Factors controlling soil erosion and runoff and their impacts in the upper Wissey catchment, Norfolk, England: a ten year monitoring programme

Short title: Monitoring soil erosion and its impacts, Norfolk, England

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Abstract

A part of the upper Wissey catchment in central Norfolk, eastern England was monitored for ten years to assess the extent and frequency of erosion and runoff, their causes and impacts. Surface wash occurred more widely and more frequently than expected. Runoff and erosion took place a number of times in a year in a range of autumn- and spring-sown crops, and occurred dominantly down tractor wheelings or ruts left after harvesting potatoes or sugar beet under wet conditions. Over ten years erosion affected about half the 105 fields monitored, although not often more than once. Erosion was more extensive in autumn-sown cereal fields, but often more severe and with greater off-field effects such as muddy flooding of roads from spring-sown late harvested crops such as potatoes and sugar beet. Runoff from outdoor pig fields also flooded roads and houses. This study confirms other studies of the extent, frequency and severity of erosion in Britain, that rill erosion does not occur in every field in the landscape, that in the main fields do not erode frequently and rates of erosion are generally small. Runoff and erosion within a field took place more frequently than had been suspected. Compaction and destruction of topsoil structure by machinery especially at harvest, or by outdoor pigs, is important in initiating runoff. Rates of erosion were generally very low and will not affect soil productivity adversely over the short-term. However, flooding of roads and property, and especially pollution of water courses by sediment, nutrients and pesticides are important off-field impacts. Monitoring such as this sheds light on the problems of modelling and predicting rates of erosion.

Key words: Soil erosion, runoff, land use, impacts of runoff, monitoring

Introduction

Assessments made by different researchers of the extent, annual occurrence and rates of rill erosion in farmers' fields in Britain give a coherent picture (Evans et al., 2016). However, much of this work is based on assessments made at a particular time of year following a noteworthy storm or a prolonged period of rainfall. There has been little monitoring of runoff and erosion to assess how often they occur over a (crop) year. Between 2003 and 2006, as part of the European Union funded Agricultural Measures for Water Management (AMEWAM) project (Evans, 2006a), a 'block' of land in the upper Wissey catchment, Norfolk, eastern England (Figure 1) was chosen to monitor runoff and erosion. The initial aims of the UK part of the

AMEWAM project were to: (1) monitor erosion; (2) provide information to model runoff and erosion risk; and (3) provide information to help alleviate erosion. Here, only the results of the monitoring part of the study, as part of what turned out to be a ten year study, will be described.

AMEWAM evolved from the Norfolk Arable Land Management Initiative (NALMI) which covered 13 parishes in mid-Norfolk (Figure 1). NALMI was funded by the Countryside Agency and aimed to improve the economic, environmental and social impacts of farming by maintaining a healthy and attractive environment and promoting thriving rural economies and communities (Appleby, 2004). One aspect of the initiative was to protect water courses, especially the quality of water flowing in them. This was done by promoting, for example, grass buffers along stream banks to cut down runoff from the land carrying into the stream sediment which could mask fish-spawning gravels, nutrients which can enrich the water course and cause excessive algal and plant growth, and pesticides which may impact on the stream's fish and wildlife.

The NALMI block of land was considered too large in area for its land use (cropping) and erosion to be monitored easily, say during a daily visit. Also, it was not ideal for a study of erosion, much of it was considered at very low or low risk of rill erosion with few fields with slopes steeper than 3°, then considered more vulnerable to erosion. For the AMEWAM project therefore a ‘block’ of land 9 x 8 km was chosen (Figure 1), some of it on the west outside the NALMI area to include slopes and soils more vulnerable to erosion. During the three years of the AMEWAM project it was realised that streamflow was more ‘flashy’ and was often more turbid than expected with little evidence of soil erosion by rills. Although at the end of the three year project other sources of flow from the land carrying sediment had been identified, roads, tracks, field drains, and stream channels themselves could erode (Evans, 2006a & in prep.), it was considered wash or near-surface flow from the land must also be important. That was confirmed shortly after the project ended, a visit made 27th February 2007 at the end of a storm (of *c.* 11 mm) falling onto saturated soil was seen to have initiated turbid wash that flowed directly to the stream from land that had been allowed to revert to grassland (set-aside; Figure 2c). To get a better assessment of runoff and erosion from farmers' fields therefore the monitoring project was extended for a further 7 years. The aims of the study were not only to monitor runoff and erosion but also to better understand why and when they took place and the factors controlling the extent and severity of runoff and erosion.

Where erosion took place is not specifically referred to in the text, to avoid embarrassing individual farmers as all farmers were following what is considered to be best practice.

Methodology

Catchment description

To ease fieldwork for the 10 year monitoring exercise, the targeted block of land was further reduced in size, stretching 7 km from north to south and 8 km east to west and is defined by national grid reference points TF860030-TF860100 and TF940030-TF940100. In the north of the 'block' of land the River Wissey flows from east to west before turning south and borders the western margin. The relief is subdued, lowest lying ground (*c.*30m OD) is in the south west corner of the block, highest land (*c.*84m OD) in the north east. Slope gradients were estimated between contour lines spaced at 5m intervals. Gradients are rarely > 3°, mostly on north and east bank tributary valley sides. Chalky till of Anglian Age overlies Cretaceous chalk. Soils on ridge crests or very gentle slopes (the Beccles 1 and 2 soil associations; Table 1) are considered at very slight risk of erosion (Evans, 1990). Better drained soils over chalky till (Burlingham 1 and 3 associations) can include coarser textured soils. The Burlingham 1 association, often on more sloping land is considered at moderate risk of erosion, the Burlingham 1 at slight risk. On the eastern side of the Wissey, flanking the valley floor, are shallow soils on chalk at moderate risk of erosion. In the main valley floor, with its high water table, the deep permeable sandy and peaty soils (Isleham 2 association) are grass covered. Mean annual rainfall is *c.*700 mm and much of the land is cultivated (Hodge et al., 1984).

Monitoring

To assess where rills occurred a route along minor roads was taken that traversed areas where slopes > 3° are more frequent or allowed access to slopes > 3° along valley sides. On most visits the same route was taken, traversing 18.5 km along roads and *c.* 6 km of walking. The round trip from Cambridge was *c.* 177 km. Land use and crop type were noted in accessible fields. The route was taken whenever rainfalls ≥ 10 mm occurred in the locality, as near in time to the event as possible, often within a few days; or to check, for example, when field drains had stopped flowing or to ascertain visually and photographically the turbidity or the state of water courses. Early in the study rainfall data were supplied daily over the internet (through the AMEWAM project) but thereafter as a guide daily rainfall was checked for 2 sites (Ipswich *c.* 62 km to south east; Cromer *c.* 45 km north east) reported in the press

(The Guardian newspaper). Local knowledge of the weather in Cambridge (*c.* 55 km south west) and its impacts on flow and (similar) soils was also used for guidance. Daily rainfall was supplied after the event by a farmer located in the monitored area.

Initially it was considered that the presence of rills should be monitored but (see above) turbidity in streams occurred more frequently than rills were identified in the field, and hence evidence for surface runoff (wash) was sought. Photographs were taken of the erosion features – rills, deposition fans, lines of deposited soil particles indicating flow, surface wash if it occurred during a field visit. After the initial erosion event had occurred on each visit thereafter photographs were taken to compare with the originals to assess if there had been a further runoff event. In all, 133 visits were made from the first visit in December 2003 to the last two visits in January 2014. Visits were made in relation to crop years, from September (cultivation and drilling) to August (after harvest) for autumn-sown crops (e.g. wheat, some barley, oilseed rape, field beans) and for spring-sown crops (e.g. barley, rarely wheat, sugar beet, potatoes) from March (planting) to whenever the last harvest for sugar beet and potatoes and the following cultivations were carried out, often early the following year. To estimate volumes of soil eroded estimates of width and depth and lengths of channels were made or volumes of deposits (area x width x depth) estimated (Evans and Boardman, 1994).

Results

Erosion was not spectacular; no gullies formed that could not be crossed by machinery. Rills were generally small (Figure 2a), though occasionally larger (Figure 2b), wash (Figure 2c) transported small amounts of soil out of the field and sometimes turbid or clear water was seen flowing only down tractor wheelings (Figure 2d). The occurrence and extent of erosion and runoff is controlled by land use and management once a rainfall threshold has been exceeded. These factors, land use and rainfall will be dealt with before amounts eroded and the factors controlling severity of erosion are discussed. The impacts of erosion and runoff are then described.

Land use

Most field visits were made in 2004 (21), 2012 (19), 2007 (18) and 2005 (17) and least in 2011 and 2013 (11), 2010 (9), 2008 (8), 2009 (4). The variability in number of visits is mostly related to the weather, more visits in wetter years and fewer in drier years (Table 2), and its impacts (or not) on runoff, streamflow and drain flow. The lower number of visits in 2008 relates to difficult family circumstances. Not all the route was covered every visit. A total of 105 enclosed fields, as recorded on the 1:25 000 scale Ordnance Survey map, was monitored. However, in some years some fields would have more than one crop, for example maize as a cover crop for birds or left fallow or allowed to revert to set-aside or drilled to grass margins as part of an agri-environment scheme and so that field was counted as two. On average land use was identified in 110.4 fields, ranging over the 10 crop years from 106-115 fields (Figure 3). Altogether 20 crops were identified over the years, but many of these crops were planted in some years and not others, often in less than four years out of ten, and in some years a very small proportion of the crops in arable fields was not identified. Grassland and cereals are the most common crops (Figure 3). Winter cereals (wheat, occasionally barley) outnumbered ‘other’ cereals, which are dominantly spring sown, often barley, but not always easily identified as such if sown in later winter. Grass fields outnumbered winter cereals fields in the first four years; they are often much smaller in size than arable fields and dominantly under permanent pasture and usually near to farm buildings. The number of autumn-sown cereal fields increased over time, 17 in crop year 2003/4, 35 in 2012/13, peaking (47 fields) in crop year 2010/2011. This increase is largely associated with the decline in number of late-winter or spring-sown cereal fields, and fields planted to potatoes. Oilseed rape fields varied in number from year to year, probably related to drilling conditions in late August/early September. Weather and topsoil conditions prevailing (too dry or too wet) at a particular drilling season, for example September and October for winter cereals, or late February and March on for spring-sown crops, probably explain much of the variability in cropping from year to year, but crop prices prevailing around the time of drilling may also have been a factor. 'Key' crops (Figure 3) are those grown in 7 or more years, but exclude Blackcurrant bushes that were grown in some fields every year (1-6 fields over 10 years) but erosion was recorded in only one year, and land that was set-aside (1-6 fields) was recorded in 8 years but runoff and erosion seen only in two years.

Land use, erosion and runoff

No erosion or runoff was seen in grassland (285 fields, 27 % of total number of fields monitored over 10 years) nor in 20.5 % of arable fields. No erosion was recorded in a number of land uses possibly due to the low numbers of fields recorded: spring-sown oilseed rape (4 fields), peas (2), grass and weed regrowth on uncultivated land (4) where runoff was inhibited and the soil protected from splash erosion; or rough bare soil (7 fields) that stored the incoming rainfall and/or rainfall rapidly infiltrated into it. Erosion or runoff was not often recorded in mustard (2 of 6 fields), brassica fodder crops (2 of 7), spring-sown beans (1 of 4), autumn-sown beans (4 of 21), maize (2 of 12), and land down to set-aside (2 of 20). Again, numbers of fields sampled are small. Rills and wash were recorded dominantly in autumn sown crops, especially cereals (Table 3) Erosion occurred every year in sugar beet fields, in many years after harvest (see below). Erosion occurred in most years (7) in fields of outdoor pigs, and wash may well have occurred in other years but left little evidence, and erosion was recorded in 6 years in spring-sown barley and in maize sown a little later. Erosion occurred in potatoes, often after harvest (see below), in the first three years of monitoring, but not thereafter as fewer fields to rent became available to growers of the crop (for reasons, see below). Rills and wash occurred when soils were dominantly bare of vegetation, but also when land was fallow with weeds or in various states of roughness from smoother, cultivated and rolled surfaces prepared for drilling to ploughed ground. Wash also occurred on fully vegetated land set-aside from cropping, or in grassed field margins or tracks. Fewer eroded fields were recorded in 2006 and 2009, most in 2012.

Over the ten years on average 37 % (range 25-53 %) of the 304 winter cereal fields suffered erosion, and 29 % of the 107 autumn-sown oilseed rape fields (0-60 %). A greater proportion of the 86 fields under sugar beet (49 %; 22-67 %) and outdoor pigs (53 %; 0-100 %) eroded, though many fewer fields (19) of pigs were monitored. Of the 43 spring-sown cereal fields 21 % (0-67 %) suffered rill and wash erosion. In the first three years of monitoring most potato fields eroded (9 of 11) but in the following seven years potatoes were grown in one field in each of four years, and no erosion was recorded in those years, a ten year average of 25 %.

Extent and frequency of erosion and runoff

Over 10 years erosion was recorded in 55 of the 105 fields (52.4 %). Almost a quarter of those fields suffered erosion once in ten years (Figure 4); some fields eroded every year and some more than once in a year as the surface changed from bare cultivated soil to become covered by crop for example, or more than one part of the field was drilled to a different crop, for example mostly to winter cereal but with a late spring sown cover crop (maize) for birds.

Erosion could occur in the same field many times in a crop year; on average erosion occurred up to 6 times year^{-1} in autumn-sown crops (range 3-9; maximum in cereals (2004/5) and beans (2006/7)), 4.7 year $^{-1}$ in spring-sown crops (2-10; maximum in potatoes (2004/5)) and 4.3 times year $^{-1}$ for other crops (2-12; maximum in outdoor pigs (2012)).

Erosion and runoff events

As noted above, over the 10 crop years no channels (gullies) formed that interfered with working or harvesting the land. Photographic evidence, often of depositional features within or at the end of channels, showed that rills could form and later incision within them could occur; the later incision was counted as a separate event. Similarly, from photographic evidence, wash could also occur as a number of discrete events. Occasionally, water clean of sediment was seen flowing down tractor wheelings or in the furrow adjacent to the grassed edge of the field or over a saturated soil surface (Figure 2d).

Monthly and annual rainfall (Table 2) varied greatly over the ten years 2004 to 2013, as do the number of fields that eroded (Table 3). The wettest year was 2008 (965.7mm), the driest 2011 (470.6 mm), and monthly rainfall varied from 0.0 mm (April, 2007) to 168.0 mm (Aug, 2008). Autumn- and spring-sown ‘crop years’ do not coincide with those for calendar years (Table 4), for autumn-sown crops the year is taken as September (drilling) to August (after harvest), and spring-sown crops March (drilling) to February (late harvested sugar beet or potatoes to next ploughing), but erosion and runoff can occur in other land uses at any time during the calendar year. The numbers of fields that erode in a calendar or crop year do not relate well to annual rainfall totals (R^2 <0.08).

Over the 10 years 788 discrete erosion and runoff events were recorded (Table 5). Rills or wash or flow occasionally happened in the same field. Erosion and runoff events occurred dominantly in autumn-sown crops (cereals, oilseed rape, beans - 53%), mostly in cereals (39%), and much less in spring-sown (sugar beet, potatoes, cereals, beans, oilseed rape - 24%). Of the other ‘crops’ erosion and runoff occurred most frequently in outdoor pigs (8 %) and 6 % of events took place in soils that were dominantly bare of cover. Of the erosion and runoff events, 70 % (550) dominantly occurred in tractor wheelings, mostly tramlines used when spraying the crop, or occasionally in ruts after harvesting of sugar beet or potatoes, though varying between crop and land use types (Table 6). Erosion and runoff also occurred down other features created by agricultural machinery, such as potato furrows or the last plough furrow by a grassed field margin, or patches of bare soil in potato and sugar beet fields in headlands or at corners to allow turning space where rows met. Only in fallow fields and outdoor pig fields did erosion and runoff occur mostly as wash/flow across the bare soil surface. Wash occasionally occurred across saturated field headlands much compacted by machinery not only when cultivating, drilling and harvesting the crop but also when further subjected to turning by machinery to work across the rest of the field.

The number of erosion and runoff events varied from year to year (Table 7), reflecting wetter and drier years and if rain fell at times when the land was most vulnerable to erosion, often when the topsoils were saturated in the winter part of the year. Annual rainfall totals for calendar years relate better to erosion and runoff events than to the number of eroded fields recorded in that year or crop year, the higher the rainfall in the calendar year the larger the number of events (R^2 0.517) as the fields often suffered more than one runoff event.

105 erosion events were classified according to how many erosion/runoff features were noted in that event: large rills (>*c.*0.1 m wide); small rills (<c.0.1 m wide); traces (small rills of short length); wash; clear flow. The most severe event was recorded in the field on 7th August 2012 in autumn-sown crops, sugar beet fields and one field with outdoor pigs. The erosion was related to a 32 mm intense storm of 5th August onto a soil almost wet up throughout the soil profile (estimated Potential Soil Moisture deficit of *c.*30 mm) and field drains were flowing. The event created in 22 fields 7 large rills; 16 small rills; 1 trace of a rill; 4 signs of wash; and some still clear water flowing down tractor wheelings (i.e. 7/16/1/4/1). Events such as this were widespread in England in August 2012 (Adrian Collins, *pers. comm*.). Other severe events were associated with rainfalls of 11.7 mm falling onto soils at field capacity with field drains flowing 14th February 2013 (6/12/6/5/0), 18.7 mm on 7th December 2012 (5/6/2/5/0) and 13.0 mm on 12th January 2011 (4/11/6/4/0). The smallest events, where clear water was still flowing down tractor wheelings in autumn-sown cereals (i.e. 0/0/0/0/1) were related to rainfalls of 3.0.mm, 3.5 mm 4.7 mm falling

onto saturated soils. Severity of erosion in an event was ranked (1-105) from most severe to least, and related to rainfall amounts. Poor correlations were found between rainfall amounts and severity of erosion for years (R^2, 0.139), winter months (Sep-Feb, R^2, 0.119) and summer seasons (Mar-Aug, R^2, 0.206), larger rainfalls being likely to cause more severe erosion.

Rates of erosion

Amounts eroded were not often measured because of lack of time when carrying out the traverses and because volumes transported were mostly (very) small, for example, often a small rill or signs of wash down the occasional compacted wheeling in a compacted headland. Estimates of volumes moved in fields were made on 55 occasions after a number of larger erosion events. The range in values of volumes eroded or deposited by rills within a field or part of a field is highly positively skewed, ranging from 0.03m³ to 150.0 m³ (Figure 5), with a mean of 5.86 m³ and a median value of 1.2 m³. Large volumes eroded in an event were recorded when erosion occurred across a field dominantly bare of crop (oilseed rape 5.08 m³, winter beans 4.6 m³), often associated with many tractor wheelings (onions, 58 m³; sugar beet, 8.03 m³, 5.76 m³, 4.07 m³; harvested potatoes 4.4 m³) or the last plough furrow separating crops (maize/winter cereal 8.23 m³, and especially in a winter cereal following a crop such as sugar beet harvested when the ground was wet and the soil became compacted (150m³, 9.36m³). In one instance, in a field of onions, an irrigation pipe leaked cutting a large rill with an estimated volume of 3.1 m³. High values were also recorded in fields of outdoor pigs (10.5m³, 5.0m³). The rate of erosion when averaged across the whole field is also highly positively skewed

(0.001-8.33 m^3ha^{-1}; mean 0.46 m^3ha^{-1}, median 0.16 m^3ha^{-1}), although higher rates were recorded when related only to contributing area, for example in strips of maize sown as a cover crop for birds 11.76 m^3ha^{-1} and 43.0 m^3ha^{-1}or a sugar beet headland 6.7 m^3ha^{-1} and 5.6 m^3ha^{-1}.

Off-field Impacts of runoff and erosion

Runoff was noted to have flooded roads 37 times in 10, years, mostly from outdoor pig fields, but also from sugar beet fields both in summer storms and after harvest, and from some winter cereal fields and harvested potatoes. Roads were flooded frequently by runoff from harvested potato fields and fields of outdoor pigs in the winter of 2004/05, and again from outdoor pig fields in October to December 2012. A number of houses in North Pickenham were flooded 5th August 2012 by runoff from an outdoor pig field after a storm of *c.*32mm. At least two houses had to be extensively refurbished after being flooded. Barriers and sediment traps were constructed on occasions to stop runoff and sediment reaching roads and property. Roadside drains were blocked by sediment so exacerbating flooding. Roads, ditches and roadside sediment traps had to be cleared of mud or sand. Turbid runoff from fields reached water courses directly on 21 occasions.

Discussion

This study confirms other studies of the extent, frequency and severity of erosion in Britain (Evans et al., 2016), that rill erosion does not occur in every field in the landscape, that in the main fields do not erode frequently and rates of erosion are generally small, especially when averaged across a field or landscape. The findings are not dissimilar to those of Prasuhn's 10 year study in Switzerland (Prasuhn, 2011; 2012), discussed elsewhere (Evans, 2013). In this study, more intensive monitoring has given better information on the causes, frequency and extent of erosion events and their impacts. Rill erosion mostly takes place down tractor wheelings, as found elsewhere in Britain (Silgram et al., 2010), especially down compacted field headlands, and down the last plough furrow or other implement induced furrows within a field. It is noteworthy that runoff takes place down tractor wheelings created both by conventional tyres and low-pressure tyres. When soils are wet conventional tyres create deeper ruts and compact the soil more at depth but for the wider profile of low pressure tyres, although spreading the load better, compaction is sufficient along with the wider width to create a greater surface area for runoff to gather. The statistical distribution of rates of erosion, markedly positively skewed, also reflect other British findings (Boardman & Favis-Mortlock, 1999; Evans, 2006b).

The extent of erosion, erosion occurring in *c.*5 % of fields, reasonably reflects the erosion classification risk (Evans, 1990) of the Newmarket 2 and Burlingham 3 soil associations, considered to be at moderate risk of erosion (1-5 % fields affected). More fields eroded than predicted with regard to the Burlingham 1 soil association considered at low risk (< 1 % of fields erode each year), the risk being largely based on the association being found dominantly on crests and gentle slopes. It is noteworthy that a heavier textured soil association on chalky boulder clay (Hanslope) is considered to be moderately at risk where slopes > 3 ° flank valley floors (Evans, 1990) and that freely drained coarse loamy or sandy soil associations dominantly under arable such as the Wick or Newport associations are at moderate or high risk

(5-10 % fields erode each year), and those soil series (Wick and Newport) are found in the Burlingham 1 association (SSEW, 1983).

It is not easy to decide for what area of land rates of erosion should be estimated. In plot experiments the rate measured for the plot is multiplied by a factor to give t ha^{-1} or m^3ha^{-1}, but to which part of the landscape should that estimate be applied? The same problem applies to estimates of volumes eroded made in the field, as here. If the estimate is just for the rilled area the rate of erosion will be very high, if it is for the contributing area, for example a tractor wheeling, the rate will be lower but still high. If it is for the catchment, that is the land sloping toward where the rill will form, the rate will likely be lower, how much lower will depend on the size of the catchment. If the estimate is for the field, the rate will generally be lower than for the catchment which will often be contained within the field. If it is for a landscape or for example a soil association, the rate will be lower still (Evans, 2002). Modelled rates of erosion are often for a field or a landscape, i.e. at the lower end of the possible range of estimates.

Estimated rates of erosion for the fields in the Wissey catchment are mostly low and within the range of previous measurements (Evans et al., 2016), and when averaged over a number of years are lower still. Thus, the largest erosion event in the ten years of monitoring was estimated at 150 m^3 over the area of the field affected but only 8.3 m^3ha^{-1} over the whole field, and over a ten year period 0.8 $m^3ha^{-1}yr^{-1}$, though slightly more than that because the field has eroded in 4 years out of ten, but the other events were small, ≤ 0.2 m^3ha^{-1}. Over ten years therefore the mean rate of erosion will likely be of the order of ≤ 1.0 $m^3ha^{-1}yr^{-1}$ or a surface lowering of ≤ 0.1 mm yr^{-1}. With regard to a reduction in soil depth affecting crop yield such a rate will not be noticeable over the short term, say a generation, especially when considered with the variability in yield from year to year related to the variability of the weather and the incidence of crop disease.

Predicting rates of future erosion in the Wissey catchment will not be easy, as noted above, for which part of the field or landscape is the rate to be estimated? Also, when, as found in this study, no factor explains much of the predictive regression equation. Rates of erosion cannot be related to slope factors; soil factors may be important, but only when the surface is bare of vegetation. Rainfall amount is a poor predictor. In this study rainfall amount could not be related to severity of erosion as indicated by numbers of large and small rills. This may be a problem of how the ranking of rills is carried out, for example one large rill will have a larger ranking than a number of smaller rills, even though that number of small rills may account for a larger loss of soil. It may be that rainfall intensity is key for predicting erosion rate. However, the rain will have to fall on to bare soil for a sufficient period of time to cause the formation of rills. Thus, a heavy storm of 14.5 mm of rain falling in 20 minutes on 15th July 2007 onto bare soil in an outdoor pig field initiated sheet flow, but no rills formed. Similarly a 25.5 mm storm of 15th June 2009 caused turbid runoff down tractor wheelings, but no rills formed. Reasons for a poor correlation between rainfall and erosion in the upper Wissey catchment are: (1) that intense storms rarely fall onto bare soil when it is most at risk of erosion for such events most often occur in summer when the ground is protected by crop; (2) soils in tractor wheelings and in outdoor pigs fields are often compact and more resistant to erosion; (3) only some parts of a field may be more vulnerable to runoff than others, for example, compacted field headlands.

Erosion occurred proportionately more in autumn-sown cereals than in autumn-sown oilseed rape. The latter was drilled earlier often with a higher nitrogen fertiliser input and covered and protected the ground quicker and tractor wheelings often became overgrown earlier. Similarly a smaller proportion of spring-sown barley eroded because the crop rapidly covered the ground in spring. Crops that were more vulnerable to erosion such as sugar beet and potatoes are more at risk not only because they often take a longer time in spring to cover the ground but also because if harvested in wet conditions rain falling onto compacted ruts or onto a structurally damaged topsoil cannot infiltrate rapidly and so runs off the land. The land most at risk of runoff in this study was the land used for rearing outdoor pigs. The soil was bare for much of the two years the pigs were on the land, and the topsoil became compacted (Figure 6); though the compact soil might be more resistant to rill incision surface wash is encouraged (Figure 7). The vulnerabilities of the different crops (including outdoor pigs) to erosion and runoff in the upper Wissey catchment relate well to those defined in earlier studies (Evans, 2006b), i.e. rill erosion occurs most widely in winter cereals as those are the most widely sown crops, but occurs proportionally more and is more severe in row crops (sugar beet, potatoes) and maize, but most at risk of erosion and runoff are fields of outdoor pigs.

It is noteworthy that some of the more severe erosion and runoff events recorded over the ten years occurred in fields of potatoes and sugar beet that were harvested under wet conditions and then drilled to a winter cereal (Figure 8) or in fields of outdoor pigs (Figure 7). In all these fields the topsoil had been badly damaged. Potato fields had often been de-stoned before planting, further disrupting the soil's structure. Machinery used to harvest potatoes and sugar beet, the latter especially, was very large and heavy and wheel tracks, and those of tractors and trailers collecting the crop from the harvester, cover a large proportion of the field. Such treatment of the field leads to soil compaction at depth, rainfall cannot infiltrate rapidly below that depth so the topsoil rapidly becomes saturated. Because of damage to the soil and associated flooding of the adjacent road one farmer stopped renting out his land for potatoes and a second farmer stopped growing sugar beet because a large part of his field became flooded for a prolonged period when runoff could not easily reach the stream channel. Similar symptoms of soil compaction contributing to runoff have been described for four catchments in England and Wales (Holman et al., 2003), and catchments in South West England (Palmer and Smith, 2013), and Norfolk (Palmer et al., 2006).

Soil structural damage can persist for a number of years. Thus, a large field taken over by a new owner in 1998 never worked as easily as adjacent land with similar soils. The field had previously been managed in a way detrimental to the soil, the land was ploughed using large machinery regardless of the soil conditions and potatoes, a crop not suited to heavy land, had been grown and harvested when the land was too wet. It was found, when a pit was dug, the field had wet top-soils over a thin saturated grey layer overlying a dry compact subsoil. In late October 2009 the top 50 mm of soil in the field headland drilled to winter cereal was saturated but it was difficult to dig below that as the soil was dry and compact. The soil had horizontal platy structures parallel to the ground surface. In early summer 2005 a large part of the field was drilled to mustard and then allowed to ‘tumble down’ to set-aside comprising grass and weeds with moss on the surface. In late October 2009 small pits were dug in the set-aside; where moss was on the surface the soil was saturated and compact below 30 mm; where the grass was taller it was easier to dig than under the winter cereal in the cropped part of the field, the topsoil was drier, its structure better and not obviously platy. In a second pit dug in January 2008 to examine the state of field drains in a field *c.*3 km to the north of the one described above a well-structured plough layer with many roots overlay a greyer compact layer mostly 50-75 mm thick. Such compact layers, as noted above, restrict infiltration of rainfall into the subsoil and the plough layer becomes saturated more quickly and surface wash can occur widely across a field. Turbid wash, with little evidence of incision (traces, small rills) has been seen to flood roads in Suffolk, East Anglia (Evans & Boardman, 2016) and is probably becoming more frequent and widespread (Evans et al, 2016).

Wash can occur widely in a catchment but flow will not last long once rainfall has stopped and may leave little evidence that it has occurred. Unless fieldwork is carried out whilst flow is taking place it can be difficult, other than a rise in stream level being recorded, to ascertain that surface flow has taken place.

Wash can also transport fine-grained sediment, nutrients and pesticides into water courses. The herbicide metaldehyde is a particular problem in the River Wissey, frequently occurring above permitted levels, and may well, like high nitrate levels (River Wissey Partnership, 2014), be associated with surface runoff (Evans, 2009) as well as field drain flow. High nitrate levels in the Wissey can occur before field drains begin flowing (Evans unpublished. Nitrate and phosphate in Eastern Region rivers – Implications for complying with the Water Framework Directive. Oral presentation, British Society of Soil Science, Annual Conference, September 2005, Belfast). Fine sediment clogging the pores of gravel bed streams is known to inhibit spawning of Trout (Kemp et al, 2011). The River Wissey downstream of the study area is in parts managed to promote the presence of fish, riffles and pools have been created to encourage Brown Trout by providing suitable spawning sites.

Conclusions

The aims of the study were not only to monitor runoff and erosion but to better understand why and when runoff and erosion took place and the factors controlling their extent and severity. Fields down to grass are not subject to rill erosion, cultivated fields are – an unsurprising finding.

Monitoring such as this confirms where rills are most likely to form: in tractor wheelings on slopes ≥ 3° below slope convexities, especially in field headlands subjected to high traffic loads but, as noted above, also shows that surface wash occurs extensively across the landscape and at frequent intervals, especially in the winter months when top-soils are saturated. Hence, runoff and erosion took place more frequently than had been suspected. As elsewhere in Britain erosion occurs most widely in autumn-sown crops, but can be more severe, with more serious off-field impacts in spring-sown sugar beet and potatoes, especially when harvested late under wet conditions. Outdoor pig fields are most vulnerable to erosion and runoff. Hence, crop type and associated sowing and harvesting dates override rainfall as the major factors governing the occurrence and severity of erosion and crop rotations that include, for example, potatoes, sugar beet or outdoor pigs will be more at risk of more severe erosion. Thus, the findings reported here suggest that the guidance given on erosion risk assessment in the UK (Defra, 2005) is adequate in pinpointing soils and crops most vulnerable to rill erosion. However, the guidance is of little use for predicting rates of erosion and there is little basis for relating erosion risk (=severity of erosion) to slope angle as specifically set out in the guidance, as the assumption that amounts eroded are related to slope angle (i.e. steeper slope, more erosion) is unproven by field monitoring. The guidance under-predicts the extent and frequency of wash, which may often be the source of pollution of water courses.

Perhaps a more surprising finding is that even on soils considered at very slight risk of erosion, surface wash occurs extensively and frequently across the landscape, especially where top-soils have become compacted. It had been considered that wash erosion must occur more widely and often than is generally accepted (Evans et al, 2016), this study confirms that. Compaction of the topsoil is an important driver of runoff and erosion. The study suggests that if farmers are not affected by erosion, for instance by gullies that affect how the land is worked or by flooding of farm buildings, runoff and erosion are not considered a problem.

Models predicting erosion risk are often based on rates of erosion measured on plots. However, as demonstrated here, extrapolating rates estimated for a (very) small catchment when averaged out over a larger catchment or landscape much of which is not subject to rill erosion, will overestimate rates and risk of water erosion. Especially if rill erosion does not occur every year. The results given here confirm the criticism made in the introductory paragraphs of using models to assess soil erosion risk. Field monitoring such as that described here is not difficult or expensive to carry out and gives a good indication of the occurrence and risk of erosion in a locality. Such information can be used either to validate a model or give the foundations on which a model giving realistic results can be built.

In the upper Wissey catchment erosion will not impact on soil productivity over the short term. However, turbid runoff enriched with nutrients and carrying pesticides floods roads, can damage property and creates serious problems for the provider of drinking water that is taken from the river. Except where farmers lose crop due to flooding erosion and runoff costs them little. That is not so for property owners affected by flooding, or their insurers, nor for the water company that supplies to homes water taken from the river. Hence, over the short term it is the off-farm impacts which cost society most, not the loss of a resource. Mitigating widespread runoff, mostly comprising surface wash carrying very small amounts of soil, is a more daunting task than targeting parts of the landscape considered to be most vulnerable to rill erosion, which is largely what the models appear to do. Such widespread wash is a result of modern agriculture.

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References

Appleby M. 2004. Norfolk Arable Land Management Initiative. Final Project Report. June 1999 - May 2004. Draft. http://www.countryside.gov.uk/Images/NALMI final report published November 2004 (VERSION 1) tcm2-221 and no longer available. See also http://ukeconet.org/wp-content/uploads/2009/10/Experiences_from_the_land_management_initiatives.pdf; pp 8-11; accessed 7 November 2016.

Auzet A-V, Boiffin J, Papy F, Ludwig B, Maucorps J. 1993. Rill erosion as a function of the characteristics of cultivated catchments in the north of France. Catena 20 (1-2): 41-68.

Boardman J, Favis-Mortlock D. 1999. Frequency-magnitude distributions for soil erosion, runoff and rainfall – a comparative analysis. Zeitshcrift fur Geomorphologie, Supplementband 115: 51-70.

Boardman J, Verstraeten G, Bielders C. 2006. Muddy Floods. In Soil Erosion in Europe, Boardman J, Poesen J (eds). John Wiley & Sons: Chichester; 743-755.

CEC. 2000. Directive on establishing a framework for community action in the field of water policy. (2000/60/EC). Council of European Communities, Official Journal L237.

Collins AL, McGonigle DF. 2008. Monitoring and modelling diffuse pollution from agriculture for policy support. Environmental Science & Policy 11: 97-101.

Collins AL, Walling DE. 2004. Documenting catchment suspended sediment sources: problems, approaches and prospects. Progress in Physical Geography 28: 159-196.

Defra. 2005. Controlling Soil Erosion. A manual for the assessment and management of agricultural land at risk of water erosion in lowland England. PB 4093. Department for Environment, Food and Rural Affairs: London. Crown Copyright. http://adlib.everysite.co.uk/resources/000/110/543/soilerosion-lowlandmanual.pdf; accessed 14 February 2017.

Edwards AL, Withers PJA. 2008. Transport and delivery of suspended solids, nitrogen and phosphorus from various sources to freshwater in the UK. Journal of Hydrology 350:144-158.

ELD Initiative. 2015a. Economics of Land Degradation Initiative: Report for Policy and Decision Makers. Available at www.eld-initiative.org.

ELD Initiative. 2015. The Value of Land. Available at www.eld-initiative.org.

Evans B. 1995. Soil erosion and land use: towards a sustainable policy. In Soil Erosion and Land Use: Towards a Sustainable Policy, Evans B (ed). White Horse Press, Knapwell, Cambridge, pp. 14-26.

Evans R, 1990. Soils at risk of accelerated erosion in England and Wales. Soil Use and Management 6: 125-131.

Evans R. 1996. Soil Erosion and Its Impacts in England and Wales. Friends of the Earth Trust, London.

Evans R, 2002. An alternative way to assess water erosion of cultivated land - field-based measurements: and analysis of some results. Applied Geography 22: 187-208.

Evans R, 2006a. Runoff, soil erosion and sediment sources in central Norfolk, England. Final Report, AMEWAM Project, Hohenheim University, Stuttgart.

Evans R, 2006b. Land use, sediment delivery and sediment yield in England and Wales. In Soil Erosion and Sediment Redistribution in River Catchments, Owens PN, Collins AJ (eds). CAB International: Wallingford; 70-84.

Evans R, 2009. Pesticide runoff into English rivers – a big problem for farmers. Pesticide News 85: 12-15.

Evans R. 2013. Assessment and monitoring of accelerated water erosion of cultivated land – when will reality be acknowledged? Soil Use and Management 29(1): 105-118.

Evans R, Boardman J, 1994. Assessment of water erosion in farmers' fields in the UK. In Conserving Soil Resources. European Perspectives, Rickson RJ (ed). CAB International: Wallingford: 13-24.

Evans R, Boardman J. 2016a. The new assessment of soil loss by water erosion in Europe. Panagos P. et al., 2015. Environmental Science & Policy 54 438-447- A response. Environmental Science & Policy 58, 11-15.

Evans R, Boardman J. 2016b. A reply to Panagos et al., (Environmental Science & Policy 59 (2016) 53-57. Environmental Science & Policy 60: 63-68.

Evans R, Collins AL, Foster, IDL, Rickson RJ, Anthony SG, Brewer T, Deeks L, Newell-Price JP, Truckell IG, Zhang Y. 2016. Extent, frequency and rate of water erosion of arable land in Britain – benefits and challenges for modelling. Soil Use and Management, Issue Supplement S1: 149-161.

FAO and ITPS. 2015a. Status of the World's Soil Resources (SWSR). Technical Summary. Food and Agricultural Organisation of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

FAO and ITPS. 2015b. Status of the World's Soil Resources (SWSR). Main Report. Food and Agricultural Organisation of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

Hodge CAH, Burton RGO, Corbett WM, Evans R, Seale RS. 1984. Soils and Their Use in Eastern England. Bulletin No. 13, Soil Survey of England and Wales: Harpenden, Herts.

Holman IP, Hollis JM, Bramley ME, Thompson TRE. 2003. The contribution of soil structural degradation to catchment flooding: A preliminary investigation of the 2000 floods in England and Wales. Hydrology and Earth System Sciences 7: 754-765.

Jones JI, Murphy JF, Collins AL, Sear D, Naden PS and Armitage PD. 2012a. The impact of fine sediment on macro-invertebrates. River Research and Applications 28 (8): 1055-1071.

Jones JI, Collins AL, Naden PS and Sear DA. 2012b. The relationship between fine sediment and macrophytes in rivers. River Research and Applications 28 (7): 1006-1018.

Kemp P, Sear D, Collins A, Naden P, Jones I. 2011. The impacts of fine sediment on riverine fish. Hydrological Processes 25: 1800-1821.

Ludwig B, Boiffin J, Chadoeuf J, Auzet A-V. 1995. Hydrological structure and erosion damage caused by concentrated flow in cultivated catchments. Catena 25: 227-252.

Montanarella L. 2015. Agriculture policy: Govern our soils. Nature 528 (7580): 32-33.

Neal C, Jarvie HP. 2005. Agriculture, community, river eutrophication and the Water Framework Directive. Hydrological Processes 19: 1895-1901.

Oldeman LR, Hakkeling RTA, Sombroek WG. 1991. World Map of the Status of Human-induced Soil Degradation: an Explanatory Note. 2nd edition, International Soil

Reference and Information Centre, Wageningen, United Nations Environment Programme: Nairobi GLASOD.

Palmer RC, Smith RP. 2013. Soil structural degradation in SW England and its impact on surface water generation. Soil Use and Management 29: 567-575.

Palmer RC, Burton RGO, Hannam J. 2006. Soil structural conditions in the Wensum catchment during February 2006. NSRI, Cranfield University. Report for Environment Agency and Rural Development Service, UK.

Panagos P, Borrelli P, Poesen J, Ballabio C, Lugato E, Meusberger K, Montanarella L, Alewell C. 2015. The new assessment of soil loss by water erosion in Europe. Environmental Science & Policy 54: 438-447.

Prasuhn V. 2011. Soil erosion in the Swiss midlands: results of a 10 year field survey. Geomorphology 126: 32-41.

Prasuhn V. 2012. On-farm effects of tillage and crops on soil erosion measured over 10 years in Switzerland. Soil and Tillage Research 120: 137-146.

Rickson J. 2014. Can control of soil erosion mitigate water pollution by sediments? Science of the Total Environment 468-469: 1187-1197.

River Wissey Partnership, 2014. The River Wissey. A plan to improve the river and an invitation to get involved. Anglian Water, Cambridge. http://www.cameopartnership.org/wp-content/uploads/2014/02/RIVER-WISSEY-PLANfinal-web-version.pdf; accessed 7 November 2016.

Silgram M, Jackson DR, Bailey A, Quinton J, Stevens C. 2010. Hillslope scale surface runoff, sediment and nutrient losses associated with tramline wheelings. Earth Surface Processes and Landforms 35: 699-706.

Soil Survey. 1976. Soil Survey Field Handbook. Technical Monograph No. 5. Rothamsted Experimental Station: Harpenden.

Sonneveld BG, Dent DL. 2009. How good is GLASOD? Journal of Environmental Management 90 (1): 274-283.

SSEW. 1983. Soils of Eastern England and Wales. Sheet 4; Legend for the 1:250,000 Soil Map of England and Wales. Soil Survey of England and Wales: Rothamsted Experimental Station, Harpenden.

Vandaele K, Poesen J. 1995. Spatial and temporal patterns of soil erosion rates in an agricultural catchment in central Belgium. Catena 25: 213-226.

Vanmaercke M, Maetens W, Poesen J, Jankauskas B, Jankauskiene G, Verstraeten G, de Vente J. 2012. A regional comparison of hillslope erosion rates with catchment sediment yields in Europe. Journal of Soils and Sediments 12 (4): 586-602.

Tables

Table 1. Soil and site characteristics, and estimated risk of erosion.

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Table 5. Number of erosion and runoff events in each crop over 10 crop years.

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Table 7. Number of rainfall and runoff events each calendar year.

Soil association*	Map symbol*	Soil texture* and parent material	Soil characteristics	Slope**	Water Erosion risk***
Newmarket 2	343g	Coarse loamy and sandy; chalk and chalky drift	Shallow, well drained over chalk rubble	Gentle-moderate	Moderate
Burlingham 1	572n	Coarse and fine loamy; chalky till and	Slowly permeable, slight	Gentle	Slight

		glaciofluvial drift	seasonal waterlogging		
Burlingham 3	572p	Fine and coarse loamy; chalky till and glaciofluvial drift	Slowly permeable, slight seasonal waterlogging	Level-gentle	Moderate
Beccles 1	711r	Fine loamy; chalky till	Slowly permeable, seasonally waterlogged	Level-gentle	Very slight
Beccles 2	711s	Fine and coarse loamy; chalky till and glaciofluvial drift	Slowly permeable, seasonally waterlogged	Level-gentle	Very slight
Isleham 2	861b	Sandy and peaty; glaciofluvial drift and peat	Affected by groundwater	Level – valley floor	Very slight****

*SSEW 1983

**Soil Survey 1976; level – 0-1°; gently sloping 2°-3°; moderate 4°-7°.

*** Evans, 1990; Risk of erosion based on soil, slope, land use; very slight: rare rill erosion, slight: < 1% land affected by rill erosion, moderate 1-5% land affected by rill erosion.

**** Land under grass in Wissey valley floor. However, moderate risk of wind erosion if cultivated.

Table 1. Soil and site characteristics, and estimated risk of erosion.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Month										
Jan	131.7	59.3	24.7	106.1	113.4	48.7	57.9	58.5	46.8	52.2
Feb	60.4	55.2	46.2	64.4	29.9	62.2	92.1	46.3	11.2	27.2
Mar	43.1	38.0	47.3	51.5	117.2	53.8	45.8	6.0	51.5	54.3
Apr	77.2	49.7	31.0	0.0	53.3	9.3	15.4	5.5	125.6	14.7

May	33.5	59.8	69.1	107.2	45.5	63.4	26.3	16.1	40.3	52.2
Jun	53.6	61.0	34.2	140.2	69.9	63.3	68.6	96.7	103.0	28.1
Jul	100.7	68.4	24.7	99.1	71.8	115.5	36.8	39.9	132.1	21.7
Aug	165.1	63.7	155.9	109.6	168.0	26.2	123.6	49.9	80.5	41.8
Sep	39.7	81.2	56.3	61.7	79.9	19.2	90.3	28.8	37.5	48.2
Oct	142.0	68.6	74.3	75.5	85.2	53.0	66.8	32.7	78.7	108.2
Nov	55.5	80.6	85.3	54.5	96.5	128.5	43.5	31.4	86.5	65.1
Dec	36.2	34.2	72.5	66.2	35.1	69.8	42.2	58.8	101.2	47.0
Total	938.7	719.7	721.5	936.0	965.7	712.9	709.3	470.6	894.9	561.3

Table 2. Monthly and annual rainfall (mm).

Crop	Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Autumn-sown*											
Cereal		9	9	9	12	12	10	12	12	11	12
Oilseed rape		4		1	3	7	2	3	3	4	4
Beans					1	1			2		1
Spring-sown**											
Sugar beet		4	5	4	2	2	4	9	3	6	2

	Potatoes	3	2	4				1	1		
	Cereal	1	2		2	1					
	Beans		1								
	Oilseed rape										
Other											
	Outdoor pigs	3	1		1		2		2	3	2
	Fallow	1	2		2	1					2
	Blackcurrant	1									
	Maize				1	1		1	1	1	1
	Mustard		1	1							
	Bare soil				4			6	2	3	
	Set-aside				1	1				1	
	Fodder crop				1			1			
	Cultivated, bare					3					
	Ploughed						1				
	Stubble								1	2	
	Grass***								2***		
	Onions										1
	Wheat, harvested										1
Total number eroded fields		26	23	19	30	31	19	33	29	31	26

*Year of harvest, sown previous autumn. Erosion recorded in December 2003

**Year of drilling and harvest, but when wet autumn can be harvested early following year

***Gamekeeper's track and field margin

Table 3. Number of eroded fields in each crop, 2003-2014.

Autumn-sown crop year

	2003/4	2004/5	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12	2012/13
Rainfall (mm)	887.8	727.5	697.6	966.5	927.0	739.1	737.0	561.7	742.7	597.0
Eroded fields	13	9	10	16	20	12	15	17	15	17

Spring-sown crop year

	2004/5	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12	2012/13	2013/14
Rainfall (mm)	960.1	675.1	821.0	908.8	933.3	752.0	664.1	433.8	916.3	633.8
Eroded fields	7	10	8	4	5	4	10	4	6	2

Table 4. Rainfall and number of eroded fields in autumn- and spring-sown crops.

Crop	Number	% Total
Winter cereals	307	39
Sugar beet	108	13.7
Oilseed rape (autumn-sown)	84	10.7
Outdoor pigs	64	8.1
Potatoes	60	7.6

Winter beans	28	3.6
Bare soil	27	3.4
Maize	22	2.8
Spring barley	21	2.7
Fallow	20	2.5
Cultivated land (smooth surface)	10	1.3
Grass	9	1.1
Mustard	4	0.5
Stubble	4	0.5
Brassica	3	0.4
Blackcurrant	2	0.3
Cover crop	2	0.3
Onions	2	0.3
Spring beans	2	0.3
Oilseed rape (spring-sown)	1	0.1
Fodder crop	1	0.1
Ploughed ground	1	0.1
Total	788	100

Table 5. Number of erosion and runoff events in each crop over 10 crop years.

Crop	Winter cereals	Sugar beet	Oilseed rape	Outdoor pigs	Pot--toes	Winter beans	Bare soil	Maize	Spring barley	Fallow	Cultivated land
%	81	84	81	41	66	61	67	64	71	40	60

Table 6. Per cent rills/wash/flow in wheelings/ruts by crop/land use type, for main crops (≥20 erosion and runoff events) over 10 crop years.

Crop year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
No. events	90	60	47	139	96	38	58	46	145	69

Table 7. Number of rainfall and runoff events each calendar year.

Figures

Figure 1: Location of the NALMI and AMEWAM study areas.

The AMEWAM study arose from the NALMI project which covered 13 parishes in mid-Norfolk, but this was too large a block of land to monitor in one day and had little land that was considered at risk of erosion, and most of that was in the west of the area. Hence, the upper Wissey catchment, outlined as a rectangular block of land, more accessible from Cambridge, containing the villages of Necton, Holme Hale and Ashill was selected. The part of the AMEWAM study area lying to the west of the 13 parishes was included to cover soils more at risk at risk of erosion. To facilitate later field monitoring the area was further reduced by strips of land 1km wide on the eastern and northern boundaries of the AMEWAM area.

Figure 2. Erosion and runoff features. a. Small rills; b. Large rills; c. Wash; d. Flow down tractor wheelings.

Figure 3. Number of fields monitored and number of fields in ‘key’ crops, in crop years 2003/4 to 2012/13.

Figure 4. Percent total number fields (55) in which erosion events recorded.

Figure 5. Volumes (m^3) eroded or deposited by rills.

Figure 6. Soil compaction in outdoor pig field.

Figure 7. Erosion and runoff in outdoor pig fields; some impacts.

Figure 8. Erosion in late-sown winter cereal crops following sugar beet harvested under wet conditions.