Natural Environment Research Council

LANDWISE NFM

Modelling Natural Flood Management in the LANDWISE project

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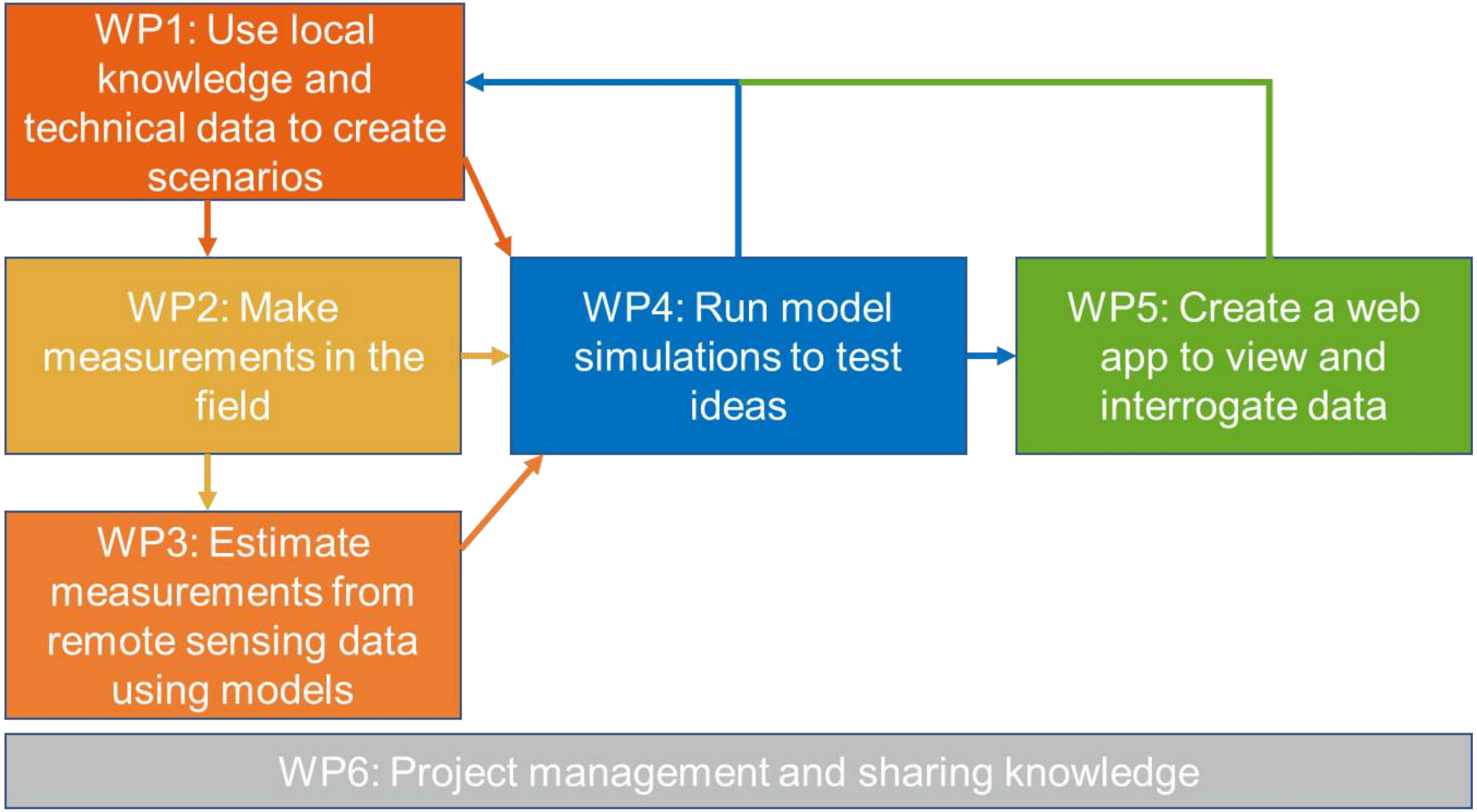
Outline

- ❖ Introduction
- ❖ Detailed 1D modelling of land management changes
- ❖ Modelling of changing land management at catchment scale
- ❖ Effectiveness of in-channel structures in reducing peak flows

LANDWISE project

- Land-based NFM measures in lowland catchments (West Thames), particularly groundwater-fed
- Evaluating the effectiveness of NFM Measures
  - Identified by those who manage land
  - Land use and management e.g. tillage practise, crop choice and tree planting
  - To increase infiltration, evaporative loss, and below ground storage
- Using simple to novel measurement techniques
  - Field soil survey
  - Remote sensing methods to measure soil moisture
- Multi-scale modelling

LANDWISE project



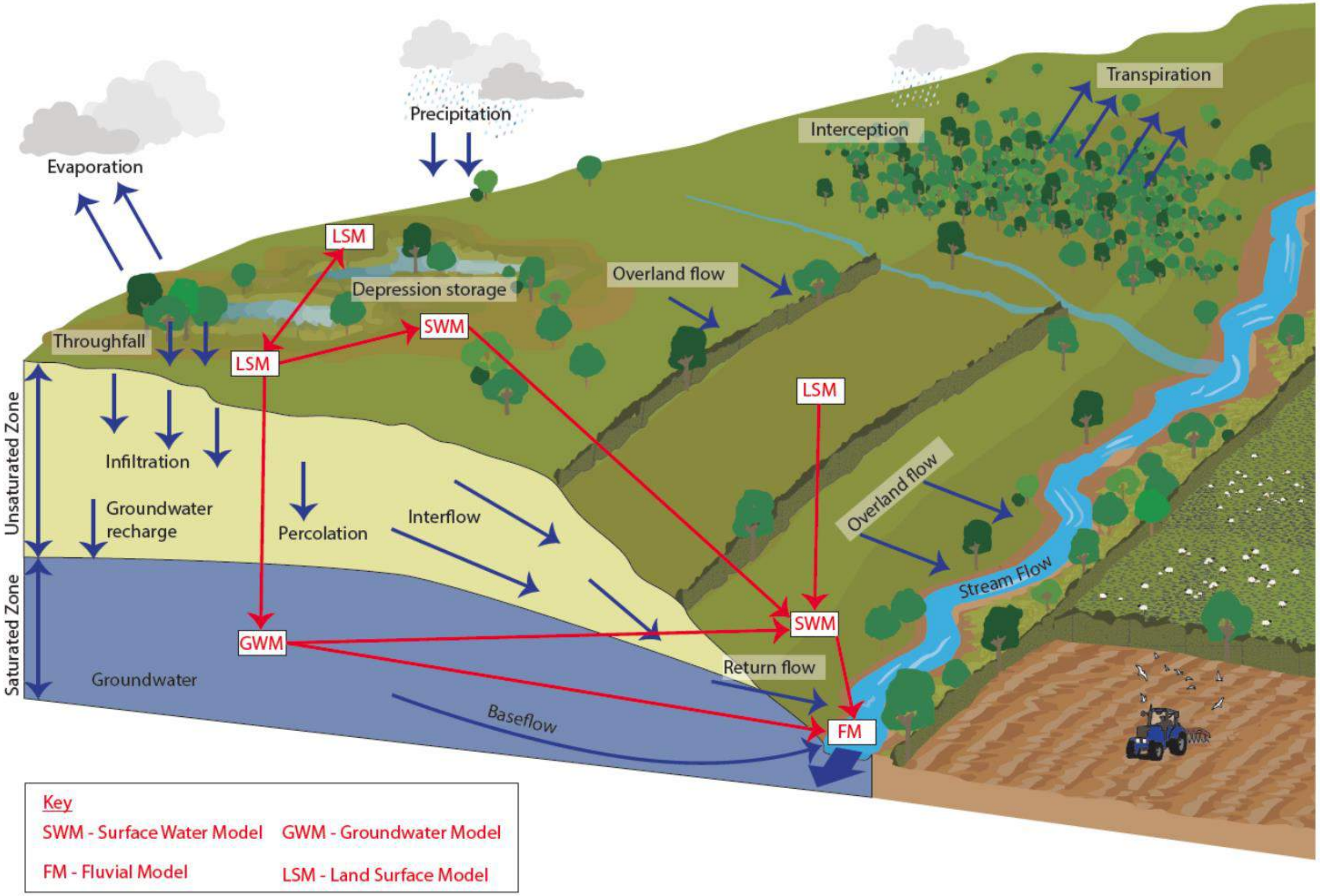
NFM measures under consideration

- Retaining water in the landscape
  - Soil water retention by managing infiltration and surface runoff
  - Soil management by improving storage and percolation
  - Crop choice & rotation, to increase root water uptake
  - Woodlands: see above, and increased interception

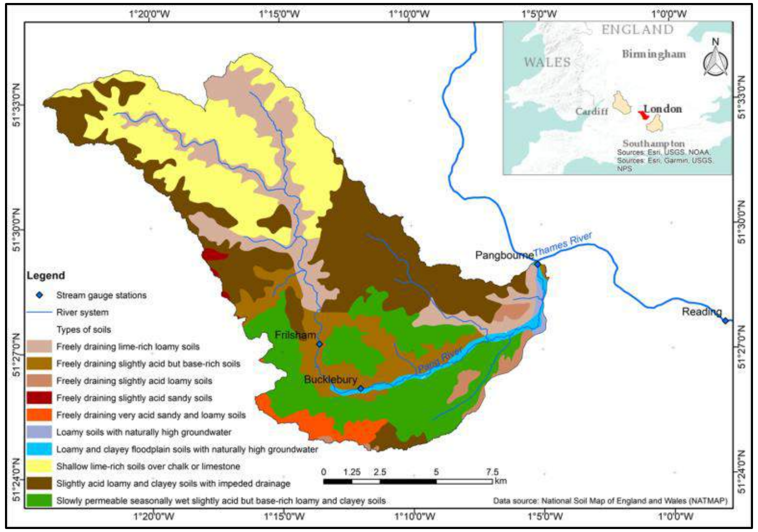
- Making space for *above-ground* water storage & attenuation
  - Water storage areas
  - Riparian buffers
  - River and floodplain restoration

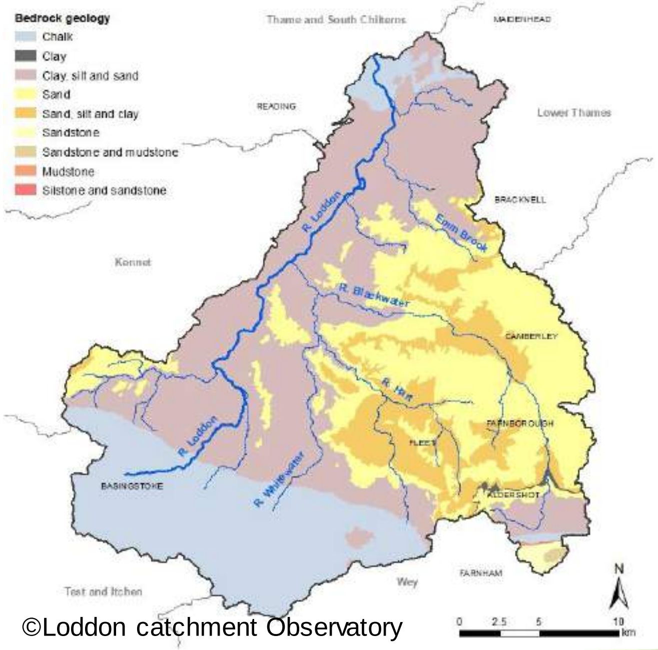
Modelling scales

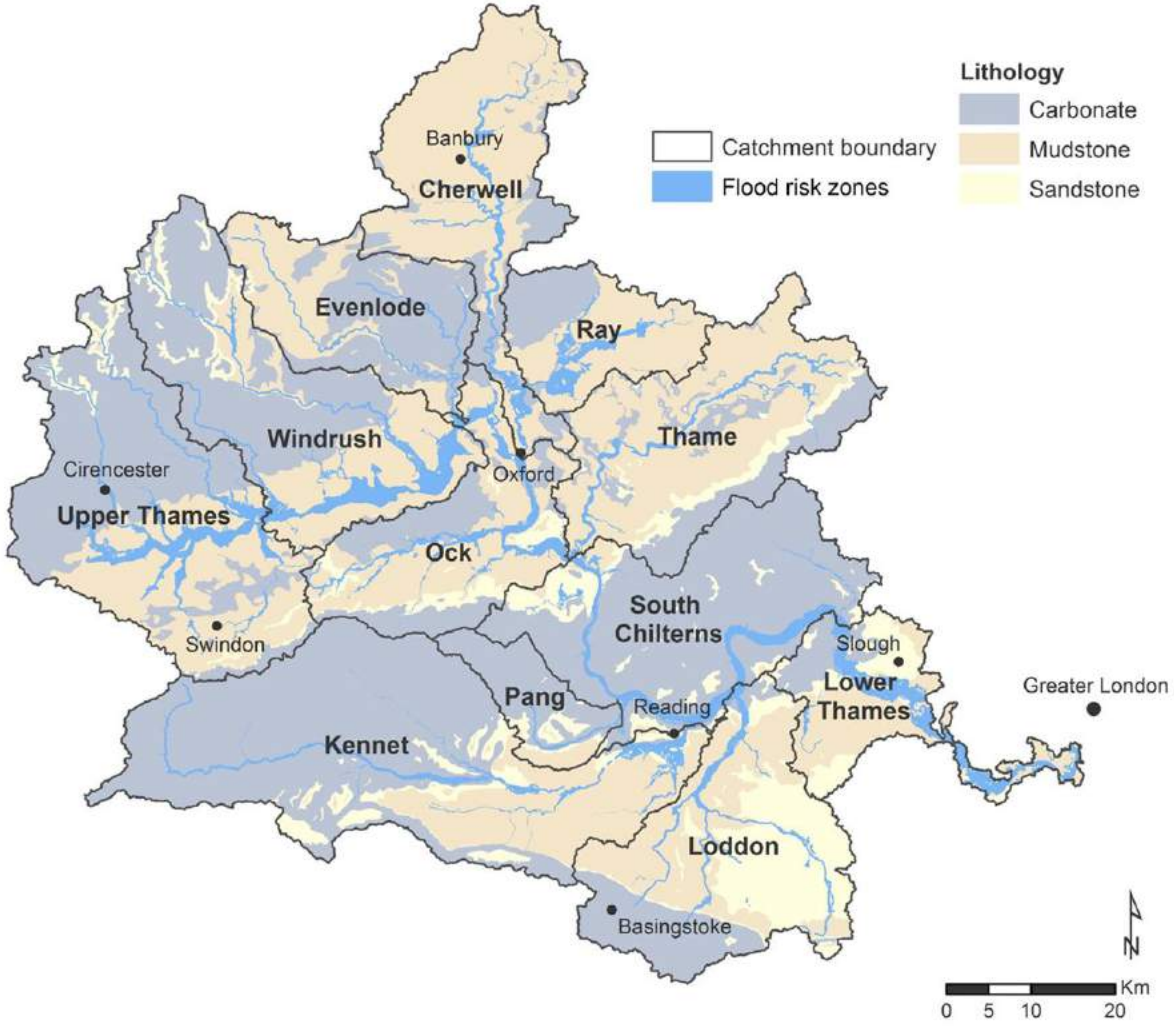
- Field scale (<10ha)
  - Translatable to other areas with similar soils, landscape, land management, climate
- Small and medium catchments (<1000 km^2)
  - Provides context for various catchment types
- Large catchment (>1000 km^2)
  - Provides generalised knowledge


Evaporation
Precipitation
Interception
Transpiration
LSM
Depression storage
SWM
Overland flow
Throughfall
LSM
Unsaturated Zone
Infiltration
Groundwater recharge
Percolation
Interflow
LSM
Overland flow
Stream Flow
Saturated Zone
GWM
SWM
Return flow
Groundwater
Baseflow
FM
Key
SWM - Surface Water Model
GWM - Groundwater Model
FM - Fluvial Model
LSM - Land Surface Model

Study areas


ENGLAND
WALES
Birmingham
Cardiff
London
Southampton
Pangbourne
Thames River
Reading
Frilsham
Bucklebury
Legend
Stream gauge stations
River system
Types of soils
Freely draining lime-rich loamy soils
Freely draining slightly acid but base-rich soils
Freely draining slightly acid loamy soils
Freely draining slightly acid sandy soils
Freely draining very acid sandy and loamy soils
Loamy soils with naturally high groundwater
Loamy and clayey floodplain soils with naturally high groundwater
Shallow lime-rich soils over chalk or limestone
Slightly acid loamy and clayey soils with impeded drainage
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils
Data source: National Soil Map of England and Wales (NATMAP)
0 1.25 2.5 5 7.5 km

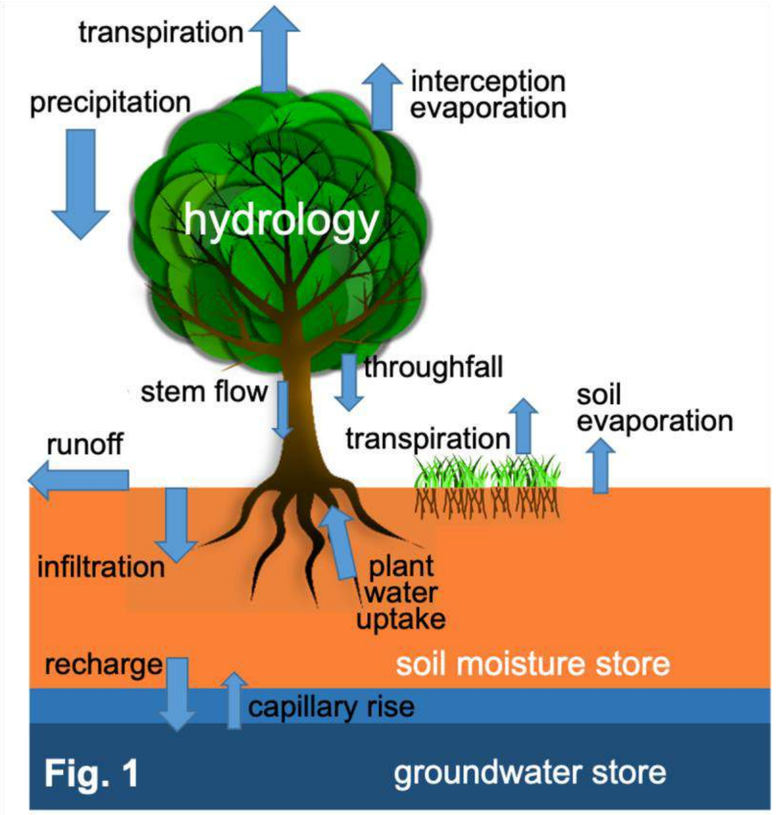

Bedrock geology
Chalk
Clay
Clay, silt and sand
Sand
Sand, silt and clay
Sandstone
Sandstone and mudstone
Mudstone
Silstone and sandstone
Thame and South Chilterns
MAIDENHEAD
READING
Lower Thames
BRACKNELL
Kennet
R. Loddon
Emm Brook
R. Blackwater
CAMBERLEY
R. Hart
FARNBOROUGH
FLEET
BASINGSTOKE
R. Whitewater
ALDERSHOT
FARNHAM
Wey
Test and Itchen
0 2.5 5 10 km


Lithology
Carbonate
Mudstone
Sandstone
Catchment boundary
Flood risk zones
Banbury
Cherwell
Evenlode
Ray
Windrush
Thame
Oxford
Cirencester
Upper Thames
Ock
South Chilterns
Swindon
Slough
Lower Thames
Greater London
Pang
Reading
Kennet
Loddon
Basingstoke
N
Km
0 5 10 20

Field scale modelling

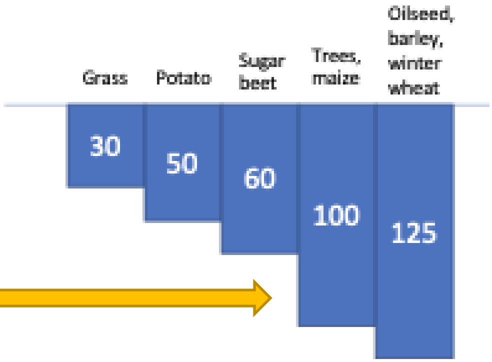
<u>Aim</u>: Unpick how **optimal combinations** of soil type, land use and soil management can reduce the likelihood of flooding

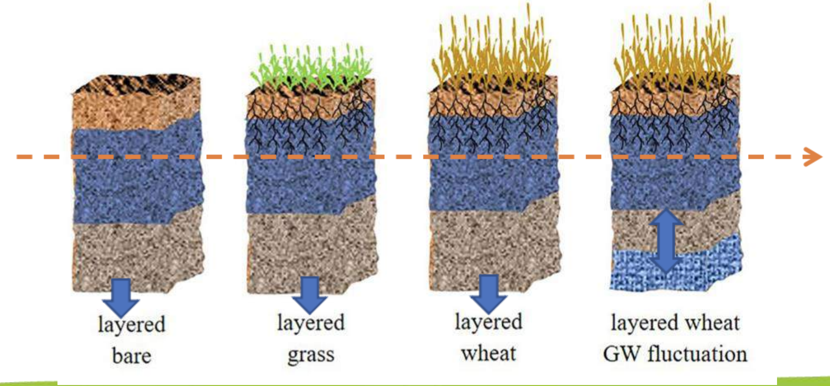
<u>Method</u>: Multi-year simulation runs using the 1-D SWAP (Soil Water Plant) process model



<u>Basic model requirements SWAP</u>:

- Daily detailed **weather** data
- **Land use** data (*WP1&2 & literature*):
    - Crops: type & rotation & tillage-type
    - **Dates** of sowing/planting & harvest
    - **Leaf area Index** & Maximum **rooting depth**
- **Soil** profile horizons & layer thickness (*NATMAP*)
- Bottom **boundary**: 'Free drainage' or interaction with groundwater? (*WP1&2/NATMAP*)

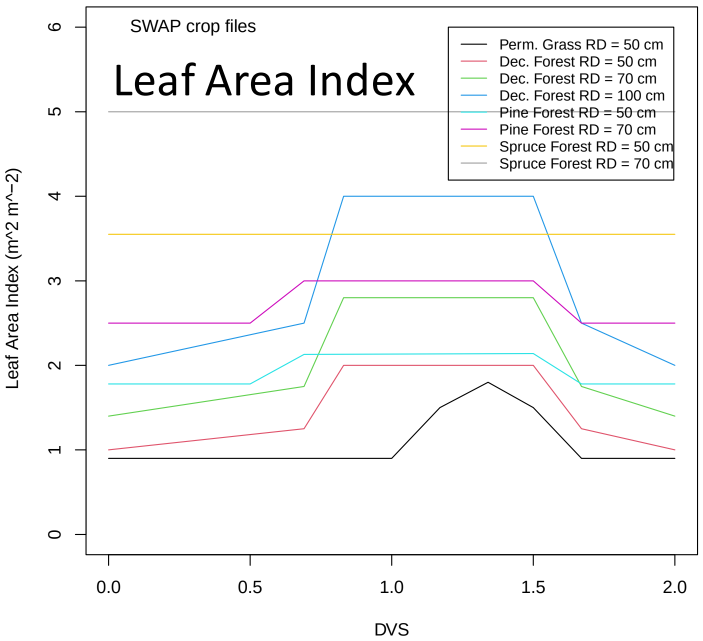


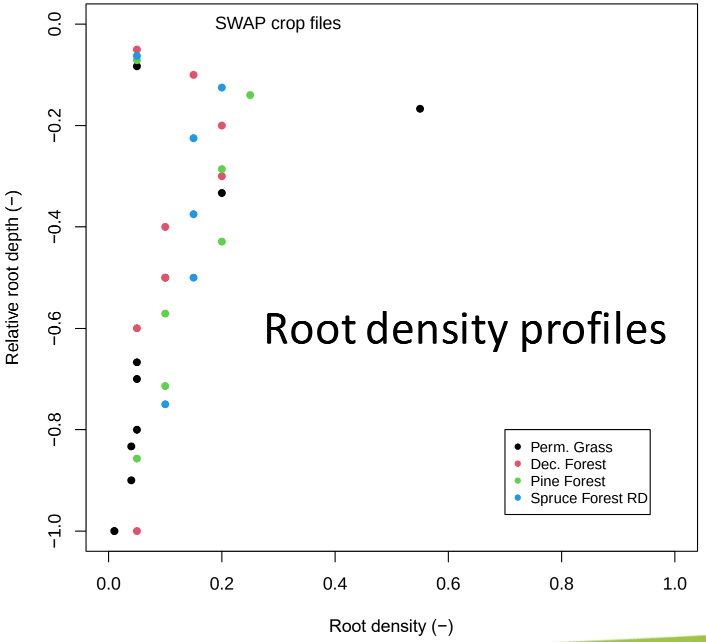


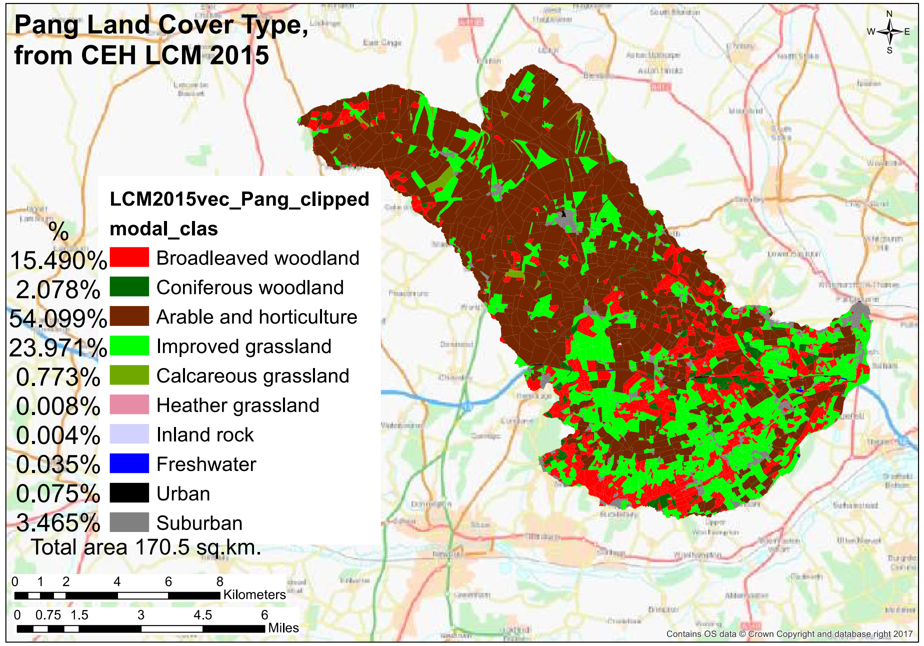
Rotations of crops, permanent grass and woodland

Model inputs

- Initial focus on the **Pang Catchment**
- 9 years (2011-2019) of **daily weather data** (rainfall, radiation, air temperature, humidity, wind speed)
- Compare and contrast LUTs: **bare soil; permanent grassland, different woodland types** (deciduous, spruce, pine)
- Inputs required on **vegetation**: LAI, RD, water stress factors

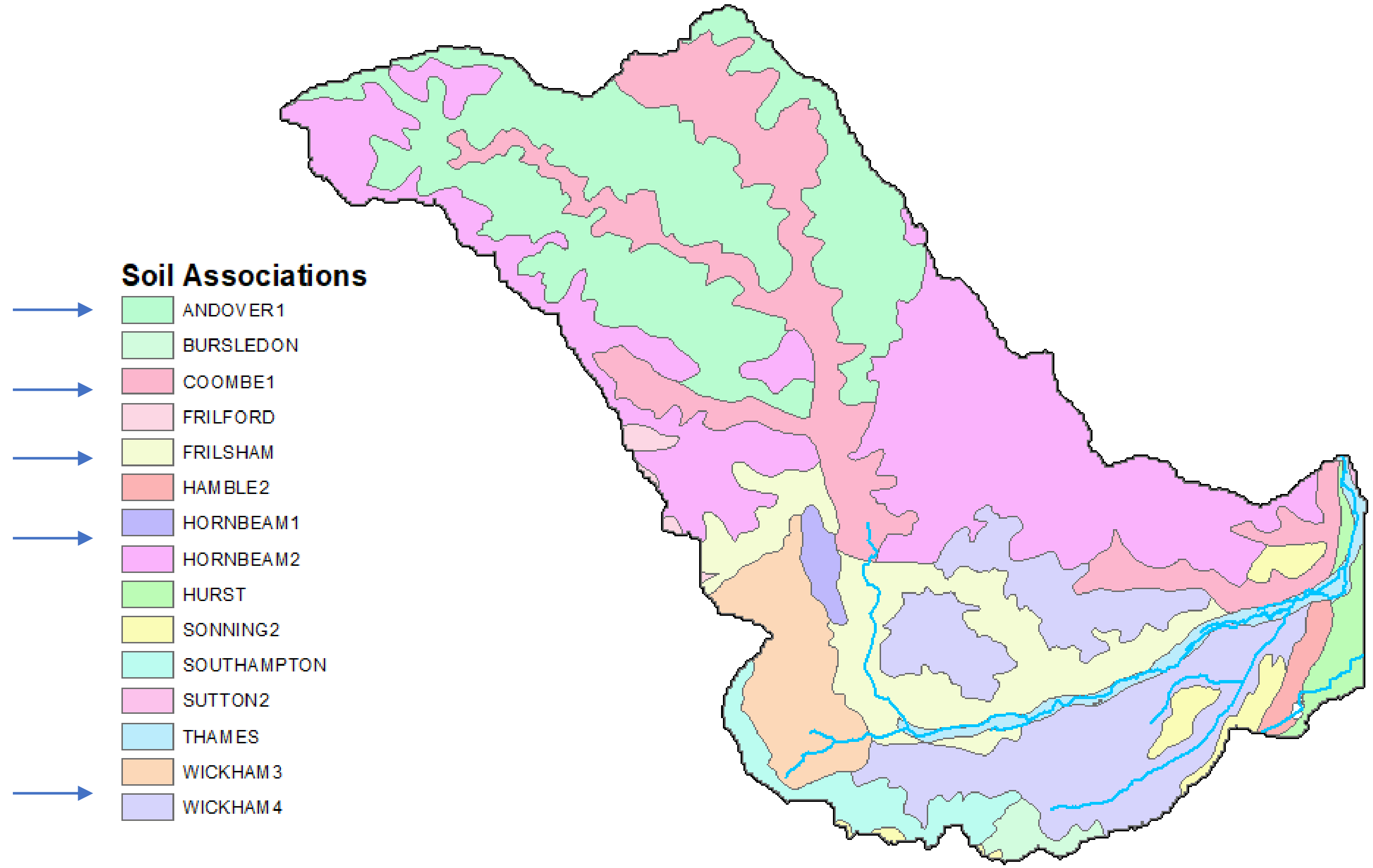






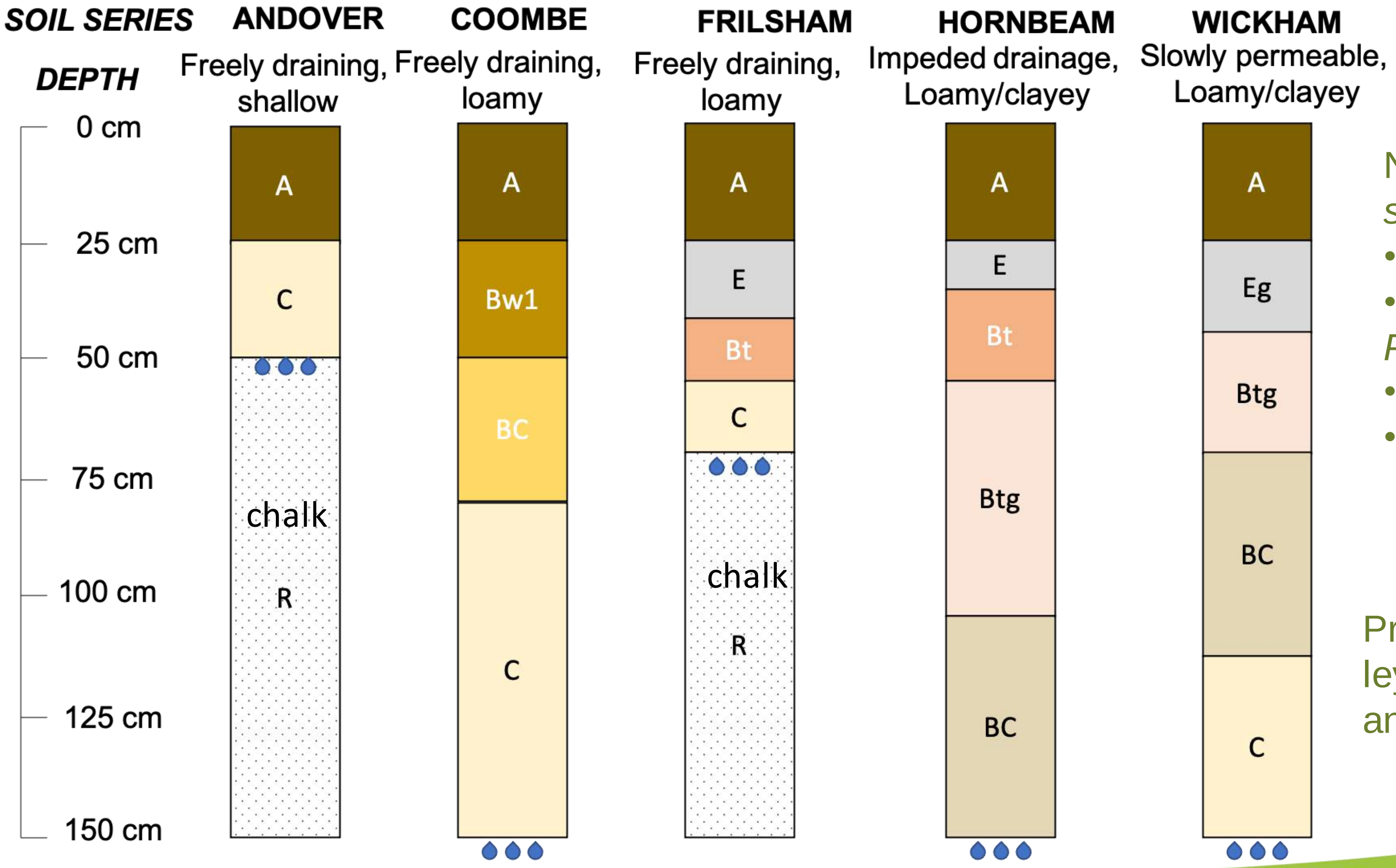
- Root water uptake affects evapotranspiration and soil water stores
- LAI affects **interception**
- **LAI** and maximum RD will be scaled on shallower soils

Soils in Pang catchment



Soil_SCAPE	SERIES_NAME	Pang	Loddon	Upper Thame
3	ANDOVER	22.56	9.78	0.27
3	ELMTON	0	0	11.27
3	SHERBORNE	0	0	38.01
5	COOMBE	14.8	2.27	0.04
5	BADSEY	0	0	6.09
6	CARSTENS	0	7.31	0
6	SONNING	1.65	0.3	0
7	FRILSHAM	9.4	0.96	0
8	HORNBEAM	26.02	0	0
9	EVESHAM	0	0	8.98
10	FRILFORD	0.38	3.14	0
14	SOUTHAMPTON	2.42	5.76	0
15	HOLIDAYSHILL	0	14.99	0
18	WICKHAM	19.14	28.53	5.73
18	DENCHWORTH	0	0	15.46
20	THAMES	1.86	0.24	1.91
22	HURST	0.4	8.69	0
27	ADVENTURERS	0	0.83	0

Soil profiles in Pang catchment



NATMAP soil information *per series*:

- Susceptibility to run-off
- Bottom boundary conditions

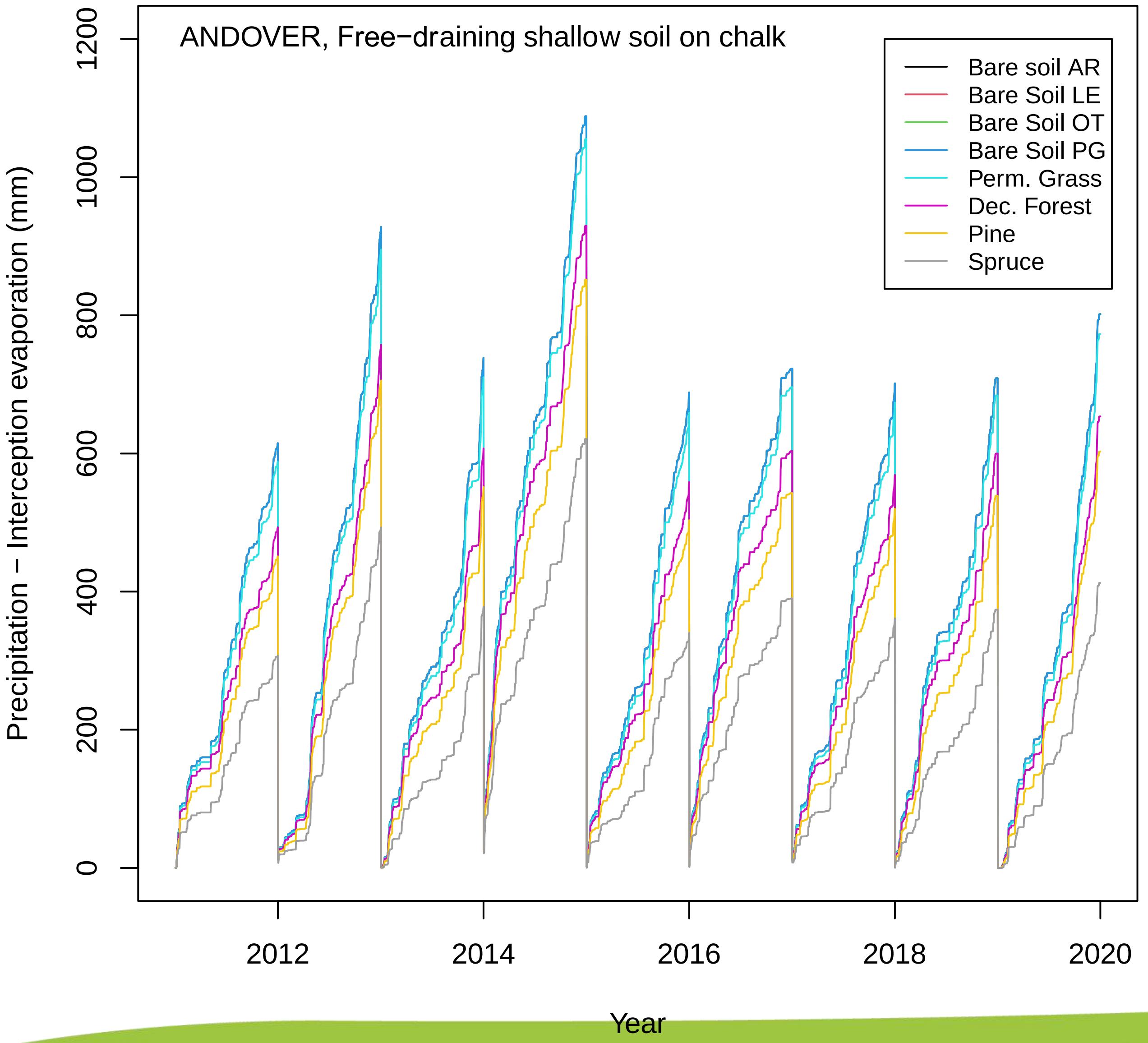
Per layer:

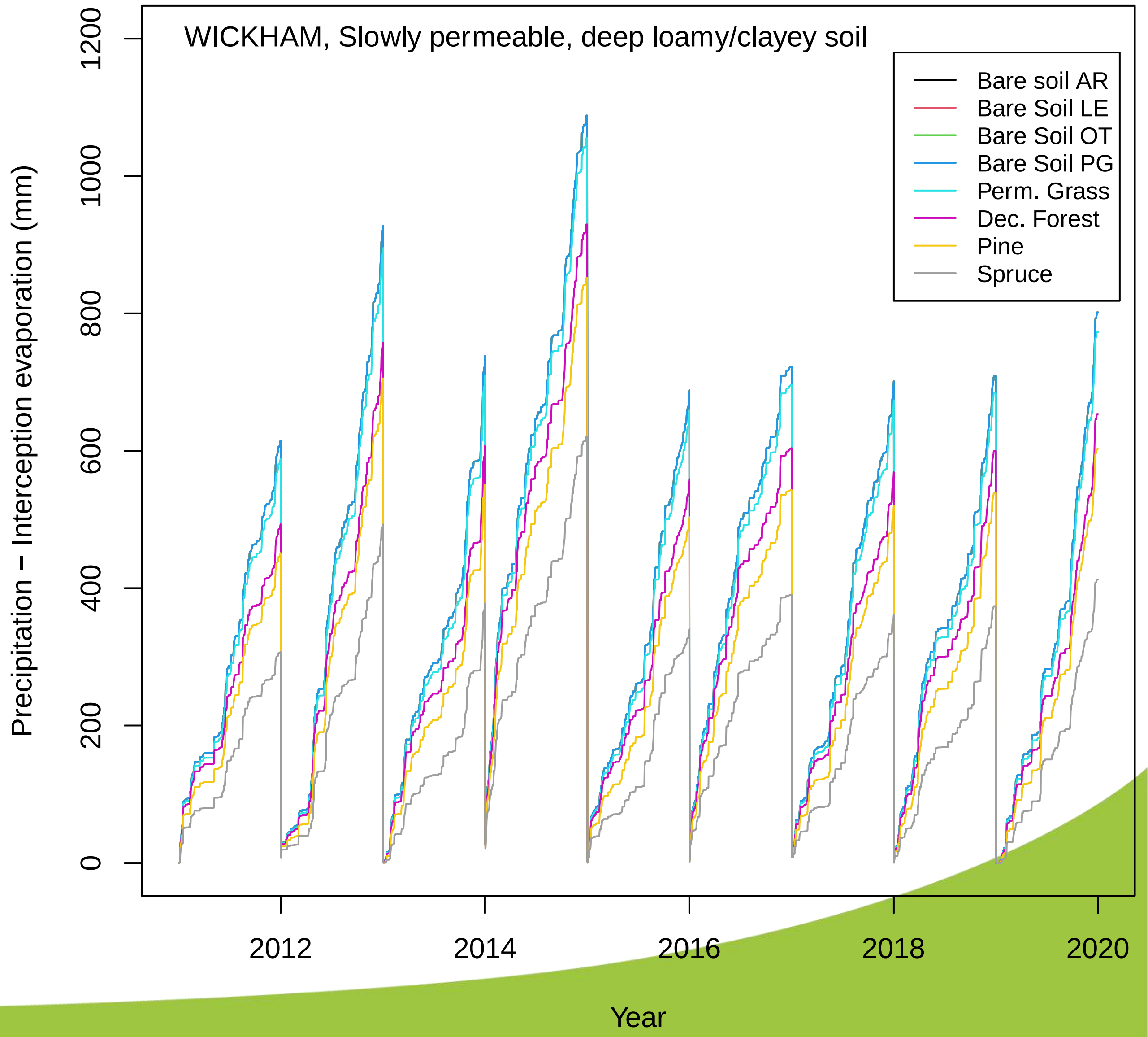
- Texture
- Hydraulic properties
    - Water retention curve
    - Saturated hydraulic conductivity

Profiles available for arable (AR), ley (LEY), permanent grass (PG) and other (OT: woodland)

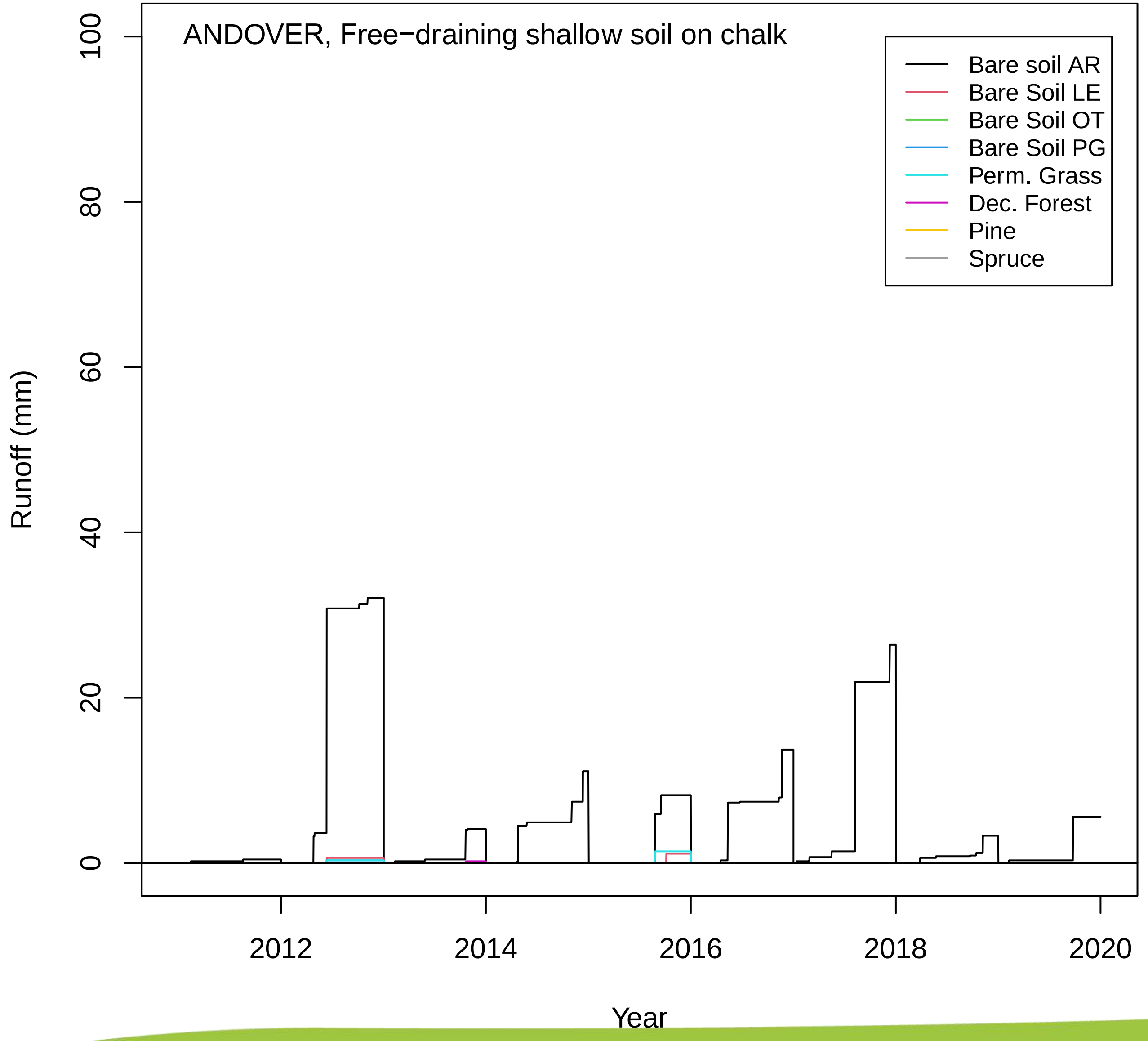
ARABLE profiles

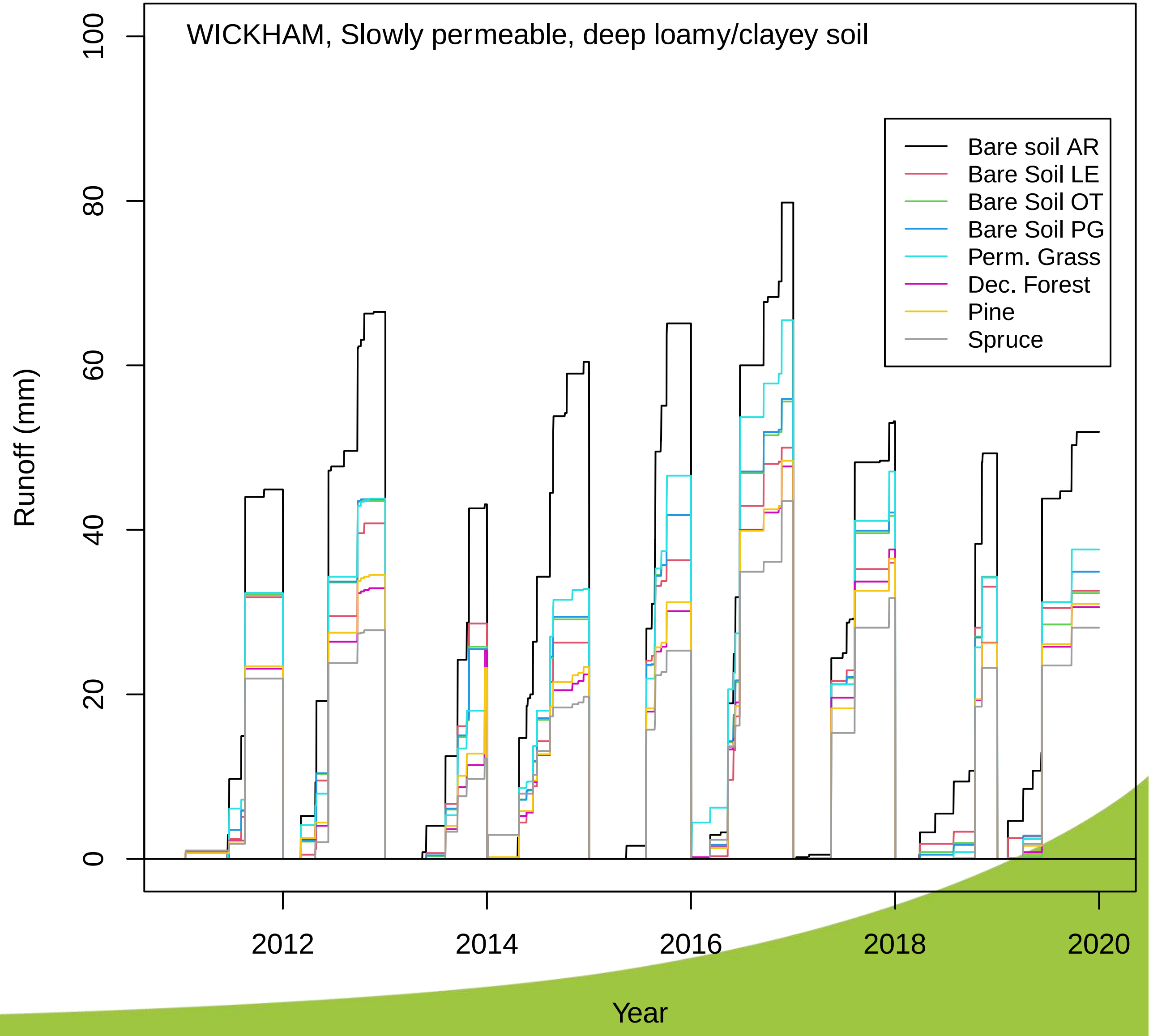
Net Precip: ANDOVER v WICKHAM



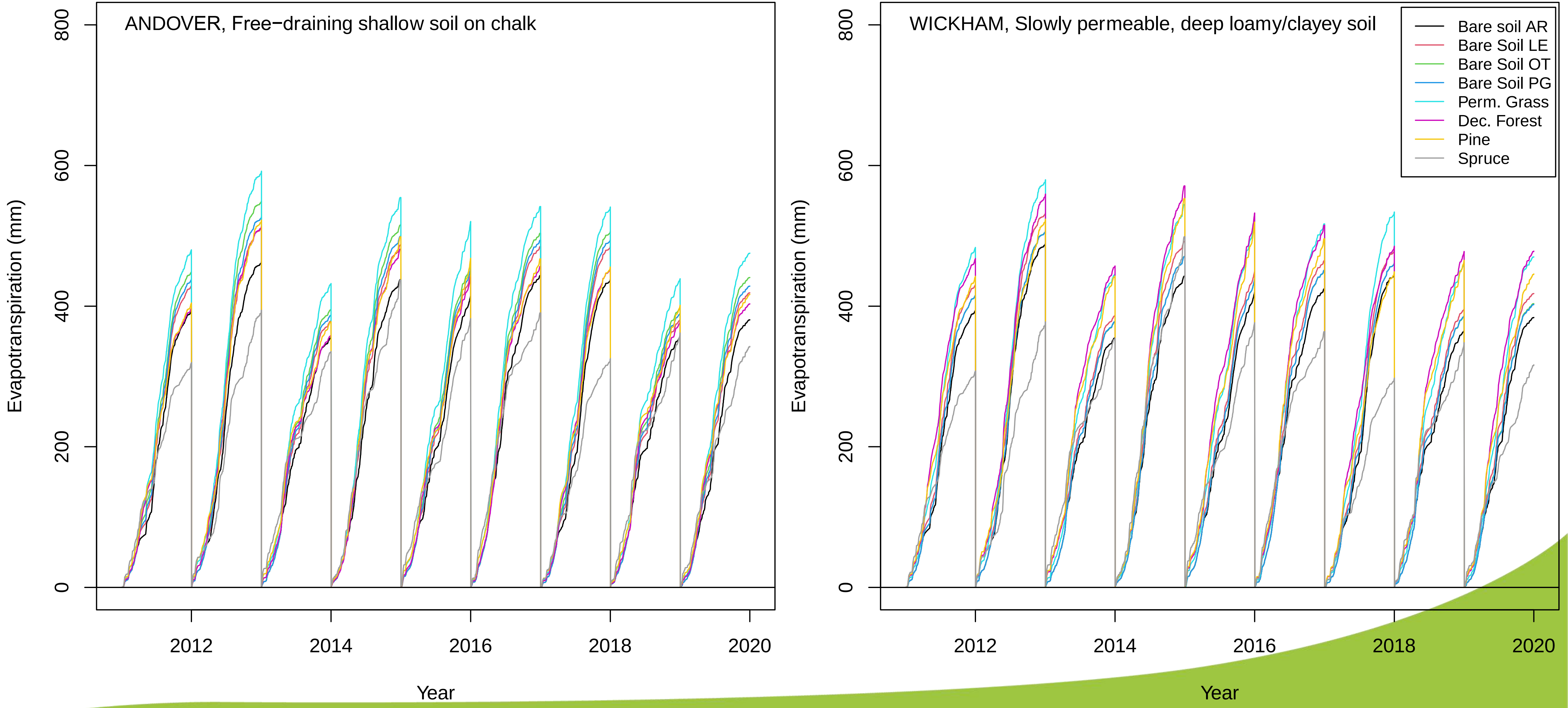


<u>Runoff</u>: ANDOVER v WICKHAM

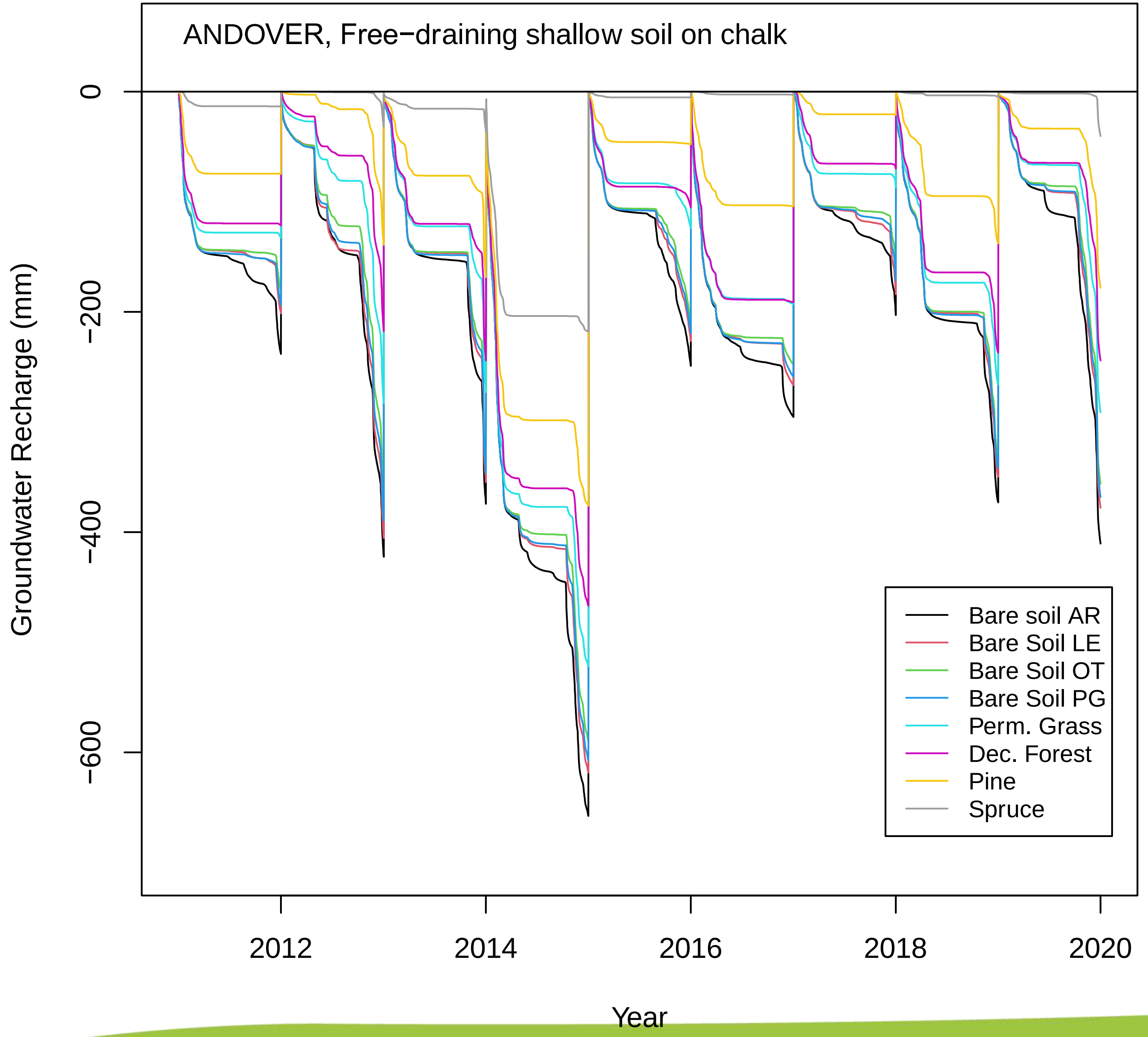


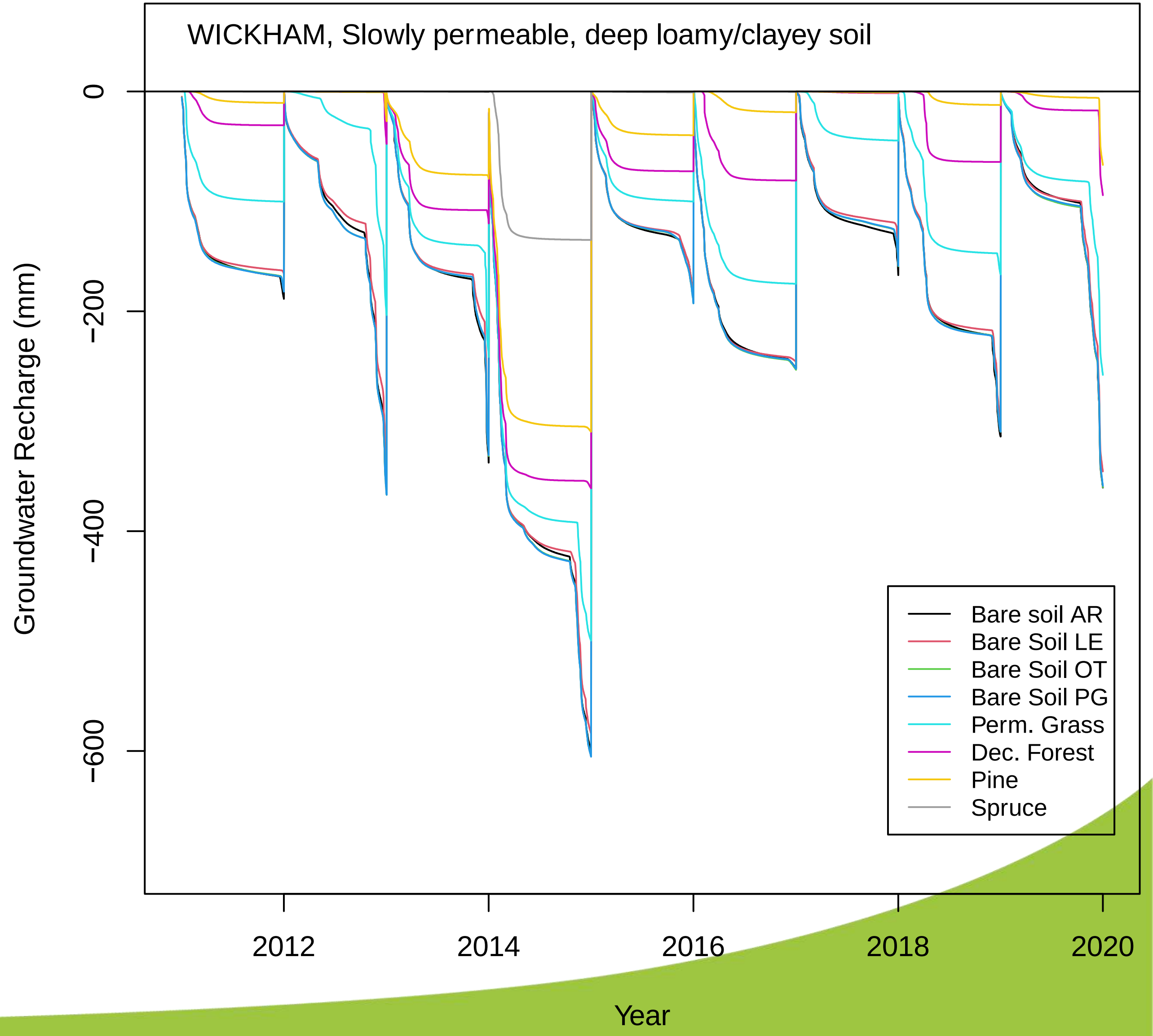


ET: ANDOVER v WICKHAM

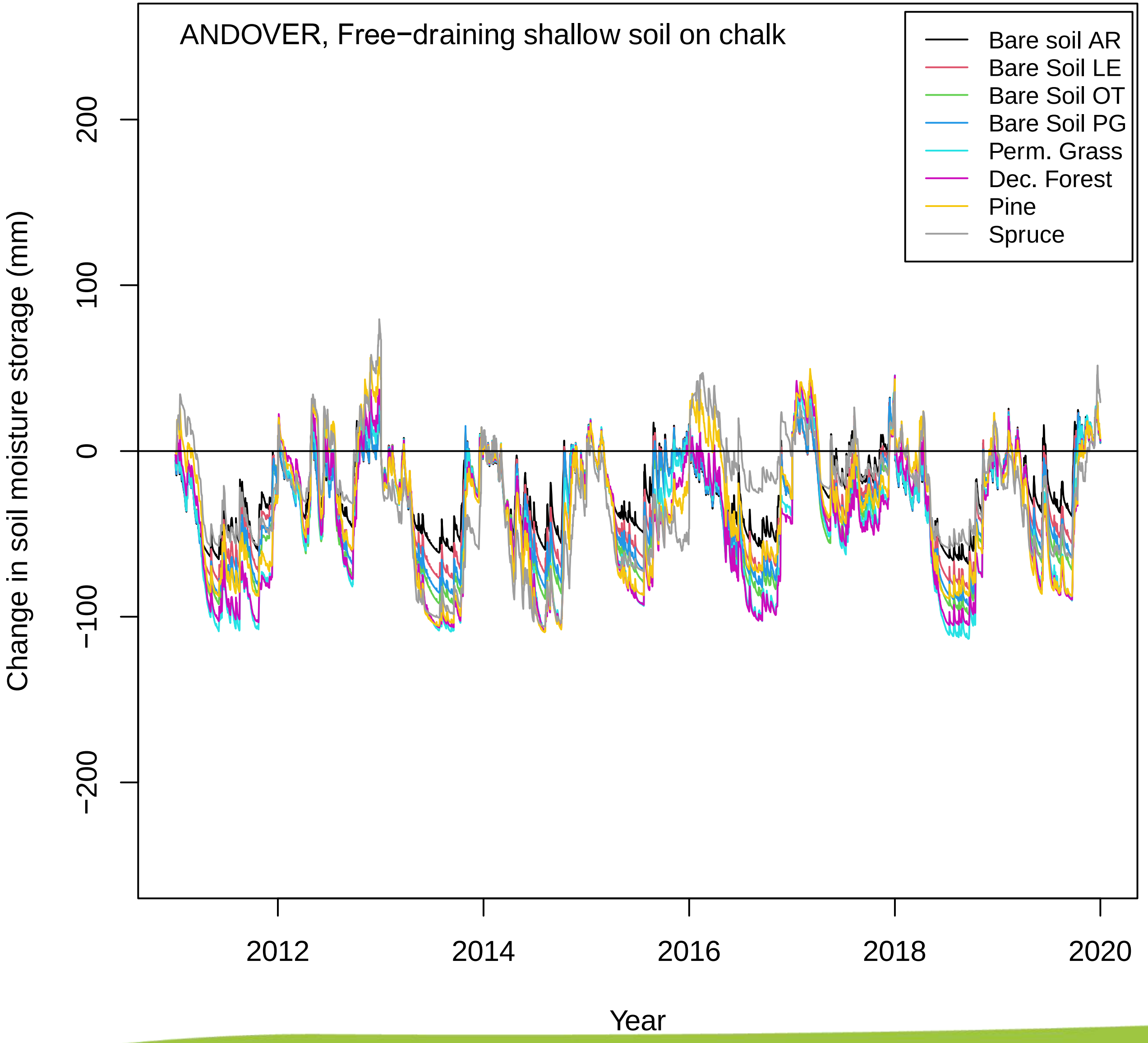


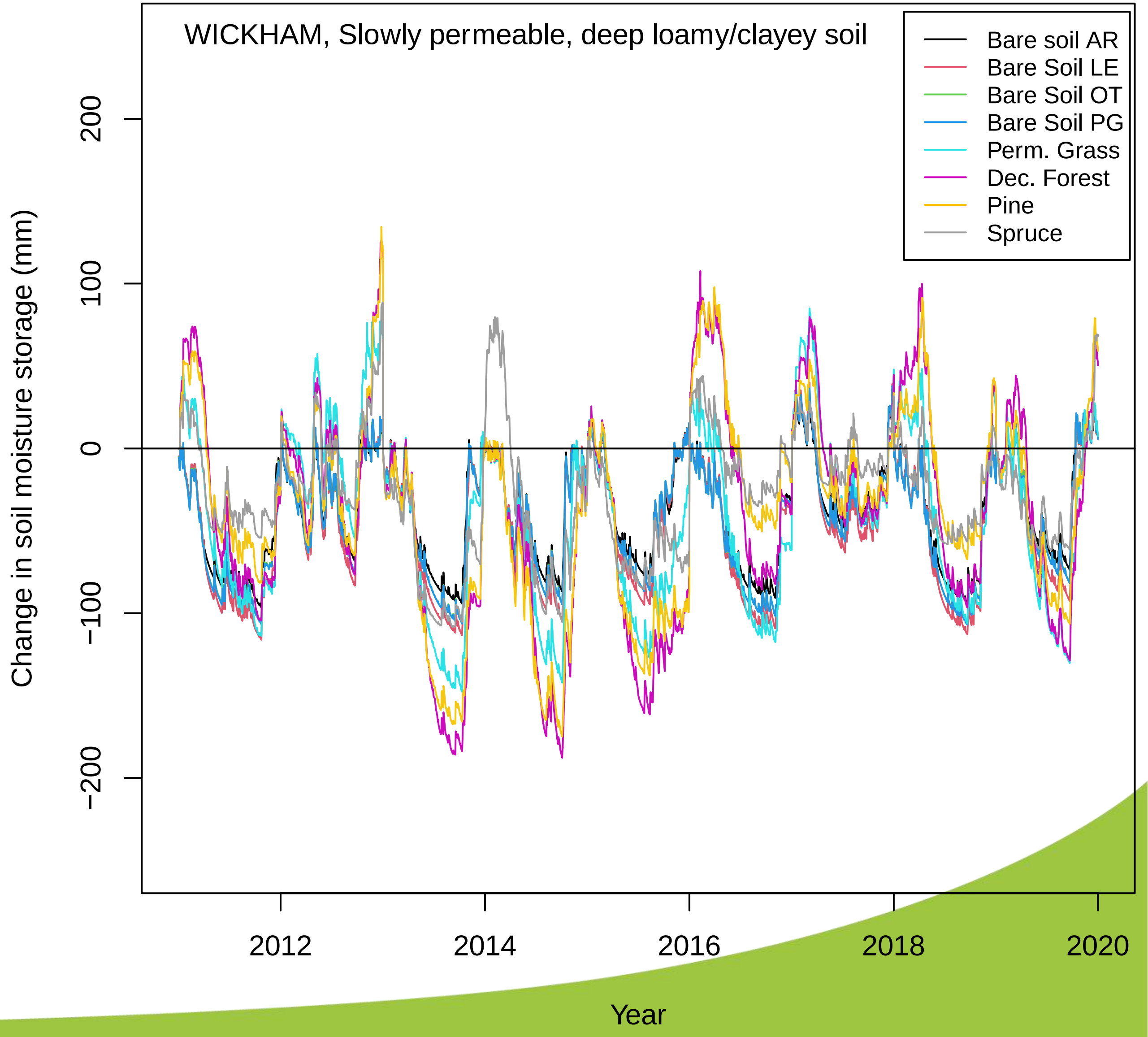
Recharge: ANDOVER v WICKHAM





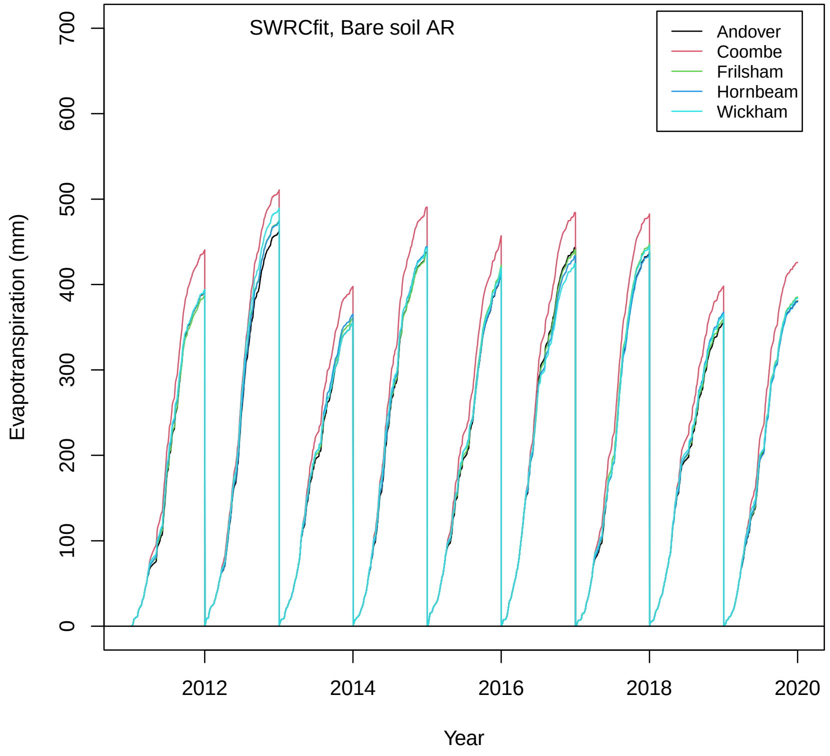
Δstorage: ANDOVER v WICKHAM



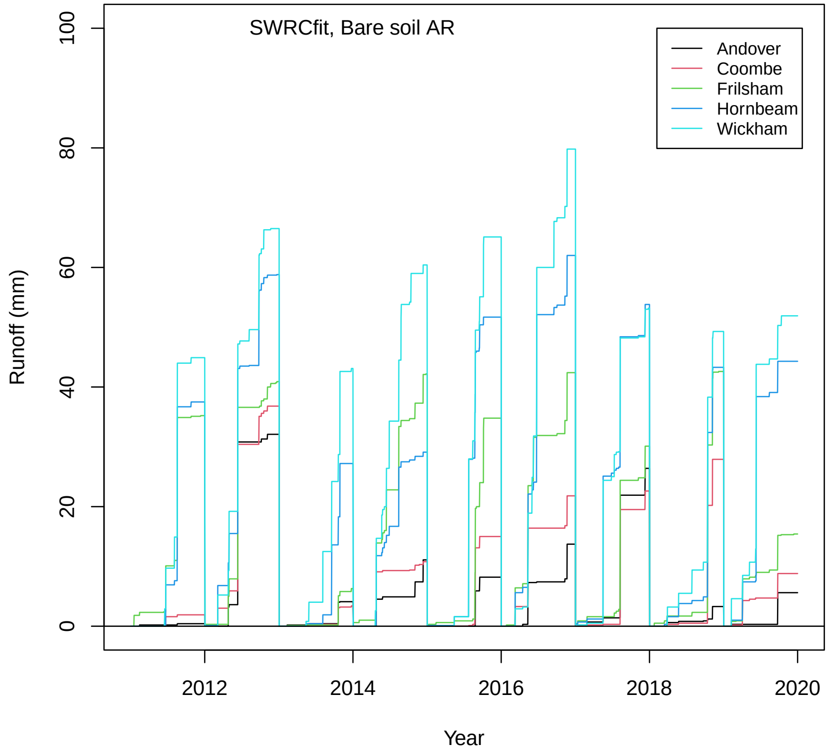


WB flows all soil series, bare soil

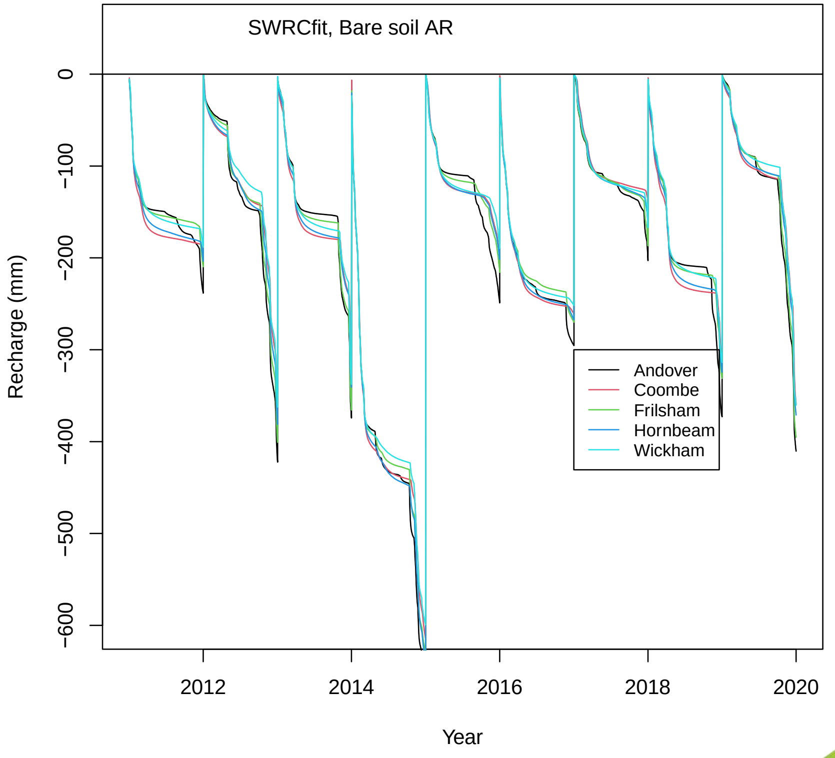
Evaporation



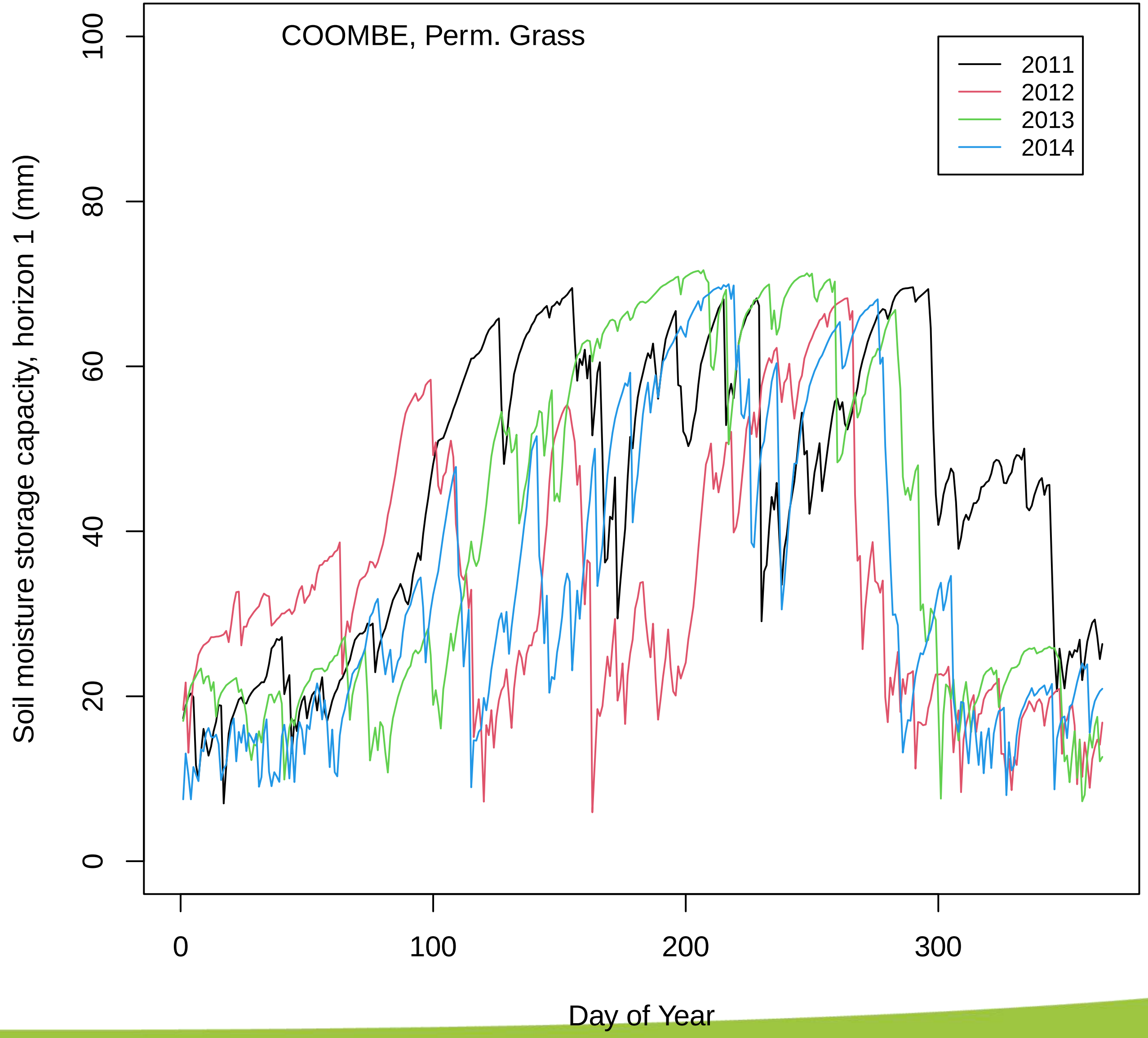
Runoff



Recharge



SWAP SM storage capacity, layer 1



Preliminary conclusions

- Effect of Δ**LUT** on WB fluxes larger than Δsoil hydraulic properties (but strong interplay between the two)
- **Above-ground** parameters (e.g. **LAI**) just as important as below-ground properties (rooting depth, soil properties)
- **Historic LU** will affect hydraulic props., and hence water flows
- Next steps: crops & **rotations**; inter-annual variation in LAI and RD; refinement using detailed WP1 & WP2 farm-level data; model sensitivity and **uncertainty** studies

Small to medium catchment modelling

Pre-investigation

- ❑ Analysis of river flows & groundwater levels
- ❑ Lumped modelling (IHACRES and GR4J)

Identification of suitable models

- ❑ SWAT
- ❑ SWAT-MODFLOW/ ZOODRM
- ❑ ParFlow

Semi-distributed Modelling

- ❑ Different model setups and parametrizations
- ❑ Modification of source code
- ❑ Different sensitivity and uncertainty analysis
- ❑ Different calibration techniques

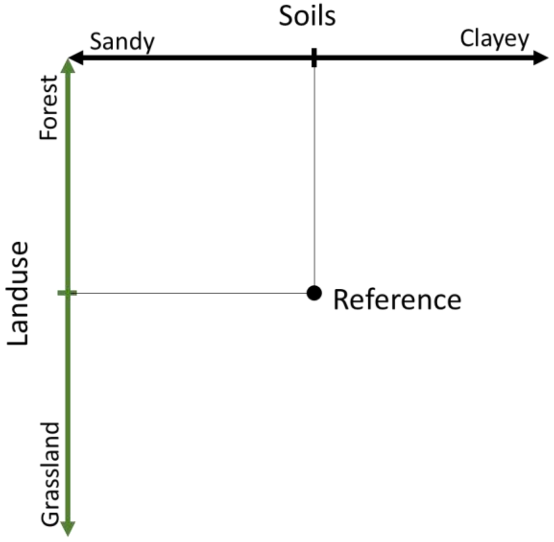
NRFA | Met Office, EA

- Rainfall
- Temperature
- Relative humidity
- Solar radiation
- Wind speed
- Elevation models
- Land cover (CEH)
- Soils

NATMAP | SoilGrids

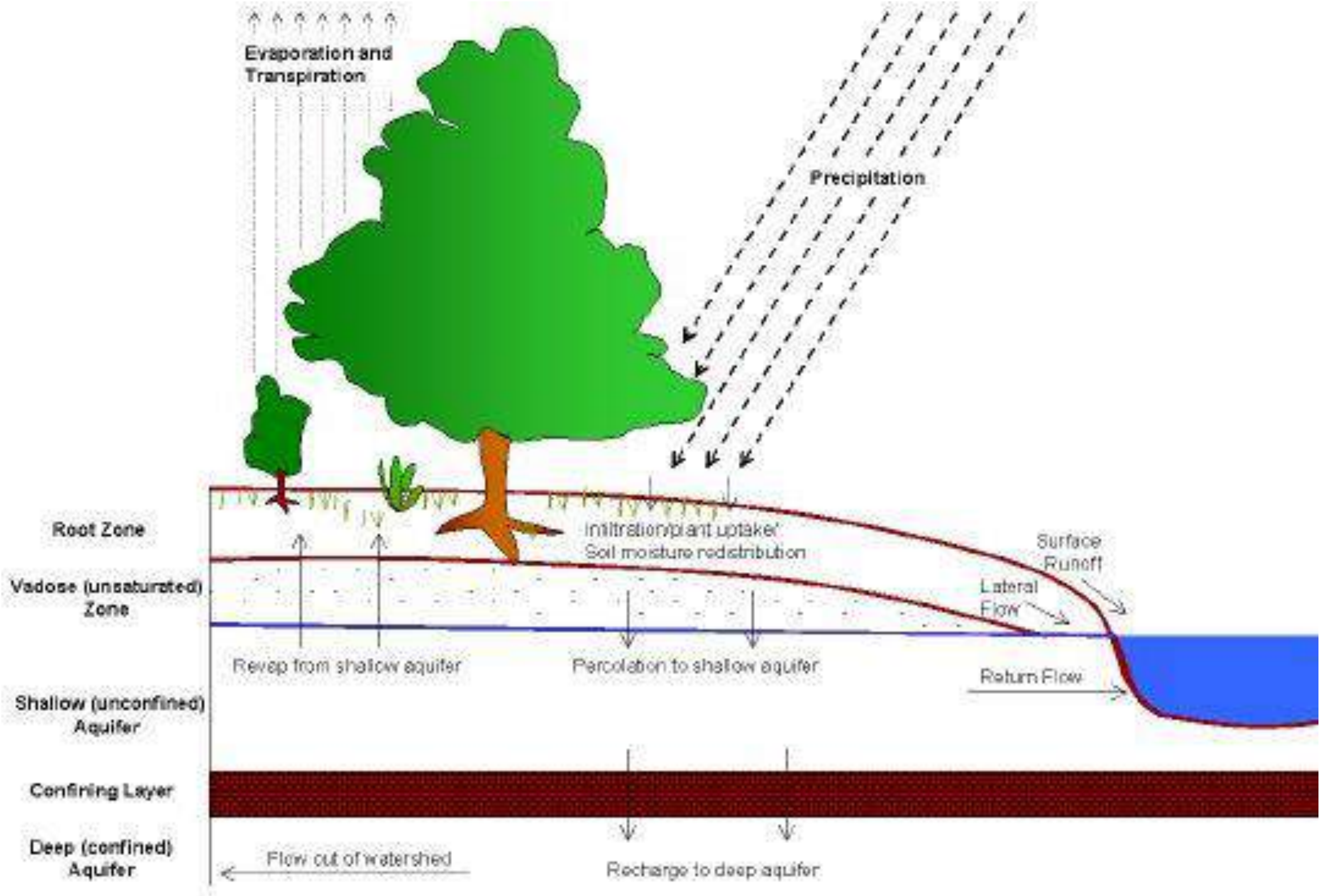
Statistical analysis and comparison

Decision on the reliability of the modelling framework for NFM



Test of NFM scenarios

Schematic representation of SWAT

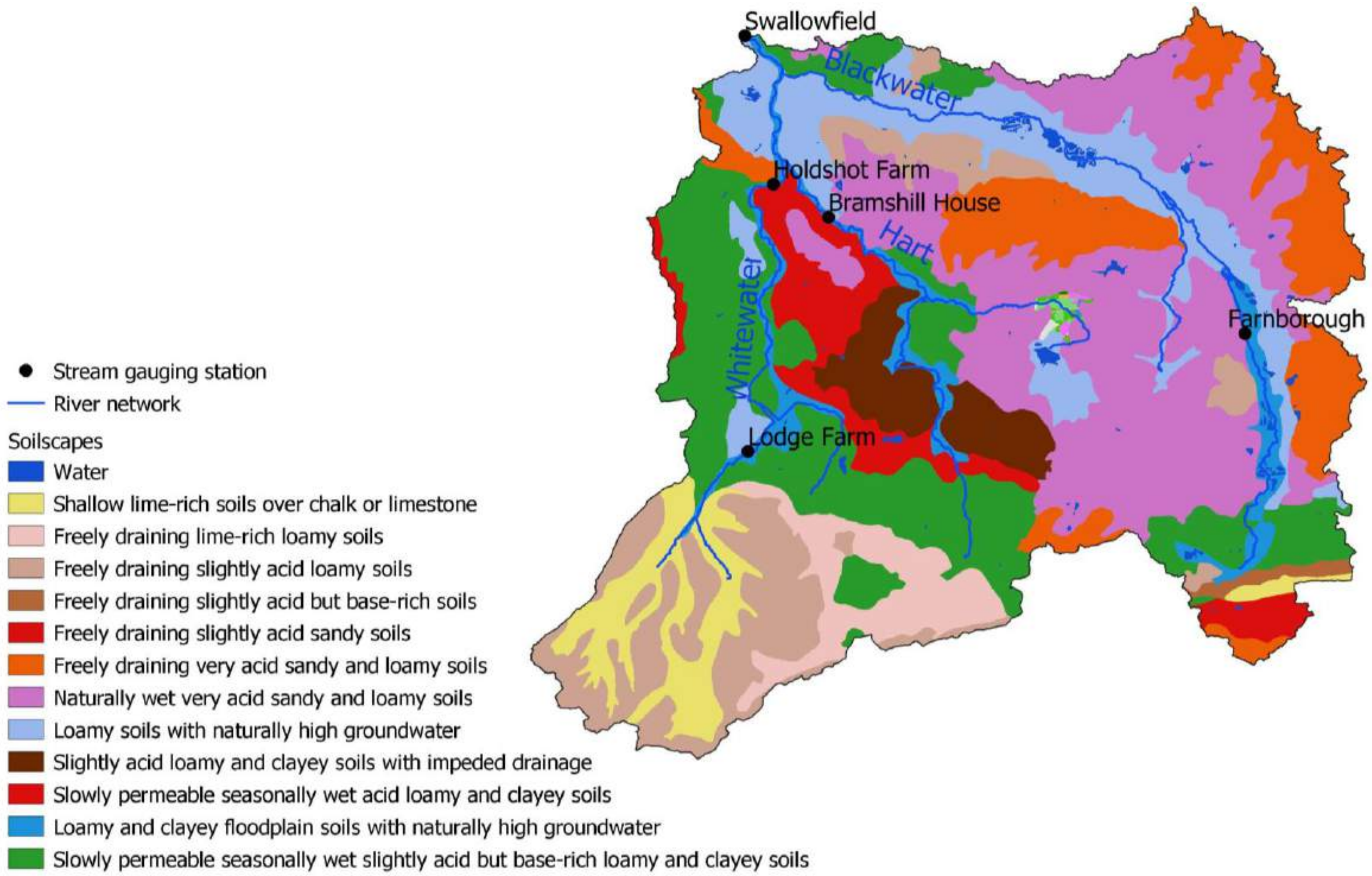


Semi-distributed model

Three levels: basin, subbasin and hydrological response unit (HRU)

Two aquifers: one shallow aquifer (unconfined) and one deep aquifer (confined)

Blackwater catchment



Area = 358 km2

Modelling approach

LANDWISE NFM

❖ Modification of the SWAT model source code

✓ Water content at wilting point

$$FC_{ly} = AWC_{ly} + WP_{ly} \qquad WP_{ly} = 0.40.\frac{m_c.\rho_b}{100}$$

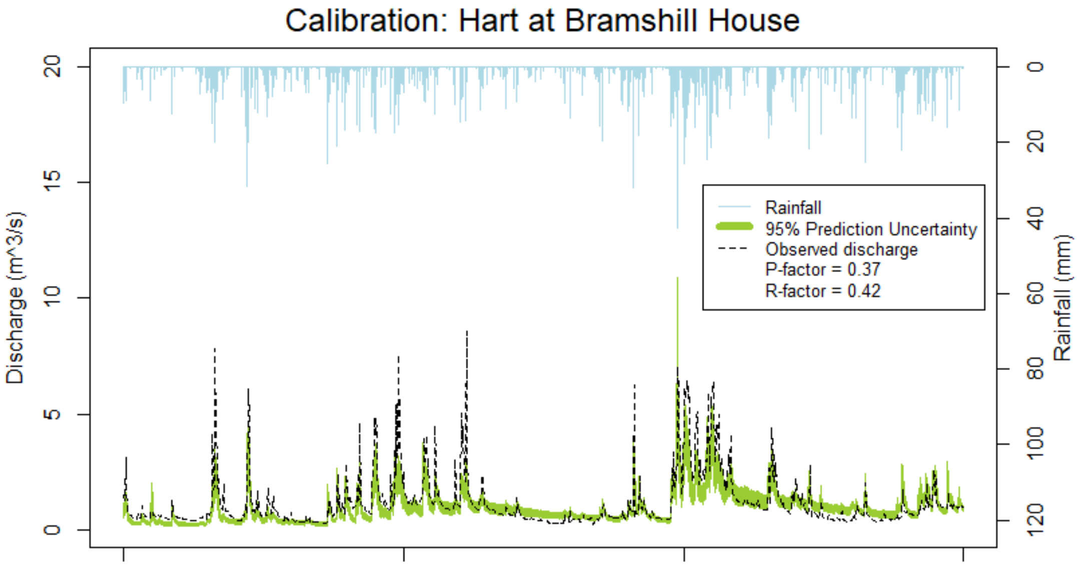
✓ Muskingum method: to discretize daily evaporation and sum up transmission losses in case of numerical instability

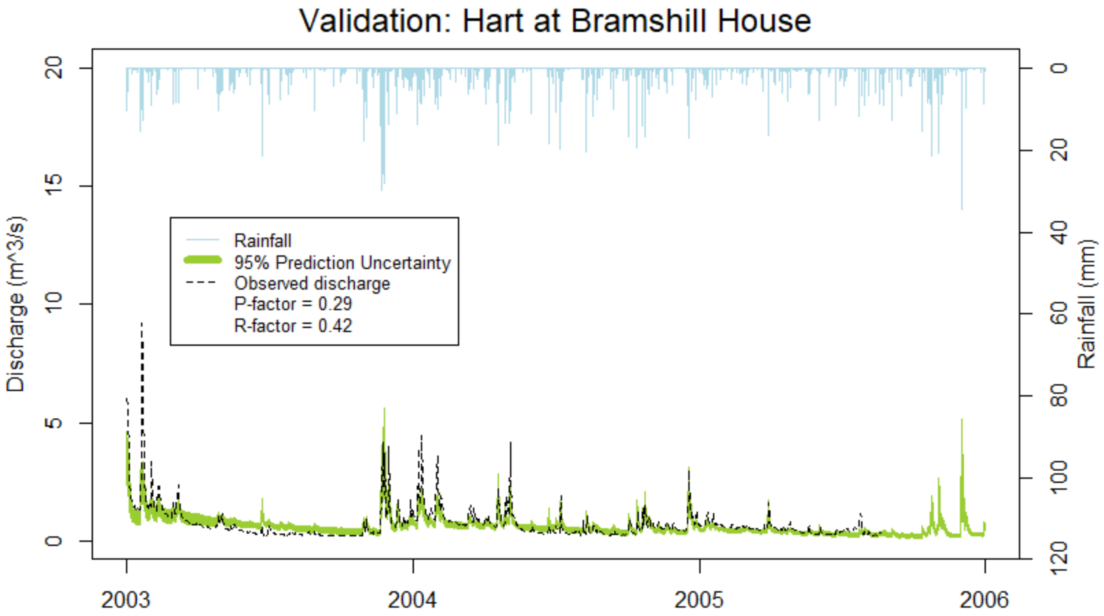
❖ Simultaneous multisite calibration

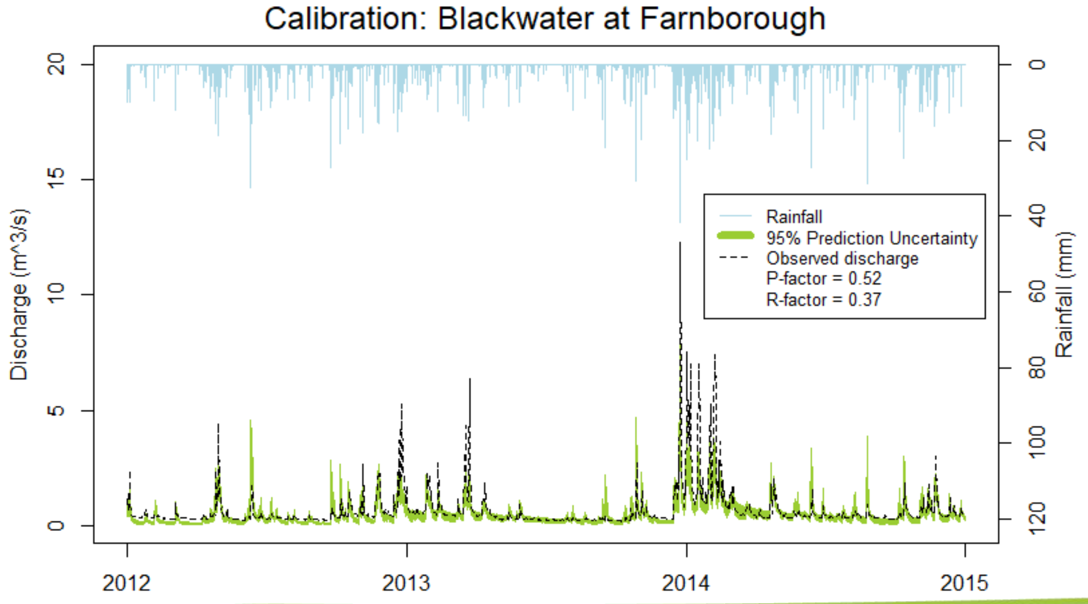
❖ Sensitivity and uncertainty analysis

- Latin hypercube sampling (10 000 samples)
- 95% prediction uncertainty

Model performance 1/3

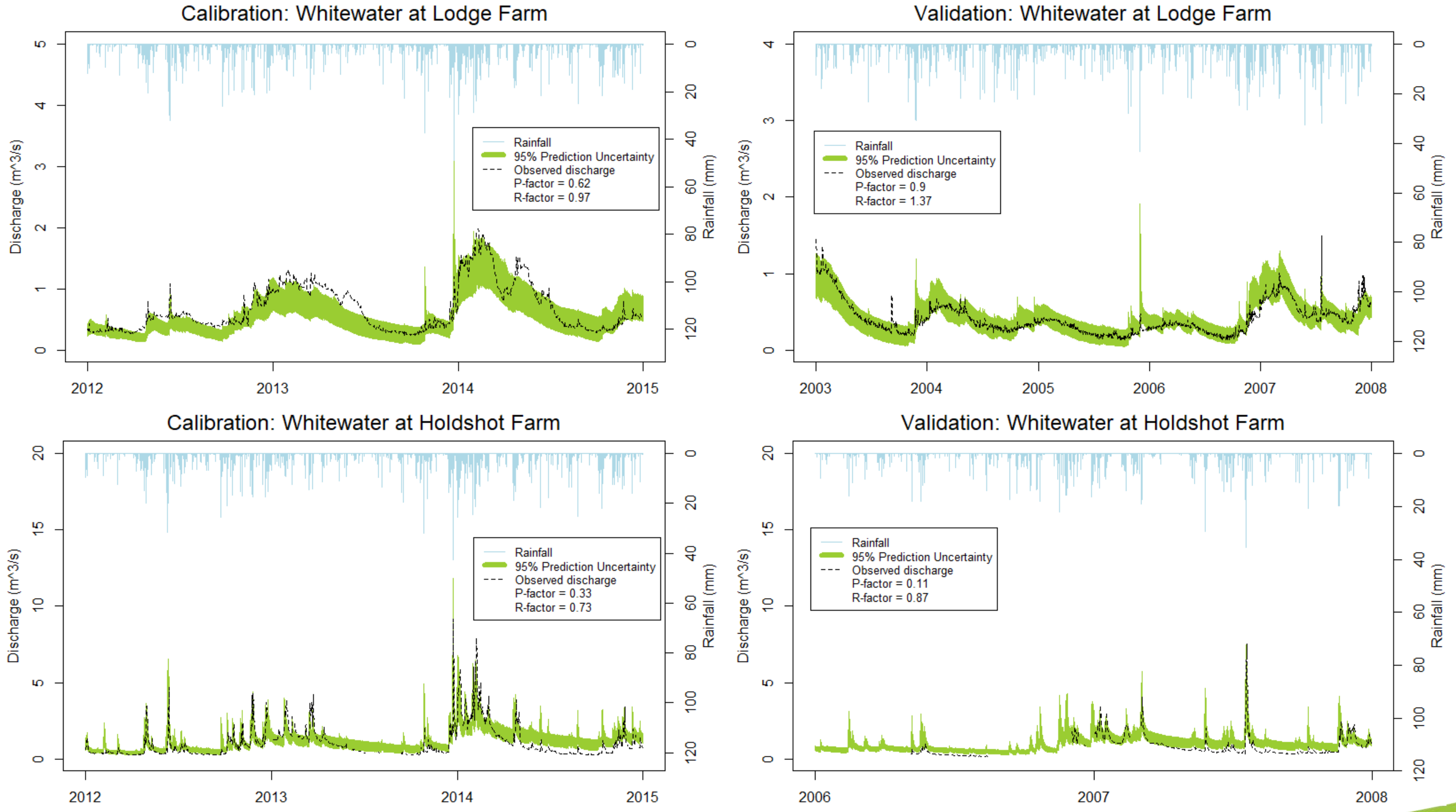




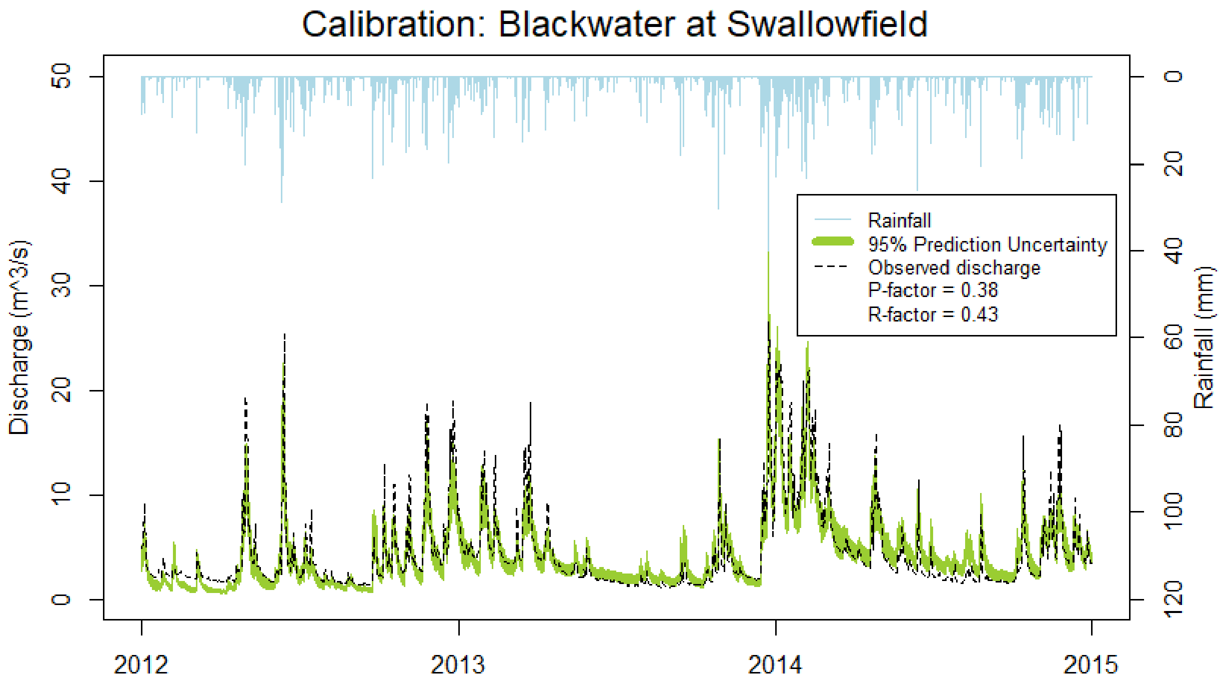


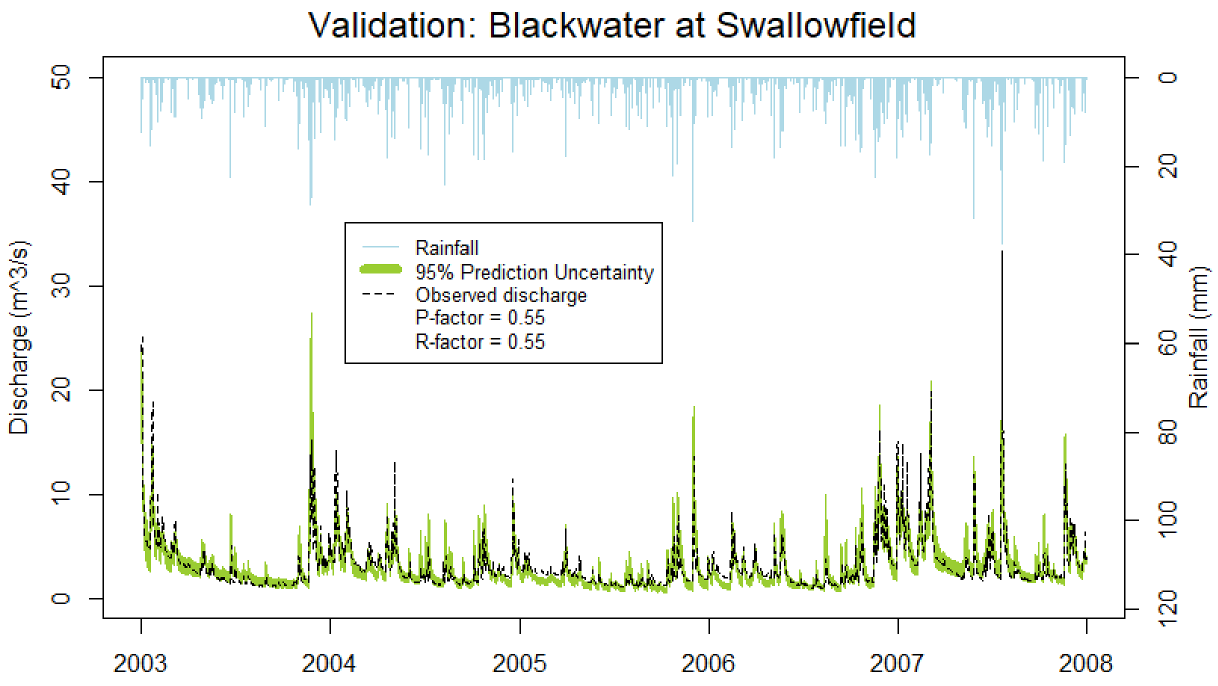
- ✓ Better modelling results obtained with EA rainfall and NATMAP soil datasets
- ✓ Issues with baseflow and peak flow estimation for Hart and Blackwater at Farnborough

Model performance 2/3



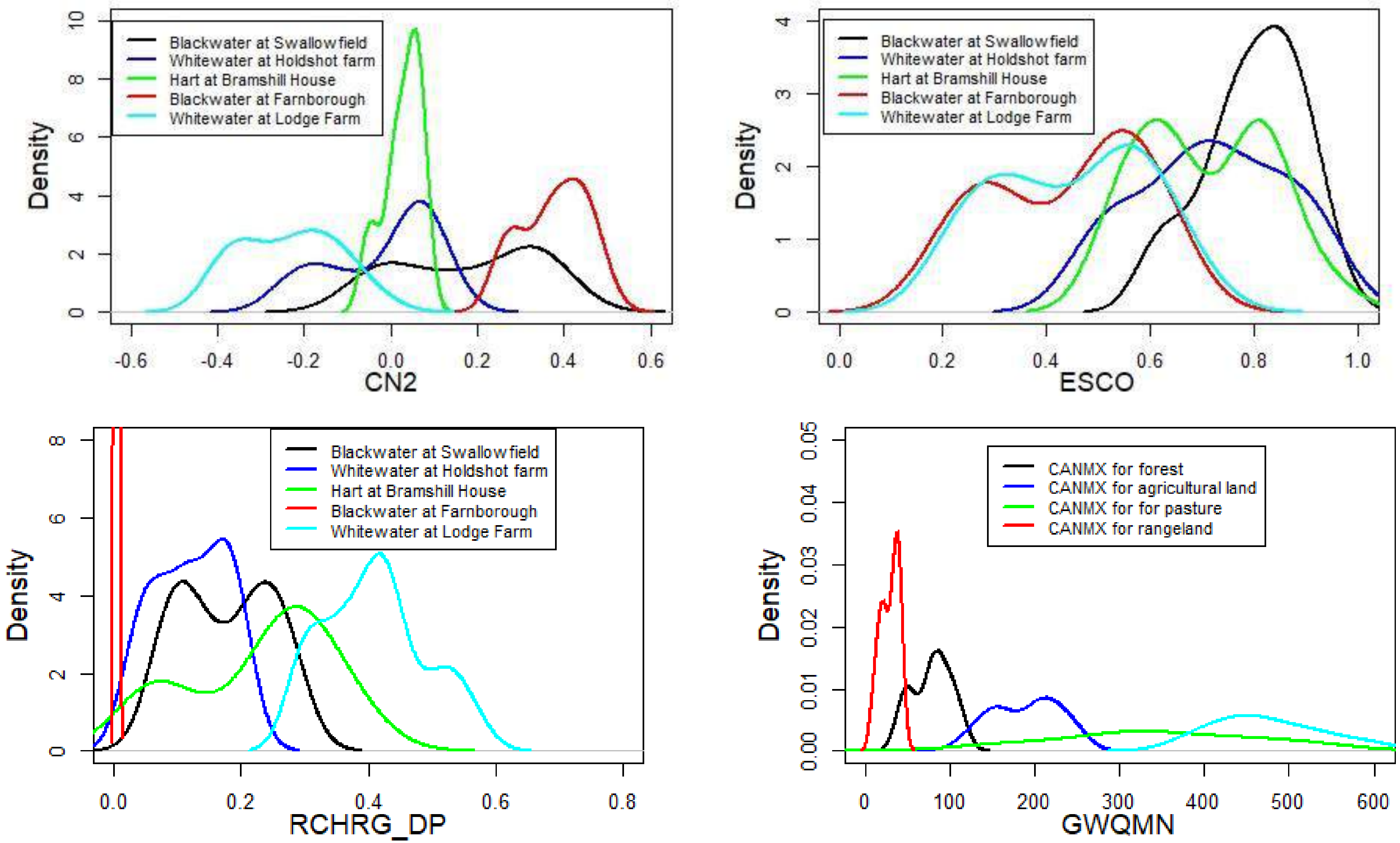
Model performance 3/3





Model verification 1/2

Parameter verification from density curves



CN2: SCS curve number

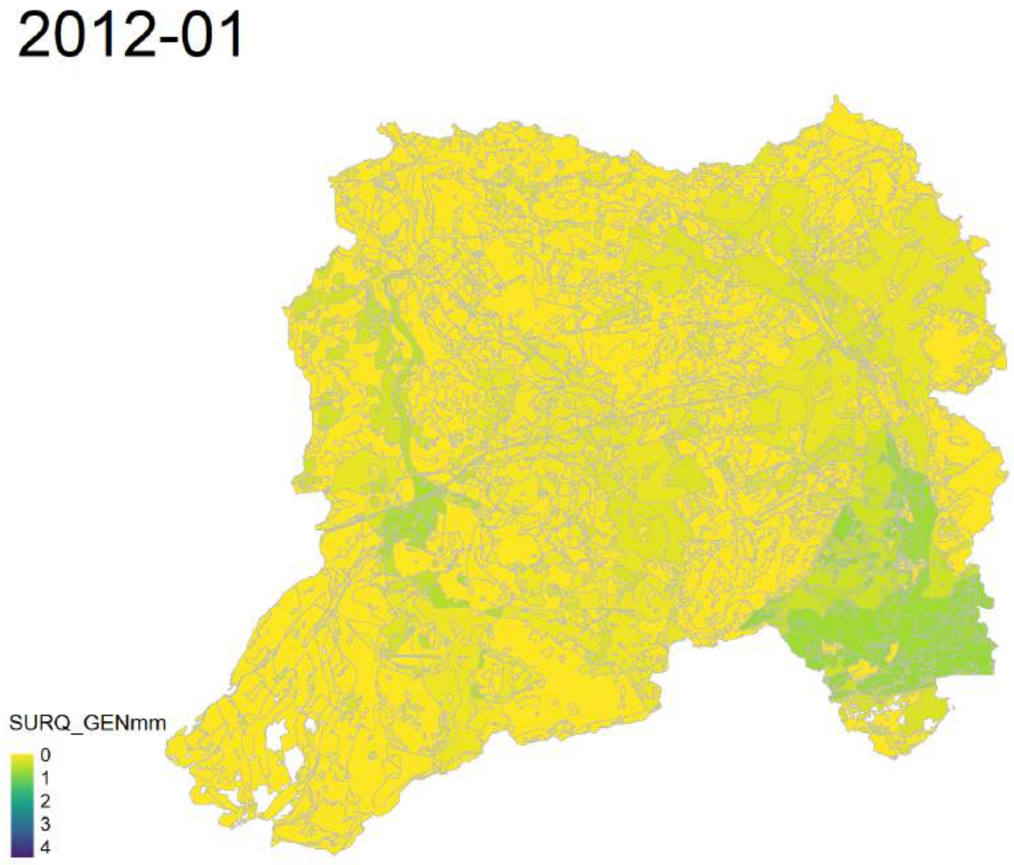
ESCO: Sol evaporation compensation factor

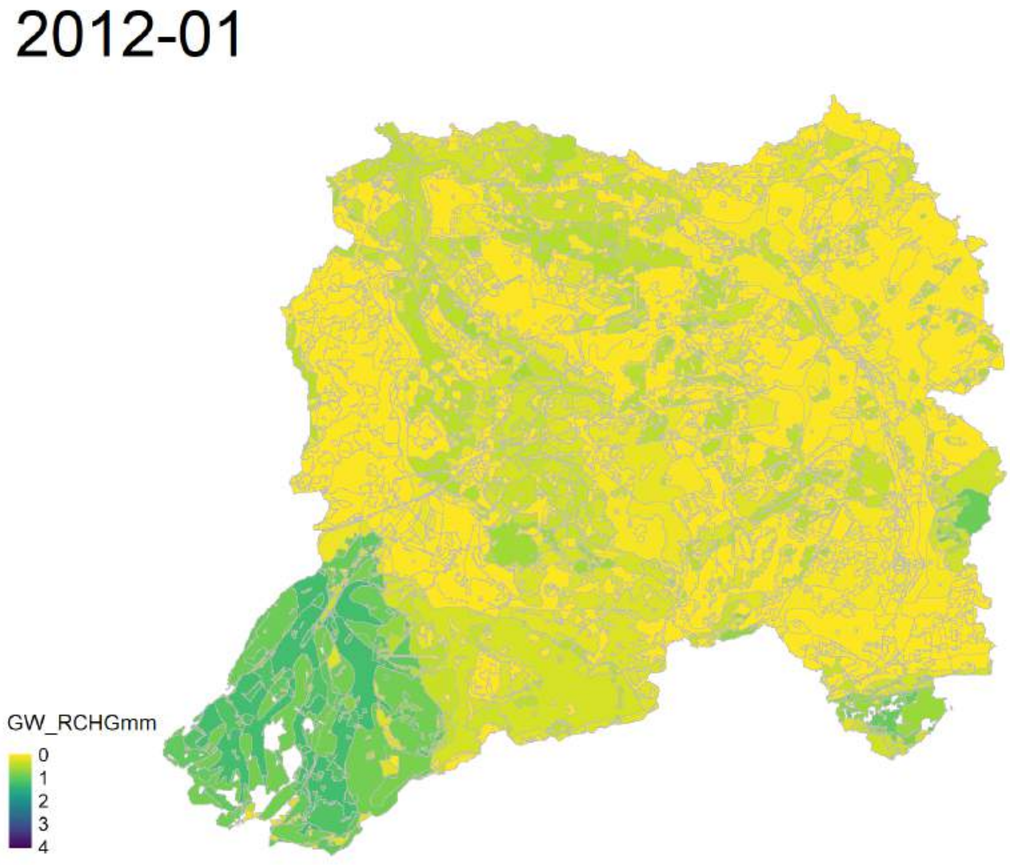
RCHRG_DP: Deep aquifer percolation fraction

GWQMN: threshold depth of water in the shallow aquifer required for return flow to occur

Model verification 2/2

Processes verification

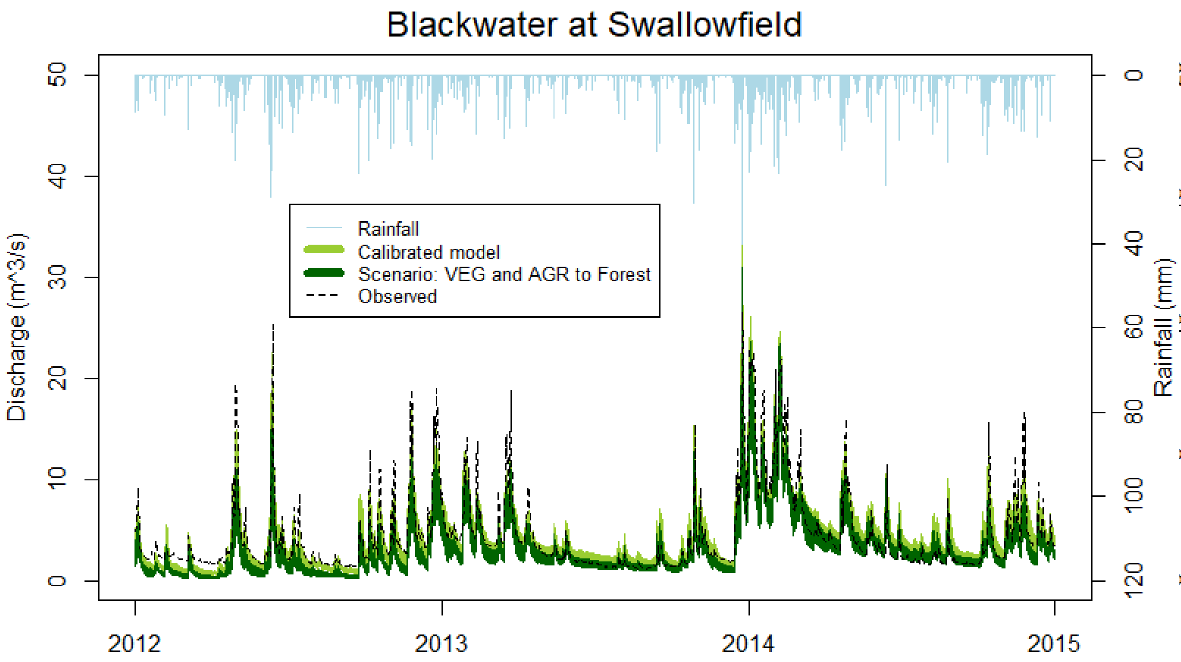


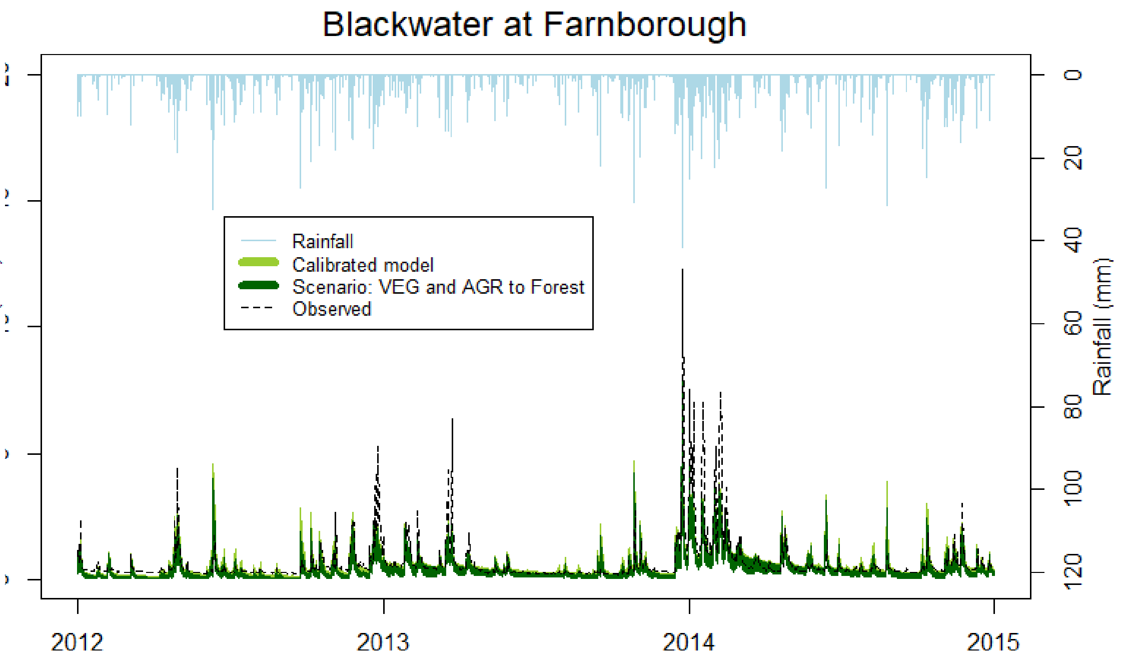


Spatio-temporal variability of generated surface runoff (SURQ_GEN) and groundwater recharge (GW_RCHRG) within the Blackwater catchment

Test of NFM scenarios (Unrealistic)

Scenario 1: all land cover to deciduous forest except water and urban areas

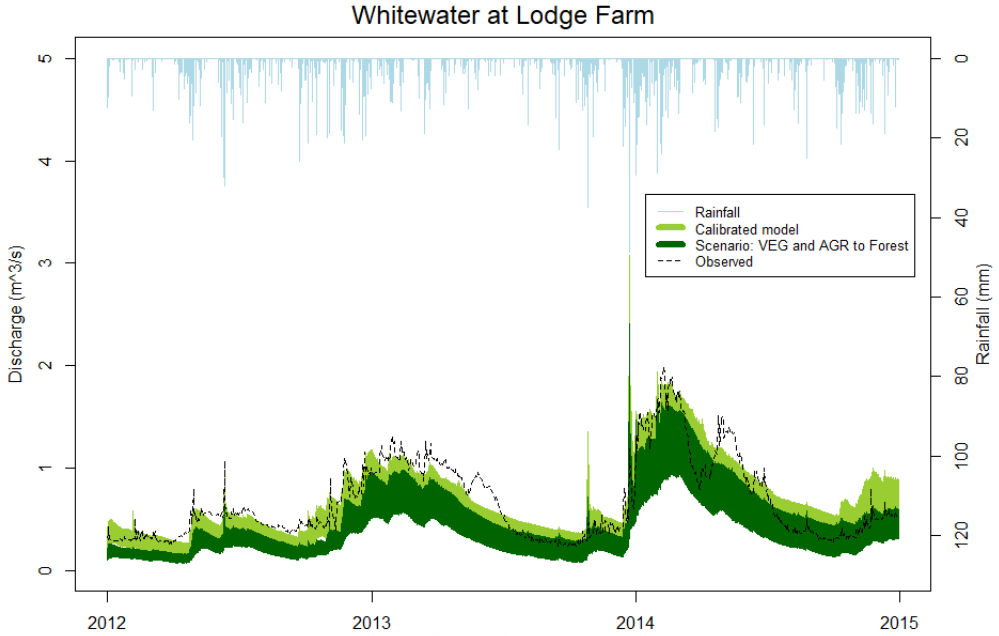


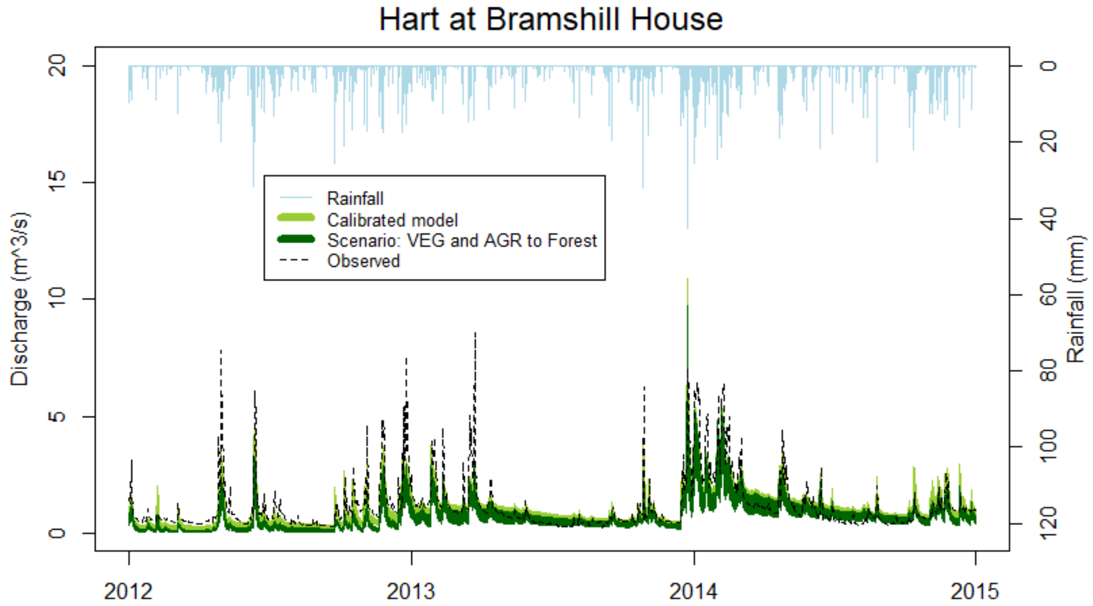


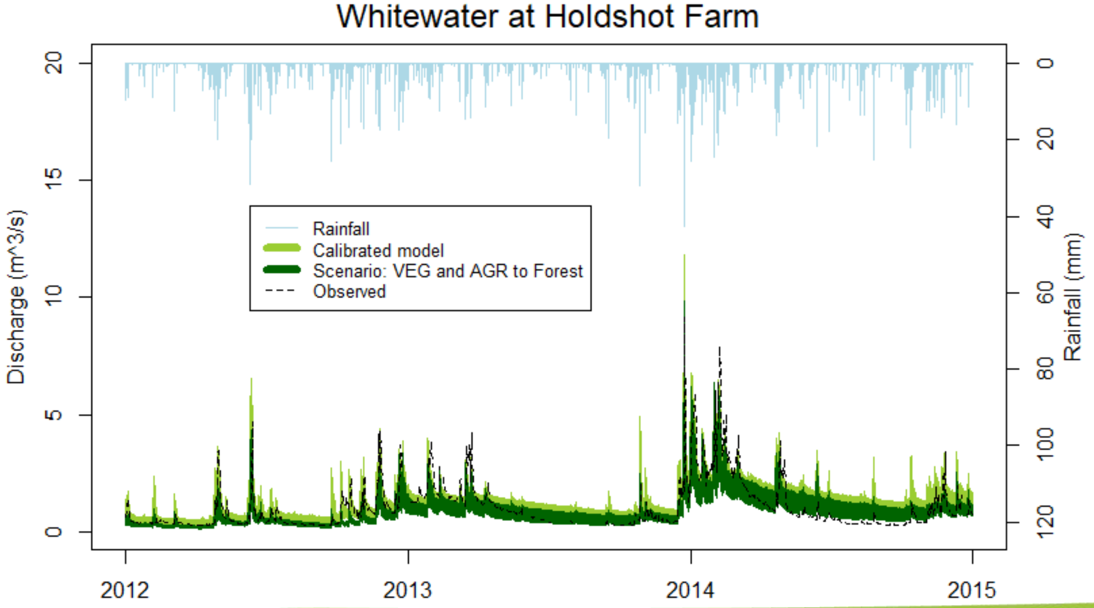
- Reduction peak flows from 0 to 56% (median = 26%) at Swallowfield with only 10 to 14% for the major events
- Reduction peak flows from 0 to 59% (median = 20%) at Farnborough

Test of NFM scenarios (Unrealistic)

Scenario 1



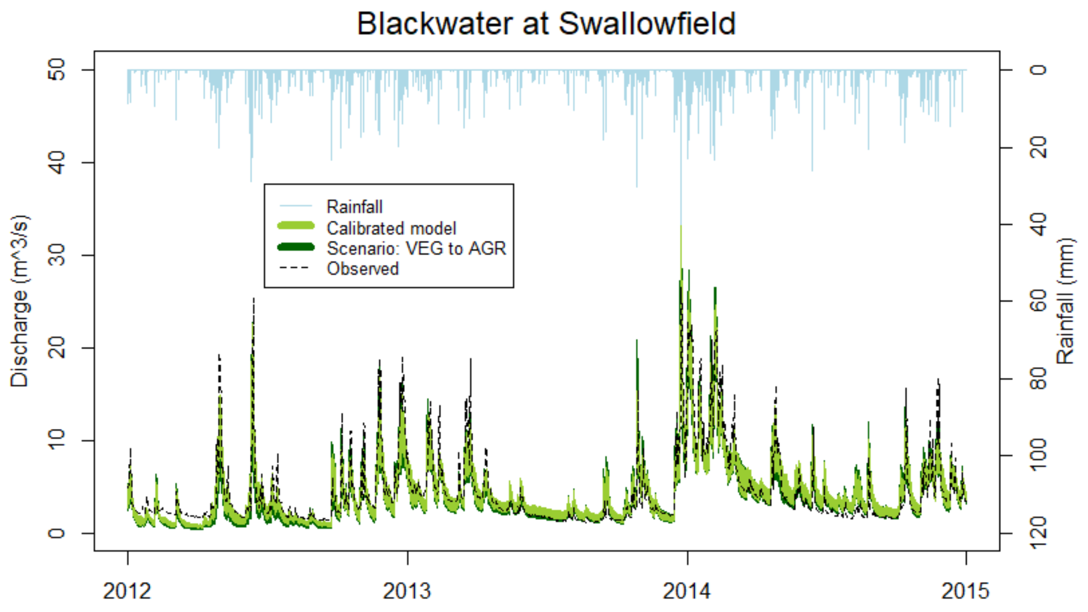


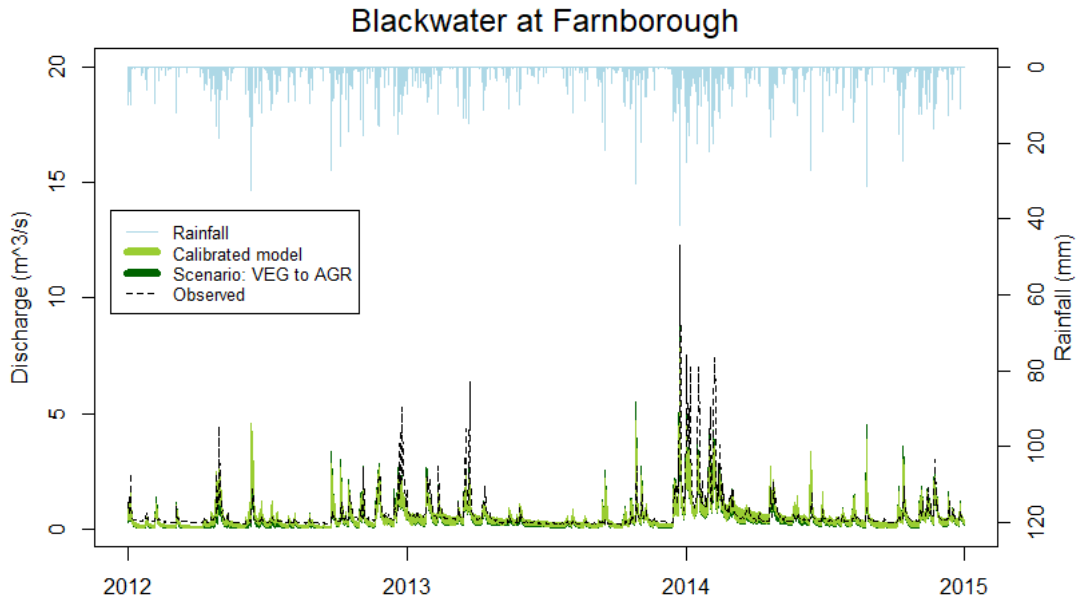


- Reduction from 5 to 60% (median = 22%) at Lodge Farm
- Reduction from 2 to 70% (median = 24%) at Holdshot Farm
- Reduction from 1 to 68% (median = 22%) at Bramshill House

Test of NFM scenarios (Unrealistic)

Scenario 2: all land cover to agricultural land except water and urban areas

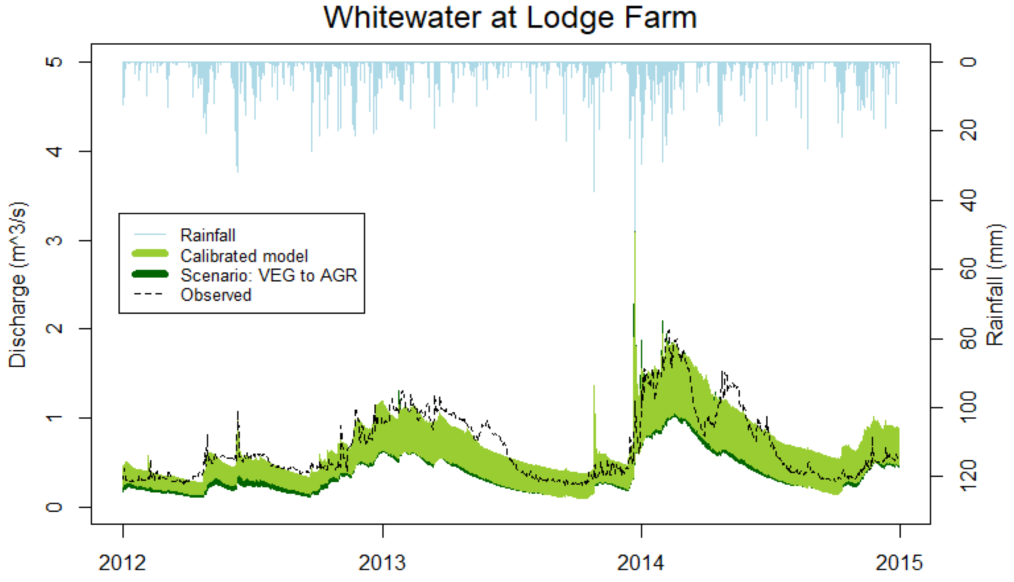


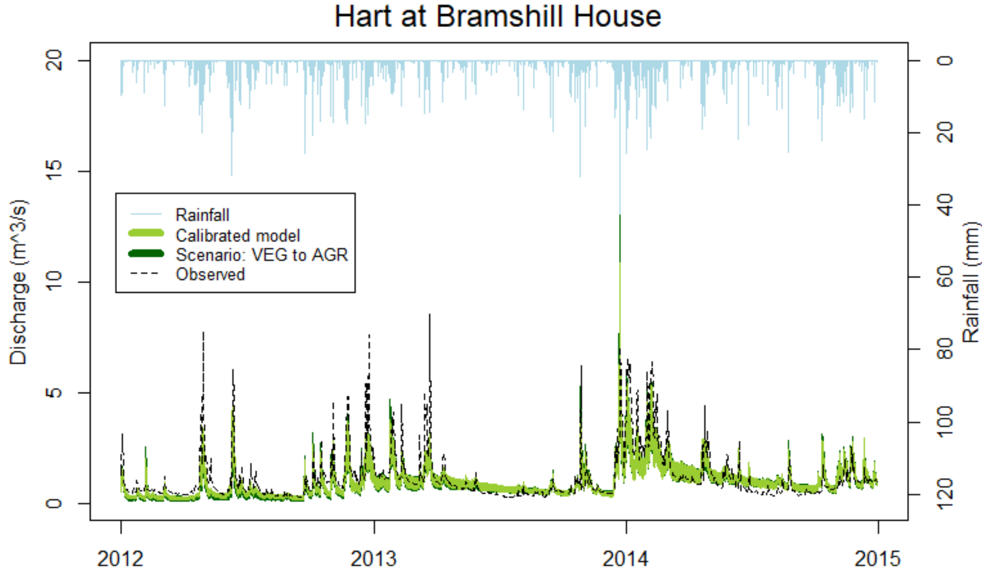


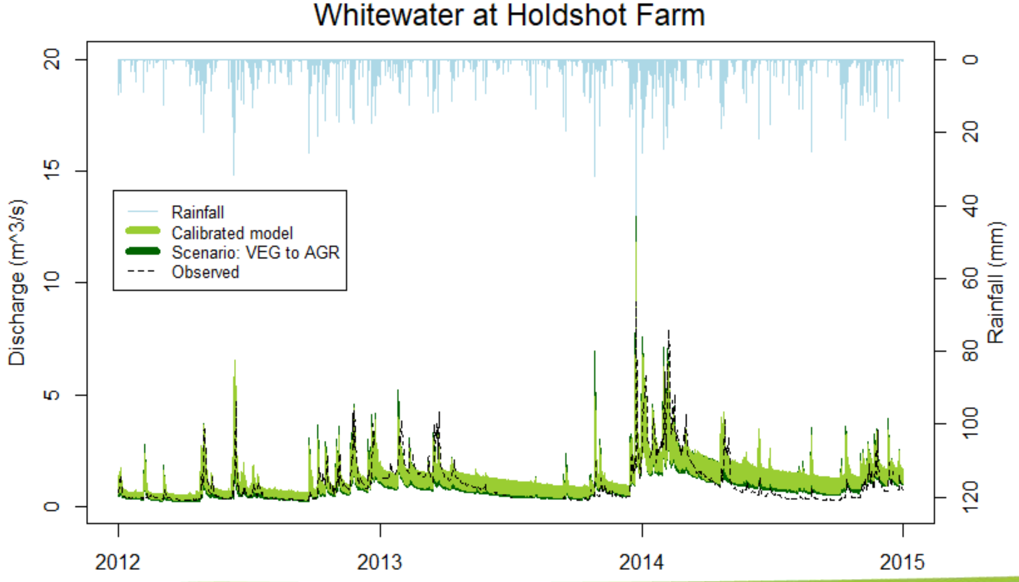
- Increase of peak flows 0 to 37% (median = 10%) at Swallowfield
- Increase of 0 to 37% (median = 10%) at Swallowfield

Test of NFM scenarios (Unrealistic)

Scenario 2







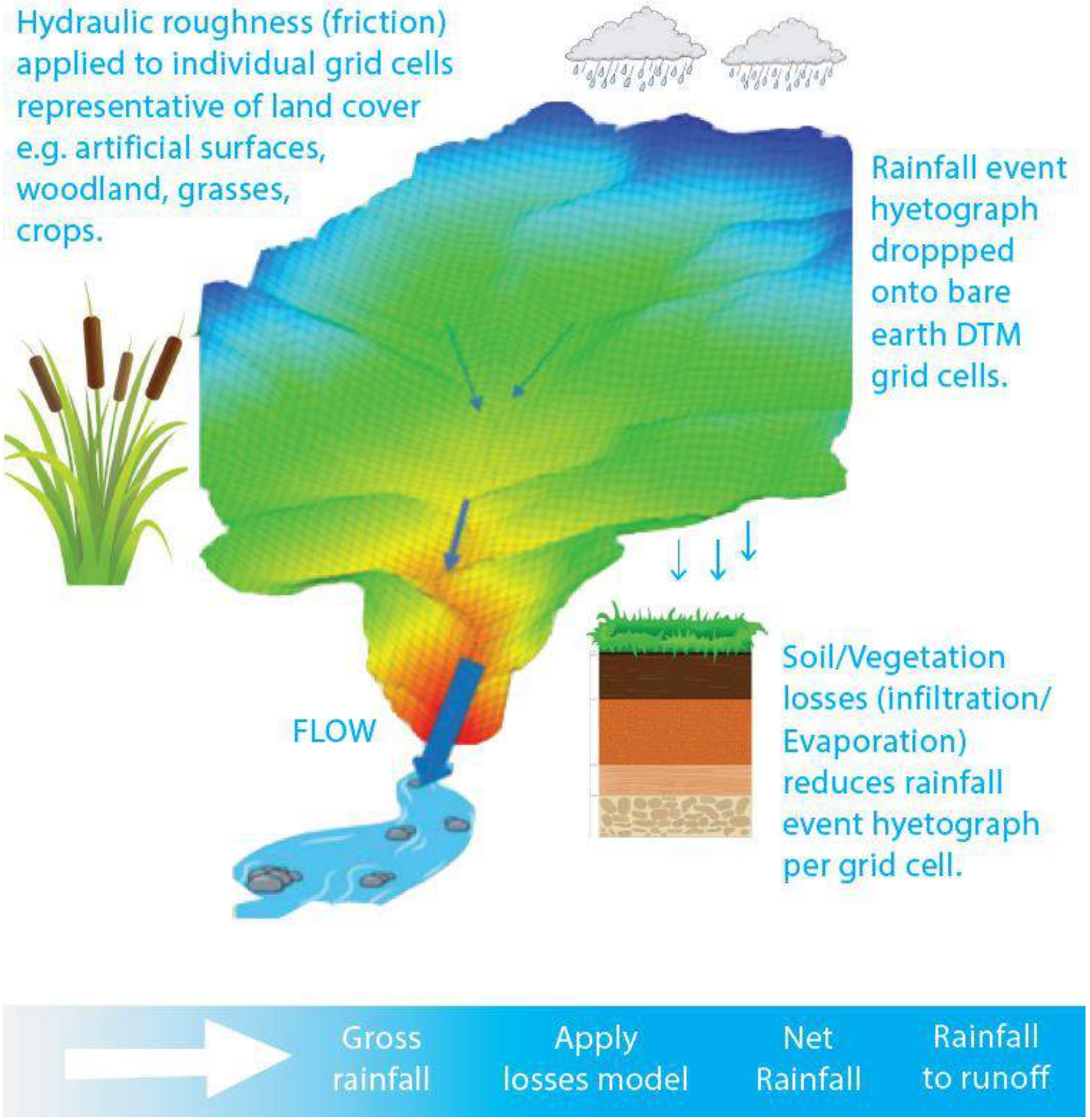
- Increase of peak flow from 0 to 13% (median = 2%) at Lodge Farm
- Increase of of peak flow from 0 to 40% (median = 3%) at Holdshot Farm
- Increase of of peak flow from 0 to 50% (median = 4%) at Holdshot Farm

Partial conclusion and outlook

- Modelling the NFM in selected catchments is challenging due to the complexity of the hydrological system

- Integration additional and comparison with other model setups

- Modelling of realistic scenarios



Two Dimensional (2D) Domain

- Digital Terrain Model (xm)
- Land Cover (Change in Landcover?)
- Catchment Rainfall / Hydrological Input
- Hydrological Losses - spatial distribution of soil condition (infiltration vs runoff generation)

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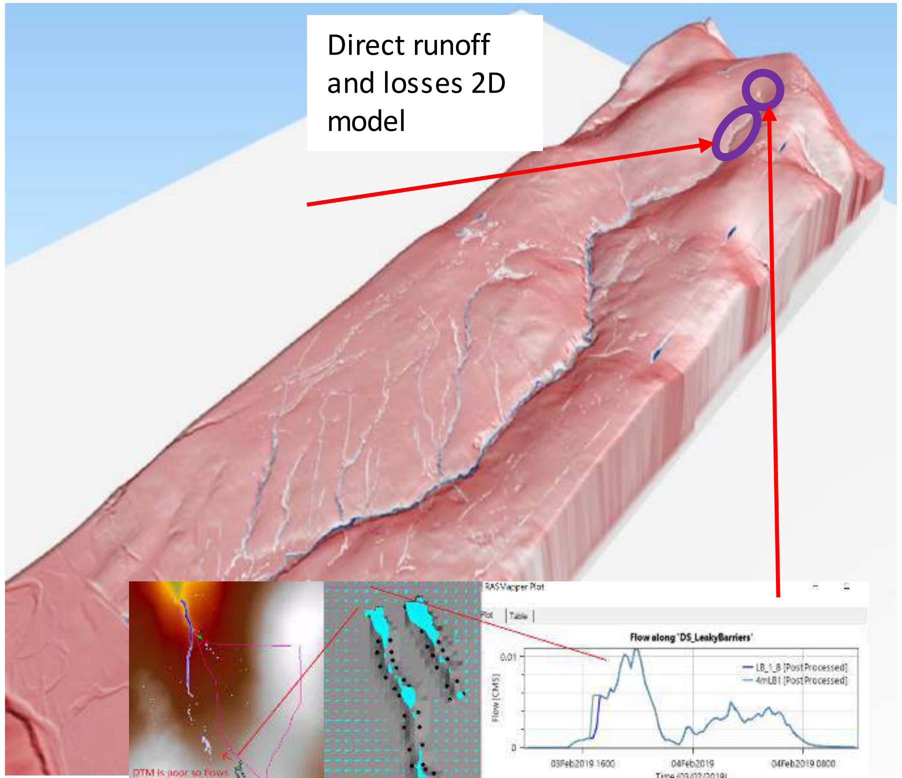
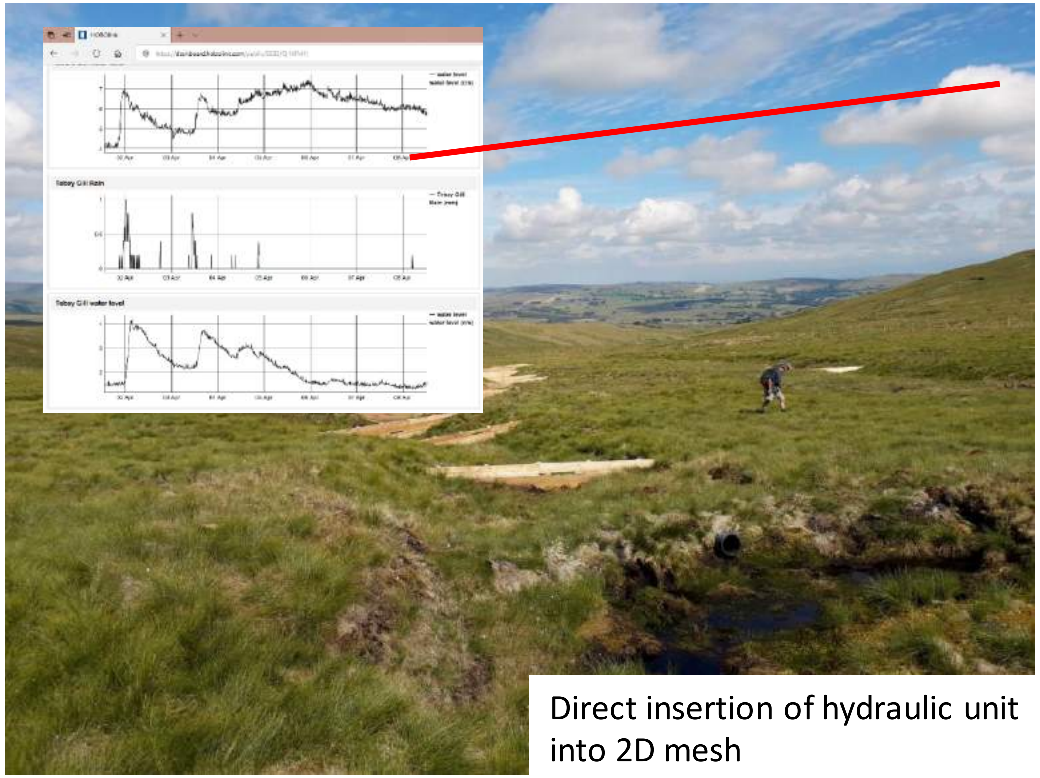
Modelling some Leaky Barriers - Q-NFM

LANDWISE NFM

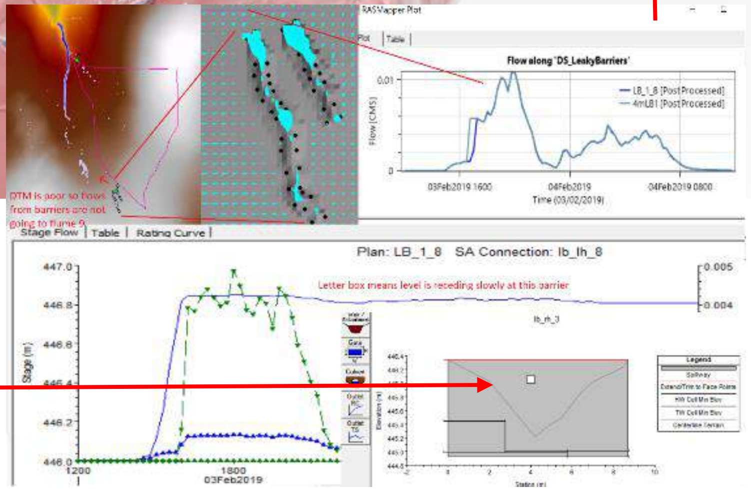


Direct runoff and losses 2D model



Direct insertion of hydraulic unit into 2D mesh

Poor quality DTM in **headwater**



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Modelling some RAFs - Belford – JBA

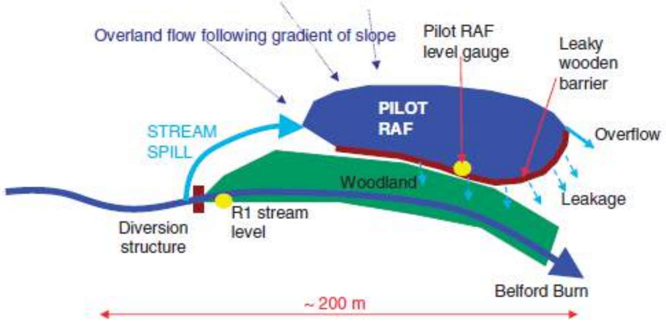
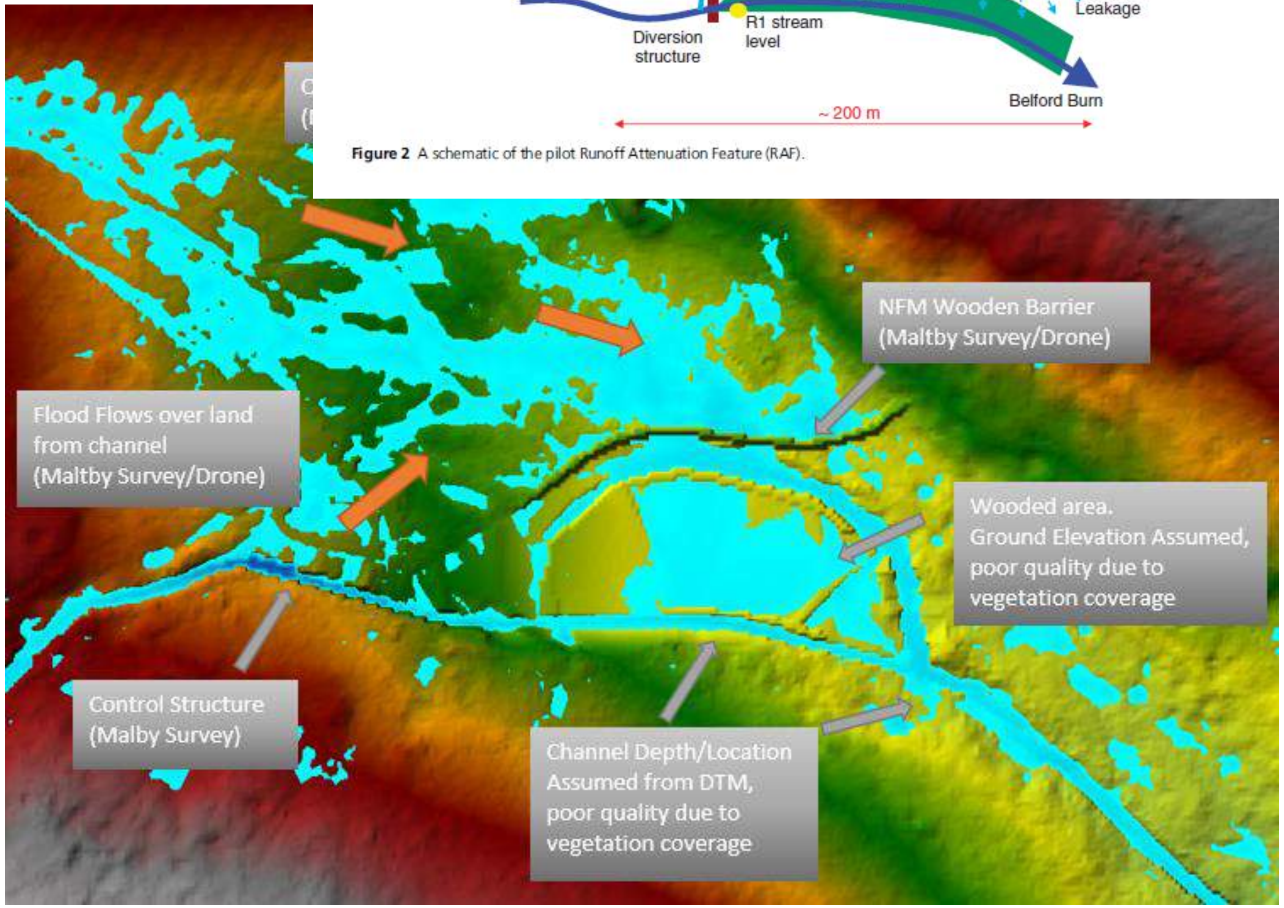


Figure 2 A schematic of the pilot Runoff Attenuation Feature (RAF).



Quantifying and simulating the impact of flood mitigation features in a small rural catchment

(Nicholson et al., 2013)

Figure 6 Photos of the pilot RAF at full capacity (a) and before the 6th September 2008 storm (b), with complementing pictures from the stream diversion structure during (c) and after (d) the same event.

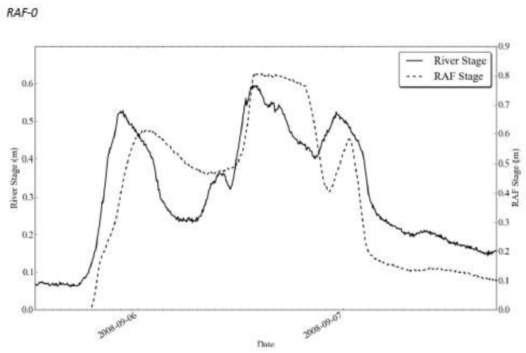
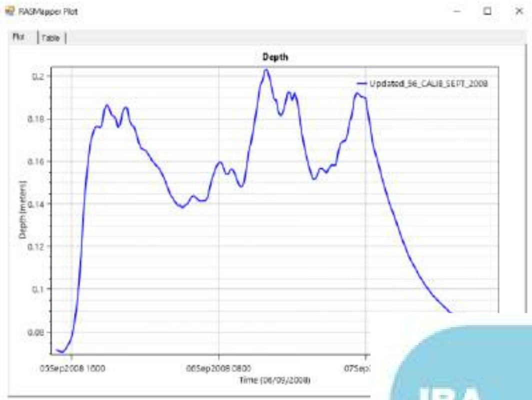


Figure 5: RAF-0 during September 2008 Storm event



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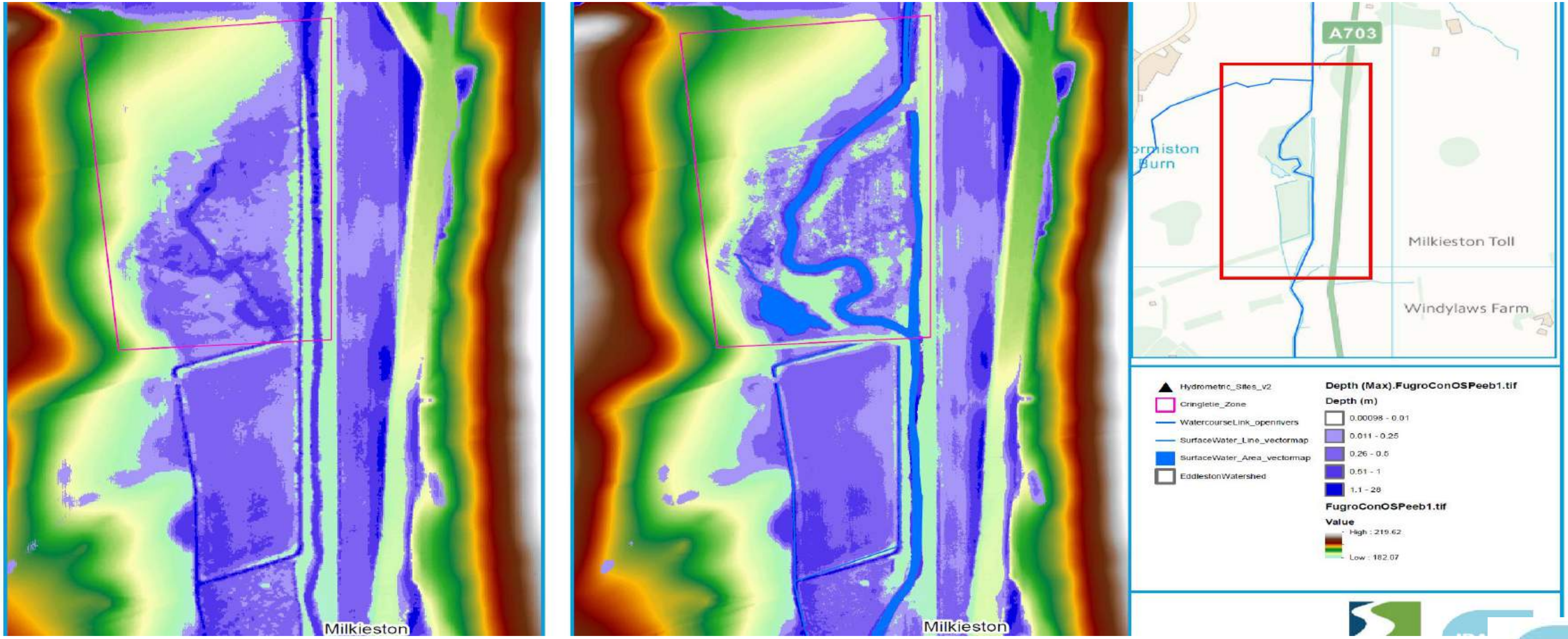
Modelling changes to floodplain storage: e.g. Eddleston Water - JBA



- Change in depth grids and floodplain storage for 30 year event

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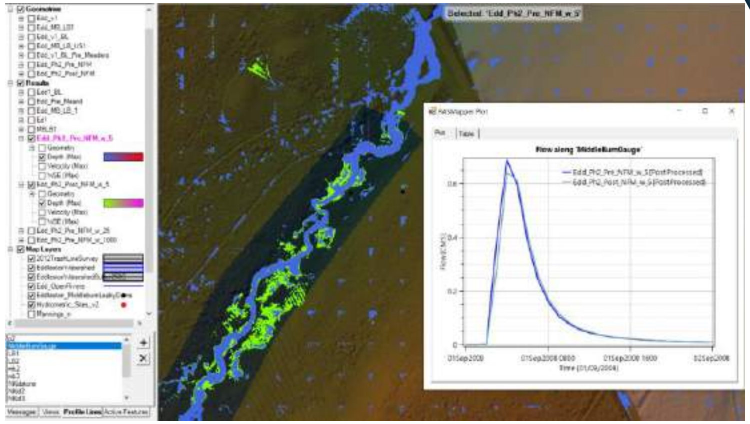
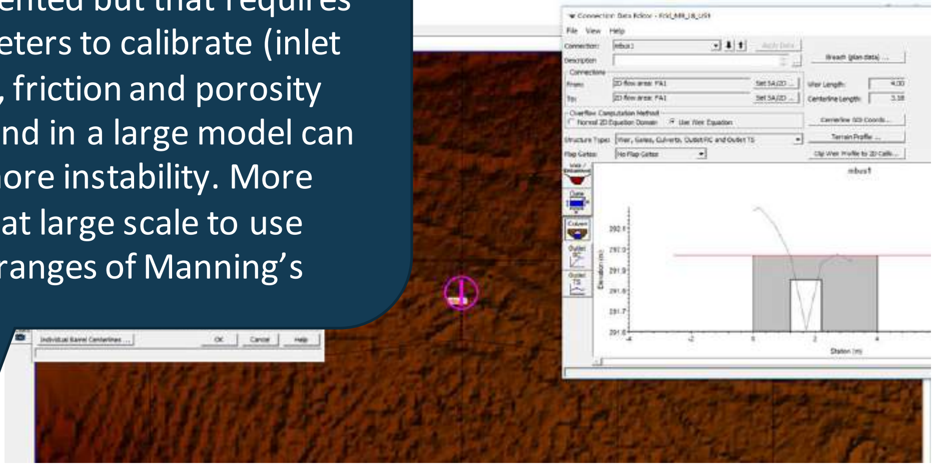
Representation of NFM – Broad-scale vs fine-scale

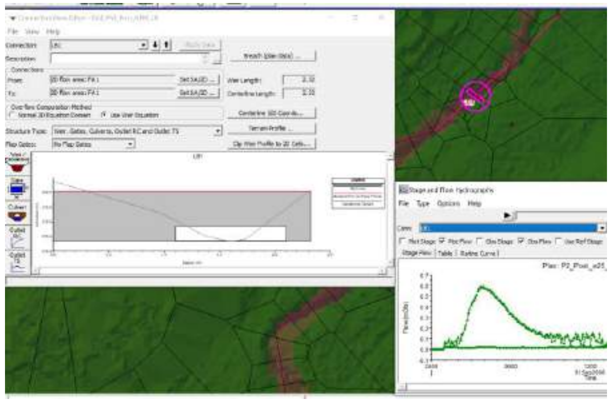
- Broader scale requires further uncertainty analysis
- Change in depth grids and floodplain storage for 30 year event



Changes represented as roughness as per Dixon in Addy (2019)

Conclusions are that yes finer features can be represented but that requires more parameters to calibrate (inlet losses, weir, friction and porosity coefficients) and in a large model can make for more instability. More pragmatic at large scale to use published ranges of Manning's





Changes represented as hydraulic units – requires time step reduction to control Instability

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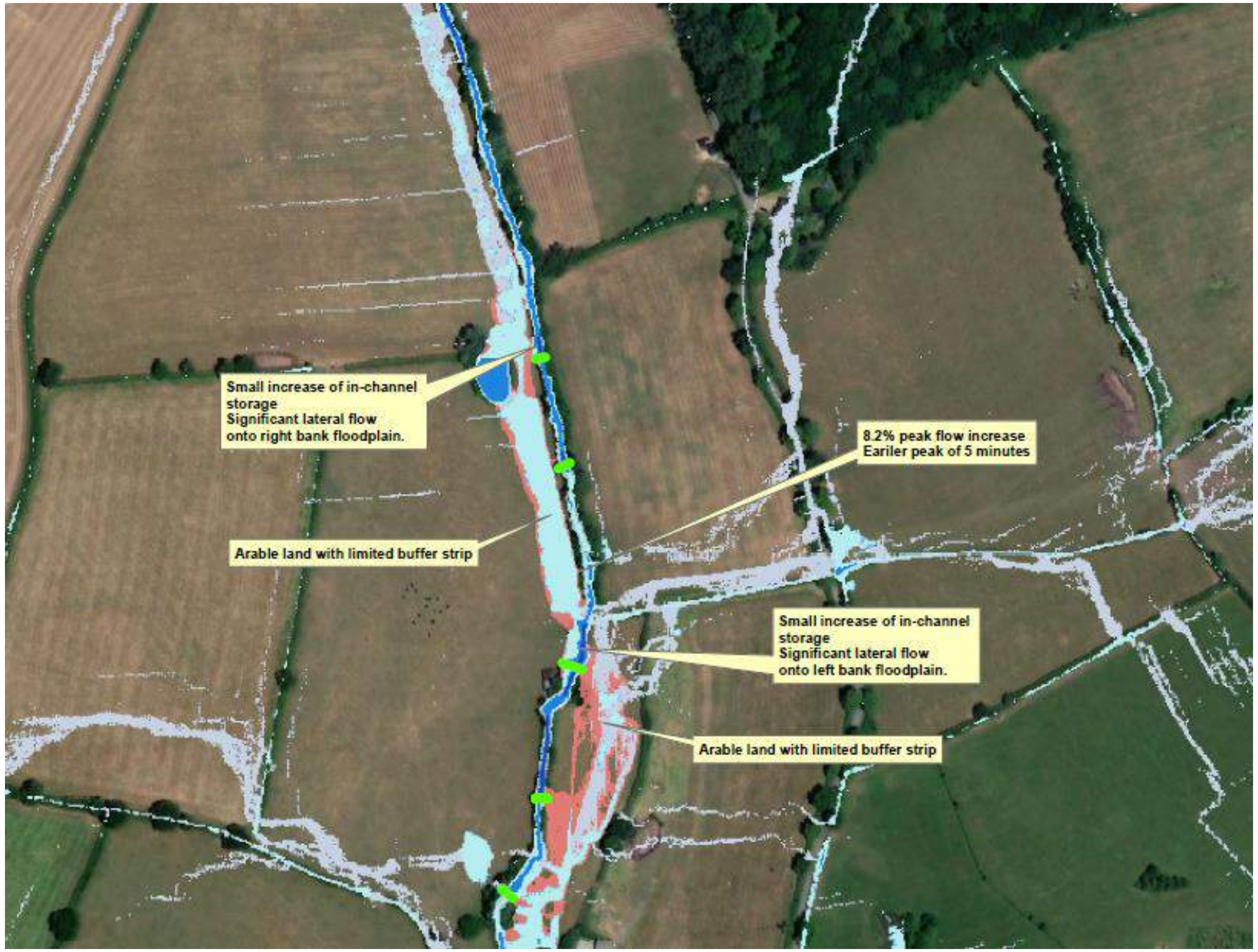
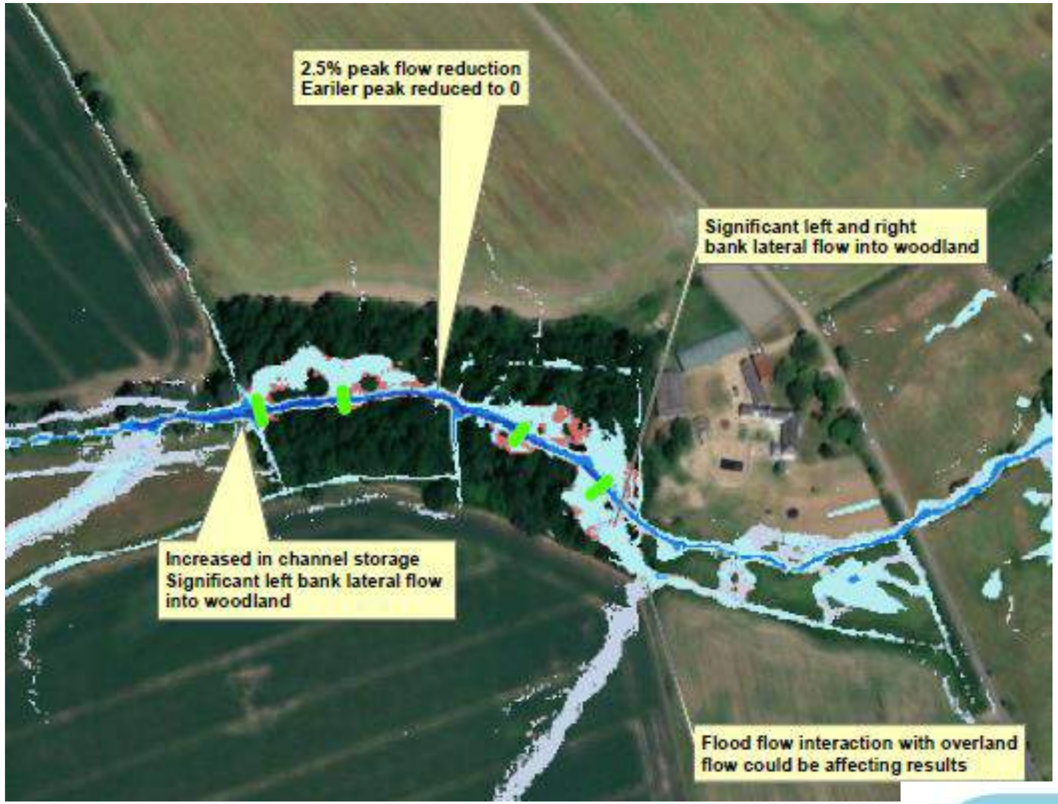
River Leck (Buckingham) – JBA

- Topographic Survey 2019 – Applied into DTM as blockage across channel at survey dimensions
- JFlow culvert unit applied to act as baseflow gap at survey dimensions





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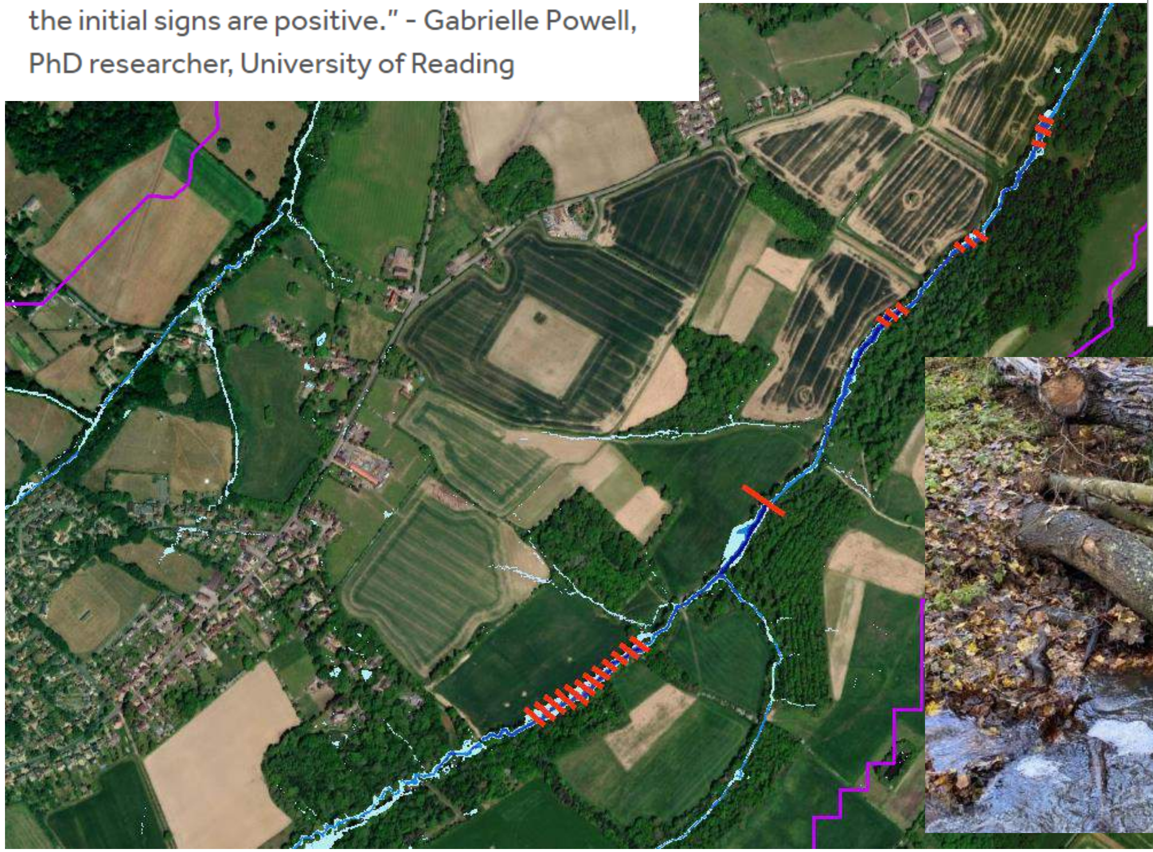
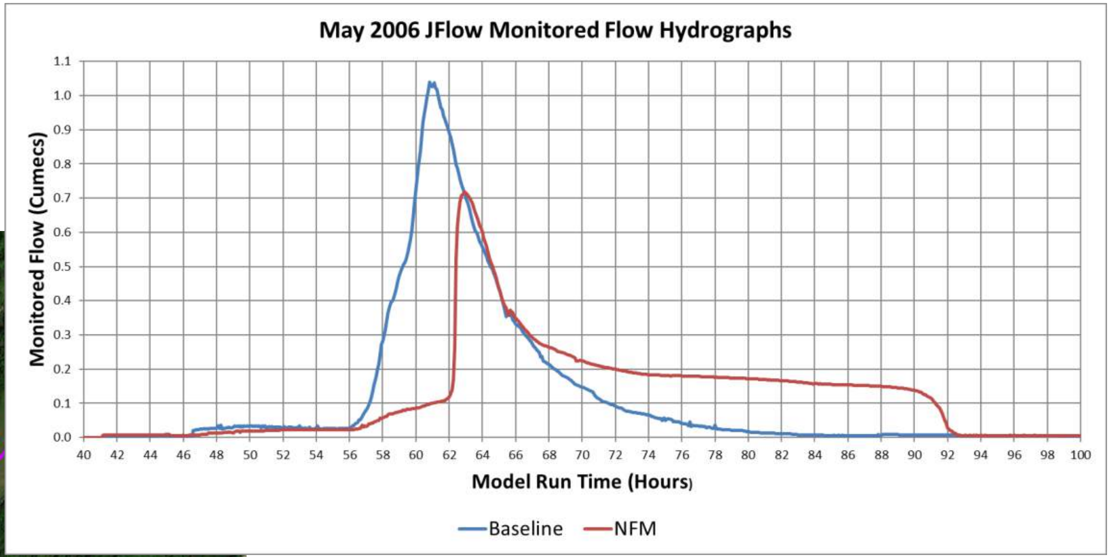
Bourne (Pangbourne) – JBA

- 22 Leaky Barriers applied to channel
- Next Steps (As built information?)

"We need to gather more data to understand the impact fully. This is early days for the project, but the initial signs are positive." - Gabrielle Powell, PhD researcher, University of Reading





Pang Valley Flood Forum (PVFF) (2018)

Gabby Powell et al (2020)

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