
Network Rail

Resilience to and recovery from unstable ground
Perspectives from the UK and further afield

Tom Dijkstra and Susanne Sargeant

outline of the presentation

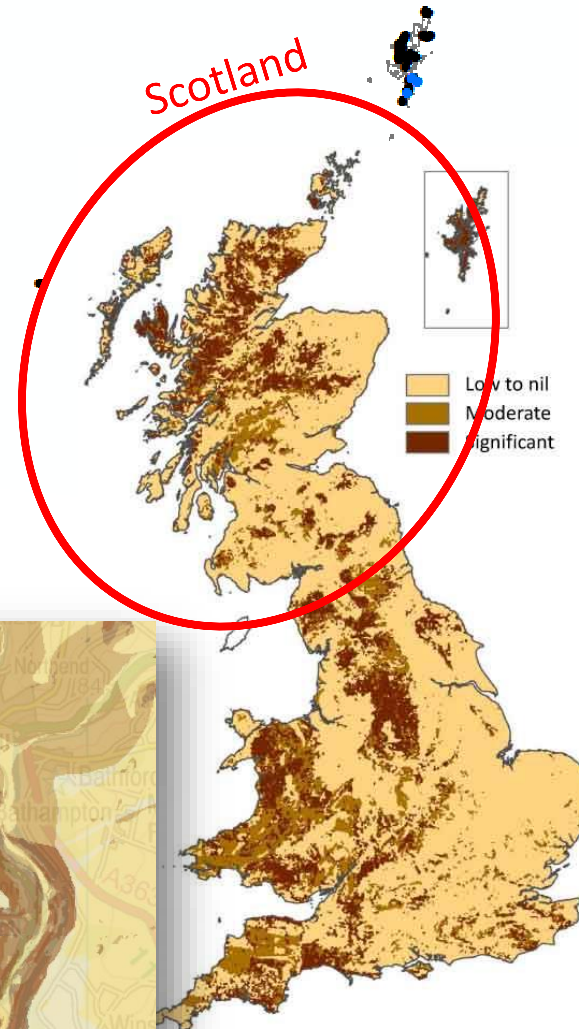
We will discuss a series of examples centred on geohazards

- **Natural terrain landslides in the UK** - highlighting research into operational national daily landslide hazard assessment (DLHA) by the British Geological Survey (BGS) as part of the UK Natural Hazards Partnership (NHP)
- **Landslides occurring in engineered assets (cuttings and embankments)** – highlighting research of the ACHILLES consortium that examines how long-linear infrastructure assets can be better maintained and monitored to make them more resilient for the future.
- **Contributing factors and responses to a debris flow disaster** – illustrated by the Zhouqu 2010 (China) event.
- **Preparing for the future** – recognising potential problems now to limit negative consequences for the future; an illustration from Lanzhou (China).
- **Self-recovery in rural and urban contexts following a major earthquake** - findings of the Promoting Safer Building consortium following the 2015 Gorkha Earthquake in Nepal.

We will then discuss how greater resilience and improved (self-)recovery can be underpinned by an improved knowledge of the geohazards

Natural terrain landslides in the UK

Water balance models to inform daily landslide hazard assessments

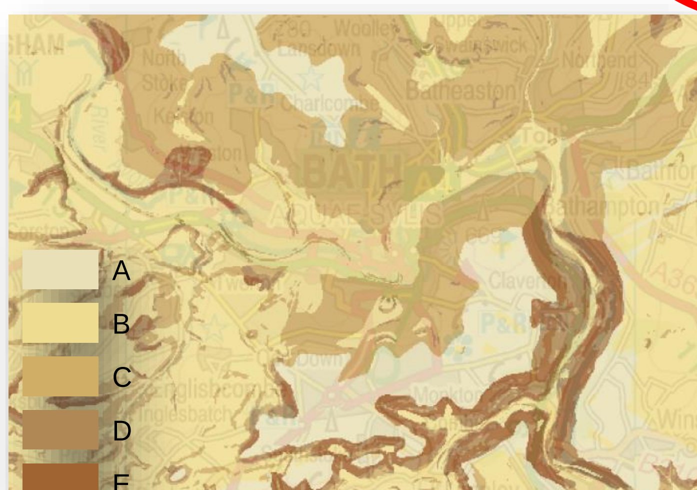


Landslides

- BGS landslides database 18k+ events
- many legacy events, few recent (reported) events
- period of 2012-15 particularly problematic
- effects on transport infrastructure/economy

Landslide susceptibility

- **Geology**
- **Slope angle**
- Quaternary history
- Aspect
- **Geological discontinuities**
- Proximity to streams



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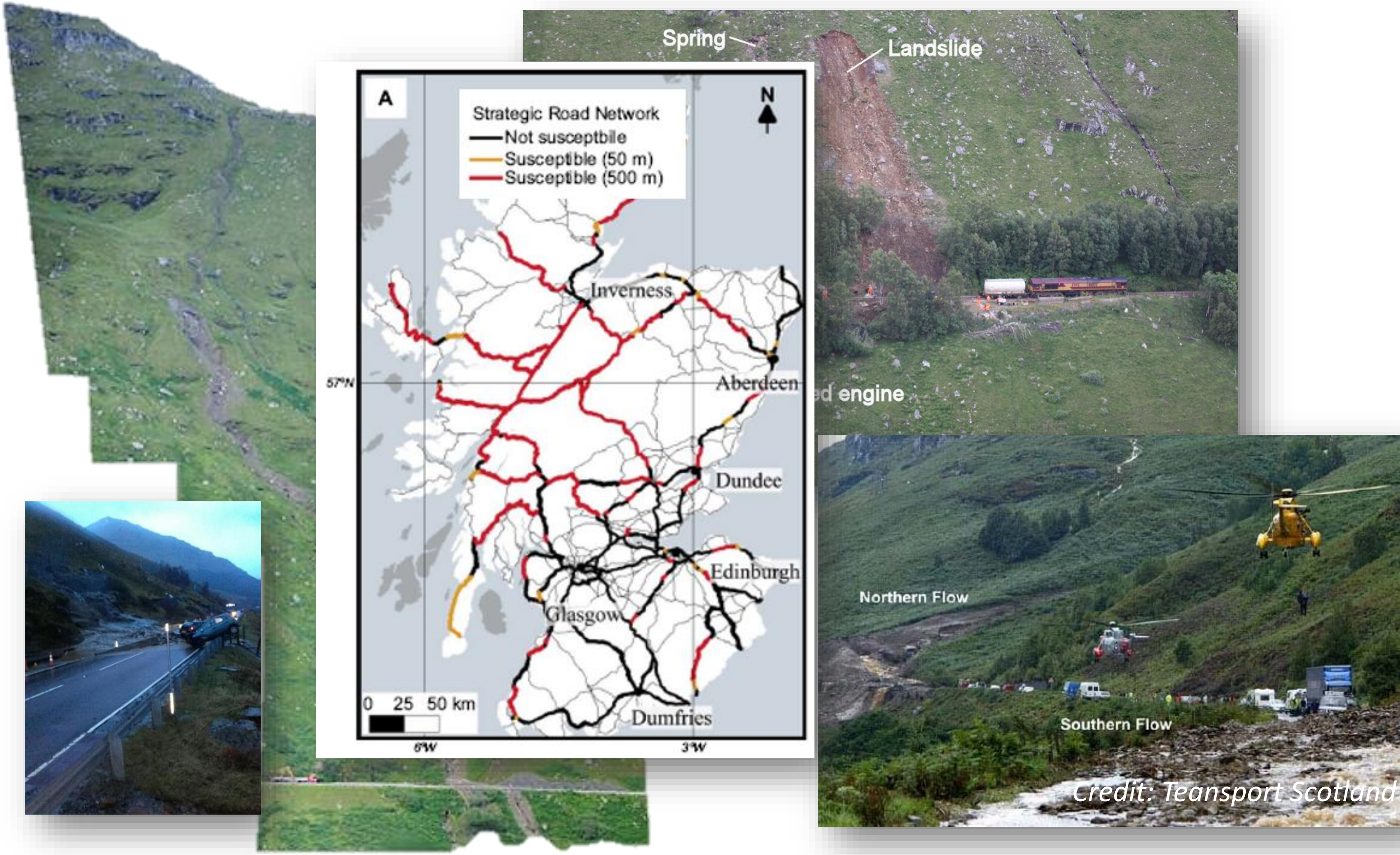
Landslides in Scotland

- attention grabbing events at RABT and Glen Ogle (2010), Loch Treig (2013)
- major concerns about effects on transport/economy (long diversions – 120 miles…)



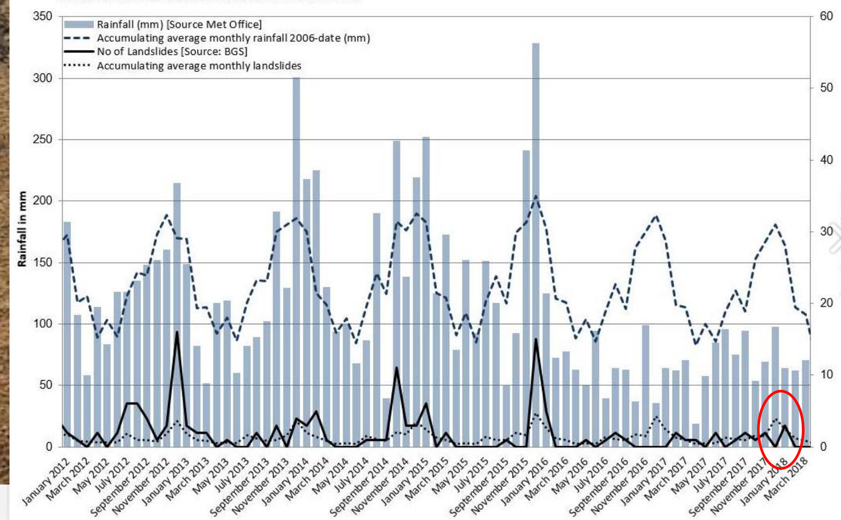
Landslip shuts West Highland Line at Loch Eilt for several days

22 January 2018

Share

SCOTRAIL ALLIANCE

Five passengers were on the train. No-one was hurt



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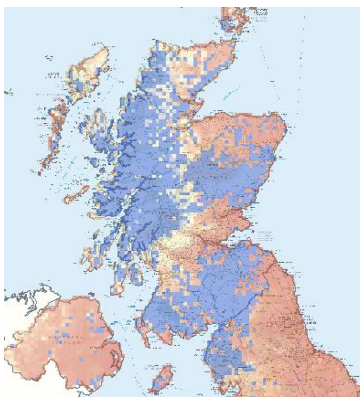
The water balance model

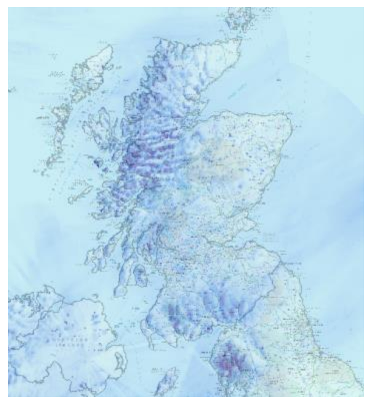
Complex interactions between landscape conditions and weather event sequences affect timing and regional granularity of various warning levels.

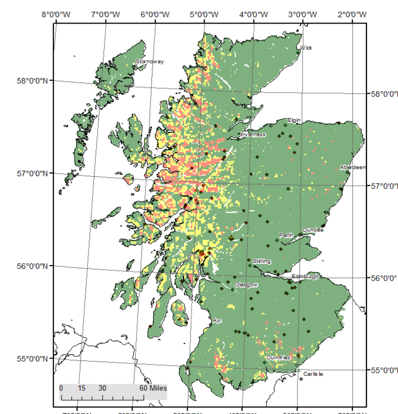
The main focus is on **precipitation-driven events; translational landslides** in the shallow sub-surface (that can potentially progress into flows). **Rapid onset events, mainly first-time…**

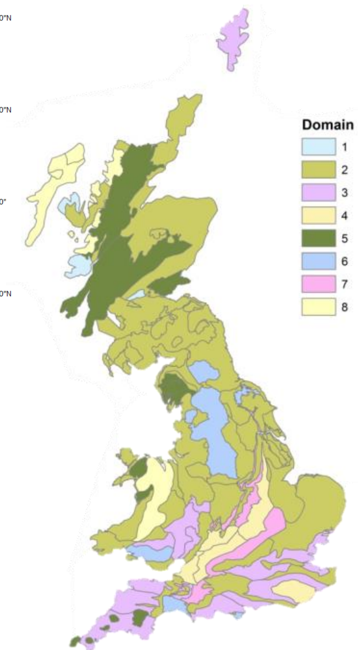
Antecedent 'slope condition' (slope hydrogeology/engineering geology) provides a baseline against which we can evaluate the potential effect of **forecasted precipitation**

soil moisture day x + precipitation day x+1 = soil water 'threshold output'







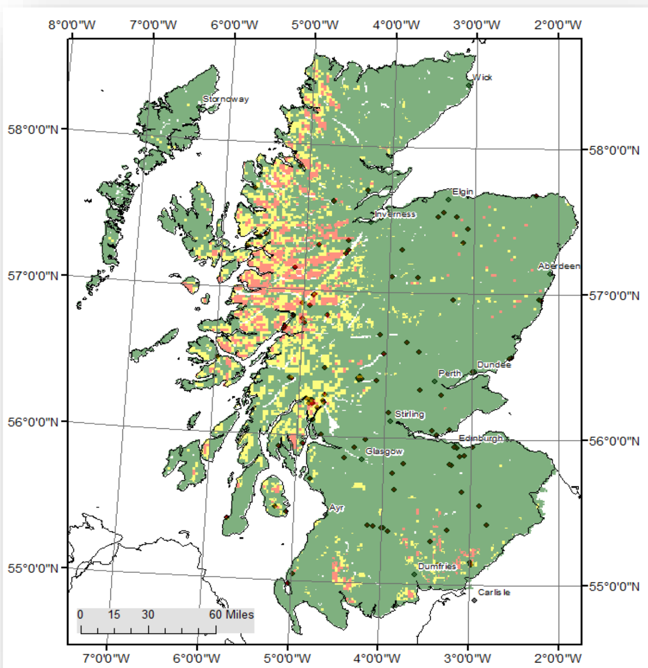


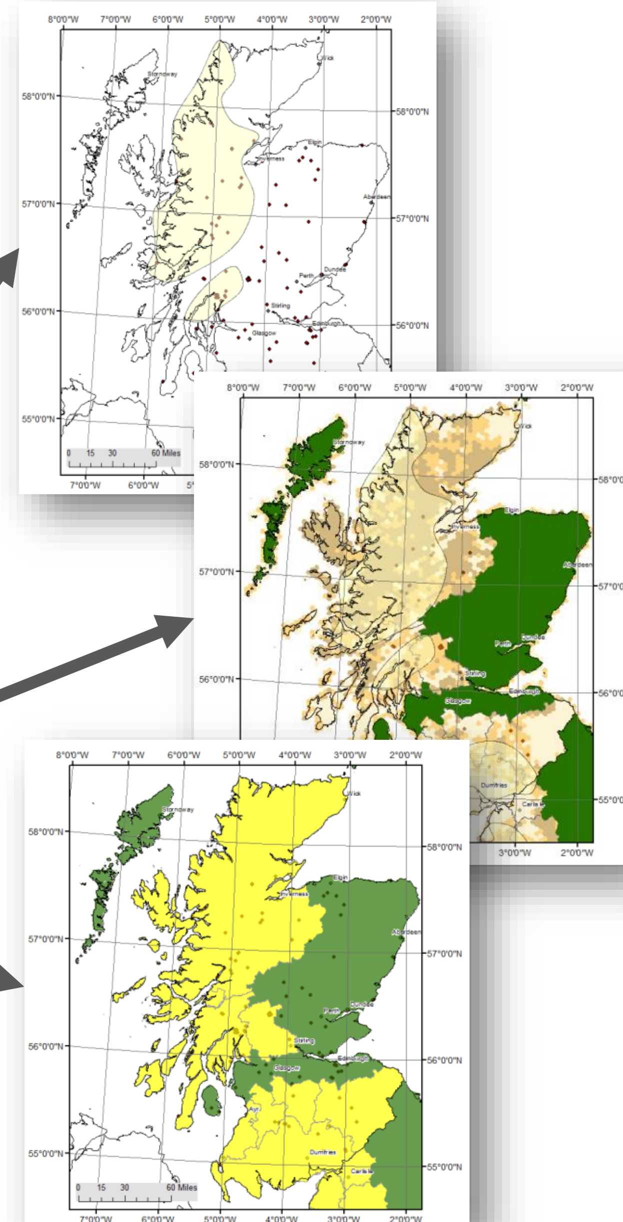
inputs from supporting projects:

- regional relevance informed by landslide domains/expert knowledge
- **natural** (dominates historical LSD) versus **engineered** slopes (reported)
- slope 'geotechnical condition' ('old' versus 'new' slopes)

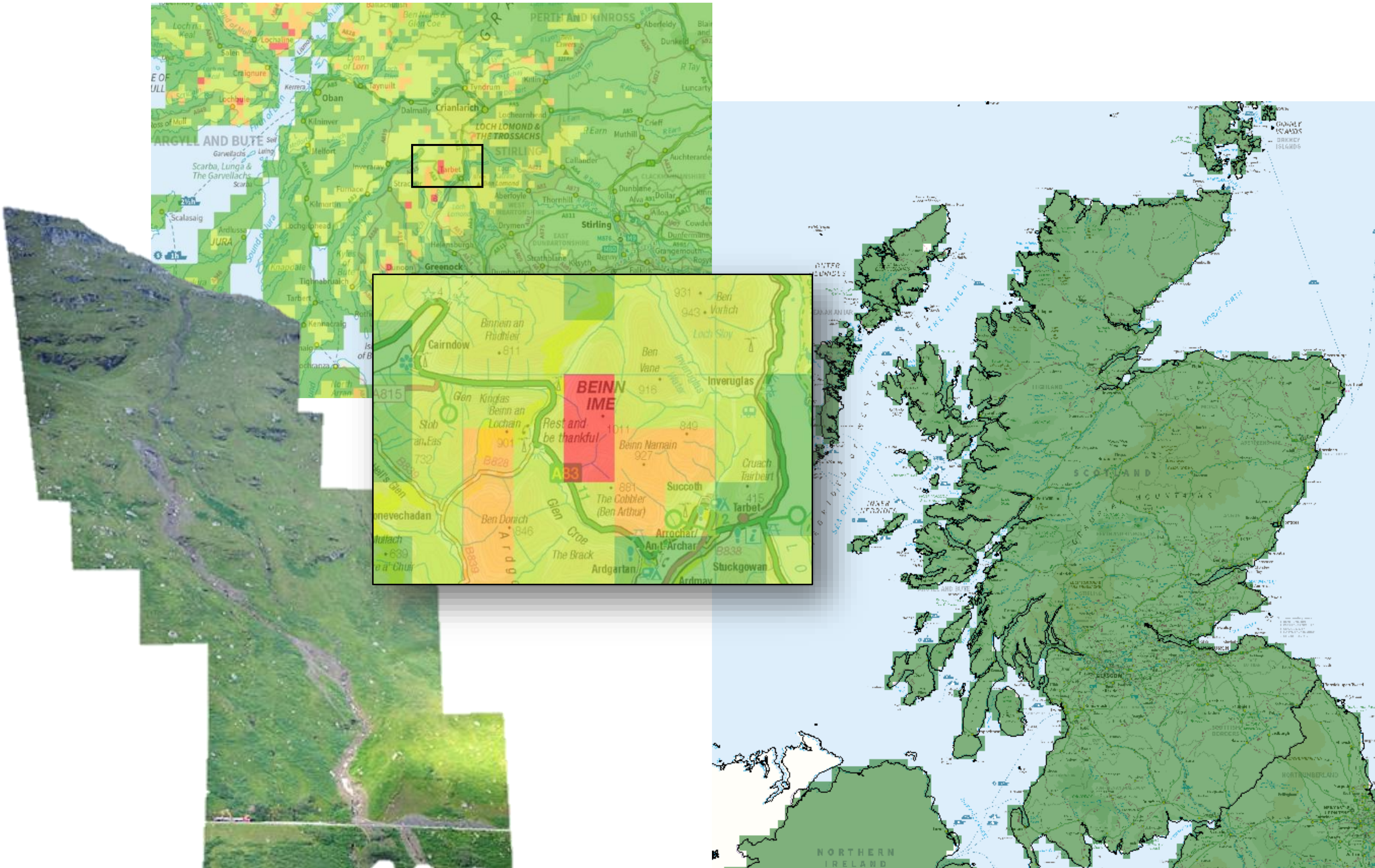
communicating the outputs

- The DLHA needs to be useful for the stakeholders
- The DLHA is considered a forward look of the wider picture
- Impact based assessment: Hazard + Exposure + Vulnerability
- Regional scale: does not replace information and knowledge held at local scale
- Working with stakeholders to address future communication options





DLHA examples



concluding remarks

- Big step forward in evolutionary process of DLHA in GB
- A pragmatic approach working with existing datasets
- Providing important information about soil moisture fluctuations on a regional scale
- Learning what it means - it's all relative…
- Plans to make model more complex better representing hydrogeology and extending to rest of GB

acknowledgements

This work is the result of contributions from a large number of individuals

We would like to specifically thank the following:

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- Jo Robbins, Rutger Dankers and Robert Neal (Met Office),

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- LiveLands (IAP/ESA; CGG)
- GO-Science (UK Gov't)
- NERC/UKRI (research council)

BEAR Scotland 16/05/2018 Soil nailing at RabT A83

ACHILLES programme grant EPSRC

Landslides occurring in engineered assets (cuttings and embankments)

the ACHILLES team

Peter Helm, Paul Hughes, Tom Dijkstra, Jimmy Boyd, Kate Dobson, William Powrie,
John Preston, Stefano Utili, Harry Postill, Ali Smith

Chris Kilsby, Ross Stirling, David Gunn, David Toll, Mo Rouainia, Stephanie Glendinning,
Darren Wilkinson, Neil Dixon, Jon Chambers, Joel Smethurst

not on photo: Kevin Briggs, Fleur Loveridge, Jon Warwick

Newcastle University, Loughborough University, Durham University, University of Southampton, University of Bath, University of Leeds, British Geological Survey (Natural Environment Research Council), EPSRC

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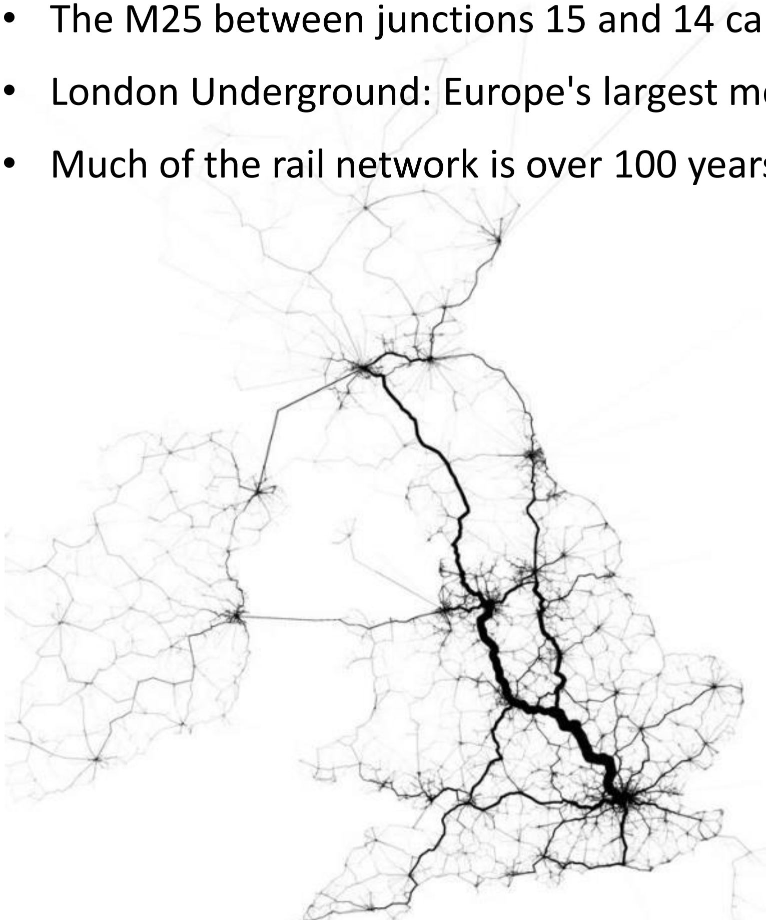
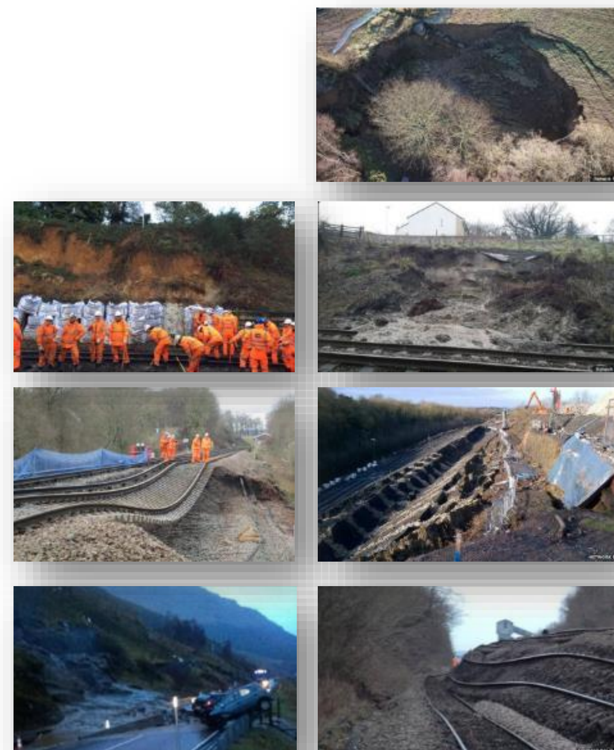
Context

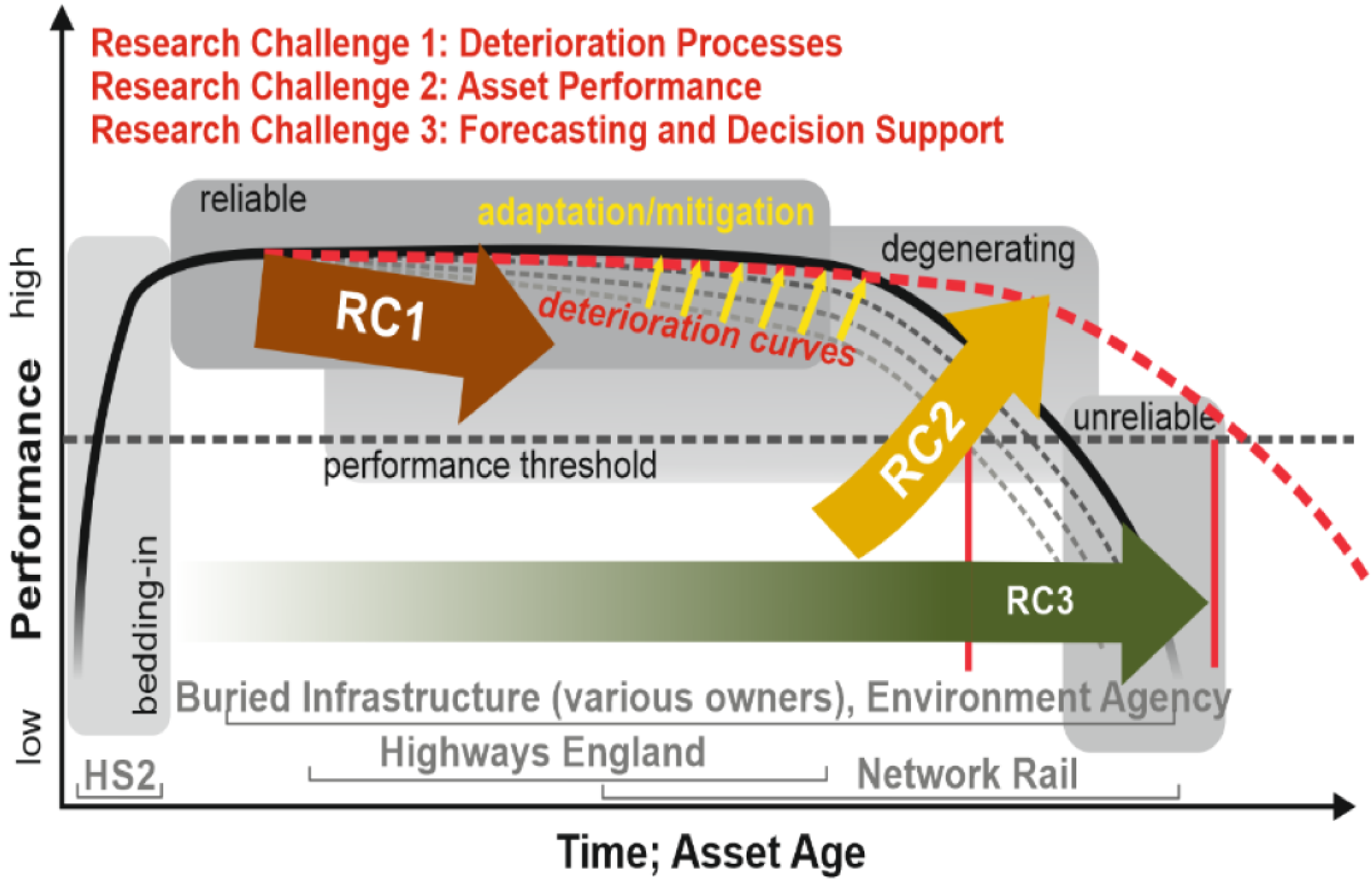
- The UK’s transport infrastructure is one of the most heavily used in the world
- The UK rail network takes 50% more daily traffic than the French network
- The M25 between junctions 15 and 14 carries 165,000 vehicles per day
- London Underground: Europe's largest metro subway system but also the oldest
- Much of the rail network is over 100 years old



Eric Fischer @enf
Mapping >1M tweet-based trips August 2011



Asset deterioration – ACHILLES programme



Processes and key questions

- **Aging of slopes**
  - rainfall and temperature cycles over a range of timescales can cause progressive failure
- **Hydrological triggering**
  - pore water pressure increases reduce effective stresses and hence soil strength and can trigger slope instability
- There are **many contributing factors**
  - geometry, stress history, vegetation, land use, engineering works, unintended human activity etc
- **Key questions**
  - Which slopes are susceptible (materials and geometry)?
  - How many cycles (i.e. years) will result in failure?
  - Will greater extremes in the magnitude of the pore pressure cycles reduce the number of years to failure?
  - Are there simple mitigation measures?

Better inputs into models

- **Soil water retention**
  - laboratory investigations
  - from field monitoring
- **Permeability/hydraulic conductivity**
  - field investigations
  - permeability functions
- **Strength**
  - water content
  - suction
- **Deterioration**
  - at the micro-scale and effect of freeze-thaw
  - at the macro-scale (cracking)

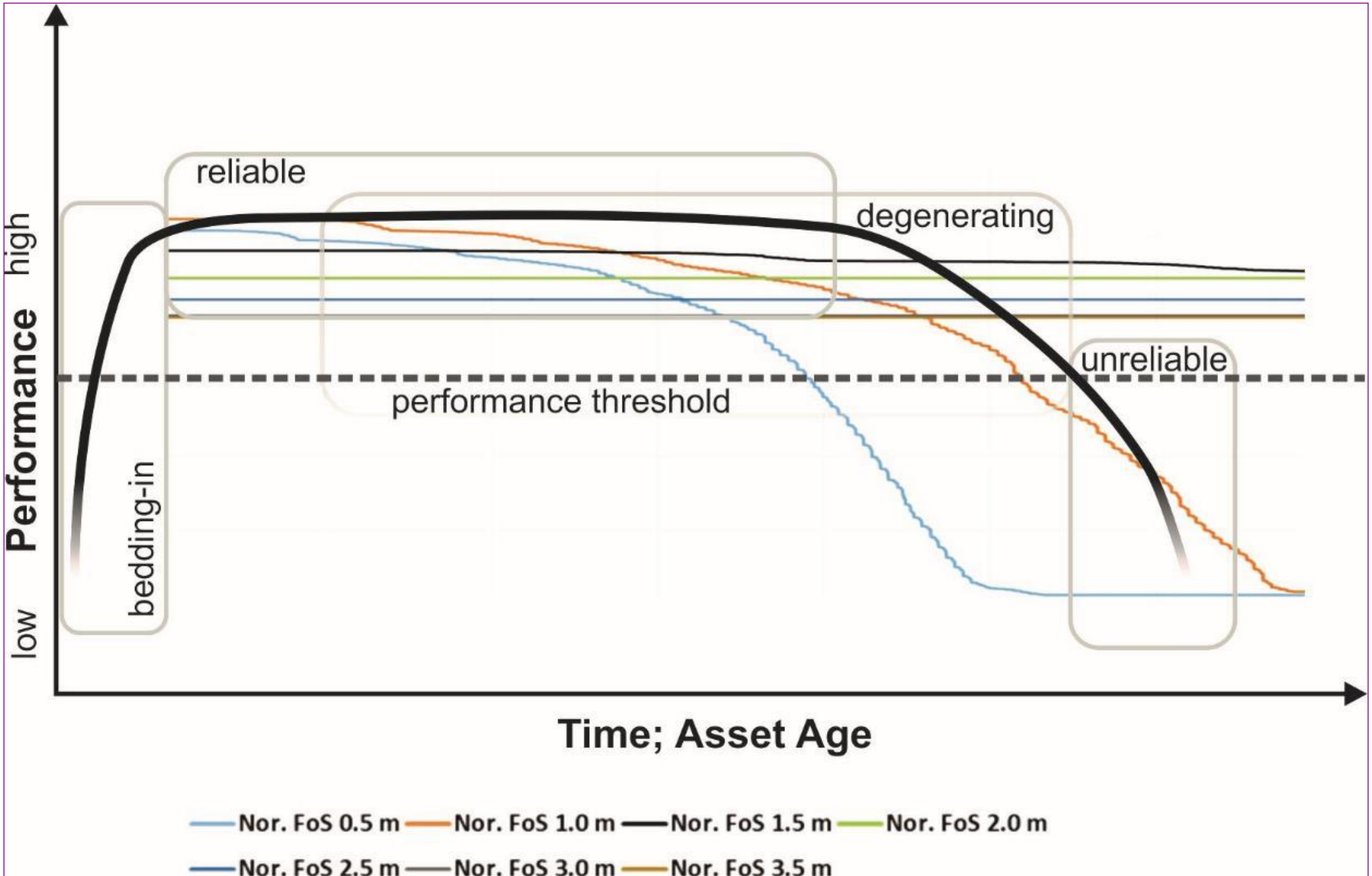
Key messages

- **Rate of change** (SWRC and strength) **is non-linear** - greatest change observed after primary drying. Subsequent rate of change and magnitude is lower BUT ***cycling effect is continuous***
- **Macro-scale cracking increasing exposure and influence** – it renews and perpetuates W/D cycle effect – deterioration at nano to macro scale.
- W/D is a pre-cursor to the initiation of **progressive failure** - causing the soil at the near surface of an engineered clay slope to reduce in strength without any change in external load.

Implications for slope condition (stability) assessment

- the need for **non-stationarity of soil parameters and ground model**, with changes occurring both seasonally and gradually over time.
- there is a need for **new constitutive soil model**(s) that can account for soil deterioration due to wetting and drying

Deterioration curve: the 'bath tub'



Modelling approach: key findings

- There is ***conclusive evidence*** for **seasonal ratcheting progressive failure** mechanisms in constructed slopes
- However, it remains **challenging to model** this seasonal ratcheting mechanism!
- Use of an **unsaturated framework** is critical
- Key input parameters are:
  - high permeability near surface layer (measured in the field)
  - SWRC
  - stiffness distribution
  - strength behaviour
  - cracking
- **Non-local strain** minimises mesh dependency

- *Our models can replicate measured pore water pressures in a slope and weather driven progressive failure – the approach has been validated!*

Conclusions

- We have considerably advanced the **numerical models** of climate driven slope failure and their **inputs**, including a **novel deterministic approach** to use UKCP09 data.

- We have successfully demonstrated the likely mode of deterioration and failure, and created **deterioration curves** that reflect these.

- The **time to failure** is still not correct, but we are working to correct this.
- Further work is also continuing to incorporate more **extreme weather** events.

- The model can be used to demonstrate that **future climate effects** have an adverse impact on slope stability.

What next?

- Greater understanding of **weather-driven deterioration processes**
- Detection of **pre-deformation deterioration**

- Embedding **new material models** in numerical analysis
- Evaluate influence of **cracking** and **vegetation** (roots, soil hydrology)

- More research on **material imaging** and **discrete element modelling**

- **Performance curves** for a range of indicators and scales
- More reliable use of **asset data** and making a business case for monitoring

- Improving our understanding **uncertainty** and **heterogeneity**
- Use of performance curves for investment in **whole-life management of assets**

Zhouqu debris flow disaster 2010

Contributing factors and responses to a debris flow disaster

འབྲུག་ཆུ་རྫོང
Zhouqu, China
7/8 August 2010

Geomorphological/geological controls and the impacts of a disastrous debris flow

a large group of people involved acknowledged at the end…

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location/geography

Zhouqu (Zhugqu) – county capital

- Bailong River, southern Gansu
- Annual average temp 12.7 degrees
- Rainfall 400-800mm

Main income

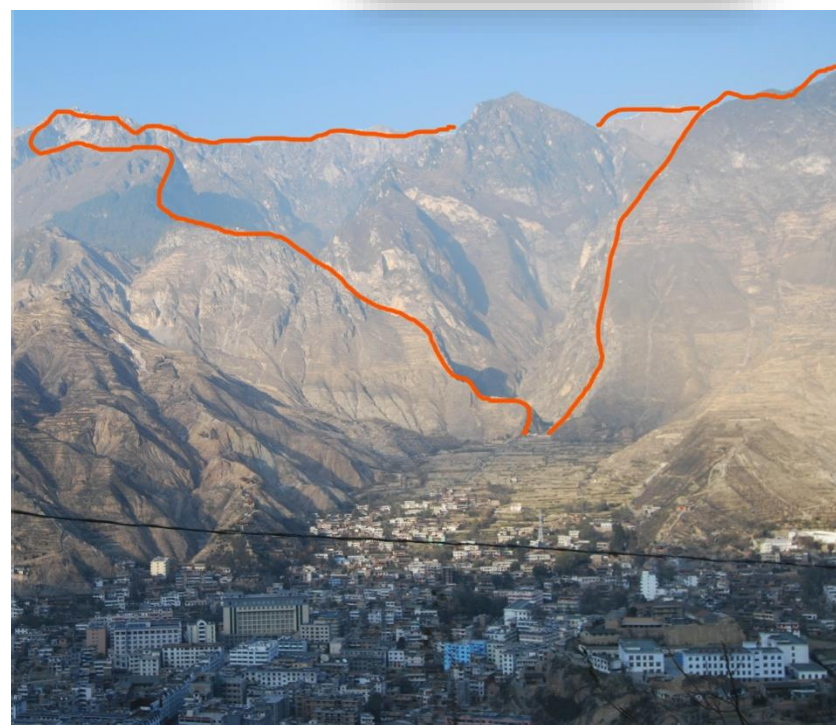
- mining, hydro-electricity,
- agriculture

Development

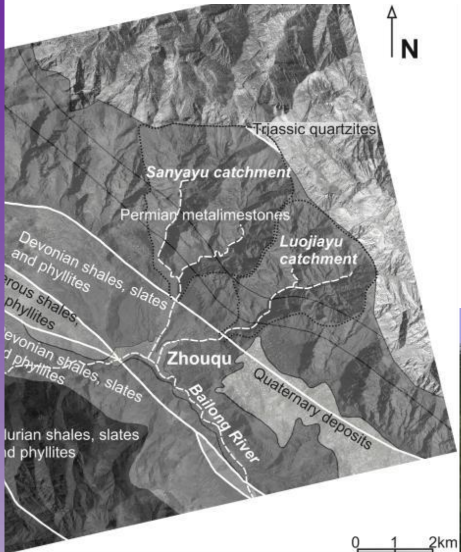
- rapid recent development,
- future train link nearby,
- 30 years ago only few buildings,
- geo/topography limits construction

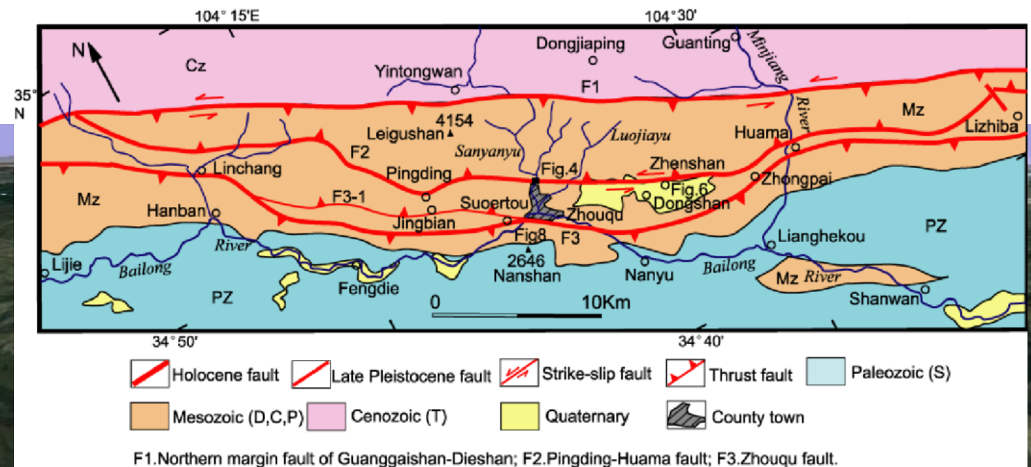
Concerns

- effects of Wenchuan 2008 earthquake
- reactivation of large landslides
- e.g. Mudan, Souertou landslides



geology and neotectonics





Geomorphology/geology/rainfall

- highest peak 3830m
- erosion base 1340m
- meta-limestones/slates
- fault controlled topography

Sanyanyu catchment

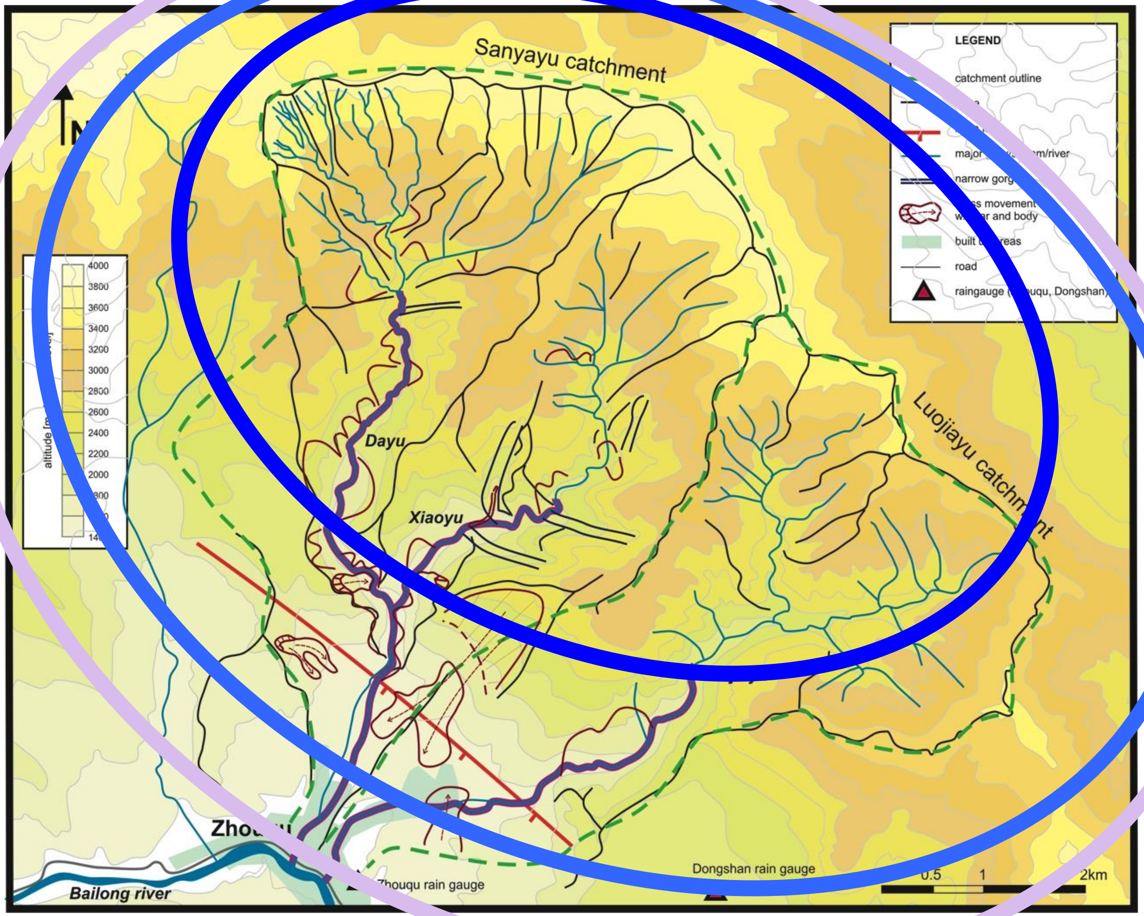
- largest 26km^2
- Dayu and Xiaoyu catchments
- max channel length 10.5km
- average gradient 14 degrees
- >35 degrees; fan 6 degrees
- exit only 40m wide

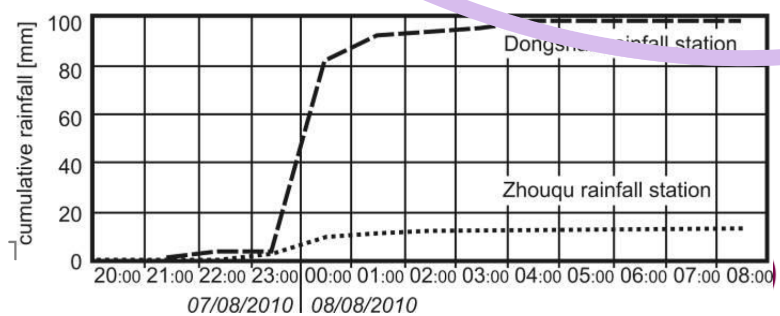
Luojiayu catchment

- 16km^2
- exit <10m wide

Rainfall trigger

- Zhouqu 1400m asl
- Dongshan 2150m asl
- > 77mm in 1 hour





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Zhouqu disaster 7/8 August 2010

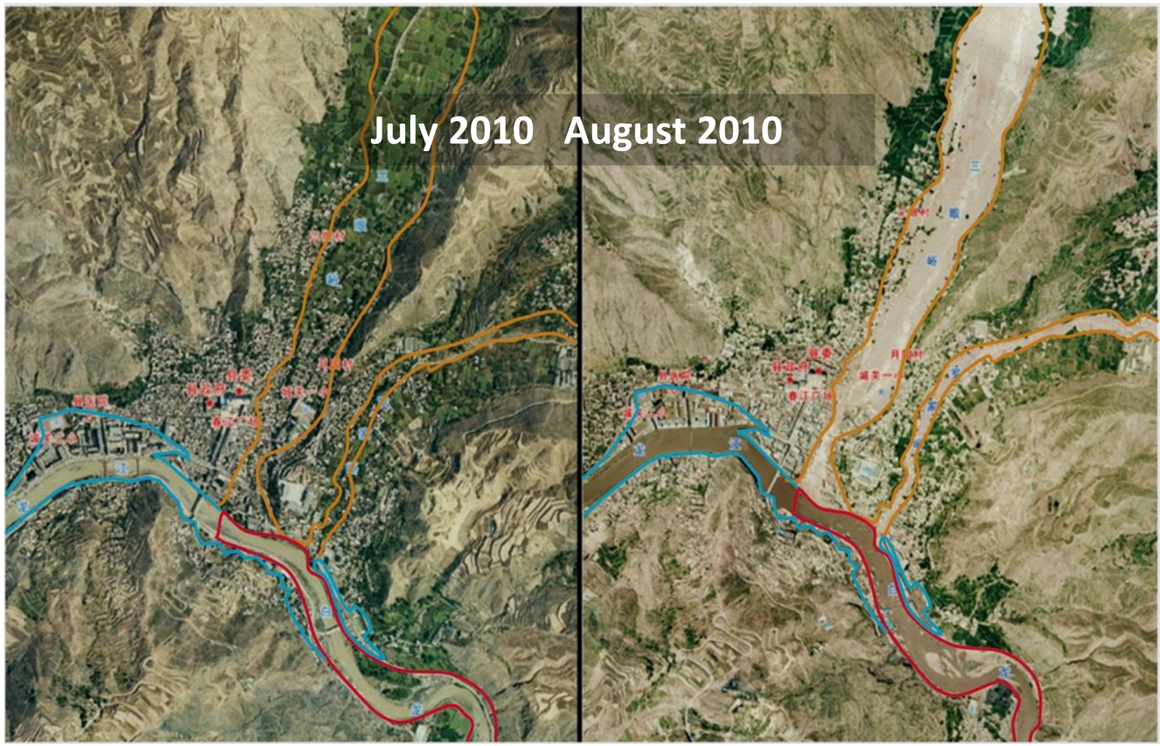
the event

11:30pm Saturday 7 August

- start of first wave of debris

00:30am Sunday 8 August

- debris flow activity ceased

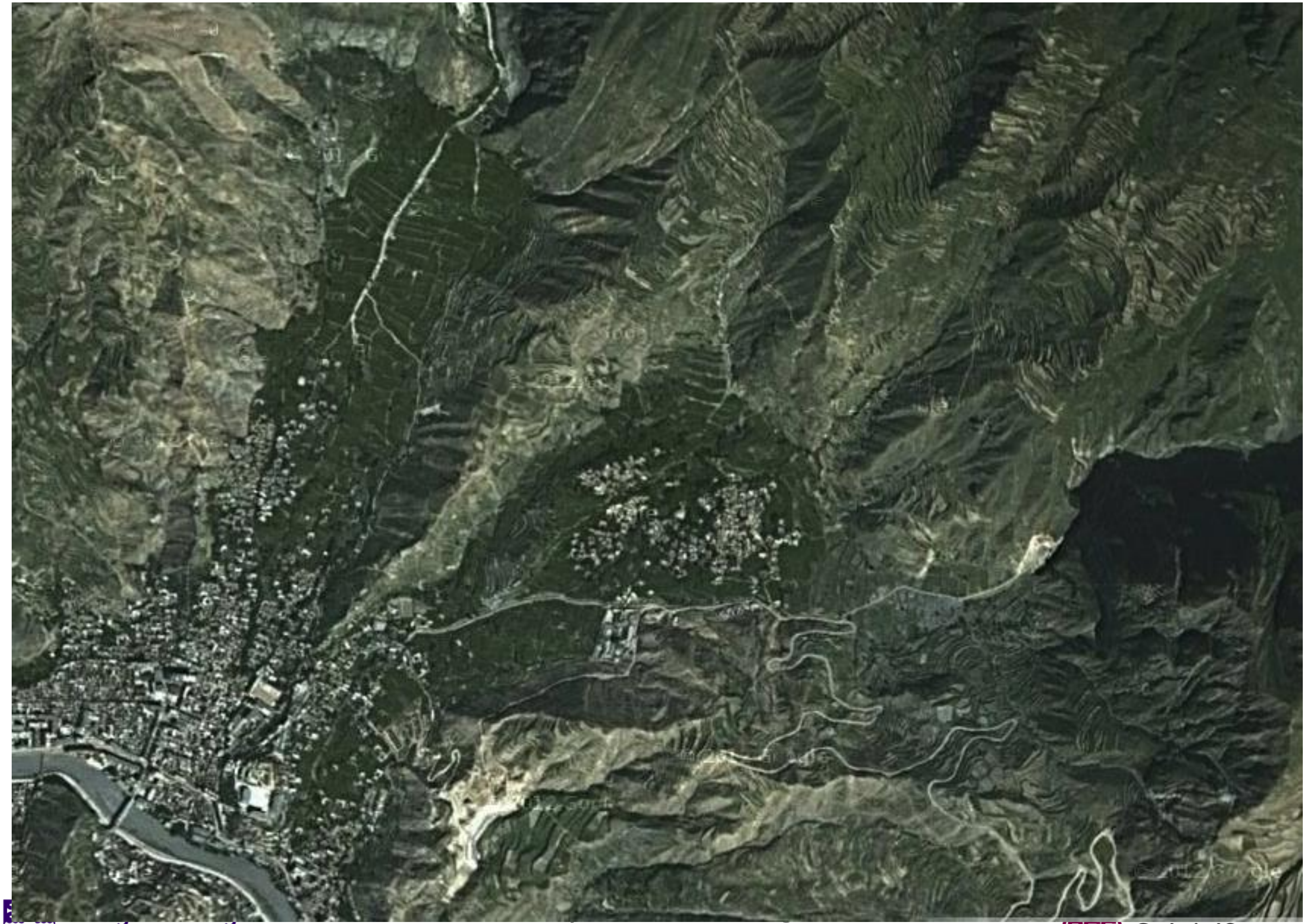


Source: State Bureau of Surveying and Mapping 2010

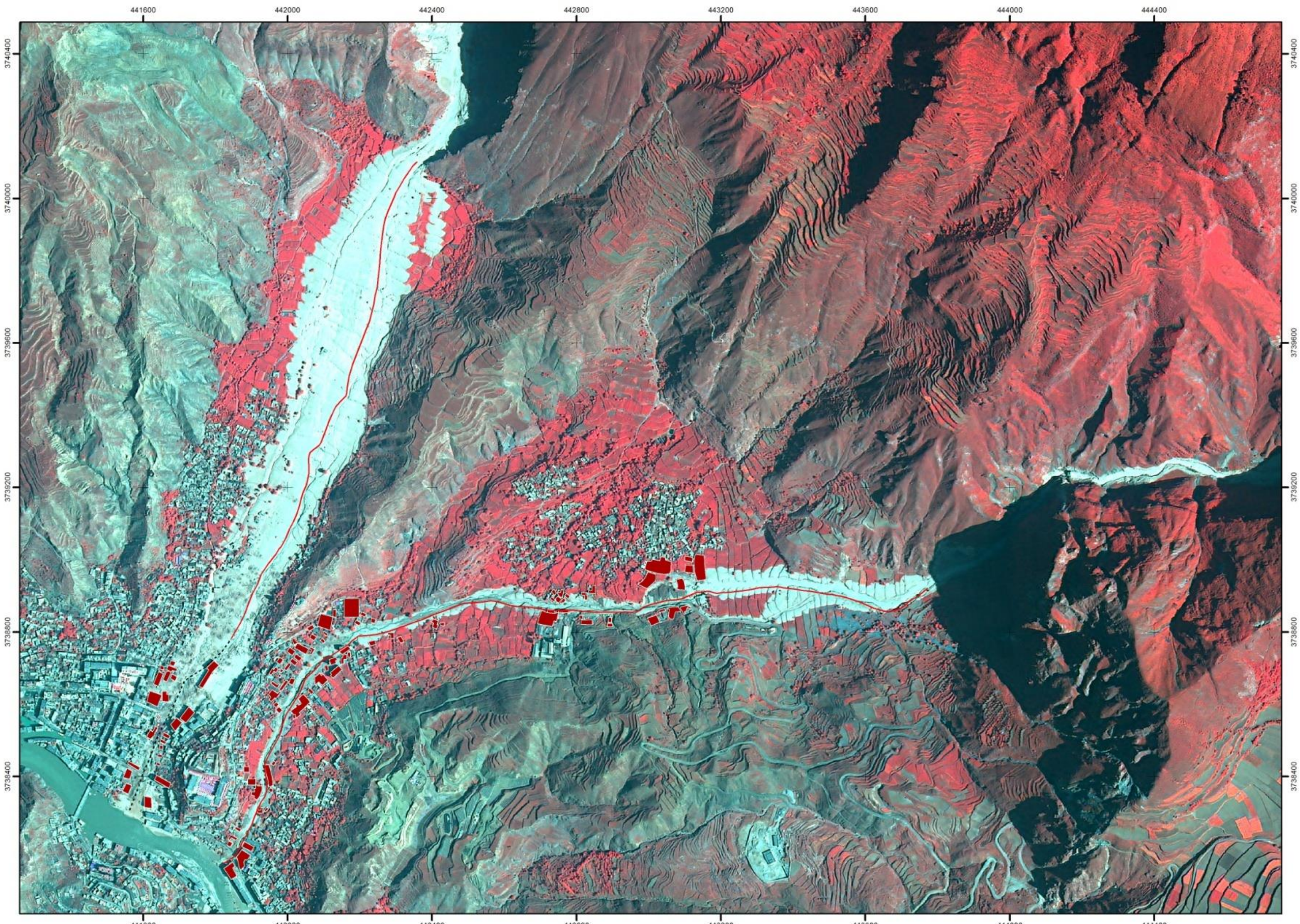
the consequences

- more than 1500 deaths
- more than 200 buildings destroyed
- blocking of the Bailong river
- enhanced instability of channels in upper catchment (Min Shan)
- significant research effort to address geohazards in Gansu/Sichuan

Quickbird pre-disaster



KOMPSAT post-disaster



Debris diversion channel: *Alignment of debris flow diversion channel mapped during a walkover survey.*

Debris diversion channel *Approximate alignment of debris flow diversion channel.*

Risk map: *Buildings and infrastructure at risk from future debris flow activity.*

Image: Kompsat colour composite (Bands 123)

N

Meters
0 75 150 300

I COUNCIL

aerial view, 08 August 2010

An aerial view of the town of Zhouqu shortly after a deadly flood-triggered landslide, seen on August 8, 2010. (STR/AFP/Getty Images) From boston.com

Zhouqu debris flow disaster 2010

st 11, 2010. (STR/AFP/Getty Images)

1500–2000 m^3/s
front 18m high,
waves a further 4m

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Zhouqu debris flow disaster 2010

ıerial view of the flooding in Zhouqu county. (STR/AFP/Getty Images)

Zhouqu debris flow disaster 2010

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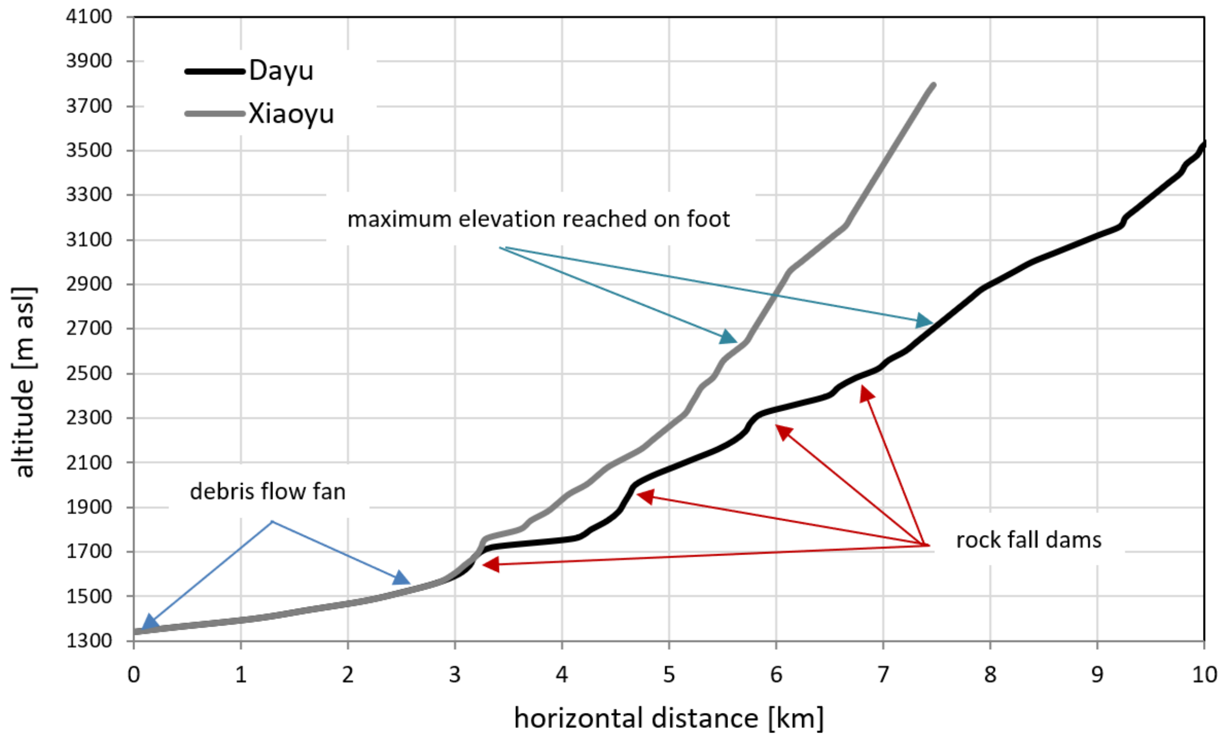
…

Chinese rescuers use explosives in an attempt to clear blockages and release the water of Bailong River in Zhouqu, China on August 11, 2010. (STR/AFP/Getty Images)

geomorphological controls

- stepped longitudinal profiles
- knickpoints formed by rockfalls, landslides
- possible correlation with historical earthquakes
- large volumes of available material



mitigation

originally planned

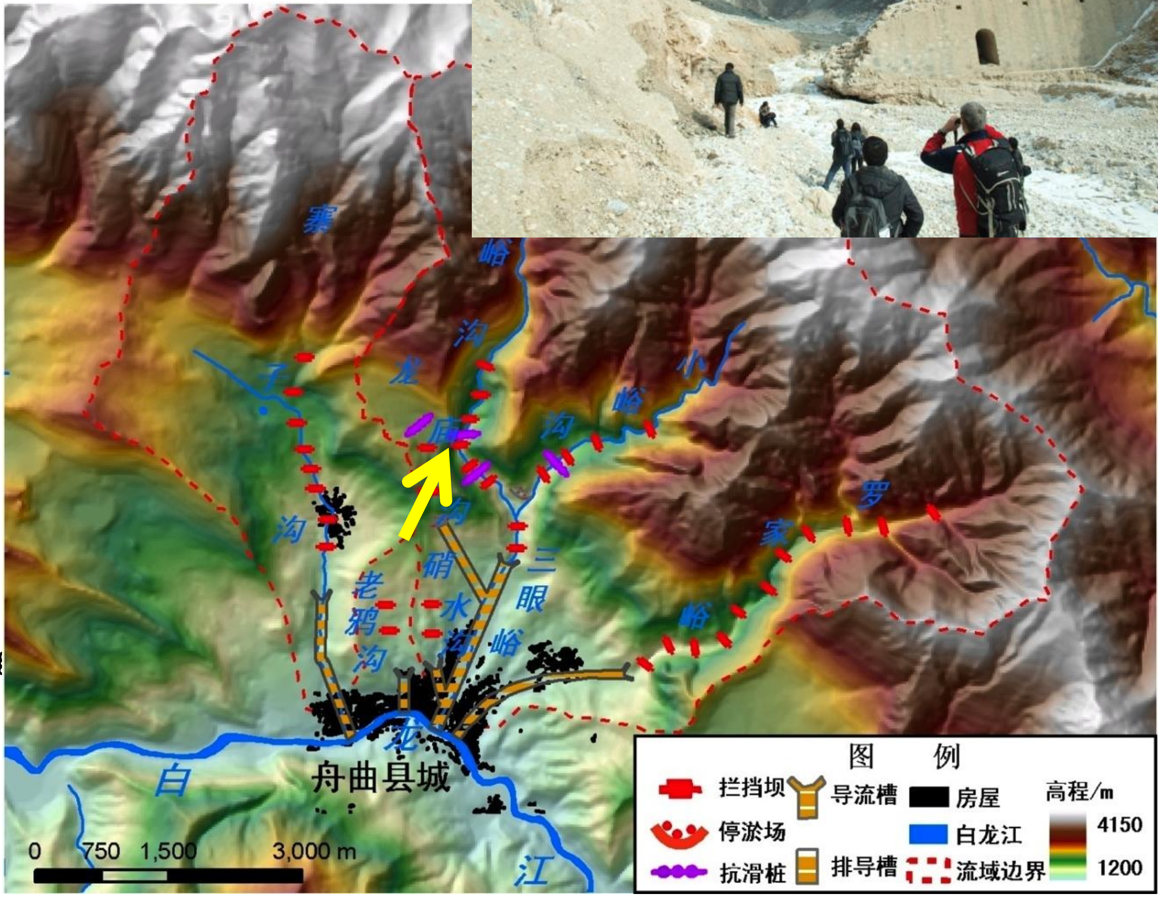
- debris collection dams
- lined channels
- high quality construction

What was in place…

- not all completed
- unreinforced
- poor construction
- debatable function…

'Stabilisation' works

- channels
- more dams
- river alignment and bank strengthening



Zhouqu debris flow disaster 2010

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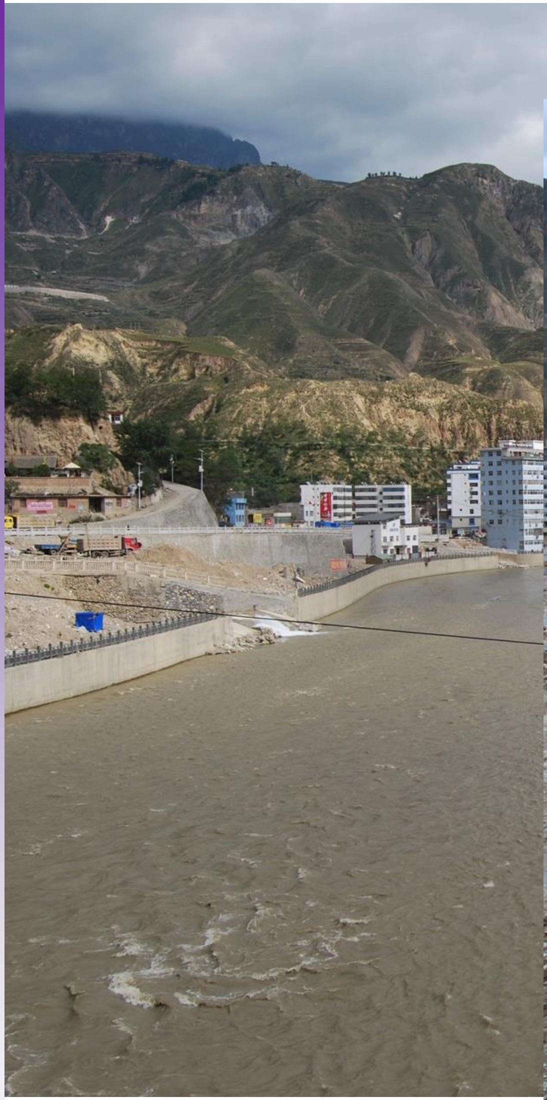

processes in a dynamic environment

- landscape evolution, process analyses
- geohazard/risk assessment

- control versus management
- can we stop these processes?
- does it result in complacency?

acknowledgements

- Lanzhou University; Prof Meng Xingmin, Dr Jinhui Ma, Dr Dongxia Yue, Dr Jie Gong
- Lanzhou University students; Peng Guo, Guan Chen, Yajun Li, Runqiang Zeng, Liang Qiao, Wei Zhou, Haixiao Zhang and Xiaobin Yang
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- Loughborough U, UK; Jim Chandler, Rene Wackrow
- BGS, UK; Helen Reeves, Claire Dashwood, Katy Lee, Pete Hobbs

University of Portsmouth

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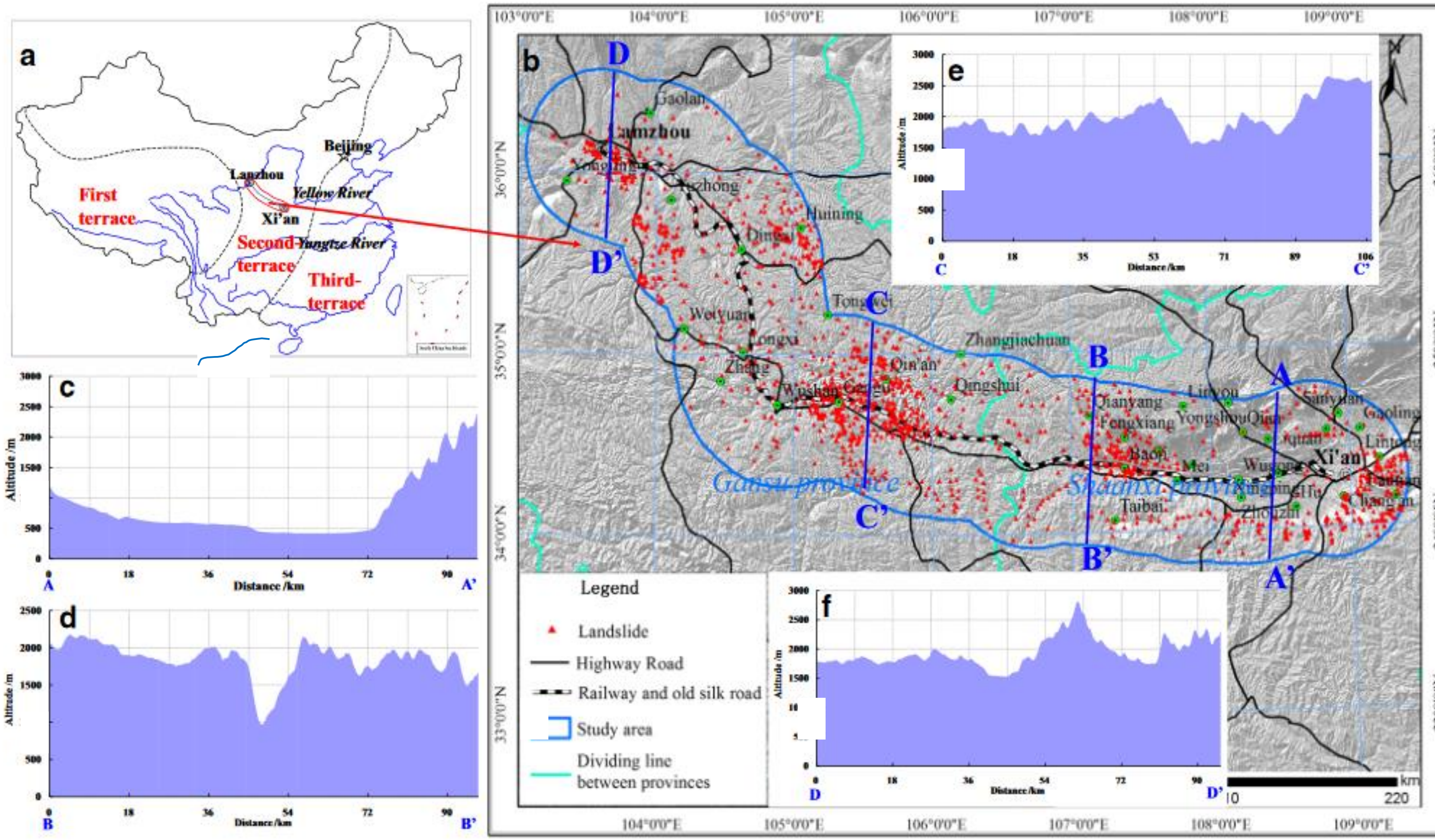
Creating a legacy- Lanzhou

黄 土

Unstable Urban Landscapes
Lanzhou, Gansu, China

What's loess got to do with it?
(cf. Turner, 1984)

The Silk Road Region Xi'an - Lanzhou



- Wei He Graben + Huang He corridor
- Loess – aeolian and reworked
- Geological controls – neotectonics, lithologies
- Geomorphological controls – landscape development

Zhuang, et al. 2016 Spatial distribution and susceptibility zoning of geohazards along the Silk Road, Xian-Lanzhou. Environ Earth Sci 75:711

Unstable urban landscapes Lanzhou

Planated river terrace surfaces and undulating bedrock covered by loess.

Max thickness 300+m

Floodplain/terraces fully developed

Many newly created plains

Highlighted in Special Themes in Quarterly Journal of Engineering Geology and Hydrogeology

Dijkstra, Meng, Winter, Wasowski 2014

Big plans for urban landscape development in Lanzhou

ualisation from an international npetition

60 km Huang He river edge
Aqua Culture parks
Redevelopment of brownfield sites
WHO pollution status
- electric mass transit
- urban forest islands
- wetlands

A greener Lanzhou….

Urban landscape development

Unstable Urban Landscapes – Lanzhou

New landscapes in Lanzhou

engineered interventions

- cuts
- fills (over old surfaces),
- tunnels

consider

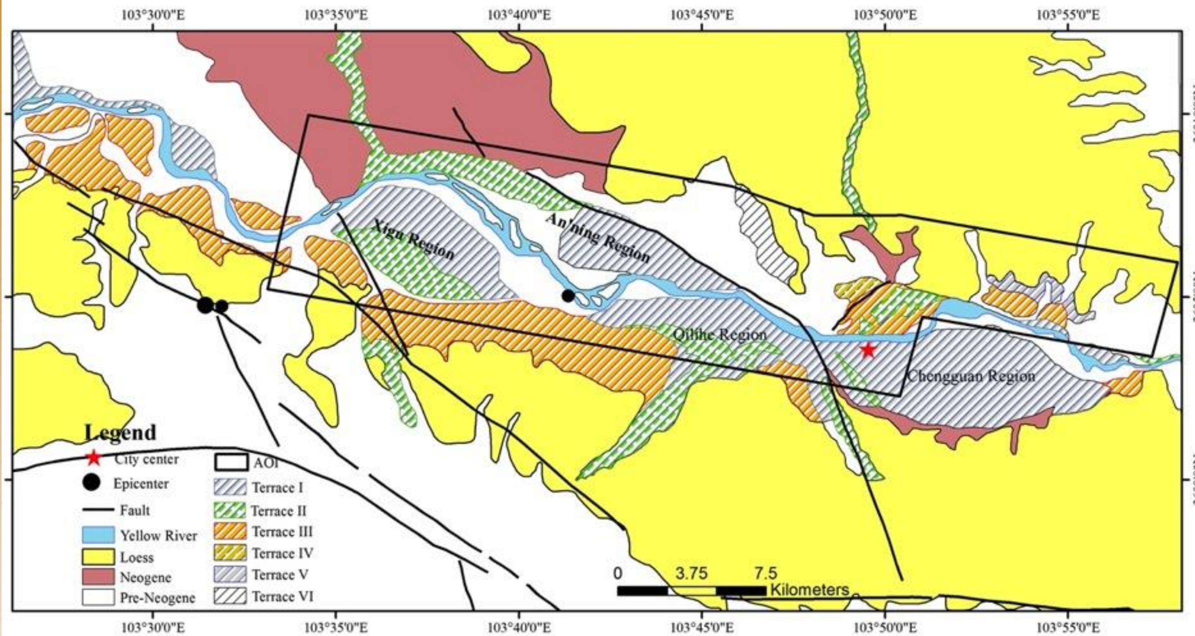
- density control,
- stability of slopes,
- stability of new surfaces

- sinkholes (internal erosion),
- soil structure interaction,

- drainage,
- preferential flow pathways,
- influence of irrigation,
- erosion (rivers),

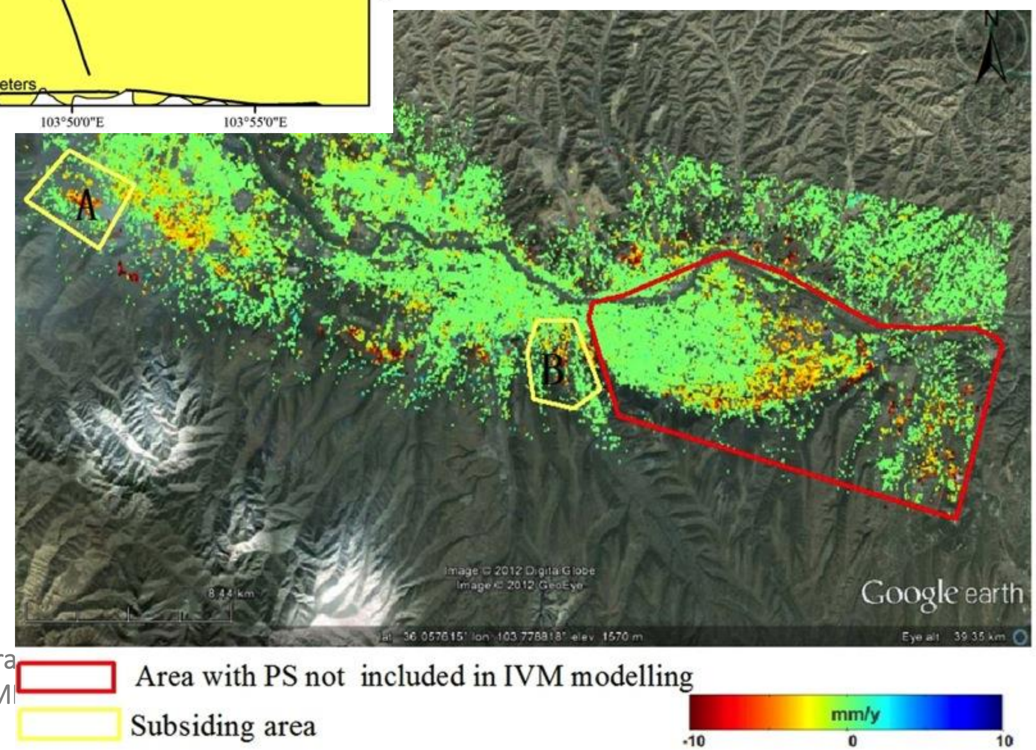
- cascade failures
- stabilisation techniques
- use of geophysics to monitor change

Unstable surfaces in Lanzhou



- planated river terrace surfaces covered by loess.
- max thickness 328m
- surface deformations picked up by PS-InSAR
- more InSAR work continuing Lanzhou-BGS

collaborative work with Prof Meng, Lanzhou and Dr Wasowski, CNR, Italy. Zeng et al 2014



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SO….What's loess got to do with it?

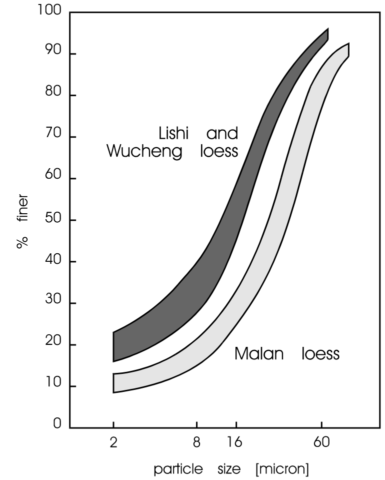
meta-stability processes in loess

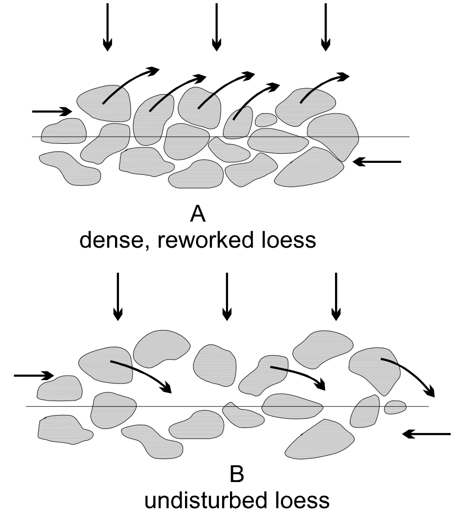
- packing transformations

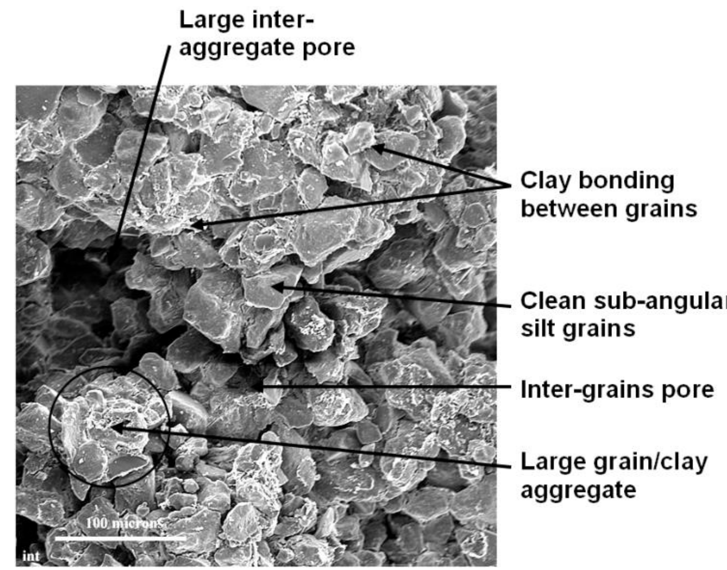
- shear strength
- soil moisture variations
- geochemistry

- stratigraphy
- palaeosols

- bedrock contacts
- old erosional boundaries
- neo-tectonic shear systems







Landslides

Widespread evidence of an unstable loess landscape

- 1920 Haiyuan earthquake
- 1983 Sale Shan catastrophic mass movement
- Landslide database (300+), mapping of 1000km^2

"mountains that moved in the night;

landslides that eddied like waterfalls,

crevasses that swallowed houses and camel trains,

and villages that were swept away

under a rising sea of loose earth"

Close and McCormick (1922) Where the mountains walked.

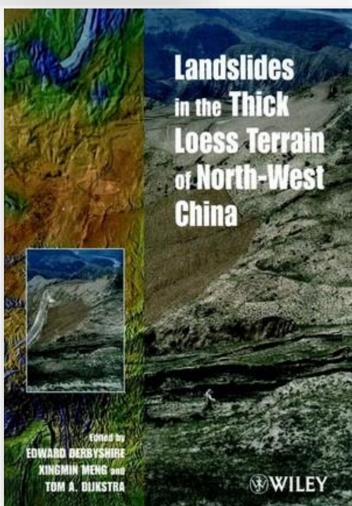
The National Geographic Magazine, Vol. XLI, No. 5

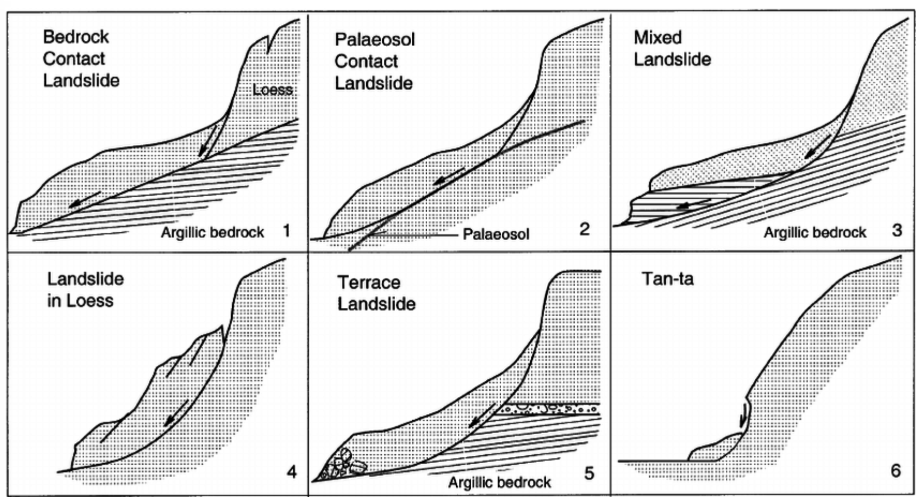
Loess landslide project

The importance of international collaboration to achieve scientific success

1987-95: European Community and Gansu Academy of Sciences
Prof Ed Derbyshire, Prof Wang Jingtai ***+ Prof Meng Xingmin***

- China - Geological Hazards Research Institute
- United Kingdom – Universities of Leicester, Liverpool, Loughborough, Royal Holloway
- France – CNRS (Meudon), IGN (Paris)
- Netherlands – Utrecht University





Urban landslides in Lanzhou

plantations/irrigation

- water management
- surface preparations?
- drainage?
- vegetation management?

unstable slopes

- stabilisation of known risky slopes
- monitoring of internal processes?
- groundwater tracing?
- fresh cutslopes

new construction

- cut and fill
- positioning?
- whole life cost planning?

risk assessments

- trigger mechanisms; EQ, rain, cuts, loading, groundwater, etc.
- impacts
- R=PVE + perceptions

industrial development and urbanisation N-central Lanzhou/Jiuzhoutai
2001 – 2002 – 2004 - 2007 – 2009 – 2010 – 2011 - 2012 - 2013

Things to consider

Loess is not uniform

- Local conditions can be extremely important
- Need for *in situ* characterisation of strength
- Site geomorphology/geology
- Geophysics? (Gunn et al. 2014; Uhlemann et al 2016)

Slope design and management

- Understanding processes, parameters, monitoring, data collection, modelling slopes? (Kruse et al. 2007)
- Engineered slopes – cuts, retaining walls, embankments
- Management of unstable natural slopes - loess stabilisation

The future challenges

- Increasing exposure to unstable terrain – societal change – appropriate solutions to cope with geohazards
- Changes in critical thresholds – climate change? (Winter et al. 2010; Dijkstra and Dixon 2010, Dijkstra et al. 2014)
- Database establishment (e.g. Pennington et al. 2015)

More room for nature

- do not constrain natural processes too much, give landslides some space, limit disruptions to potentially unstable terrain

Lanzhou University International Field Visit 2009

Recommendations

1. A systematic, holistic and detailed approach in **collecting geohazards information**
2. Continuation of **post-construction monitoring** of engineered solutions

3. Establishment of a mechanism to **share information** with stakeholders
4. **Development of geohazards** risk mapping

5. Development of an **acceptable risk framework** considering socio-economic and other relevant issues in the region
6. **Strengthen collaboration** between university and government authorities with involvement of overseas academics

7. Further engage with the development and application of **new techniqu**es of hazard identification and mitigation
8. **Educate** professional people affected and the general public on geohazards through workshops, short courses and other training and dissemination methods

Introduction

Hazard and **risk** are components of the **disaster cycle**

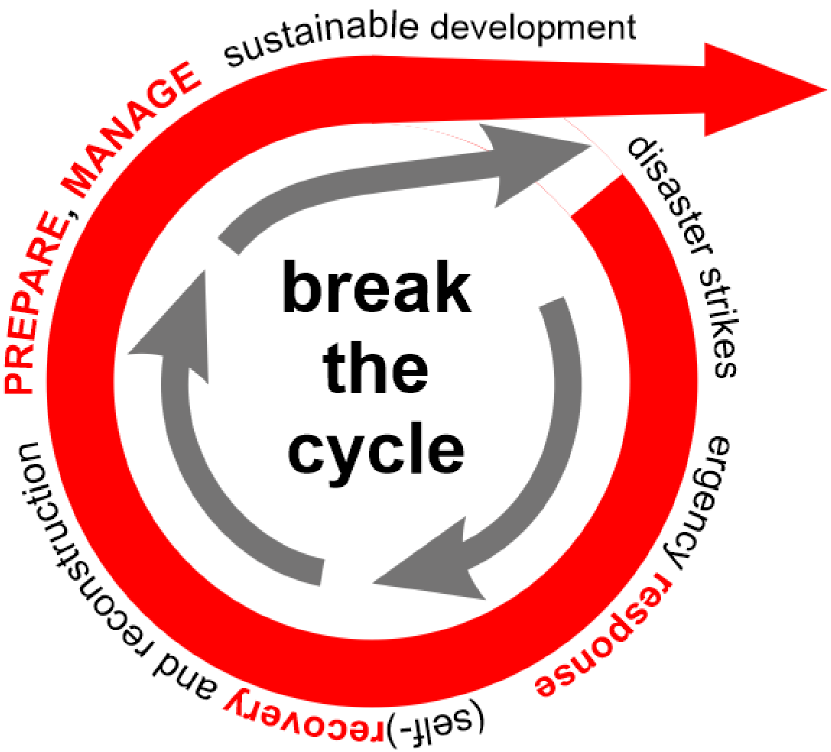
We need to try to **break the cycle**

By three methods we may learn wisdom
First, by **reflection**, which is noblest
Second, by **imitation**, which is easiest and
Third by **experience**, which is the bitterest
孔子 (Confucius, 551-479BC)

Introduction

where can we (***scientists***) have greatest impact on the disaster cycle?

- **respond**
  - have information where it is needed
- **recover**
  - use lessons learned
  - avoid complacency
- **prepare, manage**
  - better understanding of hazards/risks
  - better 'tools'; regulations, management



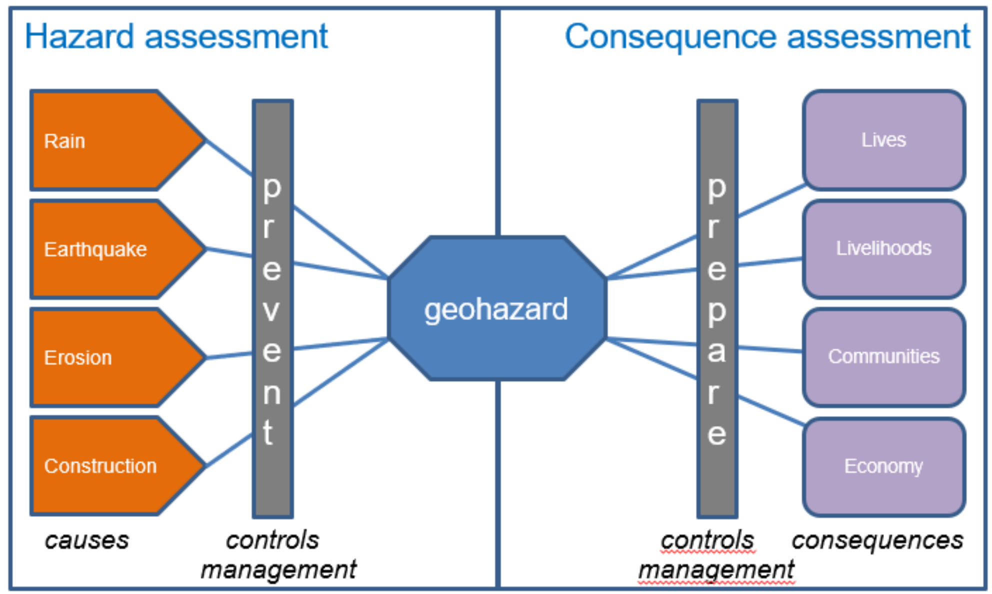
- **communicate the best available science to break the cycle**

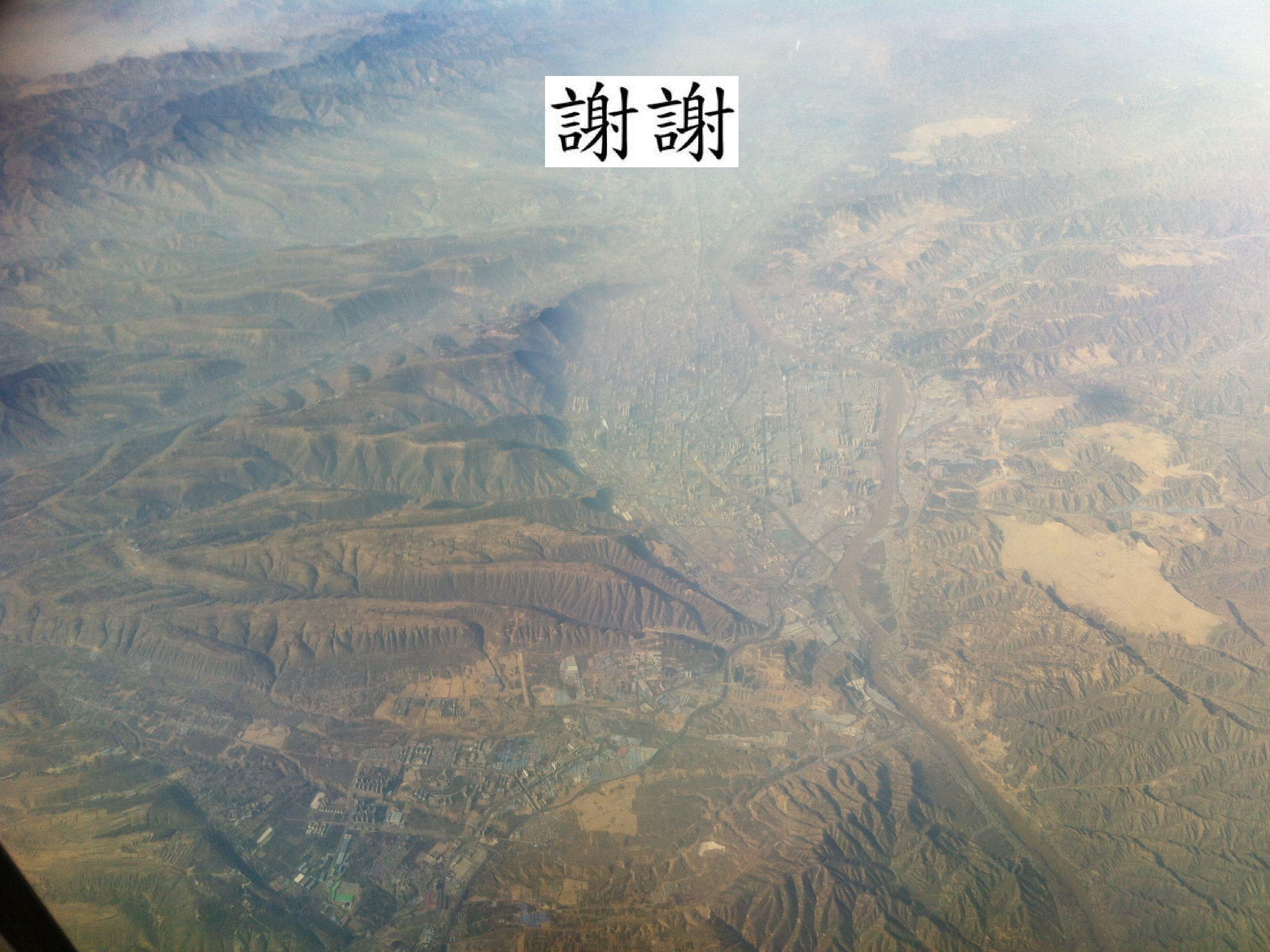
prepare, respond and recover

communication/information needs for risk management

- **susceptibility, activity**
  - distribution of geohazards in space and time
- **exposure and vulnerability data**
  - the community perspective, from **event** to **hazard**
- **hazards**
  - triggers
  - multi-hazard perspective (concurrence, cascade)
  - probabilities, uncertainty, heterogeneity
- **knowledge into practice**
  - communication
  - appropriate philosophies

control and management

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