International Journal of Disaster Risk Reduction 14 (2015) 379–387

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Sensitivity analysis of flood damage estimates: A case study in Fredericton, New Brunswick

H. McGrath [a,*], E. Stefanakis [a], M. Nastev [b]

[a] Department of Geodesy and Geomatics Engineering, University of New Brunswick, Dineen Dr., Fredericton, New Brunswick, Canada E3B 5A3
[b] Natural Resources Canada, Geological Survey of Canada, Québec, Canada G1K 9A9

ARTICLE INFO

Article history:
Received 25 May 2015
Received in revised form
12 September 2015
Accepted 12 September 2015
Available online 14 September 2015

Keywords:
Flood risk
Sensitivity analysis
Vulnerability

ABSTRACT

Recently, the U.S. FEMA's standardized best-practice methodology Hazus for estimating potential losses from common natural hazards, including earthquakes, flood, and hurricanes has been adopted for use in Canada. Flood loss estimation relies on the combination of three components: flood level, inventory of the built environment, and pre-selected vulnerability parameters such as depth-damage functions, all of which have large associated uncertainties. Some of these parameters, such as occupancy schemes and vulnerabilities, have been carried over from the U.S. version on the presumption of regional similarities between Canadian provinces and states south of the border. Many of the uncertainties can be reduced by acquiring additional data or by improving the understanding of the physical processes. This paper presents results from a series of flood risk analyses to illustrate the sensitivity that can be associated to the depth-damage function, flood level, and restoration duration and to identify their relative impacts on the resulting losses. The city of Fredericton is chosen as the test case as it was subjected in 2008 to flood water levels breaching 1.86 m above flood stage resulting in more than 680 residents evacuated from their homes, and economic costs of more than $23 million. The loss results are expressed by the number of flooded residential buildings which varied between 579 and 623 and the range of replacement cost is $21 million. These results highlight the importance of proper selection of input parameters customized to the study area under consideration.

1. Introduction

Every year disastrous climatological and geological hazards take place in Canada and across the globe [16]. Of these natural disasters, flooding of river systems is the most frequent and costly natural disaster, affecting the majority of the worlds' countries on a regular basis, and accounts for approximately one-third of total natural disasters related economic losses in Europe [4,12]. The costliest natural disaster in Canadian history, the southern Alberta flood in June of 2013, exceeds $5 billion Canadian dollars [21]. In recent decades, the trend of increased damages resulting from flood events may be attributed to a number of factors including: population growth, increased urbanization in flood-prone areas and the changing climate [1,4,12,25].

Government officials, GIS specialists, emergency managers, and first responders look for tools to develop mitigation and recovery plans as well as preparedness and response procedures in anticipation of these natural disasters [18]. Timely and accurate prediction of potential losses is fundamental for the sustainable development of a given region and provides valuable information necessary for understanding of risks and creation and implementation of mitigation measures and post-disaster emergency planning [22]. Through the use of computer models which simulate hazards and compute risk we can evaluate the cost effectiveness of mitigation measures, optimize investments, and enable insurance companies, municipalities and residents to prepare for disasters [2,4].

Flood risk analysis involves the combination of three components: a probabilistic or deterministic flood hazard model, an inventory model of the built environment defining the characteristics of the exposed elements (structural type, occupancy category, content), and a selection of respective depth-damage functions [2,4,15]. Loss estimations include physical damage and direct and indirect social and economic losses. A direct loss occurs as a result of direct physical contact of the flood water with humans, property, or other objects, while indirect losses represent those that are induced by the direct impact, and may occur (in time or space) outside of the flood event [14]. Physical damage to buildings and certain transportation and essential facilities is estimated based on depth-damage functions which represent the

* Corresponding author.

http://dx.doi.org/10.1016/j.ijdrr.2015.09.003
2212-4209/

relationship between inundation depth and percent damage ([19] and others). For buildings, depth-damage functions are developed for structural or load-bearing components; for contents (e.g.: interior furniture, art, appliances, etc.,); and for inventory (e.g.: commercial stock and inventory) [6]. These three types of damage functions are unique for a given building structural type and occupancy classification (e.g.: residential, commercial, industrial, etc.) The reason behind this is that the underlying structure, for example a single family residence has a different damage response to a given water level than would a multi-family apartment complex. Direct economic losses include calculations of repair and construction costs resulting from the flood event, whereas indirect economic losses are related to lost jobs and business interruption [6]. The analysis may also include estimates of volume of debris and removal costs. Social impact of the flood event is estimated based on population demographics, flood extent and inundation depths, and is usually expressed by the number of displaced households or people which may require shelter, time needed for re-building (or restoration), recovery needs, etc. Risk analysis can be run on aggregated data, e.g. at the census block level, where the percentage of each census block is determined for a given water level. For more accurate analyses, one can perform a micro-scale analysis where individual structures are introduced with proper parameters and physical damage and direct economic loss estimations are derived on a per structure basis.

Regardless of the applied method, one of the most important aspects of constructing a flood loss model is to identify, quantify, and incorporate uncertainties owing to approximations of the input parameters and simplifications in simulating the physical processes [15,18,6]. These uncertainties may be linked to the hazard model used (from simple interpolation to sophisticated equations solving the shallow water equations), the choice of vulnerability models and parameters, scale of the study region (micro, meso, or macro), inventory data, or any combination of these [2]. In addition, uncertainties propagate through the calculation and accumulate in the resultant damage estimate [4]. Studies acknowledge that flood damage estimates feature a degree of uncertainty, with most efforts focusing on the influence of the hydrological component [4]. Examples of such research include: Dutch FLORIS study using different inundation scenarios, flood frequency statistics and levee breach scenarios [9], boundary effects [10], and 1D and 2D numerical models [11]. Beyond the hydrologic component, [14] presented research which found considerable uncertainty in the internationally accepted damage functions–which describe the relationship between the inundation level and damage. Adjusting the value of elements at risk as performed by [5] has also shown to affect the loss estimates from a given flood scenario and [4] computed the influence of four components (inundation depth, land use, value of elements at risk, and depth-damage curves) on the outcome of flood risk analysis.

In this study epistemic uncertainties resulting from incomplete knowledge are considered as they can potentially be reduced by acquiring additional customized data representative of the study region under consideration. The well-known U.S. FEMA's Hazus software, recently adapted for use in Canada, is used to conduct this sensitivity analysis. Hazus is one of the most comprehensive and standardized methodologies presently available for the assessment of potential losses from natural hazards [6,17,18].

A number of parameters required for loss estimation including damage functions (e.g.: building, contents, and inventory), restoration functions, and economic replacement values provided with the Canadian version of Hazus are based on U.S. data. Thus the default damage functions suggested to Canadian users were derived from data collected and analyzed by the Federal Insurance Administration (FIA) and surveys completed by the U.S. Army Corps of Engineers (USACE) on U.S. infrastructure. The damage functions have been regionally adopted into the Canadian model and replacement costs per square foot have been adapted from R.S. Means Co., Inc. [9].

The parameters reviewed and varied in this sensitivity analysis include (a) structural and contents depth-damage functions for single family residences, RES1, (b) changes to flood depth, and (c) changes to restoration duration. The Hazus model was first run using the suggested default values for the considered flood scenario. Additional scenarios were completed with the parameters varied in the respective anticipated ranges to create a range of possible outcomes. Each analysis parameter was isolated so that the influence of each could be determined independently. Parametric analysis was conducted to determine the sensitivity of the final results to each parameter.

The remainder of the paper is structured as follows, in Section 2; the study area of Fredericton, New Brunswick (NB) is introduced. In Section 3 the methodology of Hazus is briefly described. In Section 4 the methodology and parameterization tests are outlined and results are presented. Section 5 contains results and conclusions and recommendations for further research are outlined in Section 6.

2. Study region

The study area selected in this sensitivity analysis is Fredericton, New Brunswick, Canada. Fredericton is located in the west-central portion of this Atlantic province and is bisected by the St. John River (Fig. 1), a major waterway which runs throughout the province. Its watershed drains an area of approximately 55,000 km^2, and encompasses much of New Brunswick and parts of Quebec, Canada, and Maine, U.S.A. [13].

Franklin and Cardy [7], in a report for the Saint John River Basin Board reviewed flood records and spending in New Brunswick between 1887 and 1971 and found total damages in excess of one million dollars. Between 1971 and 1976 (when their report was published) they report an additional 17 million dollars spent in the province on recovery from flood related damages. A comprehensive database of flood events dating back to the 1600 s is available on the Government of New Brunswick web site (www.elgegl.gnb.ca/0001/en/Home/Main). The largest of these are shown in Table 1. The second largest flood, used in this sensitivity study, occurred in 2008, with water levels 1.86 m over flood stage. Estimated expenditures across the province for the 2008 flood exceed $23 million dollars.

Fredericton was chosen as the study location due to its long flood history, the mix of government and private infrastructure, and the open data policy. Fredericton is the capital of New Brunswick, and, as a result, there are a significant number of government offices and service locations across the city. The community of Fredericton is the third largest in the province with a population of 94,000 [24] and approximately 22,000 households [3]. A mix of public (municipal, governmental) and private infrastructure is therefore potentially at risk of flood hazard. The downtown core of Fredericton (along the southern shore of the Saint John River) contains a number of historic buildings, with those in the eastern section of downtown having been built in the late 1700 s. In 2011 the City of Fredericton announced an open data policy. The data collected by the city is available to the public via the City of Fredericton (Fredericton.ca/open). This open data policy facilitates locating appropriate datasets for Hazus inventory, including essential facilities, transportation, and utility networks.

The study region created in Hazus contains 617 census dissemination blocks, over 27,000 households and 66,050 residents. Essential facilities in the area include: two hospitals, 30 schools, 4 fire stations and 3 police stations. There are 19,178 buildings