

Reassessment of flood risk for Scottish rivers using synthetic runoff data

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Abstract Increased hydroclimatic variability in recent years and the resultant flooding raise questions concerning flood risk estimation from short flow records in Scotland. Long peak flow series have been simulated using historical rainfall to reassess flood risk estimates for 11 selected rivers. Changes of >10% in the estimated value of the 100-year flood are reported for three rivers, as a result of the synthetic record extension achieved. Future changes in flood risk, as a result of possible changes in atmospheric circulation, are discussed briefly.

INTRODUCTION

Recent flooding in many areas of Scotland (Black, 1996) has been produced by a period of extreme hydroclimatic variability (Foster *et al.*, 1997), similar to patterns observed in parts of Scandinavia (Roald, 1998). However, it is difficult to place the recent past within the context of longer-term trends because of a lack of long flow records in Scotland: few records extend over more than 40 years. To compensate, Steel (1998) used long homogeneous daily rainfall series to simulate instantaneous peak flows dating back to the 1870s for 11 rivers. Recent flooding in western rivers appears to be unprecedented in terms of frequency and magnitude in the 112 years since 1885, whereas flooding in eastern rivers in the late nineteenth century appears to have been of greater magnitude than that of recent years.

By placing recent events into a longer historical context, this paper re-evaluates flood risk in 11 river basins throughout Scotland. The results are of value in informing flood risk reassessment across Scotland more generally.

DATA

The study involves 11 rivers selected on the basis of natural flow regimes, reliable high flow ratings, wide geographical distribution, and variety of basin areas and altitude ranges. The spatial distribution was important given that Scotland is dominated by a wet, westerly airstream with orographic effects and transient snow cover. Figure 1 shows the location of the study basins, and indicates the lengths of their respective simulated and observed peak flow series (the latter compiled by Foster *et al.*, 1997). The modelling of historical flows used daily rainfall and air temperature data obtained from the UK Meteorological Office, and daily mean flows from the UK National River

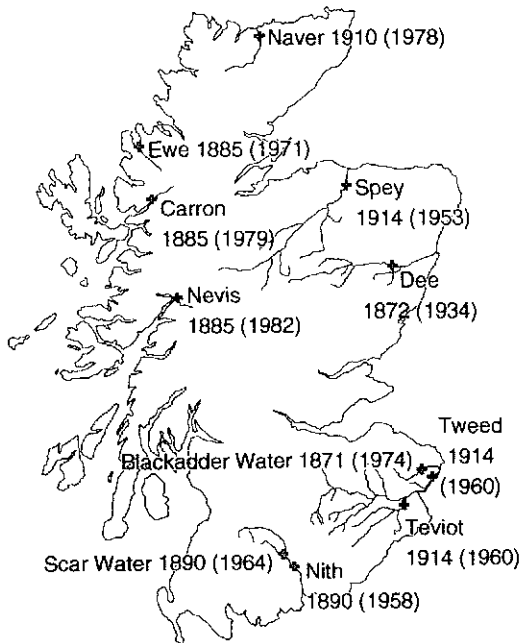


Fig. 1 Map of Scotland showing the location of study basins, including lengths of data series: start date of historic rainfall and simulated peak flow data (and start date of observed peak flow data).

Flow Archive maintained by the UK Institute of Hydrology. Basin characteristics were calculated from the Institute of Hydrology's Digital Terrain Model (DTM—Morris & Flavin, 1990) and Hydrology Of Soil Types (HOST) database (Boorman *et al.*, 1995).

MODELLING METHODOLOGY

The modelling methodology used to simulate historical instantaneous peak flows is outlined in Fig. 2. At the centre of the method is the use of a rainfall–runoff model, calibrated and used in each basin to generate time series of daily runoff values. Because of the frequent importance of snowmelt runoff in many of the study basins, the first part of the modelling work was the use of daily precipitation and maximum and minimum temperature values in a degree-day snowmelt model originally developed by Schreider *et al.* (1997), which generates daily equivalent rainfall values. This model was adapted to use data interpolated for 50 m altitudinal bands in each basin (obtained from the DTM), using assumed environmental lapse rates and precipitation gradients.

The equivalent rainfall values represent the sum of the daily rainfall and snowmelt values, and formed the input to the IHACRES (Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow data) rainfall–runoff model (Littlewood & Jakeman, 1994), selected for its structural simplicity and ability to deliver high predictive accuracy using a small number of parameters. Simulated daily runoff values were obtained from IHACRES for the full

FLOOD RISK ASSESSMENT

The most valuable records for assessing flood risk are those which are long, accurate, homogeneous and have no missing peaks. The simulated series used in this paper meet the majority of these criteria. For each river the peak flow of an event with a return period (T) of 100 years (Q_{100}) was estimated from two different AMS using the UK Institute of Hydrology's frequency analysis package HYFAP (IH, 1991) and choosing the optimal flood frequency distribution graphically. These annual maximum series were taken from (a) the entire simulated instantaneous peak flow records, and (b) the section of the simulated peak flow series corresponding to the period of observed records, to calculate Q_{100}^a and Q_{100}^b respectively (Table 1). For many of the rivers Q_{100}^a and Q_{100}^b are about 30% lower than Q_{100} calculated from observed data, because of the low variability in the simulated peak flow data (as discussed in the paragraph above).

The percentage difference between the magnitudes of Q_{100}^a and Q_{100}^b (also in Table 1) indicates the importance of the extra years of simulated peak flow data. With the exception of the Blackadder Water, the magnitude of the difference is greater than 5% for each of the five rivers with less than 30 years observed peak flow data, and greater than 10% for three of these. This is important since 70% of gauged Scottish rivers have records of less than 30 years.

Figure 3 draws on the synthetic POT series for four rivers, showing the time distribution of all events with T values greater than Q_{10}^a , and allows the importance of the timing of exceptionally large floods, in influencing the estimation of large flood magnitudes, to be recognized. For the River Dee the extreme flood of 1937 occurs in the period used for calculating both Q_{100}^a and Q_{100}^b , so the percentage difference between them is small, although as the recent period includes no other events of $T > 40$ years, Q_{100}^a is considered to be the more reliable. For the River Nevis, a cluster of floods including one extreme event (in 1989) has occurred within the observed data period, biasing Q_{100}^b and, similarly, it is likely that Q_{100} is currently overestimated when using only observed data. The -11.1% difference between Q_{100}^a and Q_{100}^b for the River Ewe (Table 1) results from a comparable situation. For the River Carron, Q_{100}^b is

Table 1 Q_{100} statistics for each study basin.

	Observed record length (years)	Simulated record length (years)	Basin area (km ²)	Q_{100}^a (m ³ s ⁻¹)	Q_{100}^b (m ³ s ⁻¹)	Percent. diff.
Spey	44	83	2852	802	800	0.3
Dee	63	125	1379	977	962	1.5
Teviot	37	83	1120	449	453	-1.0
Tweed	37	83	4407	1161	1176	-1.3
Blackadder W	23	126	155	102	101	1.8
Nith	39	107	797	663	669	-1.0
Scar Water	33	107	142	175	184	-4.6
Nevis	15	112	69	252	307	-17.9
Carron	18	112	138	202	191	6.0
Ewe	26	112	441	187	211	-11.1
Naver	19	87	474	251	213	17.8

Q_{100}^a : calculated from entire simulated peak flow data series;

Q_{100}^b : calculated from section of simulated peak flow data series, of same period as observed record;

Percent. diff. = $((Q_{100}^a - Q_{100}^b)/Q_{100}^b) \times 100$.

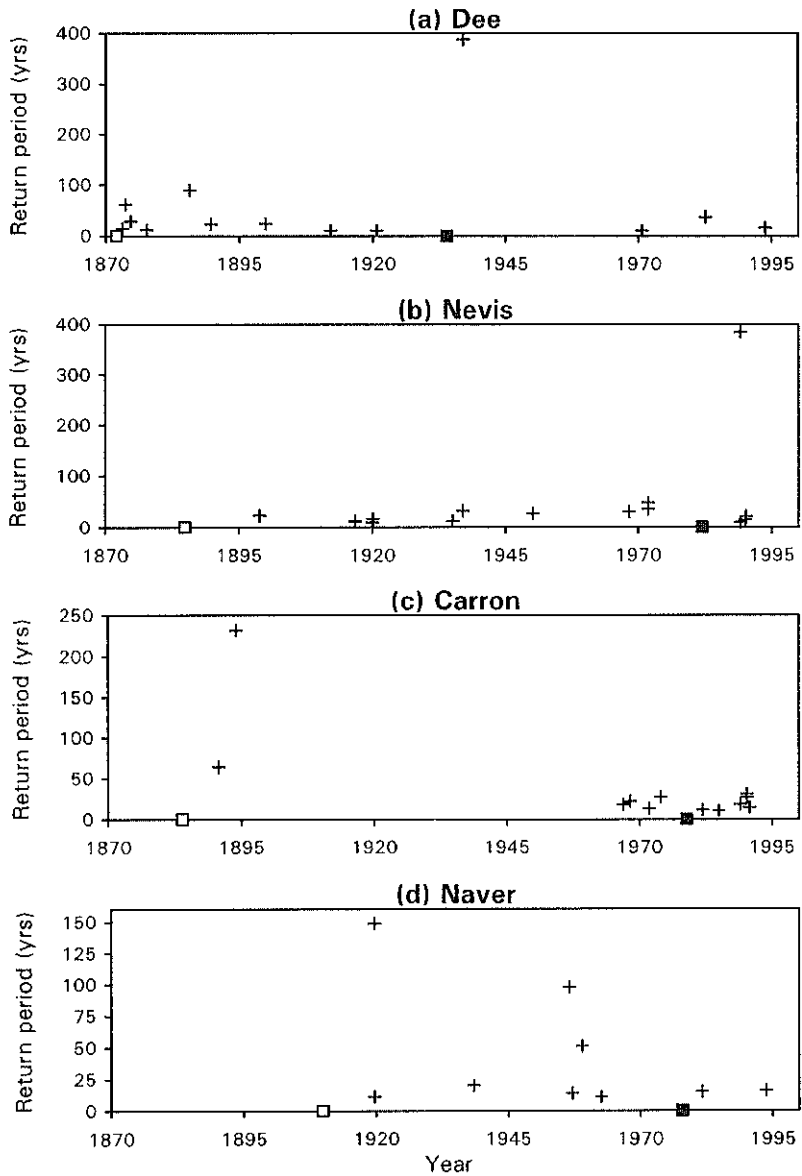


Fig. 3 Simulated peak flow events of return period T greater than 10 years (T calculated using an AMS taken from the entire simulated peak flow series). On the x-axis, a white square marks the start date of simulated peak flow data, a black square marks the start date of observed peak flow data.

less than Q_{100}^a because of the absence of any extreme floods in the period of observed data. Although the simulated peak flow series for the Naver begins relatively recently in 1910, like the Carron it includes events of a much greater return period than those occurring in the observed data period. As a result, Q_{100}^a is substantially greater than Q_{100}^b , suggesting that Q_{100} is currently underestimated from observed data. By considering all these synthetic series and the irregular occurrence of extreme floods

within them, the value of deriving records for periods far in excess of those for observed records can be demonstrated.

DISCUSSION

This study has shown that by constructing synthetic flood series for periods in the order of 100 years, the recent floods experienced in rivers across Scotland can be placed into a valuable historical context. Figure 3(b) and (c) shows how, with this extended context, periods of instrumental flood records appear to have experienced large floods of unusually high frequency and/or magnitude while, for other rivers (Fig. 3(a) and (d)), this is not the case. On the basis of reducing sampling error, it has been shown that the estimation of high return period flood magnitudes from relatively short (recent) records can be compromised. This is reduced by the use of the longer simulated flood series described. Suggestions of a step-change in Scottish hydro-climatology would imply that these longer data series will be valuable in assessing the sign and magnitude of recent trends, and may in future give way to analysis of observations post-dating such a recognized change.

Variations in the frequency and magnitude of flooding can be related to changes in atmospheric circulation patterns, which can be characterized by Lamb Weather Types (Lamb, 1972) or using airflow descriptors such as vorticity and flow strength (Jones *et al.*, 1993). Foster *et al.* (1997) have demonstrated the links between Lamb Weather Types and flood behaviour for Scottish rivers, and the potential exists to extend this work to investigate how variations in individual airflow characteristics affect flood characteristics. It will also be of value to consider how possible future changes in atmospheric circulation might affect flood risk and magnitude in individual rivers, by using past atmospheric circulation data as a historic analogue.

The difficulty in accurately representing flood magnitudes, as discussed above, remains a challenge. Nonetheless, the work reported here does provide a method of investigating the unique past behaviour of any river basin with suitable rainfall, temperature and runoff data, and can therefore be said to have value in producing flood risk estimates which relate specifically to a chosen river, rather than to the hydrology of its parent region.

CONCLUSION

This paper has described the derivation of synthetic flood series for 11 Scottish rivers, enabling reassessments of flood risk for each of them. Using two sets of synthetic annual maximum series to compare flood risk based on relatively short periods of instrumental record with that achieved with approximately 100 years of record, it was found that changes in risk assessment for the 100-year flood (Q_{100}) were greatest for sites where less than 30 years of observed data exist. For four of these five sites, estimates of Q_{100} differed by more than 5% and, for three of them, by more than 10%. Further work with long synthetic records such as these may allow possible changes in flood risk, resulting from future changes in atmospheric circulation, to be estimated.

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