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Review of trend analysis and climate change projections of extreme precipitation and floods in Europe

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SUMMARY

This paper presents a review of trend analysis of extreme precipitation and hydrological floods in Europe based on observations and future climate projections. The review summaries methods and methodologies applied and key findings from a large number of studies. Reported analyses of observed extreme precipitation and flood records show that there is some evidence of a general increase in extreme precipitation, whereas there are no clear indications of significant trends at large-scale regional or national level of extreme streamflow. Several studies from regions dominated by snowmelt-induced peak flows report decreases in extreme streamflow and earlier spring snowmelt peak flows, likely caused by increasing temperature. The review of likely future changes based on climate projections indicates a general increase in extreme precipitation under a future climate, which is consistent with the observed trends. Hydrological projections of peak flows show large impacts in many areas with both positive and negative changes. A general decrease in flood magnitude and earlier spring floods are projected for catchments with snowmelt-dominated peak flows, which is consistent with the observed trends. Finally, existing guidelines in Europe on design flood and design rainfall estimation are reviewed. The review shows that only few countries have developed guidelines that incorporate a consideration of climate change impacts.

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1. Introduction

The risk of destructive flooding has posed a threat to human settlements across Europe throughout recorded history (Brázdil et al., 2006; Macdonald, 2012) and has prompted hydrologists and engineers to develop tools for quantifying the risks such as flood frequency analysis. Standard statistical procedures for frequency analysis of extreme precipitation and floods are based on the assumption of stationarity, and historical records of extreme events are used to estimate extreme value statistics. Several European nations have developed specific methods and guidelines for use of flood frequency methods (Castellarin et al., 2012). In a changing environment, however, the assumption of stationarity might not be applicable due to changes in climate, in hydrological regime (e.g. land use changes, urbanisation, and wetland draining), and in river infrastructure. The impacts of these changes on extreme precipitation and flood frequency characteristics should be quantified and incorporated in design guidelines and standards. This includes detection and attribution of past changes or trends and projection of future changes. Improved knowledge of the likely future risk profiles also plays an important role in decision making when considering, for example, societal adaptation to future climate change (Hall et al., 2012; Bormann et al., 2012).

Changes in extreme precipitation and flood statistics has become a very active research area, and numerous studies have been published in recent years that analyse trends in historical time series of extreme precipitation and flood discharge (see review in Section 2). Investigation of possible climate change is a primary driver for these studies. With respect to changes under a future climate, climate modelling studies have shown that an increase in heavy precipitation is likely in most parts of the world in the 21st century (IPCC, 2012). As river flow is the integrated response of many driving processes, including meteorological forcing (temperature, precipitation, evaporation), morphologic

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properties of the catchment (slope, elevation), geologic characteristics (groundwater in aquifers, runoff characteristics), and anthropogenic activities (water withdrawal for irrigation or drinking, dams for flood mitigation or hydropower production, and land-use changes), such impacts on floods are challenging to assess. The projected increases in heavy precipitation as well as projected increases in temperature are expected to have an impact on flood frequency. To quantify these impacts a large number of studies have been conducted using projections from climate models as input to hydrological modelling (see review in Section 3).

While water resources management issues in Europe are complex and often predicated on local political, socio-economic, geophysical and climatic conditions (EEA, 2012), it is generally agreed that a risk-based approach to flood management is desirable. Consequently, the European Commission adopted the Flood Directive (Directive 2007/60/EC) (EC, 2007) to '*establish a framework for the assessment and management of flood risk, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community*'. The Directive requires member states to identify areas at risk of flooding and to take into consideration '*long term developments including impacts of climate change on the occurrence of floods*' (EC, 2007). However, the Directive does not prescribe actual guidelines for how best to estimate these potential impacts of climate change on flood risk.

As a first response to this gap between the requirements of the Flood Directive and the technical knowledge required to implement it, this paper presents a review of studies on detection of past trends based on observations and on likely future trends based on climate projections for extreme precipitation and hydrological floods in Europe. The review is based on a survey conducted as part of the COST Action ES0901 European Procedures for Flood Frequency Estimation (FloodFreq) and summarises results from review reports that have been prepared by 19 country members of the FloodFreq COST Action (see overview of contributing countries and organisations in Table 1). We have also included studies reported in a recent publication by the International Association of Hydrological Sciences (IAHS) on changes in flood risk in Europe (Kundzewicz, 2012). The following two sections (Sections 2 and 3) summarise, respectively, the studies on trend analysis of observed data and on projections of likely changes derived from climate model data. Each section includes a review of the methods applied and a summary of the key findings. In Section 4, existing guidelines in Europe on design flood and design rainfall estimation that have incorporated a consideration of climate change impacts are reviewed. Finally, a discussion and conclusions are presented in Section 5.

2. Trend analysis

The studies reviewed on trend analysis of extreme precipitation and floods are summarised in Table 2. The summary includes information about (i) study location and extent (i.e. European-wide, larger regions covering several countries, nationwide, smaller regions covering several catchments within a geographical coherent area, and river basins or catchments); (ii) the hydrological variable considered, i.e. precipitation or river discharge, including temporal resolution, number of stations, and length of the time series included in the analysis, as available; (iii) trend detection method(s) applied; (iv) summary of key findings, and (v) references.

Trend analyses from 46 studies representing 22 countries in Europe have been reviewed, see Fig. 1. The review includes nationwide studies of extreme precipitation from Bulgaria, the Czech Republic, Denmark, Germany, Greece, Sweden and the UK, and of extreme streamflow from Austria, Finland, France, Germany, Lithuania, Poland, Slovenia, Switzerland and the UK. In addition, studies on changes in extreme precipitation and streamflow at a European scale and larger regional studies of extreme streamflow for the Alps (Austria, France, Germany, Italy, Slovenia and Switzerland), the Baltic countries (Lithuania, Latvia and Estonia) and the Nordic countries (Norway, Sweden, Denmark, Finland and Iceland) are included in the analysis. With respect to extreme precipitation, most studies are based on daily rainfall extremes, whereas some studies also report results on trend analysis of high-resolution rainfall extremes (down to 1–10 min). For extreme streamflow the reported studies are mainly based on daily discharge values, and in some cases on instantaneous peak flow values. River stage values have been analysed in one of the reviewed studies. In most studies, extreme value indices analysed have been derived using annual maximum or peak over threshold series, considering both annual and seasonal extremes.

2.1. Methods

Methods applied for analysing trends include both descriptive analyses and statistical tests. A simple descriptive approach is to

Table 1
List of countries and organisations that have contributed to the survey.

Country	Organisation(s)
Belgium	KU Leuven, Hydraulics Division, Leuven
Bulgaria	National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences, Sofia
Cyprus	Dion Toumazis & Associates, Nicosia
Czech Republic	T.G. Masaryk Water Research Institute, Prague Faculty of Civil Engineering, Czech Technical University, Prague
Denmark	DTU Environment, Technical University of Denmark, Lyngby DHI, Hørsholm
Finland	Finnish Environment Institute, Freshwater Centre, Helsinki
France	Irstea, UR HHLY, Lyon
Germany	Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences, Section Hydrology, Potsdam
Greece	Department of Civil Engineering, University of Thessaly, Pedion Areos, Volos
Italy	GECO sistema srl – Cesena, Italy and Regione Emilia Romagna – Autorità dei Bacini Regionali Romagnoli, Forlì
Lithuania	Lithuanian Energy Institute
Norway	Norwegian Water Resources and Energy Directorate, Oslo
Poland	Department of Hydrology and Hydrodynamics, Institute of Geophysics, Polish Academy of Sciences
Slovakia	Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology, Bratislava
Slovenia	Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana
Spain	Department of Civil Engineering, Hydraulic and Energy Engineering, Technical University of Madrid, Madrid
Sweden	Swedish Meteorological and Hydrological Institute, Norrköping DHI, Göteborg
Turkey	Middle East Technical University, Civil Engineering Department, Ankara Dokuz Eylul University, Department of Civil Engineering, Izmir
UK	Centre for Ecology & Hydrology, Wallingford Department of Geography, University of Liverpool

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