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NOAA FISHERIES SERVICE

Flood Frequency Estimates for New England River Restoration Projects: Considering Climate Change in Project Design

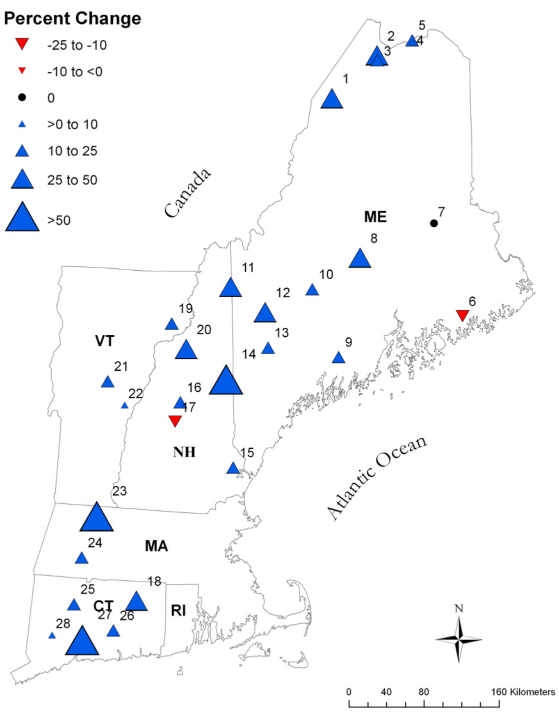

Figure 1. Trend directions and magnitudes for the 28 annual flood series analyzed by Collins (2009). Trends are expressed as percent changes in the annual flood magnitude over the period of record at each gauge.

Flood frequency estimates are used to quantify the magnitude and frequency of relatively rare or extreme river discharges. Such estimates are necessary to design many river restoration projects. For projects that include constructing new infrastructure or retrofitting existing infrastructure flood frequency estimates are required to size the infrastructure to withstand floods of specified magnitudes (e.g., events expected to recur every 100 years). For projects where infrastructure is being removed and a natural channel restored (e.g., a dam removal) flood frequency estimates are also useful because stream channel geometry, process, and habitat are very closely linked with the magnitude of comparatively frequent flood events—those with recurrence intervals between 1 and 5 years. Thus, flood frequency estimates are necessary to understand how channel changes will affect stream biota and adjacent floodplain landowners.

Flood frequency estimates are calculated either statistically by using stream gauge records of past flood events or by developing watershed rainfall-runoff models using regional rainfall frequency distributions and watershed characteristics. Data availability usually dictates the approach. A statistical estimate based on a flood record for the stream of interest is typically the preferred method since it is most closely based on floods that have actually occurred on the stream. If these data are not available, statistical estimates can also be calculated via regional regression techniques that extrapolate flood records from nearby watersheds or a rainfall-runoff model for the watershed can be employed. Here we focus on flood frequency estimates developed from a gauge record for the stream where the project is located.

One of the ways climate change can affect flooding is by changing the magnitude, duration, and timing of precipitation events that drive streamflow. Recent research suggests increases in the magnitudes and frequencies of precipitation and flooding events in New England over the last century, especially in recent decades. The purpose of this document is to describe recent research on climate and streamflow and to offer guidance to river restoration practitioners on working with gauge records to improve estimates of the magnitude and frequency of floods of interest for project design.

Regional Hydroclimatic Flood Trends

It is well known that many New England watersheds have been affected by watershed land use change and/or flow regulation, and thus flood frequency analyses in these watersheds may be affected depending on the nature and magnitude of these changes. Until recently, however, there had not been any detailed, regional investigations of climate-induced changes in New England annual flood series despite well-documented increases in precipitation nationwide and regionally—especially for infrequent, high intensity events (Karl and Knight, 1998; Madsen and Figdor, 2007). To evaluate how such precipitation trends may be affecting annual floods in New England, Collins (2009) investigated hydroclimatic trends in 28 long-term annual flood series in New England watersheds with minimal land use change, and no flood regulation, over their periods of record. The flood records were continuous through 2006 and averaged 75 years in length.

Twenty-five of the 28 annual series showed upward trends in annual flood magnitudes via the nonparametric Mann-Kendall trend test, 40% (10) of which had $p<0.1$(Figure 1; Collins, 2009). Moreover, the data indicated that increasing flood magnitudes in New England occurred as a step change around 1970—suggesting a hydroclimatic shift. Global average temperatures began a warming trend in the 1970s that has been attributed to anthropogenic greenhouse gas emissions (Hansen et al., 2001; IPCC, 2007), and numerous trends in climatic and hydrologic variables indicative of a warming climate have been documented in the northeastern United States over the last 100 years--many are especially pronounced since the 1970s (Huntington et al., 2009). The timing of observed step changes in New England annual flood magnitudes is also broadly synchronous with a phase change in the low frequency variability of the North Atlantic Oscillation (NAO), a prominent upper atmospheric circulation pattern that is known to affect climate variability along the United States east coast.

Flood Frequency Analysis

Statistical estimates of flood magnitude and frequency from a measured streamflow record at a site are developed by analyzing a time series of instantaneous peak flows, most frequently the largest instantaneous peak of each water year—referred to as the "annual series." The flood record should be a minimum of 10 years long, but considerably longer records are preferred and increase confidence in the estimates. Such statistical analyses assume that the annual floods are a series of independent events (i.e., the magnitude of a flood in a given year does not influence the magnitude of a flood in a succeeding year) representative of modern climate and watershed land use, and that the record is not affected by trends related to land use or climate changes. If an analyst believes trends in land use or climate are affecting a flood record, Federal guidelines suggest special treatment of those data (IACWD, 1981).

While the NAO is a semi-permanent feature of upper atmospheric circulation and is thus an expression of natural variability in the climate system, recent research has suggested that anthropogenic climate change may be related to the dominantly positive phase since 1970 (Hoerling et al., 2001; Sutton and Hodson, 2003; Lu et al., 2004; King and Kucharski, 2006) and could continue it (Rind et al., 2005). Hydroclimatic shifts in flood records, whether human-induced or exclusively an expression of natural variability in the climate system, present challenges for flood frequency analysis. Federal guidelines suggest that parsing affected flood series into hydroclimatically distinct time periods and analyzing each separately may produce more reliable flood frequency estimates (IACWD, 1981). Collins (2009) did so for the flood series in his study with statistically significant upward trends and evidence of a step change around 1970. For many of these sites, flood frequency curves calculated using only the pre-1970 record produced smaller flood magnitude estimates than those produced by the full record or the post-1970 record (Figure 2). In some cases the differences are considerable. Hodgkins (2010) found broadly similar results for a study of long-term annual flood series in Maine. It is important to note, however, that some very large New England floods occurred in the pre-1970 period (e.g., 1936, 1938, 1955), and these remain the floods of record for some watersheds with long gauge records. In these instances, using only pre-1970 data may indeed produce larger flood magnitude estimates for low probability events (e.g., 1 and 2 percent annual exceedance probabilities; Collins, 2009; Hodgkins, 2010).

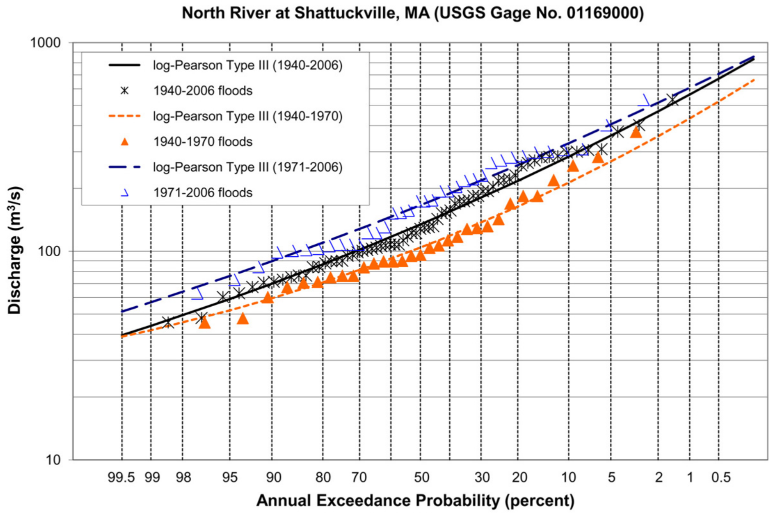

Figure 2. Partial and full-record flood frequency curves for the North River at Shattuckville, MA. Note that the curve computed using pre-1970 data (orange) predicts smaller flood magnitudes for all exceedance probabilities than the curves computed using the full record or the post-1970 record.

Project Design Guidance

In stream restoration, it is common practice to use flood frequency estimates from existing studies for design. Federal Emergency Management Agency (FEMA) Flood Insurance Studies (FISs) are especially relied upon. It is attractive to do so because it saves money, the FEMA studies have been vetted and have regulatory significance, and climate, until recently, has been considered nonvariant over comparatively short time periods. However, many FEMA studies are decades old and were produced with stream gauge records ending in the 1970s and early 1980s. The results of Collins (2009) and Hodgkins (2010) suggest that flood frequency estimates based on time series of flood data that end in the 1970s and 1980s are not representative of the modern climatic regime and will frequently produce underestimates.

The NOAA Restoration Center[1] thus recommends the following guidelines for developing flood frequency estimates for fish passage and stream restoration projects in New England and elsewhere in the northeast United States.

- At a minimum, project design teams should base statistical flood frequency estimates on flood records that include the most recent available data to the extent practical. For example, if a dated FEMA study is available that includes flood frequency estimates based on an analysis of a nearby stream gauge with a record from 1963-1981, and that stream gauge is still operating or operated until recently, the flood record should be extended and the estimates recomputed by using the entire record (e.g., 1963-present). Doing so ensures that the estimates represent modern hydroclimatic conditions and benefit from the longer record.

- When the updated flood record includes a substantial period before 1970 (e.g., 20 years), the design team should compute pre-1970, post-1970, and full record curves as shown in Figure 2 and consider choosing the most conservative (larger) estimates for design flows. The most conservative estimate of a given exceedance probability flow will frequently be given by the post-1970 curve. However, for some rivers in New England, as described above, the pre-1970 curve will provide the most conservative estimates for low probability events. Making use of multiple curves to conservatively estimate design flows implicitly recognizes that the climate system may in the future revert to a regime that preceded the most recent hydroclimatic condition.

- If the flood record for the gauge of interest has little or no data from recent decades, consider using other estimation techniques if they incorporate contemporary data and compare those results with estimates obtained from the dated gauge record. For example, the analyst could compare the gauge-based estimates with estimates from recently developed regional regression equations or a rainfall-runoff model forced with updated rainfall frequency distributions. However, these methods should also be applied to the earlier period of record to evaluate methodological bias. For example, a rainfall-runoff model forced with updated rainfall frequency distributions should also be run with older distributions derived from data contemporaneous with the stream gauge record.

[1] The NOAA Restoration Center provides technical expertise and financial assistance to remove dams and barriers and restore habitat for the many species that migrate between the ocean and the nation's freshwater rivers and streams.

Whether estimated from streamflow records, as discussed here, or via rainfall-runoff models which are forced by rainfall frequency distributions estimated from historical records, flood frequency estimates are based on the assumption that the past is a reasonable guide to the future. Anthropogenic climate change challenges that assumption and has prompted calls to develop non-stationary estimation techniques that combine paleohydrologic and historical records with projections from multiple climate models (Milly et al., 2008). Since such techniques are not fully mature, and wide availability/acceptance may be years away, the guidance offered here provides an interim approach to help project teams avoid underestimating flood magnitudes at New England project sites. These guidelines employ well-established estimation techniques, encourage evaluation of the entire updated gauge record, and ensure that data representing the recent past--and thus the modern hydroclimatic regime--inform the analysis.

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