EXCEPTIONAL RAINFALL AND MUDDY FLOODING NEAR DALE FORT FIELD CENTRE, PEMBROKESHIRE, JANUARY 2024

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Muddy flooding is the result of sediment-laden runoff leaving arable fields and damaging property, transport infrastructure, freshwater systems and giving rise to reservoir sedimentation. It is often, but not always, associated with heavy rain. We describe a muddy flood event in west Wales in January 2024 with runoff from a bare post-harvest maize field with poor soil structure. Milford Association soils are not usually associated with erosion but heavy rainfall was implicated in this case. Management of maize needs to include post-harvest crop cover or chisel ploughing to remove surface compaction to ensure the soil is more resilient to heavy rainfall, and grass buffer strips to attenuate runoff. Climate change is already increasing the frequency of high-intensity storms and management of vulnerable crops such as maize will have to adapt to this change. In high-risk locations it may be better not to grow vulnerable crops in the first place.

INTRODUCTION: MUDDY FLOODS

'Water flowing from agricultural fields carrying large quantities of soil as suspended sediment or bedload is referred to as a 'muddy flood'. Muddy floods generally originate on bare or partially vegetated surfaces. The phenomenon of muddy floods pre-dates the relatively recent adoption of the term.' (Boardman *et al*., 2006)

Muddy floods have been described in many western European countries and are one of the main societal costs of soil erosion and excessive runoff (Boardman *et al*., 1994). The impacts are on property, transport links, reservoir sedimentation and freshwater systems (because of pollutants carried in the runoff). In southern England notable examples of muddy flooding have occurred in Somerset (Morgan, 1980) and in the repeated flooding of properties on the South Downs by runoff from winter cereal fields (Boardman, 1995). In the latter area serious muddy flooding at Breaky Bottom vineyard resulted in legal action against the neighbouring farmer and his insurance company (Boardman, 2020). Perhaps most pertinent to the current case was the flooding of Faringdon in Oxfordshire by runoff from bare maize fields after an exceptional early-summer rainfall event of c. 100 mm in 4 hours (Boardman *et al*., 1996).

Most countries have struggled to predict and prevent muddy flooding although clear links have been shown between susceptible soils and arable crops adjacent to housing or other infrastructures (Evrard *et al*., 2010). EU legislation has been effective in addressing the problems caused by high-risk crops, such as maize, grown on high-risk sites in countries such as Belgium (Boardman and Vandaele, 2019). In England there is a legislative gap and a lack of enforcement by the Environment Agency (EA). In 2023, serious flooding of property in the Otter valley, Devon, due to runoff from maize fields occurred and is currently being investigated (Smith and Boardman, in preparation).

The EA in Exeter has recently issued two press releases warning about the danger of growing high-risk crops (maize and potatoes in particular) on high-risk sloping sites with vulnerable soils which can lead to runoff, erosion and flooding (EA, 2024).

THE SYNOPTIC SITUATION AND THE MUDDY FLOOD AT BUTTERHILL FARM

Storm Henk, the eighth named storm of the 2023-2024 storm season, brought damaging winds and heavy rain to southern and central parts of England and Wales on 2 January 2024. Winds gusted widely at over 50 knots, even in inland locations; Exeter Airport recorded a gust of 70 knots (81 mph, 36 ms^{-1}). Heavy rain from Storm Henk contributed to significant flooding problems, following the wet weather during the latter months of 2023. The storm caused power outages, severe disruption to road and rail transport and flooding problems. Within a complex area of low pressure, Storm Henk was an intense cyclonic system; at

12:00 on 2 January 2024, its centre was over South Wales with a pressure of 975 millibars. The rainfall-radar image shows heavy rain across much of Wales and central England from fronts associated with Storm Henk (UK Met Office, 2024). Hourly rainfall amounts at Dale Fort for this storm are given below (page 5).

Butterhill Farm (SM 830088) is 7 km west of Milford Haven in South Pembrokeshire (Figure 1). It is situated on a gently sloping (< 3°) north-facing slope at c. 40 m above sea level and is a mixed farm growing cereals, potatoes, maize and cover crops, part of the RE Evans Ltd. business (Innes McEwen, farm manager). The former farm buildings are now a series of 7 residential properties and a barn (Figure 2).

A muddy flood occurred on 2 January 2024 with flow down the track and past the houses: as in Figures 2, 3 and 4. The origin of the runoff was Field A and, to a lesser extent, Field B (Figure 2).

FIGURE 1. Location of Butterhill Farm in South Pembrokeshire.

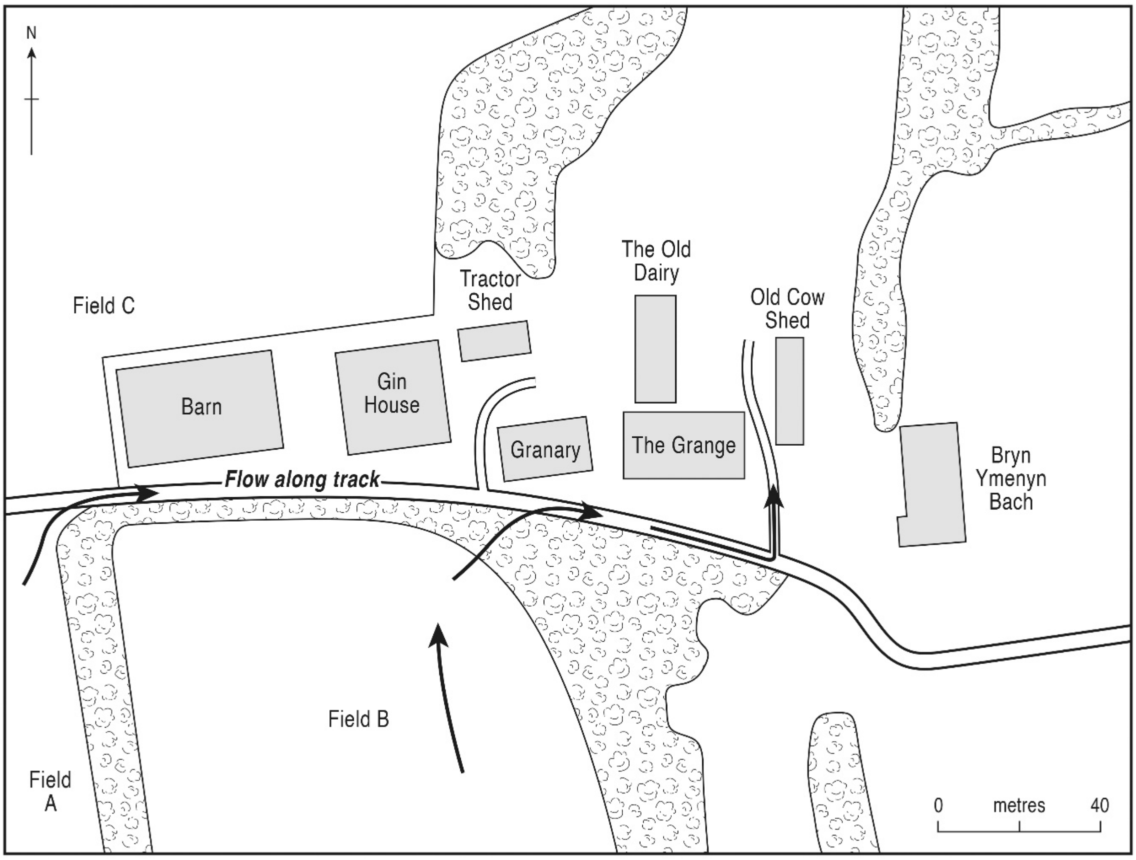

FIGURE 2. Butterhill Farm and the flow route of the muddy flood.

FIGURE 3. Muddy flow along track past The Grange. Photo, Richard Neale.

FIGURE 4. Muddy flow past The Grange and heading toward The Old Cowshed. Photo, Richard Neale.

THE SOILS OF THE AREA

The soils of the area are classified as the Milford soil association, typically a fine loamy soil over red sandstone or slates (Soil Survey of England and Wales, 1983). They are generally freely drained, do not readily cap and are at low risk of soil erosion (Evans, 1990). However, in southwest England they are not immune to compaction in wet conditions which will lead to runoff and soil erosion on steep slopes (Richard Smith, Environment Agency, personal communication).

Milford Association soils are extensive in South Wales, the Welsh Borderlands, Devon and Cornwall covering 1345 km^2. In the Milford Haven area, they overlie Old Red Sandstones of the Downton Subgroup (Silurian). The soils are described in Rudeforth *et al*. (1984) and Wright (1980). The Association includes a group of very similar soils e.g. Milford Series and Langendeirne Series. The soil is typically a reddish, fine loamy clay, slightly stony in the upper 40 cm. The soils are usually well drained and 'slightly droughty' in the summer. Spring warmth at coastal sites makes them suitable for early potatoes often with irrigation. Plate 28 in Rudeforth *et al*. (1984), shows Milford Association soils near Milford Haven being used for early potatoes and broccoli. Particle size analysis for two Milford Series profiles give very similar results for topsoil (Ap horizon): Sand 17%, Silt 58% and Clay 25% with organic carbon at 3.9% (Wright, 1980). Langendeirne Series topsoil gives Sand 27%, Silt 46% and Clay 27% (Rudeforth *et al*., 1984). Intriguingly, Wright (1980) notes the frequency of a fragic horizon at depth, which would inhibit infiltration.

SOILS AND RUNOFF AT BUTTERHILL FARM

The soil in field A was briefly examined on 11 Feb (a wet day) and on 13 Feb (a dry day). Routes of runoff from the field to the open gateway were clearly visible (Figure 5). The soil is slightly stony (4.5% >2 mm) and was compacted in areas with standing water and wheelings: a fork would only penetrate to c. 10 cm. Recent rain had left the field very wet. The soil type is normally freely draining and standing water should not be present (Figure 6). The soil is slaked with a smooth surface and poor soil structure which is relatively impermeable.

The soil on Field A appears to be very thin as bedrock is evident on farm tracks nearby. This may explain the stoniness of the soils if ploughing incorporates weathered bedrock into the soil.

Field A has debris left on the surface from the maize harvest but is largely bare (Figure 6). There were clear signs of recent runoff which exits through the gate and on to the track past the houses at Butterhill Farm (Figure 5). Most of this runoff is from Field A with a contribution from the winter cereal Field B, via the wood and onto the track opposite The Granary (Figure 2).

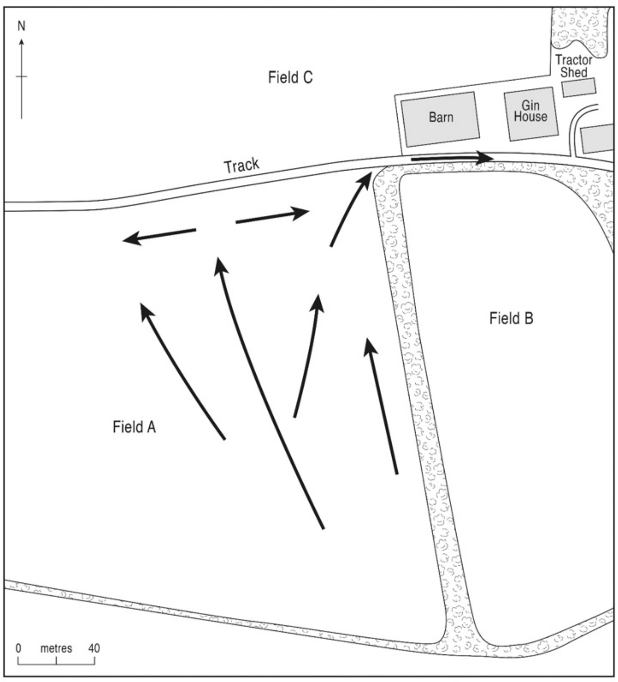

FIGURE 5. Directions of runoff on Field A.

FIGURE 6. Field A , 11 February 2024, bare with debris from previous maize crop. Photo, John Boardman.

RAINFALL

FIGURE 7. Rainfall record for 2 January 2024 for Dale Fort. The image shows a screenshot from an automatic weather station. The green lines show amounts per minute while the yellow lines show hourly totals (for the hour starting where the line is plotted).

The nearest rain gauge is at Dale Fort Field Studies Council centre, 3.5 km south of Butterhill Farm. The long-term rainfall record at Dale from 1961 has been analysed by Burt et al. (2020) and the average rainfall for January is 84.3 mm (1961-2018).

An electronic recording rain gauge has recently been installed at Dale Fort and is run by the University of Leeds. Figure 7 is from that gauge. The hourly totals (mm) on 2 January 2024 were as follows:

05:00 - 06:00	0.8
06:00 - 07:00	1.6
07:00 - 08:00	1.4
08:00 - 09:00	4.6
09:00 - 10:00	5.8
10:00 - 11:00	3.4
11:00 - 12:00	4.0
12:00 - 13:00	1.8

Thus, a total of 23.4 mm fell in eight hours. The maximum 2-hour intensity of 9.2 mm indicates heavy rain, but not exceptionally so. We cannot be precise about the likelihood of such an event being repeated but using Figure 2.29 in Rodda *et al*. (1976) suggests a return period of less than two years. We conclude that Storm Henk produced heavy rainfall but nothing exceptional. It is worth adding that return periods are based on the idea of stationarity of climate; in other words, climate is unchanging. However, we know that this is not the case, and that the frequency of intense rainfall events is increasing as climate changes, which means that similar runoff events on vulnerable soils are likely to become more common in a warmer, wetter future (Burt et al., 2016). Thus, prolonged winter rainfall event on similarly bare fields will lead to similar off-field flood impacts. Note that the mean air temperature at Dale Fort has risen from 10.5 °C (1961-1990) to 11.0 °C (1991-2020); for the same two standard averaging periods, mean annual rainfall has risen from 828.8 mm to 859.2 mm. Thus, like very many other places, Dale Fort is warmer and wetter than it used to be, and ongoing climate change can only be expected to generate even more heavy rainfall events.

PREVENTION

The risks associated with runoff from maize are twofold. In early summer, after drilling, bare ground persists for up to 3 months and is vulnerable to summer thunderstorms. In autumn, after the maize harvest, wet weather may prevent the farmer getting on the field and either establishing a cover crop or rough ploughing: bare ground will then exist for several months. The present Butterhill Farm case is of the latter variety i.e. post-harvest. As in many cases of post-harvest erosion, the desire to establish a cover crop was thwarted by wet late autumn weather which prevented work on the field. These conditions would also prevent attempts to break-up soil compaction inherited from pre-harvest and harvest working. In south-west England it is good practice to chisel plough on similar soils following maize or winter vegetables, taking advantage of any period of dry weather (Richard Smith, personal communication).

Runoff and erosion on maize has been a concern for many years and advice on prevention has been published by DEFRA, the Environment Agency and the Maize Growers Association and in many academic research papers. DEFRA (2005) advice can be summarised as follows:

- Avoid growing maize on high-risk sites (erodible soils and sloping sites);
- Sow early maturing varieties (in order to avoid harvesting in wet autumn weather);
- Prepare seedbeds to avoid compaction and wheelings;
- Reduce post-harvest risks by establishing winter cover crop;
- Break compacted surfaces to improve infiltration;
- Rough plough after harvest if no cover crop;
- Subsoil tillage to combat compaction.

Clearly, some of the measures listed above could have been taken at Butterhill Farm to reduce or eliminate the risk of damaging runoff. The fact that runoff did not enter the houses is fortunate and more prolonged rainfall may well have overwhelmed the drainage systems alongside the track. As wet winter weather continues, the risk of further flooding by runoff from Field A also continues and, in the week, beginning 19 February there were two further muddy floods along the track.

It is uncertain as to the extent of compaction in Field A. In the future, measures can and should address this issue. Maize or potatoes on Field B will also pose a risk of muddy flooding given the ease of movement of runoff through the woodland and on to the track. In both fields the establishment of grass buffer strips and winter cover crops, will reduce the risk of runoff leaving the field. The positioning of the gate at a low point in Field A is also unfortunate.

CONCLUSION

The risk of runoff from post-harvest maize is well known and mitigation measures are well publicised. At Butterhill Farm in January 2024, the farmer might have claimed that the muddy flood event was due to extreme rainfall, but in fact the hourly rainfall totals were not exceptional[1]. This emphasises the risk of muddy runoff from post-harvest maize fields even when rainfall totals are relatively modest. The lack of mitigation measures exacerbated the impact of the runoff, and future management planning needs to take account of the increase in intense rainfall events under all climate change scenarios.

FOOTNOTE

1. We have not been able to conduct an analysis of the entire hourly rainfall record for the Dale Fort automatic rain gauge. Durham is a much drier place, but for the period March 2000 to June 2020, an hourly total of 5.8 mm was exceeded 80 times at Durham. For the 16016 hours in this period when rain was recorded, this means that approximately one hour in two hundred records a total higher than 5.8 mm. Thus, in relation to the Durham record, the maximum hourly rainfall recorded at Dale Fort on 2 January 2024 may be described as notable but not exceptional.

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