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Invited research article

Storm-generated Holocene and historical floods in the Manawatu River, New Zealand

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ABSTRACT

This paper reports the first reconstruction of storm-generated late Holocene and historical river floods in the North Island of New Zealand. The sedimentary infills of nine palaeochannels were studied in the lower alluvial reaches of the Manawatu River. Floods in these palaeochannels were recorded as a series of sand-rich units set within finer-grained fills. Flood chronologies were constrained using a combination of radiocarbon dating, documentary sources, geochemical markers, and palynological information. Flood units were sedimentologically and geochemically characterised using high resolution ITRAX™ X-Ray Fluorescence (XRF) core scanning and laser diffraction grain-size analysis. The longest palaeoflood record extends back ca.3000 years. The temporal resolution and length of the Manawatu record reflects accommodation space for fluvial deposits, channel dynamics and mobility, and high sediment supply. Floods that occurred in the Manawatu during the mid-1800s at the time of European land clearance and in the first decade of the twentieth century appear to be among the largest recorded in the last 3000 years.

1. Introduction

Palaeoflood research in New Zealand to date has largely focused on volcanogenic break-out floods associated with the ca. 180 CE Taupo eruption (Manville et al., 1999, 2005), 26.5 ka Oruanui eruption from the same caldera (Manville and Wilson, 2004), and lahars generated within the Taupo Volcanic Zone (Manville, 2004; Graettinger et al., 2010; Manville and Hodgson, 2011). Little attention has been given to palaeofloods beyond New Zealand's volcanic terrain, and yet storm-generated flooding is the most frequent natural hazard in New Zealand, with over 1000 serious events in the last 100 years (Willis, 2014). Assessing flood risk is, however, presently constrained by short (generally <60 year) gauged river flow records that poorly represent the distribution of hydrological extremes (Fuller et al., 2016). The peak discharges of early twentieth century floods have been estimated on the basis of historical records (e.g., Cowie, 1957), but human recording of floods in New Zealand is limited by its very recent colonisation, and there is a paucity of documentary evidence. Recent work using meta-analysis of a radiocarbon database developed from New Zealand Holocene alluvial records (Macklin et al., 2012; Richardson et al., 2013; Fuller et al., 2015) has produced centennial-scale records of flooding in New Zealand as a whole. While this approach has been able to identify flood-rich and flood-poor episodes throughout the Holocene, and relate these events to broad-scale synoptic forcing (Richardson et al., 2013), it does not enable event-scale, storm-generated palaeoflood reconstruction.

Recent studies of lowland alluvial river systems have demonstrated that the grain size of individual flood beds, contained in the infill of abandoned meanders, can be used to reconstruct (palaeo)flood series (Munoz et al., 2015; Toonen et al., 2015). These records provide a tool to place recorded extreme events in a framework of long-term flooding variability. Moreover, longer flood series allow detection of distinctive phases and episodes of flooding in addition to individual events (Toonen et al., 2017), which allows comparison with other regional hydroclimatic and biological records (e.g. Norton et al., 1989; Richardson et al., 2013; Fuller et al., 2015). Furthermore, a longer flood series makes it possible to identify underlying forcing, such as El Niño Southern Oscillation (ENSO) for the Pacific region (Ely, 1997; Kiem et al., 2003) including New Zealand, where the Antarctic Southern Annular Mode (SAM) is also important (Macklin et al., 2012; Richardson et al., 2013); and NAO/AMO (North Atlantic Oscillation/Atlantic Multidecadal Oscillation) for the Atlantic (Foulds and Macklin, 2016; Toonen et al., 2016).

In this we paper we explore the gap in palaeoflood research in New Zealand by providing the first reconstruction of discrete storm-generated floods using analysis of the fluvial sedimentary archive, extending over the past ~3000 years. The catchment in which this work is situated lies beyond the volcanic terrain of the central North Island, removing the possibility of volcanogenic floods. The nature of topography in the Manawatu means that landslide dams in trunk rivers

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are rare, although significant elsewhere in New Zealand alpine terrain in association with coseismic events and/or rainfall (e.g. Korup 2002; Hancox et al., 2005). The flood record presented here is, we believe, truly storm-generated.

2. Site description

2.1. Manawatu catchment

The Manawatu River drains a 5885 km^2 catchment situated in southern North Island of New Zealand (Fig. 1). The catchment straddles the greywacke North Island axial ranges (Tararua and Ruahine) and comprises six primary tributaries, four of which rise on the east of these ranges (Fig. 1B). The study reach, adjacent to Palmerston North, is situated in the lower part of the catchment. Mean annual discharge for the Manawatu River is ca. 110 $m^3\ s^{-1}$ with the most significant contributions derived from the upper Manawatu (ca. 27 $m^3\ s^{-1}$), Mangatainoka (ca. 18 $m^3\ s^{-1}$), Pohangina (ca. 17 $m^3\ s^{-1}$), Tiraumea (ca. 16 $m^3\ s^{-1}$), Mangahao (ca. 15 $m^3\ s^{-1}$), and Oroua (ca. 13 $m^3\ s^{-1}$) (figures derived from Henderson and Diettrich, 2007). The catchment was extensively cleared of native forest in a period spanning the late 1800s and early 1900s to make way for mostly pastoral agriculture (Fig. 1C). Native forest remains on the greywacke ranges, which rise to 1695 m and 1505 m in the northernmost and southernmost parts of the catchment respectively. The Manawatu River crosses the axial range through the Manawatu Gorge, which is the only locality for significant dambreak floods in the trunk river and primary tributaries. However, the evidence is not clear (geological, documentary, or Maori oral tradition) of the river having been completely dammed by landslides here in the late Holocene, although the presence of large boulders in the channel floor of the Gorge indicates significant local, off-slope delivery. With the exception of the uplifted greywacke fault block, most of the catchment is underlain by soft sedimentary rock, notably mudstones and sandstones (Fig. 1D). Erosion of this terrain generates a suspended sediment yield from the Manawatu to the ocean of ca. 3.74 Mt y^{-1} (Hicks et al., 2011). While this volume of sediment discharge has no doubt been enhanced by land clearance (Hicks et al., 2011), the underlying soft-rock terrain is likely a naturally high sediment generator. Clement et al. (2017) recorded a rapid infilling of the Manawatu estuary within ca. 2700 years of the mid-Holocene sea level high-stand (7240–6500 cal. YBP). Tectonic uplift in the catchment is ca. 1–4 mm y^{-1} in the greywacke ranges (Wellman, 1972; Pillans, 1986; Whitehouse and Pearce, 1992), and river terraces generated by downcutting in response to this uplift are prominent landscape features in the upper and middle reaches of the primary valleys.

2.2. Climate

Climate in the region is humid temperate; mean annual rainfall in Palmerston North is ~980 mm, rising to >2000 mm in the Tararua and Ruahine ranges (NIWA, 2017). Most rain in the catchment is brought by mid-latitude frontal systems approaching from the west, although subtropical depressions in late summer-autumn and southerly polar outbreaks (throughout the year) can bring easterly-quarter rain. Temperatures are mild: the mean temperature in the coldest month (July) is 8 °C, rising to 18 °C in the warmest month (February). Snow at sea level is extremely rare (~30-year recurrence interval), although snowpacks above the tree line (~1000 m) can develop during sustained cold periods.

2.3. Floodplain topography

In the lower Manawatu valley in the vicinity of Palmerston North, the valley floor widens and becomes unconfined as the river emerges into the

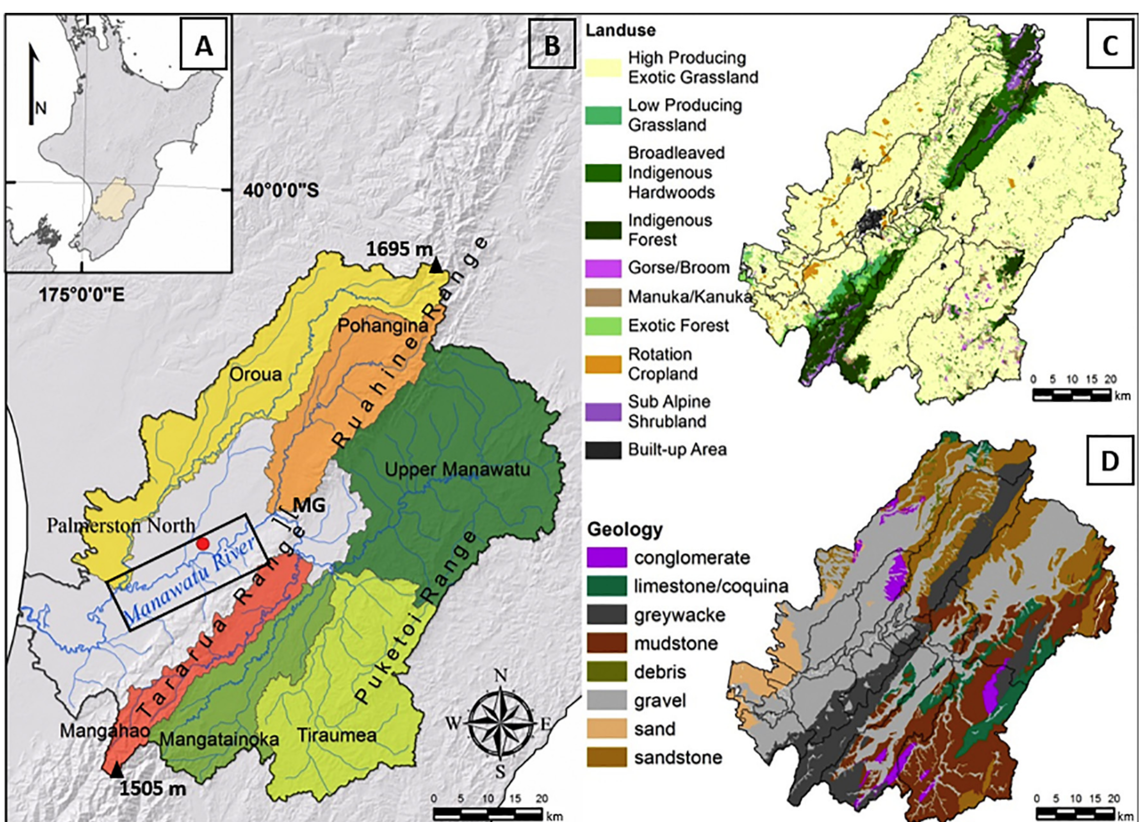

Fig. 1. Manawatu catchment: (A) North Island location, (B) primary sub-catchments and location of Palmerston North (the focus of this study), (C) catchment land use, (D) catchment geology (after Vale et al., 2016). Rectangle shows extent of study area (cf. Fig. 2).