Newcastle University

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A High-Performance Integrated Hydrodynamic Modelling System for Sustainable Catchment Systems Management

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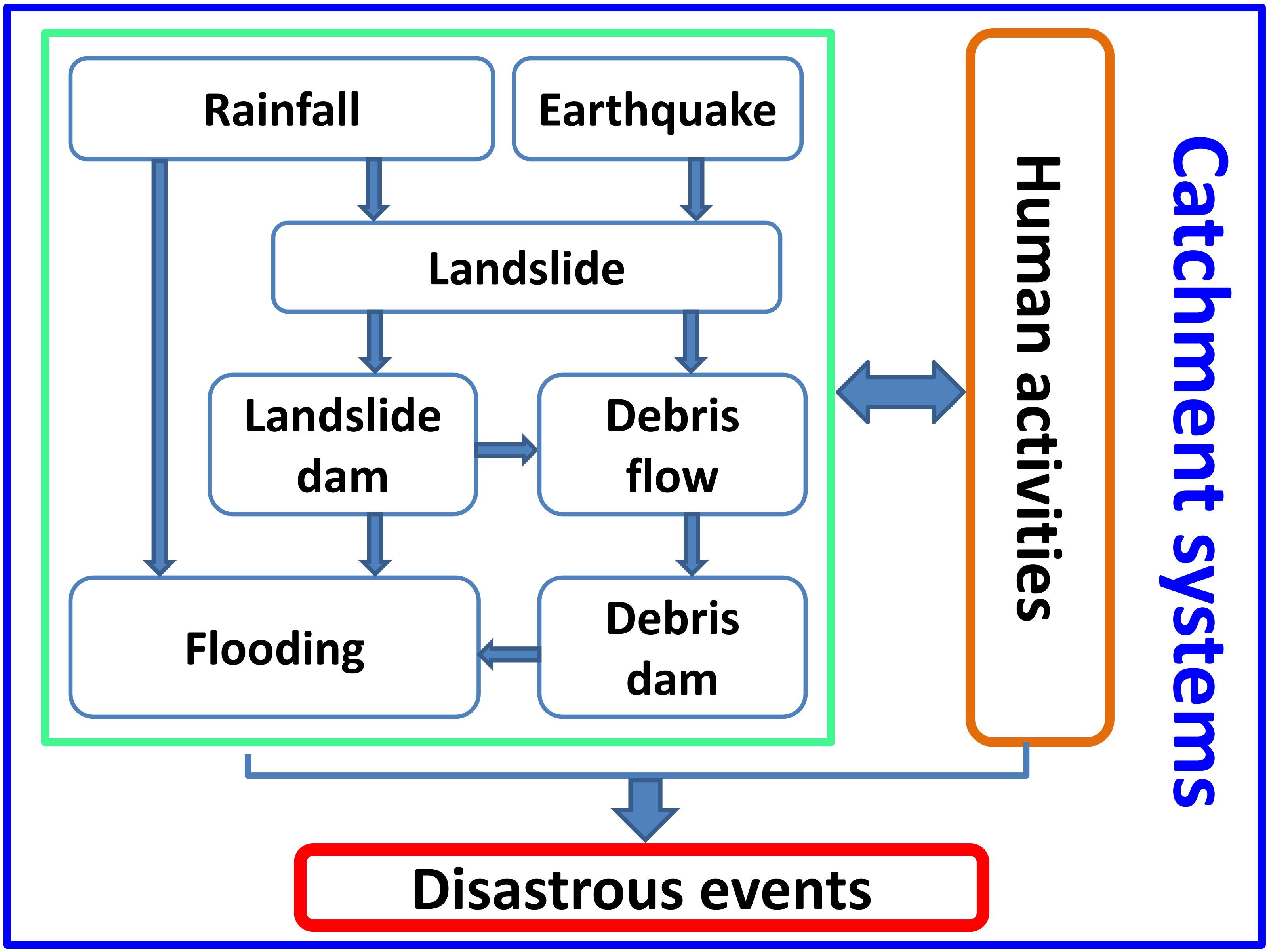
Outline

- Catchment systems and natural hazards
- Recent technology advances and opportunities
- New generation of modelling technologies for catchment systems management
  - Rainfall-runoff and overland flow
  - Landslide/debris flow
  - Flood modelling
- Conclusions

Natural Hazard Chains



Hazards risk management

- **Traditional top-down approaches**
- Rely heavily on hard engineering protection schemes
- Focus on single hazard
- Expensive, not sustainable, adverse impacts to environment …

- **The need of more sustainable strategies**
- Whole-system approaches that holistically take into account natural system, human activities and built environment
- Focus on building resilience
  -- Multiple solutions emphasising working with natural processes
  -- Bottom-up approaches through cooperating directly with communities and stakeholders

- **Challenges**
- Better understanding of the interactive systems (i.e. natural processes and social processes)
- Tools to reliably identify and quantify the risk and support disaster reduction management and resilience building
- Effective knowledge co-producing and sharing framework (social scientists, natural scientists/engineers and community members)

Technology Booming

Technology (digital) advances in recent years

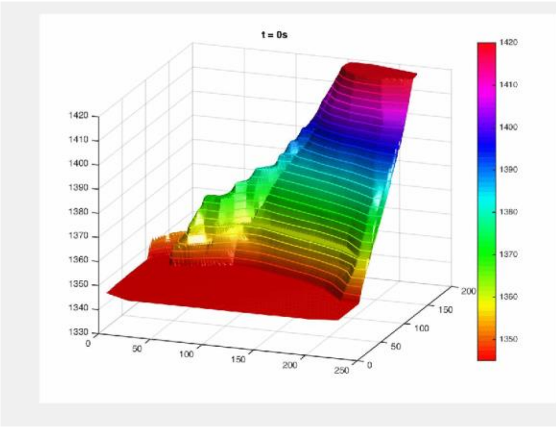
- Remote sensing/earth observation technologies
- Information sharing and big data
  - -- Real-time data (e.g. from different types of sensors and online social networks) available for monitoring different aspects of the natural and built environments and activities therein
- Information systems, e.g. GIS, BIM, for managing data and at the same time creating data
- High-performance computing (GPUs, cloud computing)
- …

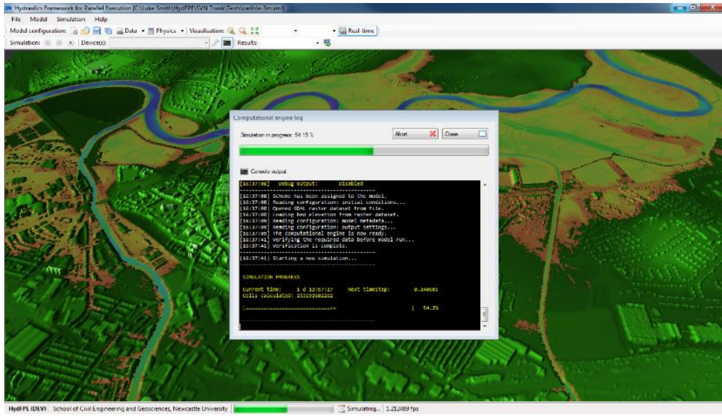
Unique and exciting opportunity to create a step change in catchment systems (hazard) management through

1) Taking advantages of the recent advances in science and technology

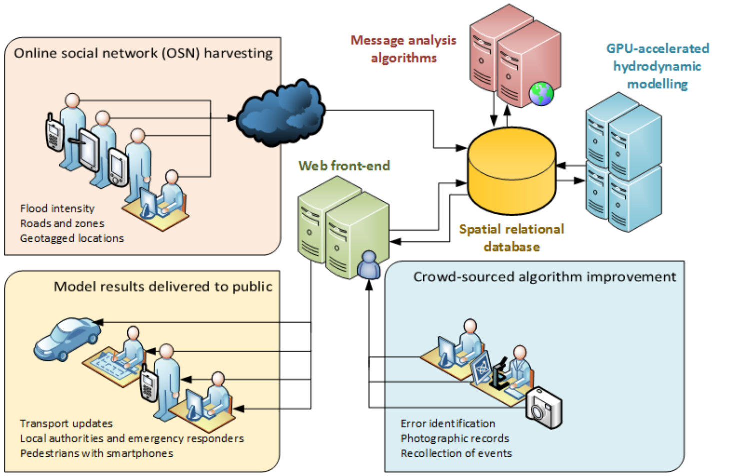
2) Working and sharing knowledge with different people

Hydrosystems Modelling @ Newcastle





- **High-performance modelling system for hydro-geohazards**
  - -- Flood, storm surge, tsunami, landslide and debris flow
  - -- Catchment processes (rainfall-runoff, hydro-geomorphology, floating debris, etc.)
  - -- Risk assessment and real-time forecasting

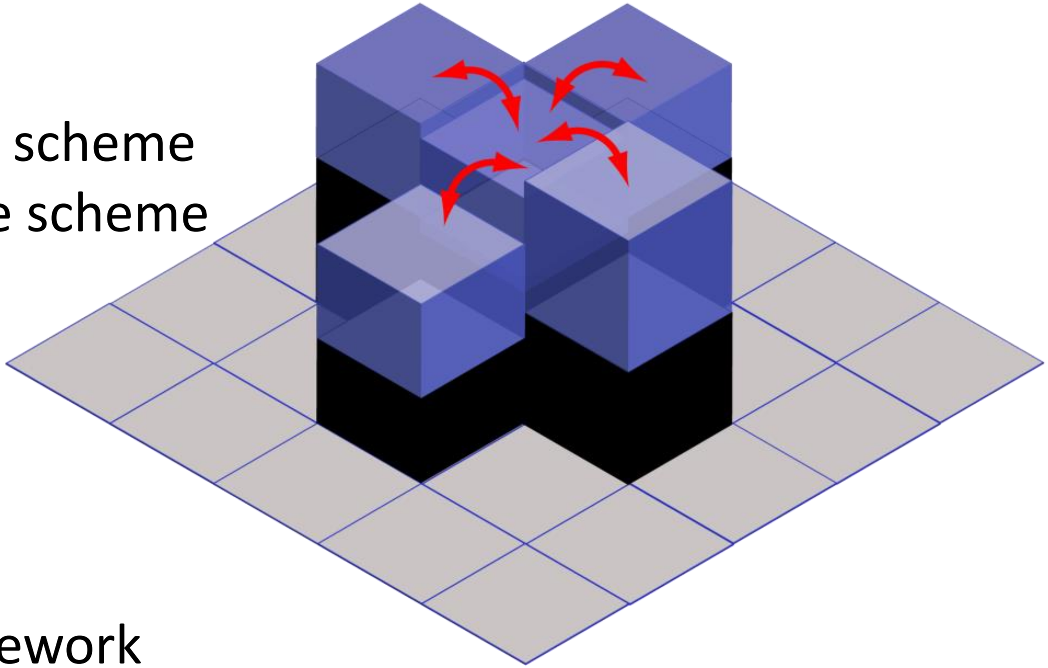


- **Crowd-sourced data (big data) harvesting and real-time flood forecasting**

- **Coupled human and natural system (CHANS) modelling**
  - -- Interactive social and natural processes during a disastrous event
  - -- Vulnerability assessment, emergency management, and city planning and design

Hi-PIMS

- **Hi**gh-**P**erformance **I**ntegrated hydro-geohazards **M**odelling **S**ystem
  - Fully 2D depth-integrated governing equations for shallow flow hydrodynamics/other processes
  - Numerical schemes
    - 1st-order Godunov-type scheme
    - 2nd-order Godunov-type scheme
  - CUDA/OpenCL
  - OpenCL-based
    - Cross-platform
    - Cross-architecture
    - Flexible modelling framework
    - Any modern CPUs or GPUs



Hi-PIMS

-- Governing Equations

Shallow water and mass flows (e.g. flooding, flow-like landslide/debris flow)

- Single phase granular flow
- Shallowness assumption, i.e. depth << horizontal dimensions
- Mohr-Coulomb frictional rheology (or other friction laws)
- Vertical pressure is NOT hydrostatic

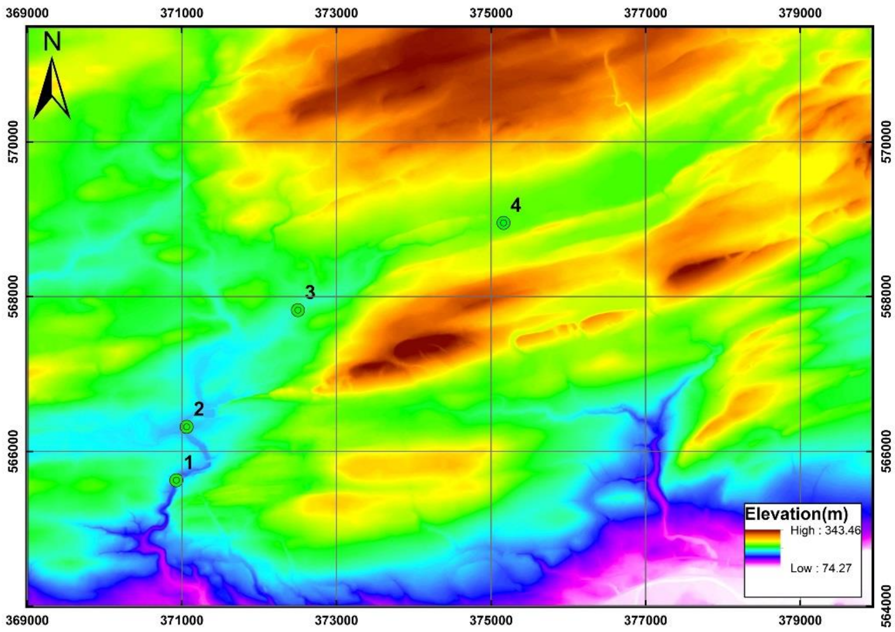
$$\frac{\partial \boldsymbol{q}}{\partial t} + \frac{\partial \boldsymbol{f}(\boldsymbol{q})}{\partial x} + \frac{\partial \boldsymbol{g}(\boldsymbol{q})}{\partial y} = \boldsymbol{S}_b + \boldsymbol{S}_f$$

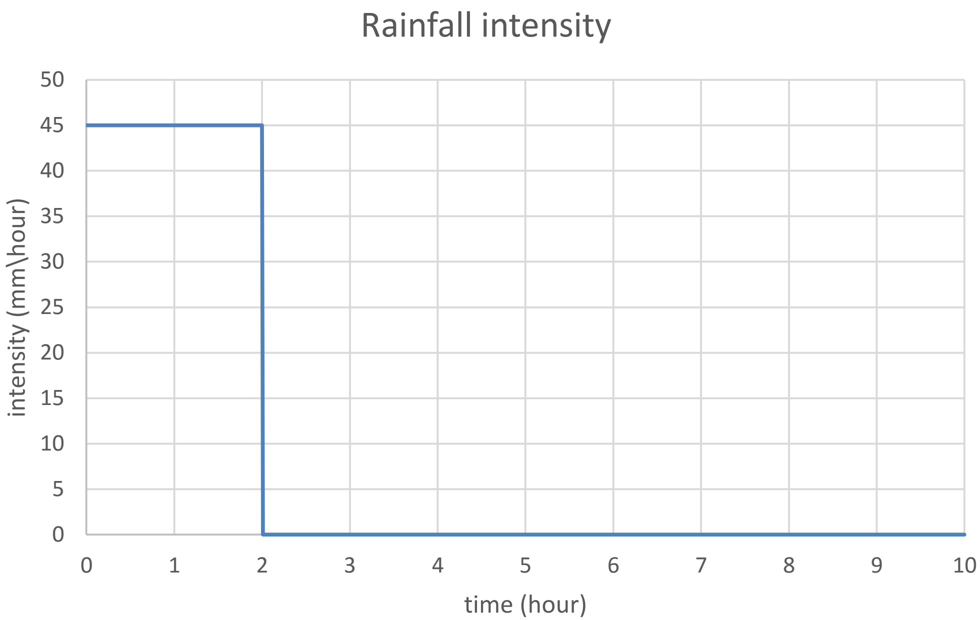
$$\phi^b = \{(\frac{\partial b}{\partial x})^2 + (\frac{\partial b}{\partial y})^2 + 1\}^{1/2}$$

$$\boldsymbol{q} = \begin{bmatrix} h \\ uh \\ vh \end{bmatrix} \boldsymbol{f}(\boldsymbol{q}) = \begin{bmatrix} uh \\ u^2 h + \frac{1}{\phi^{b2}} \frac{1}{2} g h^2 \\ uvh \end{bmatrix} \boldsymbol{g}(\boldsymbol{q}) = \begin{bmatrix} vh \\ uvh \\ v^2 h + \frac{1}{\phi^{b2}} \frac{1}{2} g h^2 \end{bmatrix}$$

$$\boldsymbol{S}_b = \begin{bmatrix} 0 \\ -\frac{gh}{\phi^{b2}} \frac{\partial b}{\partial x} + \frac{1}{2} g h^2 \frac{\partial (1/\phi^{b2})}{\partial x} \\ -\frac{gh}{\phi^{b2}} \frac{\partial b}{\partial y} + \frac{1}{2} g h^2 \frac{\partial (1/\phi^{b2})}{\partial y} \end{bmatrix} \boldsymbol{S}_f = \begin{bmatrix} 0 \\ \frac{\mu u \phi^b}{\sqrt{u^2 + v^2 + (u\frac{\partial b}{\partial x} + v\frac{\partial b}{\partial y})^2}}) \\ \frac{\mu v \phi^b}{\sqrt{u^2 + v^2 + (u\frac{\partial b}{\partial x} + v\frac{\partial b}{\partial y})^2}}) \end{bmatrix}$$

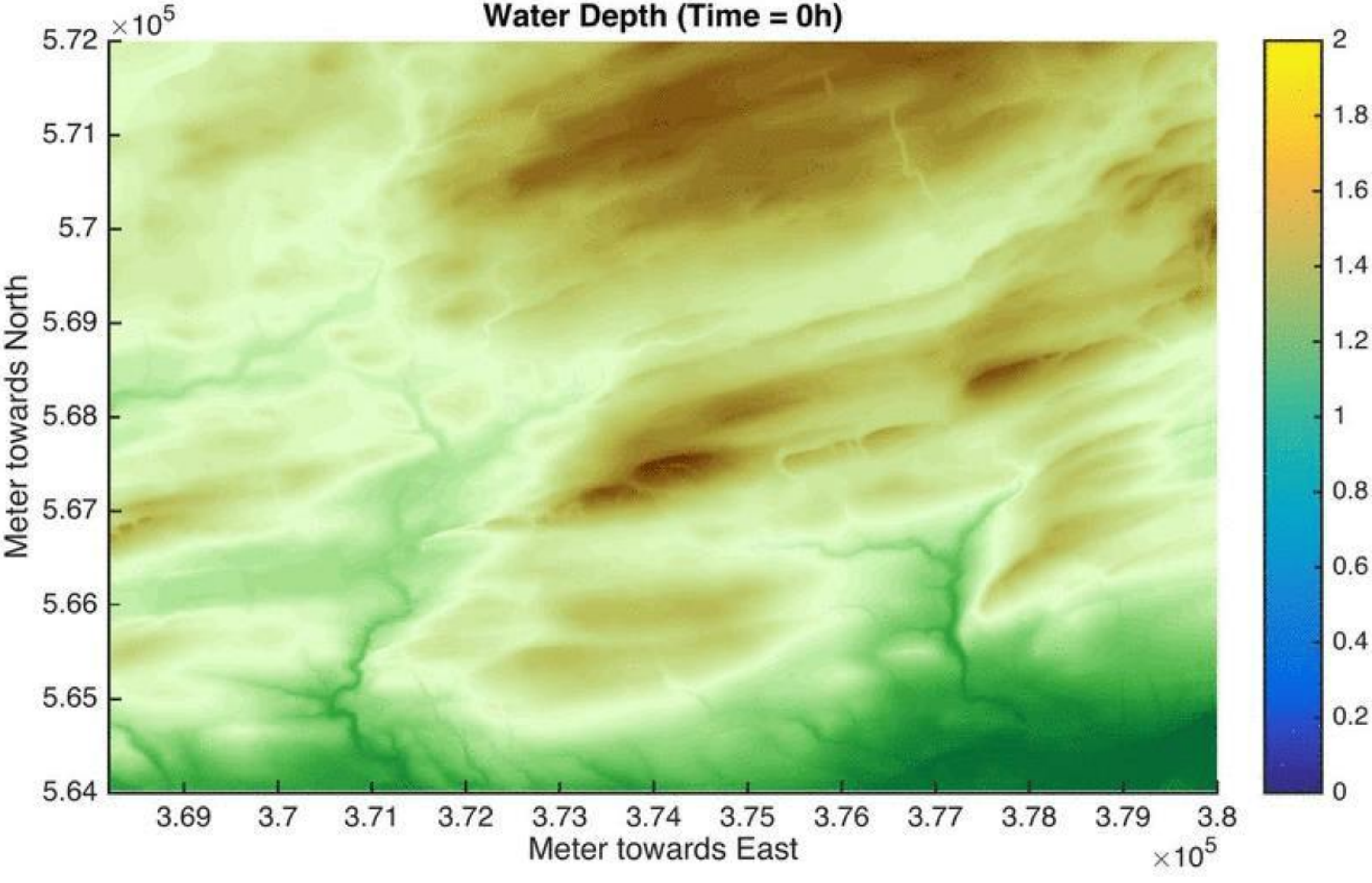
Haltwhistle Burn Catchment (42km^2)





- Rapid Response Catchment categorised by the Environment Agency, UK
- Hypothetic rainfall event
- Simulation at 5m resolution with 4 millions cells

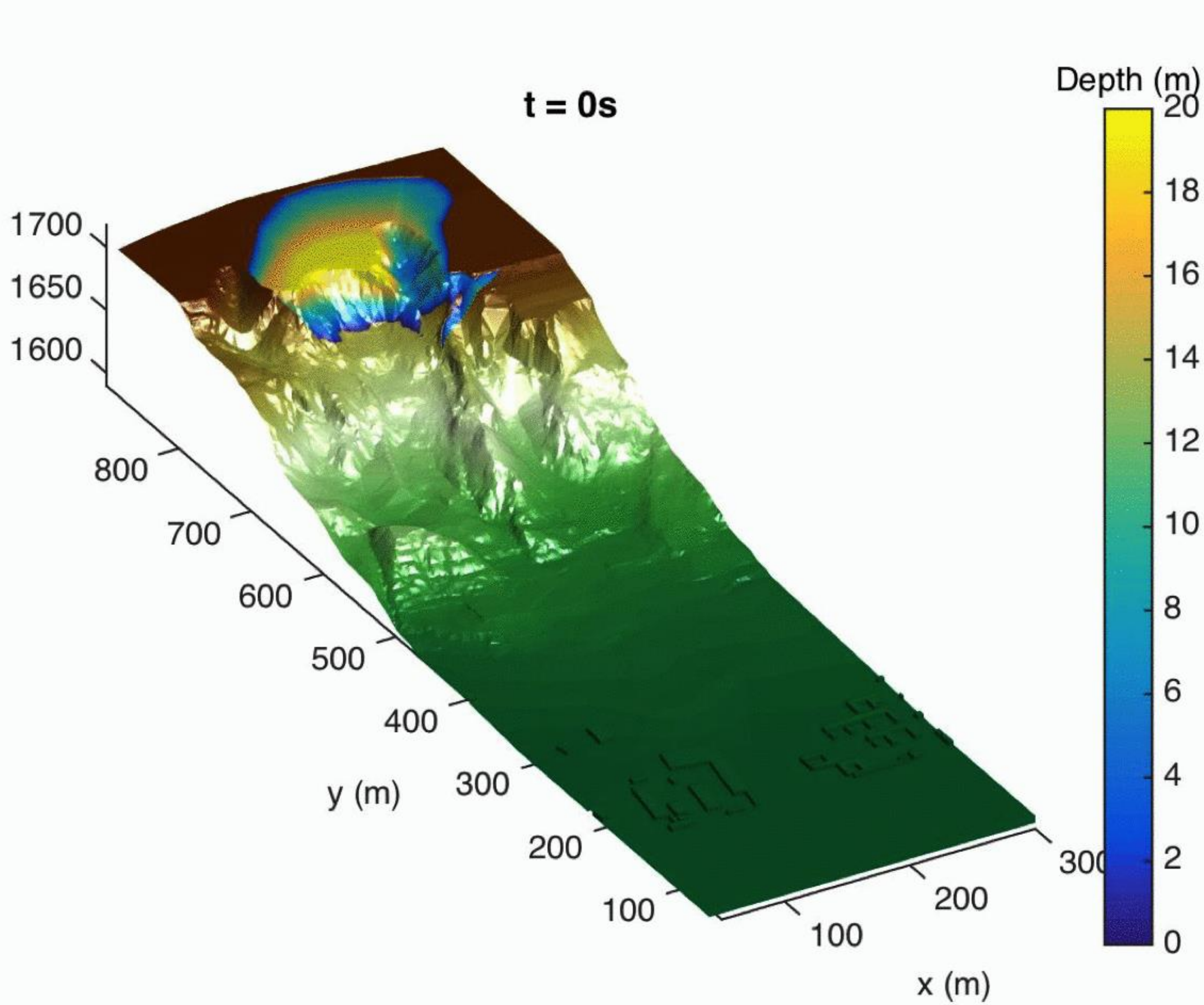
Surface flooding process

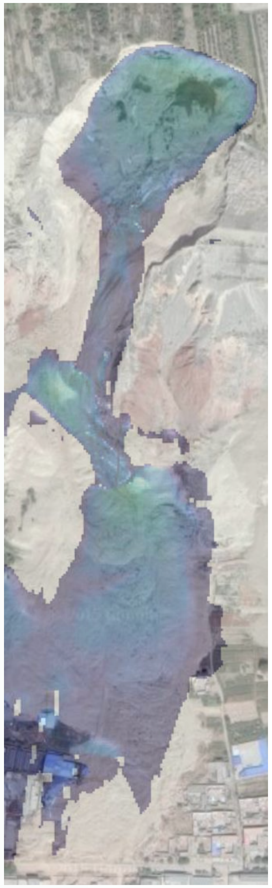


Heifangtai landslide

- Located in Yongjing, Linxia, Gansu province
- Slope angle is as large as 60 degrees
- Effective friction angle is 13 degrees
- 0.88 million cells in simulation (0.5m resolution)

Heifangtai Landslide



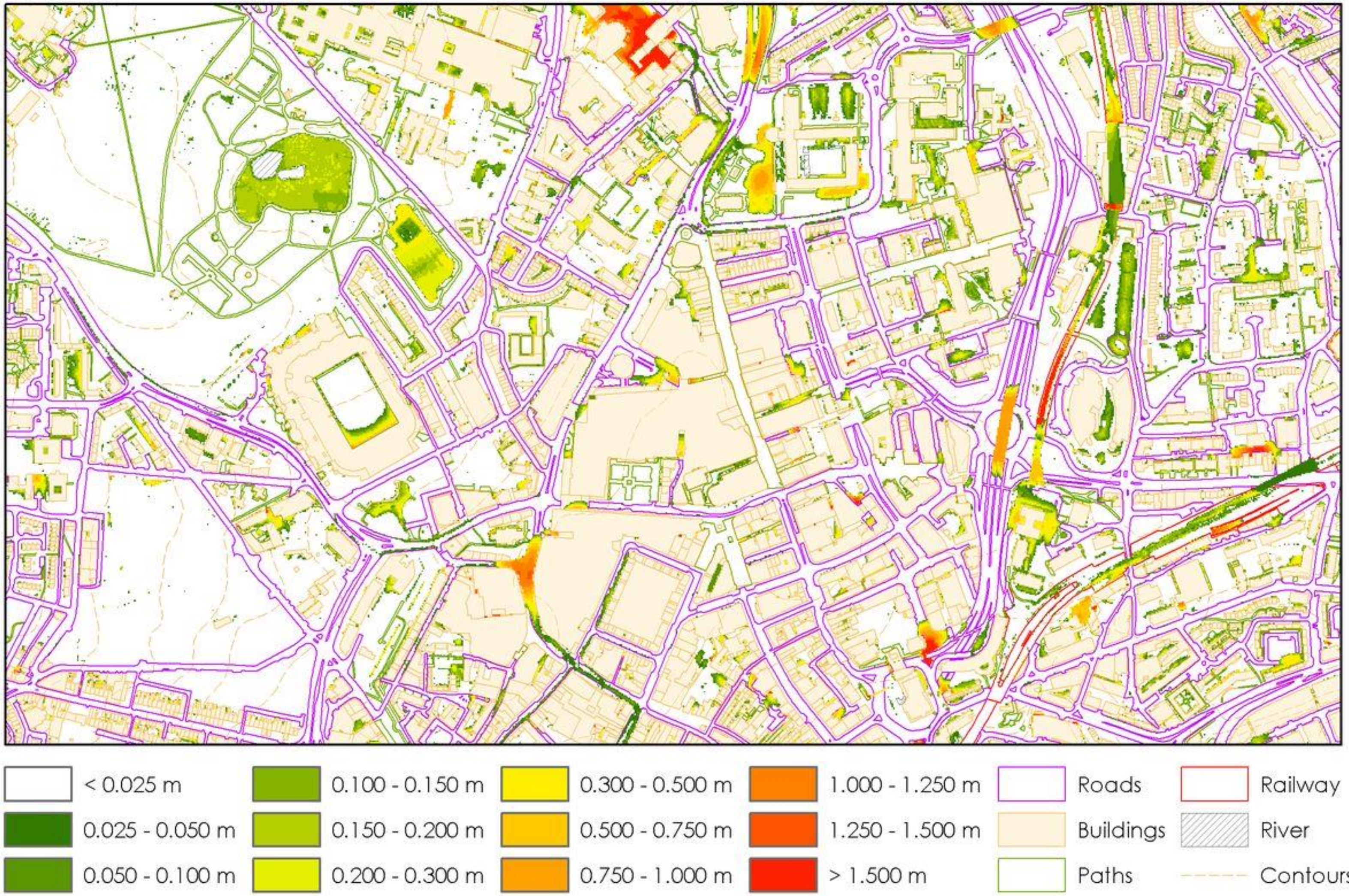


#toonflood

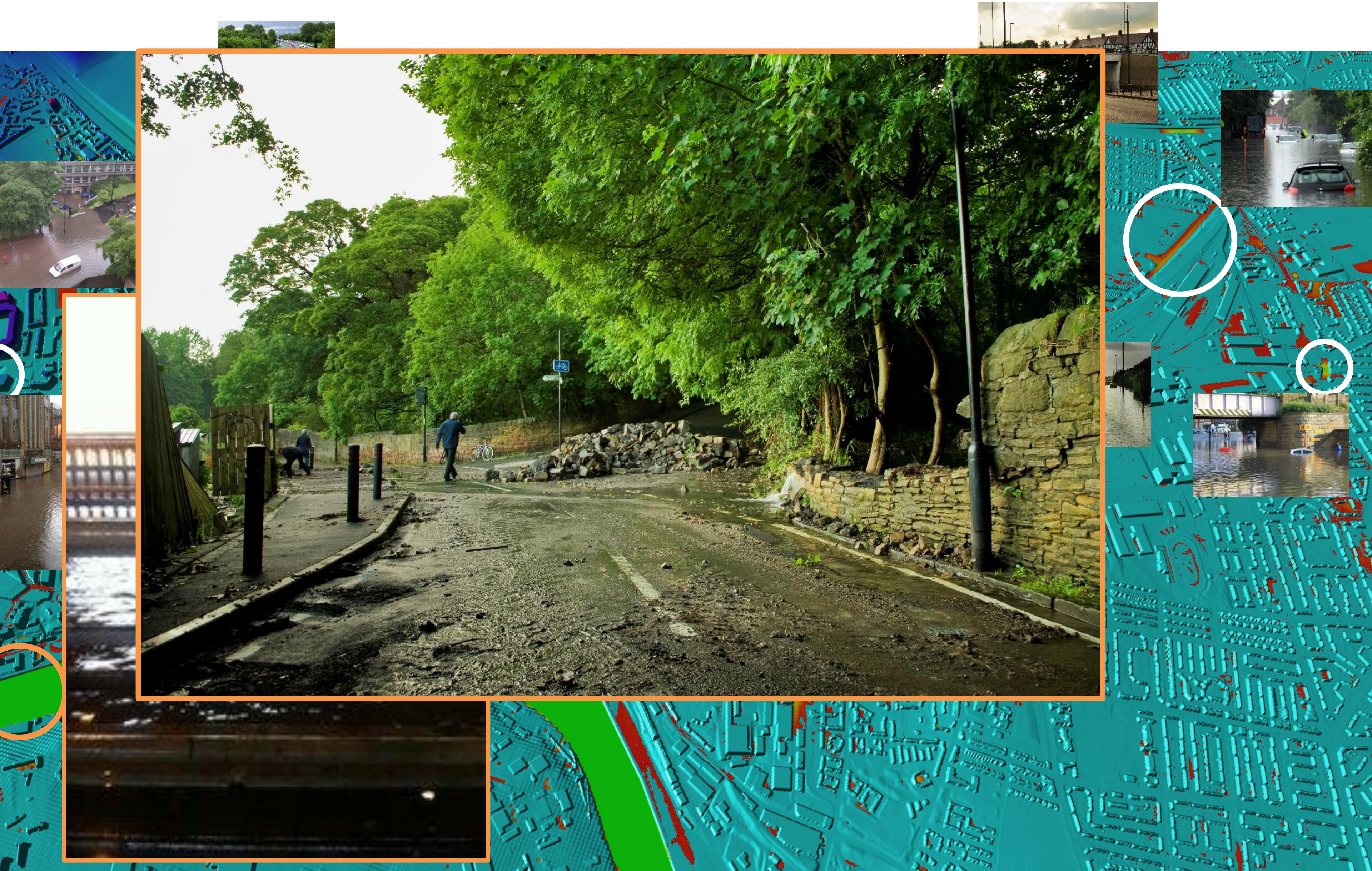
- **28th June 2012 15:55 BST**
- More than a 100 year return period event
- River Ouseburn in Jesmond Dene rose by 1m in less than an hour
- 200mm/hour rainfall rate recorded
- 500 properties flooded internally
- £3 million capital expenditure on works to prevent a repeat

Newcastle upon Tyne Surface Water Model (Input from UKMO NIMROD)

28-Jun-2012 17:55 UTC



Modelling versus Reality



Example: Results

Performance results for Newcastle flood (6 hours simulation, driven by NIMROD rainfall radar)

- Newcastle City Centre: $34km^2$, 2m resolution, ~8m cells
- Tyne and Wear Simulation: $400km^2$, 2m resolution, 100m cells

Simulation	Domain area	Resolution (cells)	Devices (4xK40Ms + 2xK80)	Runtime
Whole area	**$400km^2$**	**2m (100,000,000)**	6x	06:01:00
City centre	**$34km^2$**	**2m (8,805,496)**	6x	01:01:22

Conclusions

- Catchment processes (natural hazard chains) involve interaction between natural and human systems
- The risk of natural hazards is on the rise; a catchment systems management approach (holistically takes into account interacting natural systems, human activities and built environment) is needed for hazard reduction and resilience building
- Recent technology advances provide an exciting opportunity to create a step change; but challenges still exist
- Taking advantages of the recent high-performance computing technology, Hi-PIMS could be the next generation of catchment systems modelling tool
  - Modelling full processes of natural hazard chains from onset
  - Real-time forecasting
  - Modelling coupled human and natural systems
  - Risk assessment and sustainable catchment management