Global Water Security: Modelling for Sustainable Flood, Water Quality and Health Risk Assessment

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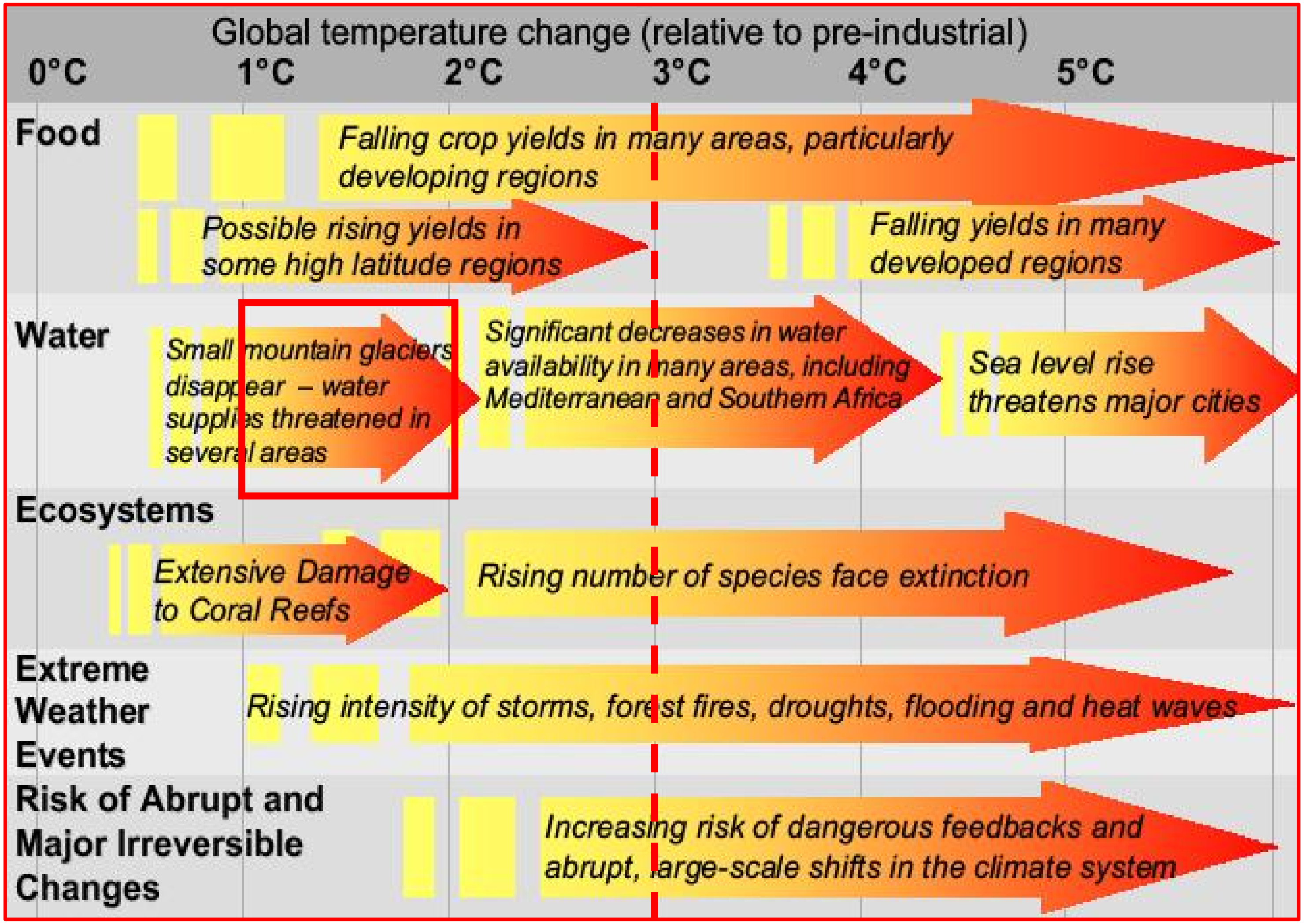
Contents

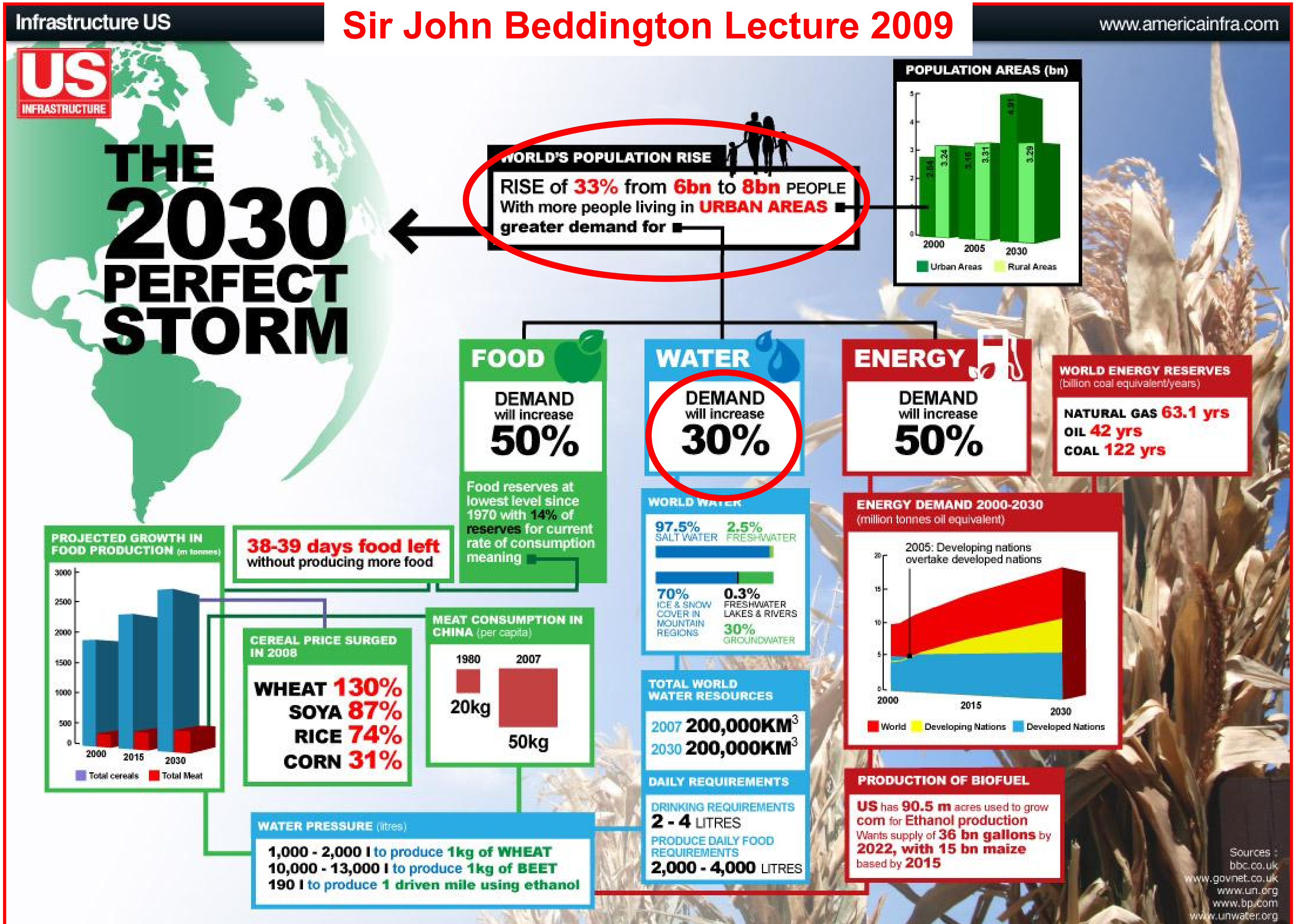
- General introduction
- Extreme Flood Events ➪ refined modelling and stability of people and vehicles in floods
- Cardiff Bay Regeneration ➪ dissolved oxygen and destratification management
- Ribble River Basin and Fylde Coast ➪ integrated hydro-epidemiological process modelling
- Concluding remarks

Climate Change ⇨ Stern & IPCC 2019



'Global temperatures on track for 3° rise by 2100: UN'

Impacts of Population Growth



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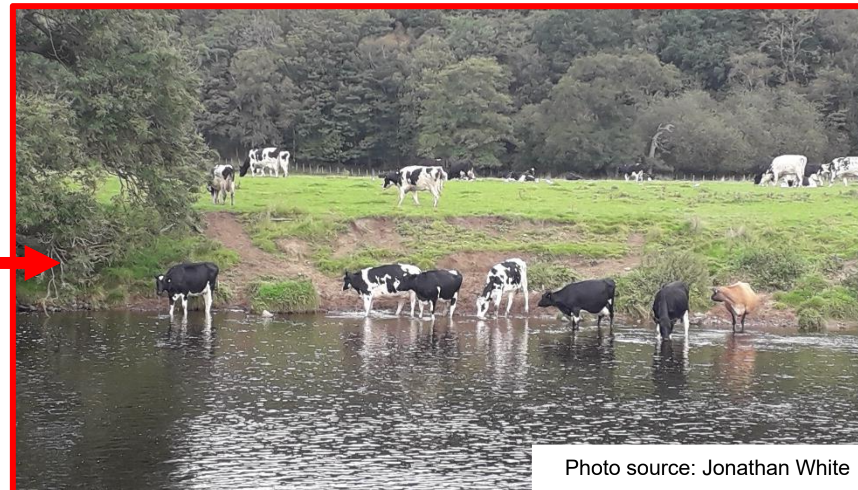
Sustainable Development Goals ⇨ 2030

6.5: Implement integrated water resources management at all levels

Global Water Security ⇨ Challenges

Diffuse & Point Source Pollution ⇨ R. Wharfe

Pristine River Wharfe at Bolton Abbey



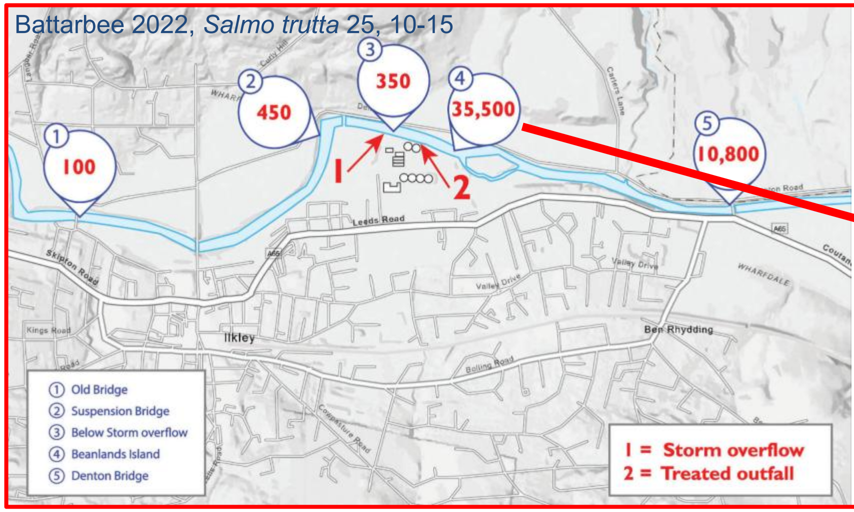
Cattle in River Wharfe ⇨ Diffuse Pollution

Combined Sewer Overflow ⇨ Point Pollution

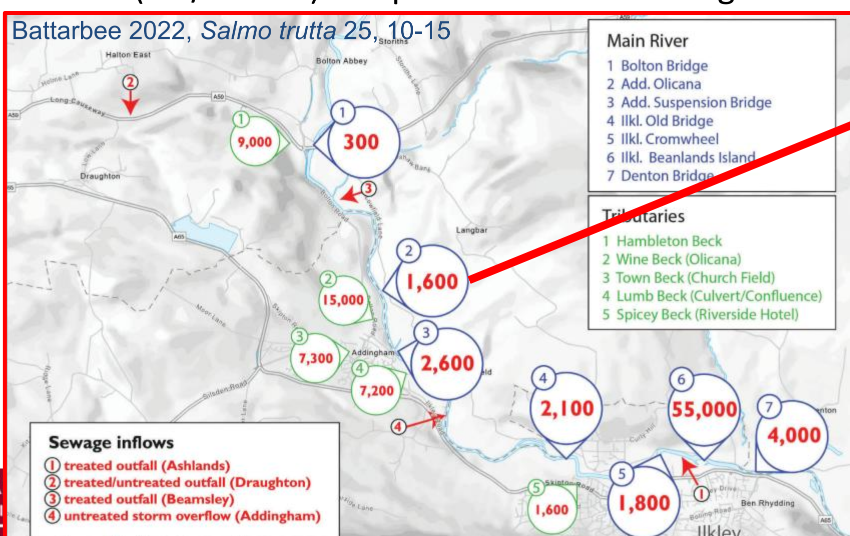
Bathers in River Wharfe ⇨ Ilkley

Measured *E. coli* in River Wharfe - Ilkley

E.coli (cfu/100 ml) samples – Ilkley 10th Jul 2019



E.coli (cfu/100 ml) samples – Wharfe 23rd Aug 2021



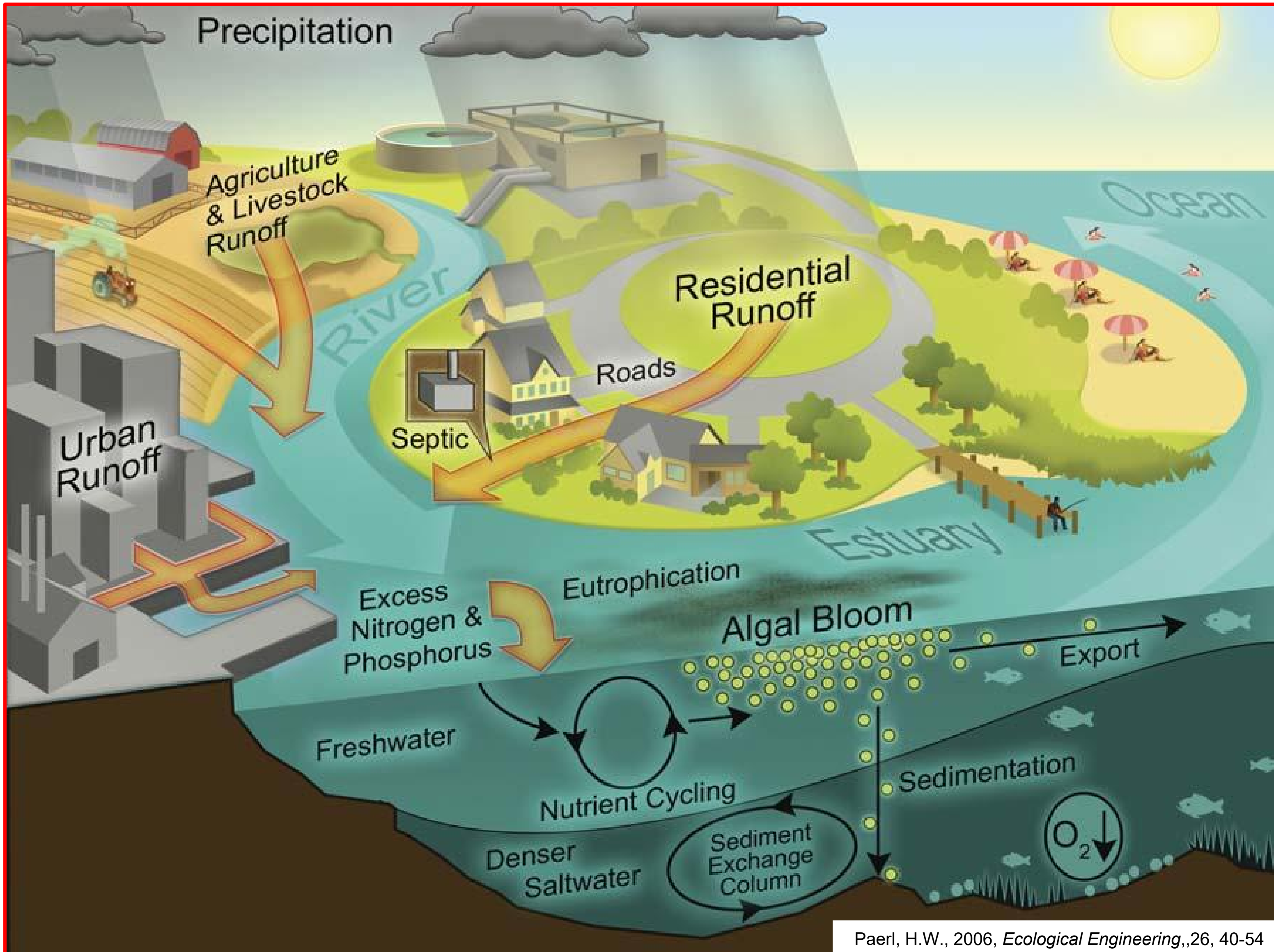
EU BWD Standards for Recreational Waters

Classification	Enterococci (cfu/100ml)	*E. coli* (cfu/100ml)	Percentile
Inland Waters			
Excellent	200	500	95
Good	400	1000	95
Sufficient	330	**900**	90
Coastal Waters			
Excellent	100	250	95
Good	200	500	95
Sufficient	185	500	90

Key observations from *E.coli* samples:

- Levels ≫ downstream of CSOs
- Exceed 'Sufficient' status for Wharfe downstream of Ashlands CSO

Water System ⇨ Source-to-Sea Approach



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Modelling Extreme Flood Events
and
Stability of Vehicles and People

General

- Flooding essentially a natural process ⇨ need to adapt to climate change and build flood resilience
- Flooding caused by high rainfall ⇨ exacerbated by poor drainage, groundwater saturation, debris etc.
- Flooding leads to water pollution ⇨ often causing significant loss of life due to water-borne diseases
- Flood impact often inadequately predicted due to:
  - Inadequate data and warning systems ⇨ poor planning
  - Inadequate drainage and/or insufficient upland storage
  - Inappropriate modelling tools ⇨ non-specialist users

Somerset Levels 2014 ⇨ Mild Slope River

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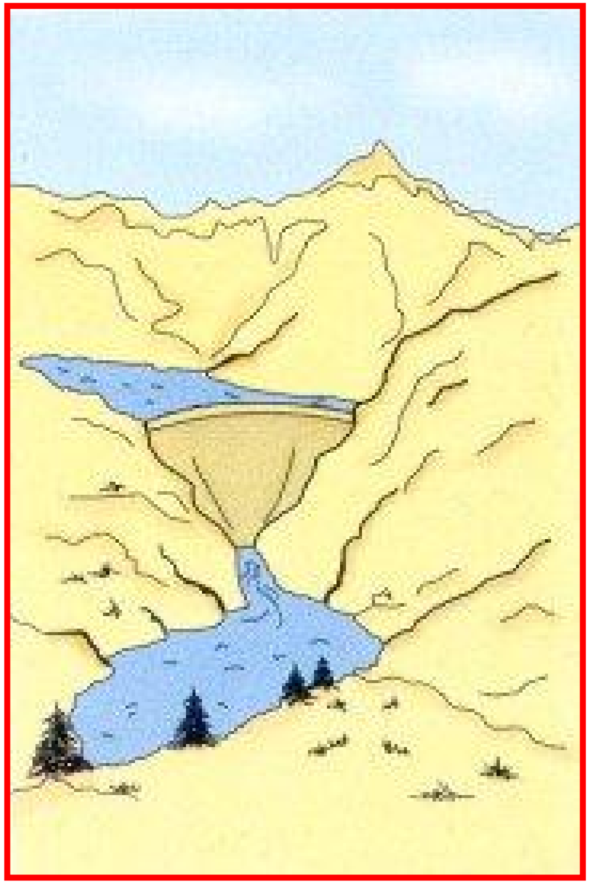
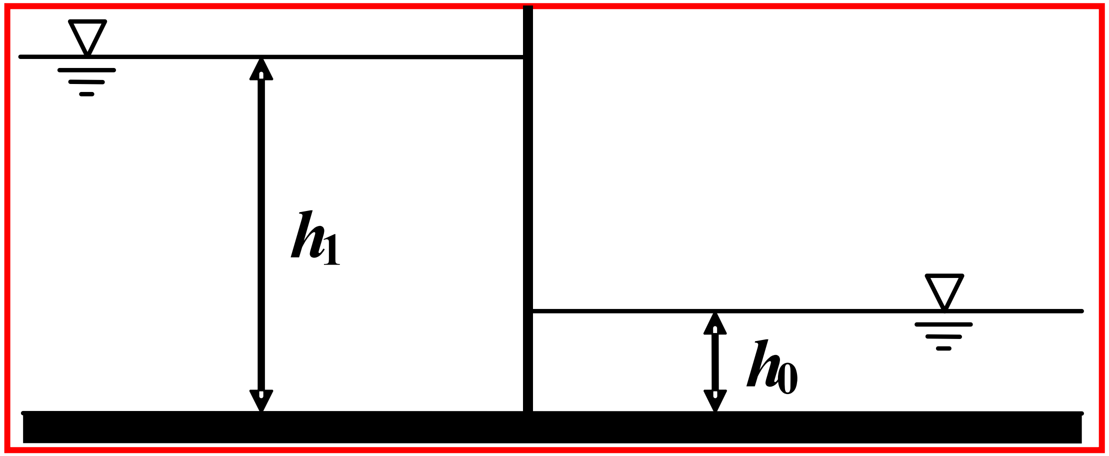
Cumbria Flood 2016 ⇨ Steep Slope River

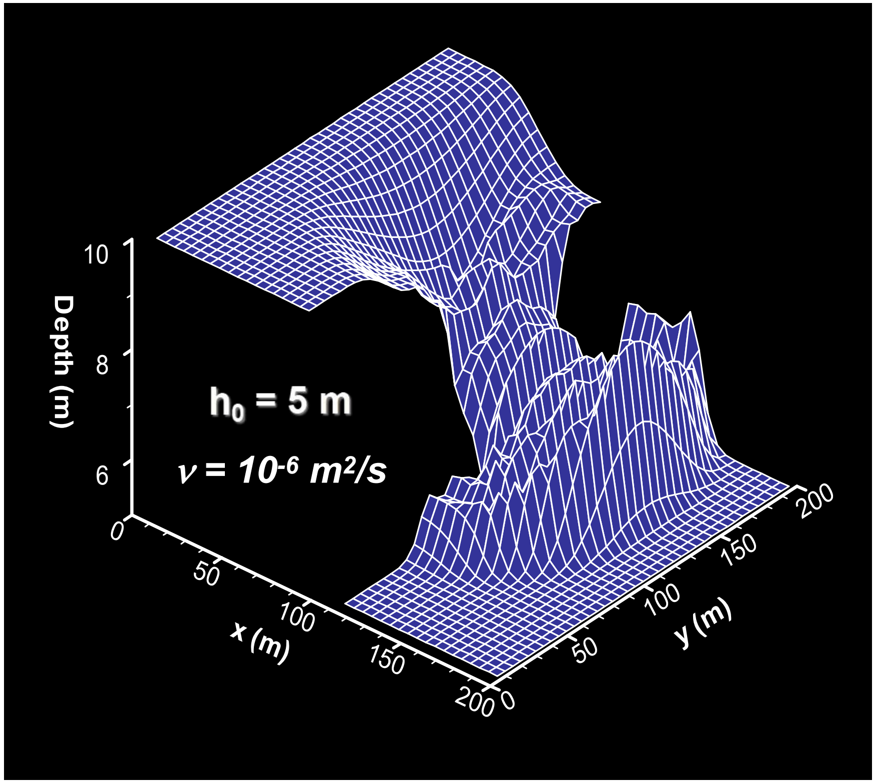
General Flood Model Studies ⇨ 2-D ADI

- Extreme flood events ⇨ similar to Dam-Break Problem with high Froude number and Trans/Super critical flow

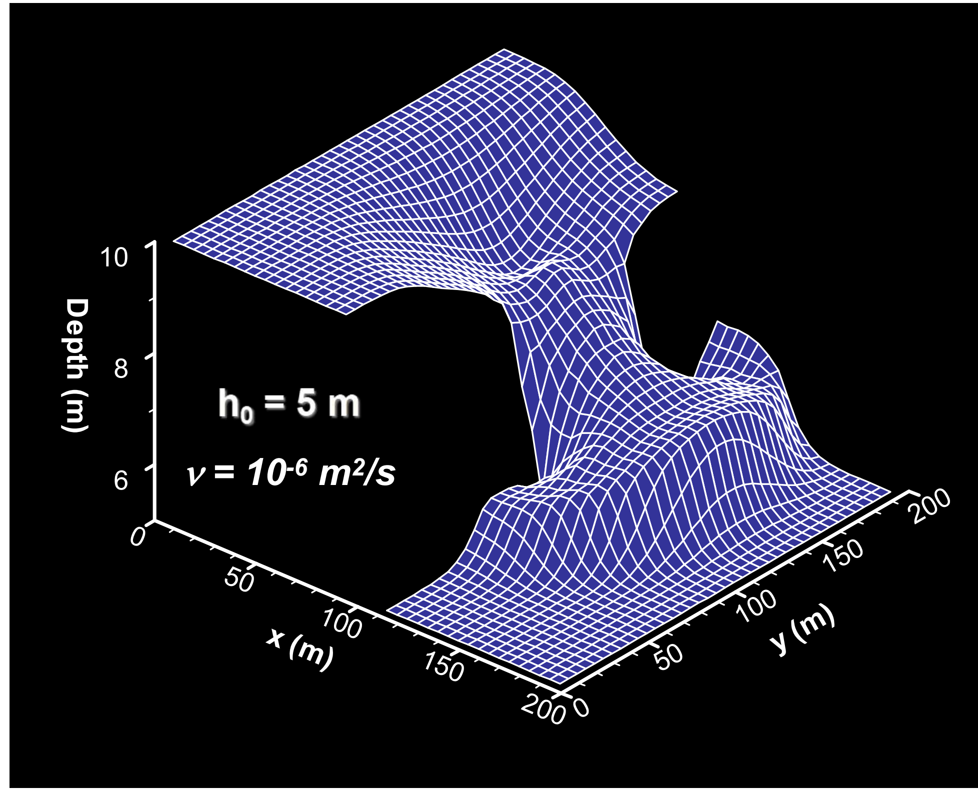




2-D Models: ADI v TVD (Shock Capturing)



ADI



TVD

Need increased dissipation to remove oscillations for ADI Scheme and high Froude number flows

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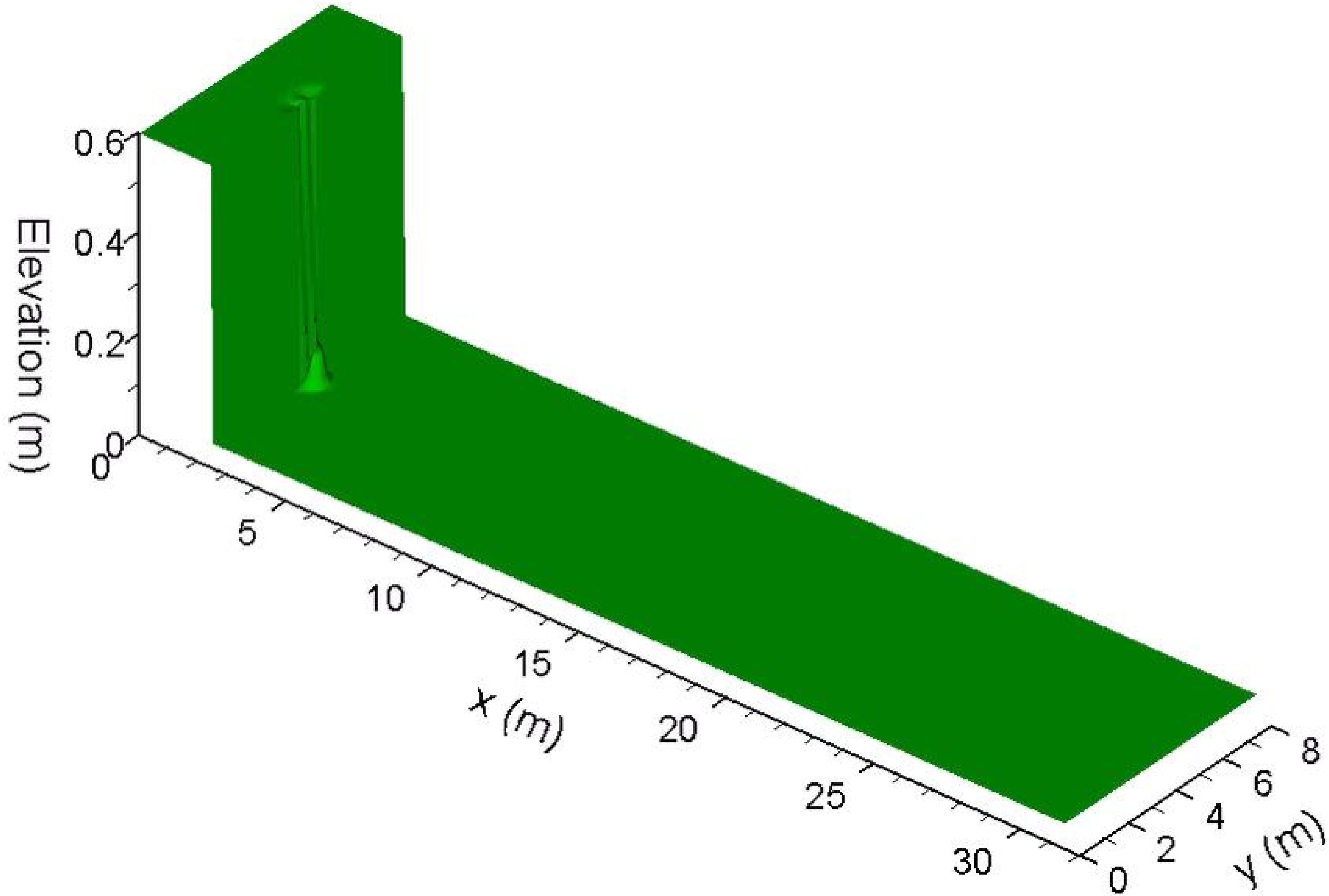
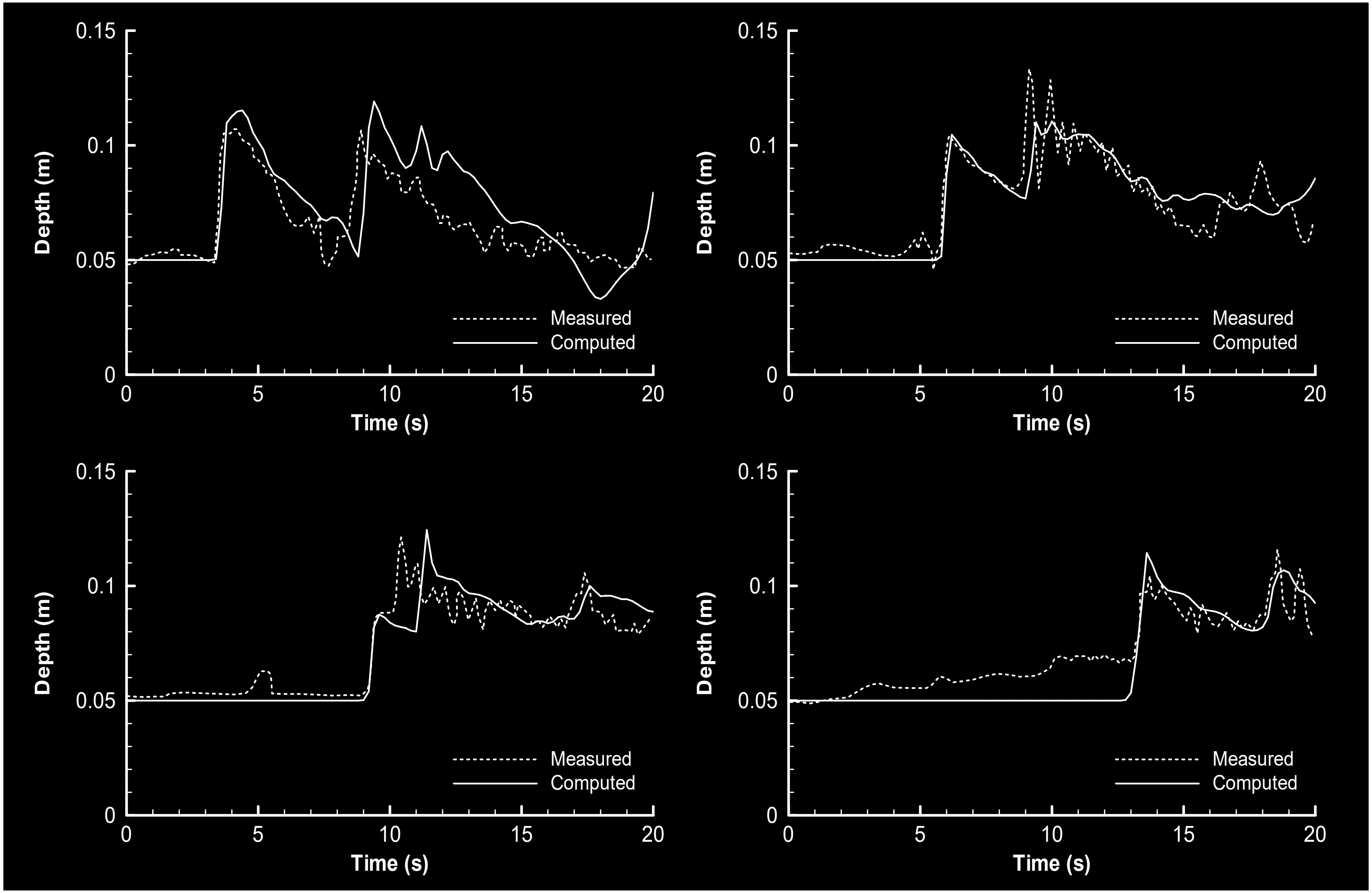
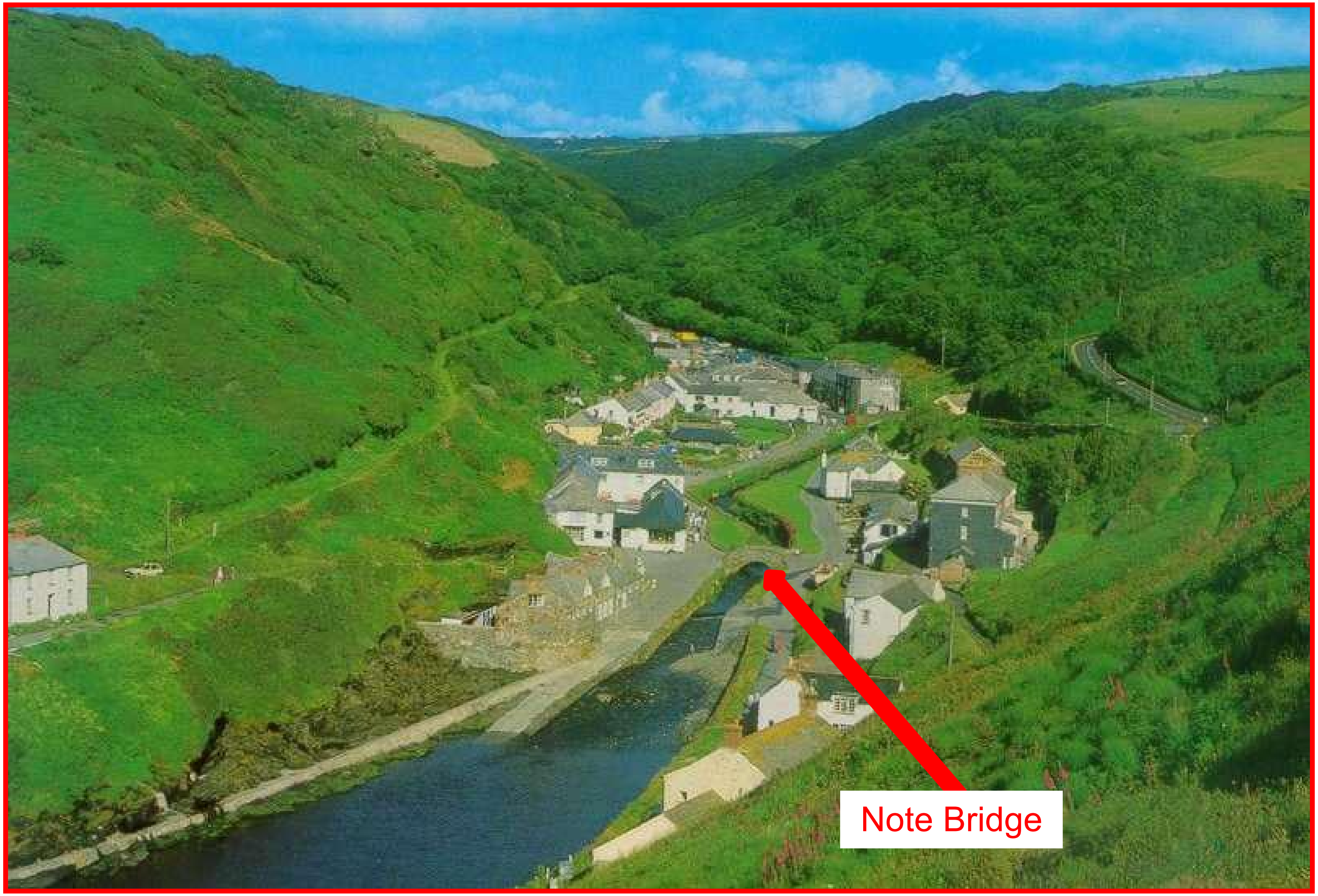
Dyke Break Experiment (TU Delft)



Dyke Break Experiment ⇨ TVD Results



Boscastle Flood 2004 ⇨ Extreme Event



Boscastle Flood 2004 ⇨ Steep River Basin

- Small coastal town in Southwest of England
- Short river basin with steep valley terrain ⇨ similar to many river basins across UK and world-wide
- Up to 200 mm rainfall fell in 5 hr and predicted to be 1 in 400 yr return period event
- Extensive damage to properties, bridges, highways and other infrastructure
- One of best recorded extreme flood events in UK with trans- and super-critical flows

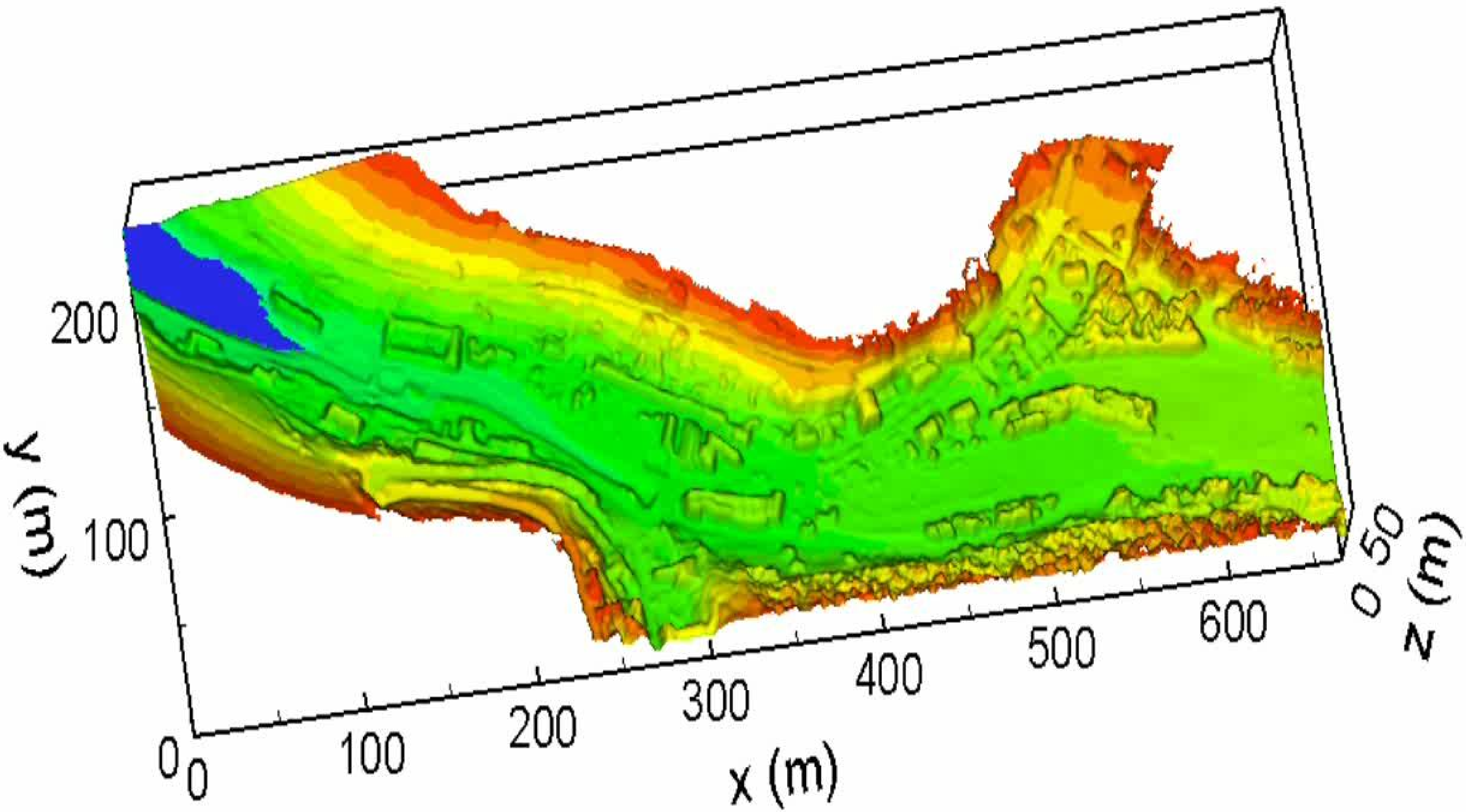
Boscastle Flood 2004 ⇨ Car Blocks Bridge

Model Study Objectives

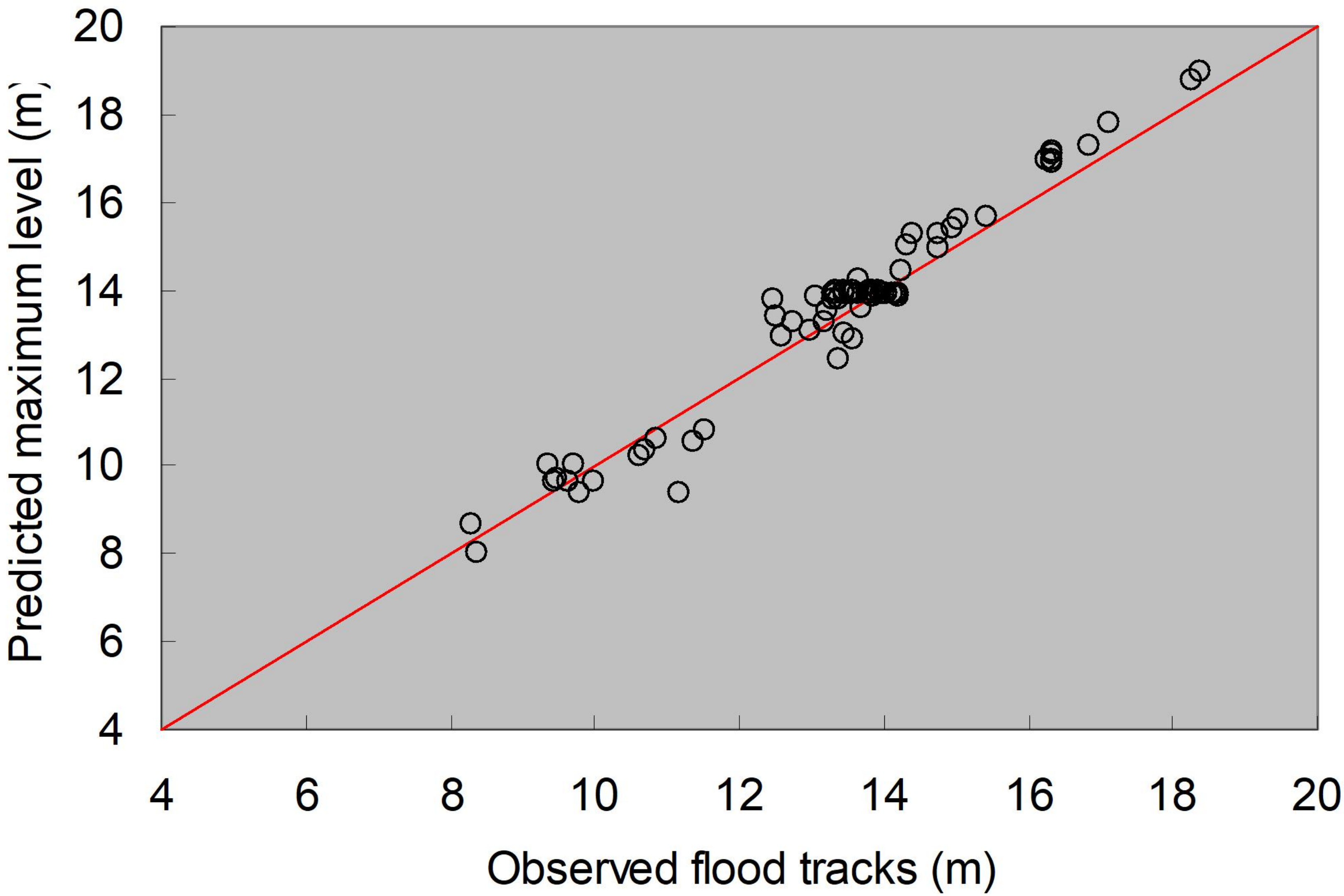
- Case study of 2004 Boscastle flash flood event
- Determine model type most accurate for predicting key hydraulic parameters for extreme event
- Three different schemes compared:
  - TVD MacCormack (i.e. with shock capturing algorithm)
  - MacCormack (i.e. without shock capturing algorithm)
  - Simple Inertia (i.e. without inertia – kinematic wave)
- Predicted main flood parameters (elevations and inundation extent) compared with wrack marks

Boscastle Study Domain

Predicted Flood Simulation (TVD Scheme)



Predicted v Observed Water Levels



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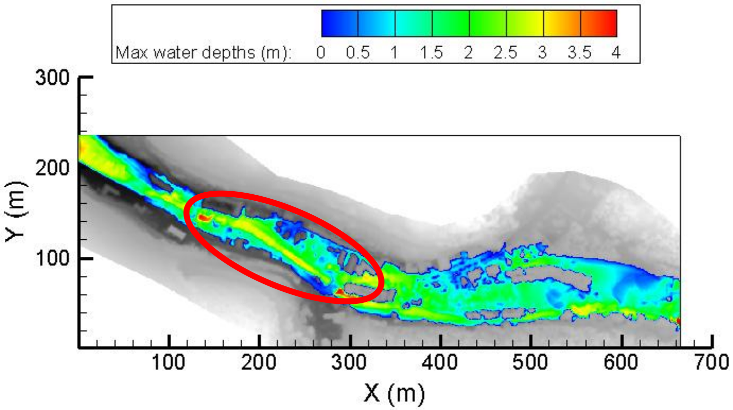
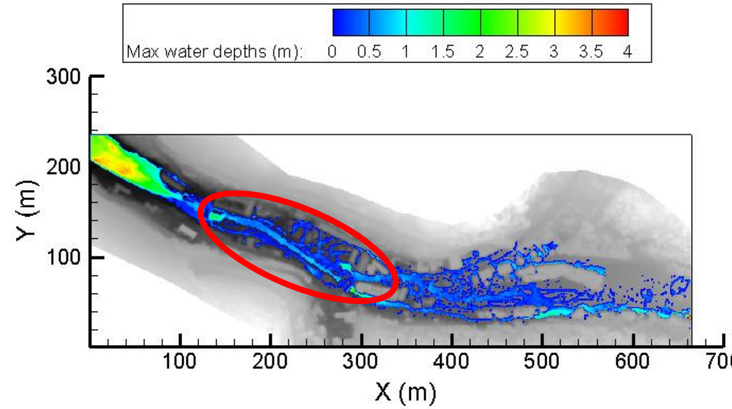
Predicted Levels ⇨ Compared to Data

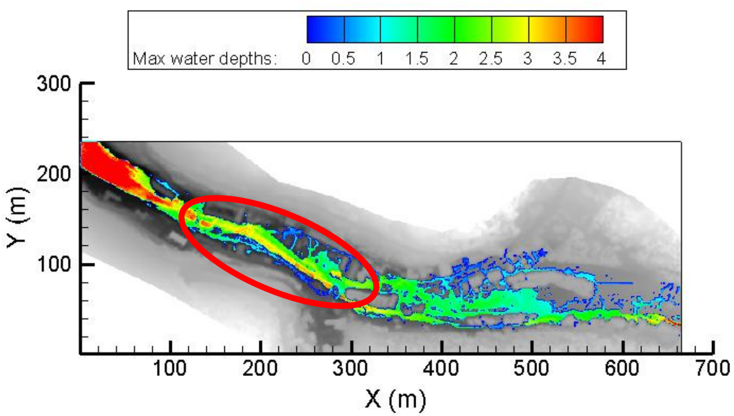
TVD case



MAC case



SI case



Model configuration	Nash – Sutcliff model efficiency
TVD case	0.9863
MAC case	0.8530
SI case	0.8684

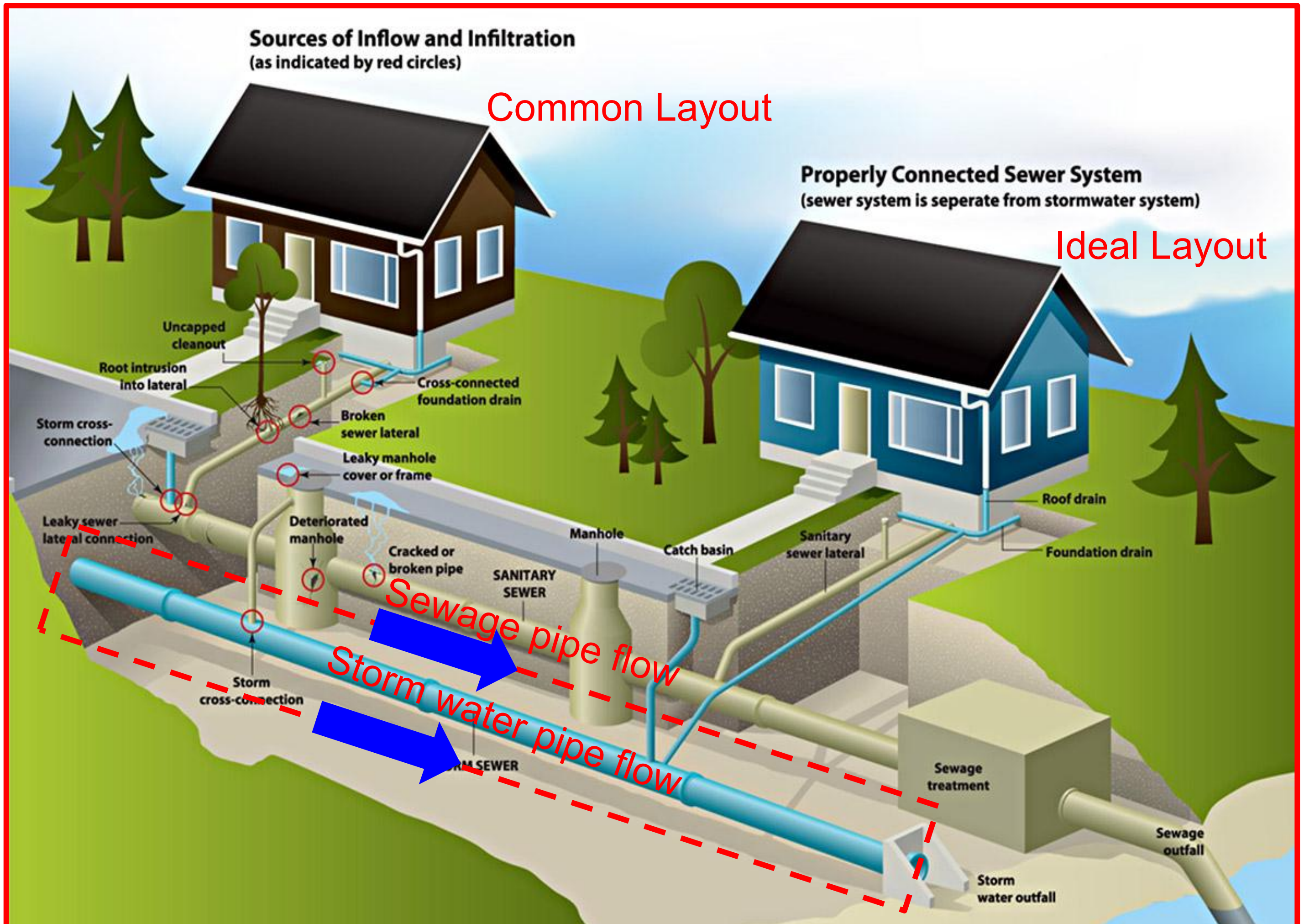
Comparisons with 30 wrack mark data points

Very different peak elevations and inundation extents

Modelling Urban Flooding ⇨ China and UK

- Funders: Newton Fund – UK Royal Academy of Engineering and Chinese Academy of Engineering
- Partners: Wuhan University, China, and Cardiff University, UK
- Brief Title: Studies on disaster-causing mechanisms and disaster counter measures of urban flooding in China and the UK
- Supervisors: Prof. Junqiang Xia, Wuhan and Profs. Reza Ahmadian and Roger Falconer, Cardiff

Urban Drainage Systems ➩ Storm & Sewer



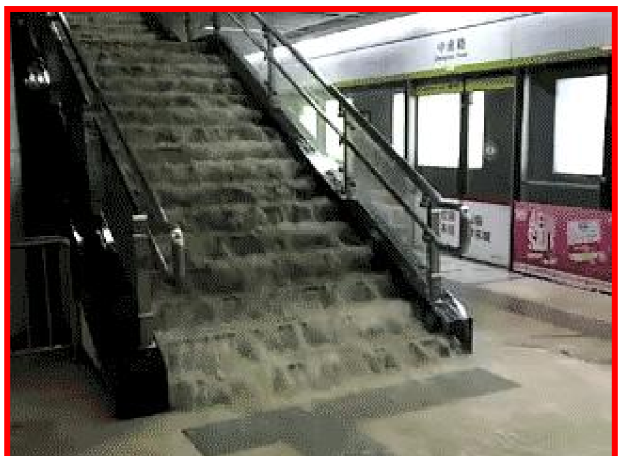
Urban drainage systems ideally include 3 parts:

- Drainage via storm water pipe flow
- Sewage flow to WwTWs
- Street inlet flow to storm water pipe ➩ but often all combined into one system

Sketch of a typical urban drainage system - https://sewerdiagnostics.com/sewer-system-explained/

Impact of Urban Floods ⇨ China & UK

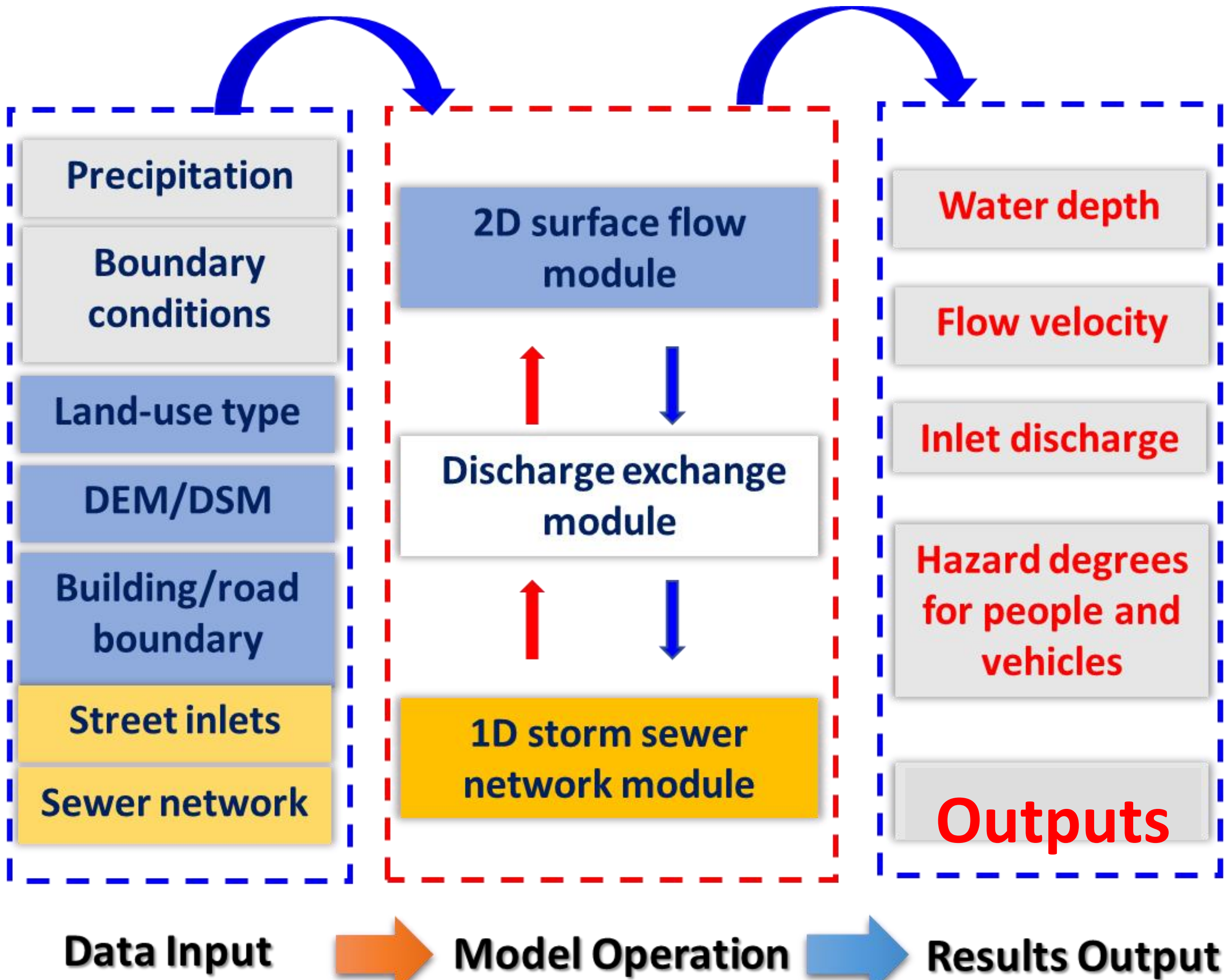
- Urban floods occur frequently with devastating impacts:- (i) flooding of buildings; (ii) stability of people and vehicles; etc.
- Various hydrodynamic challenges:- (i) 2D surface flooding; (ii) 1D stormwater sewer pipe flow and pressure; (iii) inlet discharge and overflow characteristics; (iv) impact of, and on, buildings; (v) stability and interaction of objects; etc.


Subway station in Wuhan


Human instability in Zhengzhou


Vehicle instability in Tongren

Framework for Hazard Assessment Model

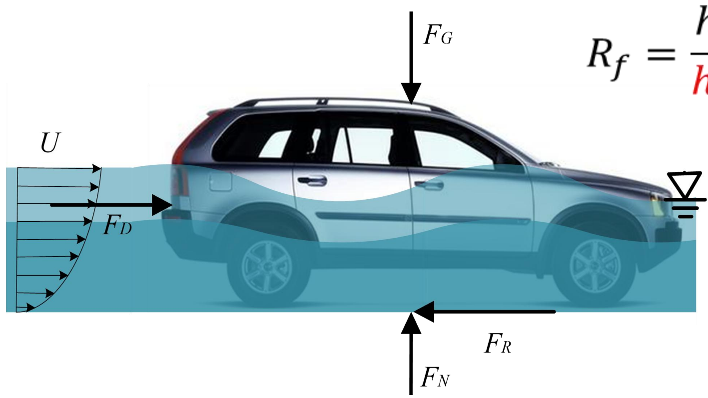


Module IV ⇨ Formula for Vehicle Stability

Partially submerged vehicles mainly controlled by 4 forces: drag force, friction force, effective gravity, and ground resistance

$$U_c = \alpha \left(\frac{h_f}{h_c} \right)^{\beta} \sqrt{2 g l_c \left(\frac{\rho_c}{\rho_f} \frac{h_c}{h_f} - R_f \right)}$$

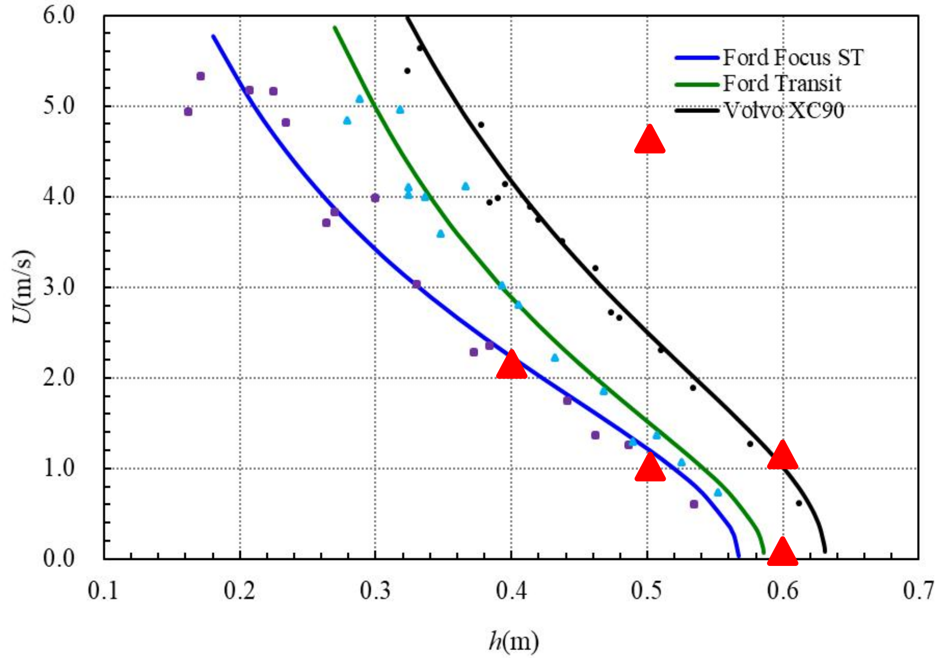
$$R_f = \frac{h_c \gamma_c}{h_k \gamma_f}$$



Sketch of 4 forces acting on partially submerged vehicle

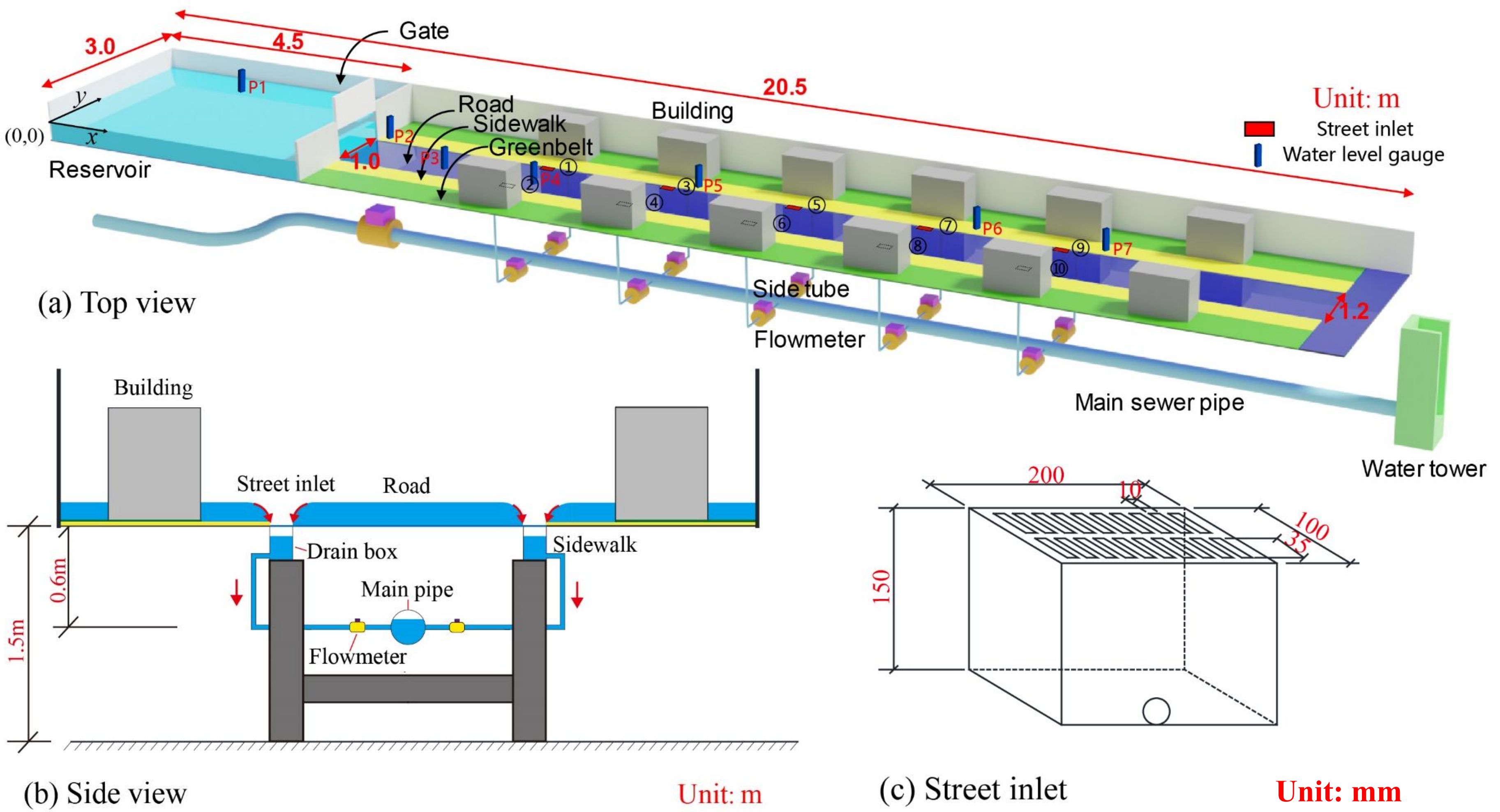
$$HR = \min(1, U_c / U)$$

HR is Hazard degree



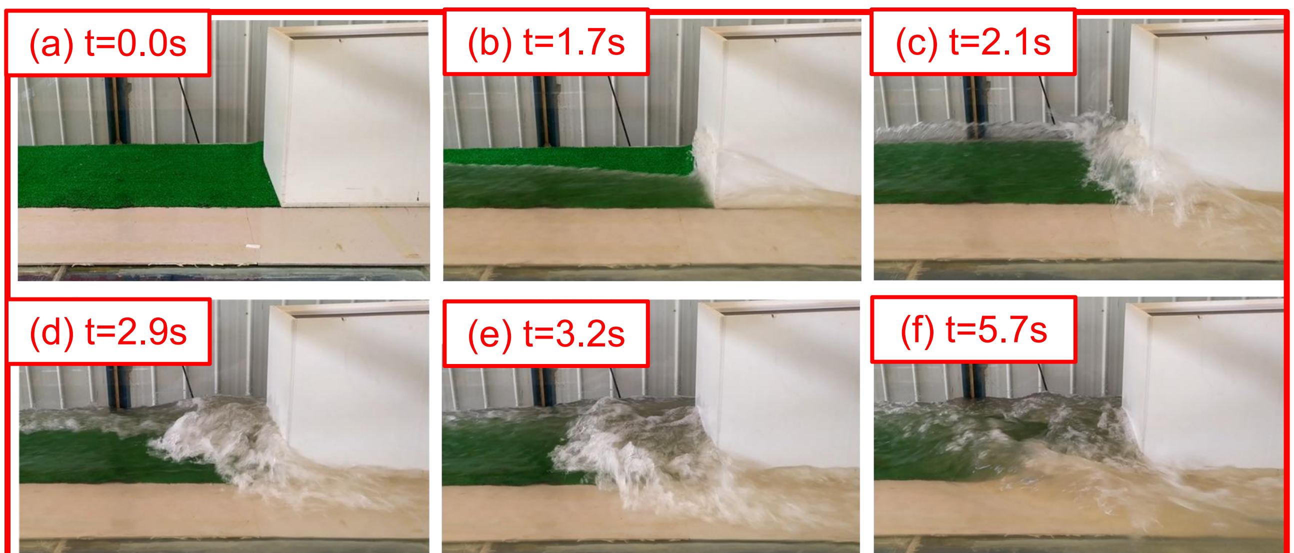
Proposed stability threshold for different vehicles in floodwaters

Laboratory Model ⇨ Typical Urban Street



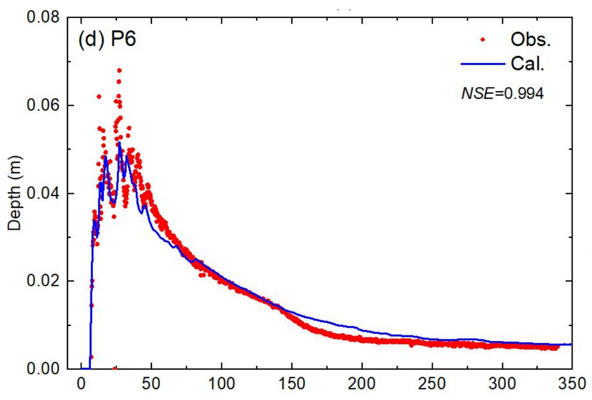
Laboratory Model Experimental Results

- General description of flood propagation and inundation processes:
  - Modelling instantaneous flood inundation process by lifting gate rapidly
  - Video images showing collision processes between dam-break flow and buildings

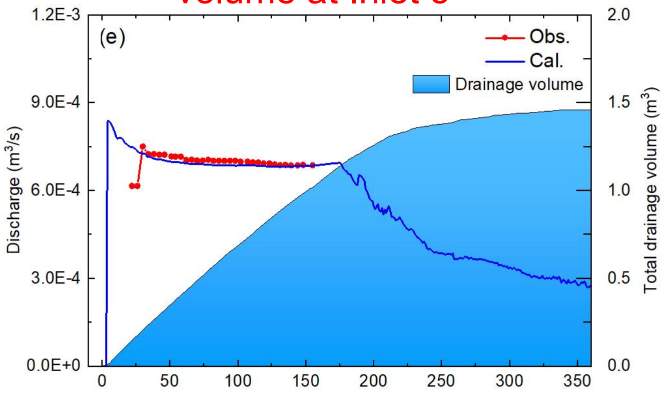


Model Validated with Laboratory Results

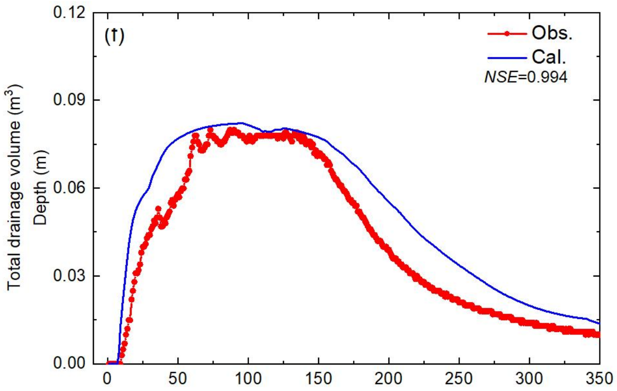
Surface water depth at P7



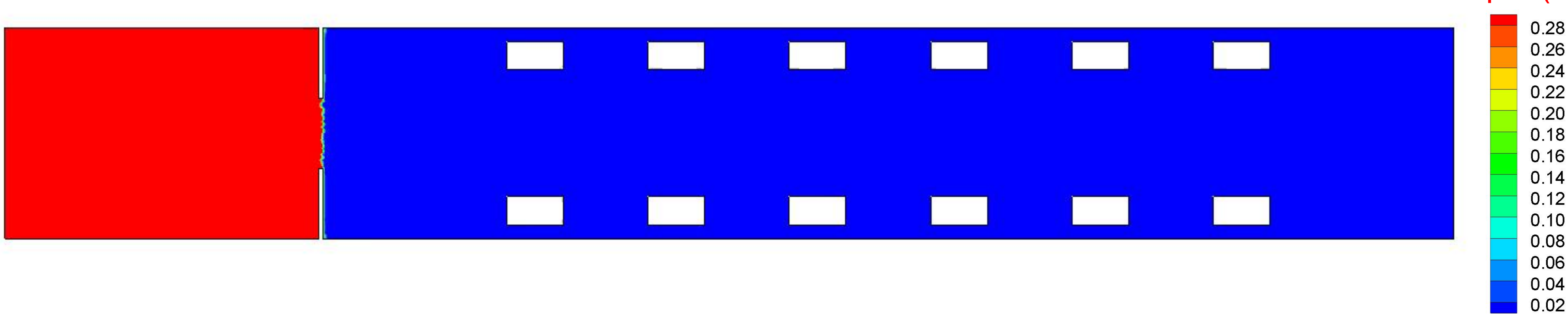
Discharge and total drainage volume at Inlet 5



Sewer water depth

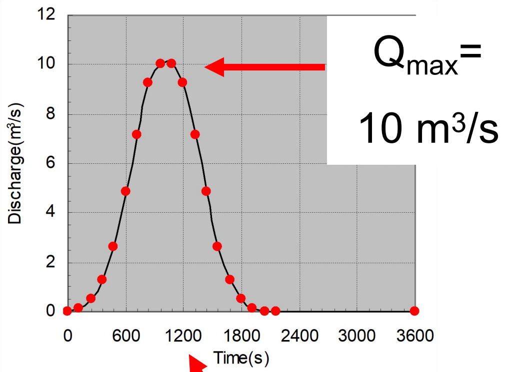


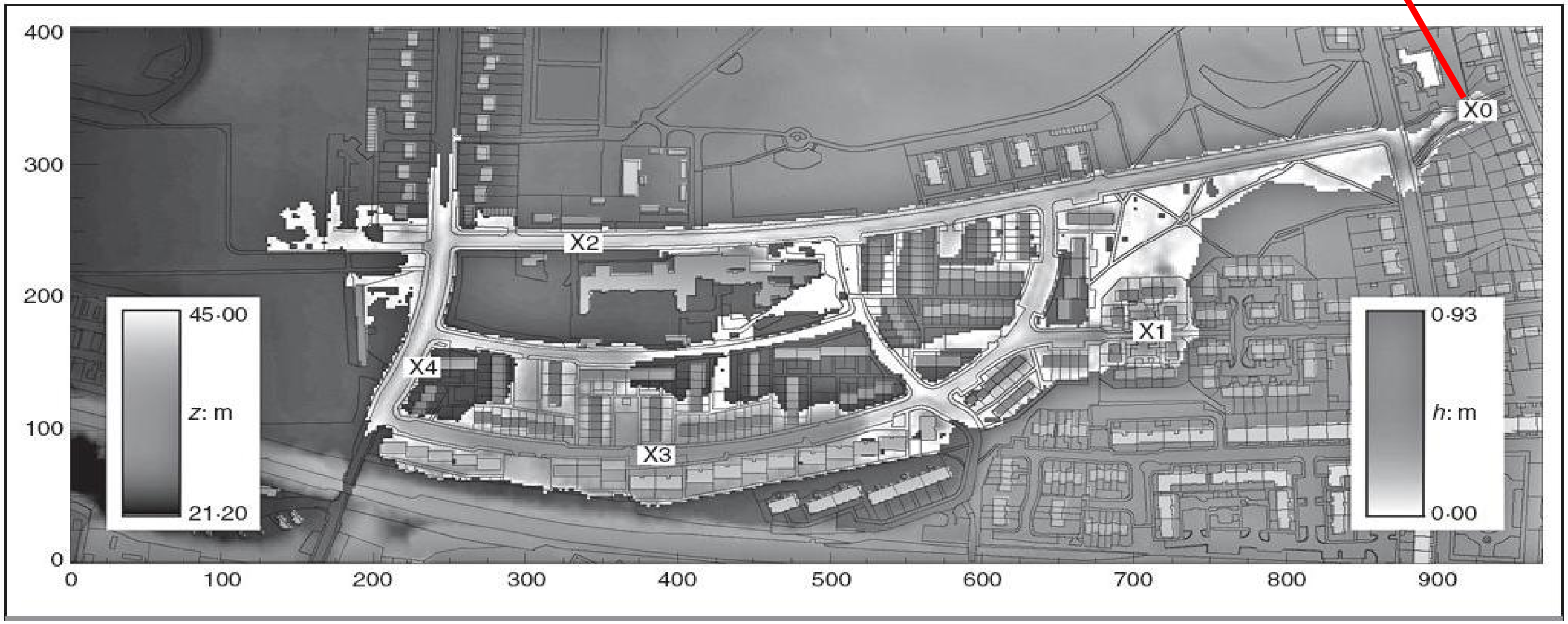
Water depth (m)



Application ⇨ Urban Flooding, Glasgow, UK

- Site located in urban streets in city of Glasgow
- Peak discharge = 10 m^3/s and volume = 8,580 m^3
- Storm-sewer system composed of 130 street inlets and 50 manholes

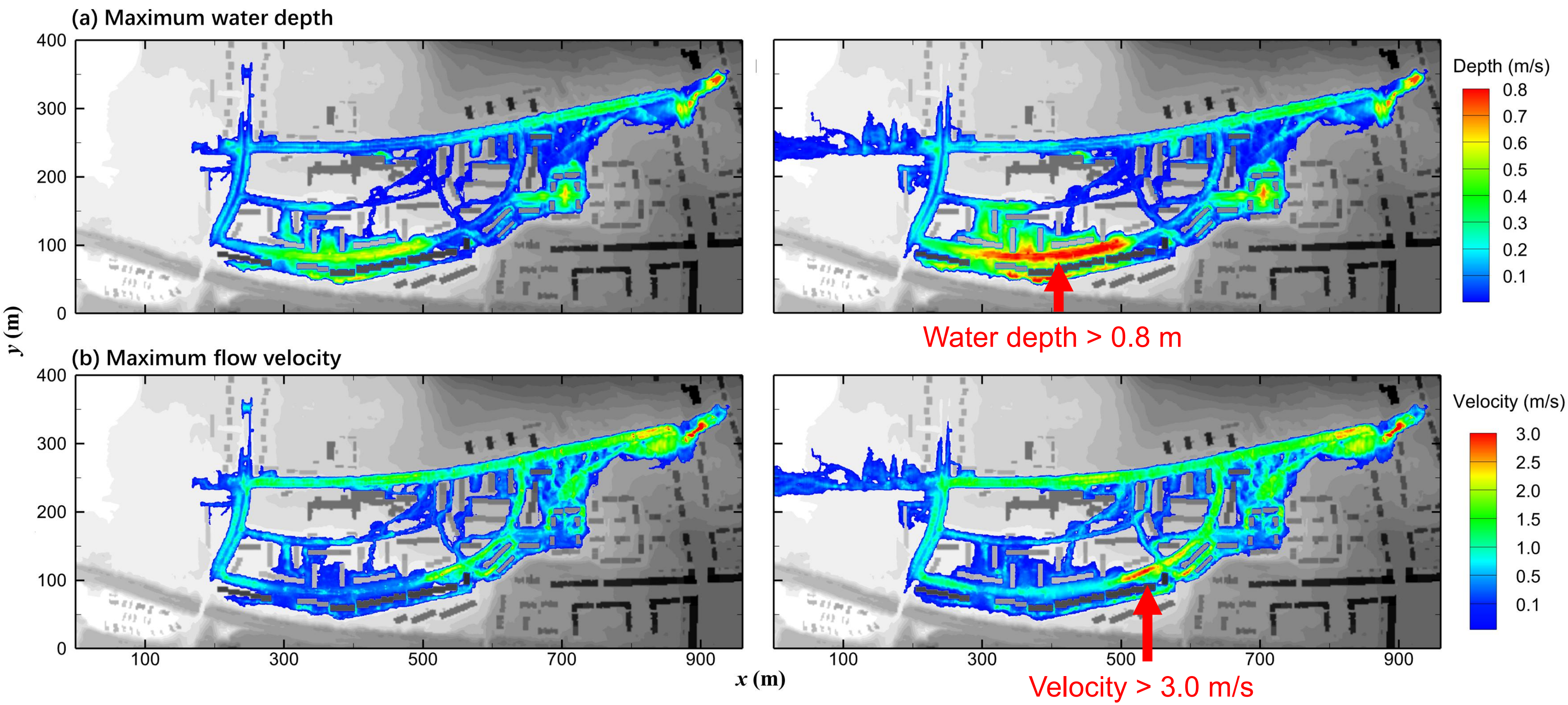




Map of small urban area in City of Glasgow

Predicted Peak Water Depths & Velocities

Influence of sewer system on water depth and flow



With sewer drainage

Without sewer drainage

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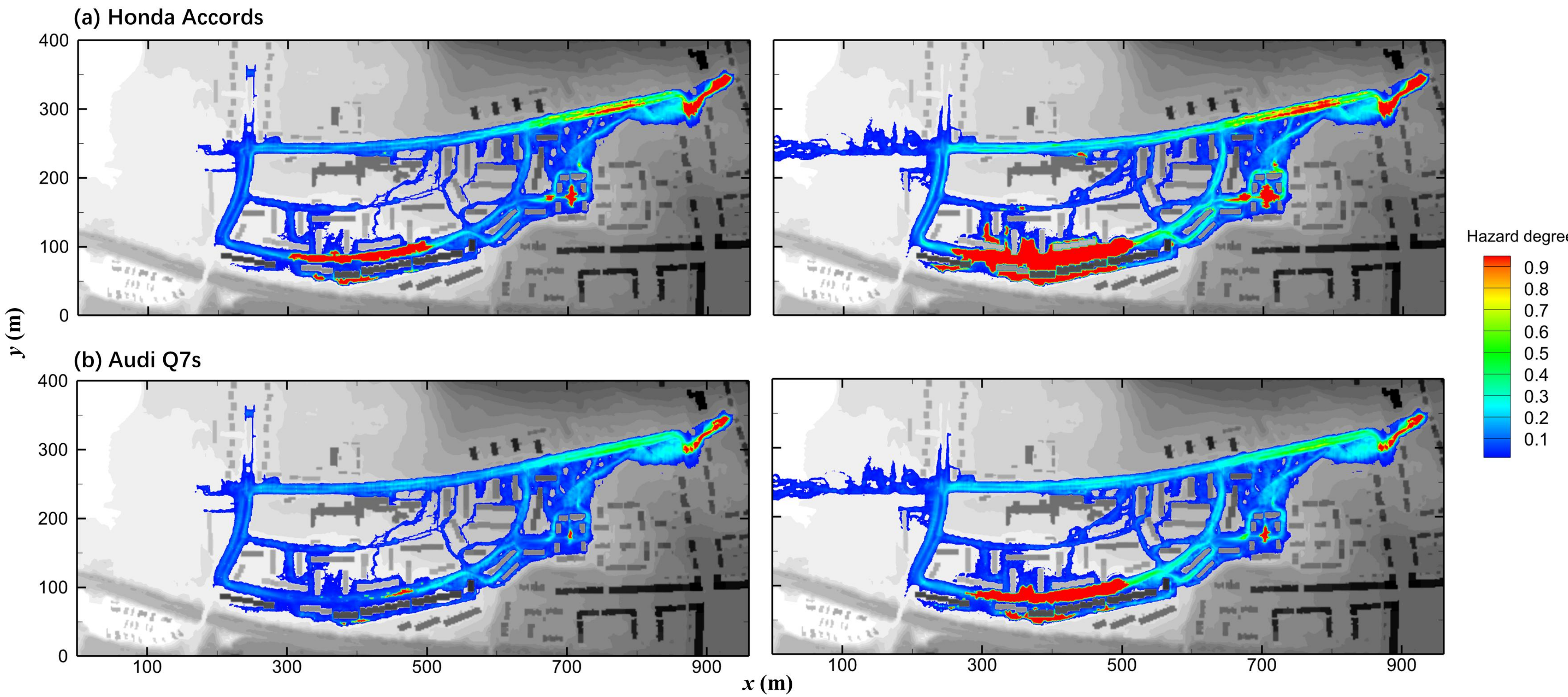
Predicted Hazard ➪ Different Vehicles

Influence of sewer on hazard degree for different vehicles



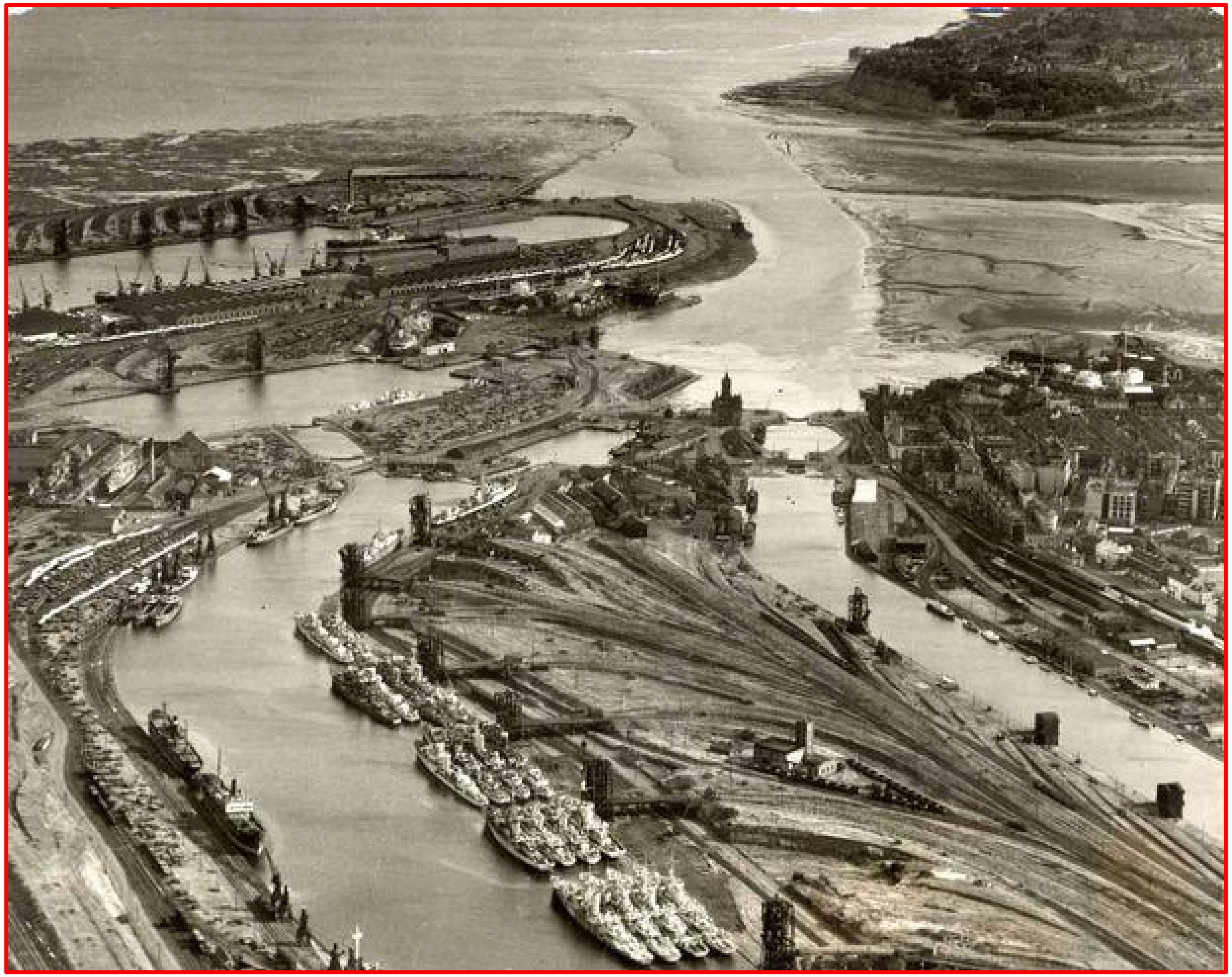
With sewer drainage | Without sewer drainage

Dissolved Oxygen and Destratification Management

⇩

Cardiff Bay Regeneration, UK

Cardiff Bay ⇨ Before Barrage



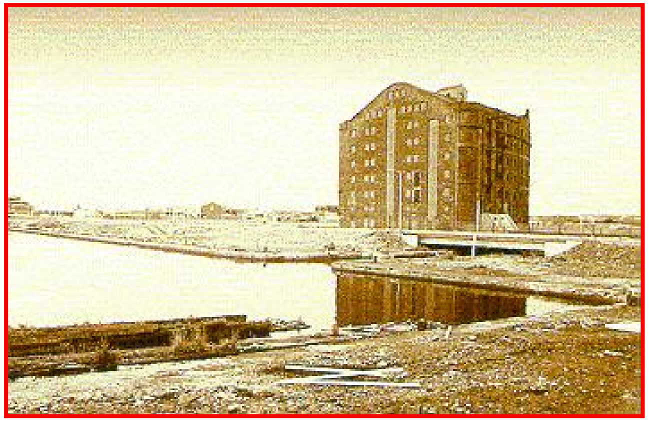
Key Details:

- Plan to reconnect City of Cardiff with its waterfront
- Barrage proposed across mouth to regenerate region
- Create 30,000 jobs, 6,000 homes, 1M m^2 commercial space
- Approved through Act of Parliament
- Legal requirement DO levels ≥ 5 mg/l

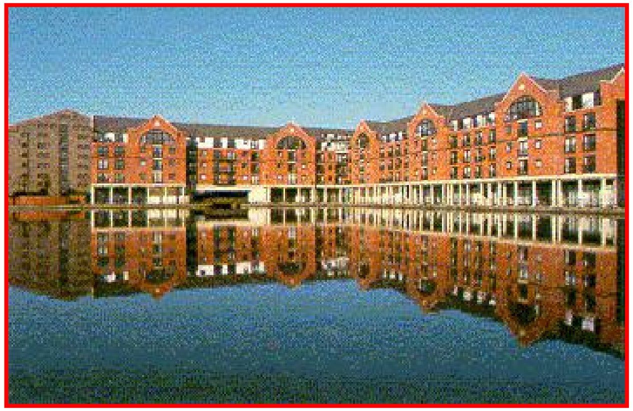
Cardiff Bay ⇨ After Barrage

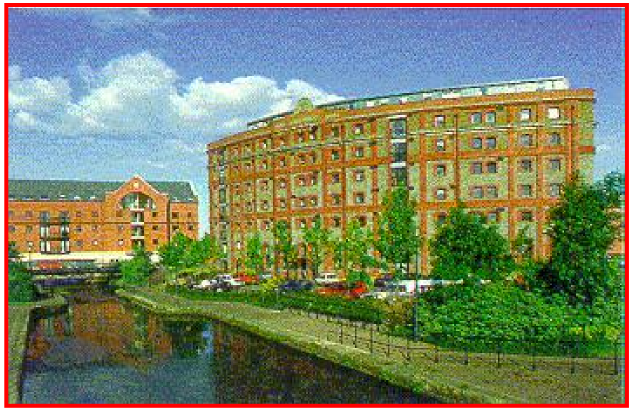
Cardiff Bay Regeneration

Before



After



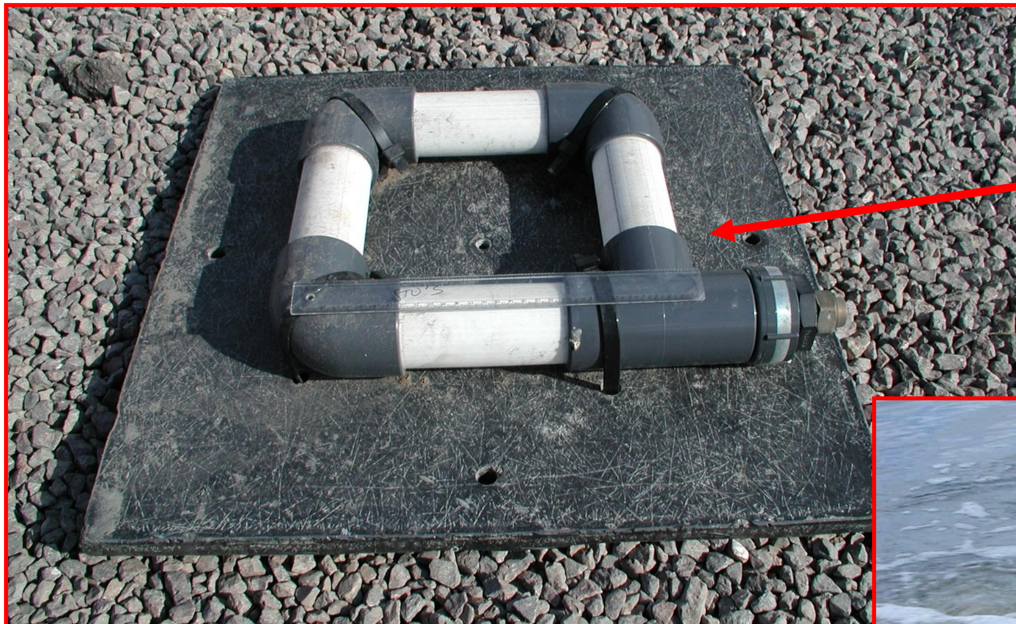


Algal Blooms ➩ Flourished in River Ely

Aeration System ⇨ Reduces Algal Blooms

- Cardiff Bay Barrage Act requires DO levels to be maintained at 5 mg/l minimum
- Required primarily for fisheries management and particularly for salmon and trout survival
- 400+ aerators located across Bay bed and rivers
- Compressed air pumped through aerators ⇨ also via a mobile oxygenation barge in summer months
- Aeration effective ⇨ works well in main body of Bay

Over 400 Aerator Devices on Bay Bed



Typical aerator on bed

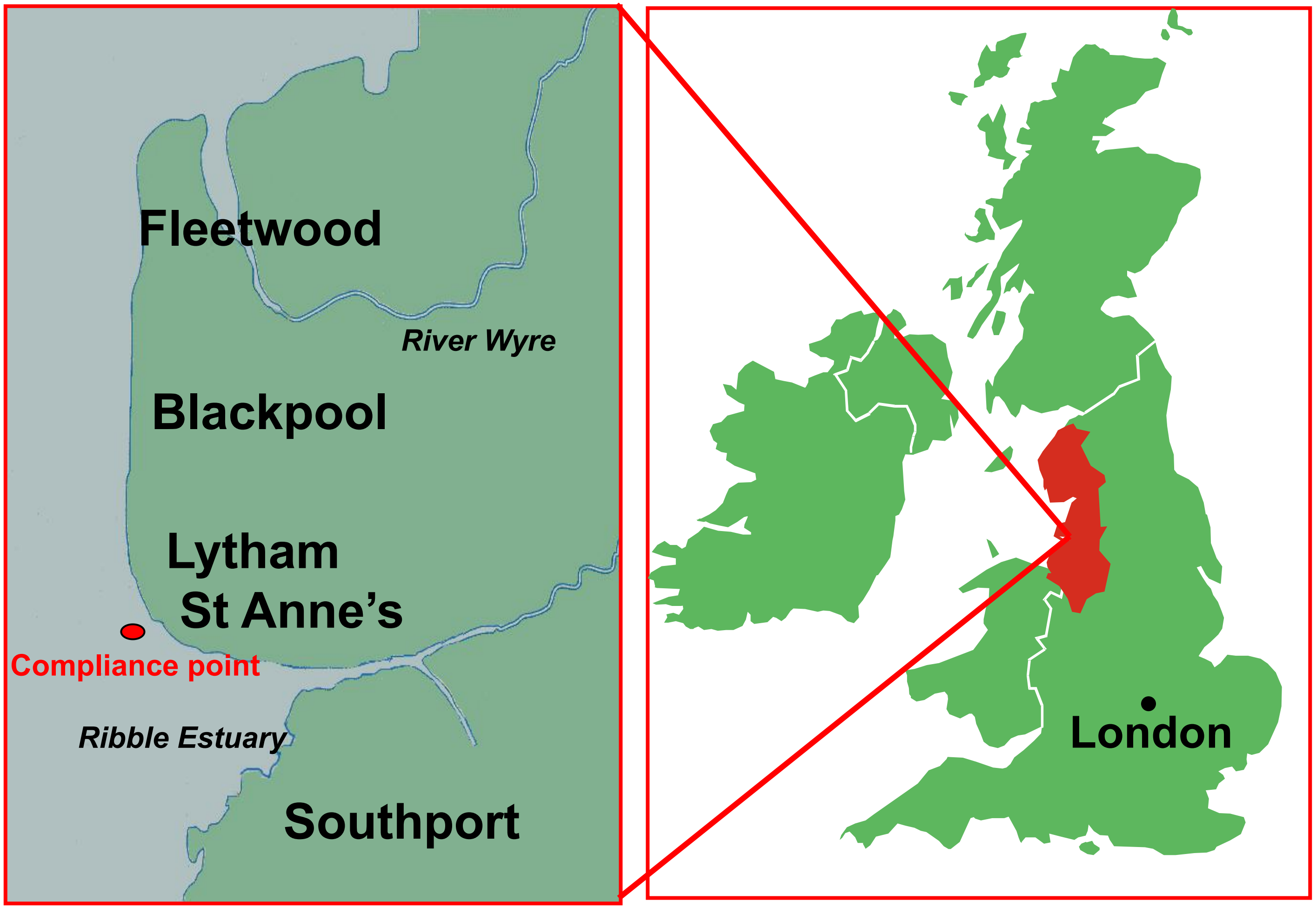
Air bubbles on surface

Integrated Hydro-Epidemiological Process Modelling

⇩

Ribble River Basin and Fylde Coast, UK

Ribble and Fylde Coast - NW England



Ribble Basin part of EU river network to test WFD guidelines

Blackpool ⇨ Prime UK Seaside Resort

Background in Mid-1990s (1976 EU BWD)

- Failure to meet 1976 EU Bathing Water Directive
- Storm sewers and WwTWs discharging along coast initially thought to be main problem
- Combined Sewer Overflows discharging into water courses and rivers also thought to be problem
- Field surveys undertaken to establish inputs and failure levels at compliance points
- Water company invested $800M in 1990s ➪ 3 new WwTWs, 5 larger pumping stations ➪ still challenges

Objectives of Study ⇨ 1998-2002

- Develop a hydro-epidemiological modelling tool
- Quantify impact of sewage inputs into tidal Ribble basin on Fylde coast bathing water quality
- Investigate influence of various parameters such as wind, tides, river inputs etc. on compliance
- Allow for continuous and intermittent source inputs
- Incorporate land use changes and diffuse source inputs as boundary fluxes when data available
- Apply model to tidal limit in River Ribble Estuary

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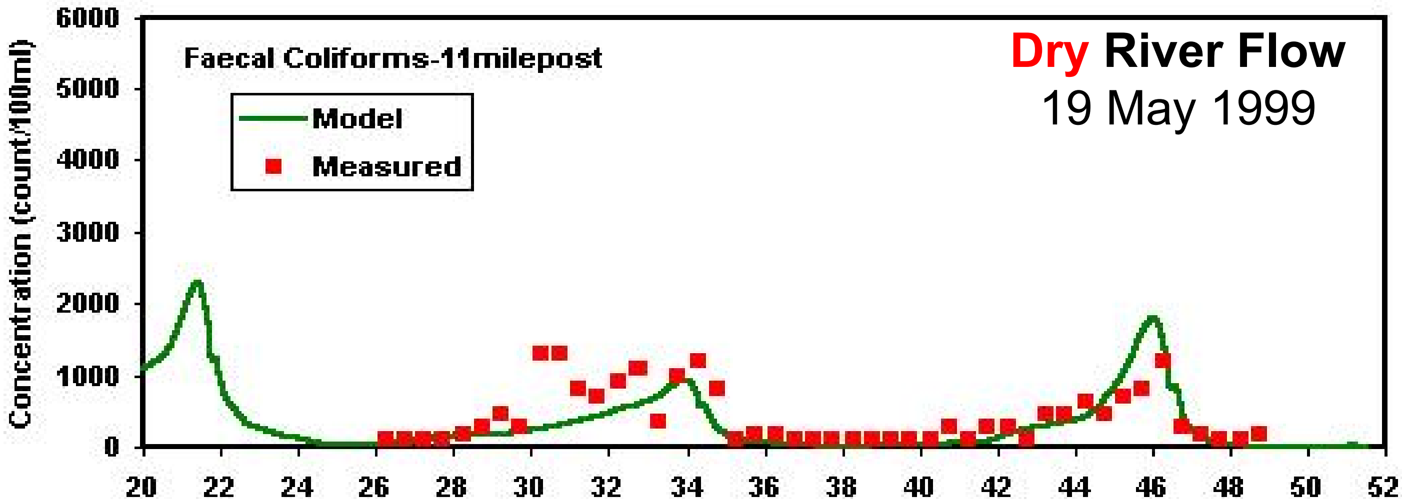
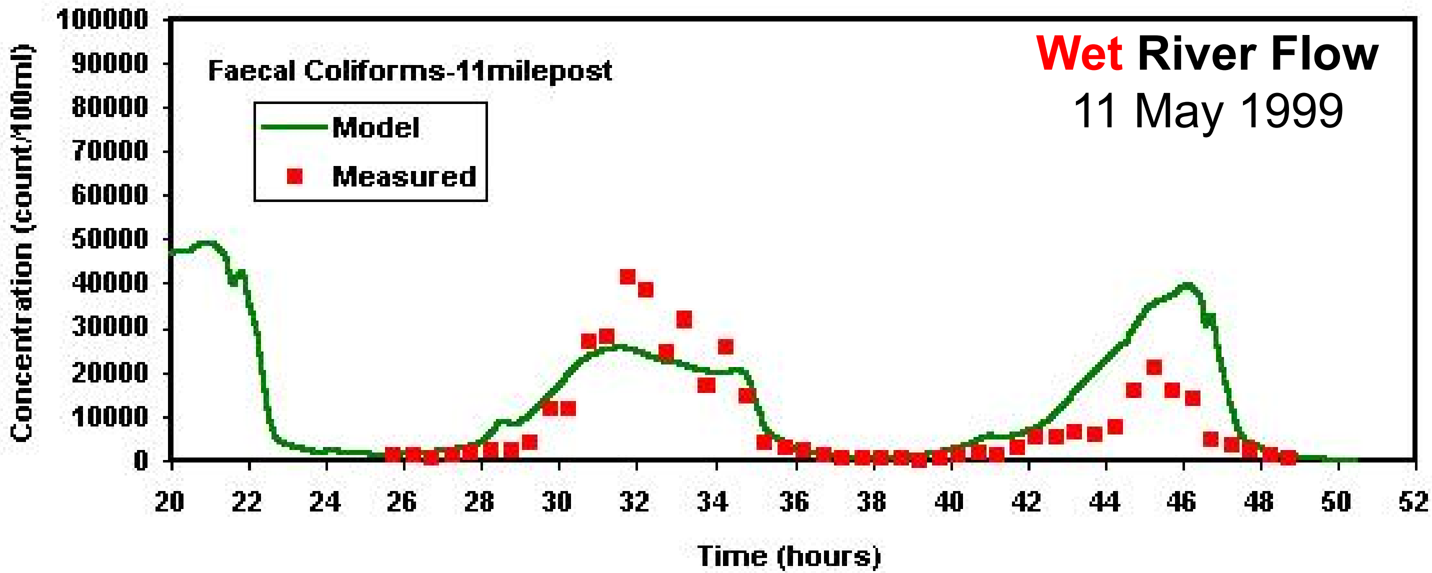
Ribble Estuary: Faecal Bacteria Calibration

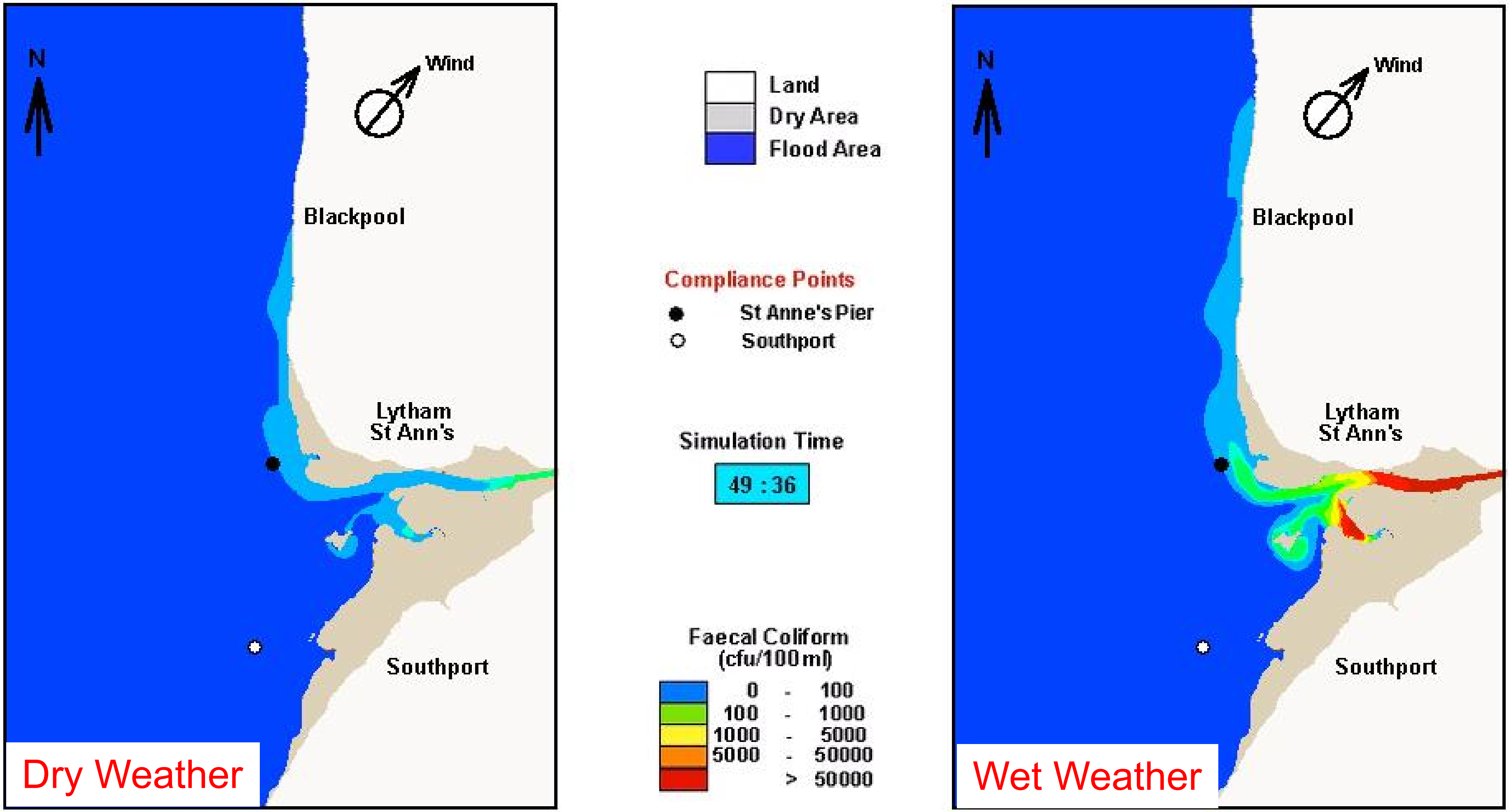
Model Calibration at 11 milepost





Faecal Bacteria Model Predictions

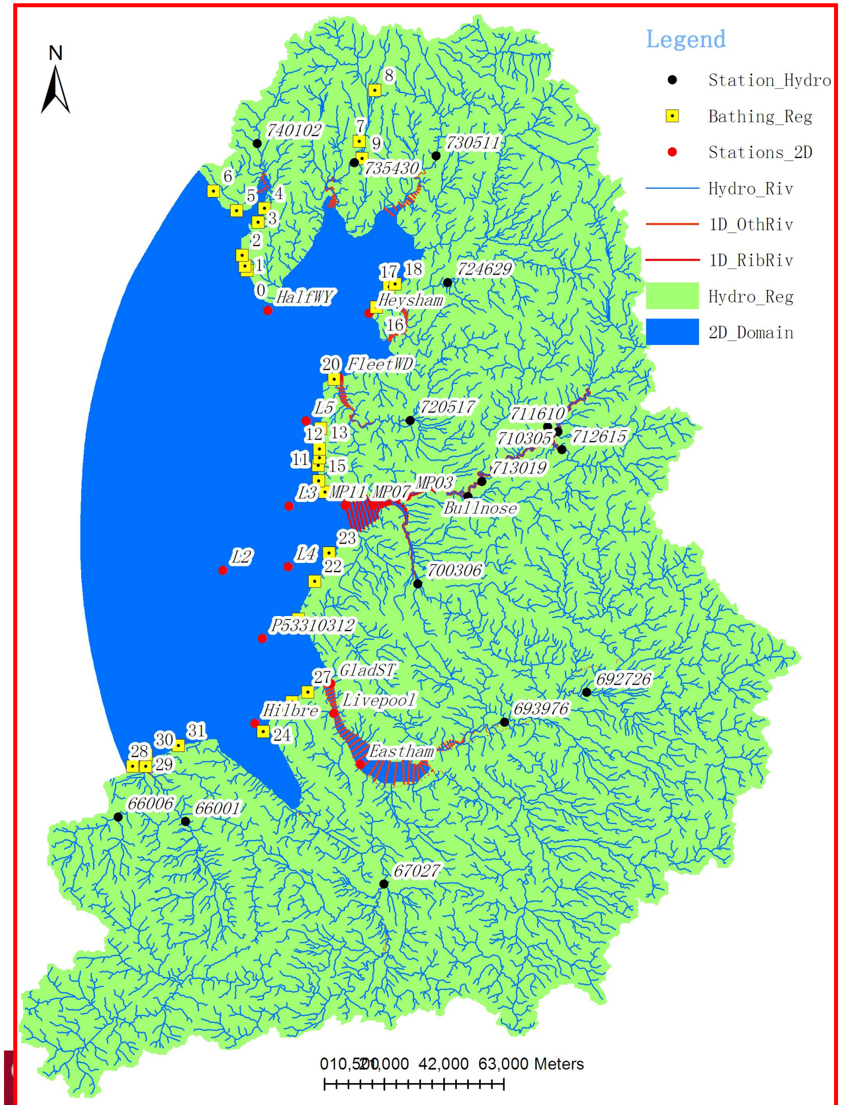
Ribble Estuary and Fylde Coast, UK



Major New River Basin Study ⇨ 2008-16

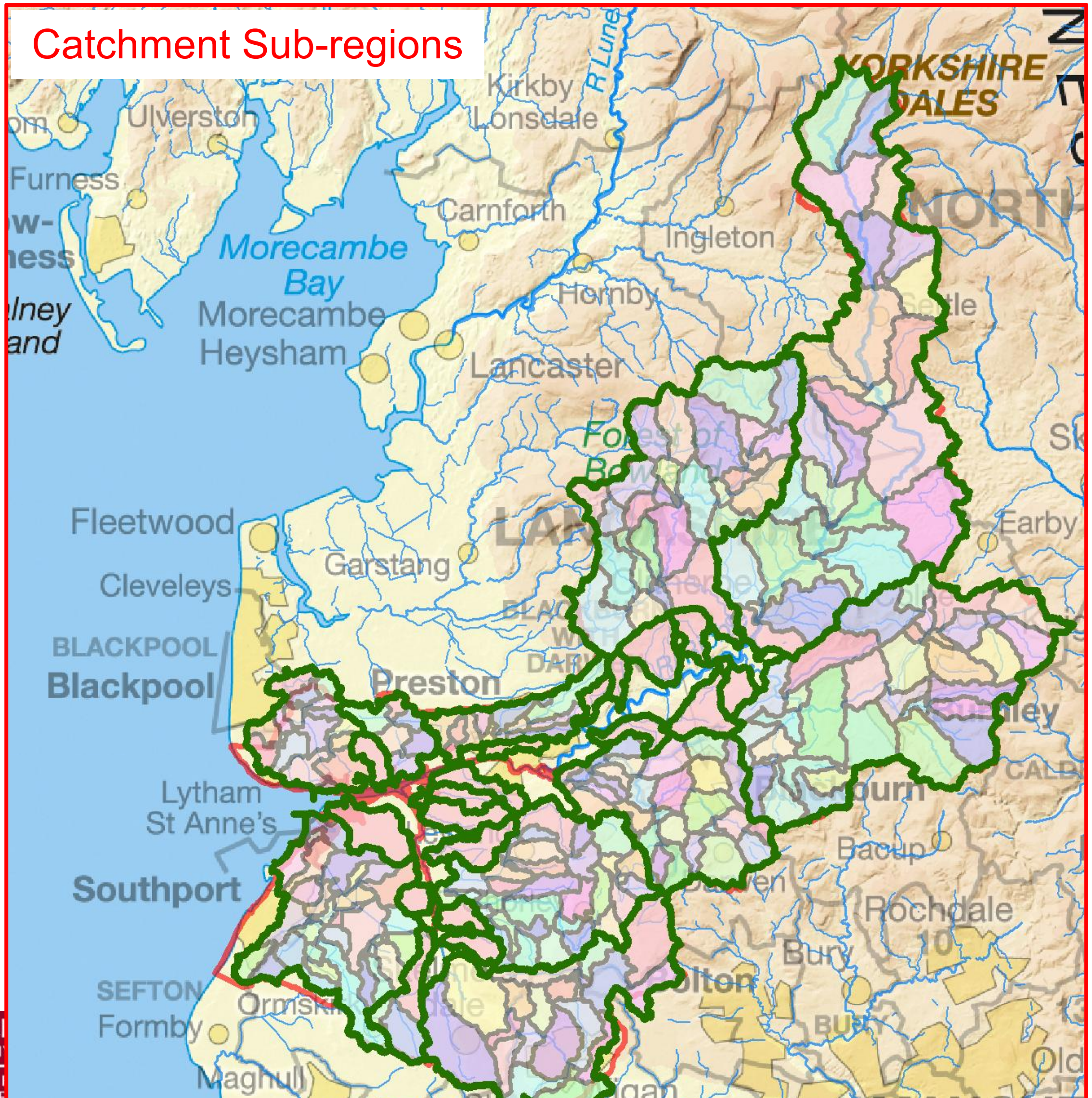
- EU Water Framework Directive 2006, applied from 2015, with much stricter Bathing Water standards
- Concern about impact of recent land use changes in upper catchments on river basin water quality
- Develop an integrated Source-to-Sea (S2S) model ⇨ with urban and rural inputs + land use changes
- Collect extensive data on *E.coli* loads and fluxes
- Model hydro-epidemiological processes to predict *E.coli* levels & health impact along Bathing Waters

Source-to-Sea ⇨ IWRM Modelling Studies



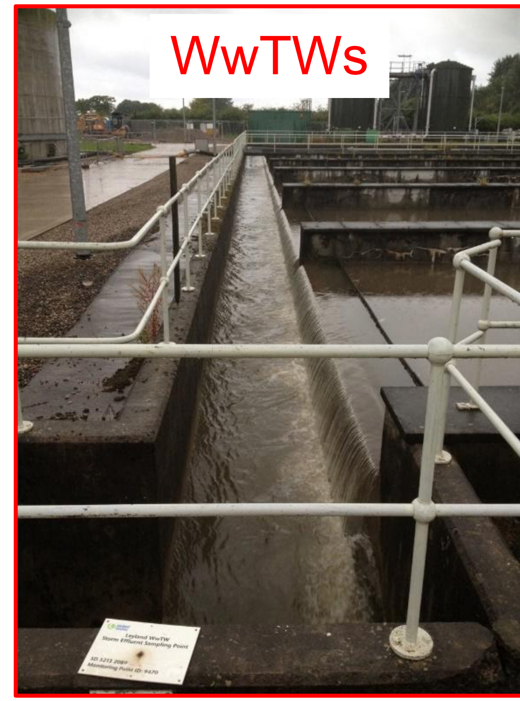
- Included: catchment, river, and coastal models of flow, sediment & FIO processes
- Included: extended coastal domain well beyond Ribble with tides, wind, sediment and FIO processes
- Included: climate and land use changes & urban point sources to assess bathing water compliance

HSPF Model Catchments & Sub-regions



- 28 catchments, all different including:
  - (i) rural and urban,
  - (ii) steep and mild slopes,
  - (iii) arable and pasture land,
  - (iv) forested land use etc.

Extensive Field Surveying Programme



Laboratory Analysed T_{90} Values (Kay *et al.*)

	n	Mean T_{90} (Hours) Irradiated	Mean T_{90} (Hours) Dark	Mean Total Irradiation D_{90} (MJ m^{-2})
E. coli				
Freshwater	68	13.61	**355.51	6.65
Estuarine	32	8.56	*30.64	5.17
Saline	20	2.33	33.77	1.41
Intestinal Enterococci				
Freshwater	68	14.87	65.70	8.99
Estuarine†	32	11.08	84.63	6.70
Saline	20	4.98	57.39	3.01

* Excludes one experiment where no decay was observed

** Excludes two experiments where no decay was observed

† Estuarine data includes a wide range of salinity (1-30 ppt)

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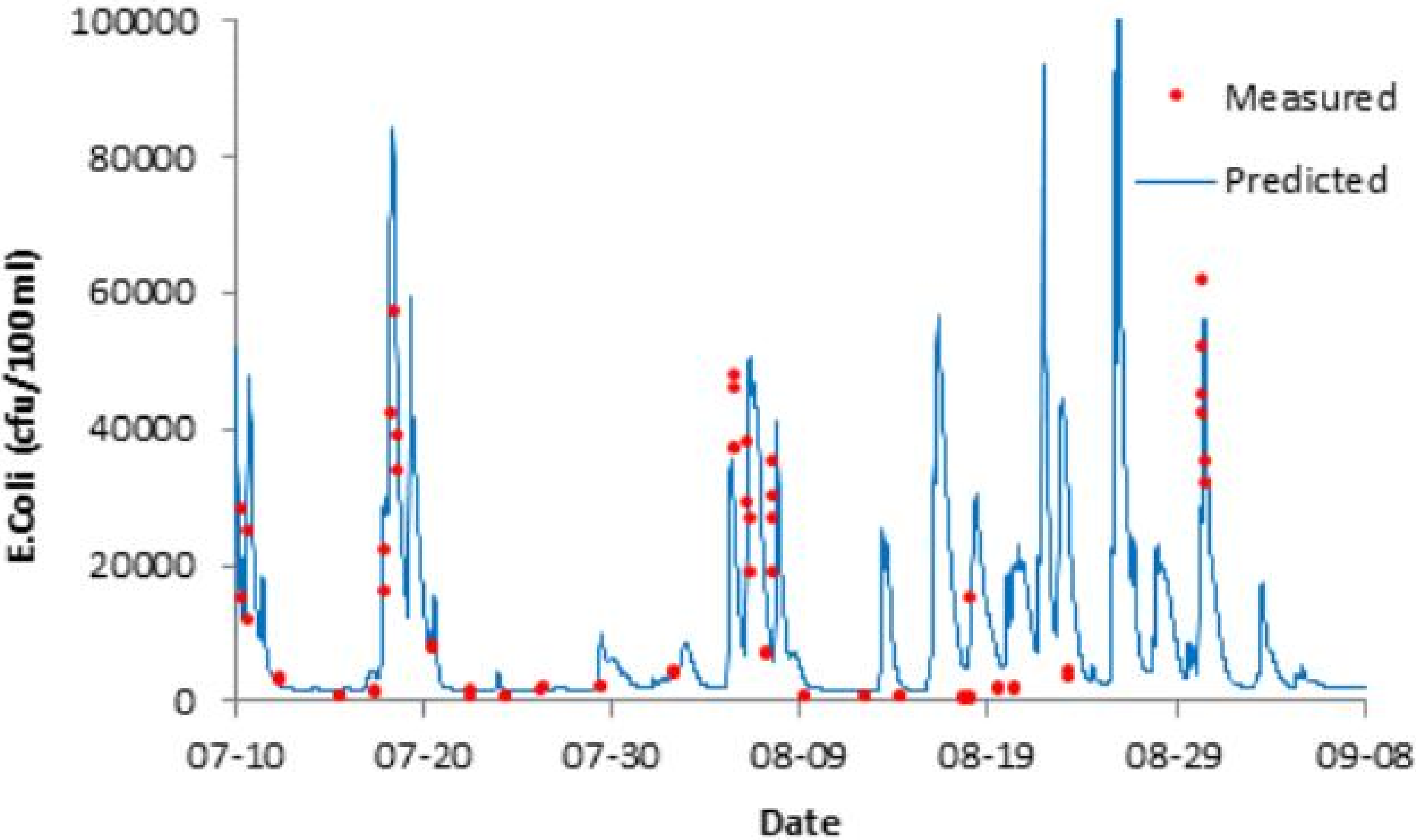
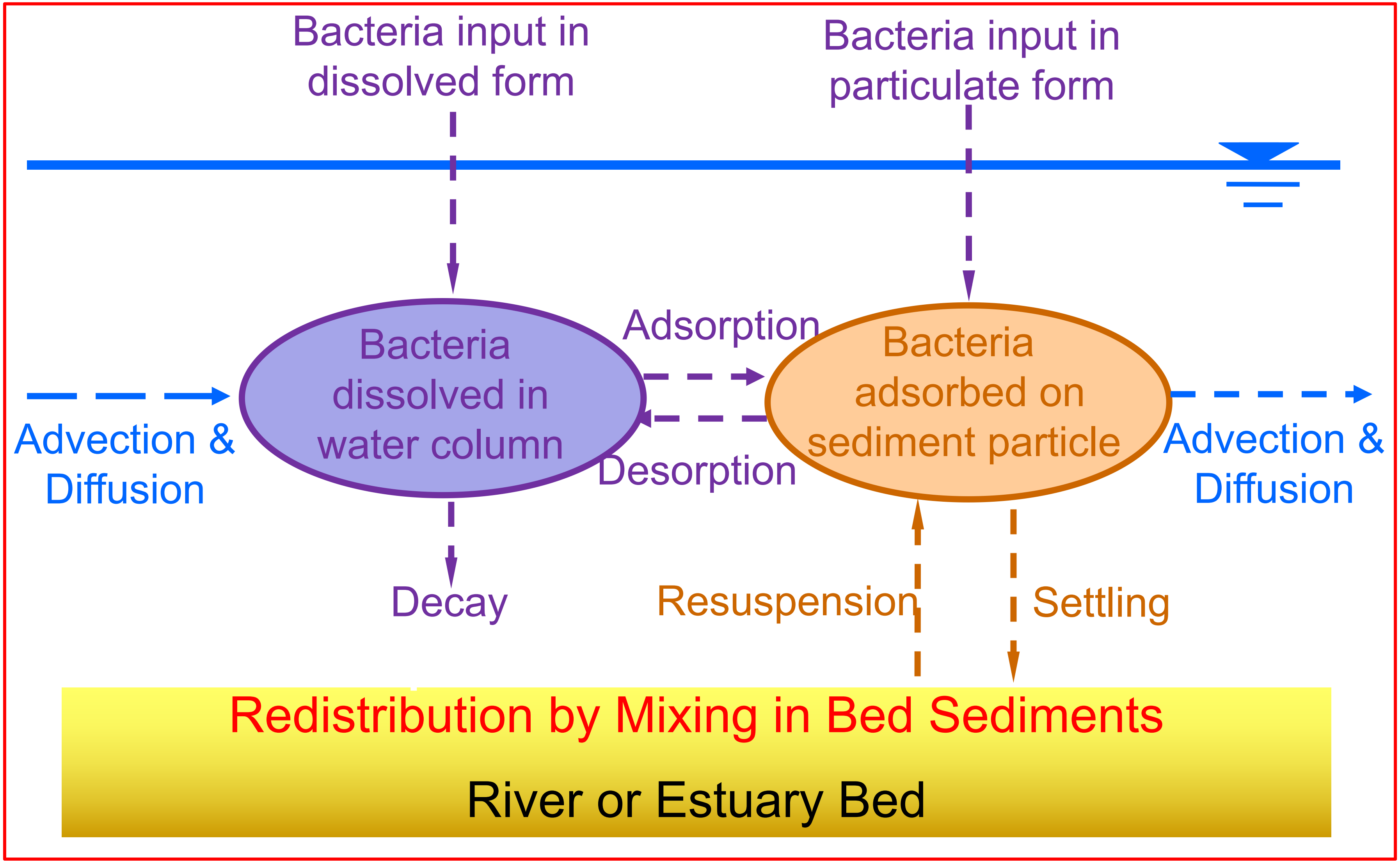
1D RNM ➪ Typical *E.coli* Verification



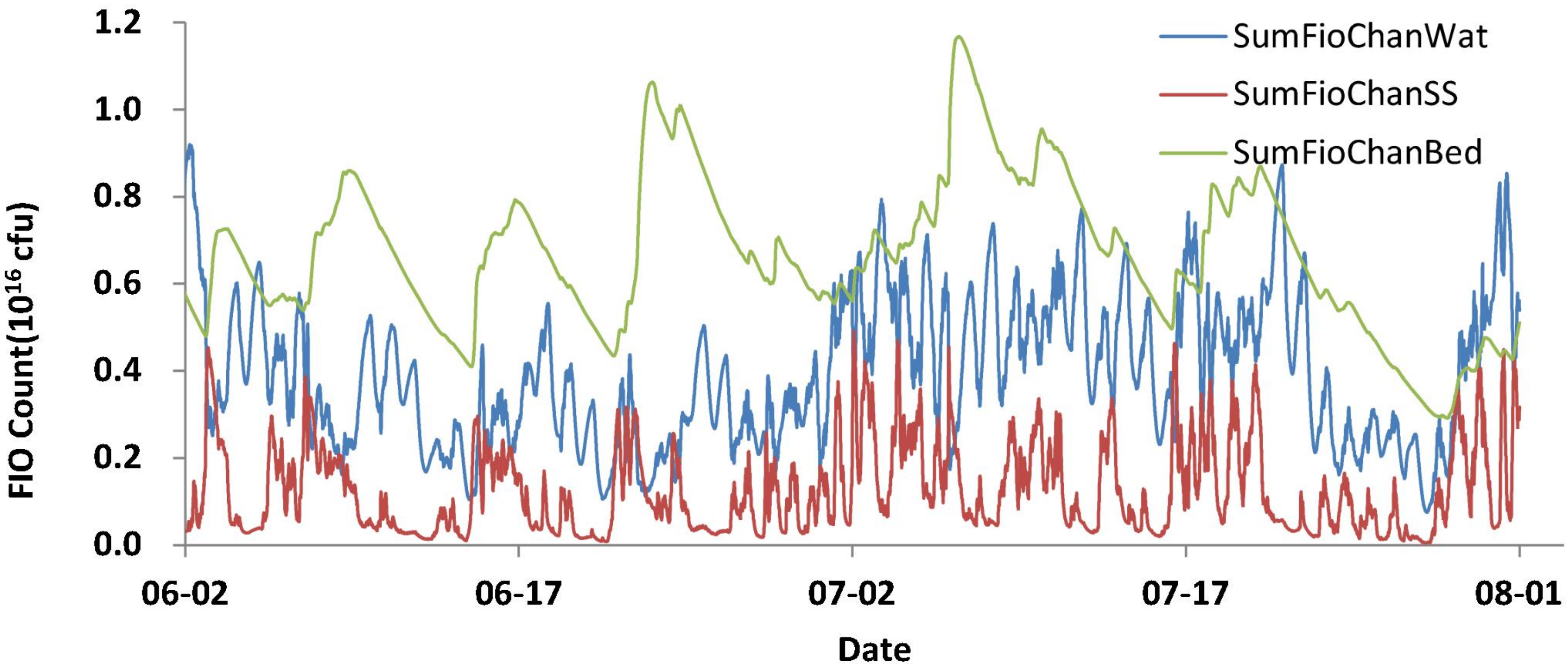
103: Ribble, Mitton Bridge

Bacteria ⇔ Sediments Interaction



FIO Levels ⇨ River Column, SS and Bed

- FIO distribution in Ribble Basin within ⇨ water column and on suspended bed sediments



Bed and suspended sediment ad-/de-sorption ⇨ important pathway for FIO transport

Concluding Remarks

- Global water security ➪ significant future challenge ➪ with increasing extreme flood and drought events
- Accurate modelling of extreme flood events in urban environments needs refined models and expertise
- Urban flood models require systems-based approach ➪ dynamically linked surface/sub-surface flows etc.
- Eutrophication commonly occurs in stagnant water bodies ➪ impacts can be reduced through aeration
- Water quality models include complex bio-chemical processes + sediment interactions ➪ need broad team

Thank You

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