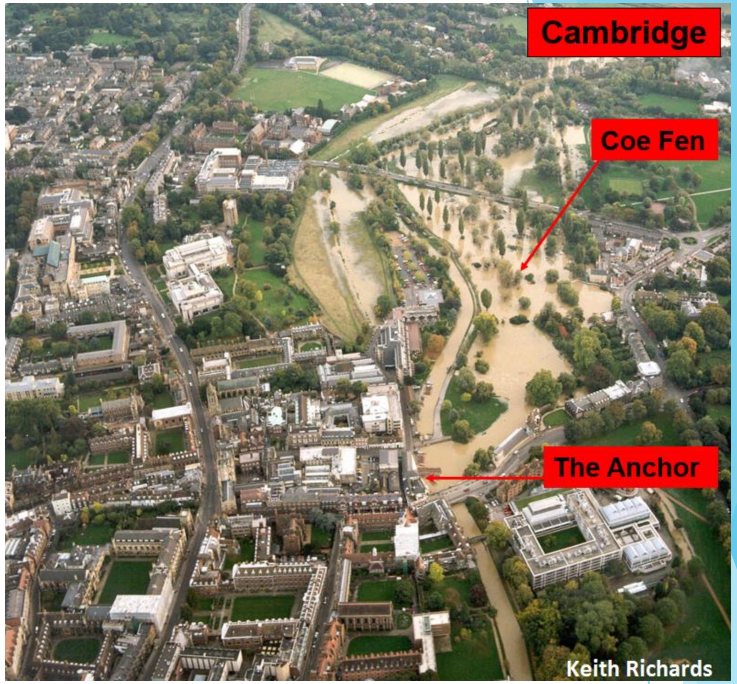
Hydraulic modelling of the River Cam

Anthony Cooper ac900

Supervisor: Dr Dongfang Liang dl359

Background to the project

- Cambridge floods a lot
- Originally intention to build model from scratch
- EA model made available
  - Very complex
  - Lots of computational power required to run
- Aim to make simple model
  - Less computational power
    - Allows repeated simulations
  - Verify it still has reasonable accuracy

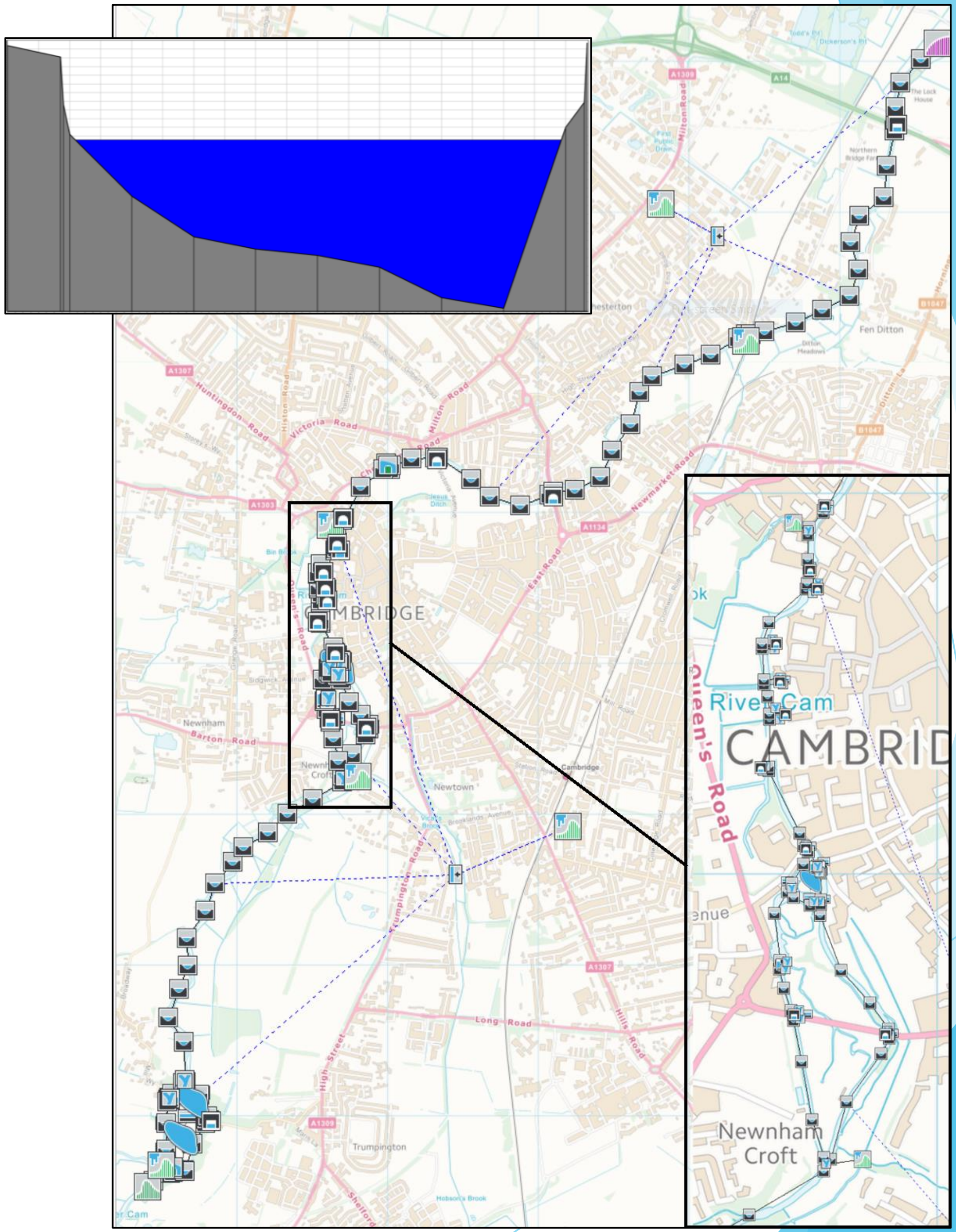


Modelling Process

1D - Saint Venant	**Continuity** $$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q$$ **Momentum** $$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{\beta Q^2}{A}\right)+gA\frac{\partial H}{\partial x}-gAS_f=0$$	Q Flow Rate (m^3s^{-1} (cumecs)) A Cross-Sectional Area (m^2) H Water Surface Elevation (mAOD) q Lateral Inflows ($m^3s^{-1}m^{-1}$) x Distance (m) t Time (s) β Momentum Correction Factor S_f Friction Slope g Gravitational Acceleration ($m\ s^{-2}$)
2D - Shallow Water Equations	$$\frac{\partial h}{\partial t}+\frac{\partial hu}{\partial x}+\frac{\partial hv}{\partial y}=0$$ $$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial(h+z)}{\partial x}+\frac{gn^2u\sqrt{u^2+v^2}}{h^{4/3}}-\frac{\boldsymbol{\nu}}{h}\left(2\frac{\partial^2 hu}{\partial x^2}+\frac{\partial^2 hu}{\partial y^2}+\frac{\partial^2 hv}{\partial x\partial y}\right)=0$$ $$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial y}+v\frac{\partial v}{\partial y}+g\frac{\partial(h+z)}{\partial y}+\frac{gn^2v\sqrt{u^2+v^2}}{h^{4/3}}-\frac{\boldsymbol{\nu}}{h}\left(\frac{\partial^2 hv}{\partial x^2}+2\frac{\partial^2 hv}{\partial y^2}+\frac{\partial^2 hu}{\partial x\partial y}\right)=0$$	u, v Components of horizontal velocity in perpendicular directions (x and y) (ms^{-1}) h Flow depth (m) z Bed elevation (mAOD (m Above Ordnance Datum)) x, y Horizontal distances in perpendicular directions (m) t Time (s) g Acceleration due to gravity (ms^{-2}) n Manning's Roughness Coefficient $\boldsymbol{\nu}$ Kinematic eddy viscosity (m^2s^{-1}) - parameter representing horizontal turbulent momentum transport, value between 0 and 1

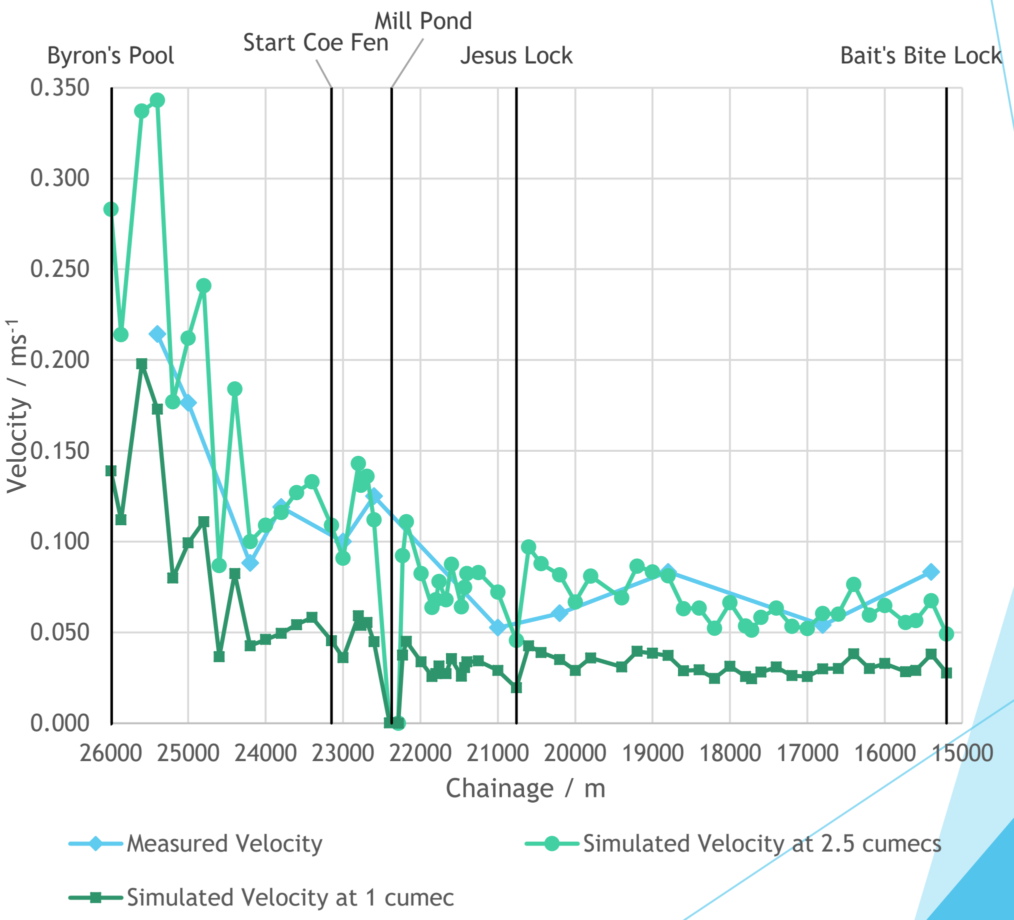
Model Design

- Initially building from scratch
- Data became available to enable simplification of an existing model
- 120 river sections
- Inflows at top, as well as from tributaries and rainfall
- Control systems and splits at Grantchester, Coe Fen/Mill Pond and Jesus
- 15 Bridges
- Linked 1D-2D for Flood Plain
- 2D region limited to area likely to flood



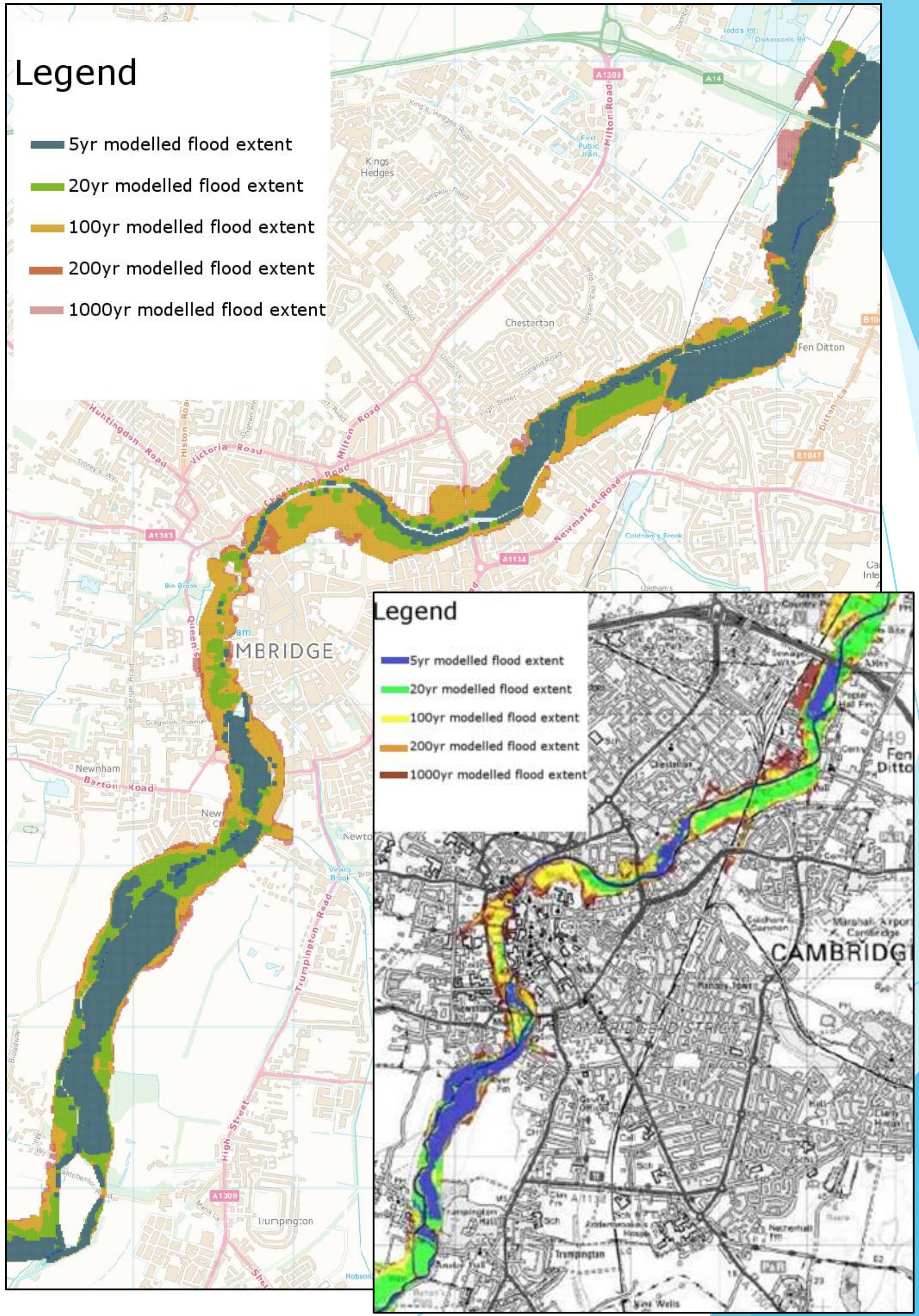
Verification: Steady Flow

- Measured flow rates at standard conditions
- Reasonable degree of correspondence, despite varying velocities due to changing cross-section and curvature



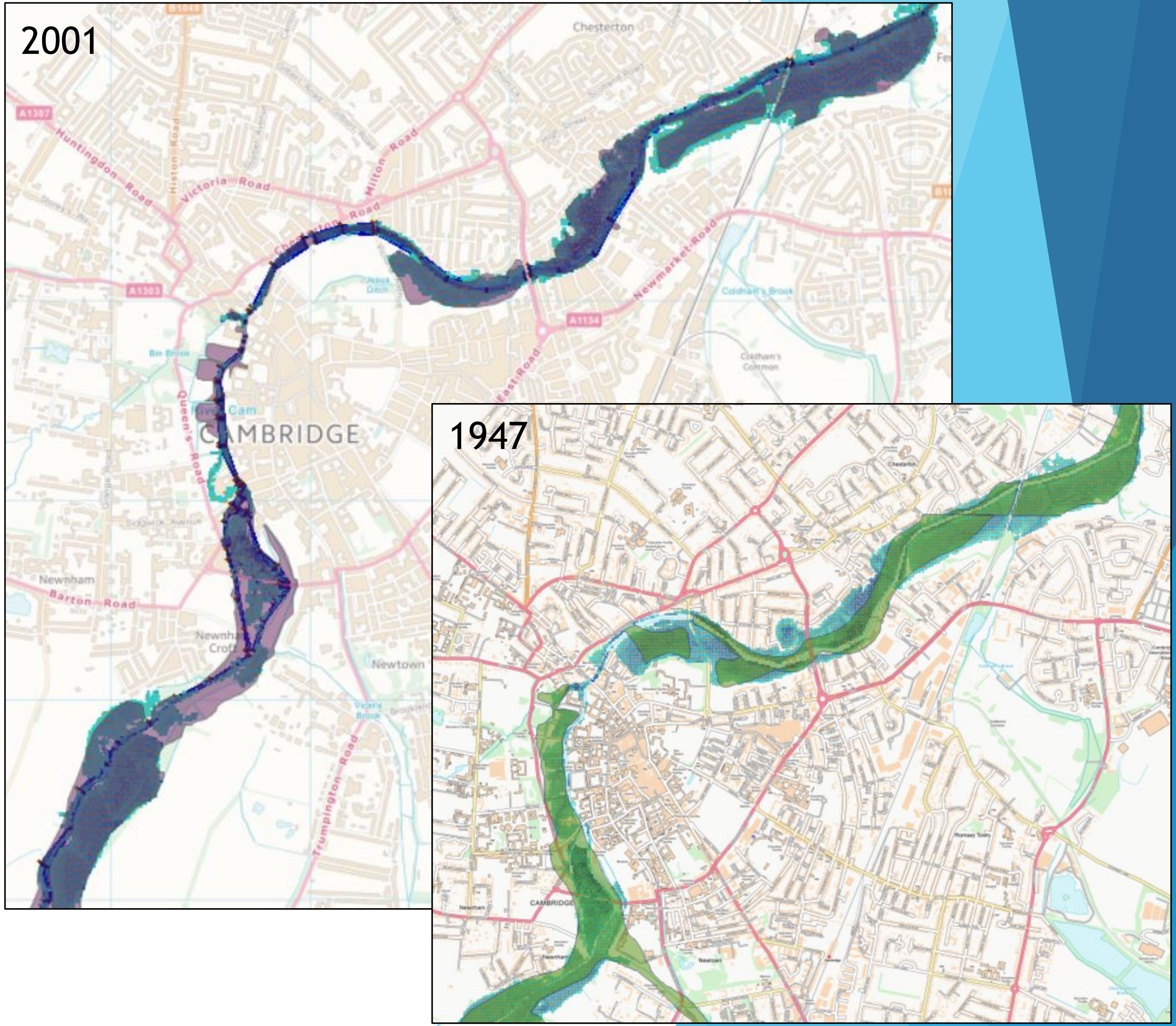
Verification: Extents

- Accurate matching between newly developed and EA/Halcrow extents maps
- Shows areas flooded with floods of different return periods
- Larger differences on flood plain between smaller floods
  - Flat areas, so extents sensitive to small variations in levels



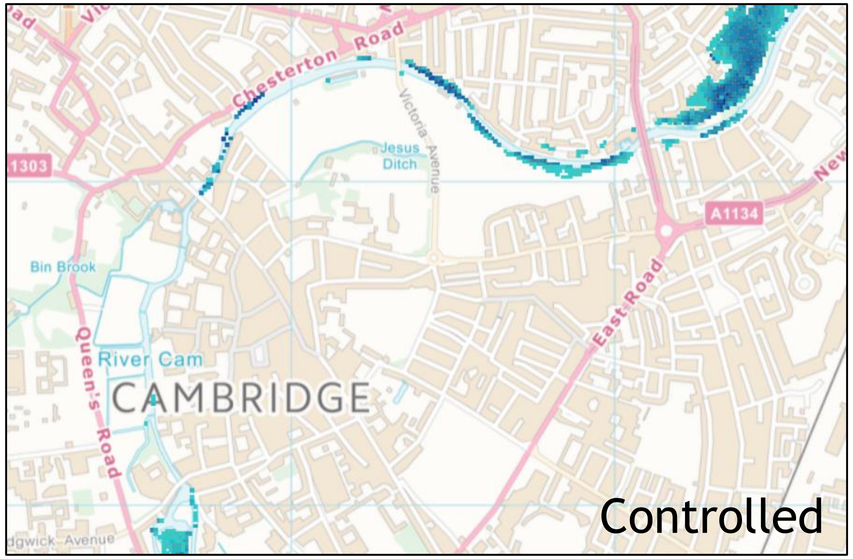
Verification: Floods

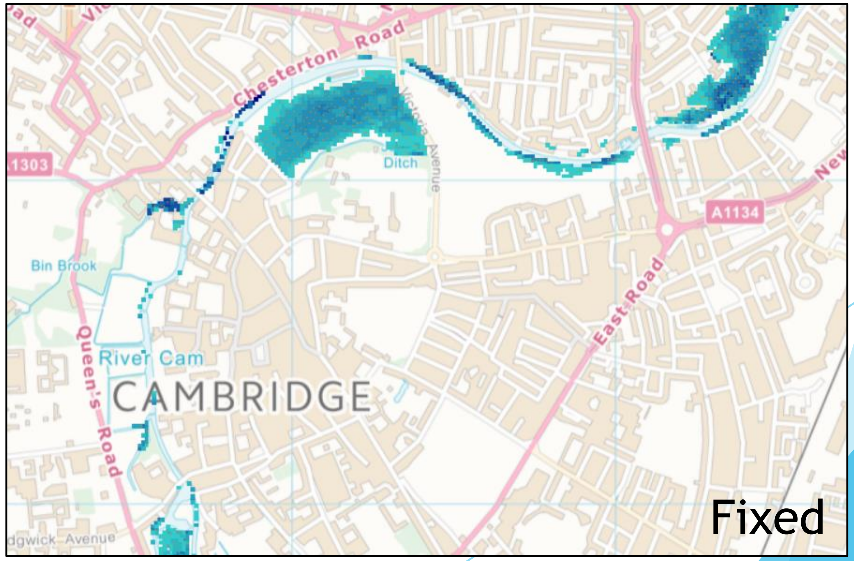
- Accurate matching of 2001 flood
  - Most recent major flood, best available flooding data
  - Backs effected by DEM not picking up walls and small structures
  - Newnham effected by Vicars Brook
- Reasonable matching of older floods
  - Changes to the river since then
  - 1947 achieves matches flood marker for levels, and some extents
  - Older large floods probably had long return periods, agreeing with simulations



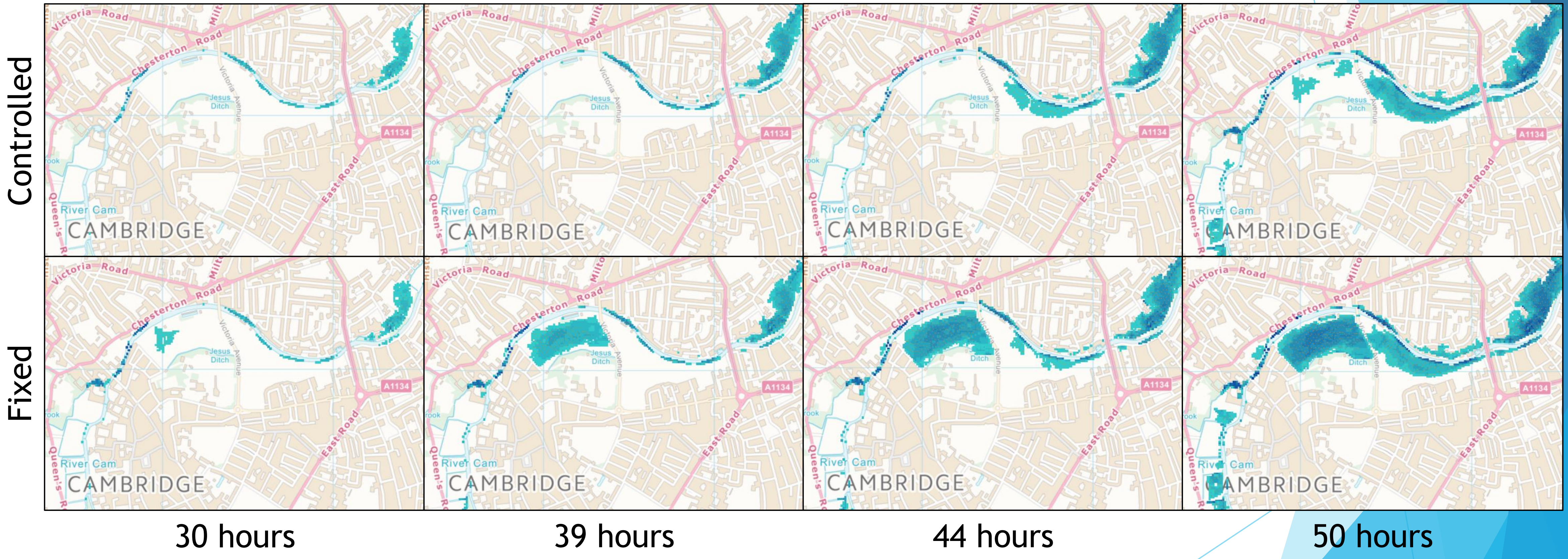
Application 1: Control Systems

- Realistic events simulated for sluices 'normally' controlled, and 'fault' fixed positions
- Tested on a small and a large flood
- Controlled mode aims to maintain water levels within fixed ranges
- Fixed keeps the sluices fully closed
- Biggest effect around Jesus Green
- Small flood had significant variation in flood extents



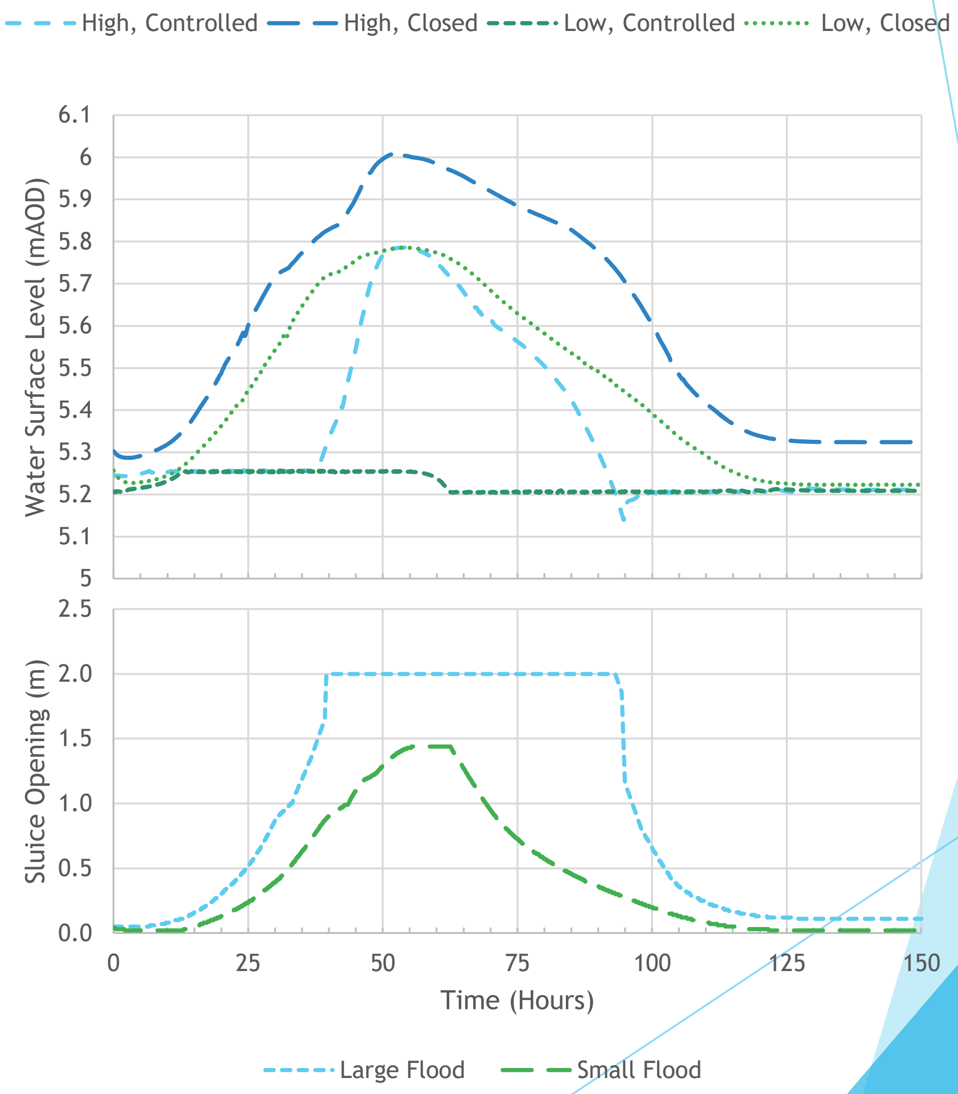


Application 1: Control Systems



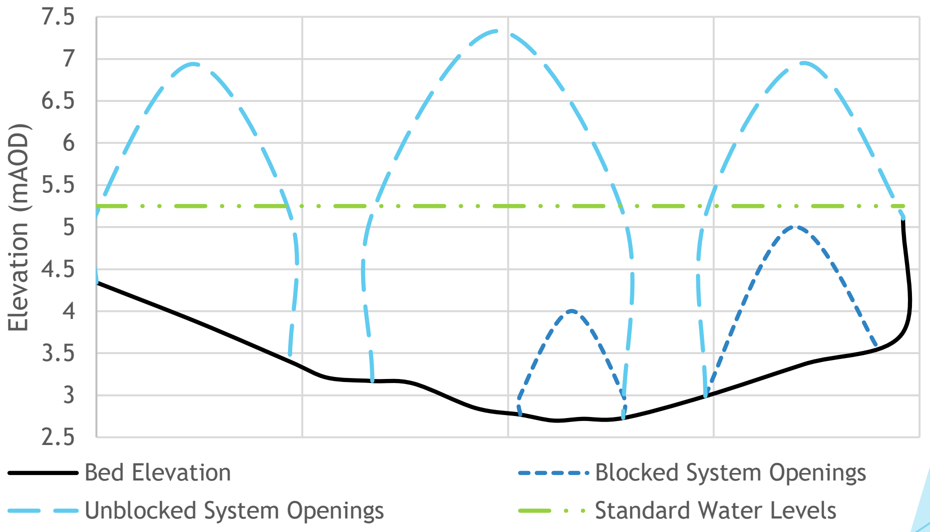
Application 1: Control Systems

- Controlled system is eventually overwhelmed in the large flood
  - Still reduces upstream levels
  - Once overwhelmed levels rise very quickly



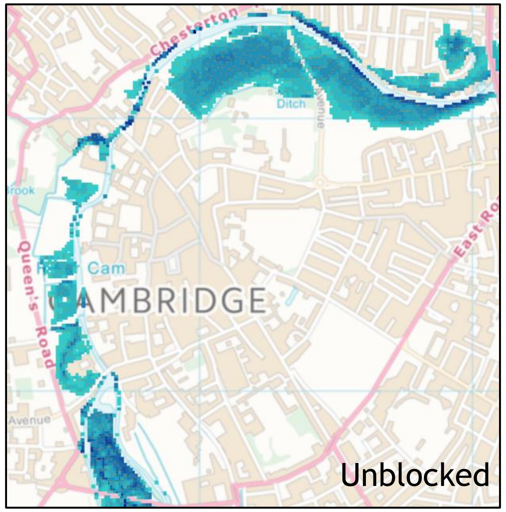
Application 2: Blockage

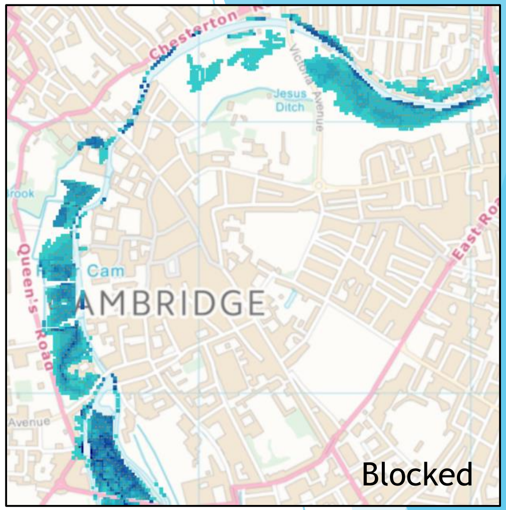
- In floods debris picked up, held against structures, restricting flow
- Choose Kitchen Bridge
  - Triple Arch design
  - Lots of trees upstream
- Significantly restricted flow
  - Realistically would build up over course of flood

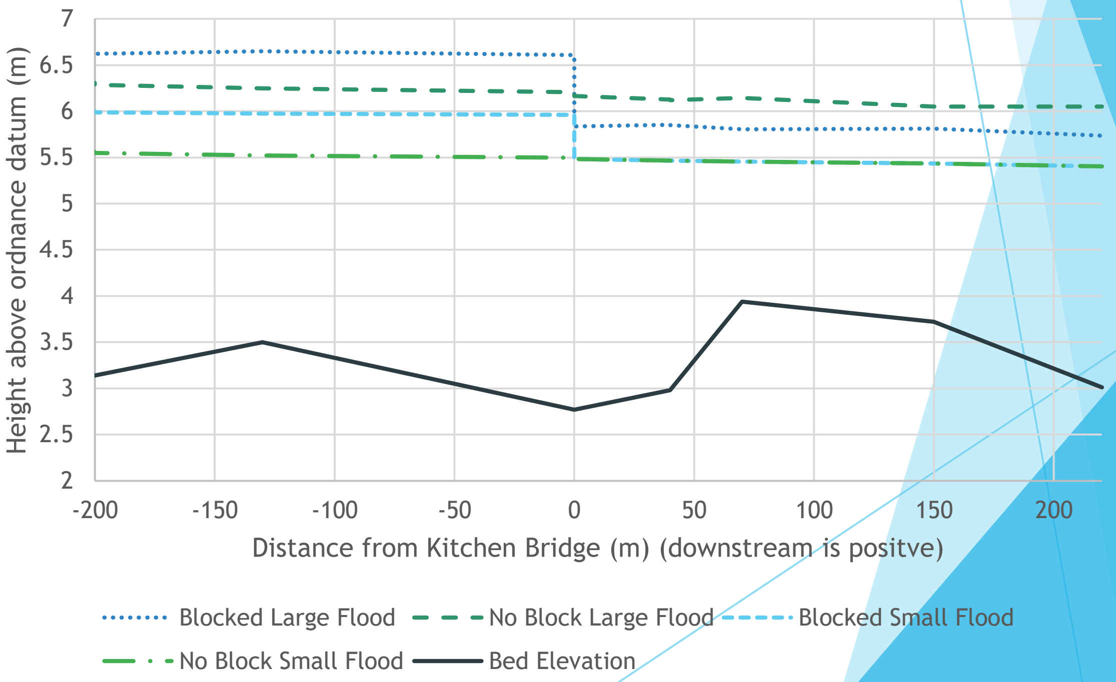


Application 2: Blockage

- Acts in similar way to sluice
- Creates hydraulic jump, raising upstream levels
- More flooding on the Backs
- Less downstream flooding
- Increased force on bridge
  - Greater risk of collapse







Conclusions

- Project showed that simpler models could still provide reasonably accurate flood modelling
- Also showed the use that a simpler, quicker model has
- Future work exists along two paths
  - Further use of the model created
    - More changes to channel and surroundings (dredging, defences, new buildings)
    - Other changes to control systems
  - See how much further the model could be simplified
    - Still verifiably accurate
    - Allow for very quick simulations

Questions?