Tracing crop-specific sediment sources in agricultural catchments with Compound-Specific Stable Isotope (CSSI) and geochemical markers

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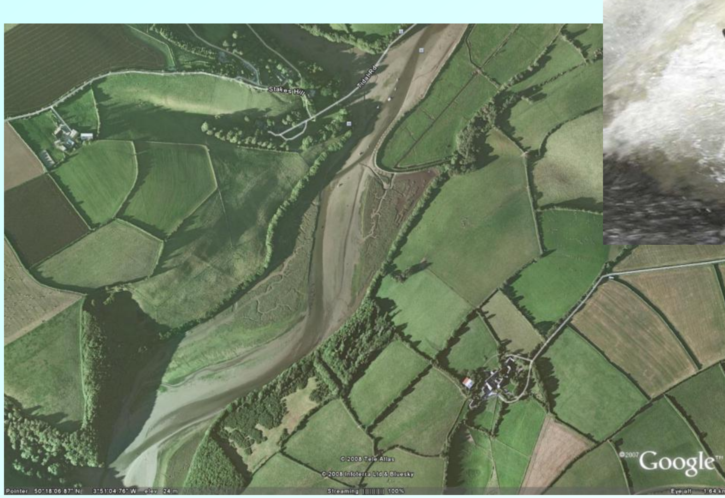
FAO/IAEA International Symposium on Managing Soils for Food Security and Climate Change Adaption and Mitigation

Off-site impacts of soil erosion: fine sediment and the EU Water Framework Directive



We need source-transfer-storage knowledge to support management solutions

Soil and sediment management in the UK: reduce impact on aquatic habitats while maintaining production

- In-field strategies (e.g. minimum till)
- Edge-of-field measures
- Riparian buffers
- Reinstatement of wetland

Ecosystem services approach to catchment restoration

Catchment Sensitive Farming

Sediment source information needed to target measures

A.L. Collins, D.E. Walling / Journal of Hydrology 261 (2002) 218–244

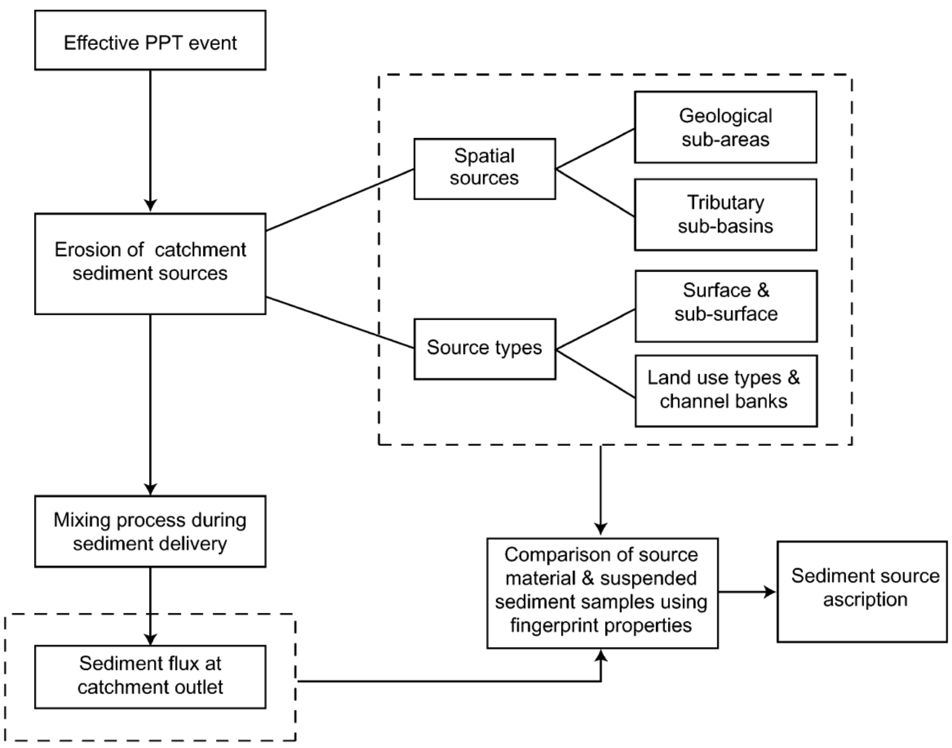


Fig. 1. A conceptual model of sediment fingerprinting. Collins and Walling (2002)

Sediment source tracing increasingly being used to underpin the design and implementation of effective sediment control strategies in river basins

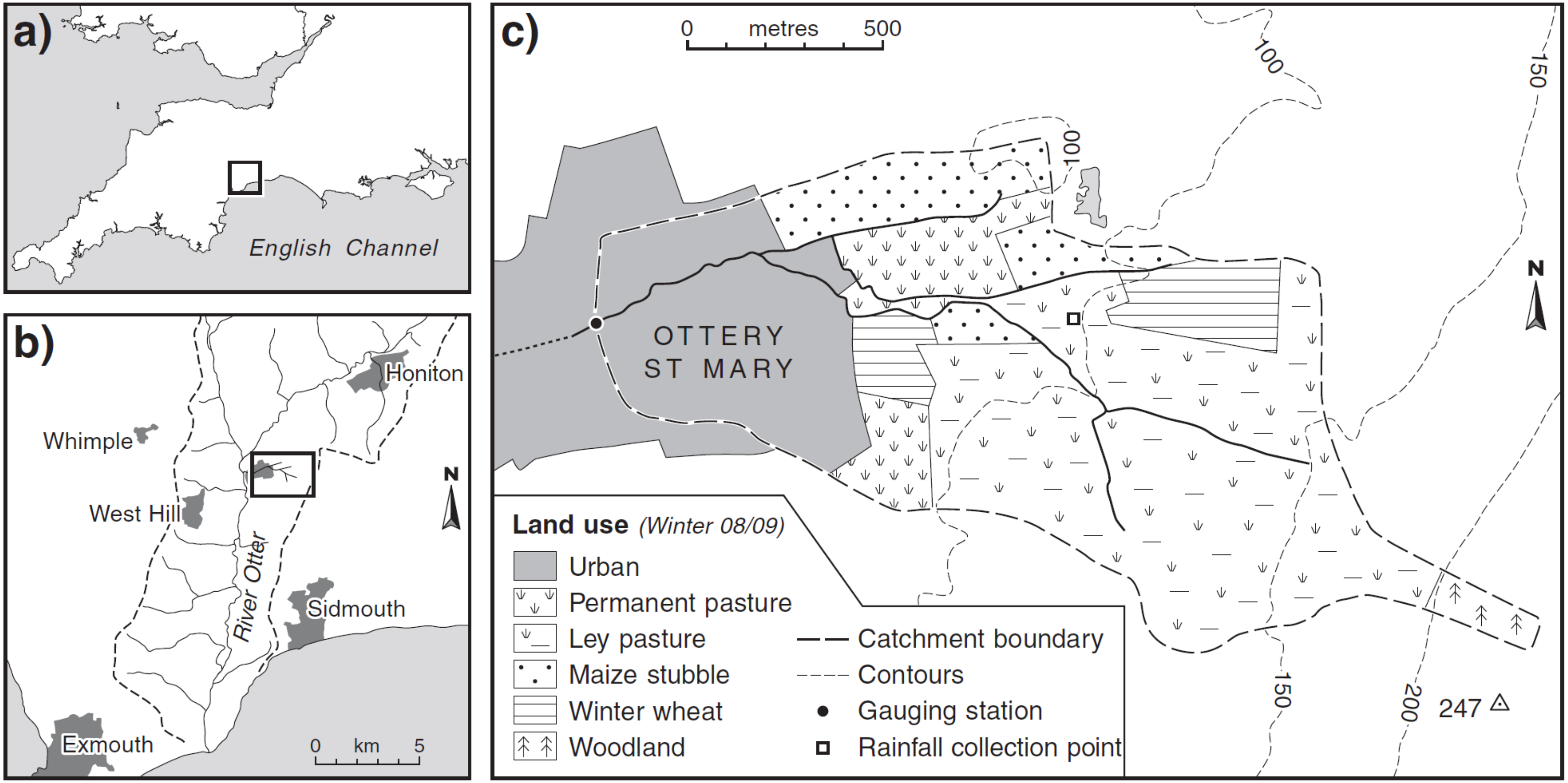
Study Objectives

1. Assess the potential use of crop-derived CSSI markers (based on Gibbs, 2008) to trace sediment back to source areas of specific vegetation cover in UK agricultural catchments

2. Compare evidence from CSSI tracers to that derived from conventional geochemical fingerprinting

3. Evaluate the relative strengths and limitations of the different approaches

Study catchment: southwest England



Surface runoff problems: Furze Brook catchment, Devon UK

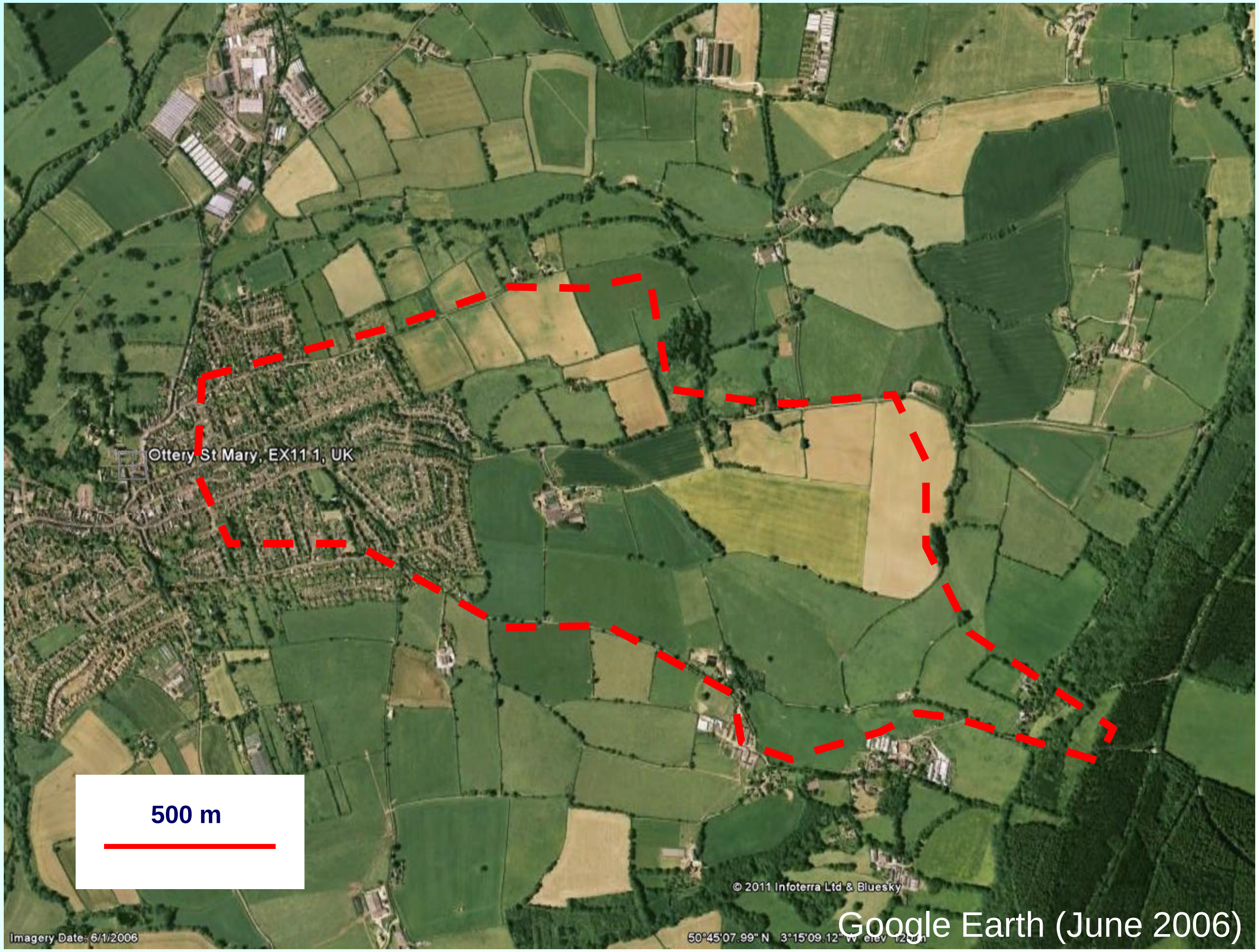
- Study catchment is prone to high surface runoff and flooding linked to soil degradation prompting two studies by UK Environment Agency

Runoff generation and landuse

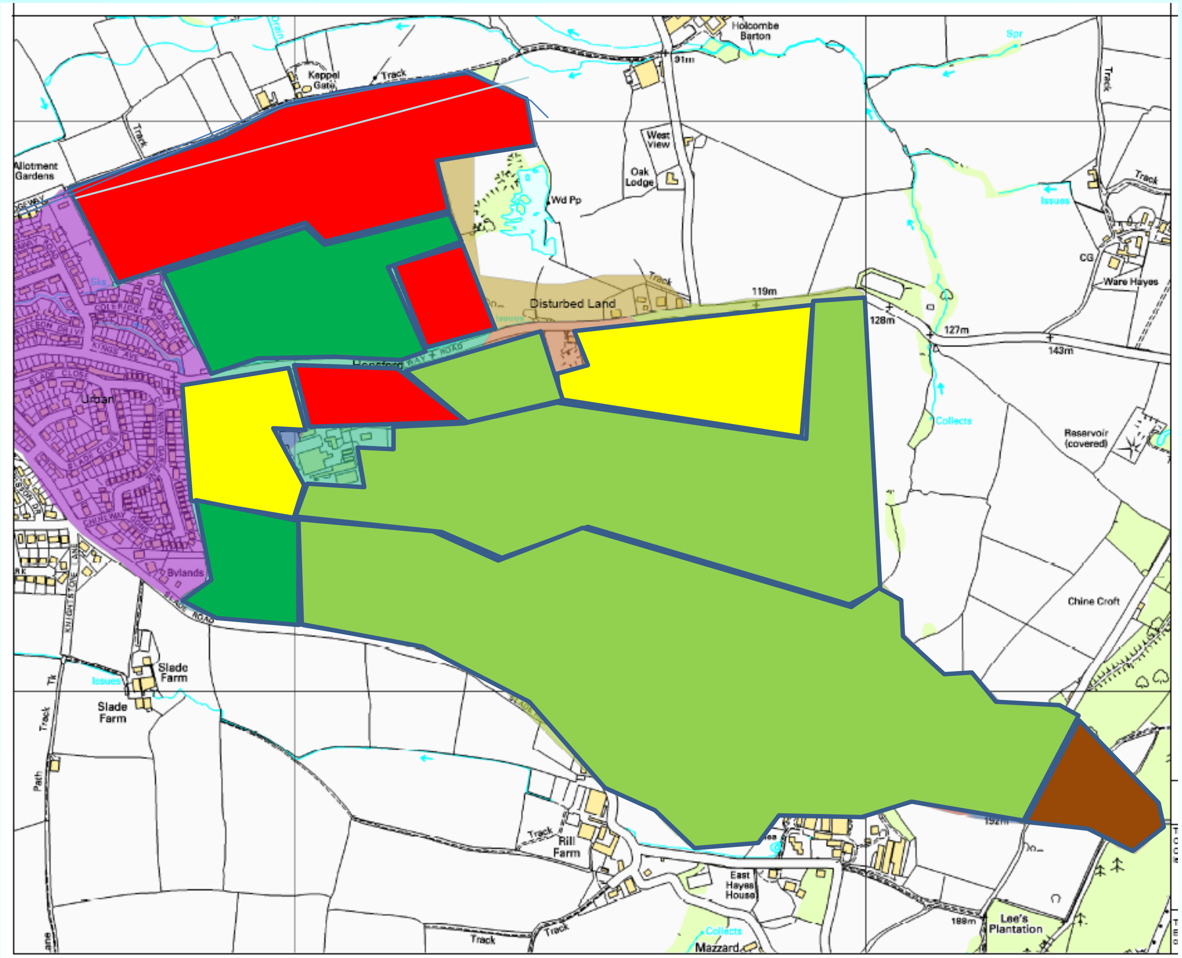
Sediment sources and landuse

Aim: to inform management decisions to reduce both runoff and sediment delivery

Catchment land use

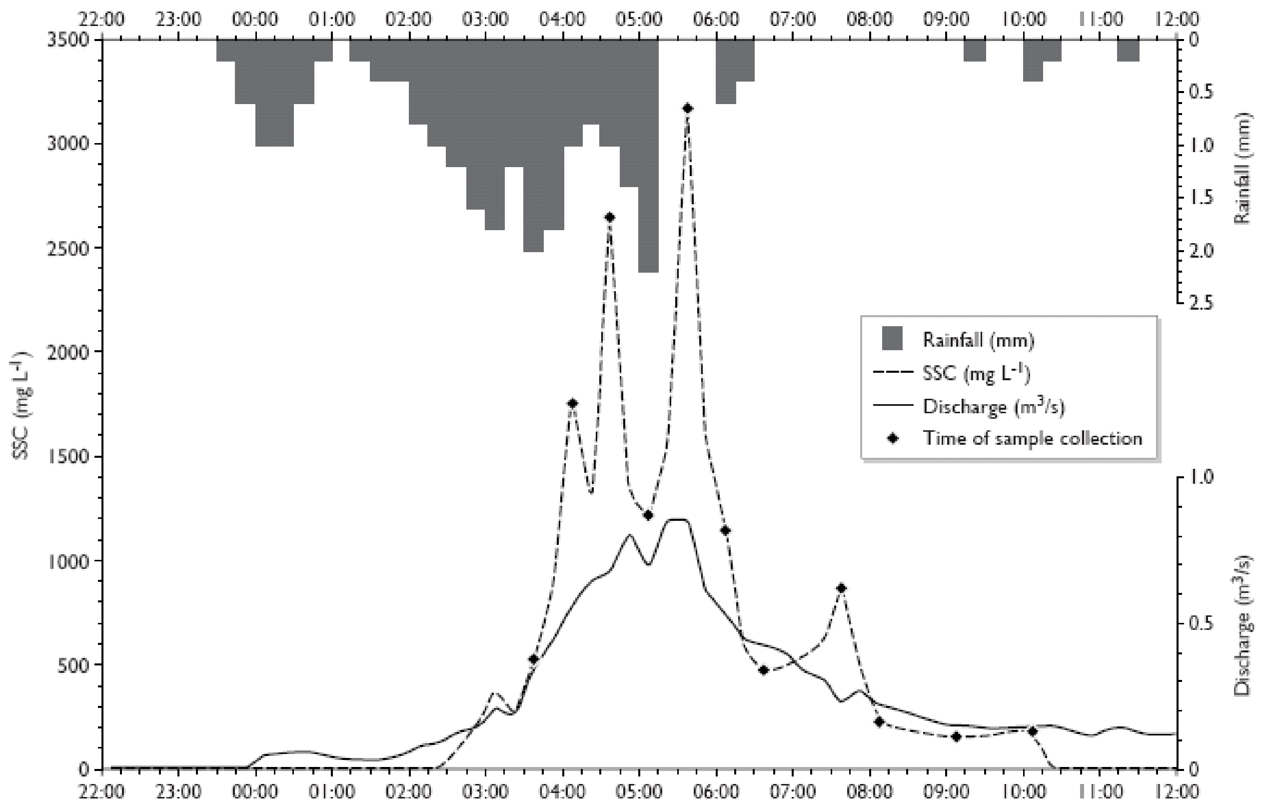


Experimental design 1: collection of source materials



- Maize stubble
- Permanent pasture
- Ley pasture
- Winter wheat
- Wooded

Experimental design 2: collection of suspended sediment samples during major storm event



Experimental design 3: comparison of CSSI and geochemical fingerprints of source material to stream sediment

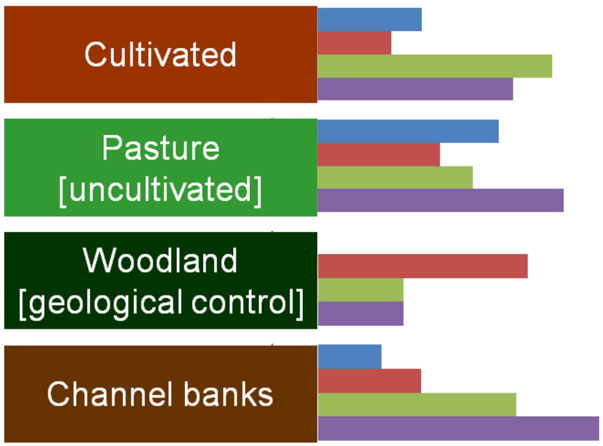
CSSIs	Geochemistry
Maize	Cultivated
Winter wheat	Pasture [uncultivated]
Grass	Woodland [geological control]
Trees and shrubs	Channel banks

Note that source end members are different for each method

Geochemical signatures of source materials

- Based on acid-soluble major and minor elements (determined by ICPMS)
- 97.1% discrimination of sources with fingerprint based on 9 elemental concentrations (based on Collins and Walling, 2002)

Geochemistry



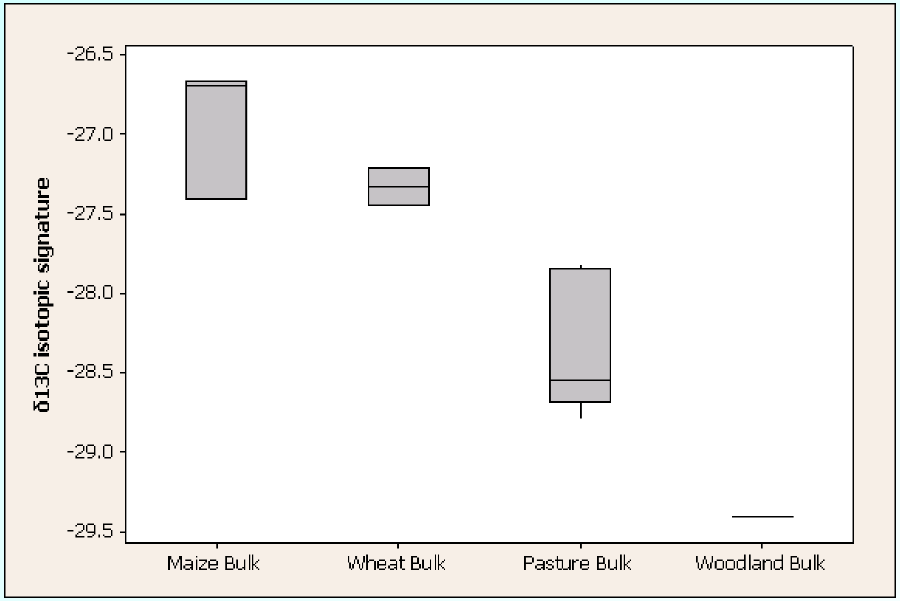
	Cultivated (n=39)	Uncultivated (n=20)	Wooded (n=3)	Channel Bank (n=7)
Pd	0.4 ± 0.1	0.7 ± 0.1	0.0 ± 0.0	2.4 ± 0.4
Sr	57.0 ± 4.3	94.6 ± 7.0	159.3 ± 8.7	77.8 ± 12.5
Cu	18.9 ± 1.5	12.6 ± 0.7	6.5 ± 0.6	15.2 ± 2.1
Ca	1501 ± 119	1931 ± 75	657 ± 62	2134 ± 434
χ_{lf}	0.2 ± 0.0	0.1 ± 0.0	0.7 ± 0.1	2.1 ± 1.1
Cd	1.0 ± 0.3	1.9 ± 0.4	0.0 ± 0.0	1.0 ± 0.5
Y	4.6 ± 0.4	6.7 ± 0.6	6.0 ± 0.6	5.7 ± 0.4
Ba	35.4 ± 2.9	62.6 ± 5.6	17.9 ± 1.9	55.8 ± 9.0
Mg	2573 ± 235	3249 ± 179	635 ± 4	2447 ± 261
Sb	1.3 ± 0.2	1.2 ± 0.2	0.0 ± 0.0	0.5 ± 0.2

Key controls:

- Weathering profiles (surface *versus* subsurface)
- Land use (cultivation impacts)
- Geological substrate

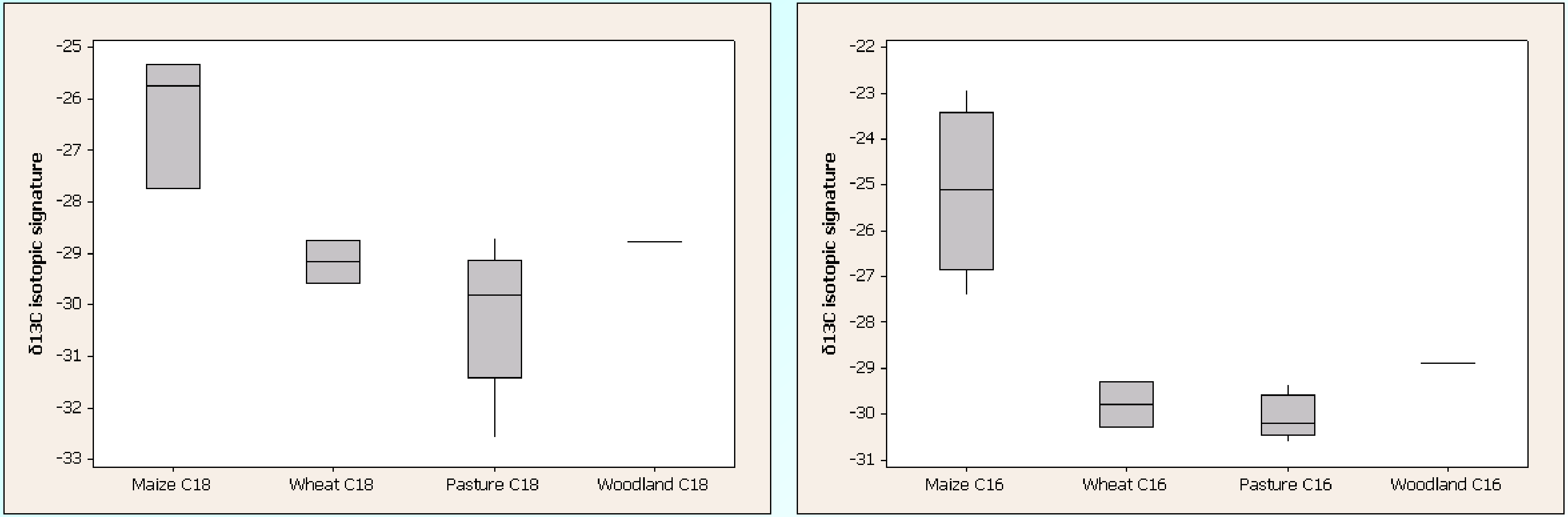
Stable isotope signatures of source materials

- Spatially-integrated samples (30 subsamples along transect) taken from fields of each source type
  - Maize (n=6 x 30); winter wheat (2 x 30); pasture (5 x 30); woodland (1 x 30)



- $\delta^{13}C$ signature of **<u>bulk</u>** C shows *some discrimination* but the signal from the maize fields is not as distinct as would be expected
  - Inclusion of C from C3 plants (grass/weeds)?
  - Soil C remaining from previous crop rotation?
- Compound specific signatures, however, are more encouraging… →

CSSI signatures of source materials



- $\delta^{13}C$ signature of **C18 and C16 chain length FAs** shows some good discrimination between sources
- Maize soil values are distinct but still lower (more negative) than literature values for maize-related soil organic matter (-18 to -20 ‰; Webb et al., 2004)
- Pasture and wheat are similar but greater range of values in pasture

Sediment unmixing

Geochemical fingerprints

- Unmixing model based on principles of Walden et al. (1997); Collins and Walling (2002); Rowan et al. (2003)

CSSI fingerprints

- IsoSource model
- Output converted to ‘soil contributions’ following Gibbs (2008)

IsoSource

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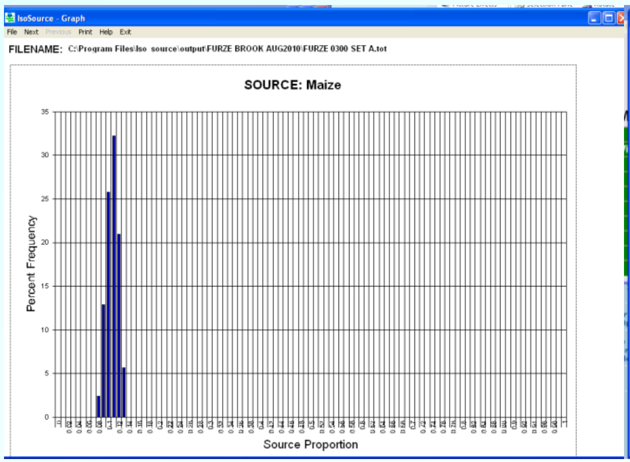
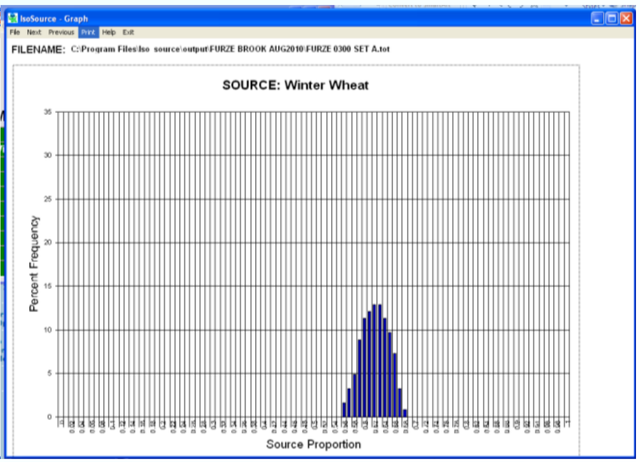
Title: Furze Brook CSSI project

Increment: 1 %

Tolerance: 0.1

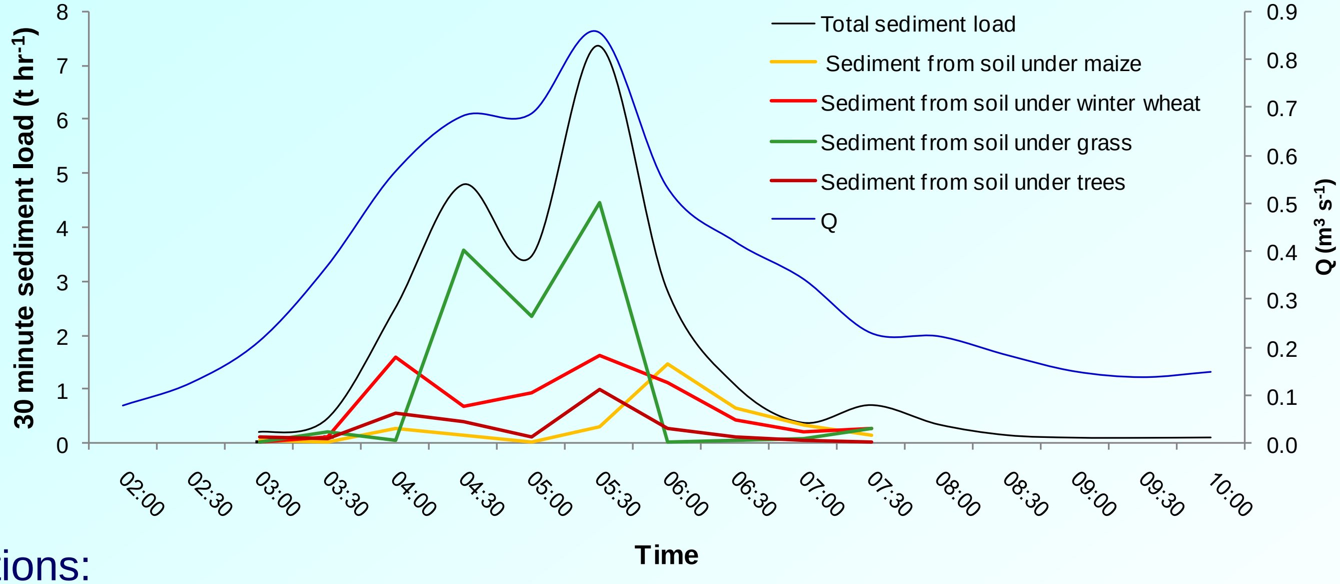
	ISOTOPES				
	13C	C16:0	C18:0	C22:0	C24.0
Mixtures	-27.9	-29.2	-28.8		
SOURCES: Maize	-27.7	-25.7	-26.9		
Winter Wheat	-27.3	-29.8	-29.2		
Pasture	-28.5	-30.1	-30.3		
Woodland	-29.4	-28.9	-28.8		





Attributing sediment load during storm event to different source areas with CSSIs

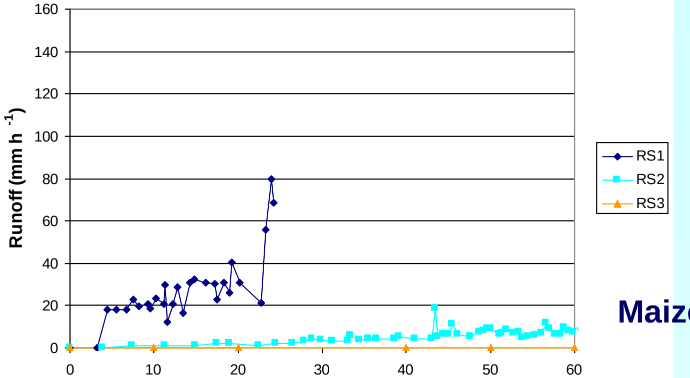
- CSSI data imply contrasting sediment generation dynamics under different land cover



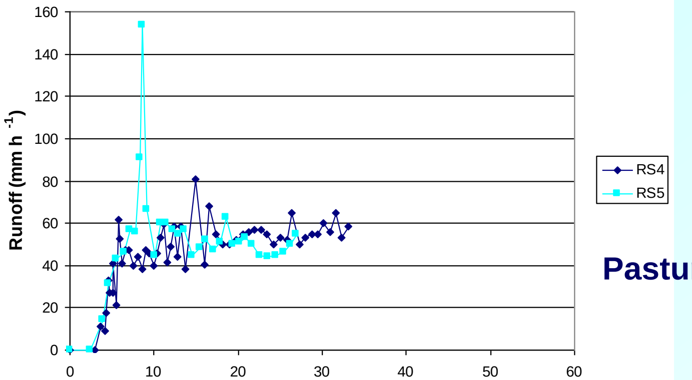
Observations:

1. Pasture an important source (NB 65% catchment area) and responds rapidly to rainfall
2. Sediment generation on bare maize soil appears to be mainly saturation driven i.e. late peak
3. Early flush from wheat with consistent input

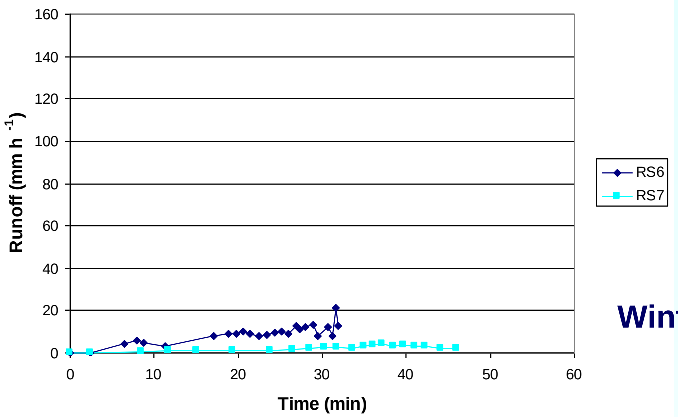
Comparison to runoff plot responses in Furze Brook (Hogan et al., 2009)



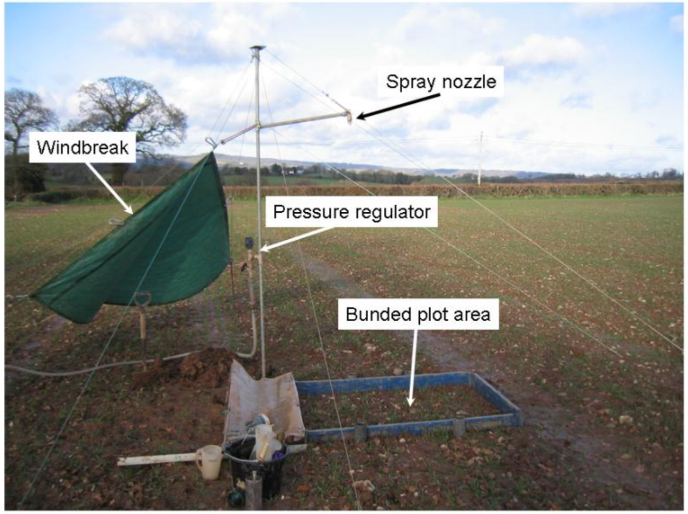
Maize stubble



Pasture



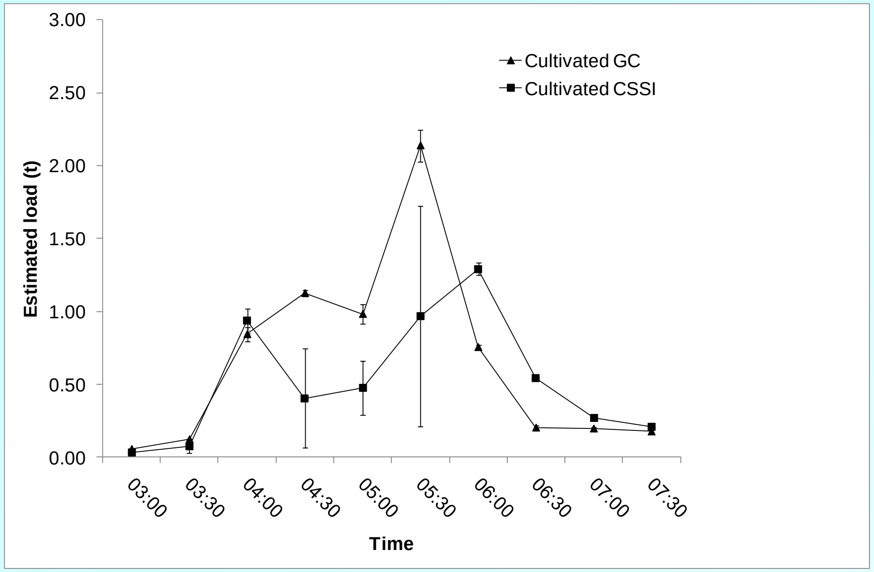
Winter wheat

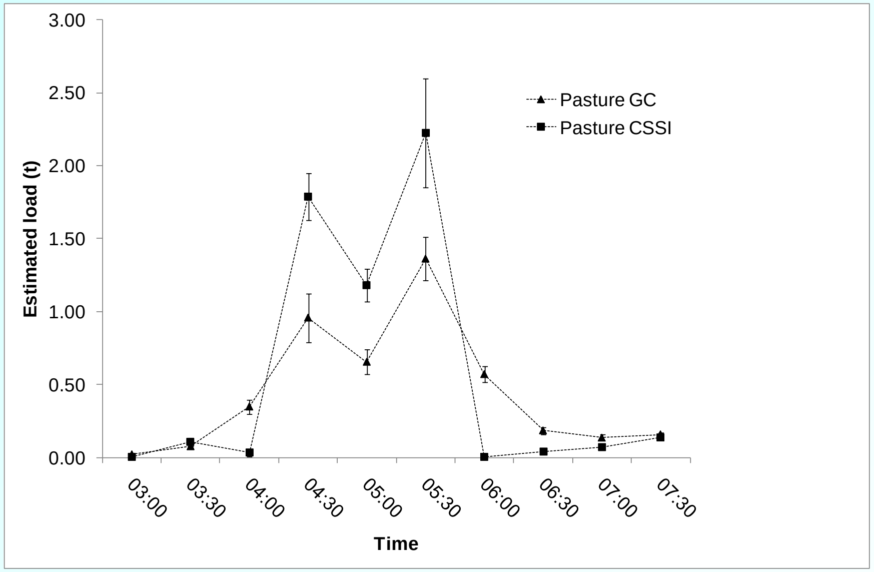


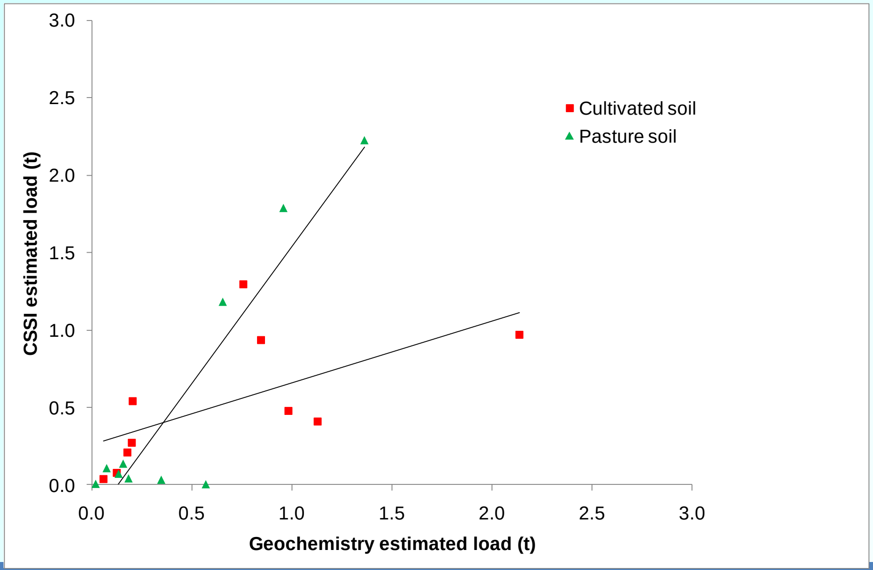
- Runoff initiation times very short for pasture – compacted surface
- Mixed for maize – compacted ground response is fast but slower SOF driven response from rest of field
- Winter wheat – also mixed but generally more responsive than maize
- Generally supports CSSI patterns

CSSI tree/shrub signature – riparian zone – channel banks

Comparing CSSI estimates to geochemical estimates







- Broadly similar with greatest discrepancy in cultivated category
- CSSI struggles with grass and wheat
- Could infer that geochemistry-based approach is overestimating cultivated contribution

  i.e. ley pasture (previously cultivated) 'looks like' cultivated land to GC model
- Need to consider areal weightings

  and uncertainties

Sediment loads as areal yields per crop/land cover

CSSI results	ha	t	t ha^{-1}	kg m^{-2}
Maize stubble	24	3.4 ± 0.5	0.14 ± 0.02	0.01
Winter wheat	16	7.0 ± 2.5	0.44 ± 0.15	0.04
Grassland	85	11.0 ± 1.4	0.13 ± 0.02	0.01
Trees/shrubs	5	2.7 ± 1.5		

GC results	ha	t	t ha^{-1}	kg m^{-2}
Cultivated*	40	13.3 ± 0.6	0.34 ± 0.02	0.03
Pasture**	85	8.9 ± 1.2	0.10 ± 0.01	0.01
Woodland	5	0.5 ± 0.2	0.10 ± 0.03	0.01
Channel banks	n/a	1.3 ± 0.8		

*Cultivated = winter wheat (16 ha) and maize (24 ha)

**Pasture = 69 ha ley (formerly cultivated) and 17 ha permanent pasture

- *If* inference about geochemical tracers and ley pasture impact is correct ...
  - 3 t of GC 'cultivated' load can be apportioned to ley pasture
  - ~8-9 t from permanent pasture (0.5 t ha^{-1}) i.e. Equivalent yield to winter wheat
- Implication: erosion of damaged pasture is extremely localised...

Conclusions and recommendations

Inferences about sediment source dynamics

- The combined use of CSSI and geochemical tracers elucidated important details about sediment source dynamics that could not have been derived from each method alone
- Winter wheat and damaged pasture appear to be the main sediment sources in this system wherein pasture erosion is inferred to be highly localised
- Combined use of tracer techniques identified erosion hotspots

Development of CSSI approach: issues to explore

- Crop rotations and residence of past crop signature in surface soil need to be explored to underpin confidence in CSSI tracers in this context
- Impact of manure application on biomarkers in cultivated fields (application of grass signature to maize stubble?) also warrants investigation