Research informed design management and maintenance of infrastructure slopes: development of a multi-scalar approach

Stephanie Glendinning
Newcastle University, UK

Background and context

- The UK’s transport infrastructure is one of the most heavily used in the world
- The UK rail network takes 50% more daily traffic than the French network
- The M25 between junctions 15 and 14 carries 165000 vehicles per day
- London Underground is Europe's largest metro subway system but also its oldest
- Much of the rail network is over 100 years old

THE PROBLEM.....

Last Updated: Saturday, 13 January 2007, 16:57 GMT

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Last Updated: Friday, 20 July 2007, 14:38 GMT 15

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Last Updated: Wednesday, 25 July 2007, 17:59 GM

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Last Updated: Wednesday, 29 August 2007, 06:09

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£1m to fix flood landslide route

The cost of repairing Gloucestershire's flood-damaged A46 will be £1m, county highways bosses have said.

The road was closed at Salmon Springs earlier this month, after a landslide

Damage to the county's roads is estimated to be £2.5m

AND AGAIN IN 2012…….

Train derails in Cumbria after landslide

Early-morning train carrying about 100 passengers left tracks following landslide near St Bees, but no injuries reported

Helen Nugent
guardian.co.uk, Thursday 30 August 2012 11.11 BST

The landslip nea

Thornhill, Dumfrieshire, 22.11.12

Two feared dead in Dorset landslide

Man and woman feared dead after being buried in their car for more than a week following a landslide caused by heavy rain

Steven Morris
guardian.co.uk, Tuesday 17 July 2012 16.03 BST

er tunnel. Dorset police said one body had been found in a car e and a second was thought to be concealed in the mud. Phot MNS.com

29 June 2012 Last updated at 13:21

Landslides and fire disrupt rail services as rains hit Scotland

Rail disruption continues

BBC News Sport Weather iPlayer TV Radio

NEWS UK

Home World UK England N. Ireland Scotland Wales Business Politics Health Education SciEnvironment

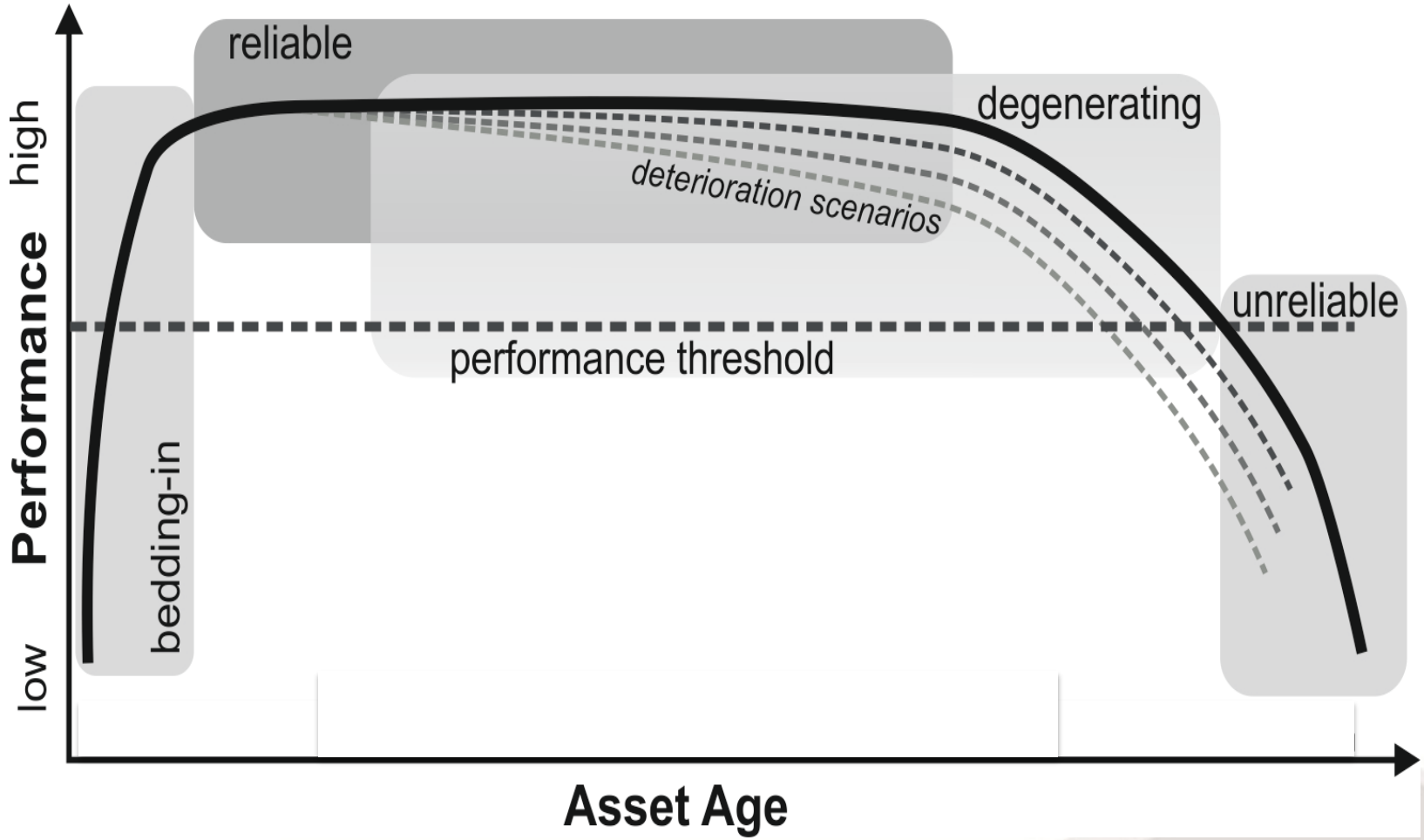
UK floods: Landslides cause rail disruption

29 June 2012 Last updated at 10:51

The East Coast main line between Newcastle and Berwick-Upon-Tweed remains closed after landslides overnight, and delays continue between Newcastle and Carlisle

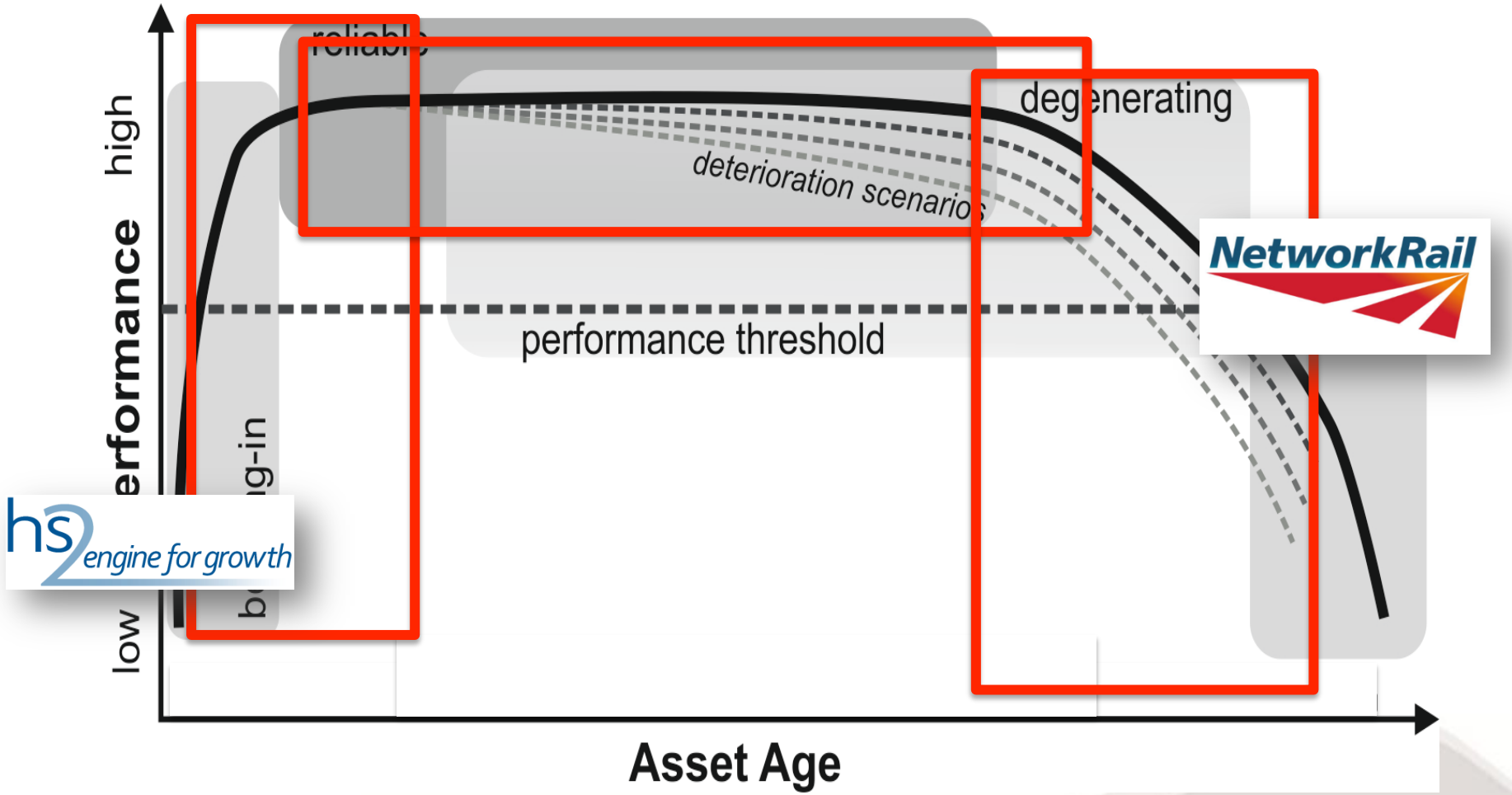
At Edinburgh's Waverley Station, Ben Hall from Network Rail said there was a lot of work to do before the line could be reopened. Mr Hall also warned travellers to expect delays and disruption for some time to come.

Asset deterioration



Generalised deterioration model for transport earthworks (adapted from Thurlby, 2013).

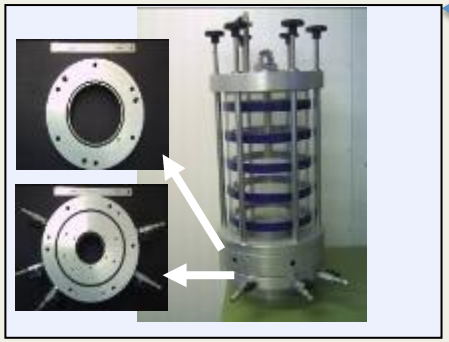
Asset deterioration

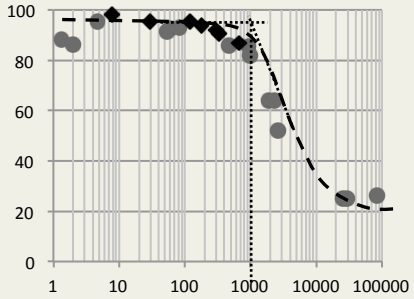


Generalised deterioration model for transport earthworks (adapted from Thurlby, 2013).

iSMART - SUMMARY

Scale 1





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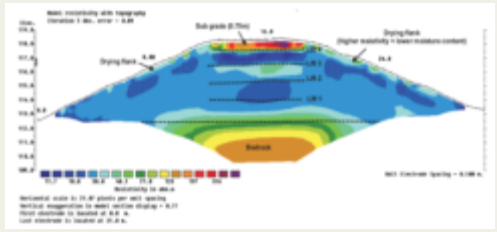

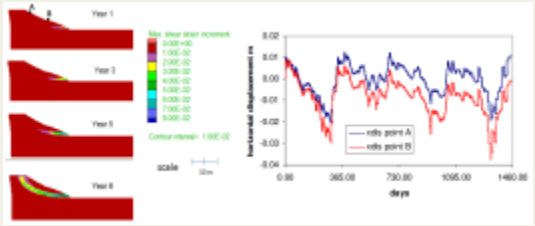

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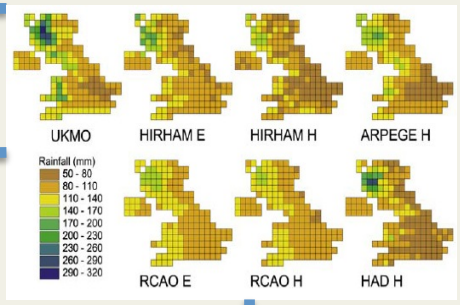

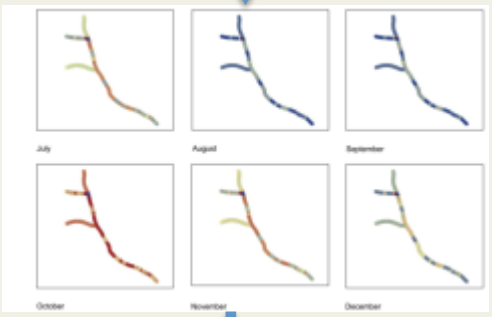

iSMART - SUMMARY

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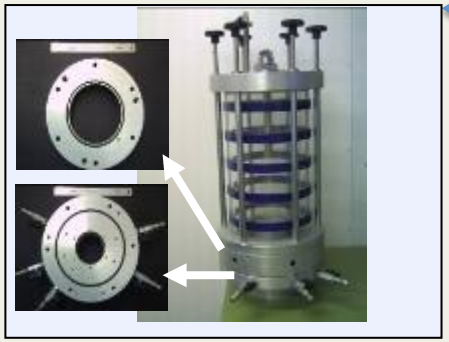

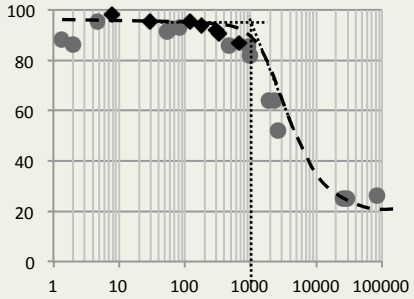

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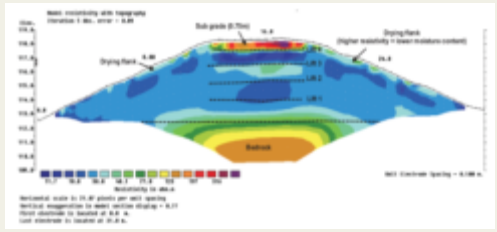

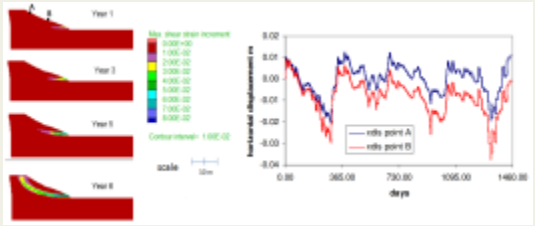

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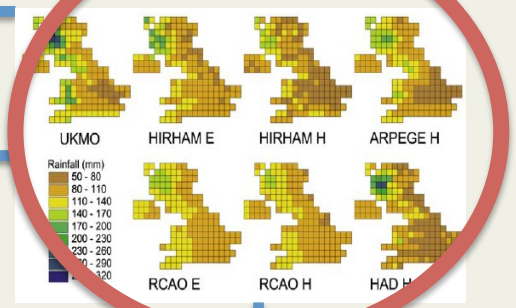
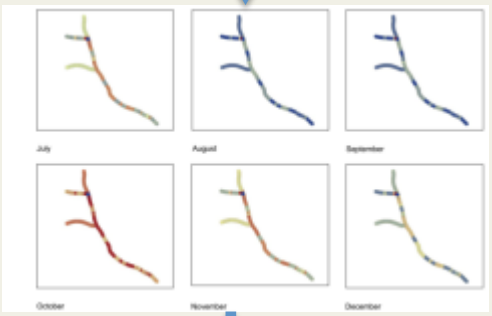
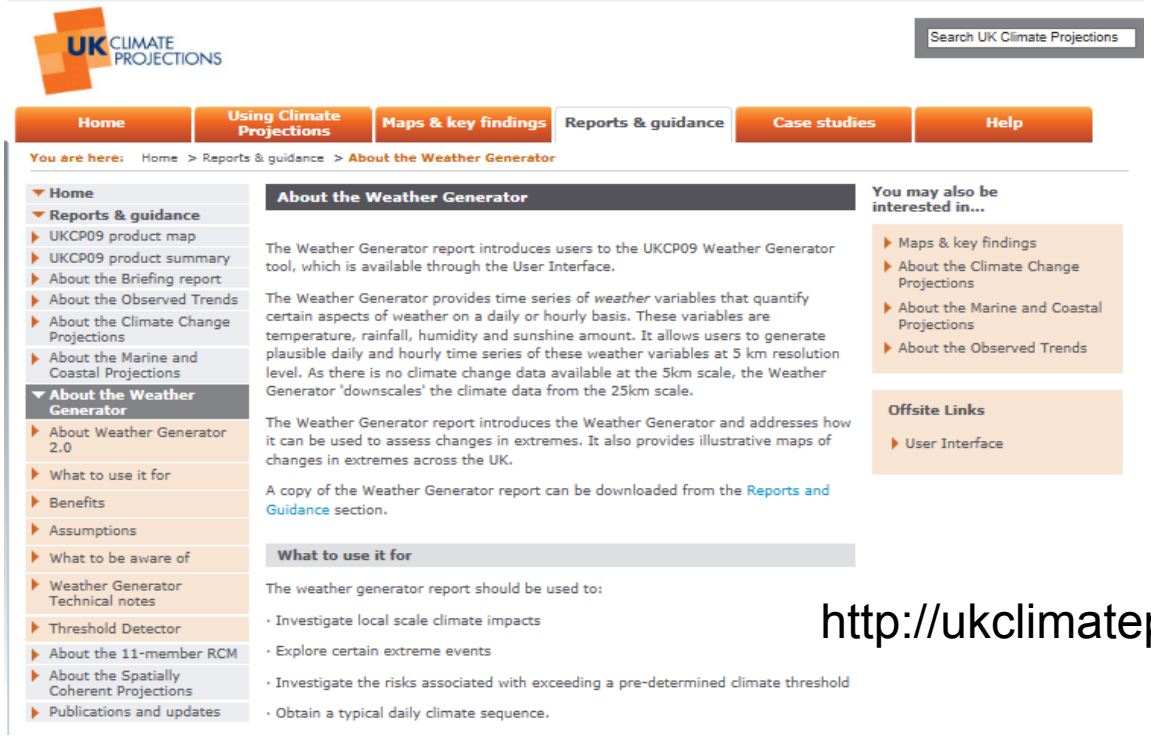




Available information - UKCP09

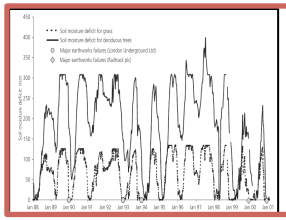
- Improved consideration and quantification of associated uncertainties - ensemble of different models used to derive probability distributions
- Improved spatial and temporal details
- Weather generator to down-scale information to provide *projections* for local area



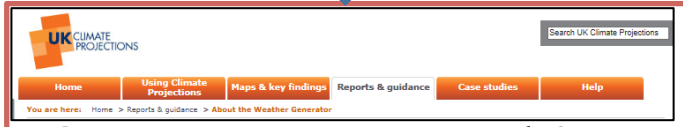
http://ukclimateprojections.metoffice.gov.uk

Using the UKCP09 data

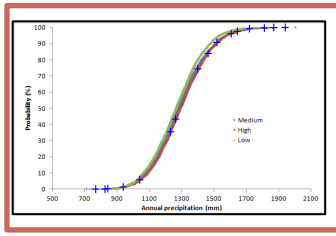
Choose representative locations in the UK



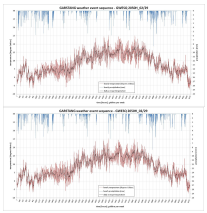
Calculate in terms of Soil Moisture deficit (Water Balance)



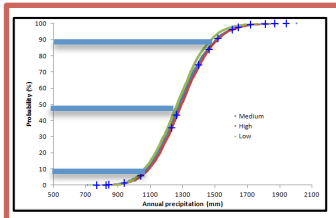
Generate current and future weather event sequences



Generate pdfs of (zero) SMD

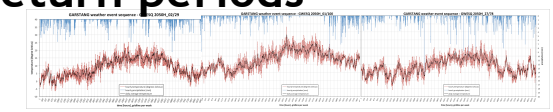


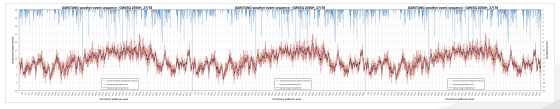
Present
2020
2050 All for the high emissions scenario
2080



Select 3 years - average, high, low

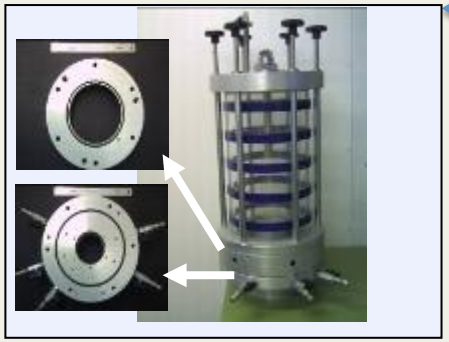
Reassemble years to generate *scenarios* containing extremes with known return periods

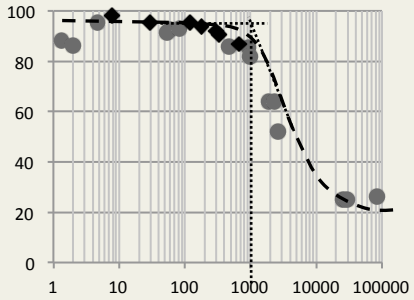




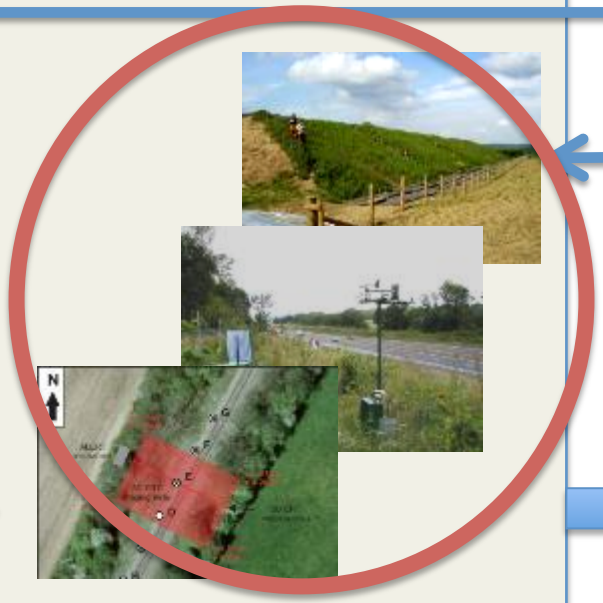
SCALE 2 – FIELD MONITORING

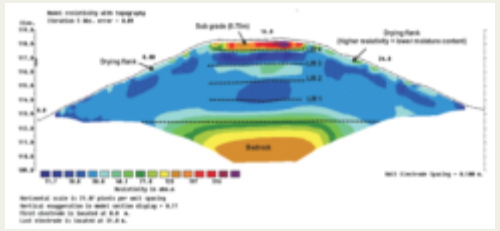
Scale 1

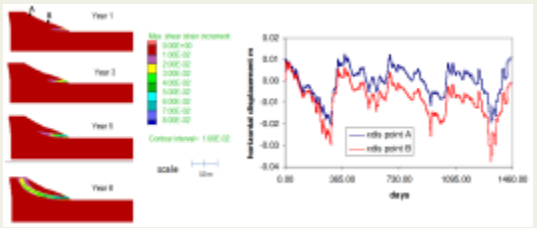




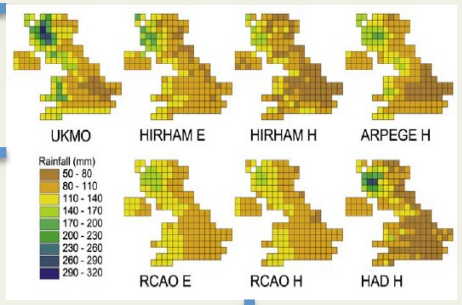
Scale 2

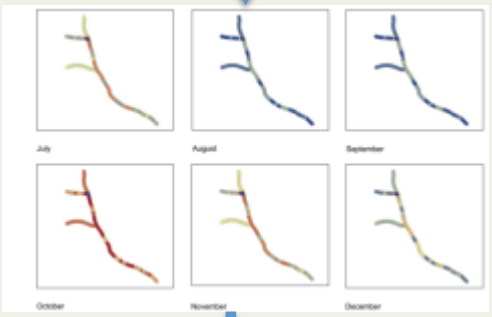






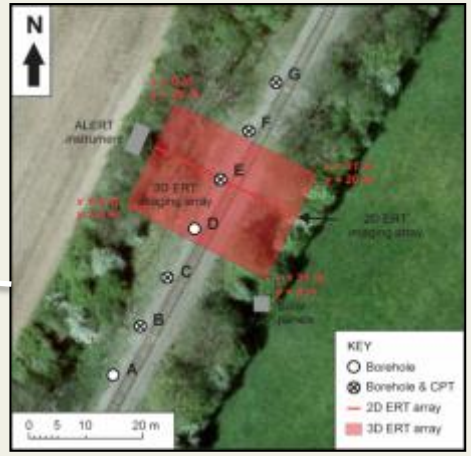
Scale 3





SCALE 2 - FIELD SITES

Newbury road cutting



Great Central Railway embankment

Loughbrickland road cutting

BIONICS model embankment

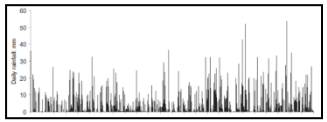
Hawkwell Railway embankment

Craigmore Railway cutting

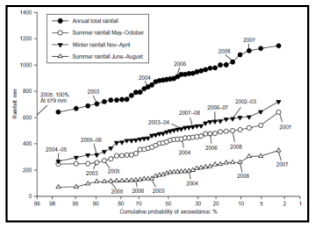
Newbury site

- Modern highway cut slope in London Clay on the A34 near Newbury

Effects of climate on pwps



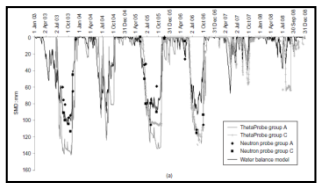
Climate observations from site



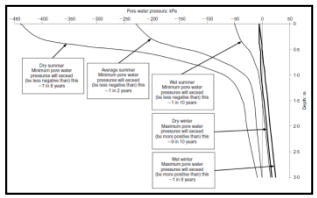
Assign return periods to climate from site

Long-term climate observations (42 years of rainfall)

Assign return periods to different events (e.g. summer/winter rainfall)



Use models to demonstrate link between climate and observations of soil water content and pwps



Say something about the return period of observed pore water pressures

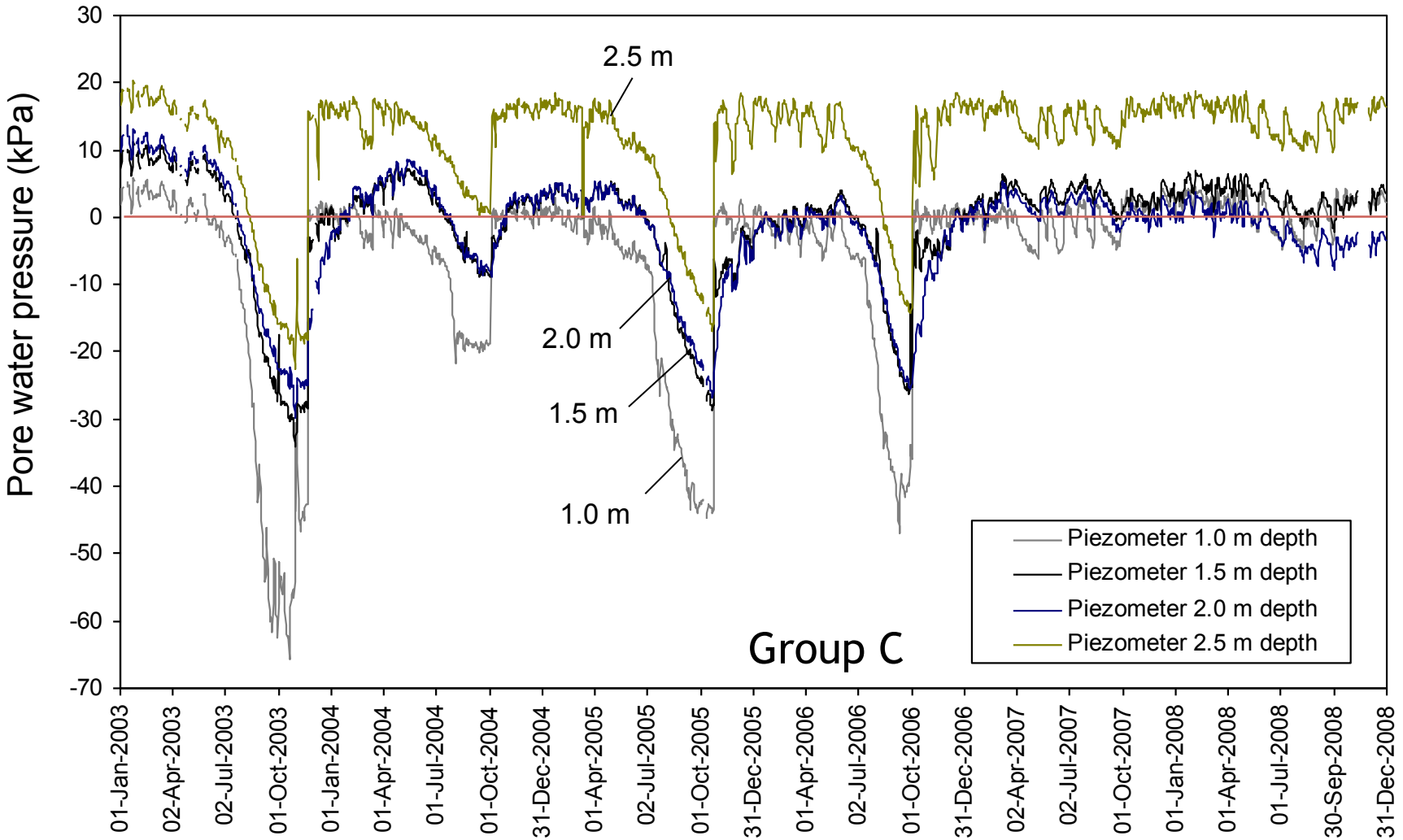
OUTPUTS:

Conceptual model for slope

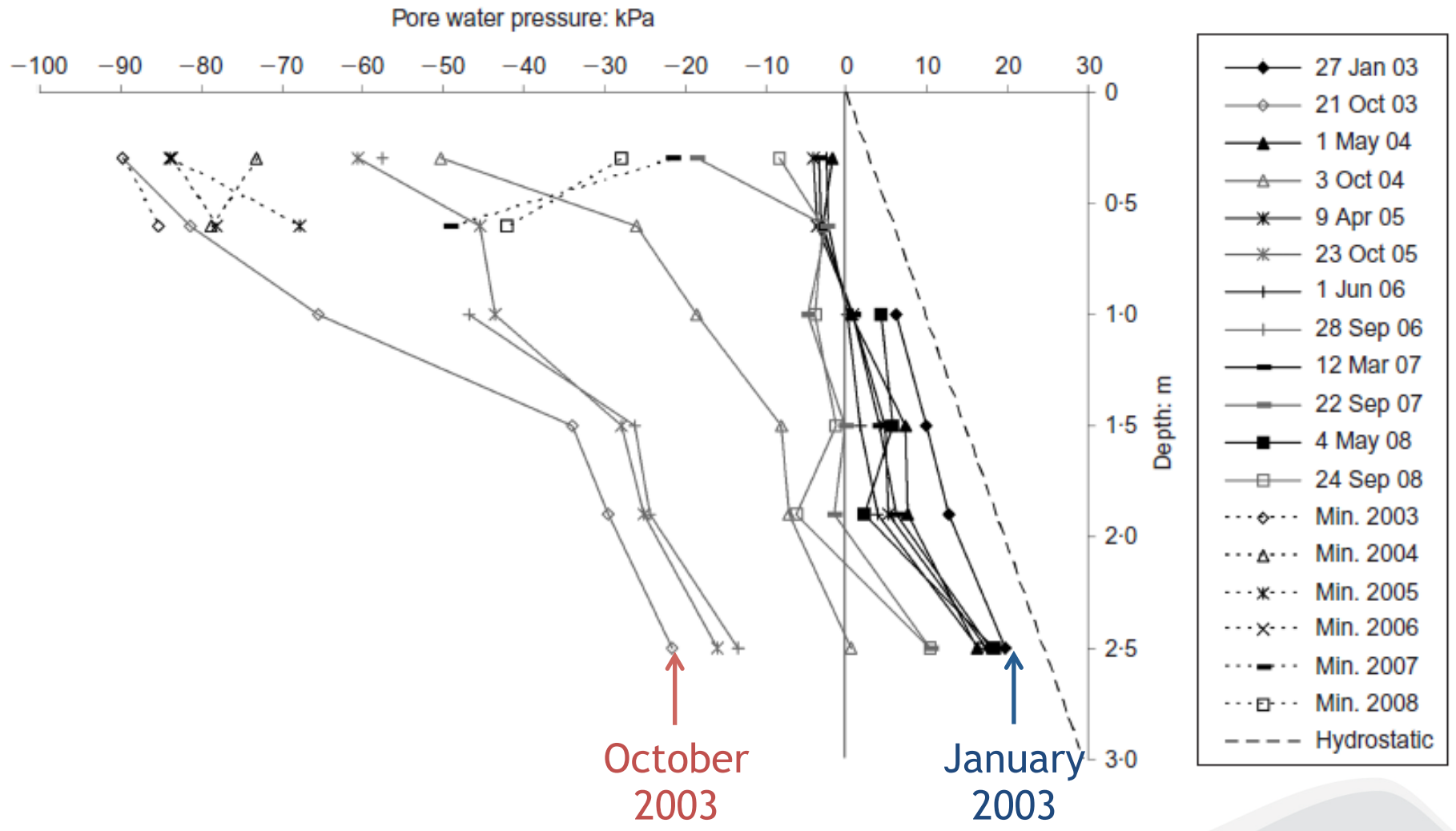
Inputs to numerical models

- Water movement in response to climate
- Extreme wet pwps and return periods
- Magnitude of cycles of pore water pressure
- Comparison with synthetic data

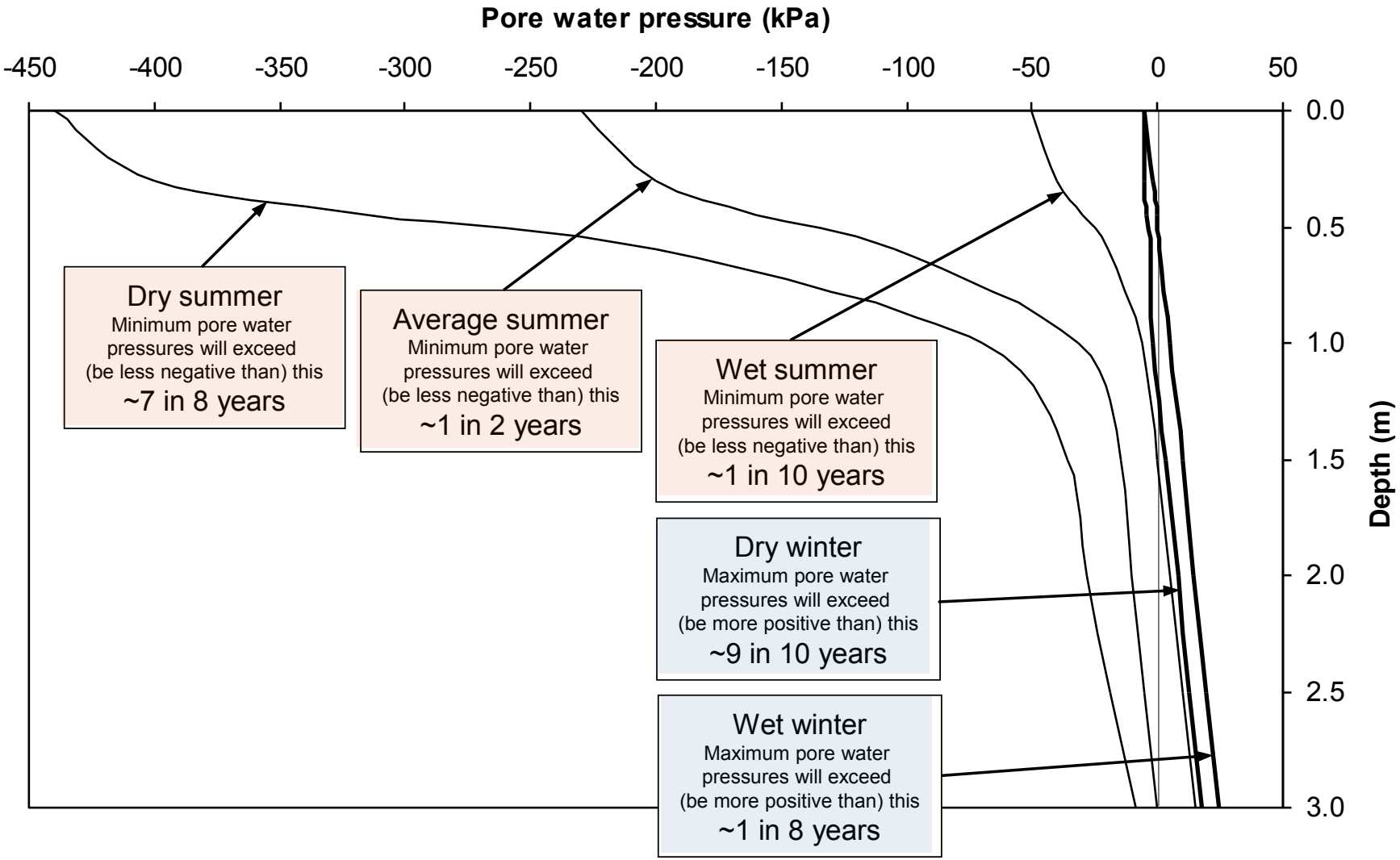
Pore water pressures



Pore water pressures



Return periods for pore water pressures



Using the field data

Generation of long-term datasets for:

- Understanding deterioration processes
- Validation of numerical models

Pore water pressure:

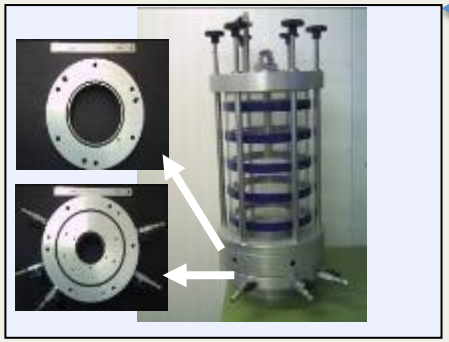
- The link between climate and changes in water content, pwps and slope movements
- The return period for worst-case pore water pressures that might cause failure
- The size of cycles of pore water pressure that may influence progressive failure

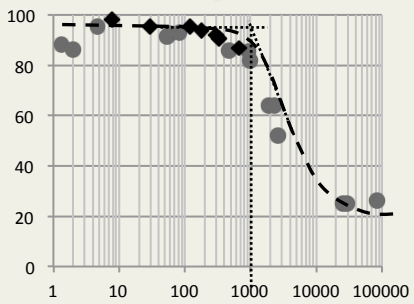
Vegetation:

- Shallow vegetation cover only influences the top 1-2 m of the soil profile
- Vegetation is unable to generate a soil moisture deficit that is not almost completely eroded in winter

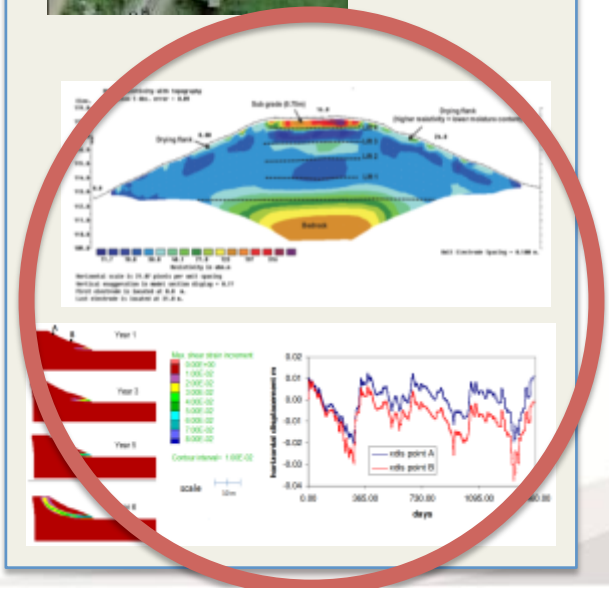
SCALE 2 - NUMERICAL MODELLING

Scale 1

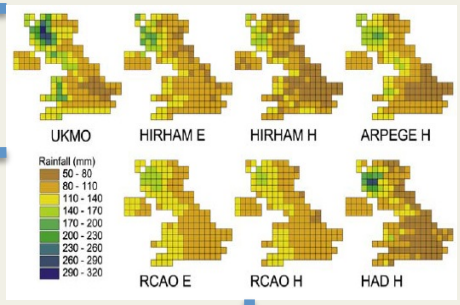


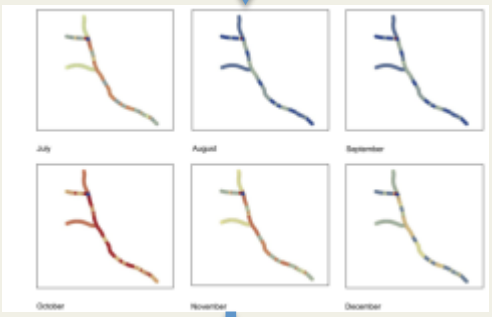


Scale 2

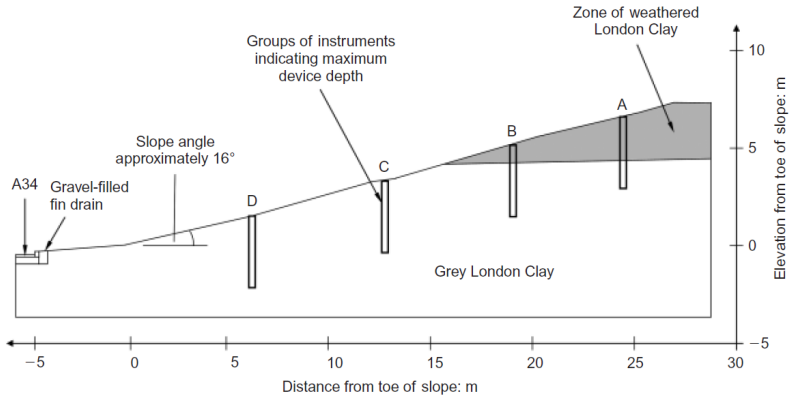


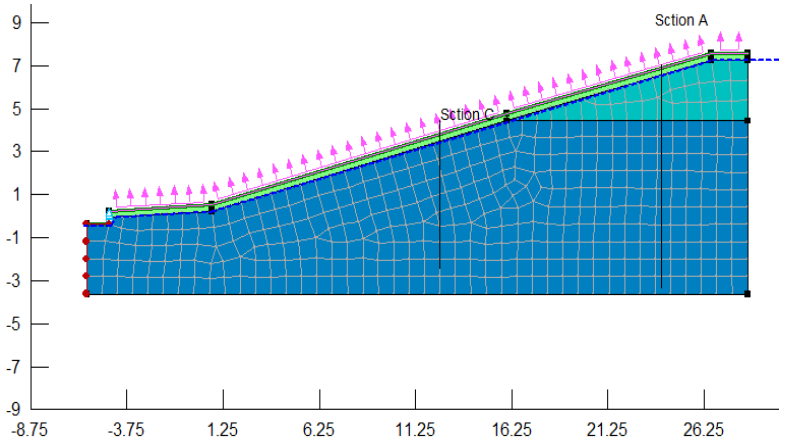
Scale 3



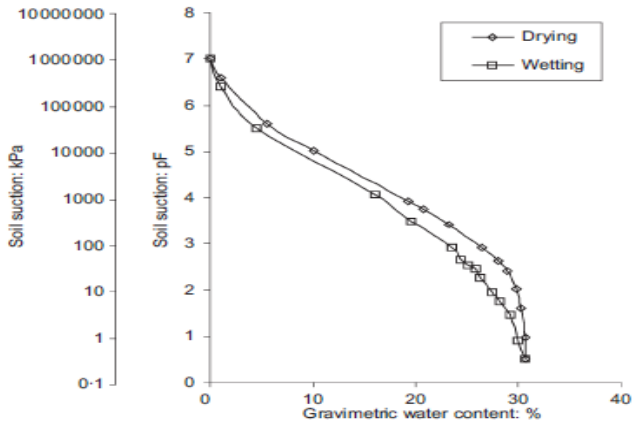


Newbury analysis (Seep/W set-up)





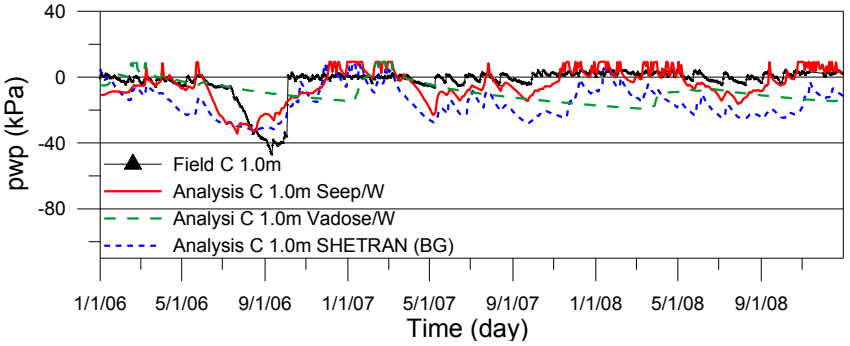
Cross-sectional details (Smethurst et.al. 2006) and geometry for Newbury cutting

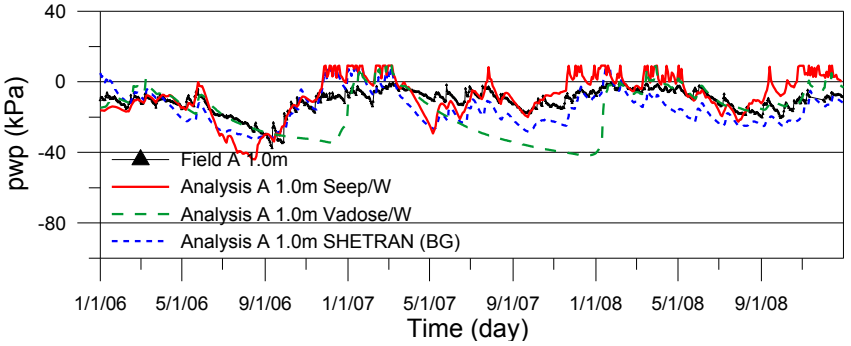


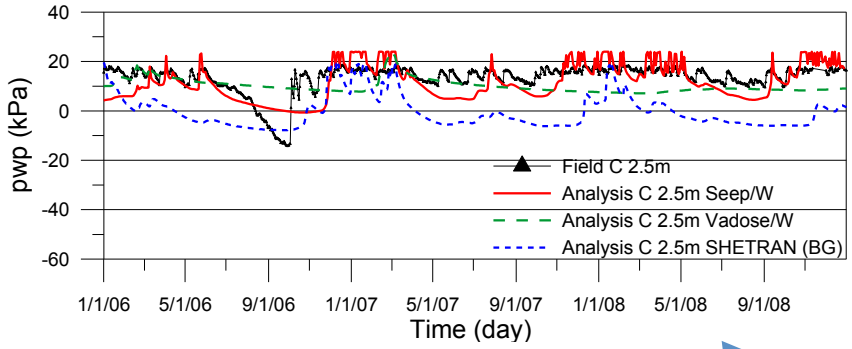
Ksat (vertical) from borehole bailout tests (m/s)	
Surface layer	4.3×10^{-8}
W London clay	4.3×10^{-8}
G London clay	3.7×10^{-9}

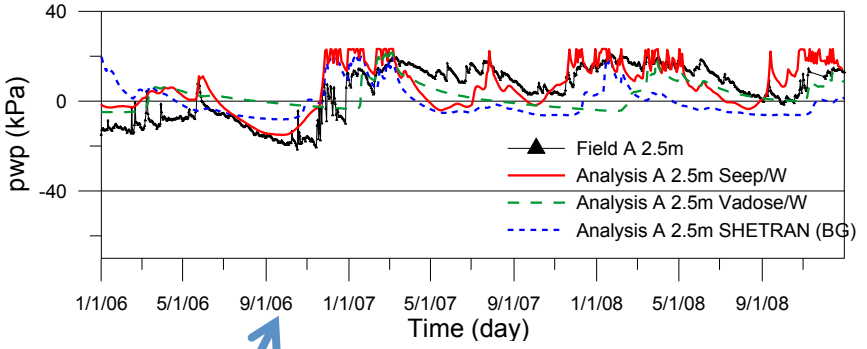
SWCC (Croney, 1977) and soil permeability (Smethurst et.al. 2006)

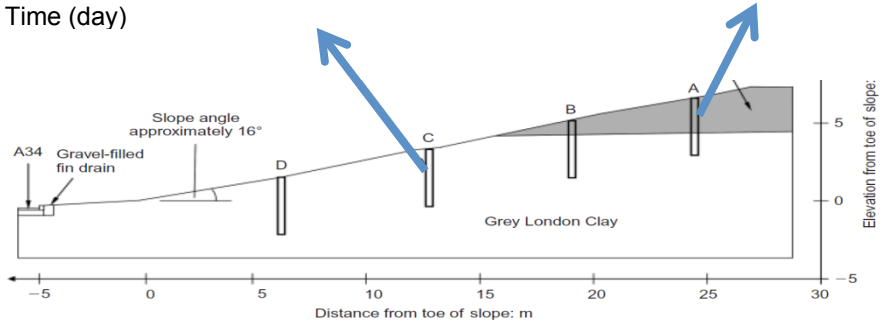
Newbury - Comparison of models







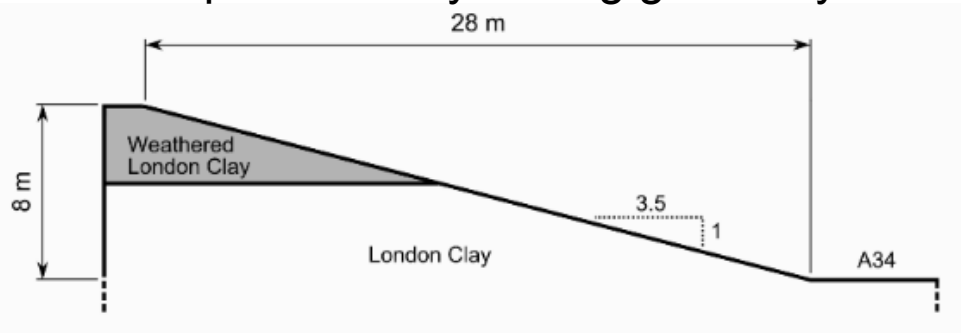


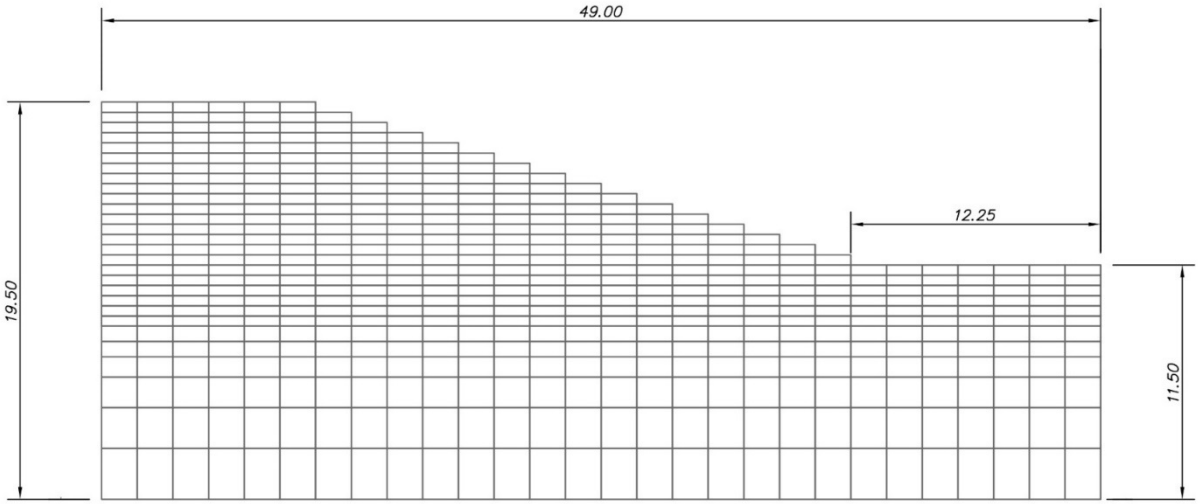


Measured and predicted pwp

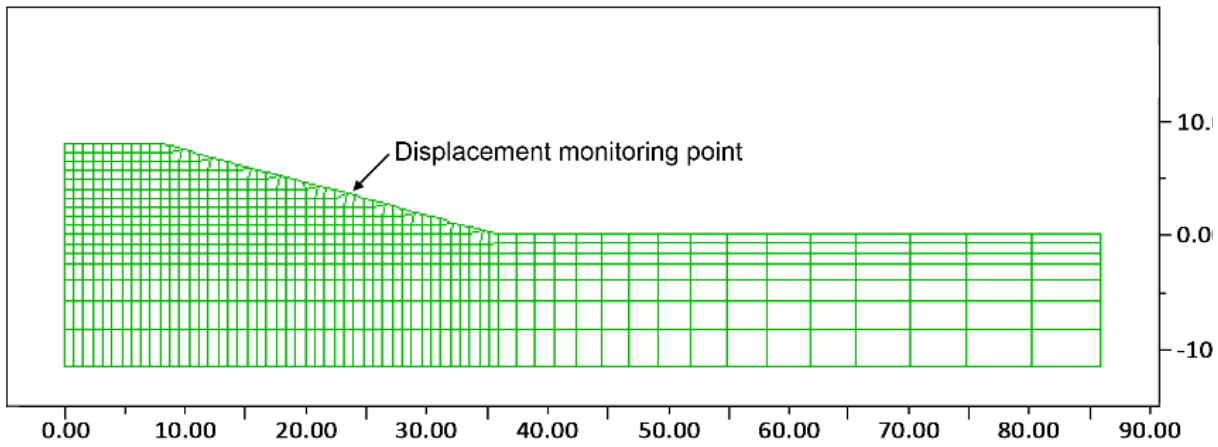
Coupled fluid-mechanical modelling

Simple Newbury cutting geometry





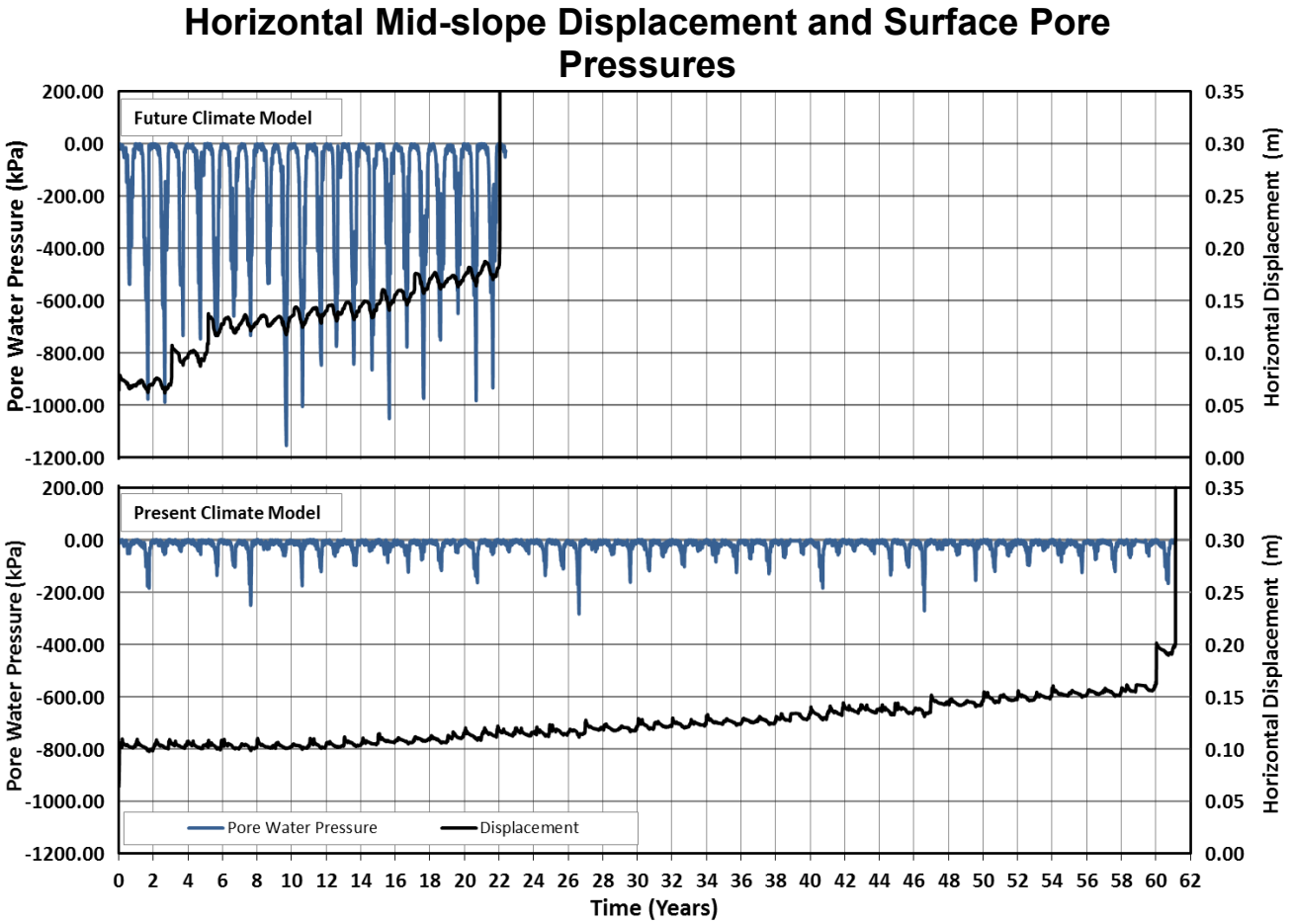
SHETRAN used for soil-surface atmosphere interaction hydrological modelling

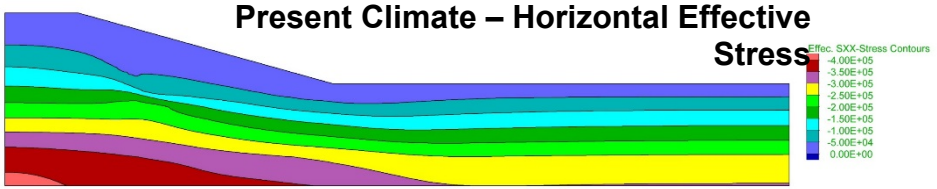


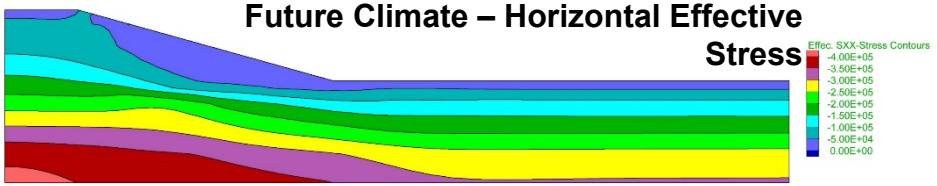
FLAC with two phase flow add on model used for coupled fluid-mechanical analysis

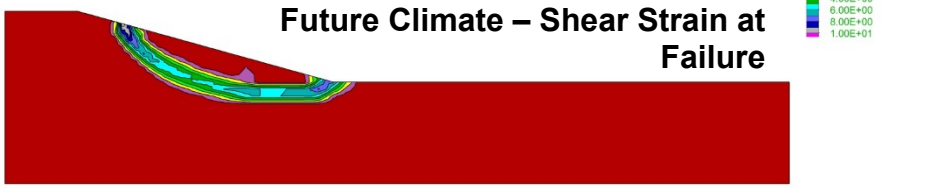
Preliminary results

- Larger surface suctions lead to larger shrink swell cycles
- Causes accelerated failure in future climate scenario
- Failure occurs in wet years in both present and future scenarios
- Effective stress elevated in crest in future scenario
- This change in effective stress state alters failure geometry

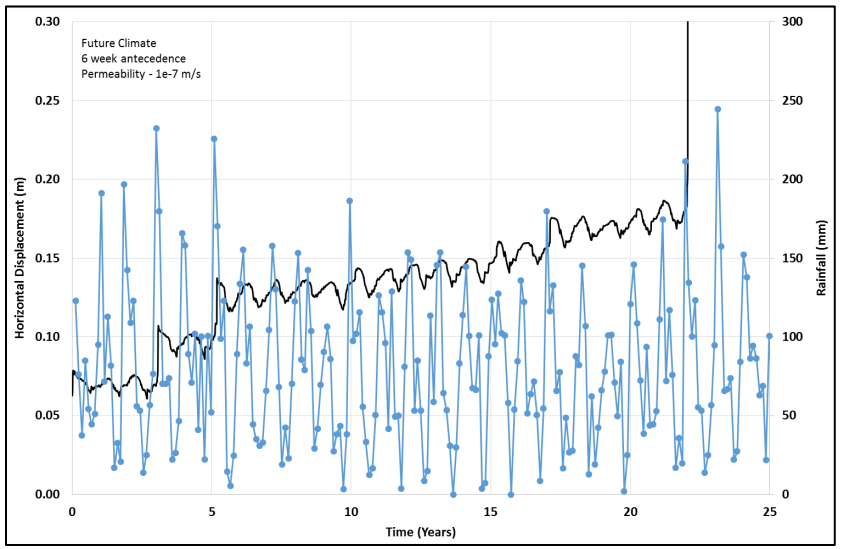


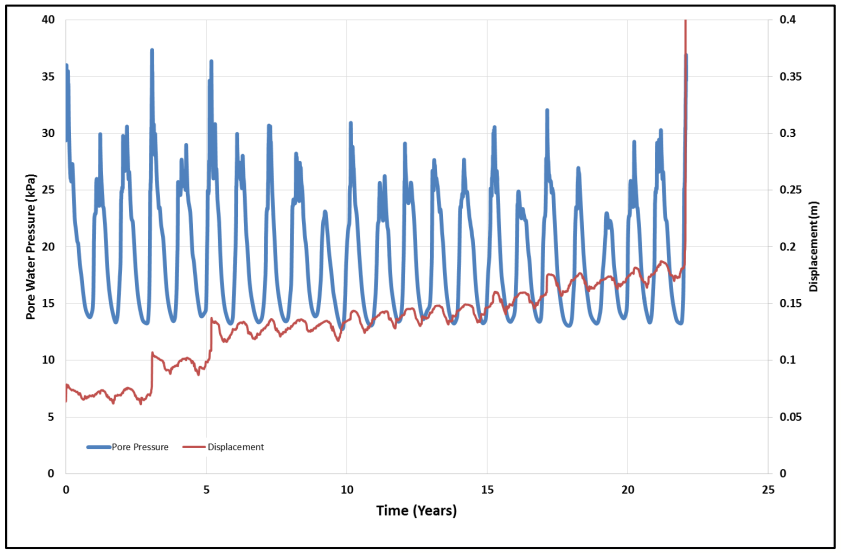






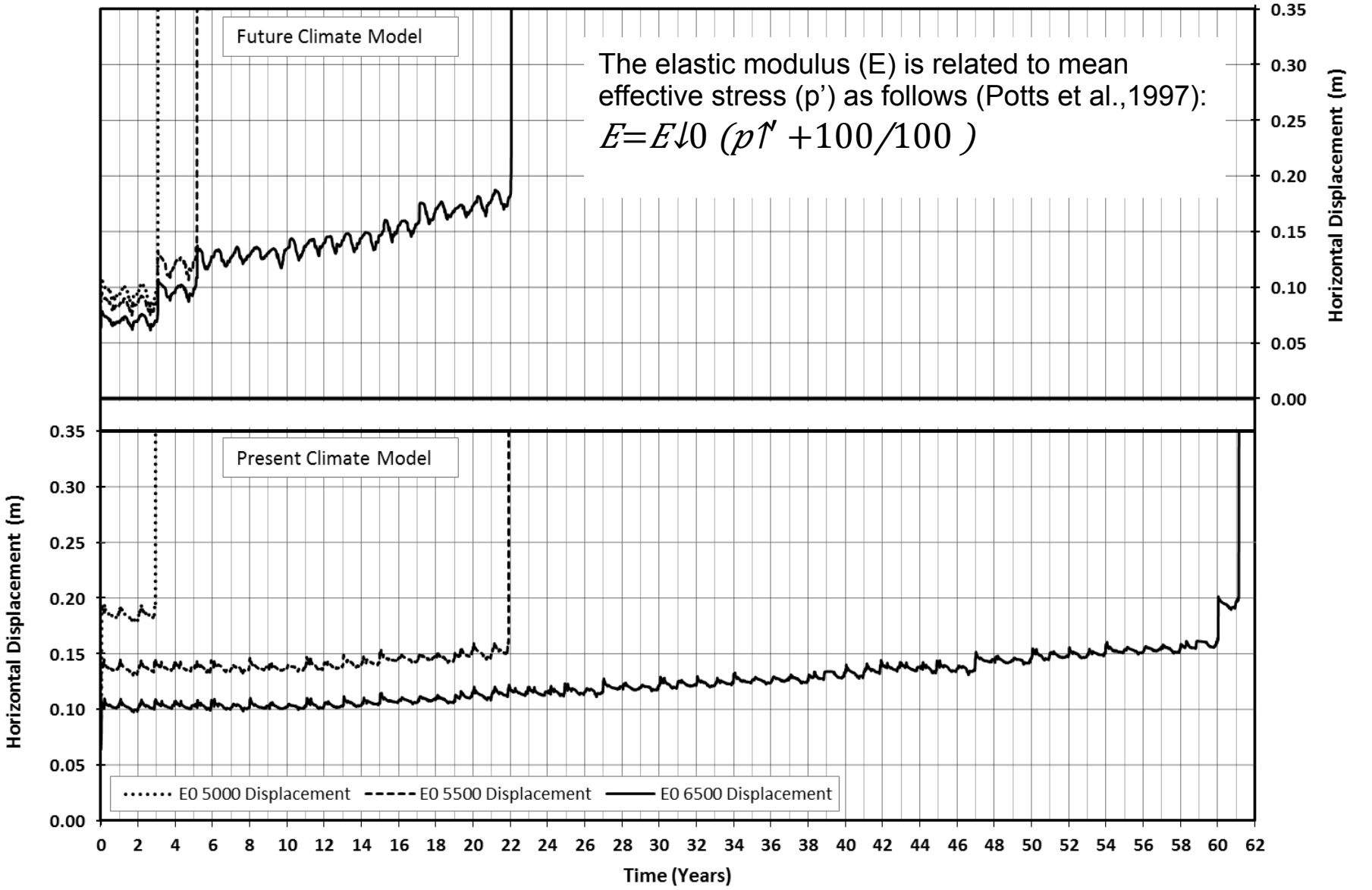
Preliminary results -Rainfall Antecedence





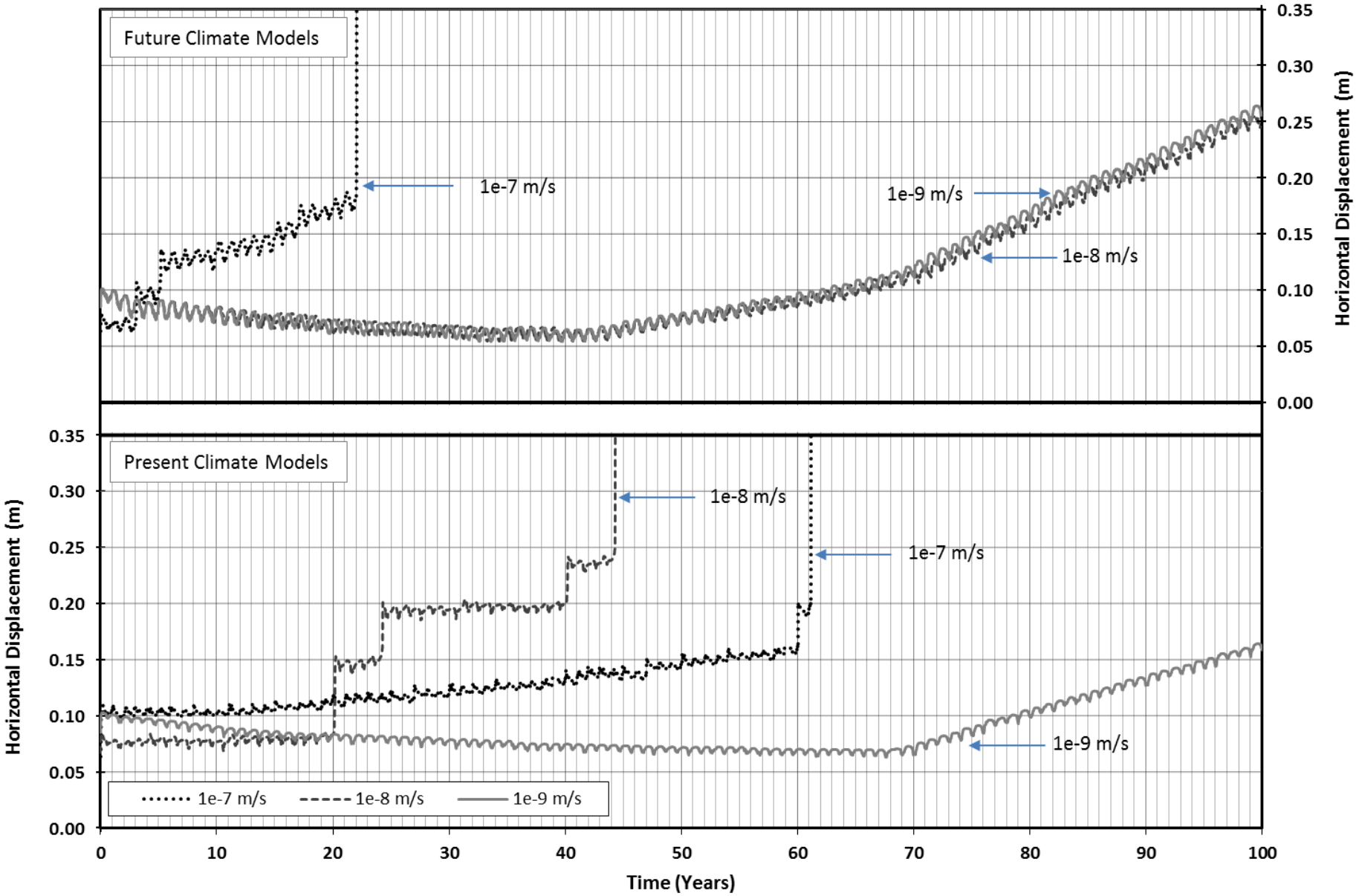
- Trigger level for modelled displacements – 6 week antecedent rainfall > 200 mm
- causes coincident spikes in PWP response at depth (> 35 kPa)
- significantly effected by material permeability.
- Difficult to identify the significant parameters and their trigger values with “real” data

Preliminary results - Stiffness



Potts, D.M., Kovacevic, K. and Vaughan, P.R. (1997). Delayed collapse of cut slopes in stiff clay. *Géotechnique*. **47**(5):953-982.

Preliminary results - Permeability



Use of the modelling data

- Understanding the factors that influence slope deterioration both now *and in the future*

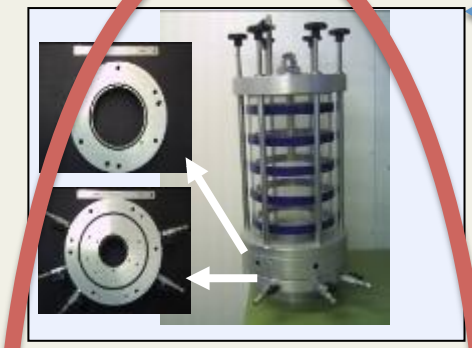
- Understanding the sensitivity to input parameters:
  - Pwps influenced by hydraulic conductivity SWRC and vegetation parameters
  - Slope movement influenced by soil stiffness and strain softening

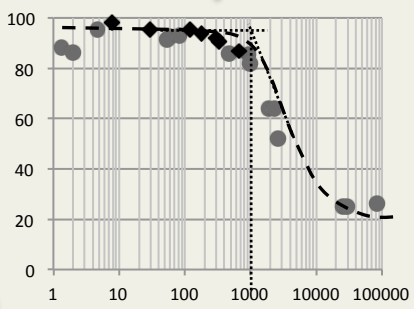
- Understanding the weather event sequences that influence failure - use to help design how we use the UKCP09 data

- Making the link between Scale 2 and Scale 3 so that the results can be used to draw conclusions at network scale

iSMART - SUMMARY

Scale 1





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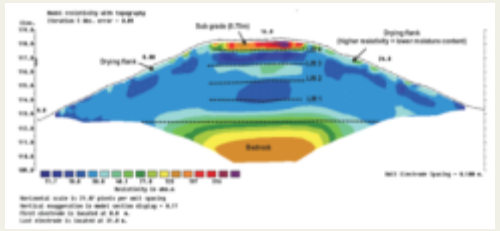
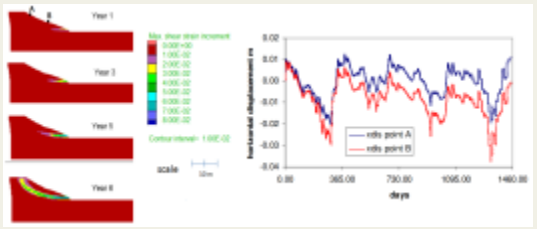
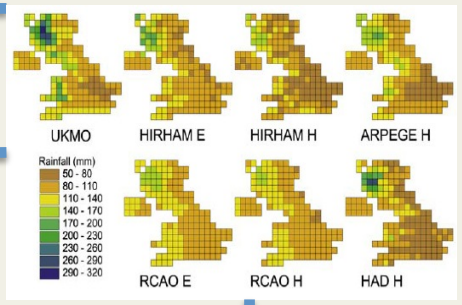
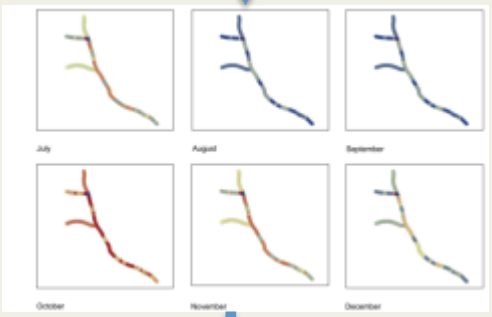


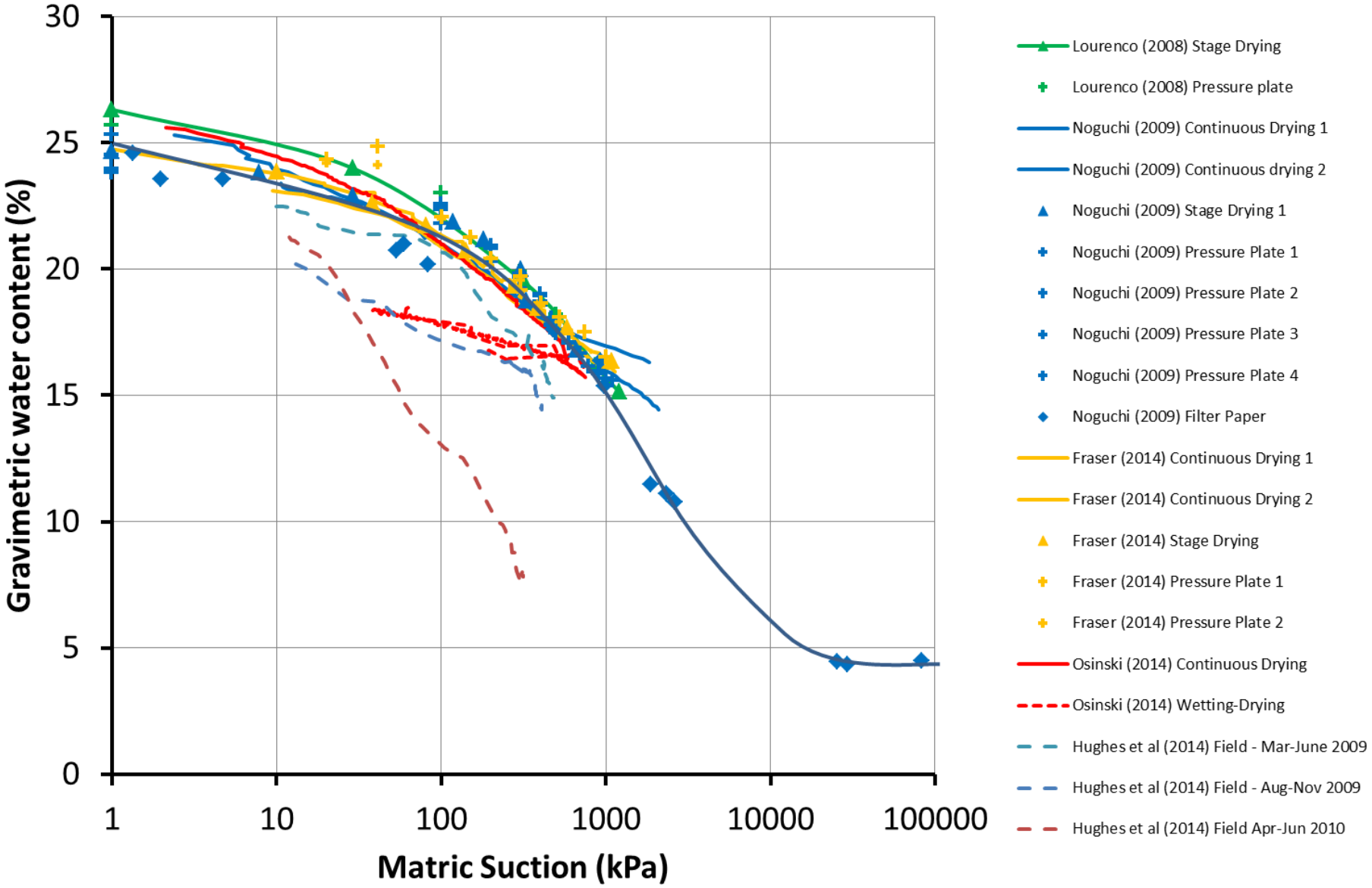


Scale 3





Example of SWRC

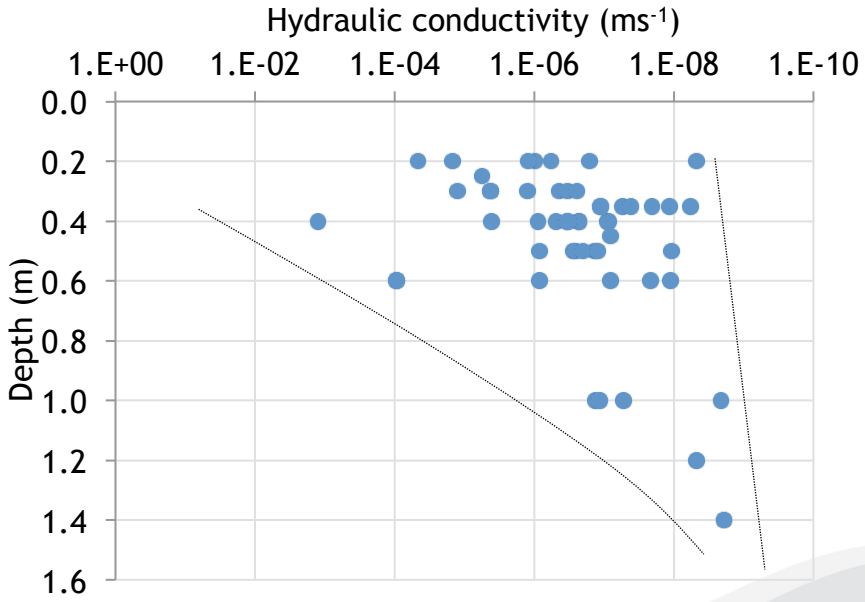


Example of hydraulic conductivity

Guelph Permeameter - constant head measurement in the field (after Soilmoisture Equipment Corp. 2008)

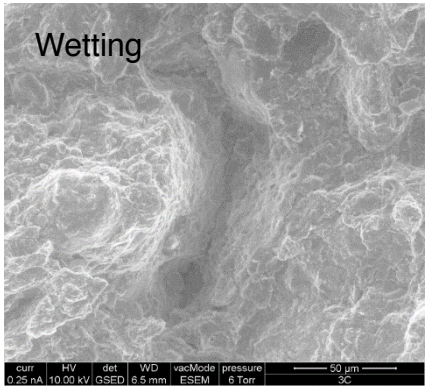
Measurement of permeability/hydraulic conductivity/ infiltration in the field is highly dependent upon antecedent conditions.

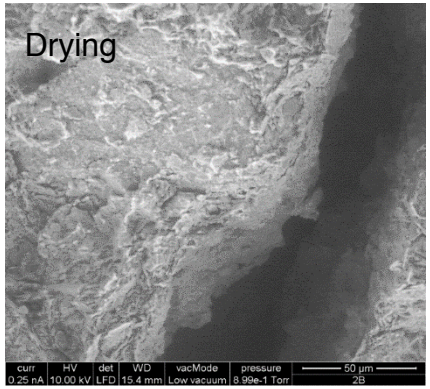
By the very nature of the constant head supply, no account of unsaturated/relative permeability may be quantified using current techniques despite this being the most common state at the near-surface, vadose zone.



Approximately 5-orders of magnitude scatter in values approaching the near-surface in contrast to a more consistent, lower conductivity at depths in excess of 1m.

Example of Micro-structural changes



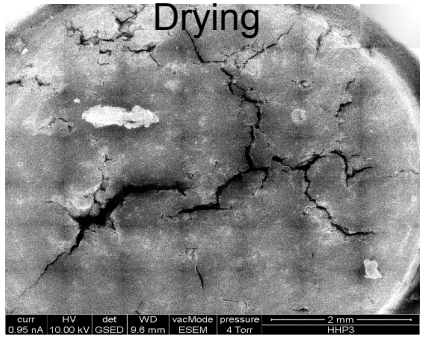


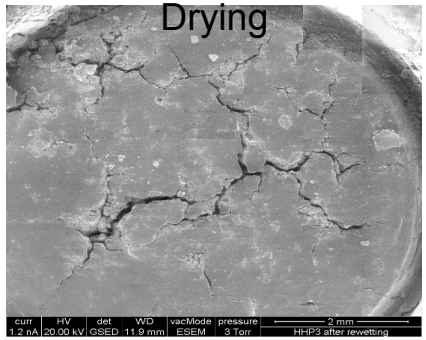
E-SEM scan of medium plasticity clay (BIONICS) at 22% and 5% respectively

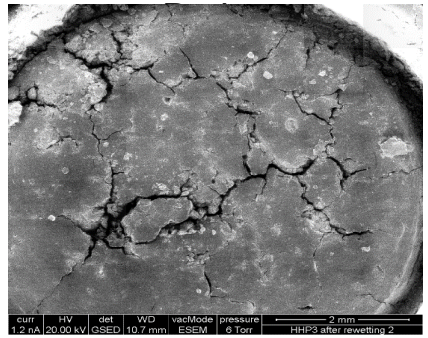
Hollin Hill compacted at P_l: 1st Drying

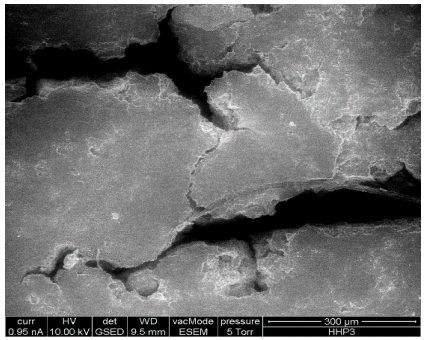
2nd Drying

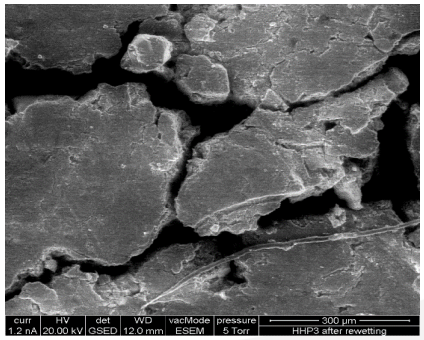
3rd

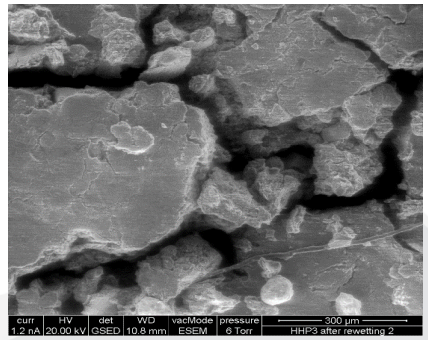






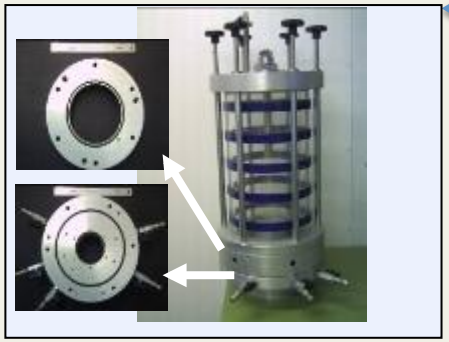


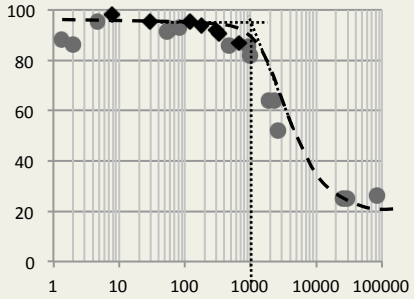




iSMART - SUMMARY

Scale 1





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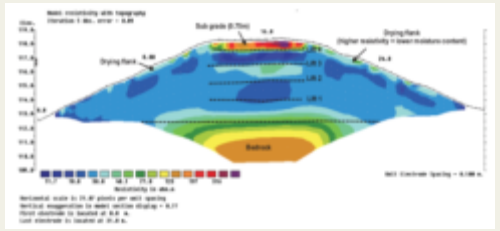

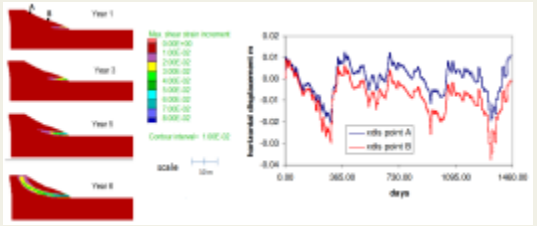

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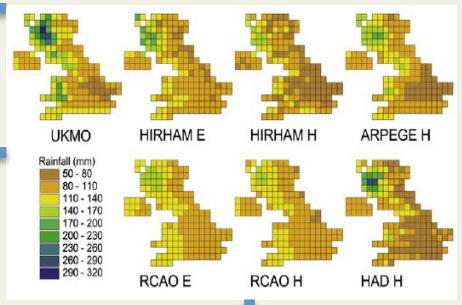
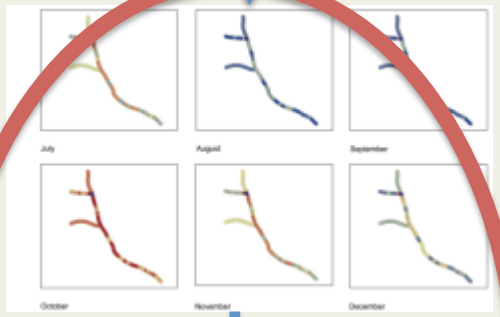
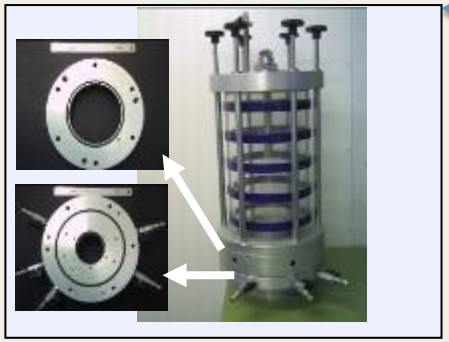
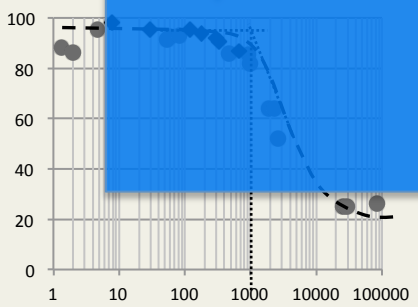




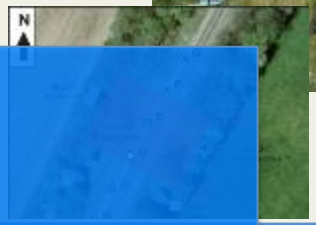
iSMART - Upscaling

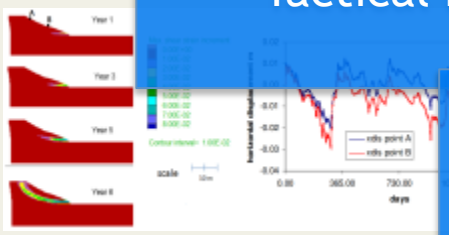
Scale 1





Scale 2





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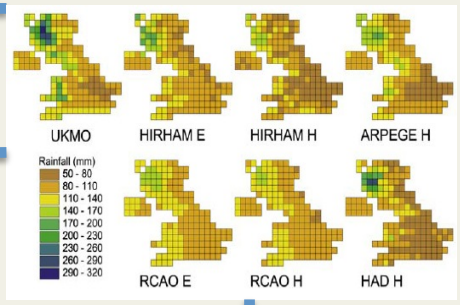
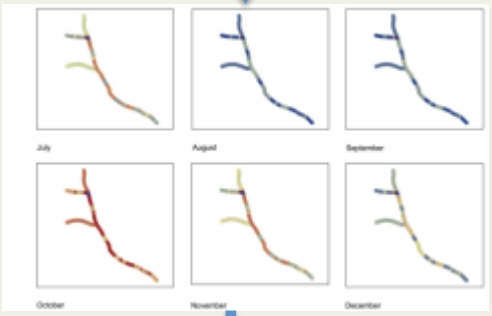




Design

Operational Decision Support

Tactical Decision Support

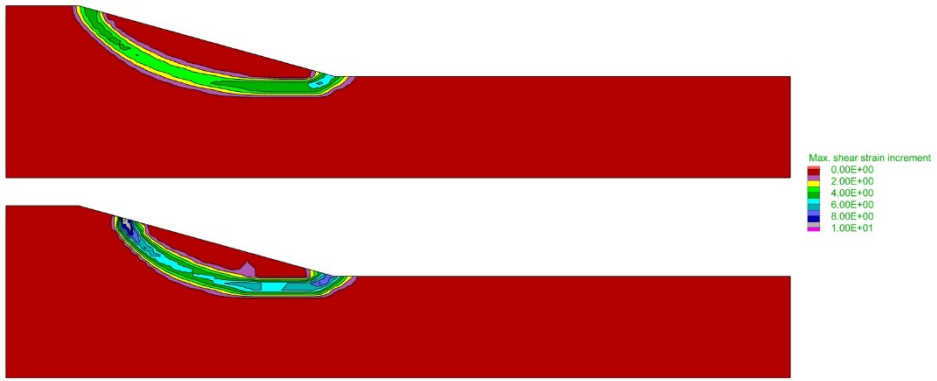
Strategic Decision Support

Network up-scaling

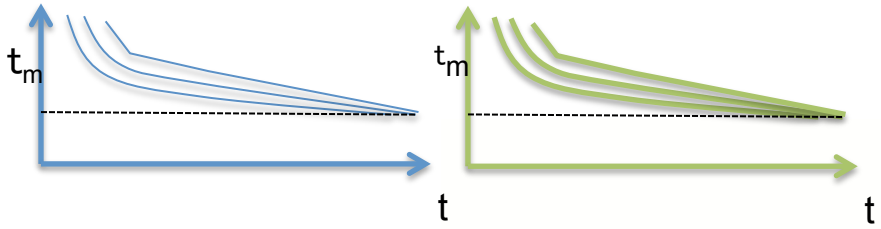
- A key aim is to incorporate results from Scales 1 and 2 into a whole-network model
- To advance systems-scale understanding of future network responses and vulnerabilities
- hence to develop slope risk/vulnerability maps for UK transport networks for both now and the future
- Provide network operators with data and methods that inform asset design, management, maintenance and investment strategies

Some first steps

Numerical modelling

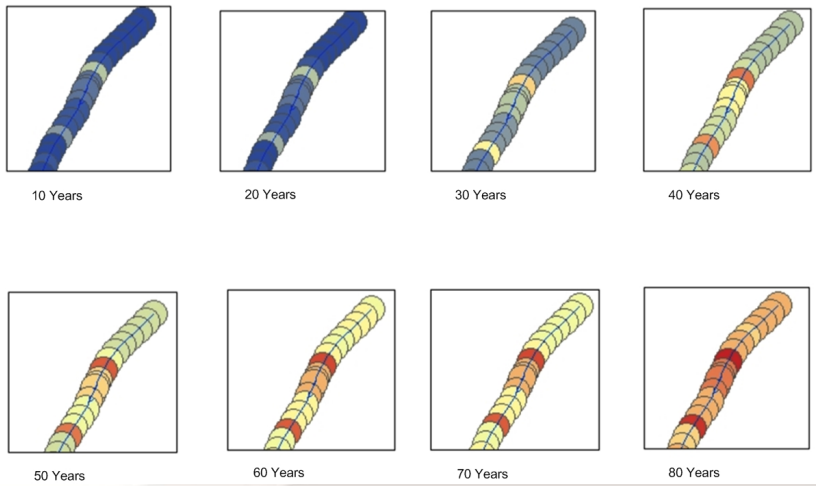


critical combinations of geology, asset condition, geometry, vegetation



Deterioration curves

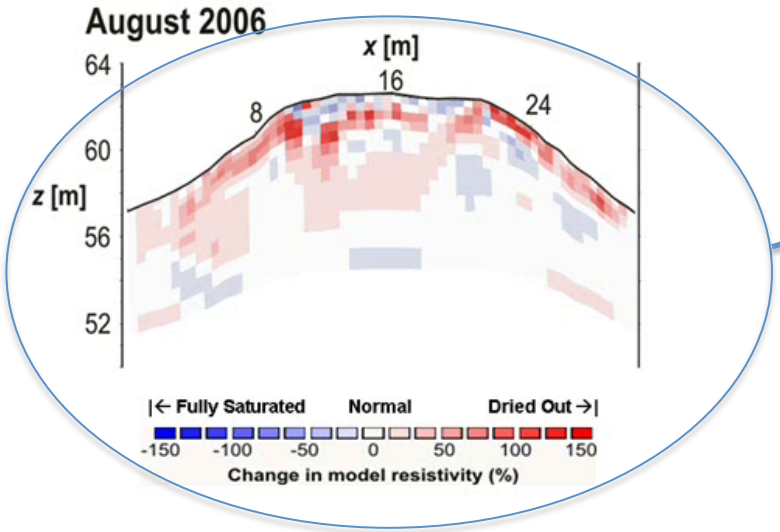
4D Vulnerability map

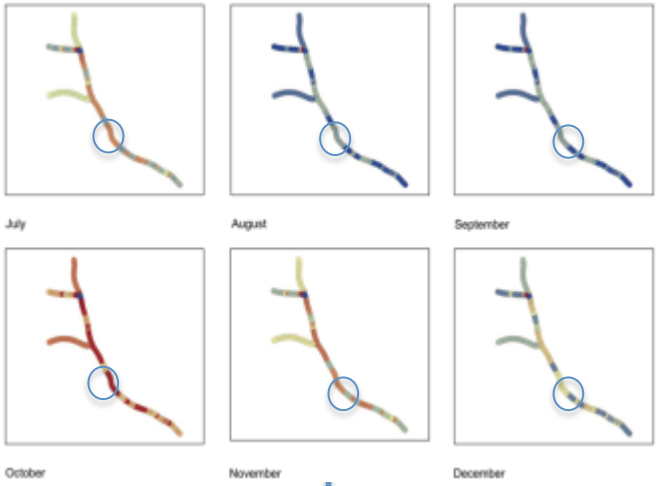


Conclusions and future work

- Methodology for integration with climate projections
- Methodology for scale-up
- Data from several sites
- Strong UK researcher and stakeholder network
- Basis for international collaborations?

A LONG-TERM VISION……





For further information visit: http://www.ismartproject.org/

Contact: Stephanie.Glendinning@newcastle.ac.uk
Tom Dijkstra - tomdij@bgs.ac.uk