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Running head: soil erosion monitoring in the Rother valley

Monitoring soil erosion on agricultural land: results and implications for the Rother valley, West Sussex, UK

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Abstract

Monitoring has played a key role in understanding the rates, extent and frequency of erosion on agricultural land and this includes projects in Switzerland, Germany and the UK. In this case we focus on highly erodible soils in the Rother valley, West Sussex, southern England on which grow a range of arable crops throughout the year. Erosion rates and extent are high, particularly in response to exceptionally wet periods in the early winter. In the monitored period, rates on summer crops were relatively low due to an absence of intense summer storms. In the years 2015-20, erosion was localised to where limited areas of bare ground coincided with heavy winter rainfall. Issues of river pollution, associated with excessive sedimentation, off-site flooding and a high degree of connectivity between arable fields and the river, are of increasing concern. Mitigation measures need to be expanded to protect freshwater systems and properties. This study has implications for similar programmes in intensely farmed regions.

Keywords: soil erosion, monitoring, river pollution, mitigation measures, connectivity

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Introduction: monitoring soil erosion

Monitoring of soil erosion has been defined as ‘field-based measurement of erosional and/or depositional forms over a significant area (e.g. >10 km^2) and for a period of over two years’ Boardman (1998a, p. 20), and is further discussed in Poesen et al. (1996). The need for long-term measurement is argued by Burt (1994) and, in an era of climate change and increasing rainfall intensities affecting erosion, the case is now even stronger (Burt et al., 2015). Ideally, monitoring should cover a variety of topographies, land uses and soils, to reflect and assess changing risks as in the case of the Soil Survey of England and Wales (SSEW) scheme (Evans, 1992, 1993). It has been argued, that all too often, monitoring has focused on areas of known risk (Benaud et al, 2020). However, local needs, such as a prevalence of off-site issues, may justify such focus (Boardman, 1995). There are economic, logistic and statistical arguments as to why monitoring at a regional or national scale is unfeasible so selection of smaller, representative areas, must be made (Evans, 2005a). Recently reported monitoring schemes in Switzerland and Germany set a high standard in terms of field-scale surveys over significant lengths of time (Prasuhn, 2020; Steinhoff and Burkhard, 2018). Both surveys show relatively low mean rates of erosion in sharp contrast to claims made in the past (Pimental et al., 1995; Boardman, 1998a). A valuable role for monitoring is to supply data for models so that predictions regarding data-poor areas and future time periods, can reliably be made. Existing soil erosion models give disappointing results when compared to field data (Evans and Boardman, 2016) and thus the need for alternative empirical approaches is acknowledged (Benaud et al., 2020).

It is not surprising that monitoring schemes come up with different results (Table 1). The factors that influence erosion are not constant e.g. the SSEW scheme stopped in 1986, and the following winter was one of the wettest on record in southern England (Boardman, 1988; Evans, 1996). There is also the problem that the methodologies used in various schemes are different and comparisons not easy (Benaud, 2020), e.g. different results are obtained if the erosional form is related to the immediate area, the field, the catchment area, or a transect including many land uses (Boardman and Evans, 2019). At the very least, the methodology should be clearly stated.

In this paper we explore the value of both long-term and short-term monitoring projects in an area of intense arable farming on erodible soils.

The Study Area

The Rother valley lies mainly within the county of West Sussex and within the administrative area of the South Downs National Park (SDNP) established in 2011. The National Park is unusual in having considerable areas of arable farming both on the Chalk of the South Downs and in its northern extension on the older rocks of the Rother valley (Figure 1). The River Rother drains a catchment of 350 km^2 and enters the Arun near Pulborough. Arable farming is concentrated on three soil associations: Fyfield 1, Fyfield 2 and Frilford of sandy and sandy loam textures developed in Lower Greensand rocks of Cretaceous age (Jarvis et al., 1984). These associations are classified as being at high risk of erosion by Evans (1990a). Guerra (1991) obtained mean values of 62% sand, 25% silt and 13% clay for Fyfield 1 soils around Rogate (n=81). Soils from eroded fields had organic matter levels of 2.1 – 3.8% and bulk

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densities of 1.3 – 1.9 g cm^{-3}. The tendency to crust and generate runoff was noted in a subsequent study (Guerra, 1994). Average annual rainfall for Petworth Park is 910 mm (sd +/-155) for 1981-2010 with highest mean falls in December of 106 mm (sd+/-54) and November of 108 mm (sd +/-63). Land use in the current arable area has shifted from grazing and dairying in the 1930s to arable at the present time. Of 194 fields monitored in the area (see below), 106 were in arable crops in 1935 and 27 were partly arable (LUS, 1935). Valley-sides near the river are generally cultivated on slopes rarely >5^{o}. The soils are fertile, easily worked and many of the crops are of high value: winter cereals, oil seed rape, maize, asparagus, potatoes, salads and vegetables, with significant areas of irrigation.

The vulnerability of Lower Greensand soils to erosion in other areas of the country is well known e.g. in the Silsoe area of Bedfordshire (Morgan, 1977; Morgan et al., 1987); in the Isle of Wight (Evans, 1993; Boardman, 1994); and in Surrey and West Sussex (Boardman, 1983a,b). Prior to the early 2000s, little attention was given to the Rother valley, the exception being work by Nortcliff (1978), Guerra (1991, 1994) and Sear (1996). The latter report is important because it focuses on increased sedimentation in the Rother, changes in agricultural land use, and the routes by which soil reached the river.

A further reason for a monitoring scheme was the increased awareness of off-site impacts of muddy runoff from agricultural fields. Roads in the area have a long history of clearance of soil after rainfall events although this is poorly documented. Similarly, increasing problems of sedimentation in the Rother are reported by local residents and anglers: this is largely anecdotal evidence. Better documented are muddy flooding problems affecting the village of Easebourne largely as a result of runoff from adjacent potato fields. Between 2000 and 2014, there were seven damaging muddy flood events in the village with repeated and persistent flooding in 2012 and 2013/14 (CH2MHill, 2015). Off-site impacts are also discussed by Shepheard (2003), Boardman et al. (2009), Boardman and Vandaele (2015) and Boardman et al. (2019). Much of the Rother, Lod and Hammer streams are classified as of moderate quality for EU Water Framework Directive (WFD) purposes with the Lod at poor quality (Environment Agency, 2016) and of concern to the Environment Agency and Southern Water. The latter extract water for domestic use at the Hardham treatment plant where excessive sediment is removed: costs are considerable (Boardman, 2020).

Within the Rother Catchment is a network of roads, tracks and footpaths. Many roads act as a barrier to flows of runoff, in other cases culverts allow flow beneath roads and are important elements in the pattern of connectivity (Boardman et al., 2020). Sunken lanes facilitate flows from fields to the river (Boardman et al. 2009; Boardman, 2013). In general, minor roads are not drained, runoff may overflow into fields or watercourses. Sunken lanes do not allow water to escape and many lead directly to the river. Points at which runoff was seen to enter the river, in a section of the study area, are shown on Boardman et al., (2009, Figure 3). Most of the study area has neither land drains nor ditches.

Aims

The aim of the project was to systematise erosion monitoring in the Rother valley. Previous projects had been *ad hoc* in that they had focused on specific high-erosion years or small

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areas of the valley – usually because of observed erosion events and sites. A 5-year project was planned with monitoring at 6-monthly intervals to include both summer and winter events. Previously, winter events had seemed dominant, as in other areas of southern England (e.g. Boardman, 2003), but occasional intense storm-related events in summer were recognised (e.g. Boardman et al., 1996). The presence of spring-planted crops in the Rother valley, and thus bare ground in the early summer, suggested that erosion in the summer may be a regular occurrence. The relationship of erosion to differing land uses and rainfall patterns was at the heart of the project. The growing emphasis on off-site impacts and the connectivity of fields to the river ensured that the project took these issues into account and in particular, what proportion of arable land contributes to pollution.

The monitoring project ran from 2015-20 and this paper reports on the main findings. It sets the project in a wider spatial and temporal context and asks the question, what have we learned from the project?

Methodology

The selection of fields to be monitored was based on a series of small-scale studies post-2000 which recorded erosion in several parts of the Rother valley. These studies enabled a database to be assembled of fields with a known history of erosion. The studies were the theses of Guerra (1991) and Shepheard (2003), air photographs from March 2001 for West Sussex County Council, Google Earth complete coverage of the area for January 2001 and January 2005, and incomplete coverage for many other years (2006 – 18). Studies of parts of the area were carried out by Boardman (unpublished) in the winters of 2006/07, 2012/13 and 2013/14.

These included measurements at sites of significant erosion. Some of this data is reported in Boardman et al., (2009, 2019); Boardman (2016); Boardman and Favis-Mortlock (2014) and Boardman and Vandaele (2015). During the period of monitoring (2015-20), some fields were added to the original database as more information became available.

The final total of fields with a history of erosion was 194 (Figure 1). The mean field size was 9.1 ha (median 9.5 ha); the mean slope of the fields was 3.0^{o} (median 3.3^{o}). The number of fields surveyed each year varied slightly (Table 2). Of 165 fields assessed in 2009, 45 had been subject to boundary changes in the previous 12 years and 39 of these were losses with 23 fields losing across-slope boundaries amounting to 7375 m. Boundaries consist of woodland, hedges, grass strips, fences and very occasional ditches.

The time taken for each 6-monthly survey was 3-4 days. More time was required when significant erosion occurred, and measurements were made. Measurements to obtain an estimate of soil lost from rills and gullies followed the volumetric approach of Boardman and Evans (2020). On the many fields with no or little erosion a qualitative approach was used with features being categorised (Table 3). With regard to wash as a minor component of total soil loss, we concur with the very modest estimates of Evans (1990b) < 0.3 m^3 ha^{-1} yr^{-1} on most arable soils, with Govers and Poesen (1988) at c. 22% of total soil losses, and with Prasuhn (2011) with interrill erosion at 10% of total erosion. Elements recorded for each field were the presence of rills, ephemeral gullies, fans, wash, crusting, standing water, crop

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type, crop cover and irrigation. Runoff leaving the field and entering other fields, roads, tracks, ditches or watercourses was noted.

Results

The number of fields surveyed each year varies (Table 2). The highest numbers are associated with years with extensive coverage by Google Earth images or air photographs (2000/01, 2004/05, 2012/13 and 2014/15). Changes in the extent of erosion are expressed as a percentage of fields affected by gullies, rills, fans or wash, compared to the total number of fields surveyed: there are notably high values for the winters of 2000/01, 2006/07 and 2013/14 (Figures 2, 3 and 4). These values of between 67 and 72% are high but it should be noted that all fields in the monitored area are, by definition, susceptible to erosion; also, a high proportion of them are arable every year. It is worth noting that in the SSEW surveys, the area affected by erosion was between 2 and 13.9% (Evans, 1993).

An erosion index is used to express the character and seriousness of erosion year by year (Table 3). In assigning features to categories there is an element of subjectivity. Gullies in all cases are ephemeral gullies occupying topographic depressions and dry valleys. Wash was more readily recognised in the later years of the survey and tended to be ignored where more serious elements of erosion existed; it is therefore underestimated. The index is a rather crude attempt to quantify erosion in the absence of direct measurements for all sites and years. The annual index is an aggregate of the values on individual fields where erosion was observed in that year. High values are seen in the winters of 2000/01, 2006/07 and 2012/13 (Table 2). The 5-year survey is seen in a longer-term context with low values for most years and modest values for the winters of 2018/19 and 2019/20. Throughout the sequence, summers show low values with between 2 and 15% of fields in summer affected by erosion or wash (Table 2).

Erosion in summer is characterised by that occurring on maize and potato crops. In other areas the risk of erosion on maize and potatoes is well known e.g. van Dijk et al. (2005), Boardman et al. (1996), Evans (2005b), as is the risk on post-harvest fields in autumn and winter: Palmer and Smith (2013). In the Rother valley, in 2006-07, erosion on two fields of post-harvest potatoes was estimated at 180 m^3 ha^{-1} and 24 m^3 ha^{-1} respectively (Boardman et al., 2009). In the monitoring period (2015-20), the amount of erosion on maize and potato fields was low because rainfall amounts were low. The number of fields under maize varied from 11 to 23 with 0-4 showing erosion and 1-9 with wash. Four to 12 fields were under potatoes with erosion on 1-5 and wash on 0-5. Some vulnerable fields had been taken out of these crops. Much greater areas of potatoes were grown in this area prior to 2008. Post-harvest potato fields were less vulnerable in winter because farmers often followed the harvest with a winter cereal crop; this was not the case with the later harvested maize crop.

Evans et al. (2015) remark that in two long-term monitoring projects on the South Downs, most fields eroded only once in five years. The current survey, with a much greater variety of land use, and monitoring twice a year, appears to have a greater frequency of erosion. All fields could have eroded 10 times – and we include wash in the term ‘erosion’. One field eroded seven times, three fields five times, nine fields four times and 18 fields three times. However, 128 fields eroded once or not at all in the monitoring period.

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Rainfall

The two major erosion event years of 2000 and 2006 were exceptionally wet with annual totals of 1429 and 947 mm respectively. In 2000 there were rainfall totals of 194 and 277 mm in September and October . Very large daily totals were recorded on 15 September (39.5 mm) and 19 September (28.3 mm) followed not long after by 49.2 mm on 9 October. The largest daily totals through this very wet autumn and winter were 66.2 mm on 5 November and 58.1 mm on 29 October. Altogether there were 20 days with more than 20 mm rainfall recorded between September and January. These very large totals were all recorded at a time of extreme vulnerability to erosion with much bare ground. Erosion continued through the winter with significant differences between the Google Earth images (01/01/2001) and later air photographs (March 2001). The photographs were taken because of extensive flooding in the Rother valley (Figure 2).

In 2006, erosion was initiated in late September with 2-day totals for 28 and 29 September varying between local gauges around Midhurst of 26, 33, 52 and 25 mm, but only 15 mm at Petworth Park (Boardman et al., 2009), although Petworth had recorded 27.2 mm on 14 September. This time there were eight days with totals over 20 mm in the period September to January, including four in October, a time of high erosion risk (Figure 3).

In the winter of 2012-13 erosion was related to a relatively wet period November-February with six days of >20 mm d^{-1} (Figure 4). The maximum daily rainfall in that period was 29.2 mm on 14 December 2012.

In 2013-14, wet weather in December (224 mm), January (268 mm) and February (221 mm) resulted in serious, localised erosion (Figures 5 – 7 and Tables 4 and 5). Exceptional erosion in Figure 5 was on an atypically steep slope of c.10°. In the period October 2013 to February 2014 inclusive, there were 12 days with at least 20 mm totals at Petworth, with a maximum of 76.3 mm on 24 December.

Erosion events during the monitoring period (2015-20), are of a lesser magnitude and restricted to a few fields. This localisation of erosion seems to be unrelated to intense local rainstorm events, but to the presence of restricted areas of limited crop cover (winter and spring cereals and post-harvest maize) in winter and early spring. Figure 8 shows that the summers were generally drier and two winters wetter than the long-term average. The number of rain days in three winters was above average but other indicators of erosion risk (rain per rain day and 2-day totals >30 mm) were generally low.

Land use and Connectivity

During the monitoring period (2015-20), erosion including wash was recorded on 230 fields. Of those fields 81 (35%) were under winter cereals, 36 (16%) under maize, 33 (14%) under salads and vegetables and 23 (10%) under asparagus. Potatoes and bare ground also

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accounted for 10% of the total respectively. The winters of 2018-19 (23%) and 2019-20 (20%) accounted for a large proportion of eroded fields in the 5-year period.

The connectivity of fields to the river was investigated for the whole period 2000-20 using remote sensing, topographical maps and field observations. Runoff from fields can connect to the river via other fields, ditches and streams, tracks, roads and sunken lanes. Observations showed fields >1500 m from the river connected during storms e.g. that in Figure 9 via flow into a sunken lane (Figure10). Since not all fields are connected every year – and some very occasionally – we refer to this as ‘potential connectivity’. Of 194 fields, 129 (66%) are potentially connected to the river (Figure 1). This relates to the concept of ‘critical source areas’ as the fields which supply runoff and sediment to the river. Important source areas are not simply defined by their closeness to the river. Major flows have occurred from fields which are distant: again, this usually relates to the role of roads and sunken lanes. Patterns of flow and points of entry to the river for 2006-07 are shown in Boardman et al. (2009, Figure 3). Alder et al. (2015) point out that many studies show only a small percentage of the agricultural land contributes to diffuse water pollution. That is not the case in the Rother valley, but the data is biased by the fact that the 194 fields are relatively close to the river, are mostly arable, and were selected because of their propensity to erode. We discuss connectivity in more detail in this catchment elsewhere (Boardman et al., 2020).

Seasonality

The seasonality of erosion and connectivity is partly related to rainfall and to land use patterns. Bare or poorly vegetated fields in winter may quickly become saturated and generate runoff. The field in Figure 9, for example, was drilled on 3 December, and this was followed by 158 mm of rain in the rest of the month.

The area occupied by summer crops (maize, potatoes, sugar beet, vegetables, salad crops and bare ground) varied between 28 and 43% of the surveyed fields for 2015-20.

Mitigation measures

Mitigation measures were not originally part of the monitoring programme. Indeed, in both Boardman and Vandaele (2015) and Boardman et al. (2019) the paucity of mitigation in the Rother valley was noted. However, during the latter stages of monitoring, mitigation measures were mapped primarily as a result of increased interest in protection of the river. We shall deal with the details and the effectiveness of the measures elsewhere, but to summarise:

In the winter of 2019/20 inspection of 180 fields with a history of erosion recorded 65 with some form of mitigation measure. Of these 65, 22 had bunds/banks/retention structures and 14 had grass buffer strips. Seven had a combination of both. A further 17 former arable fields had changed their land use over several years: 11 to grass, four to vineyards, two to trees. Mitigation measures are planned on eight fields with a history of serious erosion. The measures are largely a response to the flooding of roads, properties and pollution of the river via ditches, roads and minor watercourses (Figure 11).

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Discussion

Monitoring schemes must deal with the real world, but choices need to be made as to what to monitor including the spatial and time scale and choices will relate to the aims of the project. Prasuhn (2020), Steinhoff-Knopp and Burkhard (2018) and Boardman (2003) all focus on arable fields. The SSEW monitoring was more eclectic (in order to investigate the extent of the problem), with data from agricultural land in general along a series of transects (Evans and Boardman, 1994). In the case of the Rother valley, all fields with a history of erosion were monitored which strongly biased the sample to arable land. However, if land use is recorded, data can be disaggregated to give rates of erosion for particular crops e.g. Evans et al. (2016, Table 7).

During the monitoring period several issues came to the fore. Limited data from the later years suggest that wash and rilling is regularly associated with irrigation of potatoes and salad crops. In recent years there appears to be a pattern of increasing wash erosion on fine-grained soils (Evans et al., 2016). Off-site impacts assumed centre stage, not so much due to the occasional flooding of roads and properties as at Easebourne, but because of water pollution problems and the costs of cleaning water destined for the public supply network at the Hardham treatment plant. The connection between agriculture, runoff, erosion and connectivity was ultimately driven by WFD criteria for 'good ecological status' (European Parliament, 2000), by recent research which shows the importance of agricultural land as a source of freshwater pollution e.g. Collins et al. (2009) and by publicity over a long period of time for the erosion problem (Evans, 2010). In the Rother valley, parallel work with the SMART and SMART 2 projects showed the importance of small ponds and reservoirs in detaining coarse sediment and allowing fine-grained sediment to reach the river – with implications for pollution (Evans et al., 2017; Foster et al., 2019; Boardman et al., 2019; Evans, 2019). Burt (1994) comments that, 'once established, other benefits accrue from monitoring – from discoveries made later, not from the original questions'.

Rates of erosion were low, and, in most years, erosion was limited to a few fields, the exceptions being 2000 and 2006 when there was erosion on winter cereals and post-harvest maize and potatoes. In those years several fields had markedly high rates due to optimal conditions of little or no crop cover and high rainfall amounts with erosion widespread (Table 2). The high rates contrast with the generally very low average rates reported in the surveys of Prasuhn (2020) and Steinhoff-Knopp and Burkhard (2018). This is likely because of small field sizes in the Swiss data and far more attention to soil conservation in both of areas in comparison to the Rother valley (Boardman et al., 2019).

Variability of erosion rates from year to year and from field to field is a well-known feature of soil erosion monitoring schemes. For example, the 10-year project on the South Downs (1982-91) showed an order of magnitude range of annual rates (Boardman, 2003), and spatially for one year (1987), a range on eroding winter cereal fields from 0.2 to 202 $m^3 ha^{-1} yr^{-1}$ (Boardman, 1998, Figure 1). A wide range in mean or median values is not surprising but make quoting average values in very skewed distributions, rather problematic.

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Lessons from the monitoring project

Available resources were rarely ideal, but the best must be made of what there is. Remote sensed data were extremely useful and led to the discovery of many fields that had been subject to erosion. In some cases, past flows from field to field were revealed (Figure 2). Unfortunately, the images are intermittent and may not be related to periods of the most intense erosional activity (Boardman, 2016).

Setting up monitoring schemes does not guarantee erosion: erosion was sparse in 2015-20.

Questions asked in the original aims may not be answered. The role of intense summer rainfall events on summer crops is uncertain because such events did not occur. On the other hand, questions emerged or became more relevant during the study: for example, connectivity, off-site impacts, the role of irrigation and mitigation measures (Figure 12). On post-harvest maize fields, it became clear that non-compliance with conservation advice was a major factor in explaining the risk of runoff and erosion (Boardman and Foster, 2020). During the monitoring scheme, the role of wash (or interrill erosion) became evident. Generally, wash was only recorded on fields without rills or gullies. This meant there was an under-reporting of wash. Fields saturated in the winter clearly displayed wash, whether there were rills or gullies (Figure9). The role of wash in pollution of freshwater systems merits further study (Evans, 2017).

Figure 12. Runoff due to irrigation of potatoes, 13/06/2008, near Midhurst, West Sussex: Hereabouts

Access to data from the early years of 2000 and 2006, meant that the later period of low rainfall and very limited erosion could be seen in a longer-term context. A wet autumn, with widespread bare ground, can still lead to serious erosion.

A monitoring scheme, covering almost 200 fields, can allow for spatially focused studies where the need arises (a nested approach). An example of this is the flooding of Easebourne and parts of Midhurst in 2014 and the instigation of so-called grassed waterways as a mitigation measure (Boardman and Vandaele, 2015).

Conclusion

The monitoring scheme was set up in an area of known erosion risk on arable land. The database for the whole period (2000-20) shows some high rates, and an unusual extent of erosion with over 65% of surveyed fields eroding in two exceptional years. The project also shows the high degree of potential connectedness of fields to the river.

Erosion rates and extent in the period 2015-20 was very low due to relatively low rainfall. Erosion that occurred was localised and confined to small areas of bare ground in the winter.

The monitoring scheme provided data for emerging issues of potential connectivity of fields to the river and thus pollution, irrigation, and the need for mitigation measures especially regarding post-harvest maize.

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Conflicts of Interest

The authors declare no conflict of interest.

Data availability

The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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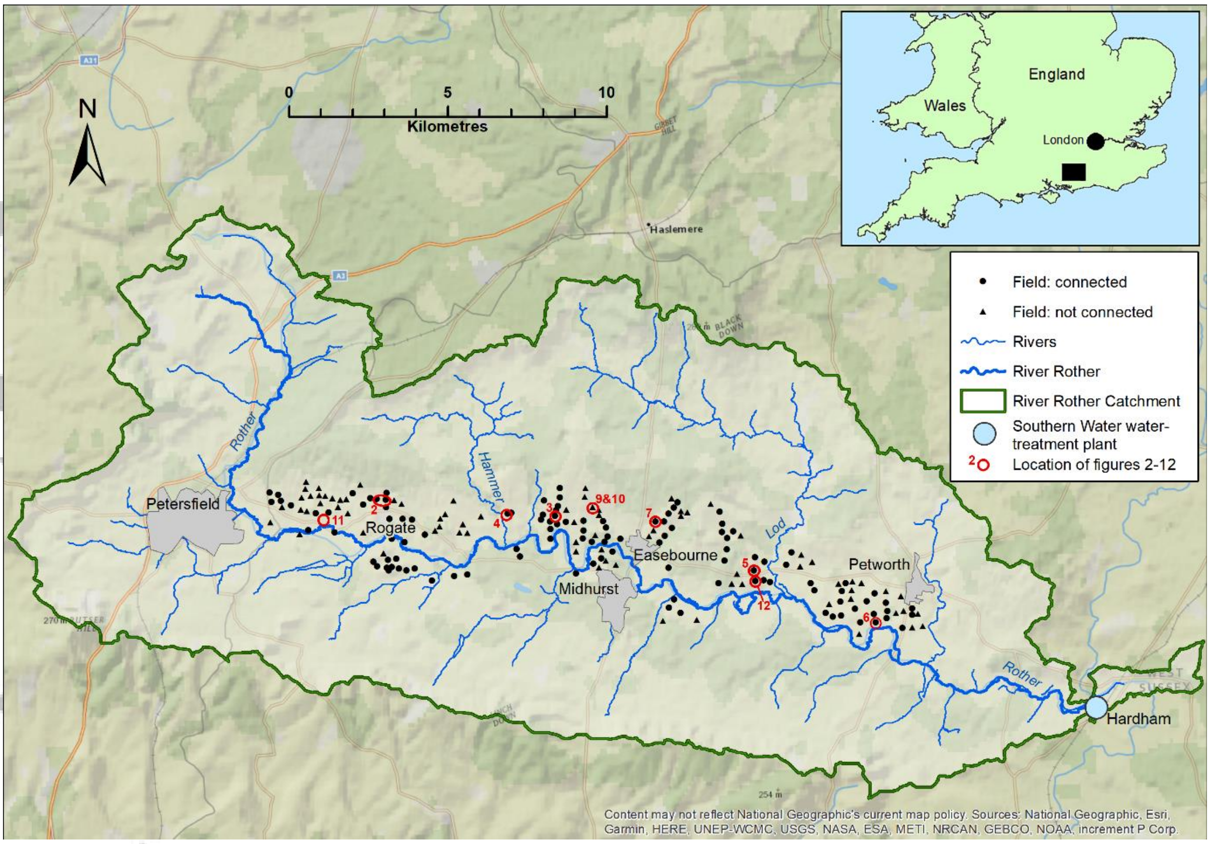

Figure 1. Location of the Rother valley; distribution of monitored fields, potentially connected and unconnected to the river

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Figure 2. Erosion north of Rogate, West Sussex, March 2001

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Figure 3. Erosion on winter cereals, 11/12/2006, near Midhurst, West Sussex with an approximate loss of $180m^3\ ha^{-1}$ for the 7.5 ha field

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Figure 4. Ephemeral gully in winter cereals, 15/01/2013, Iping, West Sussex

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Figure 5. Erosion on winter cereal, 22/01/2014, near Lodsworth, West Sussex

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Figure 6. Ephemeral gully in winter cereals, 05/02/2014, near Petworth, West Sussex

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Figure 7. Gully in post-harvest maize field, 05/02/2014, Midhurst, West Sussex

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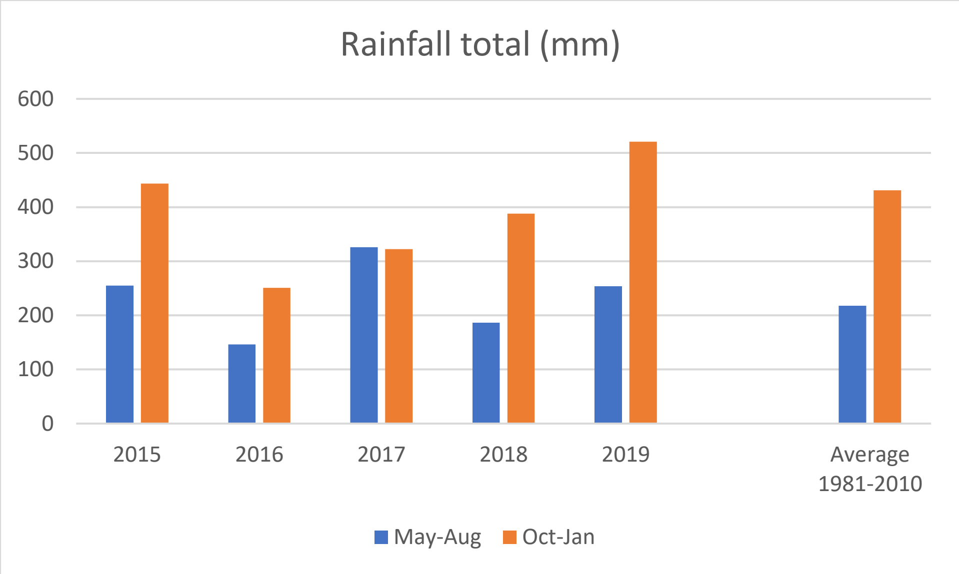

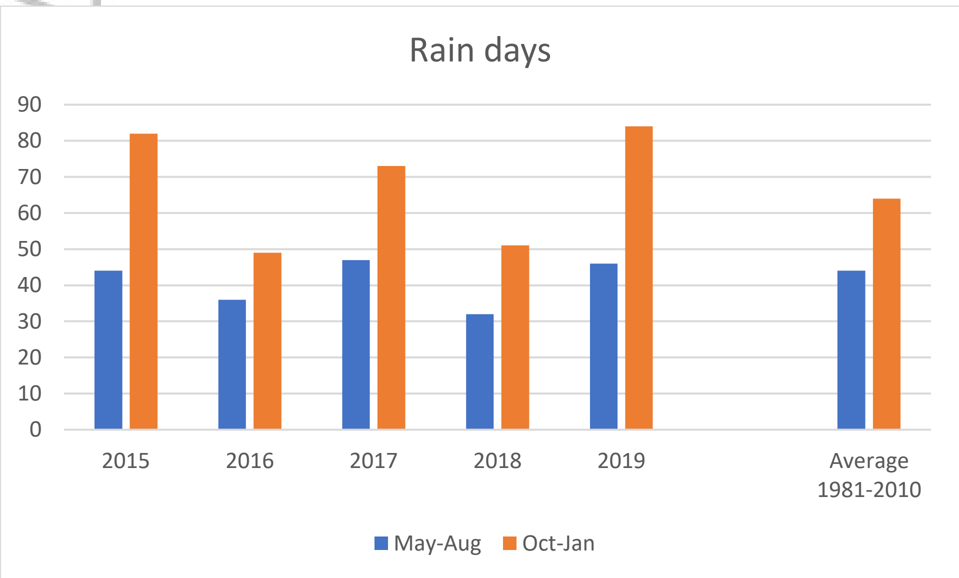

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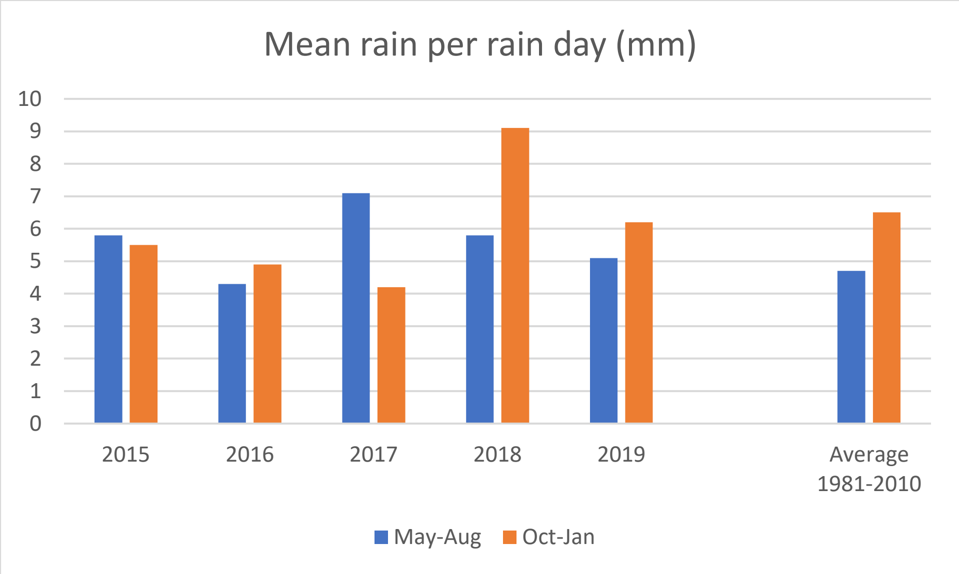

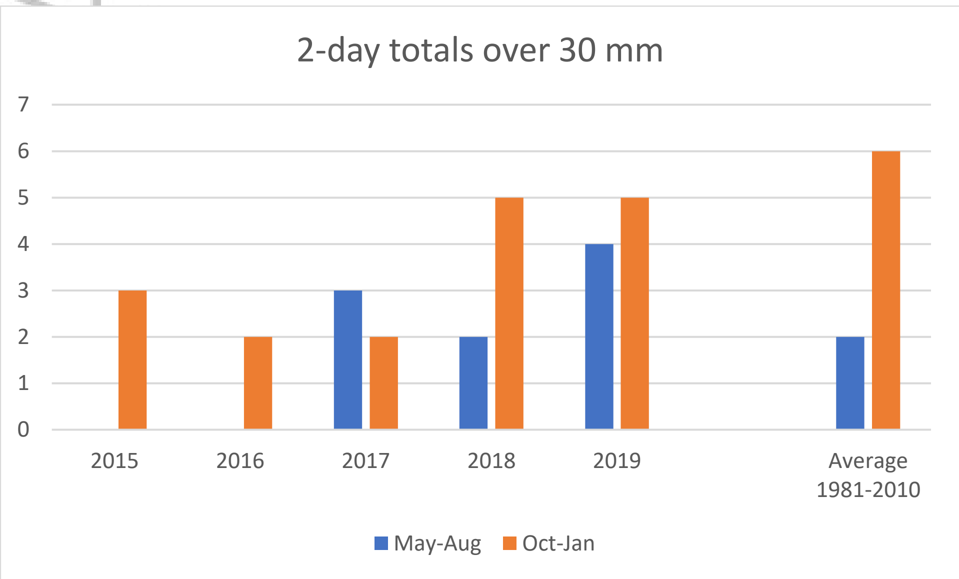

Figure 8. Rainfall data for the monitoring period (2015-20) at Petworth Park, West Sussex

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Figure 9. Erosion on saturated winter cereal field, 14/01/2019, Woolbeding, West Sussex

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Figure 10. Flow through bank into sunken lane, 14/01/2019, Woolbeding, West Sussex

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Figure 11. Ditch being dug to protect A272 road from muddy flooding, 01/11/2008, Slade Lane, Rogate, West Sussex

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Figure 12. Runoff due to irrigation of potatoes, 13/06/2008, near Midhurst, West Sussex

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Table 1. Some results from erosion monitoring in Europe: updated from Boardman (1998a)

Country and monitored area	Period	Erosion rate and source
Central Belgium 86 fields	1981-85	Mean: 3.6 t ha^{-1} (Govers, 1991)
North-east Scotland	1984-86	Mean: 6.7 m^3 ha^{-1} Median: 2.5 m^3 ha^{-1} (Watson & Evans, 1991)
UK: Soil Survey of England and Wales; 17 localities (c. 826 km^2)	1982-86	Mean: 2.3 m^3 ha^{-1} (Evans, 1995)
UK: South Downs	1982-91	Median: 0.5 – 5.0 m^3 ha^{-1} yr^{-1} (Boardman, 2003)
Southern Sweden: 90 km^2	1986-88	Median: 0.8 t ha^{-1} yr^{-1} Alstrom & Bergman-Akerman, 1992)
Northern France: 33 small catchments (3-95 ha)	1988-91	0 – 11.7 m^3 ha^{-1} yr^{-1} (Ludwig et al., 1995)
East Anglia, UK: 105 fields	2004-13	Rate not stated: low (Evans, 2017)
Northern Germany: 86 fields (465 ha arable land)	2000-16	Mean: 0.85 t ha^{-1} yr^{-1} (Steinhoff-Knopp & Burkhard, 2018)
Canton of Berne, Switzerland: 203 arable fields	1997 - 2017	Mean: 0.74 t ha^{-1} yr^{-1} (1997-2007) 0.20 t ha^{-1} yr^{-1} (2007-17) (Prasuhn, 2020)

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Table 2. Rother valley: field surveys post-2000

Year	Fields surveyed (n)	Erosion index (see Table 3)	Number fields with erosion* and (wash)	Percentage surveyed fields with erosion or wash
Winter 2000/01	194	685	124 (5)	67%
Winter 2004/05	194	164	34 (6)	21%
Winter 2006/07	71	246	51	72%
Winter 2012/13	194	261	59 (6)	34%
Winter 2013/14	28	93	19	68%
Winter 2014/15	194	72	16 (2)	9%
Summer 2015	116	20	2 (8)	9%
Winter 2015/16	134	82	17 (15)	24%
Summer 2016	151	25	4 (18)	15%
Winter 2016/17	142	31	6 (13)	13%
Summer 2017	161	7	1 (2)	2%
Winter 2017/18	172	18	4 (2)	4%
Summer 2018	175	28	13 (6)	11%
Winter 2018/19	167	171	38 (15)	32%
Summer 2019	185	48	10 (7)	9%
Winter 2019/20	180	152	29 (15)	24%

*Rill, gully or fan

Table 3. Index of erosion

Observed on field	Assigned value	Approx. rate
wash	1	<1m^3/ha
rill	2	
rills	4	
gully	5	
gullies	7	
Extensive gully/rill system	10	>40m^3/ha

Table 4. Winter 2013-14 monthly rainfall totals (mm)

Month	Monthly total
October 2013	187
November 2013	73
December 2013	224
January 2014	268
February 2014	221

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Table 5. Large-scale erosion events in the Rother valley 2000-20

Date	**Land use**	**Erosion rate ($m^3 ha^{-1}$)**	**Rainfall**	**notes**
Winter 2000-01	varied	No measurement; 105 fields with gullies	1429 mm (annual total); 80 mm 15 Sept. 194 mm Sept, 277 mm Oct	Extensive and severe erosion late 2000 (Google Earth and air photos) (Figure 2)
Autumn 2006	Post-harvest potatoes and winter cereals	180, 24, 91, 56, 50, 49, 31	947 (annual total); 28 and 29 Sept: some variation between local gauges: 26, 33, 52, 25 mm	7 fields with high rates Boardman et al. (2009) (Figure 3)
Winter 2012-13	All winter cereals	6 fields > 10 $m^3 ha^{-1}$; one at 42 $m^3 ha^{-1}$	6 days with >20 mm d^{-1} Nov - Feb	Boardman and Favis-Mortlock (2014) (Figure 4)
Winter 2013-14 February 2014	Winter cereal Winter cereal	1.54 ha section of field: 199 $m^3 ha^{-1}$ Serious erosion over limited area	Dec 13 224 mm Jan 14 268 mm Feb 14 222 mm	(Figure 5) (Figure 6)
Winter 2014	Post-harvest maize	Gully >1m deep, 1000 m long = c.250 m^3		(Figure 7)
Early spring 2019	Spring cereal	2 fields (24.5 ha); soil loss from 3 major gullies 135.5 m^3 = 5.5 $m^3 ha^{-1}$	8 Feb: 31 mm 3 March 26 mm	

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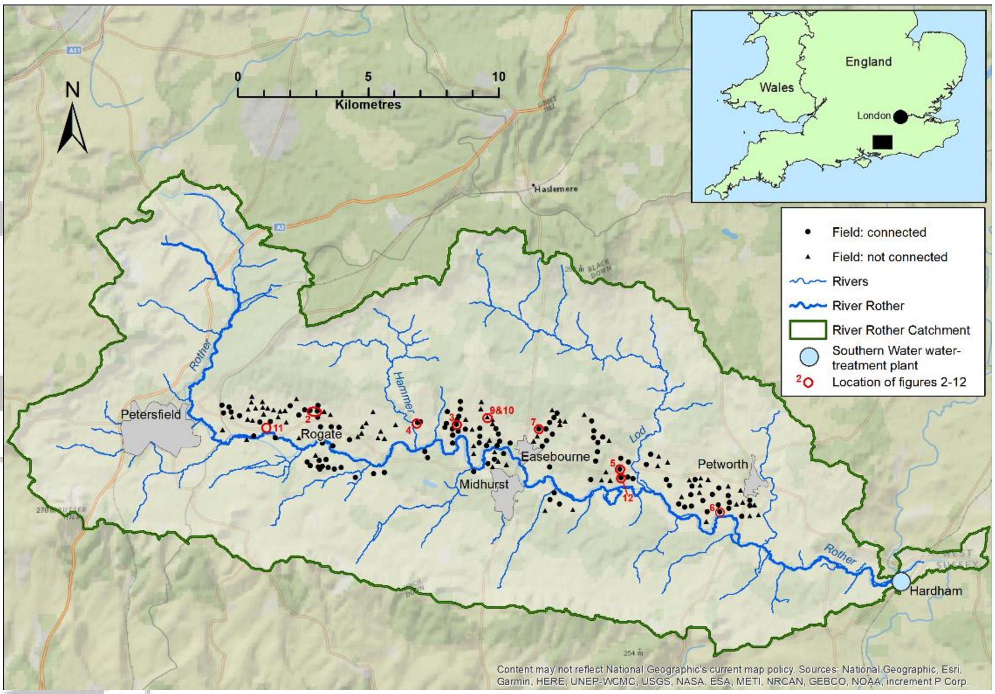

We describe a 5-year soil erosion monitoring programme in the Rother valley, UK. Monitoring is based on field observations and measurement, and remote sensing. The project is set in the context of over 20-years of erosion data for almost 200 arable fields. Occasional episodes of serious erosion lead to muddy flooding and river pollution.

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