Methodology for Quantifying System Resilience

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The approach

- Three viewpoints
  - **Policy maker:** Assessments leading to long term strategic choice (e.g. where to prioritise investment)
  - **Infrastructure manager:** Detailed assessment of local effects on specific infrastructure for different weather events (e.g. landslip, flooding)
  - **Traveller:** Calculation of journey resilience of a route (e.g. London-Glasgow)

Capacity vs. Demand

- Capacity reduction occurs due to aggregation of physical processes impacting on each asset element at a specific time
- Demand is a function of the user requirements and behaviour (i.e. time of journey, social and economic factors)
- For 2050, both are influenced by possible futures….

Limit states for performance

- Ultimate limit state (ULS)
  - **Operator:** Complete loss of function e.g. road/rail route impassable – zero capacity
  - **User:** Journey is not completed or cumulative delay makes the journey a failure as activity is cancelled
- Serviceability limit states (SLS)
  - **Operator:** Reduced function e.g. lane of motorway closed or surface conditions result in lower speed of vehicles – reduction in capacity
  - **User:** Extended journey time causes disruption to plans but journey is completed in time to allow activity to take place in some form

Weather drivers

- Climate variables (current and forecast)
  - Rainfall, temperature, wind, combined actions
  - Possible futures will influence: Duration, intensity and quantity
- Manifestation of weather events
  - Fluvial and pluvial flow (depth, velocity), groundwater (pressure), air and material temperature (intensity and flux), air speed (velocity)

Physical processes

- Physical processes resulting from weather
  - Ponding, pluvial flow, fluvial flow, ground volume change, thermal straining, wind pressure
  - Conditioning parameters: Infrastructure condition, topographic setting, ground conditions

Topography

1 – position along base of slope

2 – position on high ground/top of slope

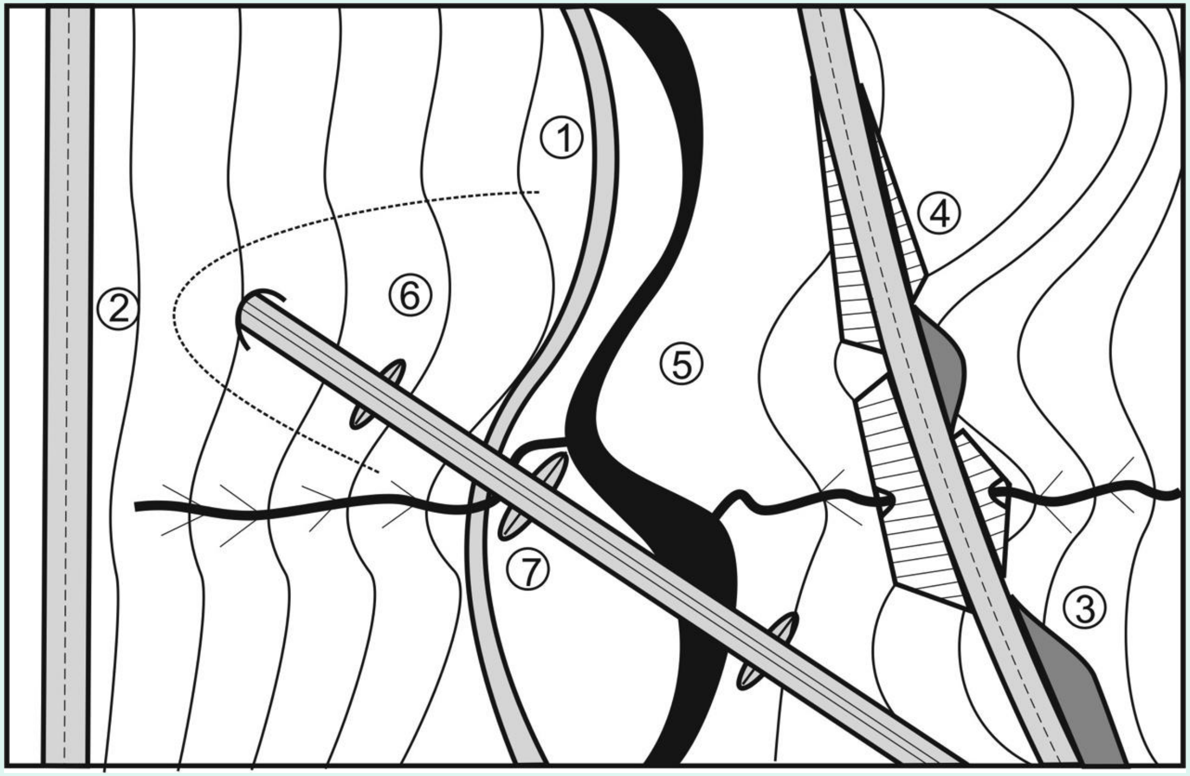
3 – cuttings

4 – embankments

5 – position in floodplain

6 – slope stability

7 – scour

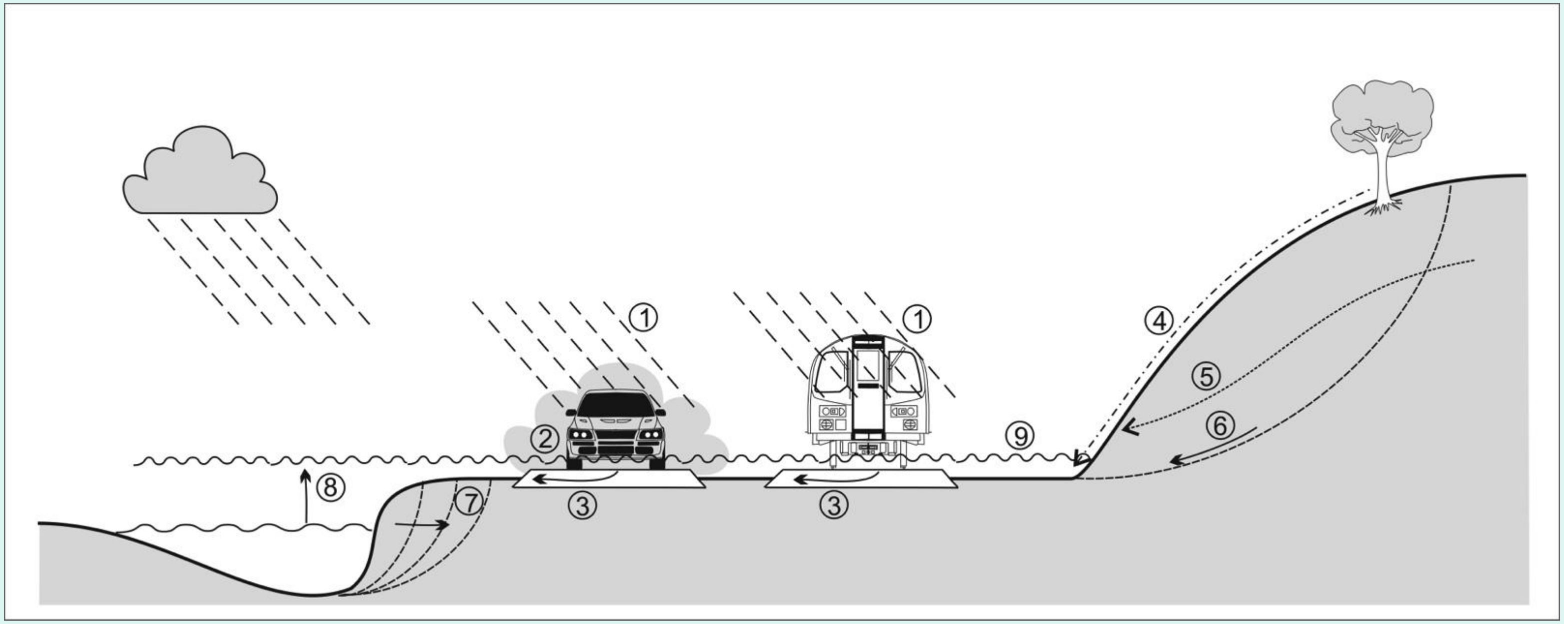


Effects on infrastructure

- Outcome events
  - Surface water depth leading to flooding and/or spray, earthwork and foundation deformation, pavement and track deformations, scour/erosion, washout, landslide
- User consequences
  - Visibility, traction, ride quality, obstruction, temperature stress
  - Reduced physical capacity → reduced speed/flow

Rainfall

1 – rainfall intensity
2 – visibility issues
3 – drainage issues
4 – overland flow
5 – groundwater flow
6 – slope stability
7 – scour
8 – flooding (regional)
9 – flooding (local)



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Temperature

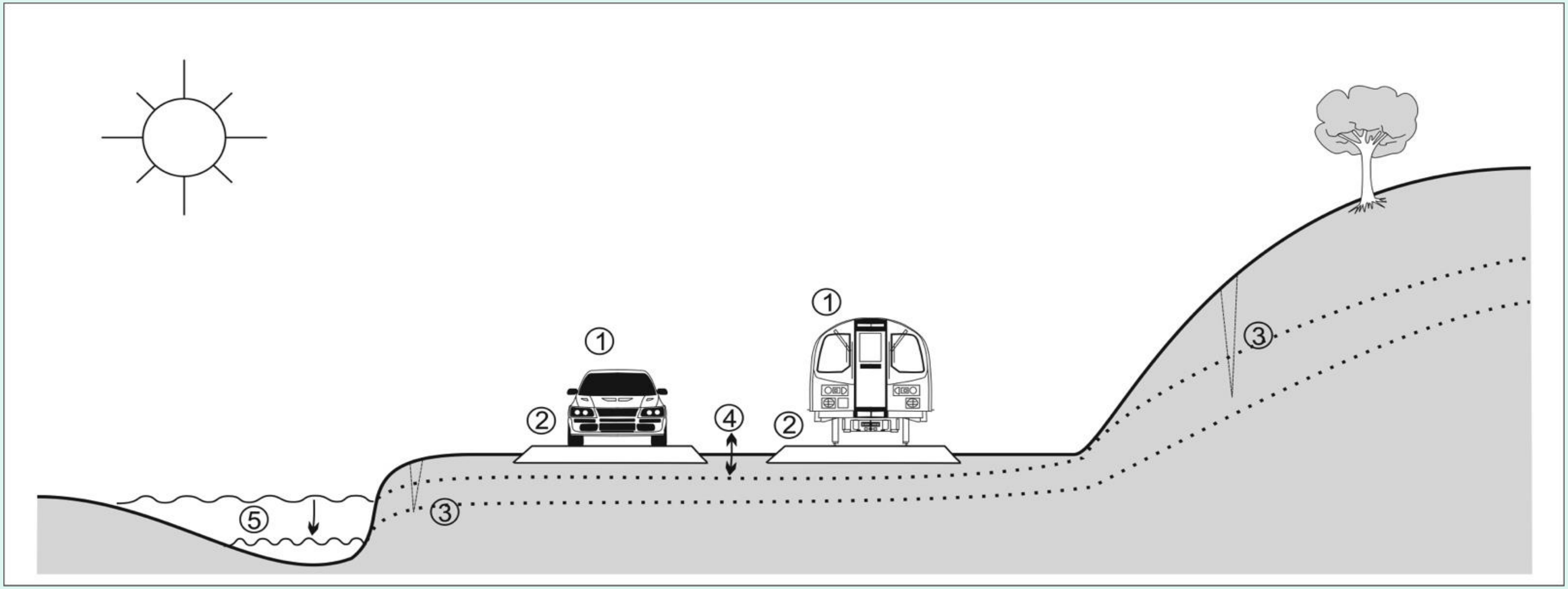
1 – heat stress inside transport modes – road and rail

2 – heat effects on pavements/rails/sub-grade including buckling, rutting, freeze/thaw

3 – soil cracking

4 – swell/shrink

5 – lowering of water levels and local/regional groundwater tables



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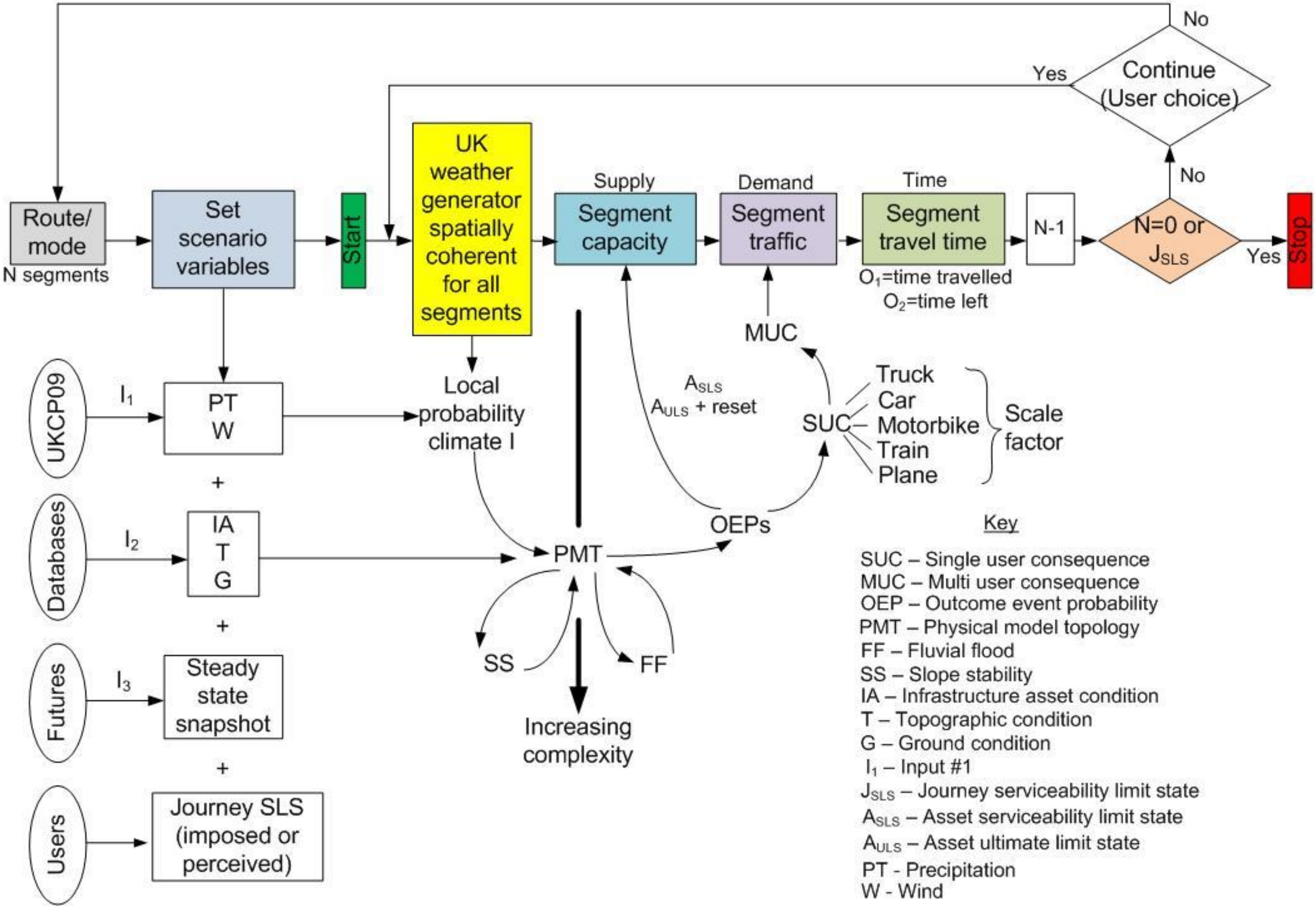
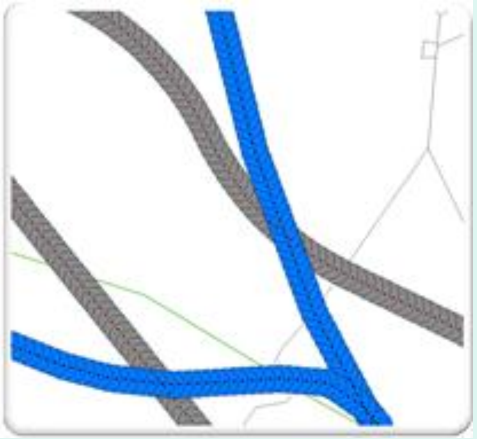


Building a basic Model

Route corridor

- Identify area of interest
- Split into 50 metre sections
- Buffer each section to capture surrounding area (75m)
- Populate each buffer with data



Data layers and sources

Digital Terrain Model (DTM)

- Panorama
- Contour 25m

Inland water

Road and rail

BGS Geology layers

- Bedrock
- Superficial
- Engineering

BGS Geosure

- Collapsible
- Compressible
- Swell-shrink
- Landslide obs
- Superficial and bedrock permeability

HA Shape files – Embankments / Cuttings

- Ditches
- Drainage + flood risk
- Culverts
- Piped grip
- Manholes
- Gullies
- Filter drains

Vegetation

- Hedges and Habitats
- Species
- Grassland

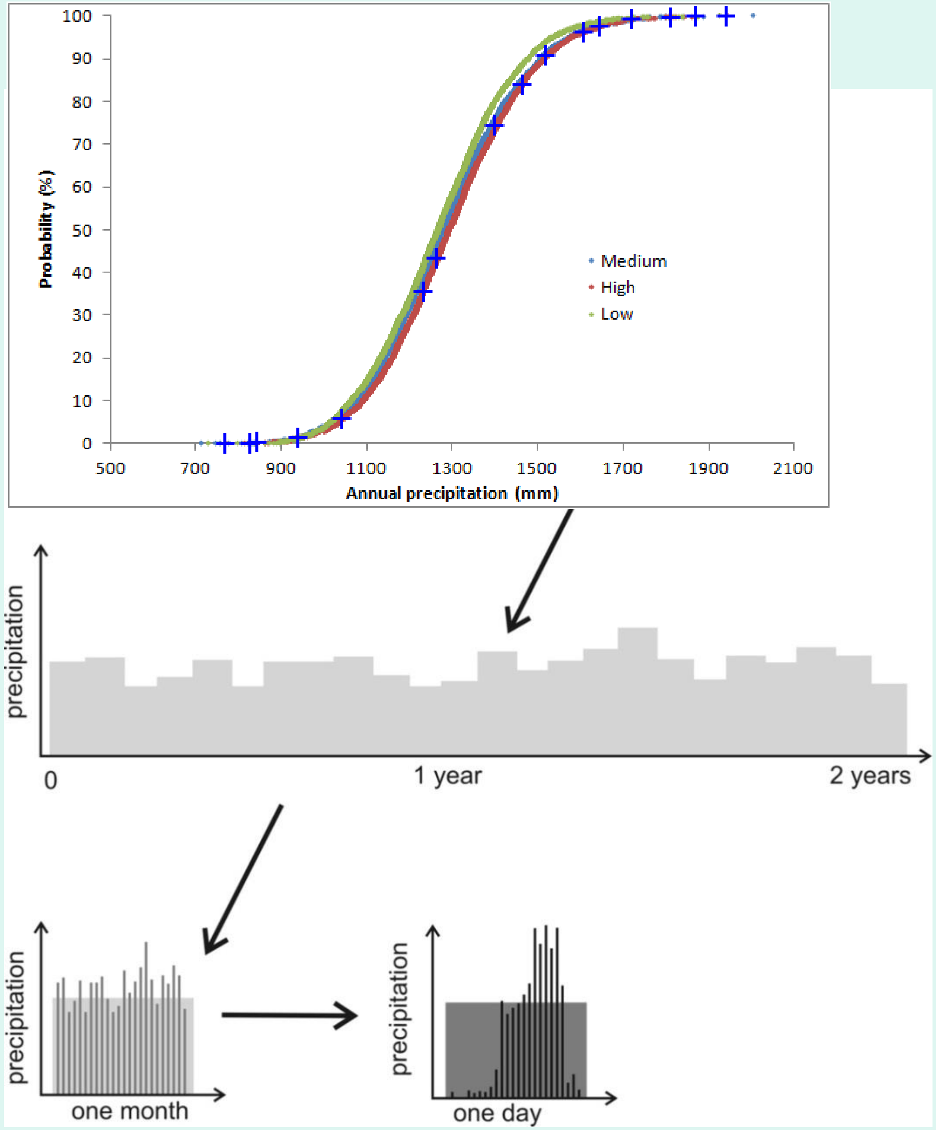
Solar radiation

- Aspect and intensity (dependent on DTM)

Hydrology

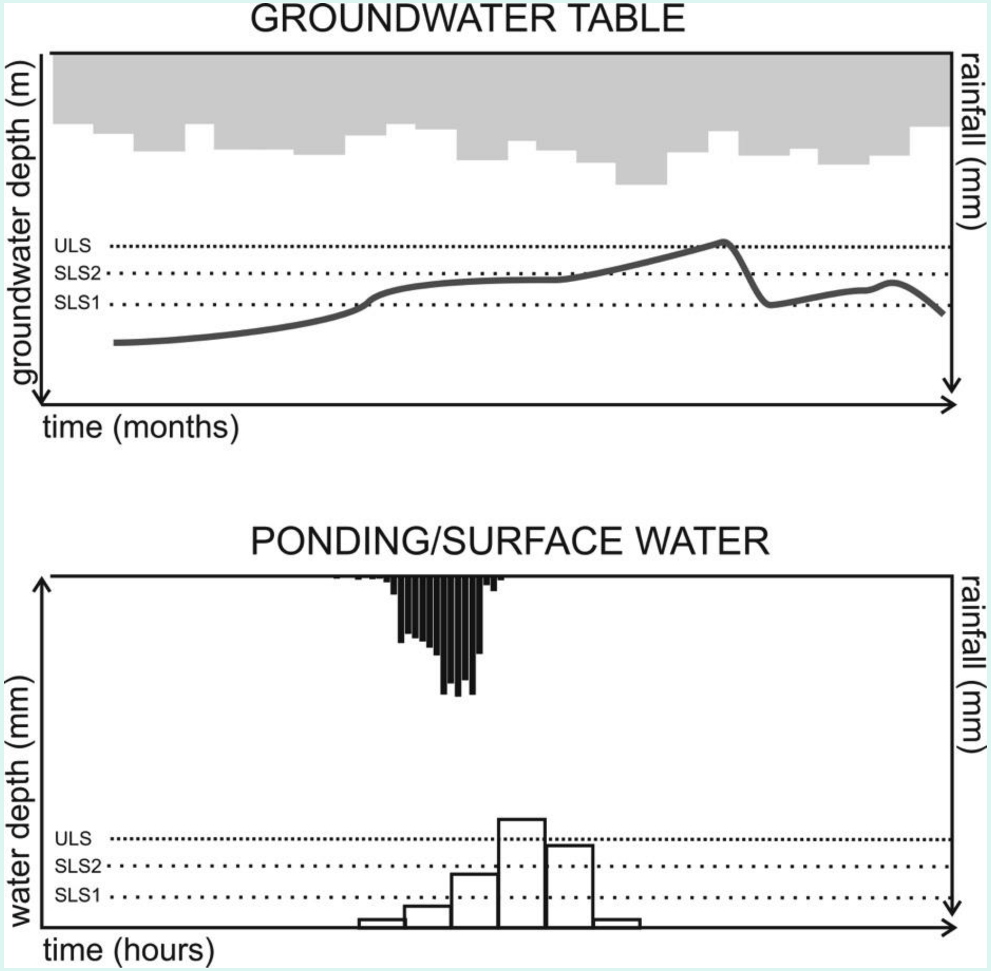
- Flow accumulation
- Flow Direction

Weather event sequences: Temporal scales



Response times of processes

- Dependent upon the process, different detail is required
- Time of occurrence of weather events is important



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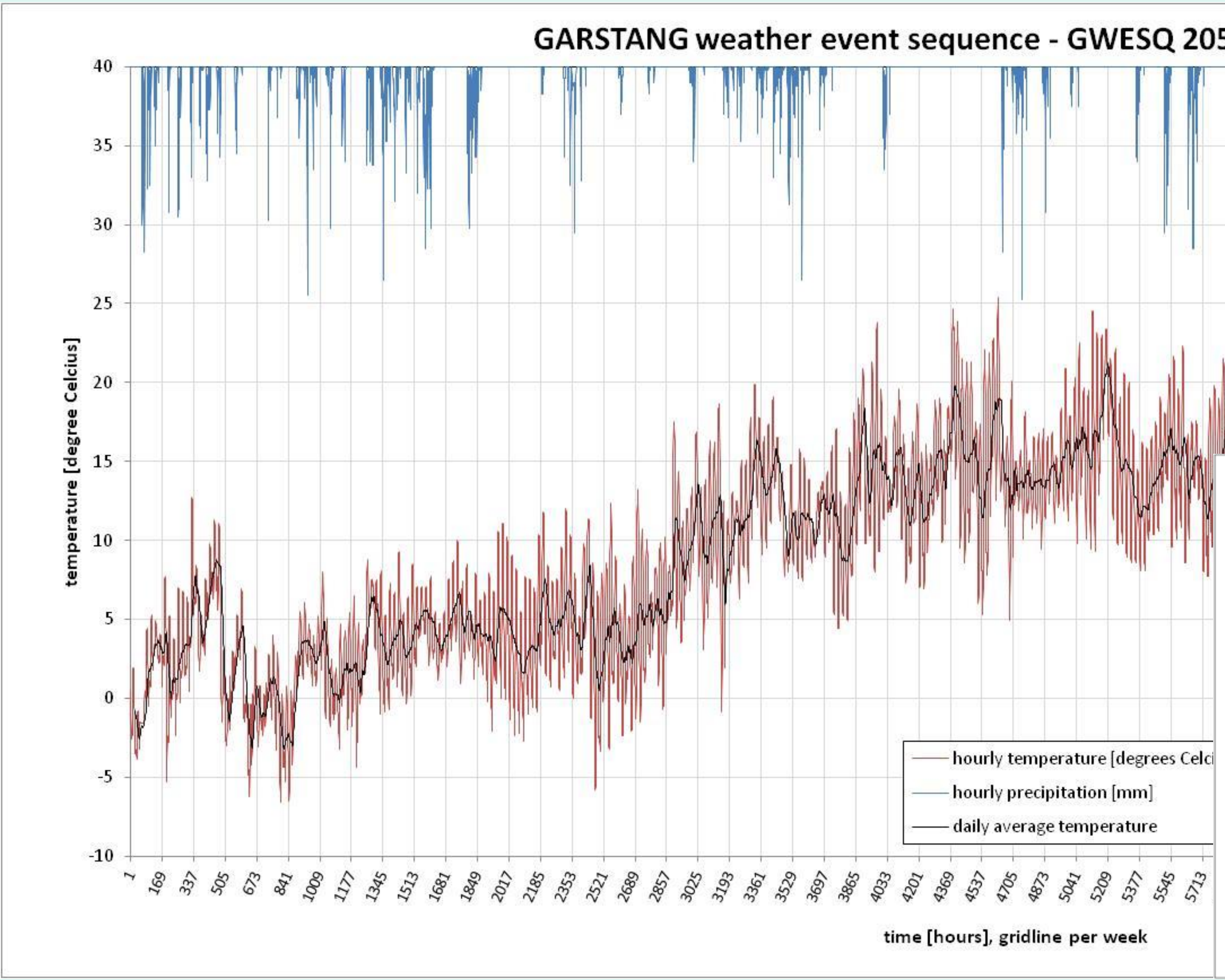
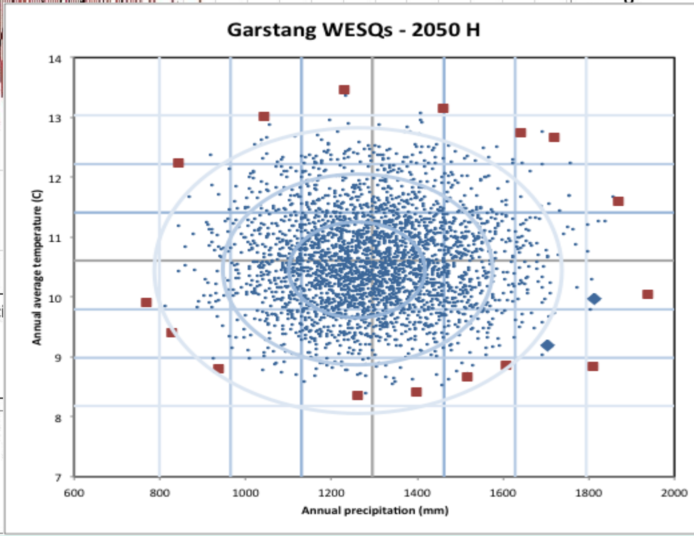
Weather event sequences (WESQs)

- 16 WESQs for Garstang 2050 High processed

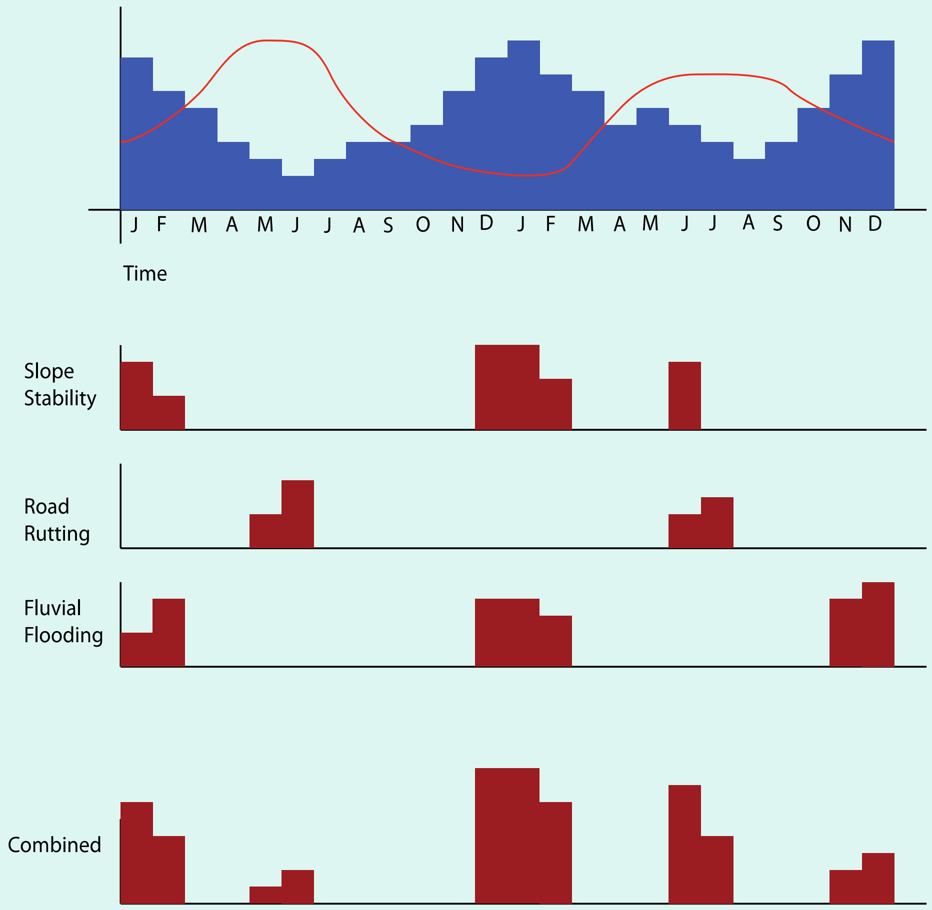




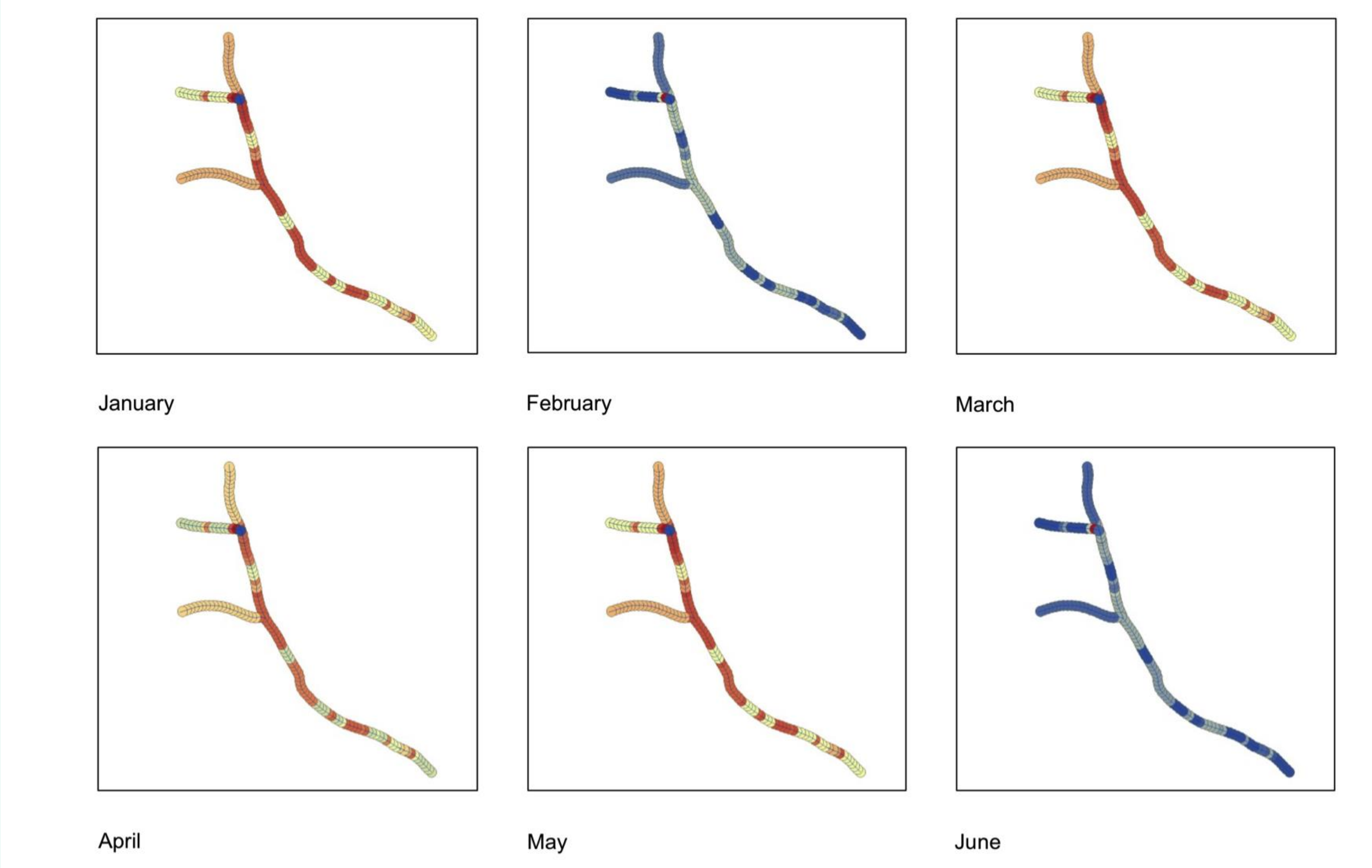
Combined physical processes

Interactions

- ➢Physical processes are driven by weather events
- ➢These are sequential and the landscape has a 'memory'
- ➢Both antecedent and immediate triggers play a role
- ➢Weather event sequences therefore enable analysis of joint occurrences and process interactions

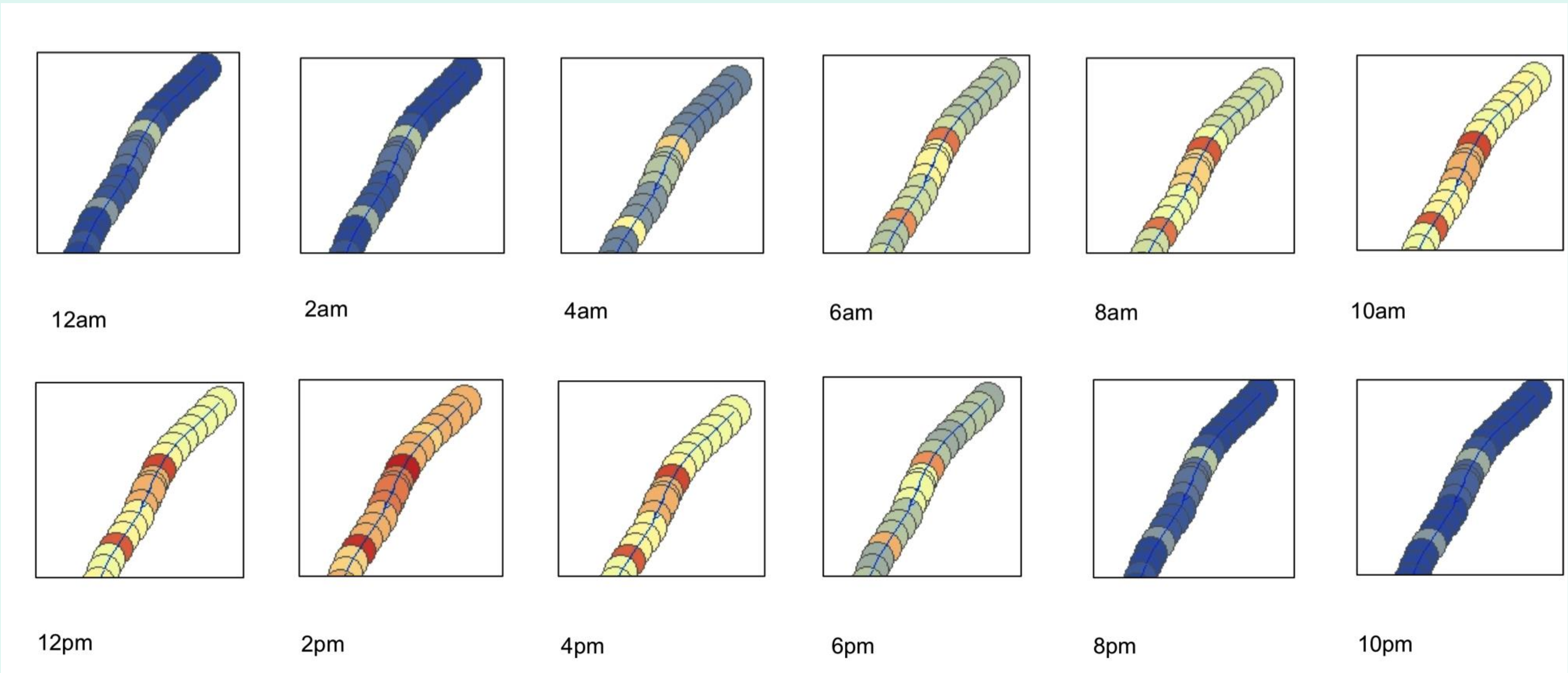


Output – Seasonal landslides



Landslide risk – Monthly temporal scale

Output – Track buckling



Track buckling – 2 hour temporal scale

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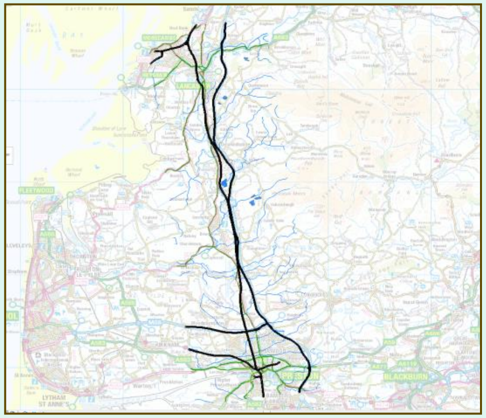
Capacity reduction factors (CRF)

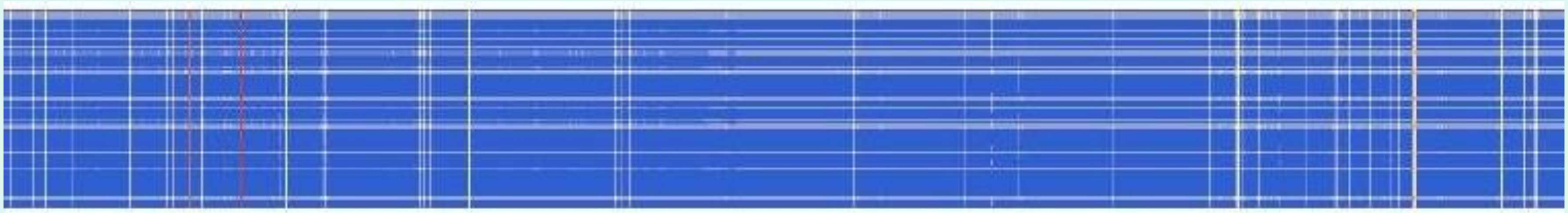
- Each physical process could result in capacity of the transport link being reduced
- Capacity reduction factors are derived for each process
- Aggregation of reduction factors for a specific weather event gives the combined capacity reduction
- These can be calculated for each segment of the infrastructure at each time interval

Capacity reduction factors (CRF)

Visualisation of capacity reduction

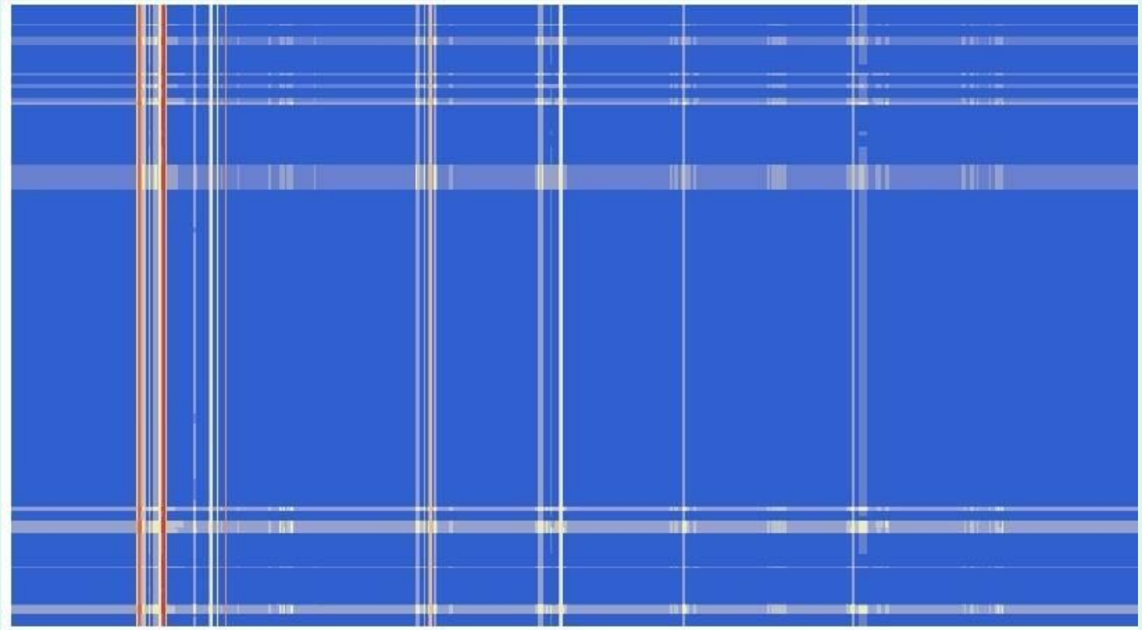
- In the vertical - each node along the infrastructure section
  (1108 nodes for 55km)
- In the horizontal - every hour in the WESQ
  (8760 hours for WESQ 02_029)





Physical capacity 2050 (WESQ 02_029) – Blue is good, yellow is poor, red is very poor

What can be done with tartans?



Things to consider include:

- Persistent nodes of reduced capacity (horizontal lines)
- Triggers of capacity reduction (vertical lines)
- System recovery versus recurrence of critical events
- Individual processes (next slide)

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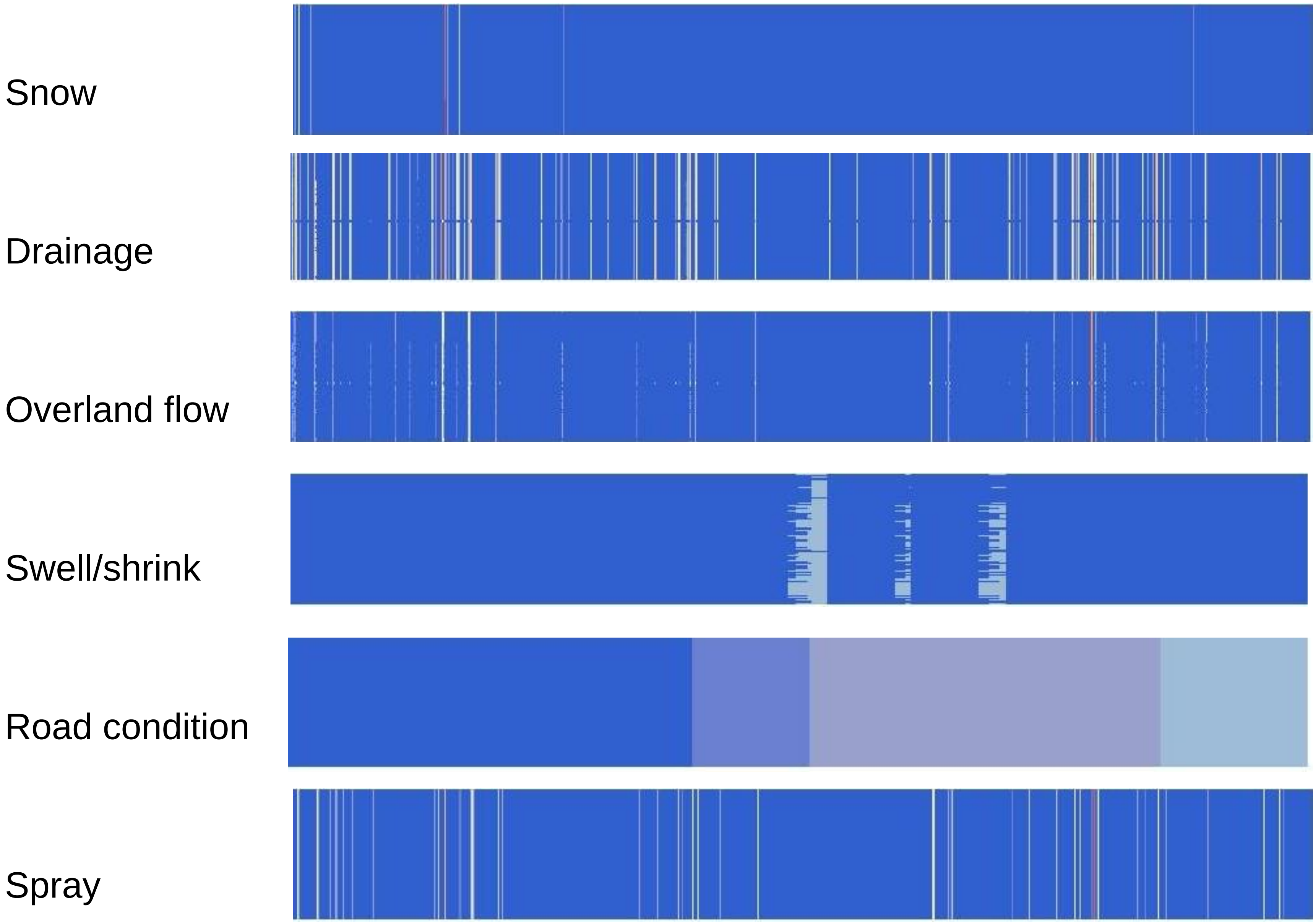
CRF: Individual processes

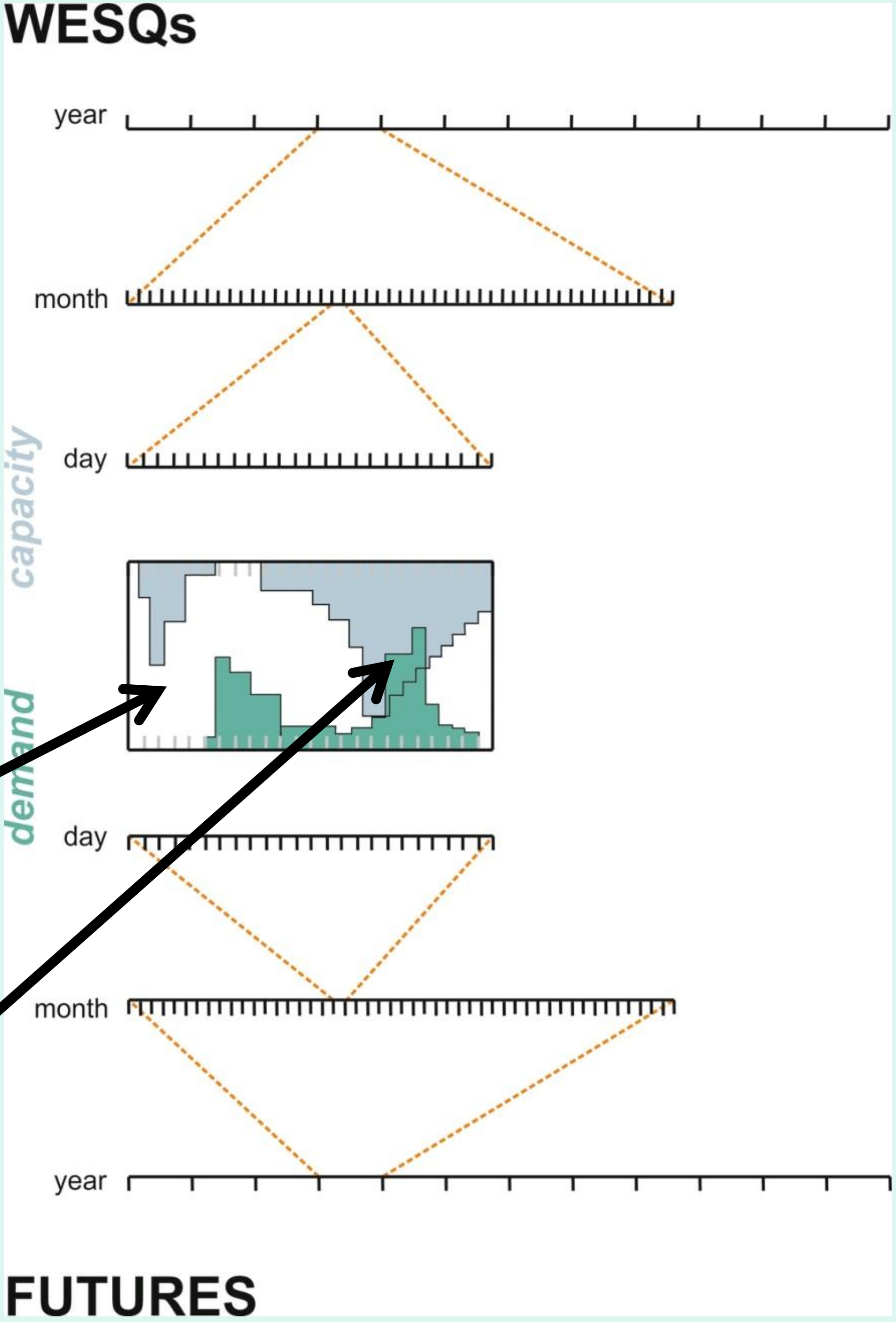


Resilience: Capacity vs. demand

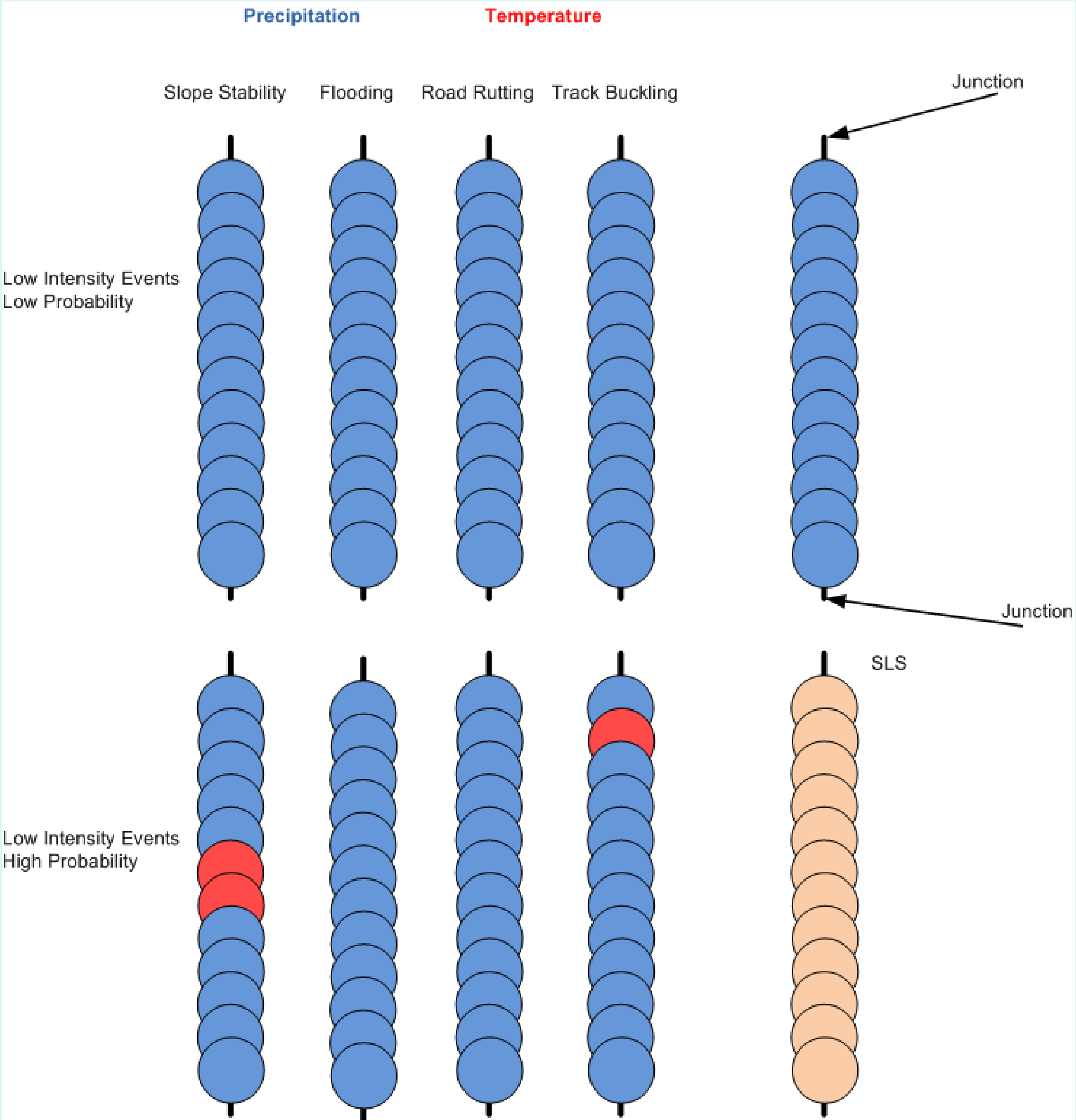
Resilience is determined by difference between physical process capacity and demand

Where capacity reduction occurs and demand is low, resilience is still high

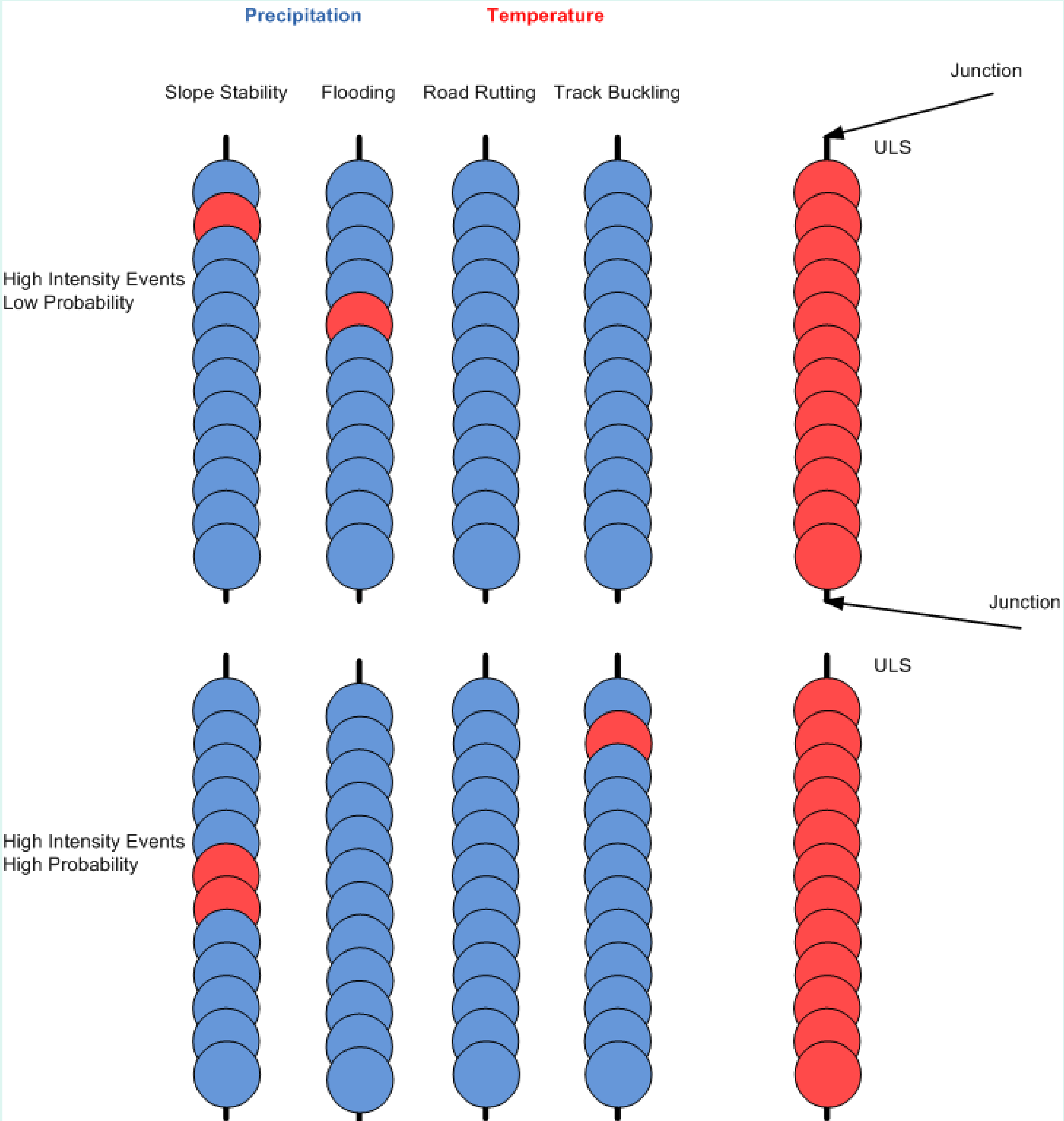
Where capacity reduction occurs as demand is high the greatest problems occur



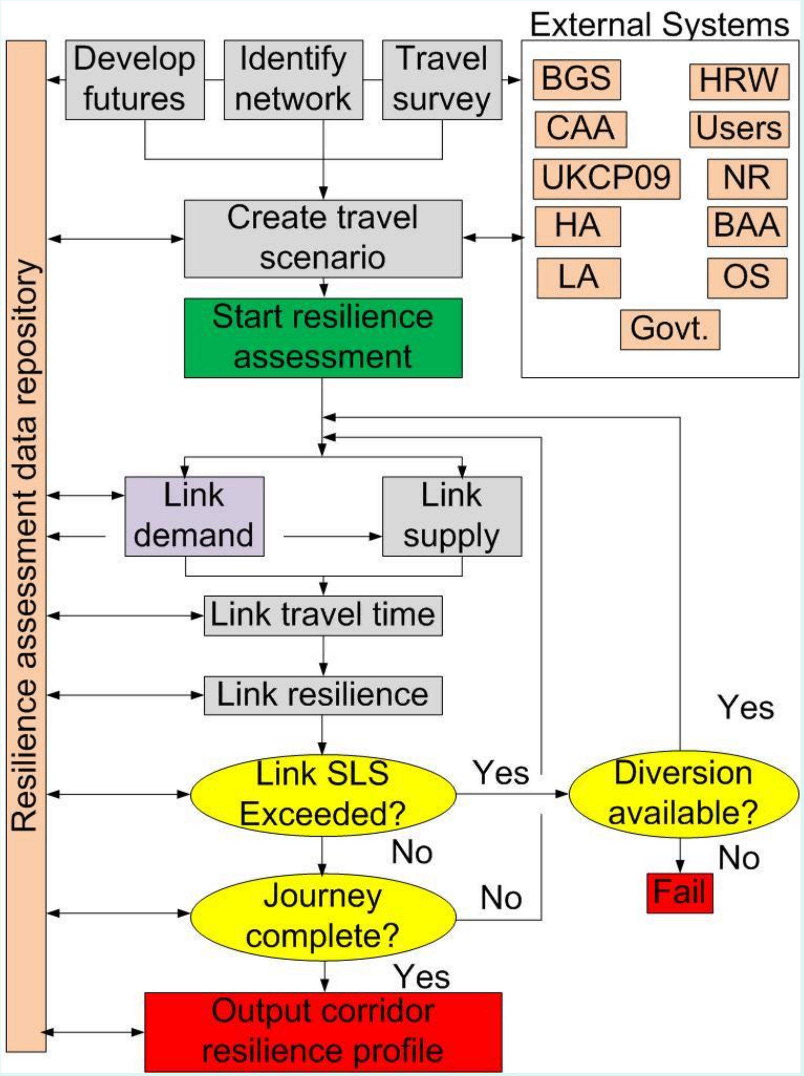
Demand > Capacity → SLS failure



Demand >> Capacity → ULS failure

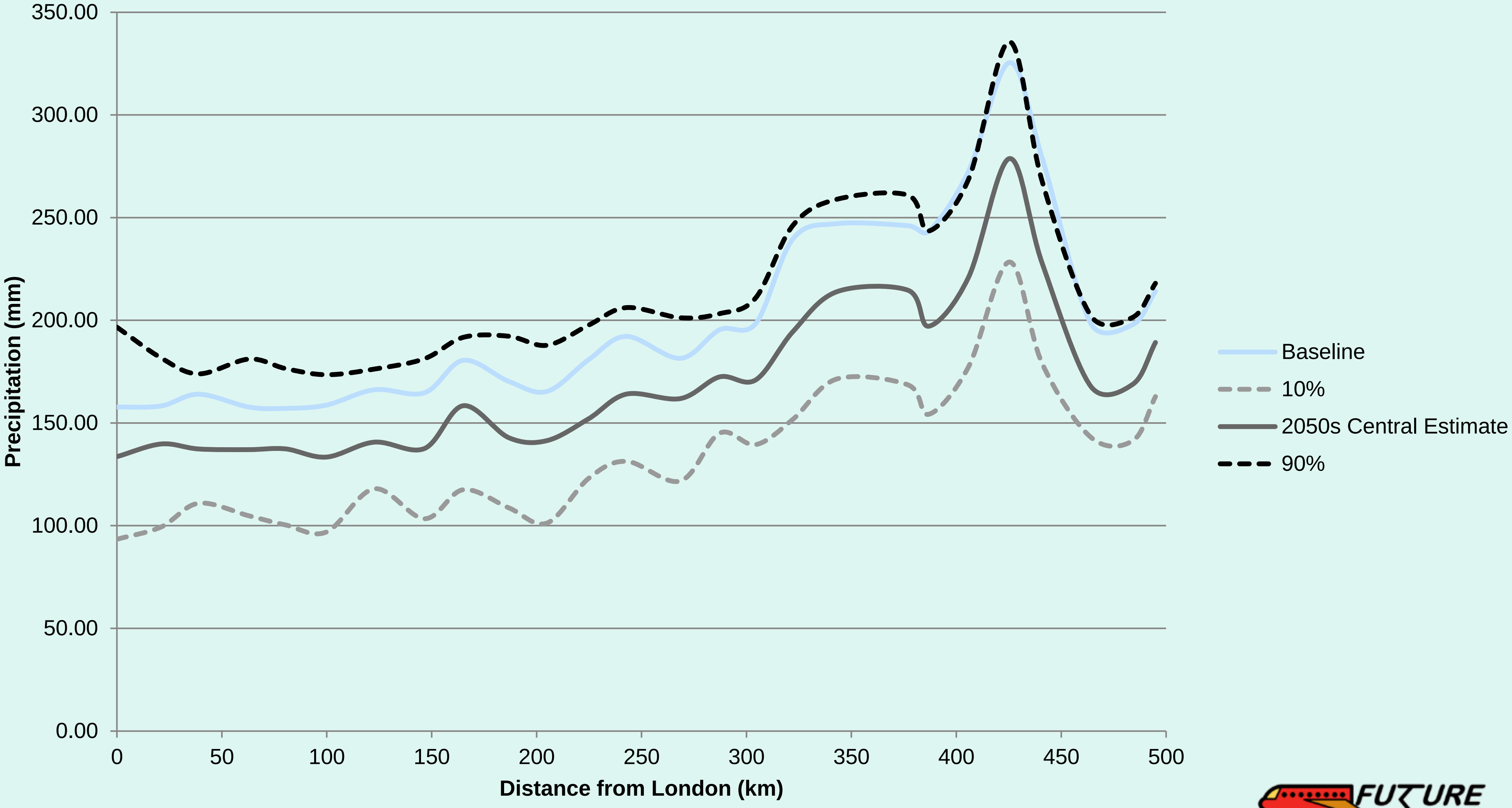


Journey resilience approach



- Model simulates journeys as a demonstration of concept
- Combines failure models
- Splits road and rail routes into links (between stations/junctions)
- Runs four journeys a day
- Uses synthetic weather to produce failures, capacity and speed reductions and calculates resulting delay on link
- Aggregates link delays
- Uses weather generator output

Need for coherent weather along length of asset (London-Glasgow)



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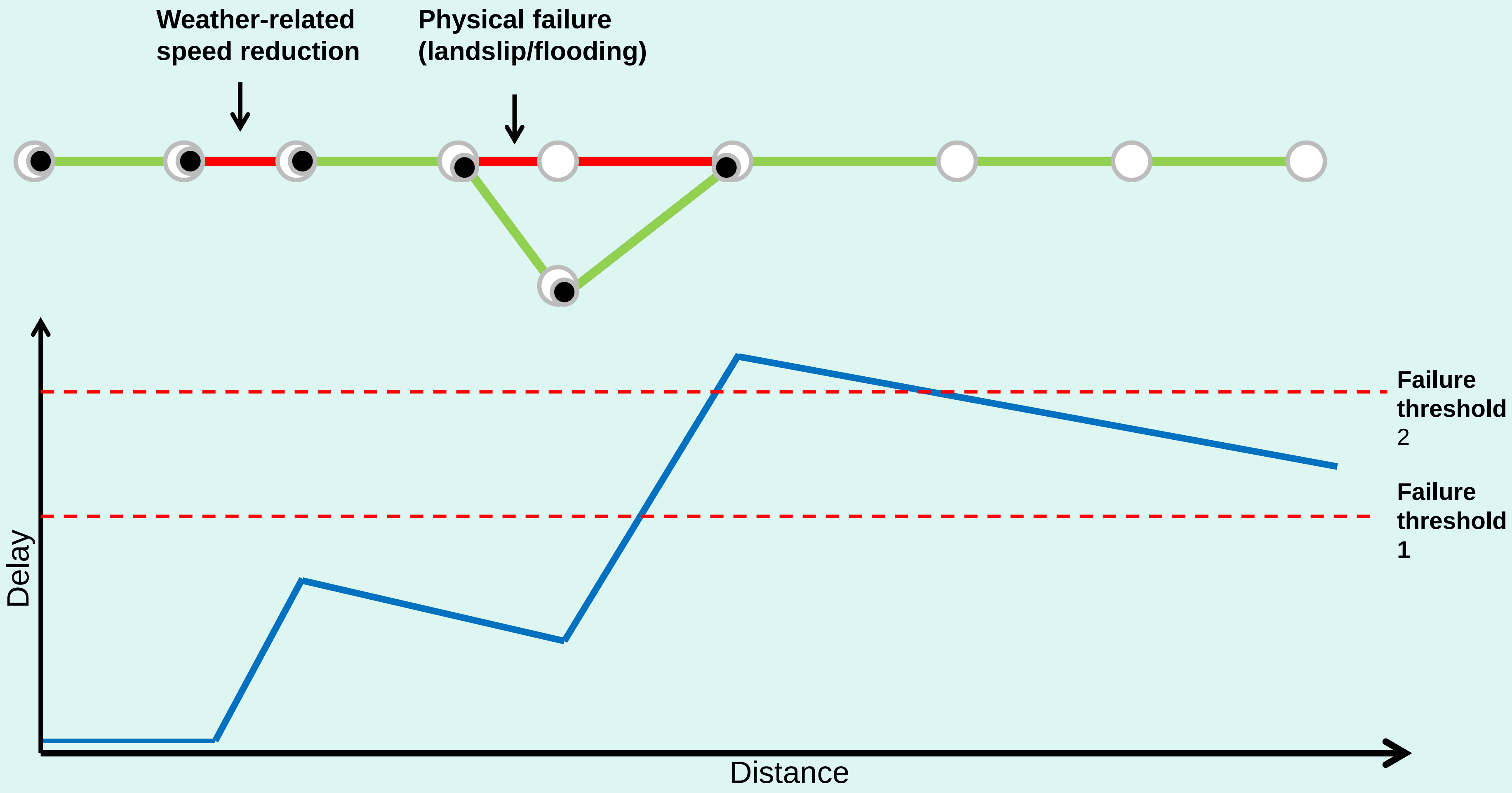
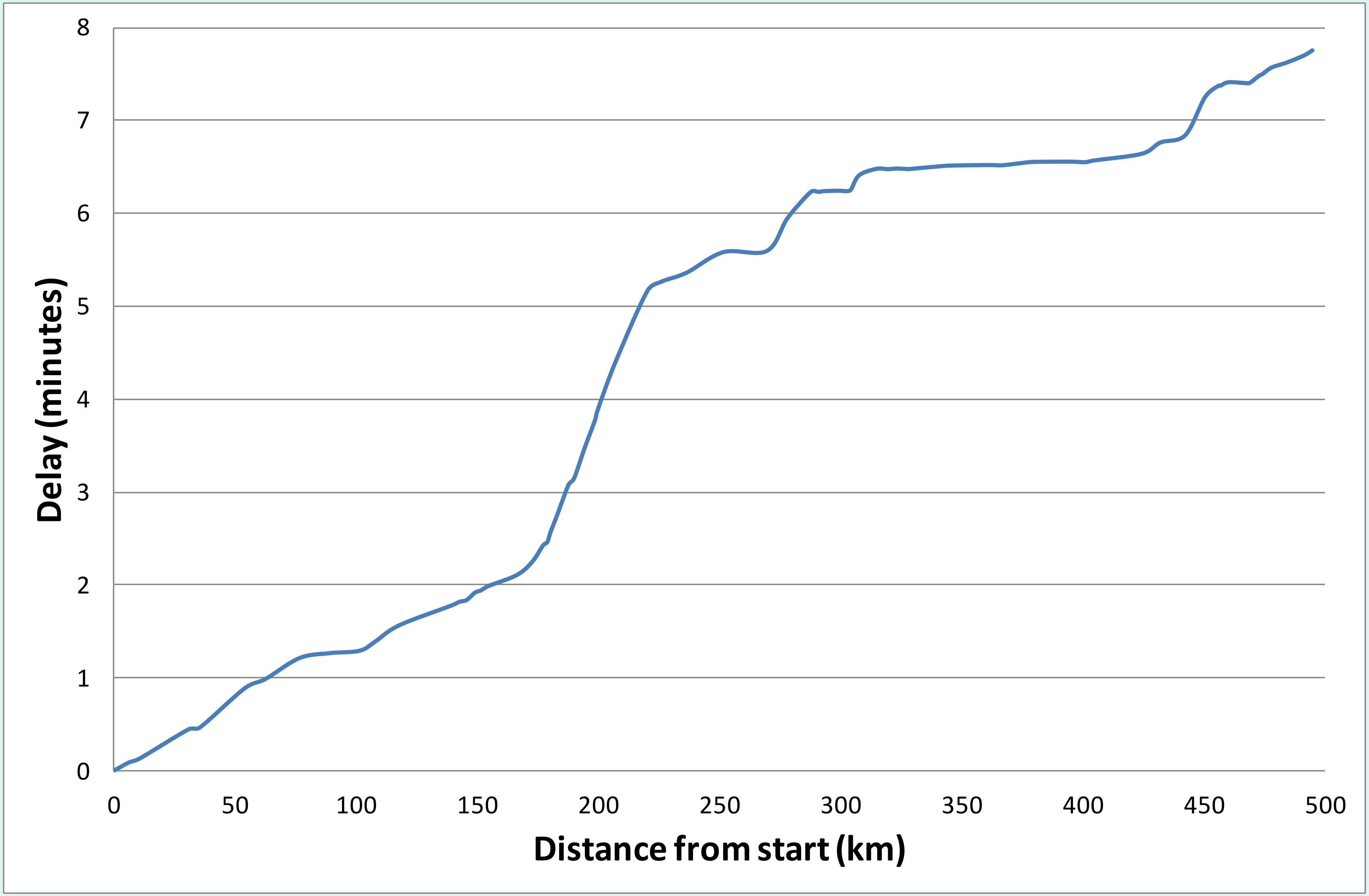
Journey resilience approach



Journey resilience output



Deficiencies in information

- Higher resolution of data – Finer detail DTM
- Road and rail network bed needs identifying on DTM
- Further road details (e.g. camber, direction and angle of road, drainage, types of road surface, previous engineered interventions)
- Railway details (e.g. track incline and camber, railway ballast specs)
- Condition of elements (e.g. earthworks, structures, drainage)
- Spatially coherent weather projections for UK

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Methodology for quantifying system resilience

- Methodology introduced….
- How can it be used to inform policy makers, infrastructure managers and traveller experience?
- Over to John Dora……

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