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Reconstruction of the 1784 flood hydrograph for the Vltava River in Prague, Czech Republic

L. Elleder

Czech Hydrometeorological Institute, Na Šabatce 17, 143 06 Prague 4-Komořany, Czech Republic

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ABSTRACT

The flood of February 1784 was one of the most extreme events, not only in Bohemia (present Czech Republic), but across Europe. This paper presents a reconstruction of the 1784 flood hydrograph based on all available, mostly non-instrumental, data. The reconstructed 1784 flood hydrograph, the oldest one available for the Vltava River in Prague, reveals the extraordinary dynamics of the flood. In comparison with the hydrographs of the most disastrous Czech historical floods (of 1845, 1862, 1872, 1890 and 2002), the 1784 flood was a very rapid event. From the onset of precipitation, it took only 45 h for the flood to peak in Prague and there was a ~4 m rise in water level during a 12-hour period. The steep gradient of the rising limb of the flood hydrograph is still a record in Prague and the recorded peak water stage was exceeded only by the flood of 2002. This paper introduces a method for flood reconstruction for the early instrumental period of hydrology and meteorology when the direct measurement of water levels was not widespread. This approach has practical applications for enhanced flood warning systems. An improved understanding of past hydrological extremes may contribute significantly to our understanding of flood dynamics in an era of global change.

1. Introduction

Global climate change predictions suggest a more frequent occurrence of hydrometeorological extremes, including floods (IPCC, 2007). The recent extreme flood events recorded at the end of the last and the beginning of this millennium in many parts of the world have drawn the attention of scientists to historical (Benito et al., 2004; Llasat et al., 2005; Calenda et al., 2005; Burger et al., 2006) and earlier palaeoflood (St George and Nielsen, 2003; Sandercock and Wyrwoll, 2005) reconstructions. The advantages and uncertainties related to the reconstruction of palaeofloods in different geomorphological settings, and the reconstruction of historical floods using different documentary sources, have been reviewed by Benito et al. (2004). Many historical flood reconstructions have been carried out for European rivers, but most have focussed on flood magnitude rather than the dynamics of the flood hydrograph for a specific event. For example, Llasat et al. (2005) analysed historical documents and meteorological data to develop a flood history for Catalonia in northeast Spain back to the fourteenth century and Calenda et al. (2005) have studied the distribution of extreme peak floods in the Tiber River basin in Italy from the fifteenth century. Burger et al. (2006) have modelled the regional atmospheric circulation and precipitation patterns associated with the 1824 flood in the Neckar River basin in southwest Germany.

The disastrous floods of 1997 and 2002 in the Czech Republic provided a new impetus to analyse the floods of the recent past. Key questions have emerged relating to what we can learn from historical floods in the context of global change predictions and the extent and reliability of the available historical documentation. From a hydrological perspective, it is the flood hydrograph that records the temporal pattern of water levels at a given location and it can be argued that this should form a key part of flood reconstruction. The hydrograph generally provides us with information on the dynamics of the event (e.g. the rate of water level rise and fall) and the volume of the flood wave. In Prague, continuous stage records for the Vltava River have been recorded since 1825. Unfortunately, the hydrological data for the first 50 years of this record (up to 1874) have been lost. Thus, the only way to obtain information on the flood hydrographs for that period (and for earlier periods) is to reconstruct them from alternative data sources. This is only possible, however, for some of the largest events. In Prague, extreme floods are documented in detail only as late as for the events that took place in 1845 and 1890.

This paper focuses on the hydrological reconstruction of a catastrophic flood in the Vltava River basin that struck the city of Prague in 1784. Table 1 puts this event into a wider European context by summarising some of the most important large floods in selected river basins over the last 500 years. The table indicates an increase in flood incidence around the middle of the seventeenth century and in the final quarter of the eighteenth century when the 1784 flood took place.

Elleder and Munzar (2004) have outlined the causes of the 1784 flood based on documentary sources in the Czech Republic and Munzar

E-mail address: elleder@chmi.cz.

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Table 1
The most extreme floods in selected European river basins over the past 500 years. Extreme flood values are given in bold and a P in the last column indicates an extreme flood in Prague. (+) is an important flood but for which no hydrological data are available. X indicates floods of lesser importance.

Year, month	Paris H_m (cm)	Cologne H_m (cm)	Vienna H_m (cm)	Dresden H_m (cm)	
1501, VIII	No data	No data	**1033**[g]	**806**[h]	P
1595, III–V	No data	**1154**[b]	No data	760[i]	
1598, VIII	No data	No data	No data	>**800**[i]	P
1649, I	**781**[a]	No data	No data	No data	
1651, I	**798**[a]	**1120**[b]	No data	753[i]	
1655, II	No data	No data	No data	**897**[h]	P
1658, II	**896**[a]	1198[b]	No data	~800[i]	
1740, XII	**805**[a]	(+)	No data	(+)	
1768, I–II	536[h]	No data	***Similar to the event of 1899***[d]	~650[i]	
1784, II	681[a]	**1260**[b]	***30 cm higher than the event of 1768***[e]	**859**[h]	P
1787, X–XI	No data	No data	**> 1784**[f]	No data	
1799, II	**765**[a]	778[f]	(+)[d]	**829**[h]	P
1830, II–III	No data	(+)	**537**[c], **695**[f]	798[i]	
1845, III	400[a]	**933**[b]	279[e]	**877**[h]	P
1862, I	No data	840[b]	**482**[c]	**824**[h]	P
1890, IX	X	No data	375[c]	**837**[h]	P
1899, IX	No data	No data	**866**[g]	~620[h]	
1910, I	**810**[a]	No data	No data	No data	
1993, XII	No data	**1063**[b]	X	X	
1995, I	No data	**1069**[b]	X	X	
2002, VIII	X	No data	**863**[g]	**940**[i]	P

Notes: Flood level peaks (H_m) according to the following sources:
a) Seine—Paris/Pont d'Austerlitz: Plan de Secours Specialise Inondations (http://www.prefecture-police-paris.interieur.gouv.fr retrieved on April 19, 2008).
b) Rhein—Cologne: Zur Kölner stadtgechichte (http://www.archive.nrw.de/index.asp retrieved on April 19, 2008).
c) Donau (canal)—Vienna/Ferdinandbrücke: Beiträge zur Hydrographie Österreichs. II. Heft, 1898.
d) Donau (canal)—Vienna/Ferdinandbrücke: Beiträge zur Hydrographie Österreichs. IX. Heft, 1908.
e) Donau (canal)—Vienna/Ferdinandbrücke: Wiener Zeitung.
f) Börngen and Tetzlaff (2000); Börngen and Tetzlaff (2002).
g) Donau—Vienna/Reichsbrücke: Stadt- und Flussentwicklung (http://www.hydro.tuwien.ac.at/lehre/wawisem/02-gruppe10/3.htm retrieved on April 19, 2008).
h) Elbe—Dresden/Augustbrücke: www.uni-leipzig.de, retrieved on April 19, 2008.
i) Estimation according to the flood marks in Decin, Czech Republic, Brazdil et al. (2005).

et al. (2005) have placed this event in a wider central European context. This late winter flood belongs to the most important extreme examples of its kind in central Europe because at this time catastrophic floods affected a large area including northern France, The Netherlands, Belgium, Germany, Bohemia, Austria and Slovenia. The concurrence of several factors resulted in this natural disaster. An extraordinarily cold, snowy and long winter formed excellent conditions for the accumulation of vast amounts of snow in the Vltava basin (Fig. 1). A great portion of the Labe River basin in Bohemia was covered by snow to a depth of more than 50 cm, catchment soils were frozen, and the thickness of river ice varied between 60 and 120 cm. A key factor behind the onset of flooding was the sudden penetration of warm air in western and central Europe around 23 February 1784, which caused rapid snowmelt followed by heavy rainfall. In the Czech territory, the immediate causes of the flood were intensive rainfall on February 26 and 27 (40 mm in 24 h in Prague), accompanied by strong snow melt (50 cm of snow melted in 24 h at low elevations) resulting from an air temperature rise during the day to 9 °C and strong winds. While the air temperature was measured systematically by the Prague Klementinum Observatory at that time, the systematic recording of precipitation inputs began much later (in 1804), and so there is only a single precipitation record for the 1784 flood (for March 26, 1784). Apart from the large extent of the inundated area, the unusual flood dynamics as well as the unprecedented high peak contributed to the formation of a distinctive "1784 flood phenomenon". Specifically, the level of the Vltava River in Prague rose by ~4 m in just 12 h. This record rate of water level rise has not been surpassed, even during the catastrophic floods in August 2002, which shifted the long-standing record peak flow of the 1784 flood to second place. The only monitored hydrological information available for the 1784 flood is the peak time and peak water level. This paper presents a hydrological reconstruction of the 1784 flood hydrograph based on an analysis of all available (mostly non-instrumental) data, supplemented by a few direct measurements, and provides a critical analysis of the approach and the outcomes.

2. Methods

2.1. Input data

A collation of all existing data (both instrumental and non-instrumental) formed the basis for the reconstruction of the 1784 flood hydrograph. The hydrometeorological measurements from the early instrumental period, cartographic sources, and the epigraphic (flood mark) and documentary sources specified below have been used as the major input data for this purpose and these data sources are briefly outlined below.

2.1.1. Hydrological data from the early instrumental period

The only information on water levels for the 1784 flood exists as explanatory notes to meteorological data from Prague Klementinum Observatory. These are unsystematic and irregular. It seems likely that it was not possible to measure water levels during the flood because the water gauge was flooded and inaccessible. As auxiliary data, the water levels from Dresden and Magdeburg—from the Czech Hydrometeorological Institute (CHMI) archive—were used.

2.1.2. Meteorological data from the early instrumental period

Meteorological data including temperature, atmospheric pressure, wind direction and velocity (each measured 3 times a day), and daily precipitation amount as measured at Prague Klementinum Observatory during the period February to March 1784 were used.

2.1.3. Cartographic sources

Historical maps of the Czech territory (to identify river channel changes) and maps of Prague (Herget's map of Prague from 1794, and the Prague map from 1889 with sketches of flood marks from the 1784 event) were used. An understanding of the historical topography