Are extremes increasing? Changing rainfall patterns in Yorkshire

This article assesses the extent to which rainfall extremes have changed in Yorkshire and whether this can be linked to both flooding and climate change.

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This contribution is in response to the article entitled "*More floods, less rain: changing hydrology in a Yorkshire context*" by Stuart Lane in a previous issue of *The Regional Review* (Lane, 2002), where it was argued that there is no trend in rainfall that can be linked to the observed increase in flooding.

Climate variability or change?

The autumn and calendar year 2000 were the wettest in England and Wales, in a record dating back to 1766. This caused widespread severe flooding, particularly in the Yorkshire region which witnessed one of the worst floods on record, and started a public debate on the apparent increased frequency of extremes: was this just natural climate variability or confirmation of a shift to a period of more frequent and higher magnitude storm events associated with climate change?

Global climate model simulations predict increases in both the frequency and intensity of heavy rainfall in the UK under climate change. It is uncertain, however, how climate change will be expressed regionally and how this may impact upon both spatial-temporal rainfall patterns and flooding.

There is evidence of a significant positive trend in rainfall intensity in the UK (Fowler and Kilsby, 2003a, 2003b) but no evidence of a similar increase in flooding at the national level. However, there is evidence of increases in regional flooding, such as at York (Lane, 2002; Figure 1). Here, the key to flooding was found to be the relative timing of the peaks of the Swale, Ure and Nidd and, not only are floods becoming more frequent, but there is a general increase in their magnitude (Lane, 2002).

In the simplest terms, an increase in flooding can be caused by either an increase in the magnitude and frequency of extreme rainfall events or a change within the catchment that causes the rain that falls to reach the drainage network faster.

Lane (2002) suggests that land use change within the Ouse catchment, particularly in upland areas, has increased the speed with which rain reaches the drainage network. Here, it is suggested that a change in rainfall seasonality and an increase in extreme rainfall events are also important mechanisms for the recent dramatic increase in flooding seen at York.

Evidence for change in rainfall magnitude and frequency

Rainfall in the Yorkshire region varies from just 600 mm in the eastern lowlands, to over 2000 mm in the western uplands. Westerly winds provide the main source of rainfall to the uplands although northerly and easterly winds bring heavy convective precipitation to the east of the region, particularly in autumn months.

Floods are largely generated in the uplands to the west of the region. Therefore, it is important to examine rainfall records from this area to consider the impact of climate variability and change upon flooding.

Few rainfall records are available and very few extend back further than 1960. To consider trends in rainfall however requires a long length of record. A good record is available from 1936 at Moorland Cottage (near to the source of the Wharfe) and, more recently, for Askham Bryan (in the lower Nidd catchment). These are likely to give us an indication of how rainfall patterns are changing in the Yorkshire uplands.

Figure 2 shows the 20-year centred means for (a) winter and (b) summer rainfall at Moorland Cottage, expressed as percentage anomalies from the 1937-96 average (from Fowler and Kilsby, 2002).

In winter, rainfall records in Yorkshire presently show a positive rainfall anomaly of 10 to 20 per cent of the 60 year average from 1937-96. This increase in winter rainfall is particularly noticeable in rainfall records from the western uplands, and is, in fact, linked to a decrease in the number of winter rainy days. In the eastern lowlands, however, many rainfall records show a decreasing trend in winter rainfall (Fowler and Kilsby, 2002).

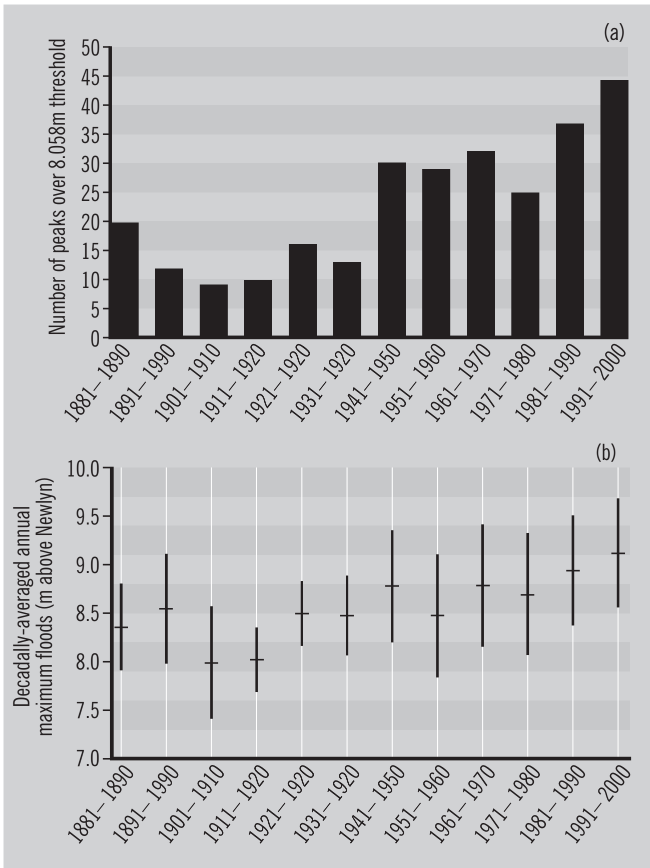

Figure 1. (a) Number of floods above the 8.058m threshold per decade, (b) the decadal mean and standard deviation of the annual maximum flood, for the Viking record, York *Figure 1 in Lane (2002)*

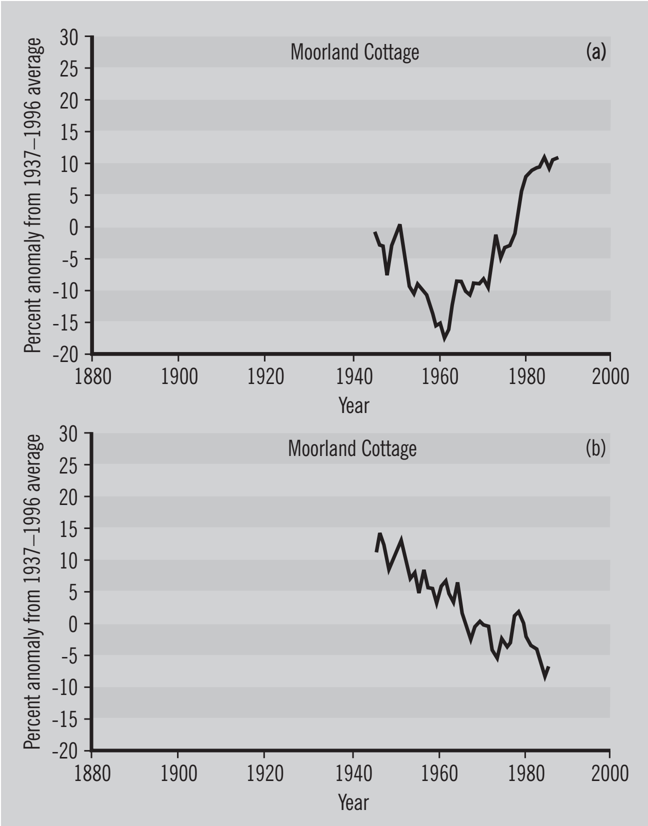

Figure 2. Anomalies in rainfall at Moorland Cottage, expressed as percentage anomalies from the 1937-1996 average for (a) winter (DJF) and (b) summer (JJA) *Fowler and Kilsby (2002)*

In summer, the regional trend in rainfall is much clearer. All regional rainfall records show a decrease in summer rainfall that is unprecedented historically (Fowler and Kilsby, 2002). Figure 2(b) shows this marked negative trend in summer rainfall for Moorland Cottage and Figure 3 reinforces how rainfall seasonality has markedly changed since 1975.

Notably, these observed trends match the trends in rainfall projected for the UK under future climate change. The UKCIP02 scenarios (Hulme *et al*., 2002) project wetter winters and significantly drier summers across the UK. However, increases in winter rainfall alone will not necessarily cause increases in flooding. Floods are caused by extreme events, whether short intense rainfall events (thunderstorms or 'convective' rainfall) or multi-day events (continuous rainfall from large 'frontal' systems).

The increase in winter rainfall but decrease in the number of rainy days suggests that rainfall intensities have increased. Extreme rainfall events are also projected to increase in both frequency and magnitude under climate change (Ekström *et al.*, 2005). However, is there evidence of increased rainfall extremes in the Yorkshire region?

Fowler and Kilsby (2003a) found that during the decade from 1991-2000, compared to the period from 1961-1990, multi-day (5 and 10 day) extreme rainfall events in Yorkshire have become more frequent, with the average recurrence interval for a 50 year event (a rainfall event whose magnitude can be expected once every 50 years on average) halving to only 25 years.

This can be explained by examining seasonal extremes. Extreme rainfall events have increased in magnitude dramatically during autumn and spring months in Yorkshire. Figure 4(a) shows the decadal change in autumn 10-day rainfall maxima in North East England (of which Yorkshire is a part) from 1961-200 fitted using a GEV distribution based on 20 station records.

The most recent decade from 1991-2000 provides a dramatic departure from previous estimates for autumn, with increases in rainfall estimates for a specific return period at both 5 and 10-day durations. This is shown in Figure 4(b), which shows the estimated 10yr and 25yr return period magnitude using a 10 year moving window fitting of the GEV distribution (using annual maximum data) at Askham Bryan. This shows clearly the increase in event magnitude since the 1980s and, more prominently, during the 1990s.

Changes in the timing and frequency of events can have as much of an impact on flooding as a change in magnitude. Figure 5 shows the annual frequency and modal month of 10-day Peak-Over-Threshold events (an event is counted if it exceeds two standard deviations above the mean rainy day amount) in the lower Nidd catchment at Askham Bryan. This demonstrates both the increased frequency of 10-day POT events in Yorkshire during the 1990s, and the change in timing from predominantly summer to greater concentrations in autumn and winter months.

What has caused the increase in extremes?

For the generation of floods, a change to the frequency and timing of extreme rainfall events may be as important as changes in magnitude and duration. Antecedent wetness of catchments, or soil saturation, is a key factor determining the timing of major flood events (Lane, 2002).

For rural catchments in Yorkshire, autumn is the dominant season of flooding. Change to the magnitude, frequency and timing of extreme rainfall events has serious economic and social implications and may be the mechanism behind the recent severe autumnal flooding in the UK.

These seasonal changes may be a consequence of anomalies in large-scale atmospheric circulation patterns such as the Scandinavia Pattern and the North Atlantic Oscillation. There is certainly evidence to suggest that the recent increase in winter rainfall in the western uplands is connected to a highly positive North Atlantic Oscillation index since 1980. This is a simple measure of pressure between Iceland and the Azores and controls the frequency and magnitude of surface westerlies across Europe; the more positive the index, the more frequently strong westerly winds will pass across the UK.

Climate change may also provide a partial explanation for the enhanced seasonality (decrease in summer rainfall and increase in winter rainfall) of recent years, and for the increase in extreme events. Global Climate Models project both enhanced seasonality and increases in extreme rainfall events under climate change (Ekström *et al.*, 2004).

It is impossible to attribute the observed changes directly to global warming but, even if current trends are the result of natural climate variability, Global Climate Models suggest that these trends are likely to continue under climate change.

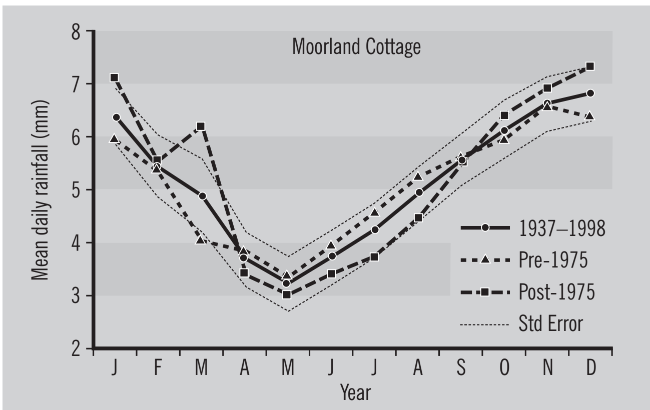

Figure 3. Mean daily rainfall (mm) for the pre- and post-1975 periods at Moorland Cottage *Fowler and Kilsby (2002)*

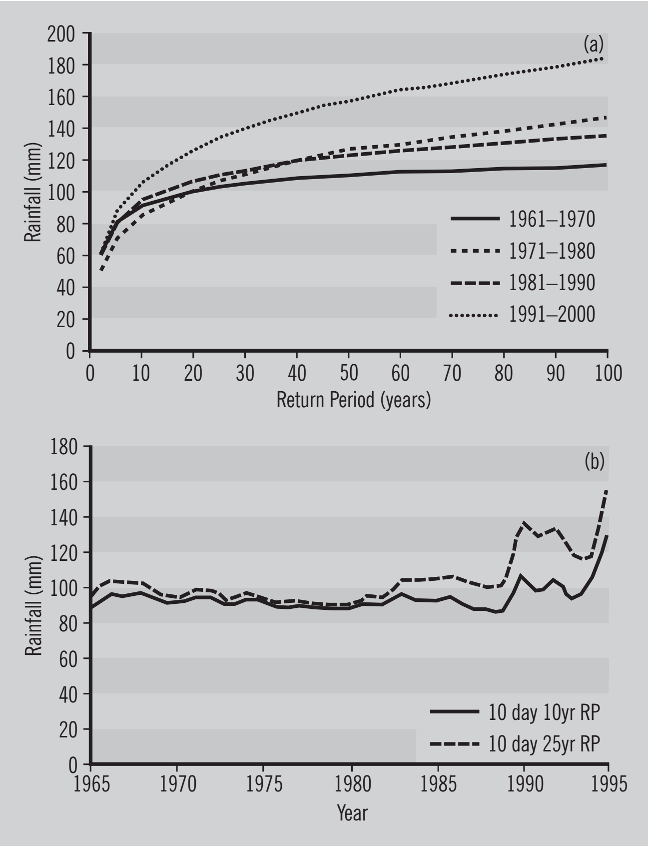

Figure 4. (a) Decadal change in autumn 10-day rainfall maxima in North East England fitted using a GEV distribution based on 20 station records; (b) estimated 10year and 25year RP for 10year moving window fitting of the GEV distribution (using annual maximum data) at Askham Bryan

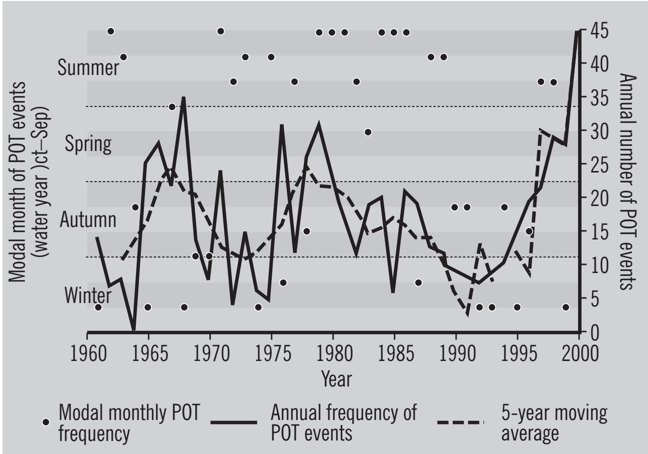

Figure 5. The annual frequency and modal month of 10-day Peak-Over-Threshold events in the lower Nidd catchment at Askham Bryan

Climate change and flooding

Lane (2002) showed that the number and size of floods in York appear to be increasing dramatically. Here, it has been shown that there has been a similarly significant increase in extreme rainfall events, particularly in autumn months.

Although this may go some way to explaining the increase in flooding at York since 1980 (certainly it is almost impossible to have a flood without rainfall), there is a need to examine whole catchment response as the key to understanding flood events.

A flood is caused not only by rainfall falling onto a catchment, but by the complex interaction of the spatial-temporal rainfall pattern (where the rain lands), hydrological connectivity (how well the catchment is connected in terms of water flows) and river conveyance (how fast the river moves the water downstream).

The Ouse catchment has undergone substantial land-use change in the past century that may have changed the fundamental processes that control flooding. Land-use change has been found to affect local runoff production, although it is uncertain how this will aggregate up to have an impact on whole catchment response and thus flooding.

Lane (2002) suggests that we may be able to manage the effects of global warming on flooding by reversing those land-use practices that have caused the increase in the frequency and magnitude of flooding at York. It is likely that land management will have an important role to play in the management of future flooding.

However, with an increased frequency and magnitude of extreme rainfall events during the 1990s and a further increase projected under climate change, it is unlikely that land management in itself will provide a robust solution to the flood problems in York. The complexity of catchment hydrological connectivity, flood-generating processes and the possibility that the effects of land-use change may be non-reversible in some cases (such as pipe development in peat) will hinder the use of land management as a single measure to control flooding.

Multi-day, prolonged heavy rainfall events are increasing in Yorkshire. These changes have huge economic and social implications for the design and maintenance of flood defences and urban drainage infrastructure.

The crux of the problem is to know what actions can be taken now to effectively manage climate change in the future given the large uncertainties attached to the likely behaviour of the climate system. Quantifying the impacts of present day climate variability on flooding may give us information about the key sensitivities of the hydrological system and thus help us to focus limited resources on the management of present and future flooding.

However, we need to further investigate the links between flood generating mechanisms, atmospheric circulation patterns and land management practices, if we are to fully understand the process of flooding, the implications of observed and future projected changes in extreme rainfall occurrence and how to manage the increased risk of flooding in York.

References

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