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The impact of flooding on road transport: A depth-disruption function

Maria Pregnolato *, Alistair Ford, Sean M. Wilkinson, Richard J. Dawson

School of Civil Engineering and Geosciences, Newcastle University, Newcastle upon Tyne, UK

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ABSTRACT

Transport networks underpin economic activity by enabling the movement of goods and people. During extreme weather events transport infrastructure can be directly or indirectly damaged, posing a threat to human safety, and causing significant disruption and associated economic and social impacts. Flooding, especially as a result of intense precipitation, is the predominant cause of weather-related disruption to the transport sector. Existing approaches to assess the disruptive impact of flooding on road transport fail to capture the interactions between floodwater and the transport system, typically assuming a road is fully operational or fully blocked, which is not supported by observations. In this paper we develop a relationship between depth of standing water and vehicle speed. The function that describes this relationship has been constructed by fitting a curve to video analysis supplemented by a range of quantitative data that has be extracted from existing studies and other safety literature. The proposed relationship is a good fit to the observed data, with an R-squared of 0.95. The significance of this work is that it is simple to incorporate our function into existing transport models to produce better estimates of flood induced delays and we demonstrate this with an example from the 28th June 2012 flood in Newcastle upon Tyne, UK.

1. Introduction

Infrastructure networks are often considered to be the backbone of cities. Ensuring their resilience, has become a vital aspect of governing and managing an economically-viable and liveable city. In particular, transport networks support the safety and wealth of communities, especially in the context of a global economy increasingly reliant on the mobility of goods, information and people (Rodrigue and Notteboom, 2013). Changes in the climate, rapid urbanisation, and increased infrastructure interdependence are putting societies, assets, and the built environment under increasing pressure. This is particularly evident in urban areas when transport systems are affected by weather-related hazards.

Flooding, especially flash flood events that start rapidly as a result of intense precipitation, is the predominant cause of weather-related disruption to the transport sector (DfT, 2014a) and this is expected to continue into the future (Dawson et al., 2016). This problem is particularly acute on the road network in urban areas owing to the high proportion of impermeable surfaces that prevent the infiltration of water into the soil. Heavy rain causes overland flow that can result in drains

* Corresponding author.
E-mail addresses: m.pregnolato@ncl.ac.uk (M. Pregnolato), alistair.ford@ncl.ac.uk (A. Ford), sean.wilkinson@ncl.ac.uk (S.M. Wilkinson), richard.dawson@ncl.ac.uk (R.J. Dawson).

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exceeding their capacity, and increasing the likelihood they become blocked by debris, before flood warnings can be widely disseminated. The relationship between adverse weather, traffic flow and congestion is acknowledged but poorly understood (Pyatkova et al., 2015; Hooper et al., 2014; Tsapakis et al., 2013; Koetse and Rietveld, 2009; Suarez et al., 2005).

On the 28th June 2012, 50 mm rain fell on Newcastle upon Tyne (UK) between 3 and 5 pm, a time typically associated with heaving commuting and school collection traffic (Newcastle City Council, 2013). This is similar to the average monthly total, and a return period of 1 in 100 years. Most public transport was cancelled, some roads were completely impassable whilst others experienced very slow running traffic for many hours (Fig. 1). Drivers reportedly abandoned their cars and some ran out of fuel after several hours of slow movement. The event flooded more than 1200 homes and caused £8m of direct damage to roads and pavements alone.

Reliable transport systems are valued for their safety, cost, travel time, and regularity of service (Koetse and Rietveld, 2009). Maintaining the volume traffic flow on the network, whether public transport or private travel, is fundamental for production, logistics, and business (Jenelius et al., 2006). Flooding impacts this in a number of ways through both direct impacts (*e.g.* physical damage to transport infrastructure) and indirect impacts (*e.g.* disruption to traffic flow, business interruption, increased emissions) (Brown and Dawson, 2016; Hammond et al., 2015; Walsh et al., 2012). Although direct damages could be consistent (USACE, 2009), the reduction in performance of transport systems due to flooding is the most detrimental factor for the society and it has been estimated at around £100 k per hour for each main road affected (Arkell and Darch, 2006; Hooper et al., 2014). Meanwhile, studies have shown that roads are among the first cause of deaths in cities during flooding, due to vehicles being driven through flooded roadways (Jonkman and Kelman, 2005; Fitzgerald et al. 2010; Drobot et al., 2007).

1.1. Flood risk analysis

The concept of risk can have a different interpretation according to the context in which it is considered (*e.g.* economic, environmental, social). A full review of flood risk definitions has been undertaken by Gouldby et al. (2005). This study considers flood risk as the product of the flooding probability and the consequences (Hall et al., 2003). In this definition consequences account for exposure (*i.e.* the people, assets and activities, threatened or potentially threatened by a flood) and vulnerability (*i.e.* physical, social, economic, and environmental factors or processes, which increase susceptibility to a flood). More formally, flood risk (r) can be calculated as a function of the probability of an event or hazard (ρ) and the consequences or impacts of that event (d) for a set of input conditions, defined by the vector $\mathbf{x}$: = $\{x_1, x_2, \ldots, x_n\}$, where each variable x_i represents a particular property of the flooding system (Dawson and Hall, 2006):

$$r = \int^{\rho}(\mathbf{x})d(\mathbf{x})d\mathbf{x} \tag{1}$$

To assess the impacts of damage to buildings, there are well established functions (damage functions) that relate depth of flooding (w) with consequent damage, *i.e.* a flood risk calculation only interested in properly damage would replace d(x) in Eq. (1) with the function $d(w)$. These functions are derived by integrating information from past flood events and building

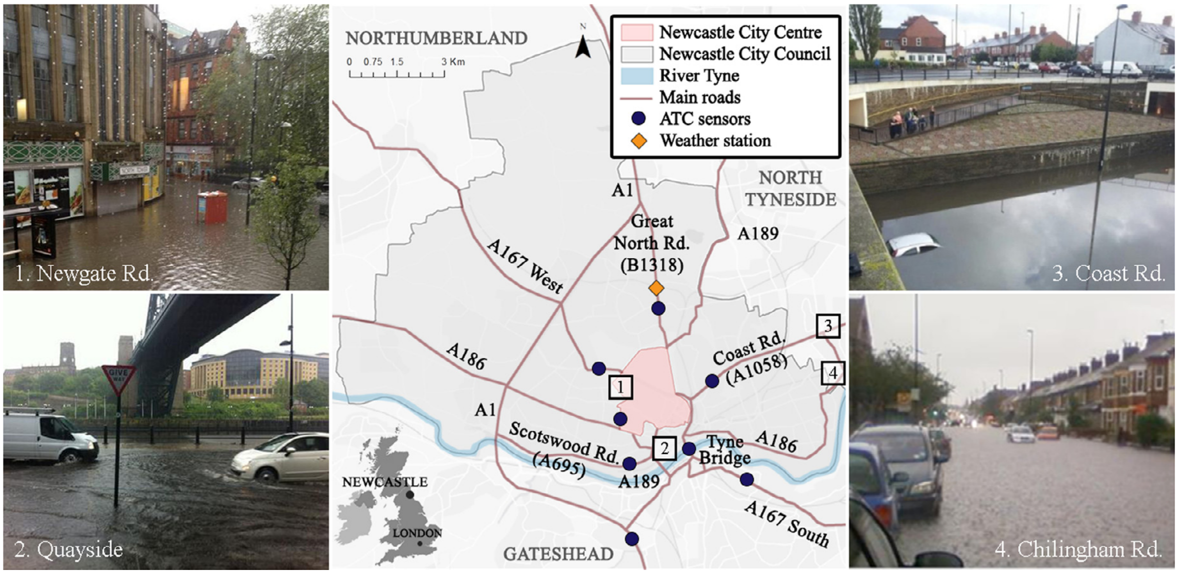

Fig. 1. Newcastle City Council boundary, and some indicative photos from the 2012 flood. Photos are from a Newcastle University website, set up the day after the flood to allow people to upload photos and observations: http://ceg-morpethflood.ncl.ac.uk/toonflood.