Dynamics of sediment delivery in drain flow on clay soils across England and Wales

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Abstract A large area of agricultural land across England and Wales is on drained clay soils. Field drains have been shown to be an efficient pathway for the delivery of sediment and associated agricultural pollutants to watercourses. As part of a major monitoring programme on agricultural diffuse pollution, sediment samples were collected from hydrologically-isolated experimental plots at two sites in England from 2007 to 2009. Temporal variations in drain sediment loss for different land use and soil types were examined and relationships between drain flow and sediment concentration were also explored. The data analysis has shown that there are significant contrasts between the two soil types under investigation and that the observed sediment concentrations are often above the limits set for freshwater fish. Efforts are being made to characterize the observed patterns with respect to soil and climate conditions to assist extrapolation to national scale for policy support purposes.

Key words sediment loss; field drains; clay soils; plot experiments

INTRODUCTION

Field drains have been installed under agricultural land across the world to remove excess water, expand the range of possible agricultural practices and increase land productivity and profitability. Subsurface tile drains are widespread in the UK (Robinson & Armstrong, 1988) especially under heavy, clay-rich soils thanks to previous government grant aid schemes. While there has been extensive research on the effects of agricultural land drains on soil moisture, river hydrology and the transfer of dissolved nutrients and pesticides (Heppell & Chapman, 2006; Withers & Hodgkinson, 2009), there continues to be a dearth of systematic studies on their role as sediment conduits. With increased recognition of field drains as an efficient pathway for the delivery of sediment and associated agricultural pollutants (Chapman *et al*., 2005; Smith *et al*., 2005; Deasy *et al*., 2009), reliable quantitative data on sediment loss from this source and delivery pathway are essential for characterising sediment pressures on watercourses in agricultural catchments, including those which risk failing to meet the obligations of the European Union WFD.

To enhance the scientific evidence base used to underpin the development of strategies for minimizing diffuse water pollution from agriculture, replicated field-scale farming system studies have been carried out by ADAS on long-established experimental platforms on drained clay soils, including the Faringdon platform in Oxfordshire and the Boxworth platform in Cambridgeshire, UK. Figure 1 illustrates the locations of these experimental platforms and the wider spatial distribution of the clay soil associations they represent. Both of the Faringdon and Boxworth research platforms use hydrologically-isolated experimental plots instrumented for the monitoring of multiple pollutants associated with agricultural practices, including sediment, nitrate-N, ammonium-N, molybdate reactive P, total dissolved P and faecal indicator organisms. This contribution only reports the results of some recent work (2007–2009) examining sediment concentrations and loads measured in the agricultural field drain pathway.

THE EXPERIMENTAL PLATFORMS

The Faringdon experimental platform consists of 18 plots (40 m × 48 m) on heavy clay soils of the Denchworth Association (54% clay). The estimated local long-term annual rainfall is 672 mm. These plots were in continuous arable production for more than 20 years before grass was established on nine of them in 2001. Each individual plot is drained by pipe drains at 48 m spacing

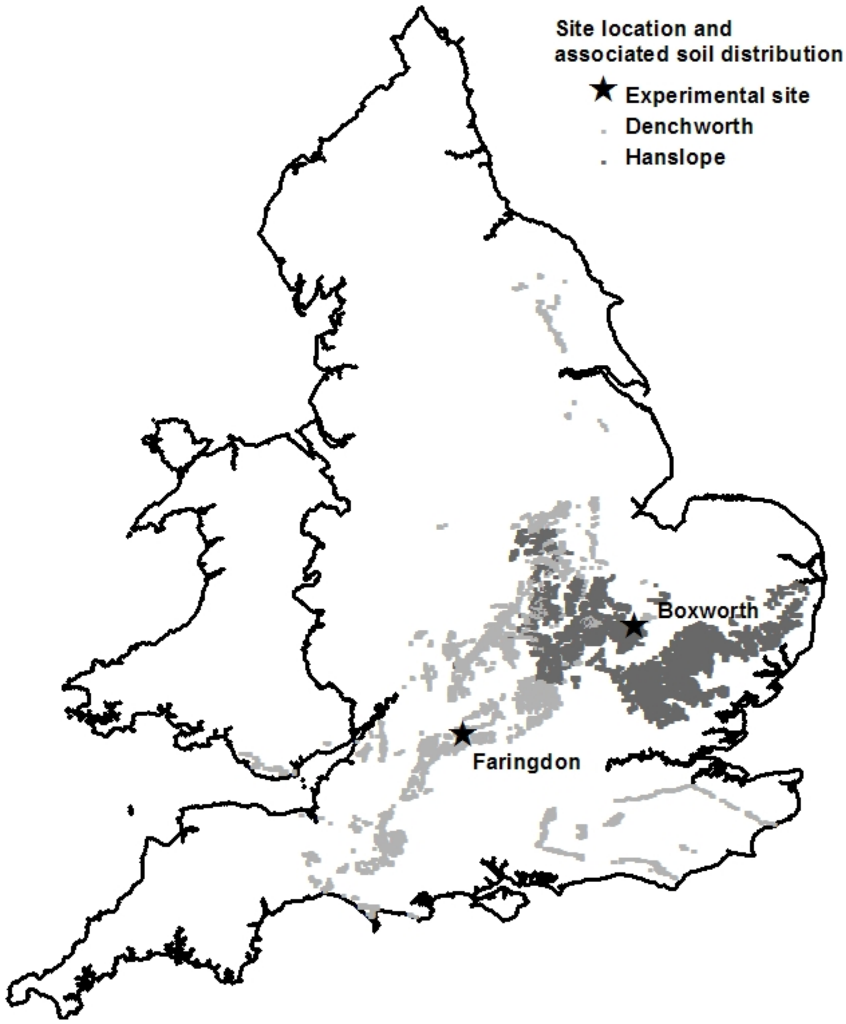

Fig. 1 The locations of the experimental platform sites and the wider spatial distribution of their soil series across England and Wales.

and 90 cm depth. Secondary drainage (mole drainage) is at 50 cm depth and 2 m spacing on all replicate plots. The site has an average slope of 2%. Cereals (winter wheat) were grown on the arable plots during the experiments with crop management practices typical for the UK.

The Boxworth experimental platform consists of 27 arable plots (12 m × 48 m) on clay soils of the Hanslope Association (35% clay). The estimated local long-term annual rainfall is 551 mm. This site has been in a commercial arable crop rotation for over 50 years. Each plot is drained with lateral drains at 24 m spacing and 90 cm depth. Secondary drainage is same as for the Faringdon platform. The site is virtually flat. Cereal crops (winter wheat and oil seed rape) were grown on the plots during the experiments with crop management practices typical for the UK.

DATA COLLECTION AND ANALYSIS

At each site, rainfall volumes were recorded every 5 minutes using automatic tipping bucket rain-gauges connected to data loggers. Drain flow volumes were measured continuously using V-notch weirs or flumes, fitted with electronic head level measuring equipment. Data loggers were also used to record flow data electronically and to control automatic water samplers that were programmed to collect samples on a flow-proportional basis during rainfall events. Representative water samples were collected for both drain flow events and base flow conditions. Each water sample was filtered gravimetrically in the laboratory to determine suspended sediment concentration using standard procedures. During data analysis, replicate plots at each platform site with the same land use were treated as single populations. Daily median values of flow and suspended sediment concentration for different land uses and individual monitoring years at both experimental platforms were estimated. These data were subsequently used to derive summary statistics to examine the relationship between drain flow and suspended sediment concentration and to explore site-specific responses for the two experimental platforms.

RESULTS

Drain flow

Observed daily rainfall and corresponding drain flow for both the Faringdon and Boxworth experimental platforms are presented in Fig. 2. Estimated flows for grass and arable plots are presented on the same graph for the Faringdon platform for ease of comparison. Summary information for each monitoring year is provided in Table 1. In comparison with the estimated long-term average annual rainfall records (1961–1990), 2007 was a relatively wet year, while 2009 could be considered as a dry year on the Faringdon platform. In the case of the Boxworth experimental platform, the observed rainfall during 2009 was near the long-term annual average, whereas the rainfall for 2008 was lower than the long-term average. No "wet year", relative to the long-term average, was encountered during the monitoring period reported in this contribution.

Clear contrasts are observed between the two experimental platforms. As expected, the higher daily rainfall amounts at the Faringdon platform generate higher daily drain flows, in comparison with the Boxworth platform. The former also tends to be more responsive to rainfall because of its well-developed preferential flow pathways, such as surface cracks and soil macropores. Drain flow generation also varies with land use. On the Faringdon experimental platform, the ratios of drain flow to rainfall are consistently higher on grass plots than those on arable plots. Statistical analysis using the Mann Whitney U-test confirms that these contrasts are significantly different at $\alpha = 0.05$. It is also worth noting that there seems to be more drain flow on the arable plots in the early part of the monitoring period. This more rapid response might be attributable to higher soil moisture deficits on the grass plots as a result of the continuous presence and growth of vegetation cover. In the case of the arable plots, the ratio of drain flow to rainfall is quite similar on the two experimental platforms.

Table 1 Summary of observed rainfall and drain flow for the two experimental platforms.

Monitoring year	Land use	Faringdon Platform		Boxworth Platform	
		Rainfall (mm)	Drain ratio	Rainfall (mm)	Drain ratio
2007	Grass	711.4	0.44	367.4	
	Arable	(557.1)*	0.39	(406.1)	0.34
2008	Grass	507.6	0.42	281.8	
	Arable	(571.4)	0.37	(406.1)	0.34
2009	Grass	412.1	0.54	318.2	
	Arable	(515.9)	0.35	(307.9)	0.39

*Values in parentheses are estimated long-term annual average values for the monitored period.

Drain pathway suspended sediment concentrations

Respective totals of 521, 577 and 950 water samples were analysed for suspended sediment concentrations from the replicate grass plots on the Faringdon platform, the arable plots on the Faringdon platform and the arable plots on the Boxworth experimental platform. Table 2 provides the corresponding summary statistics. Nonparametric statistics were used for this summary since the relative frequency of the suspended sediment concentrations were not normally distributed with skewness varying from 3.8 to 4.3. Clearly, the measured suspended sediment concentrations

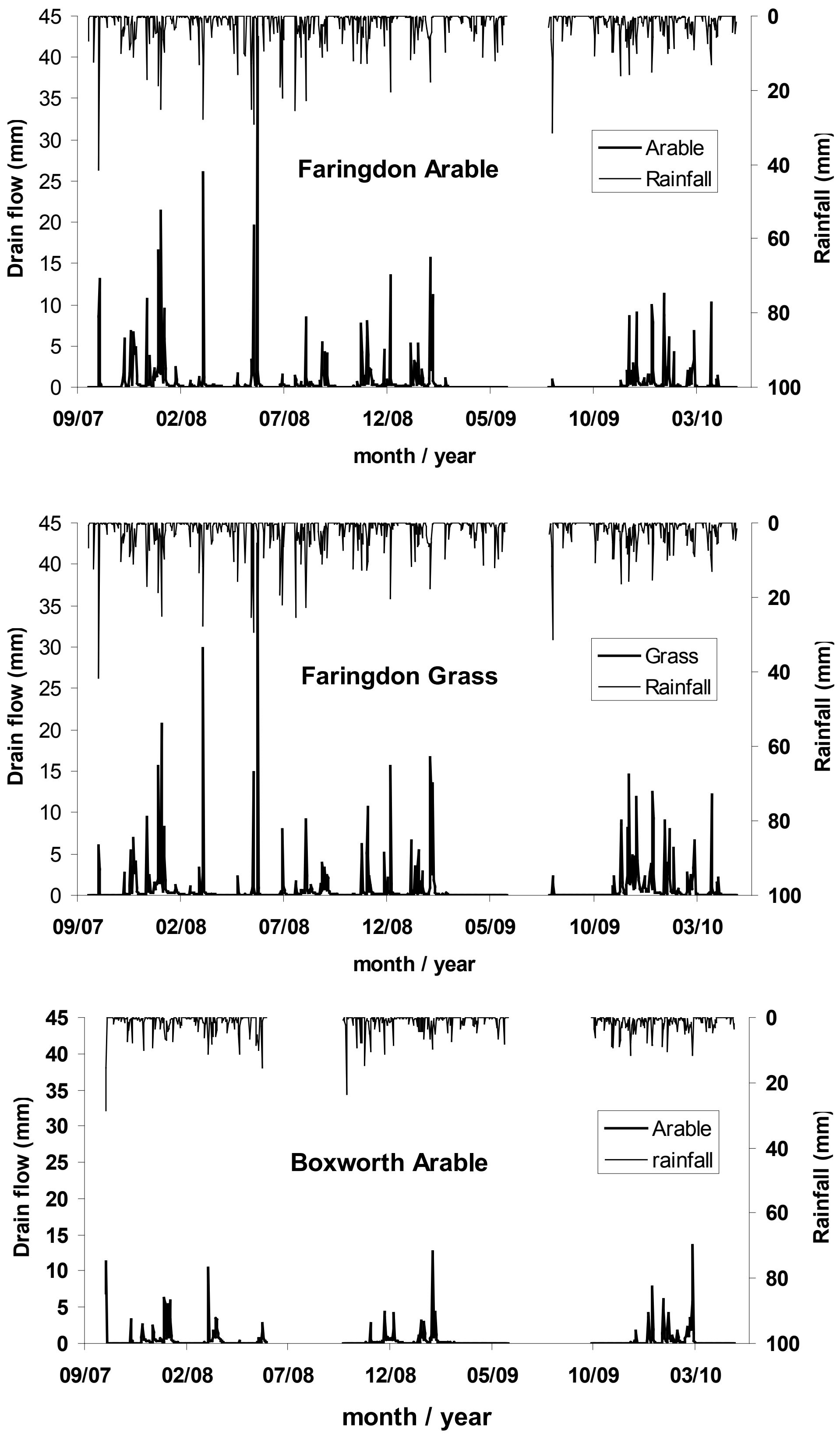

Fig. 2 Observed daily drain flow at the Faringdon and the Boxworth experimental platforms.

Table 2 Summary statistics of the observed drain flow suspended sediment concentrations (mg/L).

	Maximum	Median	Q1*	Q3*
Faringdon Grass	4445	170	84	383
Faringdon Arable	5697	238	90	464
Boxworth Arable	1255	24	11	55

* Q1 and Q3 are the first and third quartiles of the sample population, respectively

on the Faringdon experimental platform are much higher than those on the Boxworth platform. In addition to reflecting the lower drain flow on the latter site, it is likely that the calcareous soil of the Hanslope association at the Boxworth platform has a greater aggregate stability and thus resistance to mobilisation and transfer. At the Faringdon experimental platform, suspended sediment concentrations on the arable replicate plots are also slightly higher than on its grass plots. Because drain flow from agricultural land generally has very good connectivity with receiving water bodies, the observed high suspended sediment concentrations, especially at the Faringdon platform, have serious environmental implications during lower flow conditions with reduced dilution potential, since they are much higher than the 25 mg/L guideline annual mean specified in the EU Freshwater Fish Directive.

With increasing focus on the ecological impacts of sediment pressures on watercourses, the timing of sediment influx also becomes very significant because different aquatic receptors have contrasting sensitive periods, which are frequently related to critical phases in their life cycles. To examine the temporal dynamics of the drain flow suspended sediment concentrations over the monitoring period, monthly average suspended sediment concentrations were estimated based on the observed daily values. The results (Fig. 3) suggest there is much higher temporal variability at

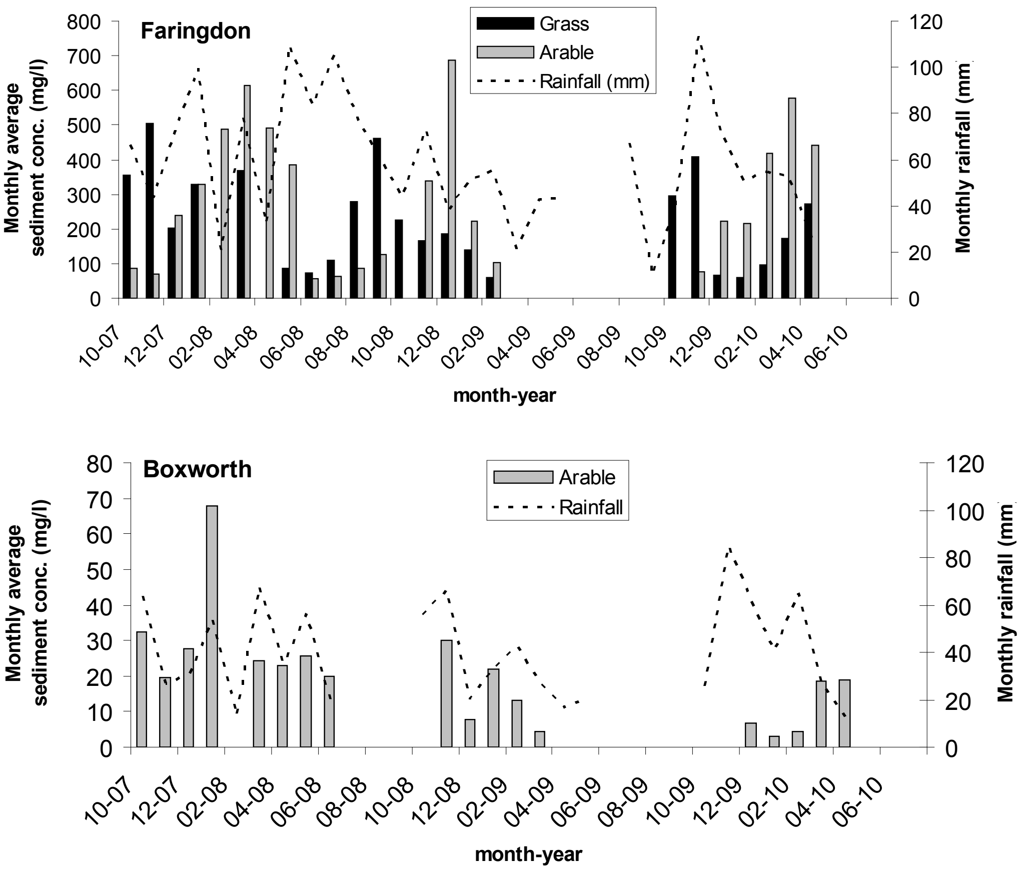

Fig. 3 Estimated monthly rainfall and suspended sediment concentrations for the Faringdon and the Boxworth experimental platforms.

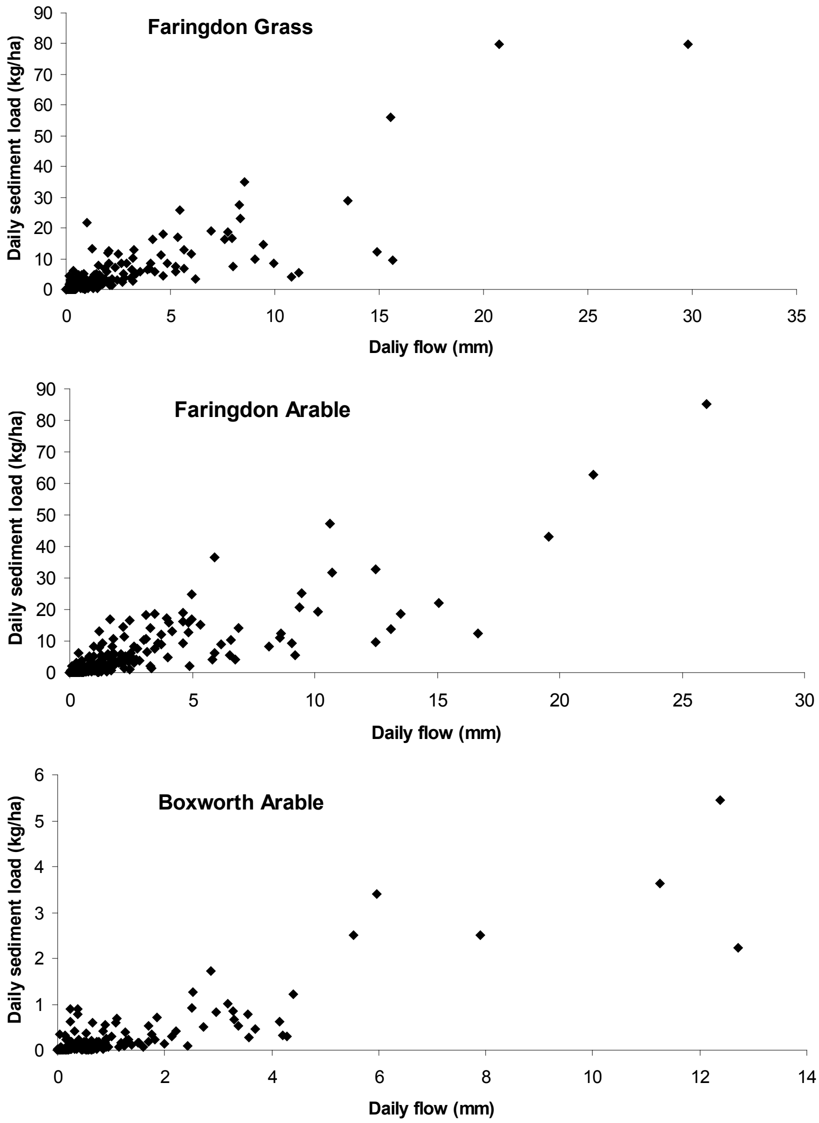

Fig. 4 Relationships between daily flow and drain pathway suspended sediment load at the Faringdon and Boxworth experimental platforms.

the Faringdon experimental platform. In addition, grass plots tend to generate higher suspended sediment concentrations at the beginning of the water year (October to December), whereas arable plots have higher concentrations after February. The lower sediment concentrations at the beginning of the water year on arable plots on the Faringdon experimental platform could be attributed to the disruption of preferential flow pathways associated with the cultivation practices involved with crop sowing, e.g. ploughing and harrowing.

Relationship between daily flow and drain pathway suspended sediment loads

In order to examine the relationships between measured daily drain flow and suspended sediment load, a subsample of observed daily flows was extracted to only include those days that have actual sediment concentration measurements. Daily specific suspended sediment loads (in kg/ha) were calculated to account for the different plot sizes on the two experimental platforms. Scatter plots of daily flow and corresponding estimated suspended sediment loads can be seen in Fig. 4.

Although the data exhibit the expected differences in the magnitude of the suspended sediment loads between the two platforms, the relationships between observed flow and sediment loads are quite similar. Under low flow conditions, the suspended sediment load exhibits high uncertainty within a narrow range. When flow exceeds a certain threshold value, a proportional increase in sediment load can be seen with increased drain flow. The flow threshold value for the Faringdon experimental platform is between 10 to 15 mm. For the Boxworth platform, it is about 4 mm. These observed relationships are slightly different from those reported in Chapman *et al.* (2005), who found a reasonably linear relationship for the whole range of drain flow conditions. It is speculated that the change in the relationships between flow and drain pathway suspended sediment load could be an indication of a change in dominant flow pathways. On this basis, the dramatic increase in suspended sediment load associated with the above-threshold-value flow conditions could be attributed to the contribution from connected preferential flow pathways. Accordingly, flow from the soil matrix is hypothesized to represent the dominant pathway when the flow is below the observed threshold values.

CONCLUSION

Three years (2007–2009) of daily drain flow and suspended sediment data have been analysed from two research platforms which cover representative land uses and different clay soil types across England and Wales. The data analysis suggests that there are significant contrasts between the two clay soil types under investigation and with respect to drain flow production and corresponding suspended sediment temporal dynamics. The observed drain pathway suspended sediment concentrations are often above the limits considered to be safe for freshwater fish. Examination of the relationships between daily flow and drain suspended sediment loads have highlighted the difference between high and low flow conditions. The different clay soil types represented by the experimental platforms appear to have different threshold values for separating these two basic flow conditions. These datasets and the improved understanding they provide have already been employed to develop a new national sediment pressure modelling tool for representing the interaction between daily weather, soils, land use and cropping. Since the drain flow sediment samples were collected as part of multi-pollutant monitoring schemes at the experimental platforms, further analysis will be undertaken to characterise the delivery of sediment-associated agricultural pollutants, e.g. phosphorus, from field drained clay landscapes.

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