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Long-term changes in flood event patterns due to changes in hydrological distribution parameters in a rural–urban catchment, Shikoku, Japan

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ABSTRACT

This article describes the principal control parameters of flood events and precipitation and the relationships between corresponding hydrologic and climatologic parameters. The long-term generation of runoff and associated processes is important in understanding floods and droughts under changes in climate and land use. This study presents detailed analyses of flood events in a coastal amphitheatre catchment with a total area of 445 km^2 in western Japan, followed by analyses of flood events in both urban and forest areas. Using long-term (1962 to 2002) hydrological and climatological data from the Ministry of Land, Infrastructure and Transport, Japan, the contributions of precipitation, river discharge, temperature, and relative humidity to flood events were analysed. Flood events could be divided into three types with respect to hydrologic and climatologic principal control parameters: the long-term tendency; medium-term changes as revealed by hydrographs and hyetographs of high-intensity events such as the relative precipitation, river discharge, and temperature; and large events, as shown by the flow–duration curve, with each cluster having particular characteristics. River discharge showed a decreasing tendency of flow quantity during small rainfall events of less than 100 mm/event from the 1980s to the present. An approximately 7% decrease from 44.8 to 37.3% occurred in the percentage of river water supplied by precipitation in the years after the 1980s. For the medium-term changes, no marked change occurred in the flow quantity of the peak point over time in event hydrographs. However, flow quantities before and after the peak tended to decrease by 1 to 2 m^3/s after the 1980s. Theoretical considerations with regard to the influence of hydrologic and climatologic parameters on flood discharge are discussed and examined in terms of observational data. These findings provide a sound foundation for use in hydrological catchment modelling.

1. Introduction

The hydrological and meteorological roles of land use in both urban and forest areas have attracted considerable attention in flood research. Loss rate methods such as the rational method and storage routing model are still widely used for calculating rainfall excess, despite increasing evidence for the spatial variability of catchment flood generation and awareness that, in decision making and river management, these methods could be misleading due to their inherent assumption of uniform catchment response. This paper describes a method that can overcome this deficiency. Many water resource management issues require an understanding of how hydrological, climate, and land use contexts will influence the distribution of daily base flows, large events, and long-term change in the flow duration curve. This paper focusses on the hydrological and climatological parameters of the flood–rainfall relationship to suggest how alterations to land use in a catchment can affect floods. Using

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assumptions on how changes in land use might influence runoff processes, the potential for flood runoff reduction can be estimated (Naef et al., 2002). The effects of land use changes on flooding are presented in terms of the long-term pattern, medium-term changes, large events, and temporal scales.

Depending on land use, various surface flow processes may be expected (Merz et al., 2006). Because all rainfall events have spatial variability, no logical cut-off point exists for rejecting events that show too much variability. Recognising both this and the fact that any analysis assumptions made should match those of the design synthesis, all major time-separable precipitation and stormflow events were included in this analysis (Clark, 1980). To understand flood generation under different conditions, runoff generation has been studied extensively throughout the world (Pearce et al., 1986; Uhlenbrook, 2005). Following formal principles of classification is important when attempting to identify regional groupings. In particular, groupings should be based on factors that directly describe the attribute of interest, rather than on factors that supposedly influence that attribute (Mosley, 1981; Řezáčová et al., 2005).

The lack of a linear relationship between precipitation and flooding on annual, seasonal, and monthly time scales may be related to either short study periods or the large range of evapotranspiration scenarios (Estrany et al., 2009). Consequently, researchers have only been able to observe a succession of different hydrological periods throughout the year as conditioned by the potential evapotranspiration. Rather strong correlation has been observed between principal components of discharge and meteorological parameter anomalies. Thus, as described by Pand and Trnini (1992), a hydrological problem could be solved in terms of a meteorological problem. In their study, a particular discharge anomaly pattern (type) was followed by a mesoscale precipitation anomaly or Palmer 'drought index' as well as by the macroscale surface pressure anomaly type (Pand and Trnini, 1992).

Event runoff coefficients can also be used in event-based flood frequency models (e.g., Sivapalan et al., 2005) that estimate flood frequencies from precipitation frequencies. These coefficients are useful for understanding the flood frequency controls in a particular hydrologic or climatic regime. Although the event runoff coefficient is a key concept in hydrology, most regional-scale studies have analysed a relatively small number of events. For example, runoff coefficients for the Swiss high alpine catchments studied by Gottschalk and Weingartner (1998) were smaller and more skewed than were those for the alpine region studied here (mean of 0.10 in the Swiss study compared with 0.40 in the present study). The Swiss prealpine region was similar to the southern prealpine region studied here in terms of the distribution of runoff coefficients (mean of 0.33). The Swiss midlands had a mean of 0.16, and the distribution was highly skewed; the Swiss southern alpine region had a mean of 0.19, and the distribution was moderately skewed. Interestingly, Gottschalk and Weingartner (1998) interpreted the Swiss runoff coefficients mainly by topographic characteristics such as altitude and slope, and to some degree by stream network density and geology.

The effects of long-term variability of climatic inputs on mean annual and monthly water balances and the roles of climate, soil properties, and topography were shown by Yokoo et al. (2008) to modulate these impacts. The results of that study were summarised in terms of the soil type and three dimensionless numbers: climatic dryness, storage capacity, and drainability. Precipitation volume, as well as antecedent soil moisture conditions and groundwater levels, are of major importance in determining the degree to which land use can influence storm-runoff generation (Naef et al., 2002). Cosandey and de Oliveira (1996) examined runoff-contributing areas in the Can Vila research catchment, Spain, providing new data on the seasonal dynamics of those areas, which had seldom been investigated at the catchment scale. Based on the information derived from eight field surveys, contributing areas for either infiltration or saturation excess runoff were identified as key zones for stream-flow generation. Their study of seasonal dynamics of variable runoff-contributing areas in the Can Vila catchment provided a fuller picture of its hydrological behaviour and confirmed the relevance of saturated areas (at least seasonally) in Mediterranean conditions. One major difference between findings from that study and findings reported for other contributing areas concerns the observed spatial patterns of saturated regions. In the Can Vila catchment, saturation patterns were much more scattered than typically found in other areas. This pattern was probably influenced by the terraced topography present in more than 70% of their catchment, but also by soil properties (rapid decrease of hydraulic conductivity with depth) and precipitation seasonal dynamics. The highest scatter of the saturated area distribution corresponded to the wetting-up transition. When associated with saturation restricted to the upper soil areas, this dominated the saturation pattern (Latron and Gallart, 2007).

Here, detailed event analyses were performed to investigate when and under which conditions runoff occurs, and under which conditions important floods are generated under climate change. The event analyses here were performed in the Shigenobu River basin, and important floods are described in Table 1.

This study examined changes in the spatial and temporal distribution functions of runoff coefficients and in the effects of event precipitation characteristics, climate characteristics, and river discharge regime types on runoff coefficients. In addition, water income and expenditure were examined in the study basin. The analysed dataset included 2437 flood events, all over 1 m^3/s, for the time starting 3 days before and ending 10 days after the flood peak, over 40 years from 1961 to 2002. The relationship between precipitation and river flow quantity was examined for each event, revealing the long-term tendency of change in terms of basin water income and expenditure and the relationships to the quantity of precipitation loss. These findings are considered in terms of change in precipitation loss and climate change, and possible causes of the change in river-flow quantity are discussed. The findings can serve as a foundation for hydrological catchment modelling and address a wide range of problems related to various purposes. Existing models address some problems better than others. The present applications are intended to address the dynamic problem of estimating the flood peak (an hourly or daily scale phenomenon), the base flow (a weekly or monthly scale phenomenon), and the catchment water budget associated with river flow, evapotranspiration,