Cover crops as land management measure

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MSc in Environmental Water Management

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  - Sarah De Baets
  - Shaun Dowman, Affinity Water Ltd - Catchment Management team

Background

- 70% of the land in England is used for agriculture
- Intensive agricultural practices contribute to soil degradation: compaction and tillage

- Increased erosion and reduced infiltration lead to higher water pollution, water scarcity and floods
- Serious problems for catchment managers

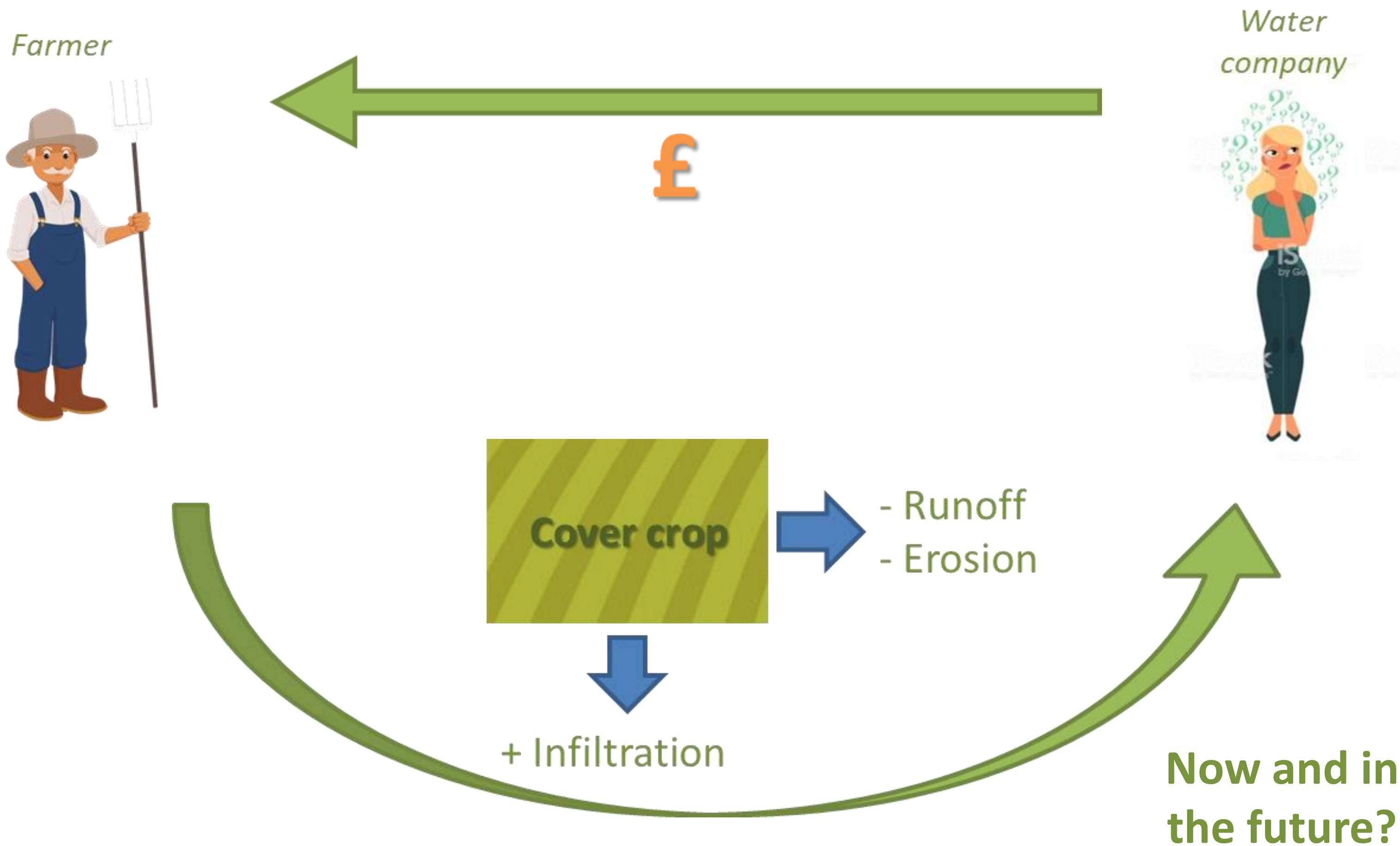
Cover crops

- Fast growing annuals
- Planted between cash crops
- Planted immediately after harvest
- Grow all winter
- Cover and protect the soil against erosion
- Boost soil health and reduce the negative impact of agro-management on the environment
- Die off or are destroyed in early spring to make way for the cash crop

However…

- Non-profit expense
- Additional work to grow and harvest

Research questions



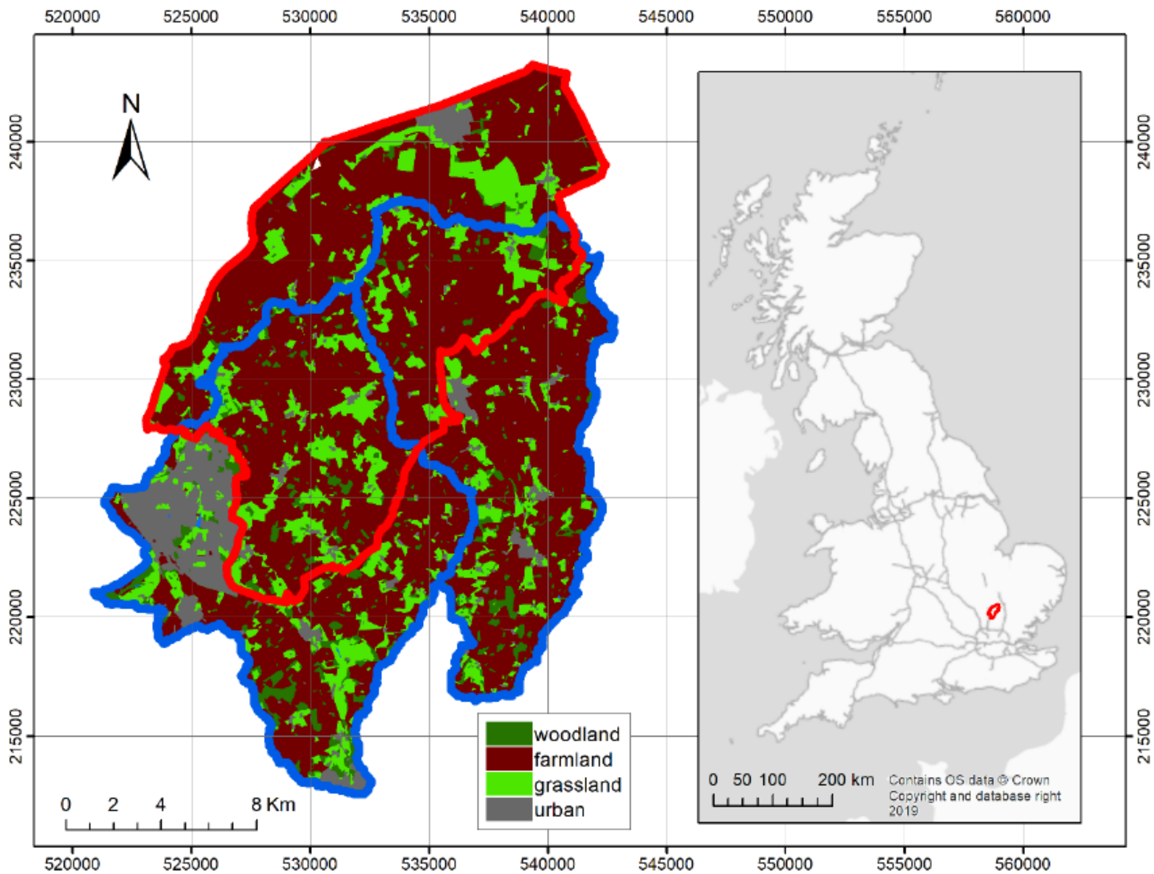
Aims and objectives

Assessing the effectiveness of different cover crop mixes on infiltration and soil erosion at catchment scale under current and future rainfall conditions, by:

1) Conducting laboratory **controlled trials**
2) Using experimental results to parameterise catchment scale **infiltration and erosion models**

The study area

River Lea Catchment in Hertfordshire

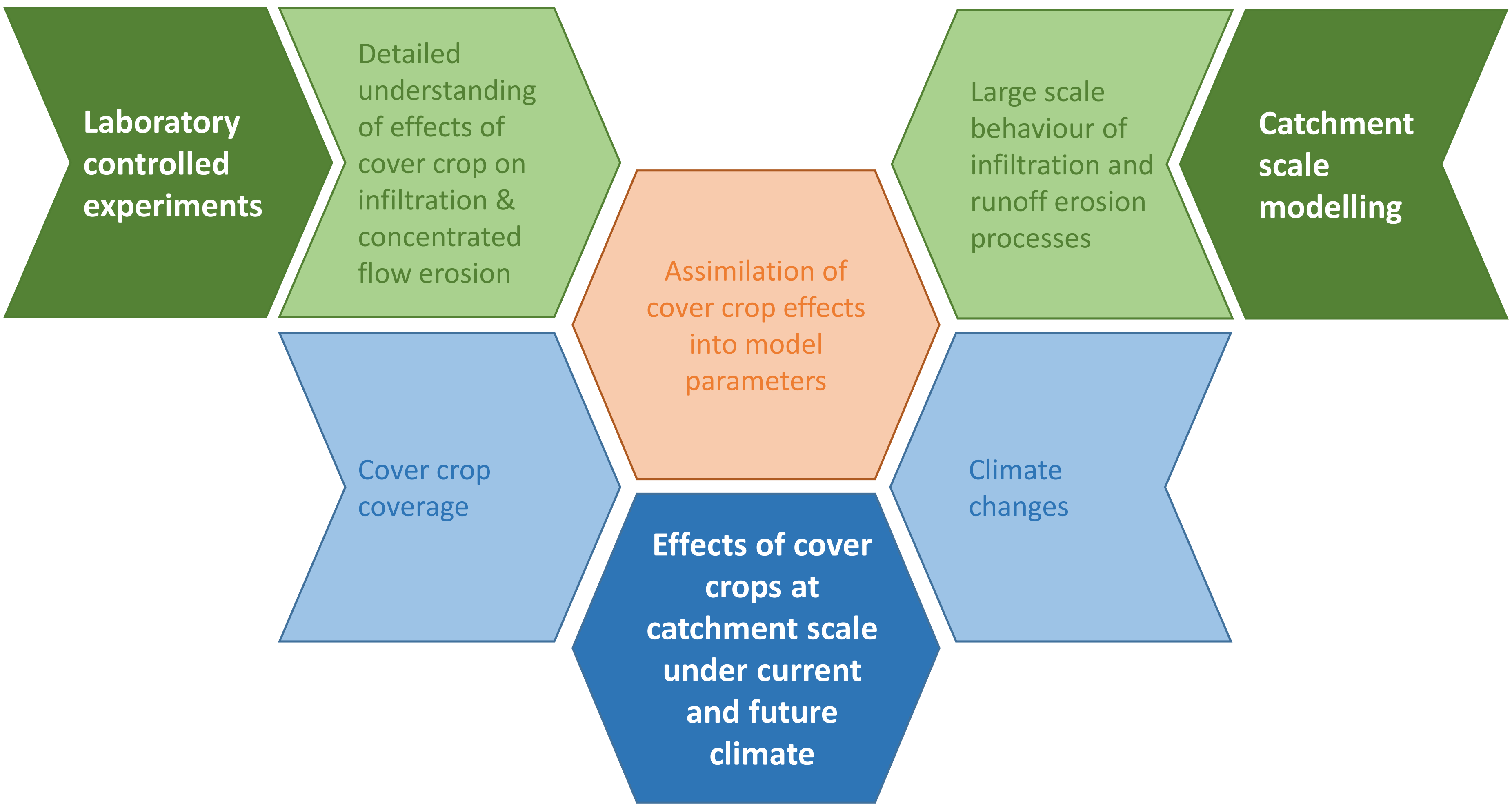


- Area = 218km^2
- Managed by Affinity Water
- Cover crop scheme in ~25% of the area
- Fallow from August to January
- Soil: Clay & loam
- Slope < 5^o

Cover crop scheme

Sub-catchments boundaries

Methodology



Laboratory controlled trials

Facilities at Cranfield

Plant Growth Facilities

Clean water Pilot Hall

Laboratory controlled trials

	Infiltration experiments	Erosion experiments
Plots	1m x 1m x 80cm	30cm x 30cm x (10+20)cm
Soil type	Sandy-clay-loam: 20% clay + 52% silt + 28% sand	
Bulk density	1286 ± 35 kg m^{-3}	1168 kg m^{-3}
Environment (during 8-9 weeks)	Glasshouse	Day time (6am-7pm): 19°C, 70% RH, 25% light intensity Night time (7pm-6am): 15°C, 82% RH
Cover crop mixes	**Seeding density & replicates**	
OTMS - 50% oat (Avena sativa) - 50% mustard (Sinapis alba)	138 seeds m^{-2} 3 replicates	900 seeds m^{-2} 3 replicates
OTMSPH - 33% oat (Avena sativa) - 33% mustard (Sinapis alba) - 33% phacelia (Phacelia secunda)		
RYMSPH - 33% rye (Secale cereale) - 33% mustard (Sinapis alba) - 33% phacelia (Phacelia secunda)		
Bare soil	Available from previous experiments	3 replicates

Laboratory controlled trials

Infiltration experiments

- Device: Mini Disk Infiltrometer (Decagon Devices Inc.)
- Variable (k_h) Unsaturated hydraulic conductivity
- Test: 3 measurements per plot
  - Infiltered water volume every 30 seconds

$$I = C_1 t + C_2 \sqrt{t} \quad ; \quad \boldsymbol{k_h} = C_1 / A$$

  - Root collection and scanning: development and features

Laboratory controlled trials

Erosion experiments

- Device: Sediment Erosion Flume S28 (Armfield Ltd.)
- Variables: Water depths, sediment load, turbidity, and plant features
- Test:
  - Measurements at varying discharges (0.5 to 11 l/s) every 1.5 minute
  - Water samples downstream, dried and weighted
  - Above and below ground plant features

$$\tau = \rho_w \, g \, R \, S \quad ; \quad v = \frac{Q}{A_{flow}} \quad ; \quad ASD = \frac{SC \;\; Q}{A_{plot}} = K \, (\tau - \tau_{crit})^b$$

Laboratory controlled trials - Results

Plant features

- Below ground

- Above ground

	OTMS		OTMSPH			RYMSPH		
	OT	MS	OT	MS	PH	RY	MS	PH
Germination rate (%)	78	90	95	84	53	94	89	62
Plant height (cm)	84	129	85	149	82	86	152	88
Stem diameters (mm)	2.39	4.61	2.11	5.09	1.67	3.50	5.37	2.14
Stem density (m^2/m^2)	0.00854		0.00653			0.00768		
ADB (kg/m^2)	0.59		0.61			0.65		

Laboratory controlled trials - Results

Unsaturated hydraulic conductivity (k_h)

	Bare	OTMS	OTMSPH	RYMSPH
k_h (mm month^{-1})	**4.60 x 10^{-4}**	**4.56 x 10^{-4}**	**18.5 x 10^{-4}**	**4.05 x 10^{-4}**
Standard deviation	-	2.08 x 10^{-4}	19.6 x 10^{-4}	1.49 x 10^{-4}

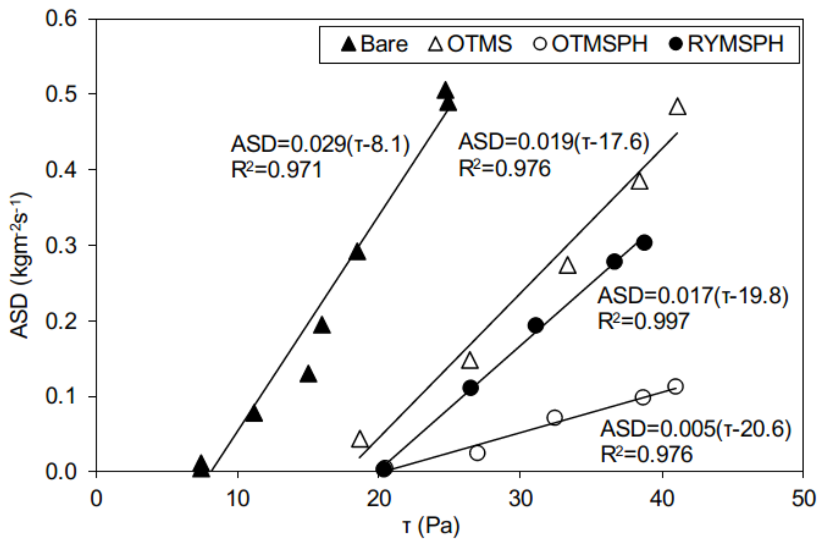
- Most improved under OTMSPH mix
- Higher root density and more diverse root system structure
- Better than mono-crop

Concentrated flow erodibility (K_c)

- K_c = Slope of the linear regression
- τ_{crit} = Intersection with horizontal axis

	Bare	OTMS	OTMSPH	RYMSPH
K_c (t ha^{-1} year^{-1})	**0.029**	**0.019**	**0.005**	**0.017**
τ_{crit} (Pa)	8.1	17.6	20.6	19.8

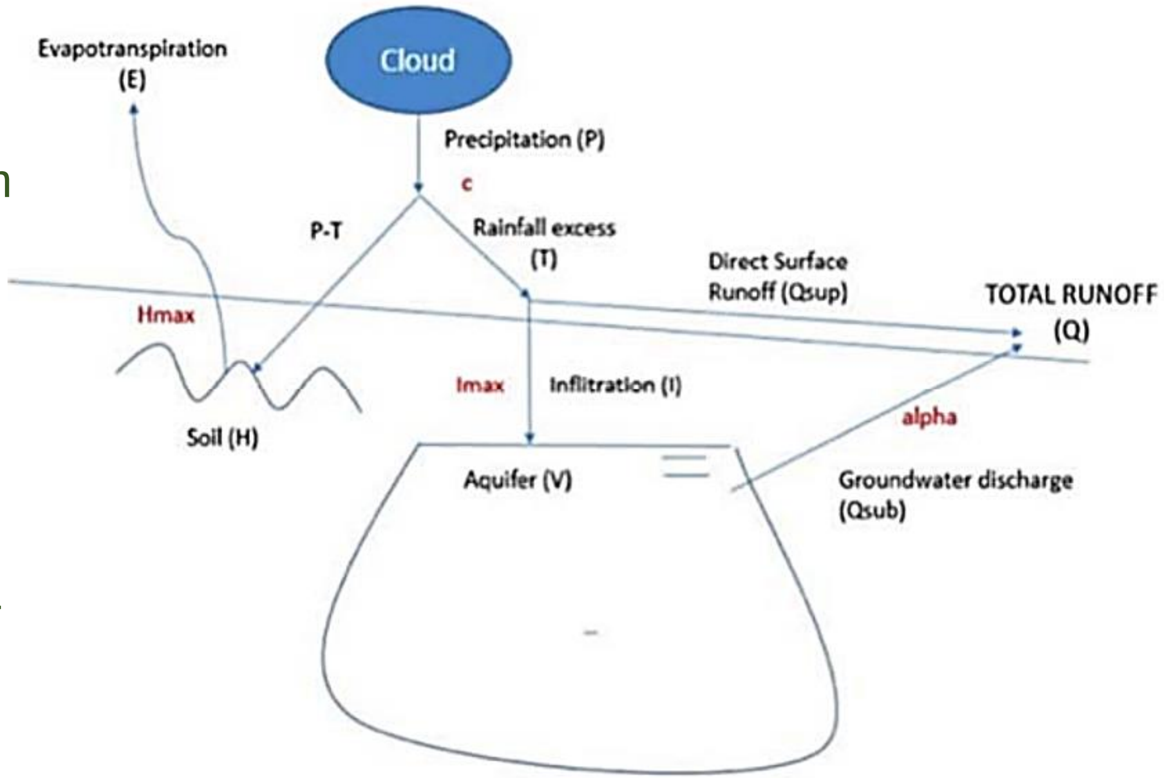
- Critical shear stress ~ 20Pa for all mixes
- Erodibility lowest under OTMSPH mix
- Combination of flexible and stiff stems is able to attenuate the flow velocity and turbulence



Catchment scale modelling

Infiltration experiments: Témez model

- Set-up:
  - Daily time step
  - Precipitation from NRFA
  - Land cover and PET from CEH
- Parametrisation:
  - H_{max}, I_{max}, C and alpha
  - Observed flows at two gauging stations (NRFA)
  - Calibration: 1980 to 2004
  - Validation: 2005 to 2015
  - Pearson's correlation coefficient (R^2)

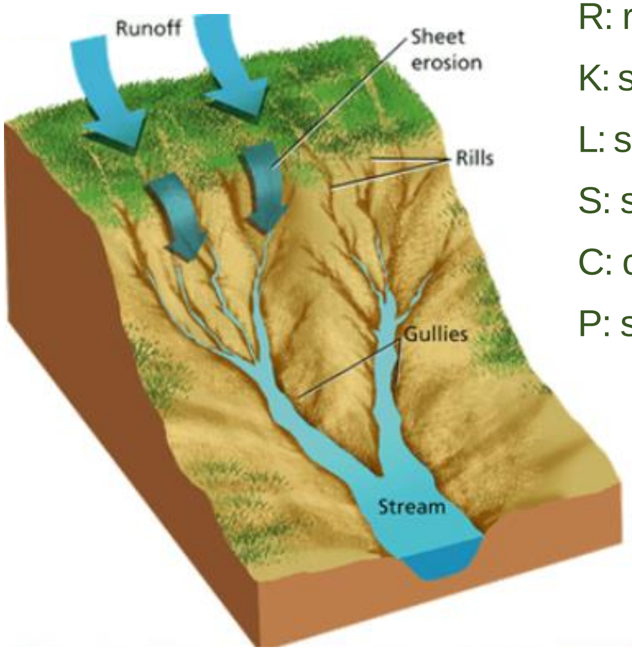


(Maidment, Tarboton and Catalá, 2013)

Catchment scale modelling

Erosion experiments: Universal Soil Loss Equation

- Set-up:
  - Annual average (over 6 fallow months)
  - Precipitation from NRFA
  - Land cover from CEH
- Parametrisation:
  - R, K, L, S, and R from European Soil Data Centre
  - P=1
  - C=1 (bare soil)
  - Evaluation based on the basis of general soil loss on cultivated land in the UK



A = R K L S C P

A: average annual soil loss

R: rainfall-runoff erosivity factor

K: soil erodibility factor

L: slope length factor

S: slope steepness factor

C: cover-management factor

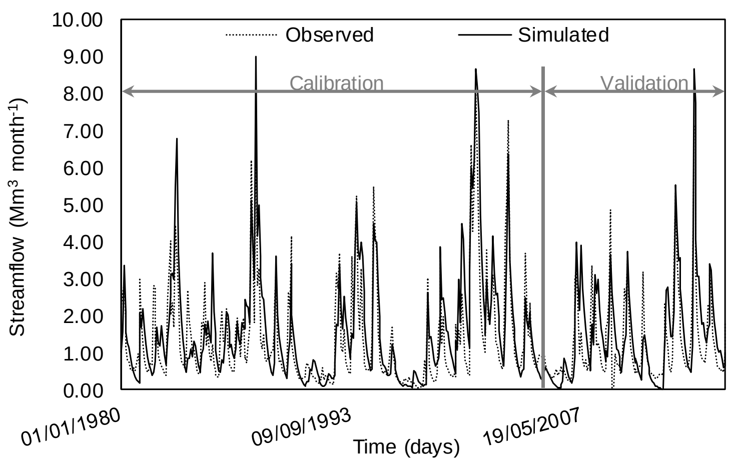
P: support practice factor

Catchment scale modelling - Results

Témez model

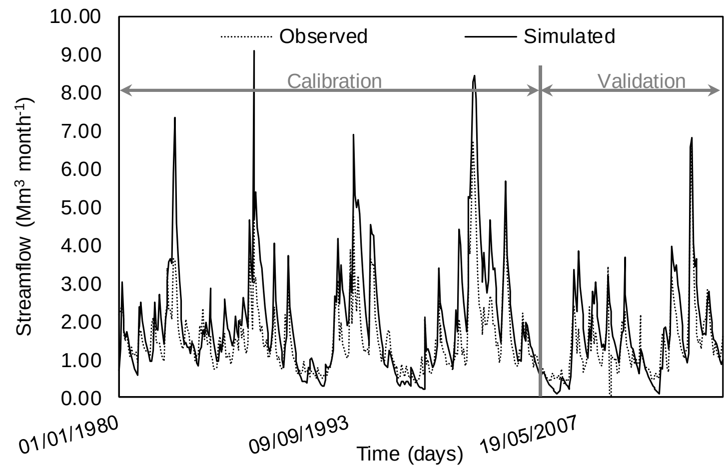
- NRFA ID 38004

	R^2
Calibration	0.836
Validation	0.835



- NRFA ID 38030

	R^2
Calibration	0.883
Validation	0.859



USLE model

- Average soil erosion over fallow months in a year = 3.03 t ha^{-1} 6months^{-1}
- Soil loss on cultivated land in UK [0.1, 20] t ha^{-1} year^{-1}

Assimilation of cover crop effects into model parameters

Infiltration process

- The infiltration effectiveness of cover crops reflected in Imax
- Calibrated value corresponds to 0% application (baseline)
- Imax values in different coverage conditions:

$$I_{\max crop\%} = I_{\max crop0\%}\ F_{crop\%} \quad ; \quad F_{crop\ a\%} = \left(\left(\frac{k_{h\ ccrop}}{k_{h\ bare}}\ crop\% + (1 - crop\%)\right) farm\% + (1 - farm\%)\right)$$

Erosion process

- According to the definition of the USLE parameters, cover crops affect the C factor
- Calibrated value corresponds to 0% application (baseline)
- C values in different coverage conditions:

$$C_{crop\ coverage} = C_{bare}\ (1 - crop\%) + C_{crop}\ crop\% \quad ; \quad C_{crop} = \frac{K_{ccrop}}{K_{bare}} C_{bare}$$

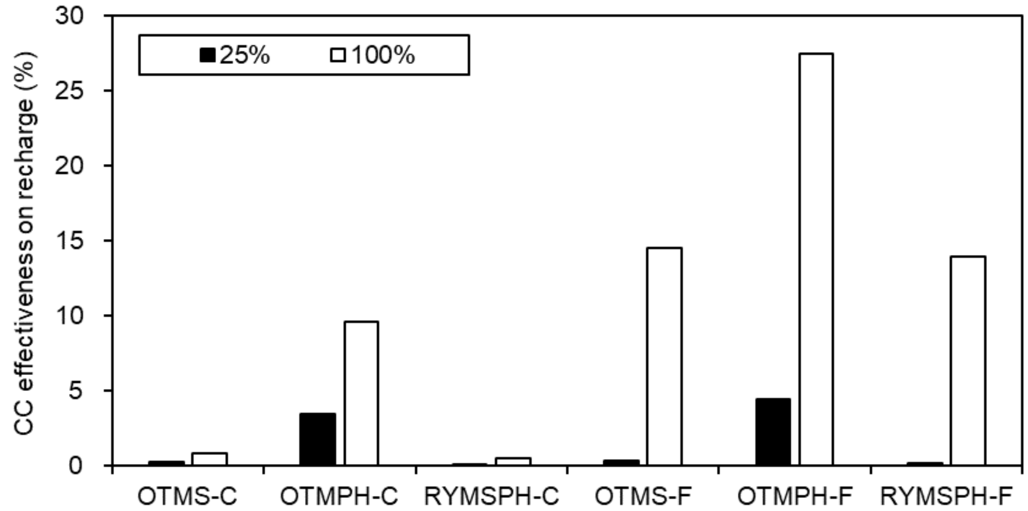
Scenario analysis

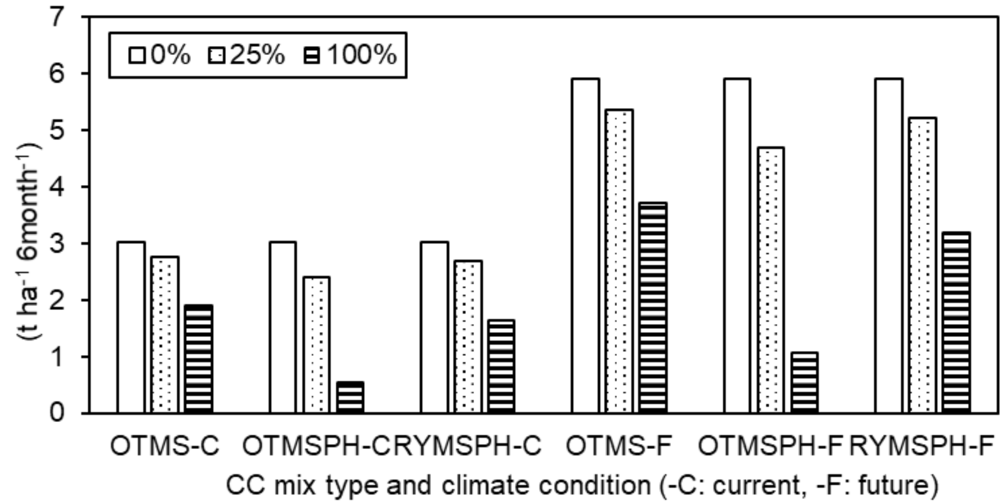
	Cover crop mix	Cover crop coverage	Climate
Scenario 0 (baseline)	-	0%	Current
Scenario 1	OTMS	25%	Current
Scenario 2	OTMS	100%	Current
Scenario 3	OTMSPH	25%	Current
Scenario 4	OTMSPH	100%	Current
Scenario 5	RYMSPH	25%	Current
Scenario 6	RYMSPH	100%	Current
Scenario 7	OTMS	25%	Future
Scenario 8	OTMS	100%	Future
Scenario 9	OTMSPH	25%	Future
Scenario 10	OTMSPH	100%	Future
Scenario 11	RYMSPH	25%	Future
Scenario 12	RYMSPH	100%	Future

- Future climate change scenario:
  - UKCP18 RCP4.5
  - Mid and end of century projections
  - Precipitation change:
    - -55% in summer
    - +35% in winter

Scenario analysis - Results

- Most improved under OTMSPH mix
- Infiltration significantly increased in summer, especially in the future
- Erosion benefits are more significant in future conditions
- Further research:
  - More replicates in laboratory controlled experiments
  - Process-based models





Other benefits of cover crops

Flood mitigation

- Increased infiltration + Decreased flow velocity → Flood abatement
- However, the time scales of the processes are different → New laboratory experiments needed to test response of soil to extreme rainfall events under saturated conditions

Pollution control

Soil structure improvement

Biodiversity enhancement

Cranfield Water

Questions? Comments?

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