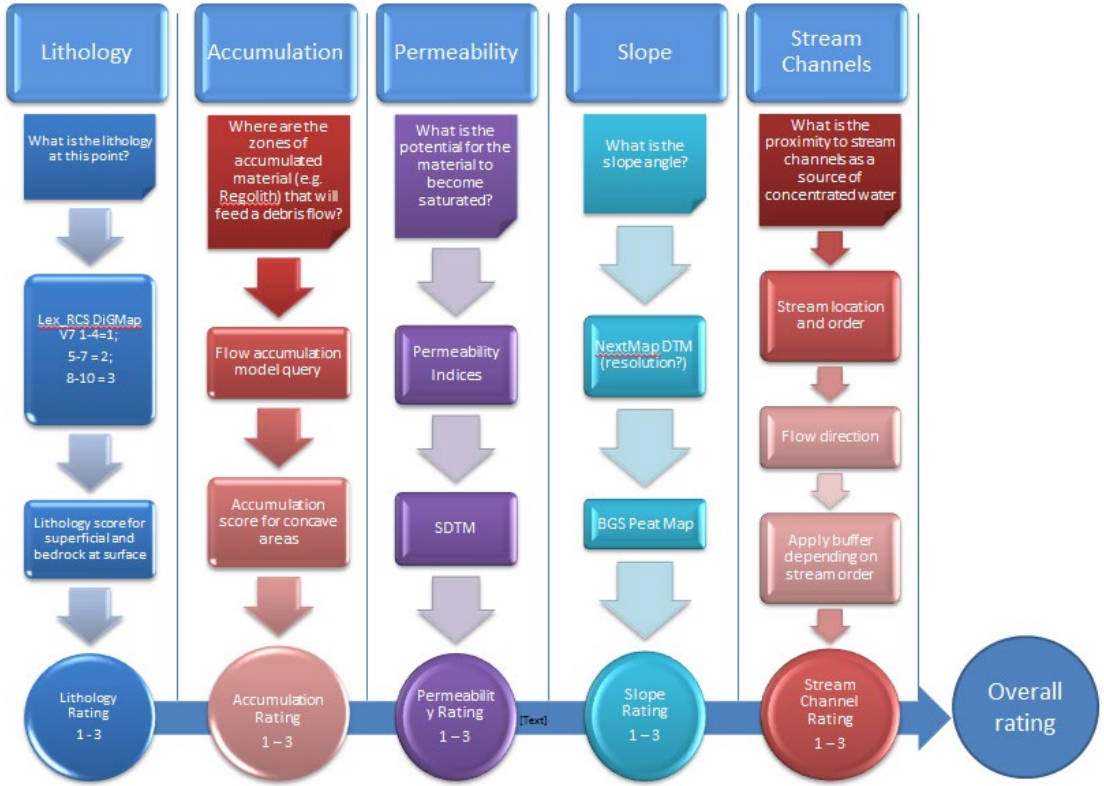
- Characteristic of mountainous regions of Scotland, Wales and the Lake District
- Debris flow: rapid downslope flow of poorly sorted debris mixed with water
- Debris flow: tracks of individual flows
- Flows at velocities of several m/s
- Water content rarely > 10-30% by weight
- Water and debris move *en masse*
- Momentum of flow maintained by inter-particle collisions and partial buoyancy in the “mud”
- Viscosity influences runout form

Main Characteristics of a debris flow on A83 Cairndow

(http://www.gov.scot/Publications/2005/07/08131738/17507)

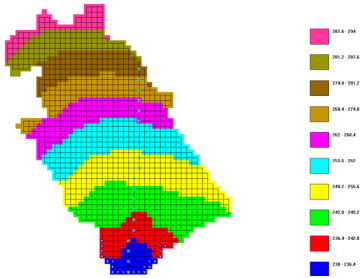
Debris flow susceptibility

- Consider process and data representation
- Non-availability of data of a required scale precluded some datasets, e.g. vegetation
- Balance the weighting in the algorithm
- Good datasets for validation



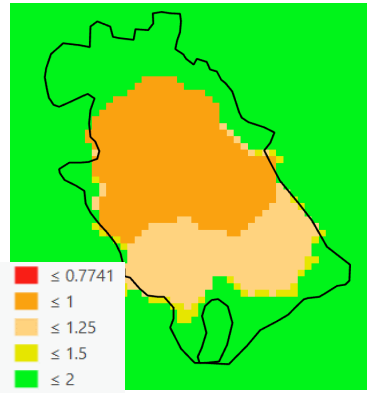
Landslide susceptibility – other approaches

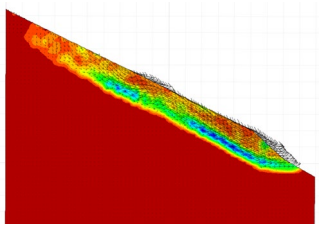
- Nikhil Nedumpallile-Vasu BGS lead
- Geotechnical and hydrological factors
- Scale dependent requires climate data downscaling
- Open Source code where possible



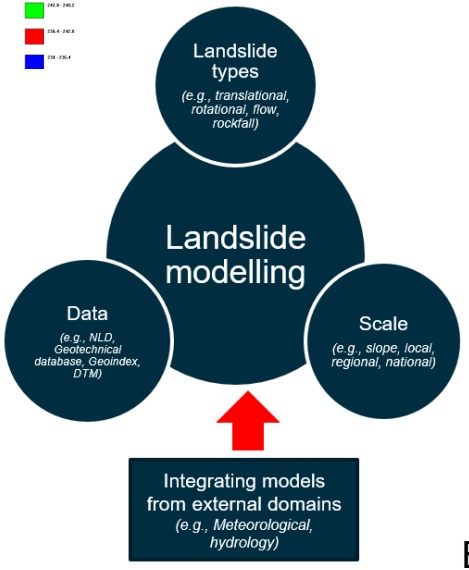
ZOODRM
or
Water balance

E.G. TRIGRS+ SCOOP3D





Flac (finite difference) or similar for the coastal landslides



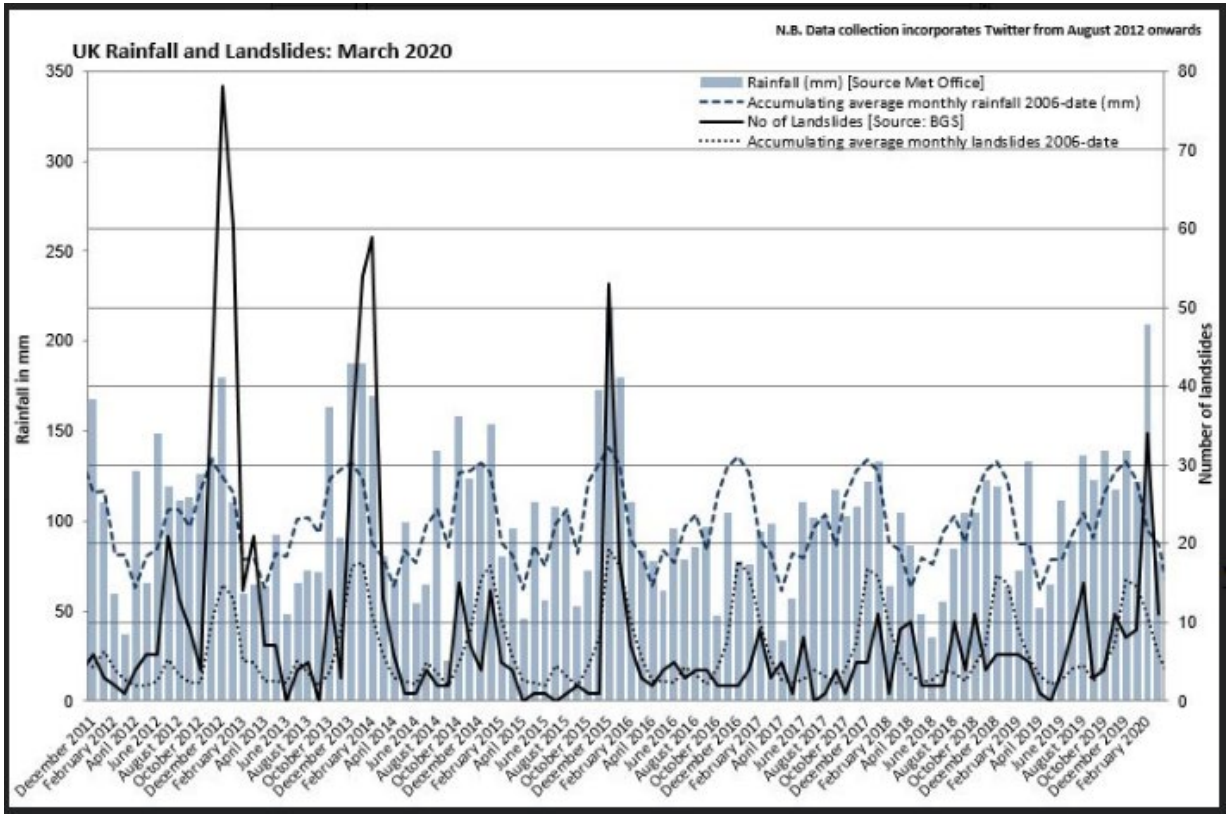
Process-chain modelling
Stability and flow-runout

SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

Climate change induced triggering processes

Rainfall triggering of landslides

- Good visual correlation of landslides and rainfall
- Data biases – not a reliable forecasting tool
- Covers all reported landslide occurrences



Triggers that might be impacted by climate change

- Rainfall
- Coastal surge
- Pore water pressures
- Clay shrink-swell
- Heat

Decreasing confidence

The BGS Landslide Response Team waiting for access to the beach to carry out a survey of the landslide on 25 July 2012. BGS © UKRI.

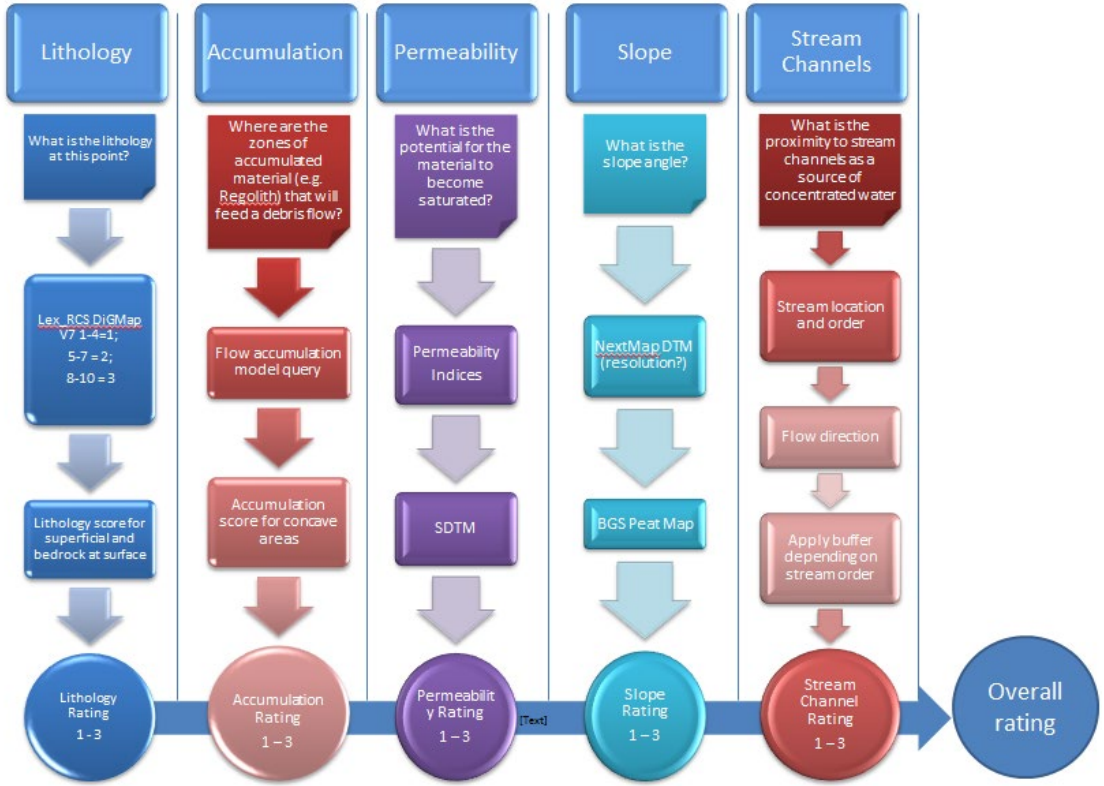
Should triggering be included in landslide susceptibility mapping or should it be included in the hazard process-based susceptibility mapping? The former seems favourable, but requires improved trigger threshold modelling
Might this exclude climate change induced process changes?

Climate change response?

- ✓Lithology
- Accumulation
- ✓Permeability
- Slope
- ✓Stream channels

BUT there will likely be a lag associated with each of these.

This favours the application of CC through TTV development



SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

Climate change induced landslide processes

Climate change processes induced by climate change

- In the UK a higher incidence of piping (subrosion)
- Correlation of rockfall with thermal events
- River/ coastal flood and undercutting

Soil piping-induced landslides. Patterdale in the Lake District, Cumbria. BGS © UKRI.

BGS © UKRI

Burton Bradstock

SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

Climate change and reactivation of landslides

Reactivation of landslides and landslipped material

- Mam Tor, prone to winter reactivation. Dixon and Brook 2007 Climate change (UKCIP, 2002) forecast rainfall in the context of the one month trigger threshold value and six month threshold. Return period predicted to reduce from 4 to 3.5 years by 2080s.
- Other considerations might be stress relief and changes to hydrology associated with landslide leading to changes in susceptibility

Mam Tor landslide. Photo taken from the debris flow looking towards the backscarp. BGS © UKRI.

Anthropogenic change and the feedback to climate change

Impacts of development and land-use change

Environmental factors – anthropogenic + climate change

- Land use change, especially vegetation
- Surface sealing – buildings and pavements focus of flow
- Thermal effects – urban heat islands
- Demand for water – impact on pore water pressure
- Groundwater management for construction
- Legacy Infrastructure groundwater management
- Quarries for resources
- Air Conditioning

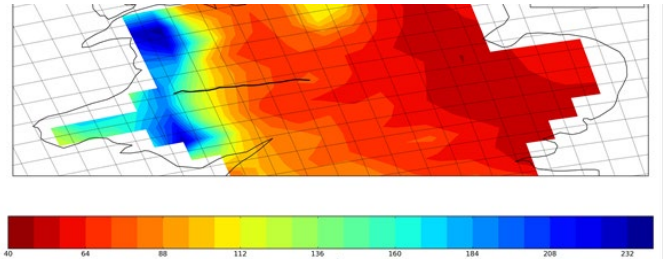
- Anthropogenic factors as triggers: roads, reservoirs, land-use change; irrigation, e.g. loess, China

SUSCEPTIBILITY MODELLING AND CLIMATE CHANGE

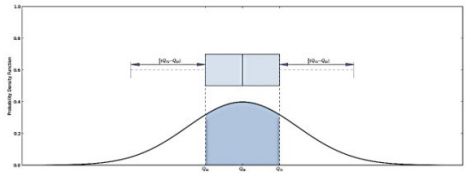
Geoclimate data and model validation

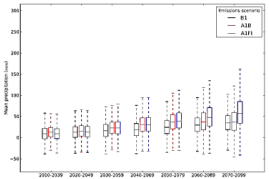
Data availability

- UK Climate Projections – UKCP09; UKCP18; 2.2km grid
- 12-member perturbed parameter ensemble of global climate simulations from the Met Office HadGEM3-GC3.05 coupled ocean-atmosphere model CMIP5 – Climate Model Intercomparison Project (5th IPCC)
- Climate-ADAPT – Adaptation information for across Europe (EU and EEA)
- (EEA): The climate change data centre
- JRC European Data Centre (ESDAC)
- Local governments
- Public sector organisations
- Historic England
- National Trust
- transport sector
- heritage sector
- EURO-CORDEX: https://www.ucl.ac.uk/statistics/research/eurocordex-uk



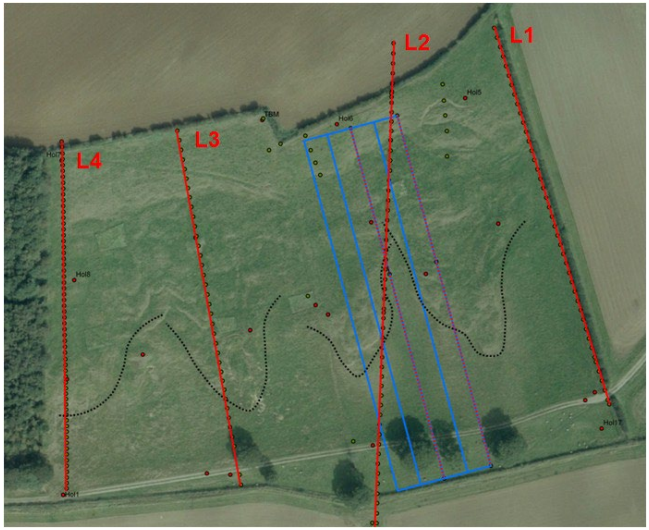
30-year average (1961 -1990) December precipitation

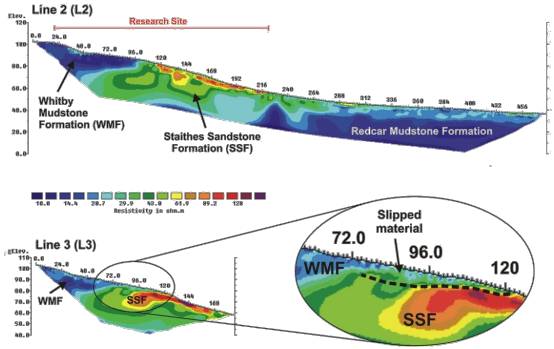




Model validation

- NLD
- Underlying dataset validation
- Event data
- Monitoring and observation
  - Expensive demanding collaborative effort
  - Field based observatories
  - Soil moisture for rainfall triggered landslides
  - Earth observation
- Nesting modelling
  - For landslide
  - For climate change data





Hollin Hill, Chambers et al.

British Geological Survey

THANK YOU