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

WP1: Use local knowledge and technical data to create scenarios

WP2: Make measurements in the field

WP3: Estimate measurements from remote sensing data using models

WP4: Run model simulations to test ideas

WP5: Create a web app to view and interrogate data

WP6: Project management and sharing knowledge
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
Study areas

©Loddon catchment Observatory
Field scale modelling

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

**Method:** Multi-year simulation runs using the 1-D SWAP (Soil Water Plant) process model

**Basic model requirements SWAP:**
- 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 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)
Net Precip: ANDOVER v WICKHAM

ANDOVER, Free-draining shallow soil on chalk

WICKHAM, Slowly permeable, deep loamy/clayey soil
Runoff: ANDOVER v WICKHAM

ANDOVER, Free-draining shallow soil on chalk

WICKHAM, Slowly permeable, deep loamy/clayey soil
ET: ANDOVER v WICKHAM

ANDOVER, Free-draining shallow soil on chalk

WICKHAM, Slowly permeable, deep loamy/clayey soil

Evapotranspiration (mm)

Year

2012 2014 2016 2018 2020

Evapotranspiration (mm)
Recharge: ANDOVER v WICKHAM

ANDOVER, Free-draining shallow soil on chalk

WICKHAM, Slowly permeable, deep loamy/clayey soil

Year
Groundwater Recharge (mm)
Bare soil AR
Bare Soil LE
Bare Soil OT
Bare Soil PG
Perm. Grass
Dec. Forest
Pine
Spruce

ANDOVER, Free-draining shallow soil on chalk

WICKHAM, Slowly permeable, deep loamy/clayey soil
△storage: ANDOVER v WICKHAM

ANDOVER, Free-draining shallow soil on chalk

WICKHAM, Slowly permeable, deep loamy/clayey soil
WB flows all soil series, bare soil

Evaporation

Runoff

Recharge
SWAP SM storage capacity, layer 1

Soil moisture storage capacity, horizon 1 (mm)

Day of Year

Coombe, Perm. Grass
Preliminary conclusions

• Effect of \( \Delta \text{LUT} \) on WB fluxes larger than \( \Delta \)soil 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 \(\rightarrow\) 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

❖ Modification of the SWAT model source code

✓ Water content at wilting point

\[ FC_{ly} = AWC_{ly} + WP_{ly} \]

\[ WP_{ly} = 0.40 \cdot \frac{m_c \cdot \rho_b}{100} \]

✓ 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
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 3/3

Calibration: Blackwater at Swallowfield

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

Scenario 1: all land cover to deciduous forest except water and urban areas
Test of NFM scenarios (Unrealistic)

- 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 peak flow from 0 to 40% (median = 3%) at Holdshot Farm
- Increase 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)
Modelling some Leaky Barriers - Q-NFM

Direct insertion of hydraulic unit into 2D mesh

Poor quality DTM in headwater

Direct runoff and losses 2D model
Quantifying and simulating the impact of flood mitigation features in a small rural catchment (Nicholson et al., 2013)

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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
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

- 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)

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