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AN ANALYSIS OF THE FACTORS THAT DETERMINE THE ECONOMIC IMPACT OF FLOODING ON ROAD TRANSPORT INFRASTRUCTURE IN AUSTRALIA

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ABSTRACT

The prospect of flooding is a natural disaster faced by an increasingly broad demographic in the context of global warming. Flooding impacts the full compass of developed and developing economies. The consequences of flooding create one of the most costly natural disasters in social, economic and environmental terms. Despite the growing significance of flooding, there has been a limited scope of empirical studies undertaken to inform our flood risk management strategies. In particular, the impacts of floods on transport infrastructure and the factors influencing the extent and significance of transport infrastructure damage are poorly understood. This paper details a recent review of the literature and statistical analysis of primary data obtained from survey and secondary data collected from databases to investigate the correlation between flood characteristics, exposure and the vulnerability of transport infrastructure towards flooding and post-flood reconstruction cost in New South Wales, Australia. The analysis finds that the original choice of construction material for roads is a significant determinant of reconstruction costs, with the reconstruction of unsealed roads contributing substantially to the financial impact. It is also found that insufficient priority is given to riverine transport networks over those roads and bridges which are located in coastline areas. The overall study identifies a series of flood risk reduction factors that collectively contribute to the resilience of transport infrastructure in flood-affected jurisdictions.

Keywords: flood risk management, post-flood reconstruction, transport infrastructure.

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC) a flood is “the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged” (IPCC, 2012:175). Flooding is already the most frequent natural disaster in the world and with climate change floods are occurring ever more often (Sohn, 2006). Not only more frequent, but flood events are increasingly more expensive in financial and human loss of life terms (Guha-Sapir et al., 2014). The United Nations Office for Disaster Risk Reduction (UNISDR) estimates that 800 million people are currently living in flood-prone areas and approximately 70 million people are subjected to floods each year (UNISDR, 2011).

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Australia is one of the most susceptible countries to flood damage in the world. According to the international disaster database EM-DAT (http://www.emdat.be/), floods have cost Australia almost US$12 billion in economic damage in the past decade alone. Whilst there has been some research investigating flood damage and flood risk management in Australia (e.g. Blong, 2004), this has tended to focus on building damage and there has been no previous consideration of flood impact on Australian transport infrastructure and/or the factors influencing the extent and significance of transport infrastructure damage in Australia due to flooding. Research internationally has also tended to focus on the response and recovery strategies that address more immediate humanitarian, economic and political concerns. Whilst response and recovery are critical issues, greater attention needs to be given to a more holistic approach that includes mitigation and preparedness (Guha-Sapir et al., 2014). Improved mitigation and preparedness inevitably leads to a reduction in the potential impact of flooding and thereby reduces the scale of response and recovery required.

This study presents an analysis of 11 causal factors identified from the literature as key potential determinants for the economic impact of flooding on transport infrastructure in Australia. The study draws on two Australian national databases maintained by the Road and Maritime Services (RMS) and Bureau of Meteorology (BoM). It also includes a recent survey of Local Councils in New South Wales (NSW) that was specifically undertaken to identify and measure relevant flood characteristics, the vulnerability of transport infrastructure, and the associated transport infrastructure post-flood reconstruction costs particular to a locality. The most significant factors in determining the post-flood costs of a locality are found to be the severity, frequency and type of flood. A number of strategies are recommended to help improve flood risk management in Australia.

CONCEPTUAL FRAMEWORK

The conceptual framework for analysing the factors that determine the economic impact of flooding on transport infrastructure is developed in Figure 1. It indicates that two primary factors influence transport infrastructure post flood reconstruction costs: (1) flood characteristics, and (2) transport infrastructure condition. Each of these two primary factors is then comprised of more specific sub-factors or indicators.

Flood risk management aims to reduce the exposure and vulnerability of society, the economy and the built environment to floods (Samuels et al., 2006). It consists of specific processes for designing, implementing and evaluating the strategies, policies and measures available to understand, reduce and improve flood mitigation, preparedness, response and recovery activities (IPCC, 2012). A number of recent studies have highlighted the need to determine flood characteristics as an essential component of flood risk management (Balica et al., 2012; IPCC, 2012; Lamond et al., 2012; Mirfenderesk, 2009). Exposure and vulnerability of the built environment have also been shown to be key factors in determining the magnitude of flood damage (IPCC, 2012).
Flood characteristics

- Flood Type
- Flood Severity
- Flood Frequency

<table>
<thead>
<tr>
<th>Flood Type</th>
<th>Flood Severity</th>
<th>Flood Frequency</th>
<th>Transport infrastructure post-flood reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash flooding</td>
<td>Intense rainfall</td>
<td>Relatively short bursts</td>
<td>Prevalent in urban areas where drainage systems are often unable to cope</td>
</tr>
</tbody>
</table>

Ocean flooding can occur around coastal lakes and lagoons from a combination of high tides, entrance constriction (by fluvial sedimentation, etc.), river floodwaters discharging into the lake or lagoon, and/or wind generated waves and surges. Elevated ocean levels can increase flood levels in the lower reaches of rivers, either by preventing floodwaters from discharging into the ocean or by filling up low lying land and estuarine flood storage areas before the river flooding arrives. Flooding of rivers in the vast flat areas of central Australia may last for one or more weeks, or months on some occasions. Floods in these areas can lead to extensive damage to rural towns and road and rail links (NSW Government, 2005 and Bureau of Meteorology, 2014). In Australia, low lying coastal areas can be inundated by storm surges typically caused by tropical cyclones. Overflow of drainage systems in urban areas can also be a major problem, particularly in heavily populated areas. However, according to the Australian Greenhouse Office, easily the most common form of flooding in Australia is river flooding (Australian Greenhouse Office, 2006).

Figure 1: Conceptual framework for transport infrastructure post flood reconstruction.

FLOOD CHARACTERISTICS

There is clear evidence to support the expectation that the more frequent the flooding, the greater the human and economic costs (Masozera et al., 2007). Other flood characteristics are more contentious. Following the propositions of Merz and Blöschl (2004) and others, this study measured flood characteristics by (i) flood type, (ii) flood severity, and (iii) flood frequency.

Flood type

A range of flood types has been classified internationally. In this study, flood type is classified as flash flooding, ocean flooding and river flooding. Flash flooding is sudden and unexpected. It is generally caused by local or nearby heavy rainfall (NSW Government, 2005). Flash flooding typically results from the relatively short, intense bursts of rainfall often associated with severe thunderstorms. It can occur in almost all parts of Australia and poses the greatest threat for loss of life. These floods can also result in significant property damage and major social disruption. They are a serious problem in urban areas where drainage systems are often unable to cope (Bureau of Meteorology, 2014). For example in 2010 and 2011, severe storms caused flash flooding in the state of Victoria resulting in widespread damage across western and central Victoria, stopping all modes of transportation in Melbourne CBD. The Insurance Council of Australia estimated the preliminary 2011 damage at $126 million (Australian Emergency Management, 2015). Flash flooding can also occur in rural areas where the nature of the terrain can lead to the very rapid development of flooding.

Ocean flooding can occur around coastal lakes and lagoons from a combination of high tides, entrance constriction (by fluvial sedimentation, etc.), river floodwaters discharging into the lake or lagoon, and/or wind generated waves and surges. Elevated ocean levels can increase flood levels in the lower reaches of rivers, either by preventing floodwaters from discharging into the ocean or by filling up low lying land and estuarine flood storage areas before the river flooding arrives. Flooding of rivers in the vast flat areas of central Australia may last for one or more weeks, or months on some occasions. Floods in these areas can lead to extensive damage to rural towns and road and rail links (NSW Government, 2005 and Bureau of Meteorology, 2014). In Australia, low lying coastal areas can be inundated by storm surges typically caused by tropical cyclones. Overflow of drainage systems in urban areas can also be a major problem, particularly in heavily populated areas. However, according to the Australian Greenhouse Office, easily the most common form of flooding in Australia is river flooding (Australian Greenhouse Office, 2006).
Flood severity
Flood severity is classified as follows (Emergency Management Australia, 1999):

- Minor flooding: Causes inconvenience. Low-lying areas next to watercourses are inundated, which may require the removal of stock and equipment. Minor roads may be closed and low-level bridges submerged.
- Moderate flooding: The evacuation of some houses may be required. Main traffic routes may be covered. The area of inundation is substantial in rural areas requiring the removal of stock.
- Major flooding: Extensive rural areas and/or urban areas are inundated. Properties are likely to be isolated and major traffic routes likely to be closed. Evacuation of people from flood affected areas may be required.

Flood frequency
Flood frequency has been measured by Annual Exceedance Probability (AEP) and Probable Maximum Precipitation (PMP). The AEP is the probability that a particular flood discharge will be equaled or exceeded in any one year. For example, a flood with a 10% AEP has a one-in-ten chance of occurring in any year. The PMP records the largest rainfall/depth of precipitation for a particular location at a particular time of the year.

TRANSPORT INFRASTRUCTURE CONDITION
An effective natural disaster risk management approach requires information on: (i) the characteristics of the natural disaster, and (ii) the degree of exposure and vulnerability of the society, economy and the built environment (Hochrainer, 2006). Exposure and vulnerability are key determinants of natural disaster risk (IPCC, 2012). Exposure refers to the presence of people, livelihoods, environmental services and resources, infrastructure and other assets in places that could be adversely affected by flood. Vulnerability is the propensity of an asset to be adversely affected in the event of impact by flood.

Transport and associated infrastructure such as roads, railways, bridges, warehouses, airports, ports and tunnels are often exposed to the risk of direct damage from climate events. Transport infrastructure vulnerability will vary by region, location/ elevation and condition of transport infrastructure (Meyer, 2008). In areas where projected increases in flooding are most extreme, bridges and culverts are the most vulnerable elements because of their propensity for catastrophic collapse (IPCC, 2012; Meyer, 2008).

Flood damage
Flood damage is measured in monetary terms and comprises tangible and intangible costs. Tangible costs include the immediate damage caused by actual contact with flood water (direct damage) and the broader cost of disruption caused by the flood (indirect). Intangible costs include the increased levels of emotional stress, mental and physical illness and deaths caused by a flood episode. It is difficult to quantify intangible damages in monetary terms and tangible costs represent a significant majority of flood damage impact. For the purposes of this study, indirect costs are not included and direct costs are estimated based on the probable cost of transport infrastructure reconstruction.
RESEARCH METHOD

The study focused on New South Wales as a representative jurisdiction in Australia. Research data specific to NSW was collated from two national databases maintained by the Road and Maritime Services (RMS) and Bureau of Meteorology (BoM). RMS provided access to their post-disaster reconstruction projects database. This database includes a broad range of detailed information on the transport infrastructure recovery projects across NSW between 1982 and 2013. Data from BoM documented a range of flood characteristics. Sourced data was complemented with a specific questionnaire survey of all Local Council members of the Floodplain Management Association (FMA) in NSW. The survey was administered online and distributed to specified Local Council staff working in floodplain management (floodplain engineers, planning and infrastructure engineers, emergency management officers, etc.). The response rate was good, with 36 out of 74 (48%) Local Council members of FMA providing a response.

Table 1: Description of independent and dependent variables.

<table>
<thead>
<tr>
<th>Code</th>
<th>Variables</th>
<th>Code</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>FD</td>
<td>Flood damage ($A)</td>
<td>FC6</td>
<td>River flooding</td>
</tr>
<tr>
<td>FC1</td>
<td>Frequency (AEP)</td>
<td>FC7</td>
<td>Ocean flooding</td>
</tr>
<tr>
<td>FC2</td>
<td>Rainfall (PMP)</td>
<td>FC8</td>
<td>Flash flooding</td>
</tr>
<tr>
<td>FC3</td>
<td>Minor flooding</td>
<td>TI1</td>
<td>Local non-urban sealed roads (km)</td>
</tr>
<tr>
<td>FC4</td>
<td>Moderate flooding</td>
<td>TI2</td>
<td>Local non-urban unsealed roads (km)</td>
</tr>
<tr>
<td>FC5</td>
<td>Major flooding</td>
<td>TI3</td>
<td>Total bridge length on local roads (m)</td>
</tr>
</tbody>
</table>

In this study 11 independent variables and one dependent variable were considered, as shown in Table 1. Pearson’s correlation coefficient was used to measure the relationship between variables. Pearson’s correlation coefficient returns a value between negative 1 and positive 1, where a coefficient of positive 1 indicates a perfect positive relationship, negative 1 indicates a perfect negative relationship and 0 indicates no linear relationship at all. Pearson’s correlation coefficient was generated using the IBM SPSS Statistics software.

RESULTS

The analysis of correlation based on Pearson’s correlation coefficient is shown in Table 2. The results show that particular flood characteristics (Frequency, r=0.59; Major Flooding, r=0.56; and River Flooding, r=0.77) and transport infrastructure conditions (Local non-urban unsealed roads, r=0.81) are significantly related to transport infrastructure flood reconstruction cost (Flood damage). A Local Council area with a higher score in terms of those particular flood characteristics is more likely to have more costly flood damage. These findings are generally consistent with those of Ho et al. (2008) who also found that flood characteristics have a significant and direct impact on flood damage. However, the current study is more specific about which particular flood characteristics are the most significant. McKenzie et al. (2005) have also shown that river flooding is more significant, finding that fatalities and economic losses have mostly been a consequence of river flooding.

Results from this study also indicate that there is no significant relationship between flood damage and other potential factors, including: Rainfall (r=0.16), Minor flooding (r=0.27), Moderate flooding (r=0.14), Ocean flooding (r=-0.18), Flash flooding.
(r=0.05), Local non-urban sealed roads (r=0.11), and total bridge length on local roads (r=0.22).

Table 2: Analysis of correlation based on Pearson’s correlation coefficient.

<table>
<thead>
<tr>
<th></th>
<th>FC1</th>
<th>FC2</th>
<th>FC3</th>
<th>FC4</th>
<th>FC5</th>
<th>FC6</th>
<th>FC7</th>
<th>FC8</th>
<th>TI1</th>
<th>TI2</th>
<th>TI3</th>
<th>FD</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC1</td>
<td>1</td>
<td>-0.07</td>
<td>0.36*</td>
<td>0.41*</td>
<td>0.79**</td>
<td>0.86**</td>
<td>-0.19</td>
<td>-0.18</td>
<td>0.12</td>
<td>0.07</td>
<td>0.07</td>
<td>0.59**</td>
</tr>
<tr>
<td>FC2</td>
<td>1</td>
<td>0.04</td>
<td>0.03</td>
<td>-0.16</td>
<td>-0.06</td>
<td>0.4*</td>
<td>0.07</td>
<td>0.26</td>
<td>-0.09</td>
<td>-0.11</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>FC3</td>
<td>1</td>
<td>-0.08</td>
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<td>-0.08</td>
<td>-0.02</td>
<td>0.18</td>
<td>0.15</td>
<td>-0.17</td>
<td>0.15</td>
<td>0.27</td>
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</tr>
<tr>
<td>FC4</td>
<td>1</td>
<td>0.12</td>
<td>0.14</td>
<td>0.28</td>
<td>-0.02</td>
<td>0.07</td>
<td>0.05</td>
<td>-0.18</td>
<td>0.14</td>
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<tr>
<td>FC5</td>
<td>1</td>
<td>0.79**</td>
<td>-0.21</td>
<td>0.18</td>
<td>0.25</td>
<td>0.81**</td>
<td>0.21</td>
<td>0.56***</td>
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<tr>
<td>FC6</td>
<td>1</td>
<td>-0.22</td>
<td>-0.01</td>
<td>0.18</td>
<td>0.75**</td>
<td>0.25</td>
<td>0.77***</td>
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<tr>
<td>FC7</td>
<td>1</td>
<td>-0.11</td>
<td>0.07</td>
<td>0.2</td>
<td>0.03</td>
<td>-0.03</td>
<td>0.03</td>
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<tr>
<td>FC8</td>
<td>1</td>
<td>0.23</td>
<td>0.04</td>
<td>-0.11</td>
<td>0.22</td>
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<td>TI1</td>
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</table>

( *p < .05, **p < .01, ***p < .001)

**CONCLUSIONS AND RECOMMENDATIONS**

This study confirms that flood characteristics and transport infrastructure conditions have a substantial impact on flood damage in Australian transport infrastructure. More particularly, the most significant flood characteristics in determining the costs associated with flood damage are the severity, frequency and type of flood. The most significant factor influencing flood damage overall is the total length of local non-urban unsealed roads. More generally it is clear that Australian transport infrastructure is highly susceptible to major river floods as the key type of natural disaster.

A number of more general recommendations for effective flood risk management relevant to transport infrastructure in Australia also emerge from this study:

- Greater control of the zoning and use of land in areas prone to river flooding is required in order to reduce the need for/extent of roads and bridges built in those areas.
- Upgrading unsealed roads to sealed will make them less vulnerable to flood damage and significantly reduce the costs of flooding when it occurs.
- Implementing a more comprehensive flood risk management approach that incorporate more proactive strategies will better address the full range of factors.
- The significant financial impact associated with roads and bridges warrants more emphasis on road and bridge flood risk insurance.
- The fact that Australian coastal areas do not appear to be as vulnerable to floods as riverine areas calls for a review of the current funding model for flood risk management which prioritized coastal vulnerability.

Further research is needed to assess the broader socio-economic conditions and flood risk management capabilities particular to individual Local Councils and relevant jurisdictions. Analysis of longer-term post-flood reconstruction effort will also be useful in developing policies that ameliorate the risks associated with floodplain management.
REFERENCES


