ID: 172 642 828

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A NEW METHODOLOGY FOR FLOOD DAMAGE ASSESSMENT IN URBAN AREAS

NOVA METODOLOGIJA ZA PROCENU ŠTETA USLED PLAVLJENJA URBANIH POVRŠINA

ABSTRACT

Urban flooding caused by extreme rainfall events is becoming considerably more frequent and more destructive. Thus, enhanced models to predict accurately flood magnitude and location are of paramount importance. These models can then be used for urban planning, flood forecasting, flood management (real-time control, raise of flood alerts (emergency services management, etc.) and, ultimately, to estimate flood damage assessment. This paper demonstrates the capability of the Automatic Overland Flow Delineation (AOFD) methodology developed by the authors for flood damage estimation in urban areas. Properties in risk of flood are identified based on a spatial analysis, using the locations of flood-prone areas (ponds) and the location of buildings. The results obtained in this study open new research directions to estimate flood damage with even more detail, and extend flood damage estimation beyond property level, i.e. considering also traffic disruption, health issues and alike.

Key words: advanced urban drainage modelling, flood damage assessment, Geographic Information Systems, urban flood modelling.

APSTRAKT

Plavljenja urbanih površina usled jakih pljuskova postaje sve češće i opasnije. Zbog toga je neophodno raspolagati sa kvalitetnim modelom koji može predvideti intenzitet i lokaciju plavljenja. Takav model se može koristiti za urbanistička planiranja, predviđanje poplava i šteta usled poplava, kao i za upozorenja usled očekivanih poplava. U ovom radu se istražuje mogućnost primene metodologije za automatsku delineaciju površinskih tokova za procenu šteta u urbanim površinama. Objekti koji se plave se određuju na osnovu prostorne analize, koristeći rezultate analiza depresija na urbanim površinama. Dobijeni rezultati u ovom radu otvaraju nove oblasti za istraživanje: uticaj bolje prostorne rezolucije na proračuna šteta, i uticaj poplava na saobraćaj, zdravlje ljudi i slično.

Ključne reči: napredno modeliranje oticaja u urbanim uslovima, procena šteta usled poplava, GIS, modeliranje plavljenja u urbanim uslovima

1 INTRODUCTION

Damage caused by flooding depends mainly on flood depth, flow velocity and flood duration, as well as on characteristics of buildings affected by flooding, such as type, use, content and number and social class of inhabitants. In the case of flooding originated from combined sewers there is also public health risk. In addition to the damage caused to the properties (i.e. direct damage), floods can also have significant effects on economic and social activities, which are called indirect damage. Indirect damage includes, for instance, loss of production and profit, disruption of road and traffic, additional cost for emergency and cleaning work and health and psychological problems resultant from flooding. Estimation of damage caused by flood is therefore a complex task due to the uncertainties in both flood characteristics and uncertainties in evaluating its consequences.

A large number of studies have tried to quantify flood damage in accordance with the classes described above (type of property, use, content, etc.). Most of the studies conducted so far have dealt with direct flood damage. It seems that no agreement has been reached on what methodology to use for estimating indirect damage caused by flooding (Ryu, 2008).

Flood depth is often used to create flood-damage functions, i.e. cost depending on flood depth. However, as highlighted by other authors, other flood characteristics such as flood velocity and duration, should also be used for estimating flood damage (Balmforth et al., 2006).

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Methodologies to estimate damage caused by flooding events should be based on the floodable areas and its characteristics, characteristics of properties and results from hydraulic simulations (water depth and flow velocity).

In this paper, the Automatic Overland Flow Delineation (AOFD) methodology developed by Maksimović et al. (2009) is used to identify areas likely to flood, enabling flood damage assessment to be made. It is aimed to demonstrate the applicability of this methodology to deal with practical problems, namely to identify the properties at risk and estimate the damage associated to flooding events. Flood damage cost is then calculated using the flood depth-damage cost functions developed by Penning-Rowsell et al. (2006).

This study takes into account only flood depth and duration in the case of residential properties; it does not take into account flood velocity to estimate flood damage. Nevertheless, the results obtained are encouraging to further develop the proposed methodology in order to generate more detailed flood damage estimation.

2 MATERIAL AND METHODS

2.1 *Case study*

The area of study to estimate flood damage is located in the Torquay town centre (UK). Flooding events caused by extreme rainfall events is frequent in Torquay, making this a suitable location to test the applicability of the flood damage assessment methodology presented in this paper, which was developed in Leitão (2009). Only part of the Torquay town centre catchment was used to demonstrate the applicability of the flood damage assessment methodology; the area used in the analysis presented herein corresponds to the area where flooding events occur more frequently and where the damage caused is more significant. Figure 1 illustrates the area of analysis.

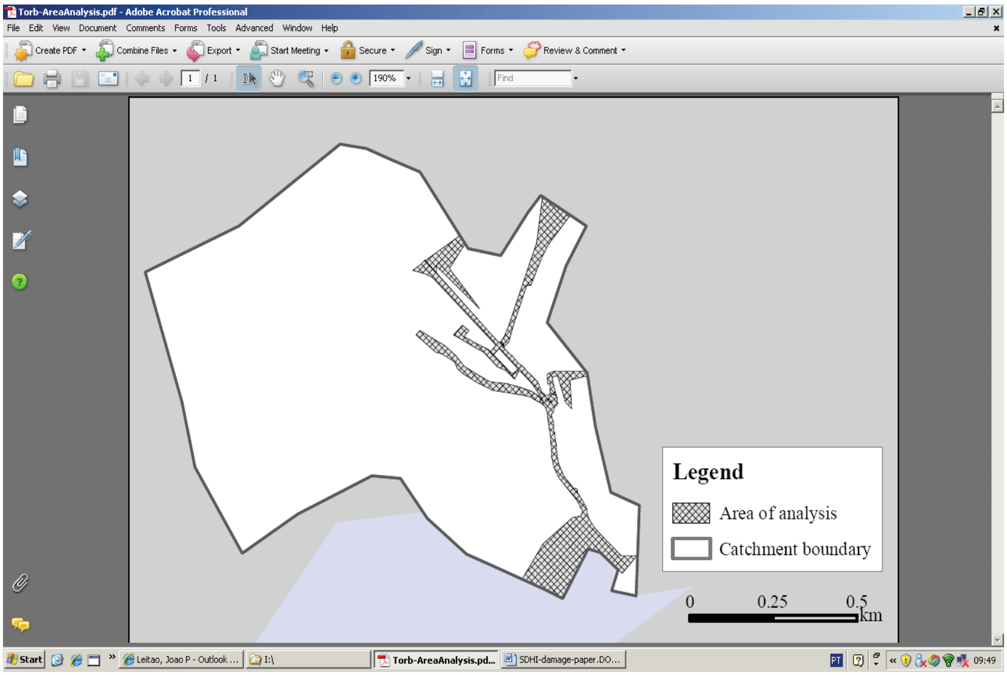

Figure 1. Area of analysis

2.2 *Methodology*

The analysis procedure proposed in this paper can be divided in the following steps:

a. Identification of flood-prone areas (by AOFD method);
b. Identification of properties affected by floods, using a spatial intersection operation between flood-prone areas and polygons of properties;
c. Estimation of flood depth for each flood-prone area, based on the hydraulic simulation results or on the flood-prone area maximum depth;
d. Estimation of flood damage based on flood depth-damage cost functions (for example, Penning-Rowsell et al. (2006)) and properties flooded; and
e. Mapping the results.

2.2.1 *Floodable areas (ponds)*

The floodable areas were identified using the AOFD methodology developed by Maksimović et al. (2009). Figure 2 illustrates the flood-prone areas resulting by the analysis of the Digital Elevation Model (DEM) of the analysis area.

2.2.2 *Flood depth-damage cost functions*

The UK Environment Agency has carried out a thorough survey to identify the type and use of all properties in the UK; the results of the survey are compiled on the National Property Database (NPD). The example of the results generated by the proposed methodology to estimate flood-damage presented in this paper does not use the information from this data base, but is based on a simplified field survey carried out on a catchment area. Only direct flood damage is considered in this thesis due to the lack of agreement on how to estimate indirect flood damage.

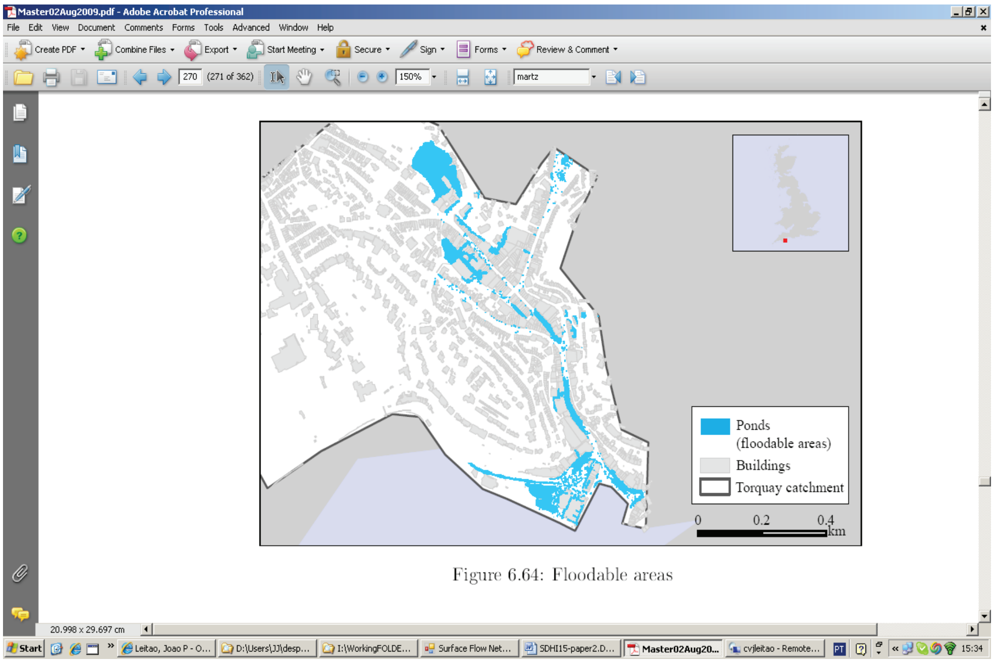

Figure 2 Floodable areas

The cost functions developed by the FHRC also take into account damage associated with traffic disruption; this was not considered in this analysis.

The flood depth-damage cost functions available in Penning-Rowsell et al. (2006) were developed based on 2005 costs. Thus, when these functions are applied to a different year, the damage costs need to be updated. The update can be based on the Consumer Price Index (CPI) available in Office for National Statistics (2009).

Table 1. Averaged flood depth-damage cost functions (*adapted from* Penning-Rowsell et al., 2006)

(A) NON-RESIDENTIAL BUILDINGS

DEPTH	DAMAGE COST
M	£ M^{-2}
<0.00	68
[0.00; 0.25]	[68; 199]
[0.25; 0.50]	[199; 336]
[0.50; 0.75]	[336; 470]
[0.75; 1.00]	[470; 570]
[1.00; 1.25]	[570; 637]
[1.25; 1.50]	[637; 695]
[1.50; 1.75]	[695; 738]
[1.75; 2.00]	[738; 776]
[2.00; 2.25]	[776; 805]
[2.25; 2.50]	[805; 834]
[2.50; 2.75]	[834; 855]
[2.75; 3.00]	[855; 881]

(B) RESIDENTIAL AREAS (EVENTS LESS THAN 12H DURATION)

<0.00	11.28
[0.00; 0.05]	[11.28; 202.50]
[0.05; 0.10]	[202.50; 249.25]
[0.10; 0.20]	[249.25; 429.80]
[0.20; 0.30]	[429.80; 481.75]
[0.30; 0.60]	[481.75; 440.11]
[0.60; 0.90]	[540.11; 576.97]
[0.90; 1.20]	[576.97; 609.72]
[1.20; 1.50]	[609.72; 638.92]
[1.50; 1.80]	[638.92; 671.71]
[1.80; 2.10]	[671.71; 698.51]
[2.10; 2.40]	[698.51; 725.26]
[2.40; 2.70]	[725.26; 786.03]
[2.70; 3.00]	[786.03; 814.10]

These functions are based on the duration and depth of flood, and on a detailed description of property type (e.g detached, semi-detached, terrace, bungalow), construction, use and age of property (Penning-Rowsell et al., 2006). The estimation of cost using these functions also takes into account the social class of the property's occupants. The methodology presented in this analysis does not take into account flood velocity to estimate flood damage.

The detailed description of the damage associated with flooding represented by the cost functions developed by the FHRC, the averaged functions for residential and non-residential properties were used in this thesis. These flood depth-damage cost functions were calculated taking into account the various cost functions for the different types of properties and uses; the averaged cost functions are presented in Table 1, and illustrated in Figure 3.

The linear interpolation technique was used to estimate the value of the flood damage for a specific depth, between two depth-damage values, as defined in Penning-Rowsell et al. (2006). The aim was to know the value of the flood depth-damage function for $x = b$, i.e. $f(b)$, where b is the actual flood depth and $f(x)$ is the flood depth-damage cost function.

Assuming $a < b < c$, the linear interpolation uses the two closest observations to b to estimate $f(b)$ using the Eq. 1.

$$f(b) = f(a)\frac{b-a}{c-a} + f(c)\frac{c-b}{c-a} \qquad (1)$$

where a, b and c are flood depth values.

The linear interpolation method assumes that the interval $(c - a)$ is short enough to guarantee that the

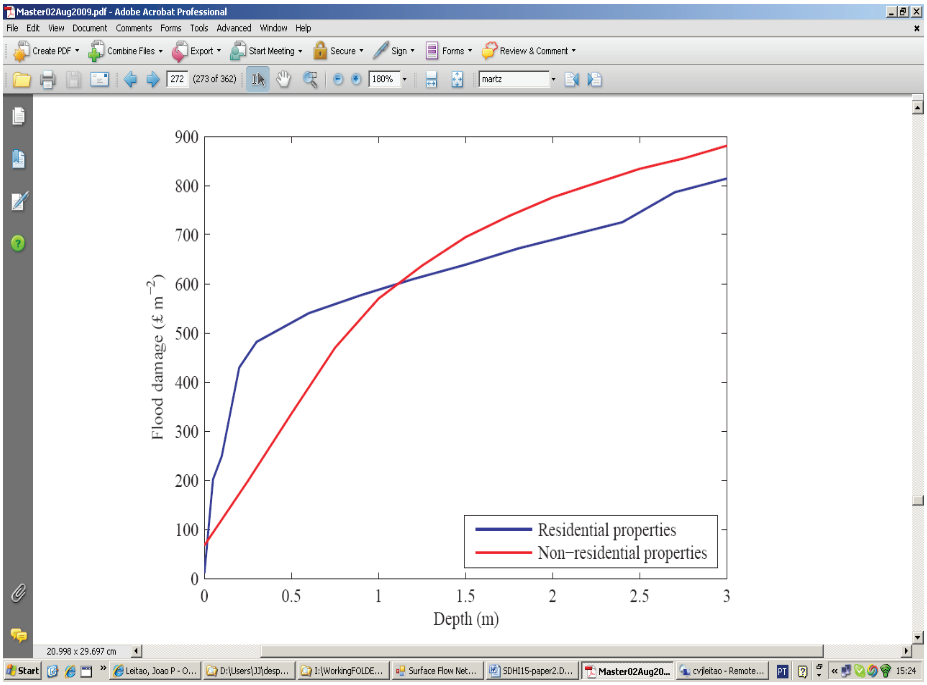

Figure 3. Averaged flood depth-damage cost functions (*adapted from* Penning-Rowsell et al., 2006)

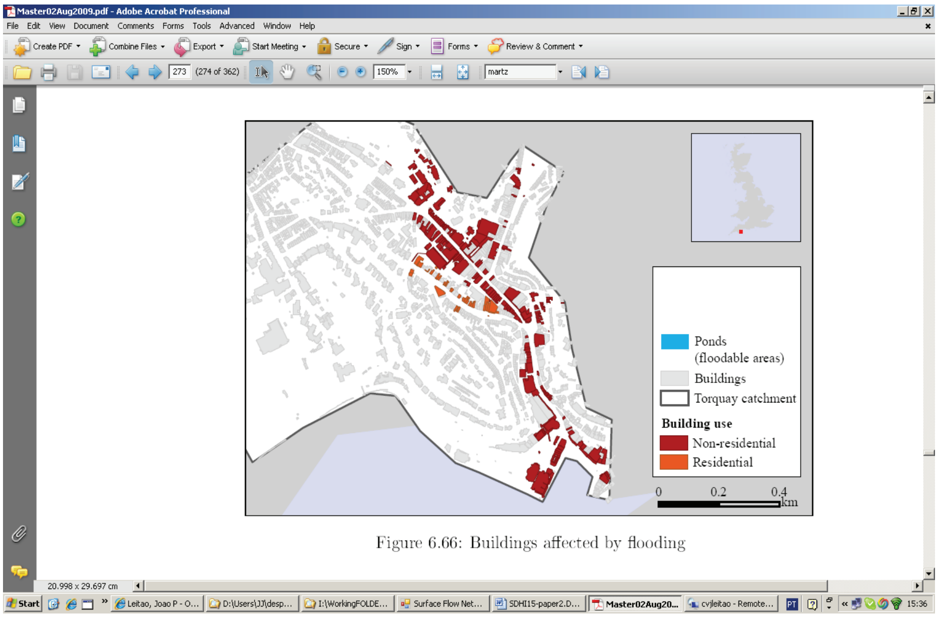

Figure 4. Buildings affected by flooding

function *f(x)* has a linear behaviour in this range.

3 RESULTS AND DISCUSSION

The flood damage assessment undertaken in this study does not take into account the results of hydraulic analysis for a particular flood event or a selected return period. In fact, this flood damage assessment represents the maximum damage that it is likely to occur in the area, as it is based on the maximum depth of the flood prone areas (ponds).

By performing a spatial analysis on the location of flood-prone areas and buildings in the area of study (Torquay, UK), 37 residential buildings and 273 non-residential buildings were identified as potentially affected by flooding (Figure 4).

Based on: (i) the area of the properties; (ii) maximum depth of ponds; and (iii) UK FHRC flood depth-damage cost functions, for both residential and non-residential properties, the maximum damage caused by flooding was estimated. The results presented in Table 2 were obtained for year 2007 (i.e. damage costs were updated using the CPI equal to 104.7) when this catchment reported flooding events caused by extreme rainfall.

The total property damage estimated for an extreme flood event, i.e. assuming that water reaches the top level of all ponds, is approximately £12.6m. Due to the simplification resulting from the use of only flood depth to estimate flood damage, the total damage cost might have been underestimated. The results of the GIS analysis, i.e. spatial distribution of flood damage, are illustrated in Figure 5.

The results presented in this Section indicate that the methodology carried out is

Table 2. Flood damage results

	RESIDENTIAL	NON-RESIDENTIAL
	£	£
MINIMUM	403	81
MAXIMUM	80,182	2,738,396
MEAN	17,274	43,977
ST. DEVIATION	16,326	180,418

a simple way to estimate flood damage. Although some simplifications have been considered to estimate flood depth, such as taking into account the maximum pond depth, and to calculate the flood damage

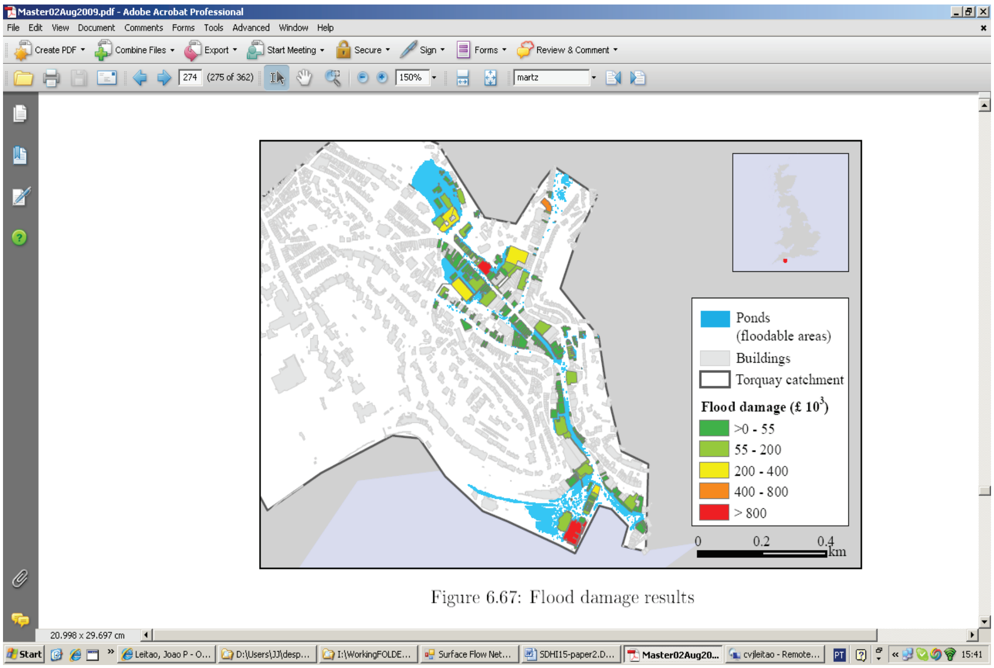

Figure 5. Flood damage results

cost the methodology demonstrates that it can be used for: (i) identifying properties in risk of flood; and (ii) estimating flood damage/cost.

The effect of the simplifications considered in this study should be analysed in detail by taking into account the detailed information available in Penning-Rowsell et al. (2006), and by linking the flood depth and duration to the hydraulic simulation results. By comparing these results with actual flood damage, it would then be possible to assess the accuracy of this methodology to estimate in detail direct damage caused by a selected flood of a given return period or by a documented historical flood event. In the second case, it would be also possible to calibrate the results of simulation.

In this study, flood was only accounted in flood-prone areas (terrain depressions); hence no damage was calculated along overland flow paths. Thus, the number of properties flooded and the resulting damage cost associated might have been underestimated. On the other hand, because flood depths were calculated based on the maximum pond depth, the damage cost values might have been over-estimated.

It is important to highlight that this study has only considered property damage. To estimate the total flood damage, other factors, such as disruption to traffic, economic activities and other non-direct damages should be considered separately.

4 CONCLUSIONS

It was demonstrated that the developed methodology can be applied for estimation of damage caused by pluvial (surface) flooding in urban areas. Although the study presented in this paper rely on some simplifications, such as using the FHRC average depth-damage cost functions (Penning-Rowsell et al., 2006), and considering maximum flood depth, it proved to be a simple and reliable methodology to: (i) identify properties at flood risk areas, and (ii) assess the maximum flood damage caused by flooding.

Further analyses need to be carried out in order to take full advantage of the AOFD methodology results (ponds and flow paths depths), hydraulic simulations and detailed information available in the data base created by Penning-Rowsell et al. (2006).

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