THE IMPACT OF INDIVIDUAL BUILDINGS ON URBAN FLOOD RISK ANALYSIS

L'impact des bâtiments individuels sur l'analyse du risque dû aux inondations en milieu urbain

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KEY WORDS

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ABSTRACT

When performing an urban flood risk analysis, it is often difficult to take individual buildings into account: doing so requires the availability of a high resolution 2D hydrodynamic model for the preparation of flood maps and detailed land use maps for the preparation of flood damage maps. As a consequence, a simplified approach is often required, involving the use of low resolution models and simplified land use maps. This study aims at evaluating the impact of such simplifications on the flood risk by means of a case study: the flooding of the city of Antwerp (Belgium) caused by wave overtopping of the flood defenses along the river Scheldt. Two methods for computing flood maps were combined with two methods for computing damage maps, yielding four different methods for computing urban flood risk. The results obtained with the four methods differ significantly. The flood risk predicted by a combination of the detailed approaches was found to be less than 30% of the flood risk predicted by a combination of the simplified approaches. From this study, we can conclude that the procedures used for dealing with the presence of buildings can be a significant source of uncertainty in urban flood risk analysis.

RESUME

Lorsque vous effectuez une analyse du risque dû aux inondations en milieu urbain, il est souvent difficile de prendre en compte les bâtiments individuels: ceci nécessite la disponibilité d'un modèle hydrodynamique 2D d'une résolution élevée pour la cartographie des zones d'inondation et de cartes d'utilisation du sol détaillées pour la cartographie des dommages dus aux inondations. En conséquence, une approche simplifiée est souvent nécessaire, impliquant l'utilisation de modèles à basse résolution et de cartes d'utilisation du sol simplifiées. Cette étude vise à évaluer l'impact de telles simplifications sur le risque dû aux inondations par le biais d'une étude de cas: l'inondation de la ville d'Anvers (Belgique) causée par le franchissement par la houle des ouvrages de protection le long du fleuve Escaut. Deux méthodes de cartographie des zones d'inondation ont été combinées à deux méthodes de cartographie des dommages, produisant quatre méthodes différentes pour le calcul du risque dû aux inondations en milieu urbain. Les résultats obtenus avec les quatre méthodes diffèrent signicativement. On observe que le risque prédit par une combinaison des approches détaillées est inférieur à 30% du risque prédit par une combinaison des approches simplifiées. De cette étude, nous pouvons conclure que les procédures utilisées pour traiter de la présence de bâtiments peuvent être une source importante d'incertitude dans l'analyse du risque dû aux inondations en milieu urbain.

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1. INTRODUCTION

When performing an urban flood risk analysis, it is often difficult to take individual buildings into account. Accounting for individual buildings requires the availability of a high resolution 2D hydrodynamic model for the preparation of flood maps and detailed land use maps for the preparation of flood damage maps. As a consequence, a simplified approach is often required, involving the use of low resolution models and simplified land use maps. This study aims at evaluating the impact of such simplifications on the final flood risk by means of a case study: the flooding of the city of Antwerp (Belgium) caused by wave overtopping of the flood defenses along the river Scheldt.

2. STUDY AREA

The study area corresponds to the central part of the city of Antwerp. It is located on the right bank of the river Scheldt and bordered by the ring road surrounding the city. This area is shown in Figure 1.

Figure 1: Study area [1].

The river Scheldt is a tidal river, affected by storm surges originating in the North Sea. During extreme storm events, river water levels rise above the quay walls located along the right bank. In the past, such storms used to cause inundations in some parts of the city center. To prevent this from happening, a concrete flood wall has been erected along the full length of the quays. During very extreme events (return periods of several hundreds or even thousands of years), some wave overtopping will occur.

In the past, a lot of commercial activity took place in a narrow strip along the quays. This activity has now shifted entirely to the docks to the north of the city. Therefore, a masterplan for the redevelopment of the quay strip is being drafted. One of the technical studies underpinning this masterplan aims at evaluating the risk associated with wave overtopping of the planned flood defenses. This requires the construction of a flood model and a damage model.

3. FLOODS

3.1 Hydraulic model

Wave overtopping of the flood defenses leads to overland flow in the city center. This overland flow was studied by means of a numerical model. A 2-dimensional hydrodynamic model was constructed by means of the software package Mike21, developed and distributed by the Danish Hydraulic Institute [2]. The surface elevation was derived from a detailed DEM, with a grid size of 5 m [3]. Mean wave overtopping discharges were computed by means of other software and subsequently imposed as a boundary condition. The maximum water depths computed by the hydraulic model were used to construct flood maps.

3.2 Simplified approach

The available DEM was constructed by means of photogrammetry and doesn't include buildings. In the hydraulic model, the presence of buildings can be partially accounted for by increasing the surface roughness to an artificially high value (Manning's roughness coefficient equal to 0.1). This increased roughness will delay flood propagation, but flow paths will still be inaccurate and building footprints will not be excluded from the flood map. Figure 2 shows the original DEM and Figure 4 the flood map for a synthetic storm surge with a very high return period. The flooded area covers 2.2 km^2 and the average flood depth equals 0.44 m.

3.3 Detailed approach

The existing DEM was modified on the basis of a detailed vectorial map showing the footprints of all buildings in the study area [4]. All pixels belonging to the footprint of a building were raised, to keep them from flooding. In the hydraulic model, a roughness representative of a street surface was used (Manning's roughness coefficient equal to 0.02). Figure 3 shows the modified DEM and Figure 5 the associated detailed flood map. The flooded area is reduced to 1.7 km^2 and the average flood depth increased to 0.53 m.

4. DAMAGE AND RISK

4.1 Damage and risk model

Flood damage and flood risk were calculated by means of a stepped procedure. In a first step, the study area is subdivided into subareas according to land use. Some linear objects (e.g. roads and railroads) and point objects (e.g. public buildings) are also inventorized. In a second step, the maximum damage corresponding to each land use or object is determined. This maximum damage is defined as a replacement value. The highest value is assigned to residential buildings, while roads and open areas are given a much lower value. In a third step, the actual damage is obtained by multiplying the maximum damage by a damage factor (range 0-1), derived from a damage function. A damage function expresses the value of the damage factor as a function of the flood depth. Examples of such functions are shown in Figure 6. In the fourth step, the actual damage caused by a single storm event is computed from:

$$D_a = \sum_i n_i \ \alpha_i \ D_{m,i} , \qquad (1)$$

where D_a is actual damage (€), n is the number of units (m^2, m or -), α is the damage factor (-), D_m is the maximum damage (€ per unit) and the index i refers to the land use or the object class.

In a final step, the risk associated with a single event is computed from:

$$R = D_a / RP , \qquad (2)$$

where R is the risk (€/year) and RP is the return period (years).

The damage and risk model is described in detail in [5]. It has been implemented in a software package called Latis [6].

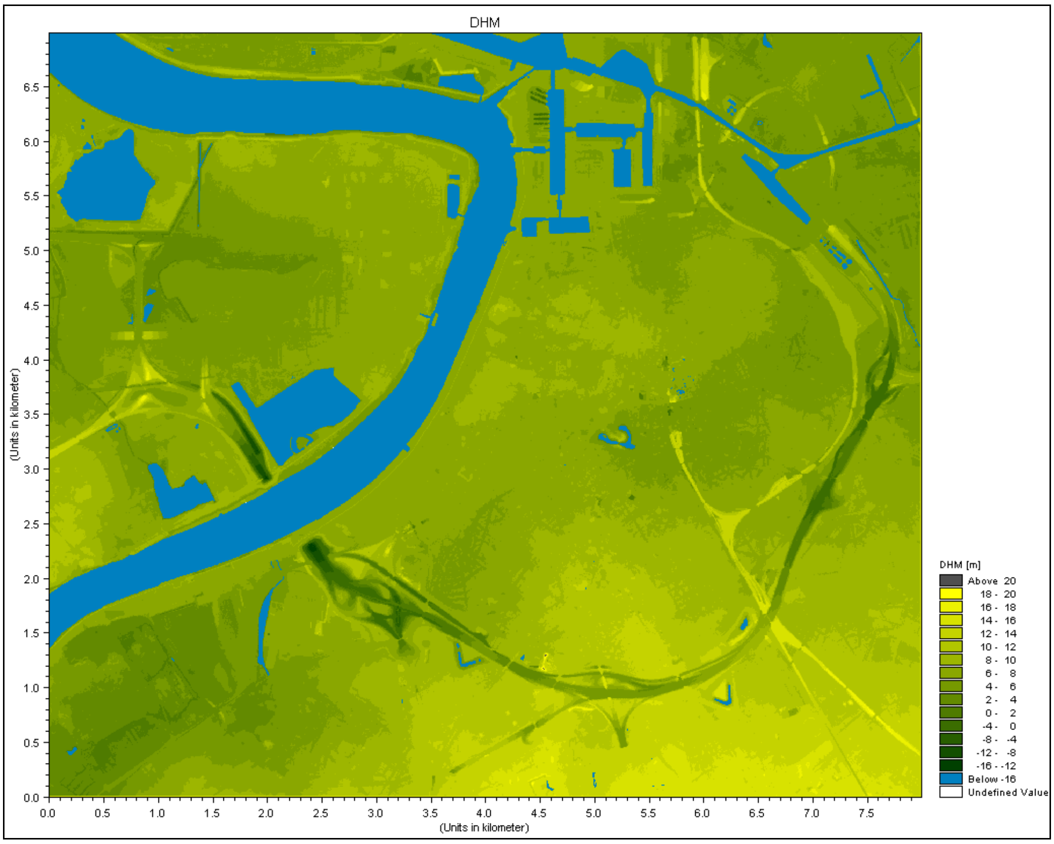

Figure 2: Original DEM (without buildings).

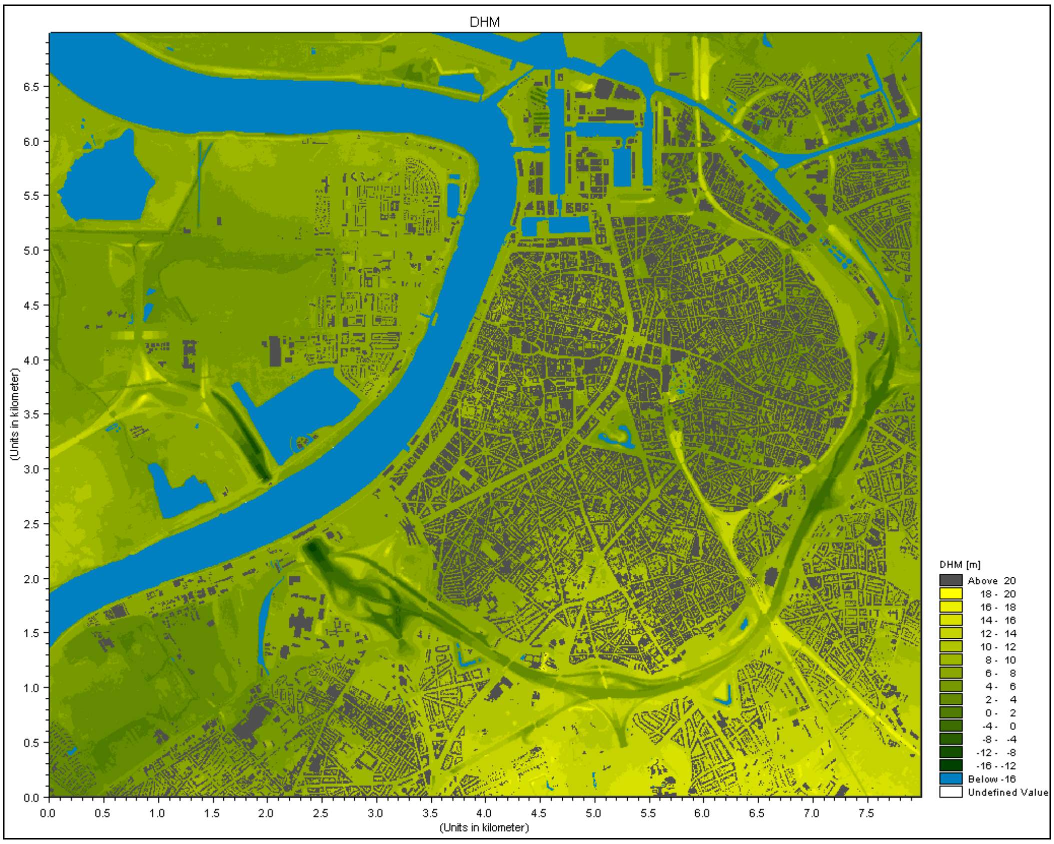

Figure 3: Modified DEM (including buildings).

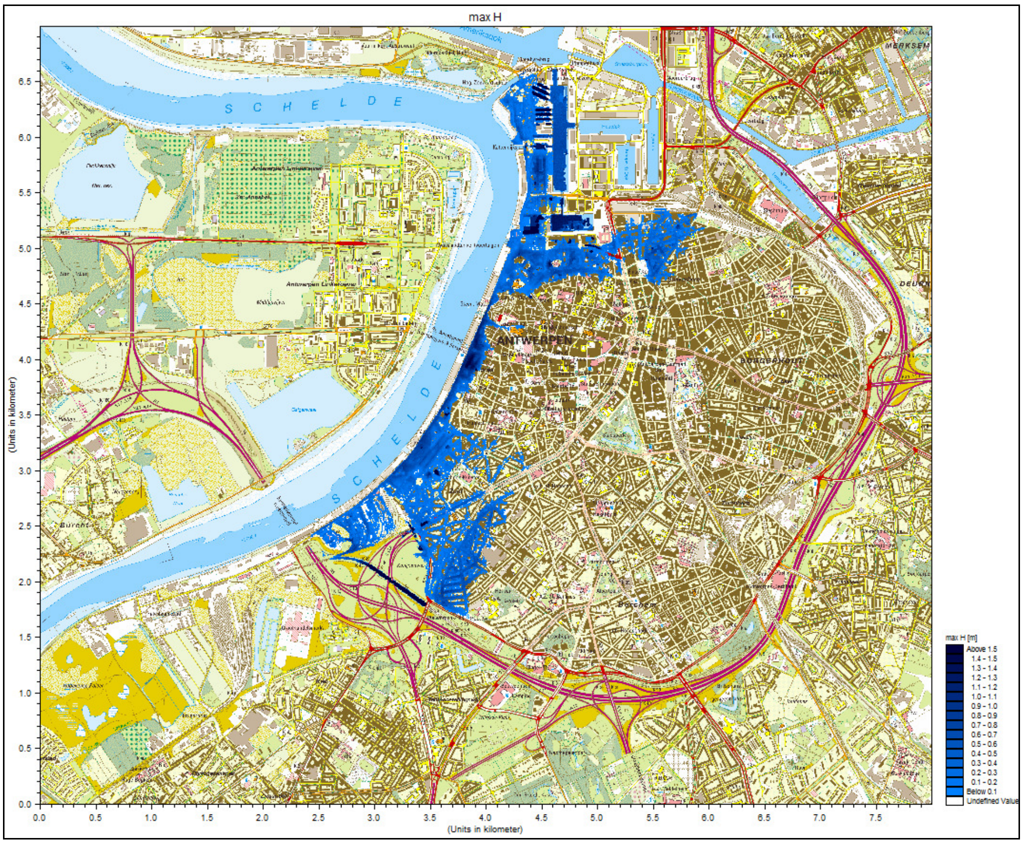

Figure 4: Simplified flood map.

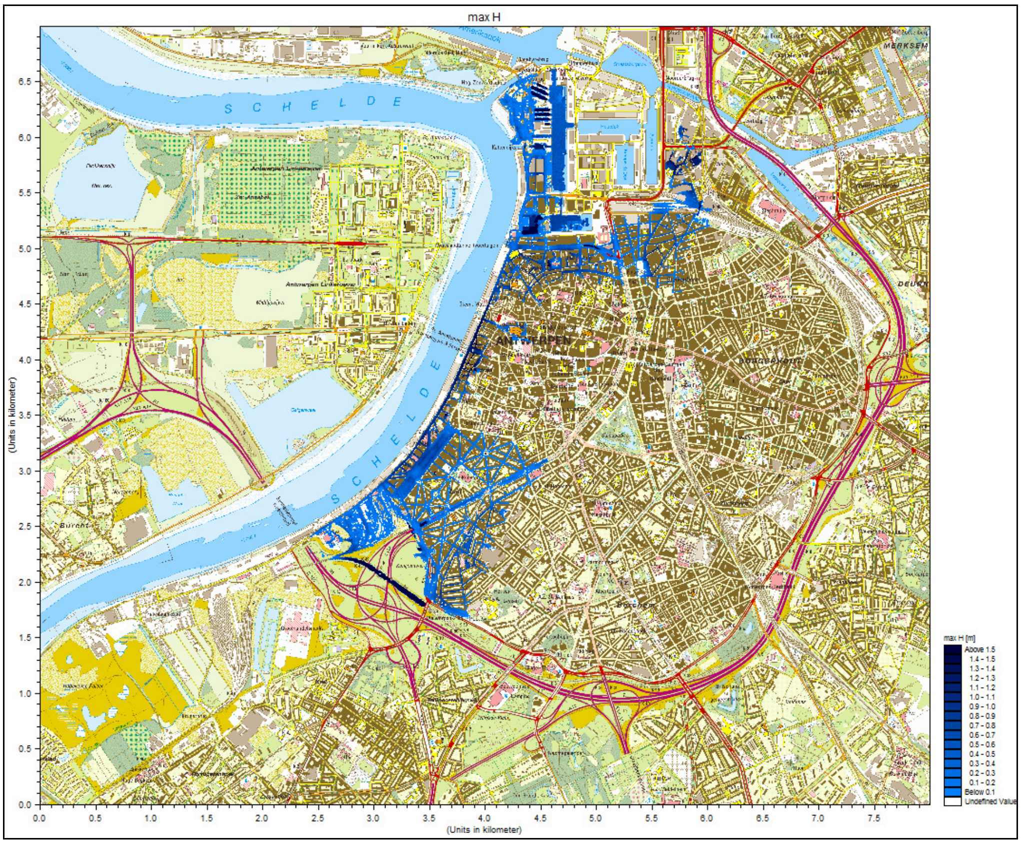

Figure 5: Detailed flood map.

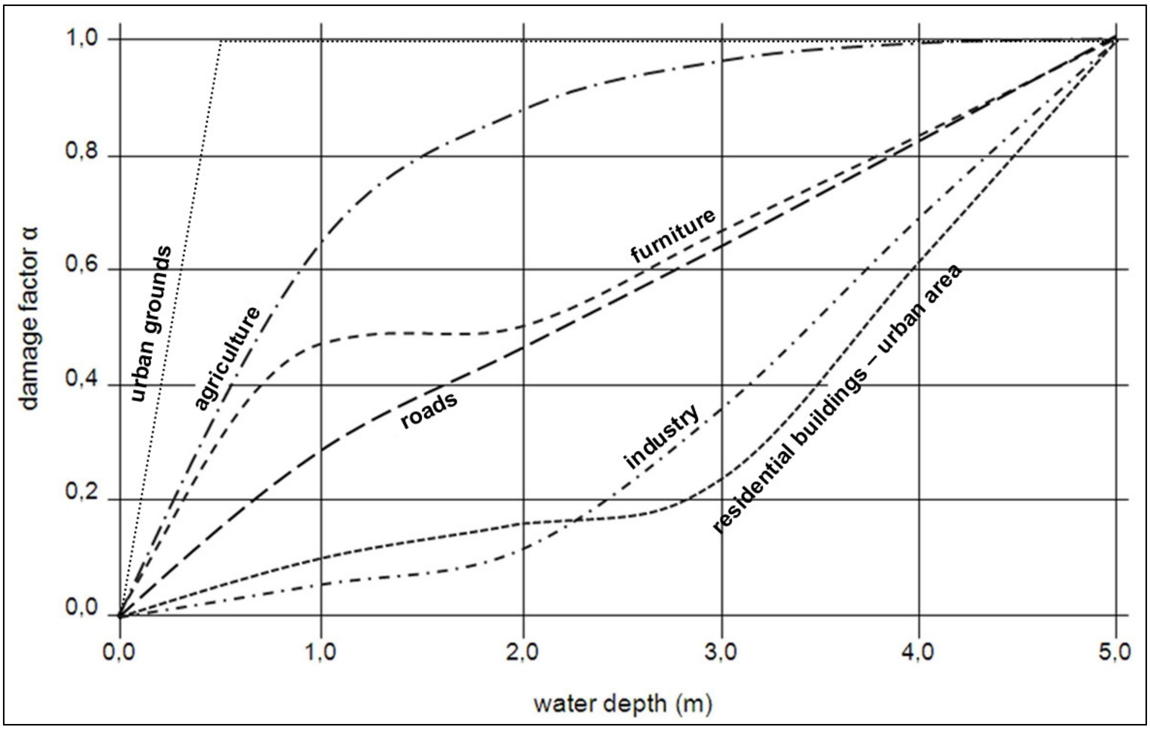

Figure 6: Damage functions.

4.2 Simplified approach

The standard damage model is based on a simplified land use map in which city blocks are treated as homogeneous areas, without distinguishing between buildings and their surroundings. Buildings and surroundings are represented by a single land use category “urban area” (Figure 7). This land use category is characterized by a single maximum damage value (average for buildings and surroundings) and the actual damage is calculated by means of a single damage function (Figure 6).

4.3 Detailed approach

The improved damage model is based on a very detailed land use map in which buildings are represented individually. The land use category “urban area” is subdivided into two categories, namely “residential buildings” and “urban grounds” (Figure 8). A high maximum damage is assigned to the buildings and a much lower maximum damage is assigned to the surroundings. The actual damage is calculated by means of two different damage functions (Figure 6).

5. SENSITIVITY ANALYSIS

The two methods for computing flood maps were combined with the two methods for computing damage maps, yielding four different methods for computing urban flood risk. The results obtained with the four methods are listed in Table 1 and differ significantly. The flood risk predicted by a combination of the detailed approaches for flood maps and damage maps was found to be less than 30% of the flood risk predicted by a combination of the simplified approaches for both map types. The damage maps for the two extreme combinations are shown in Figure 9 and Figure 10.

Flood risk (%)	Simplified flood map	Detailed flood map
Simplified damage map	100	77
Detailed damage map	82	29

Table 1: Variation of urban flood risk as a function of the approach for flood maps and damage maps.

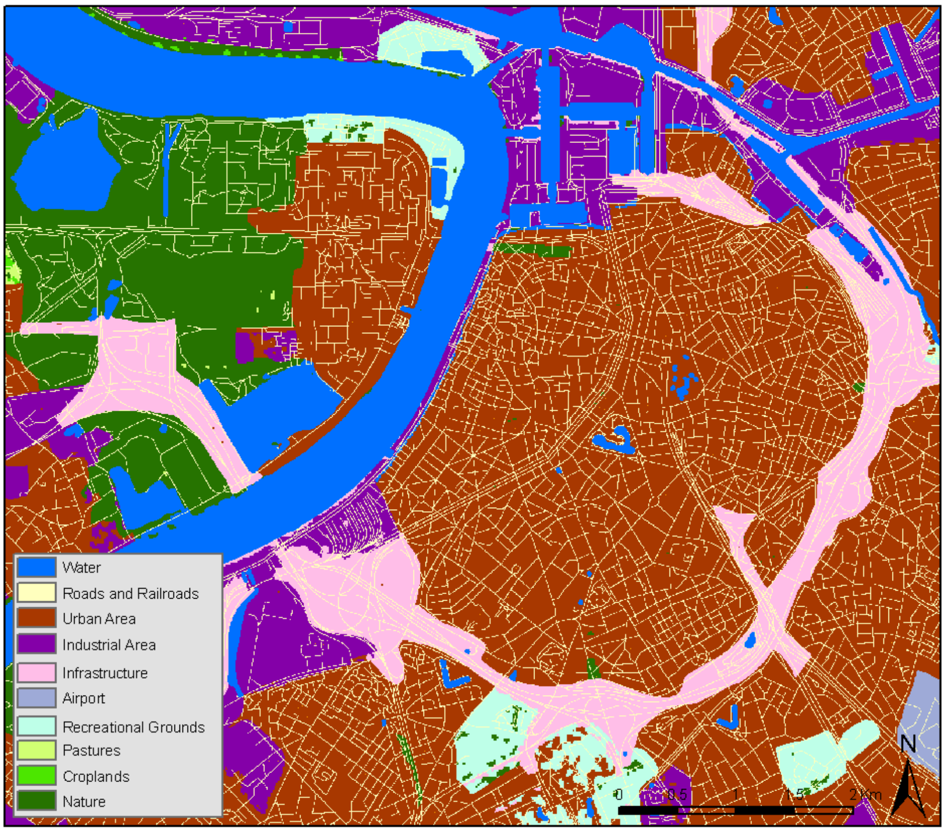

Figure 7: Simplified land use map.

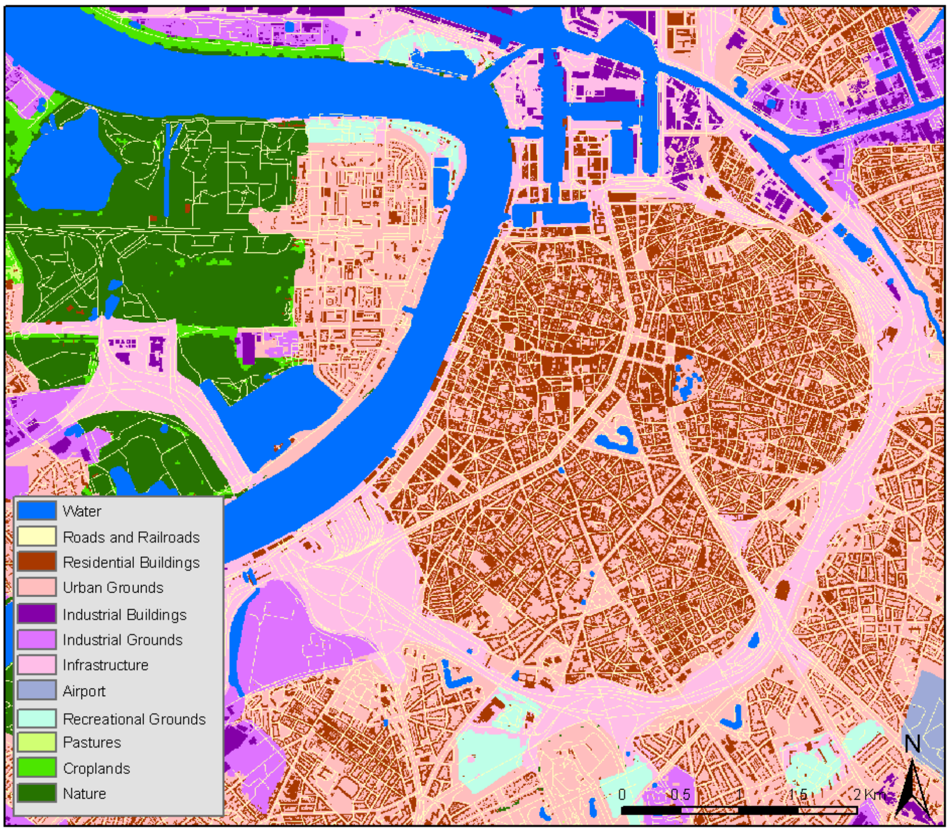

Figure 8: Detailed land use map.

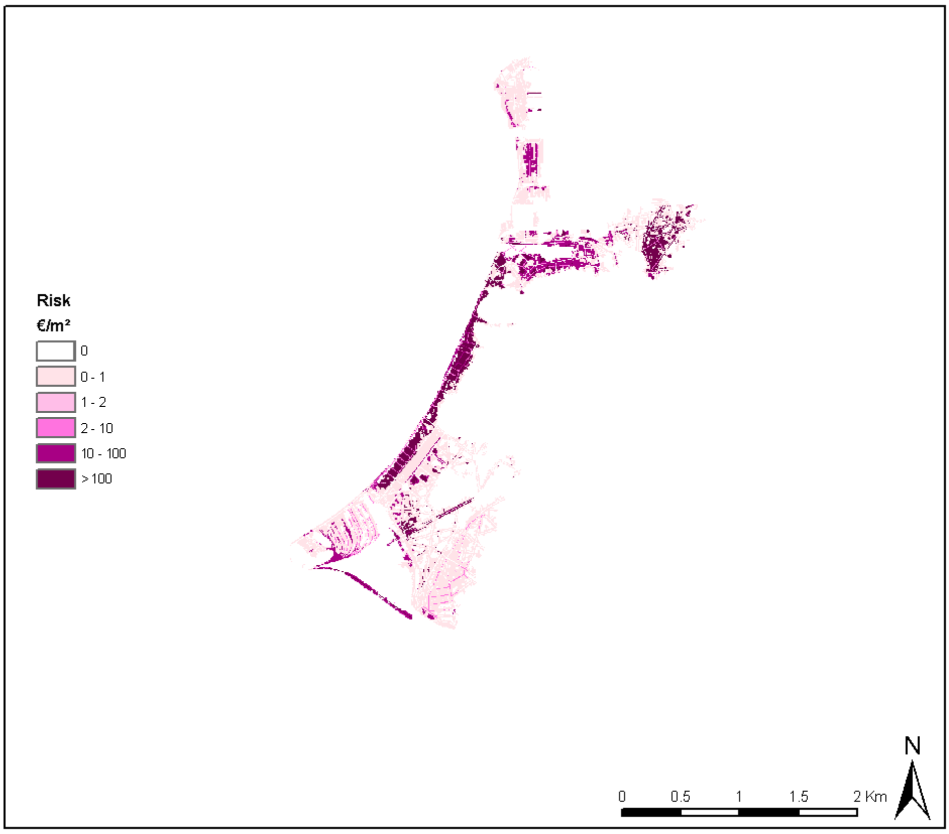

Figure 9: Simplified flood damage map.

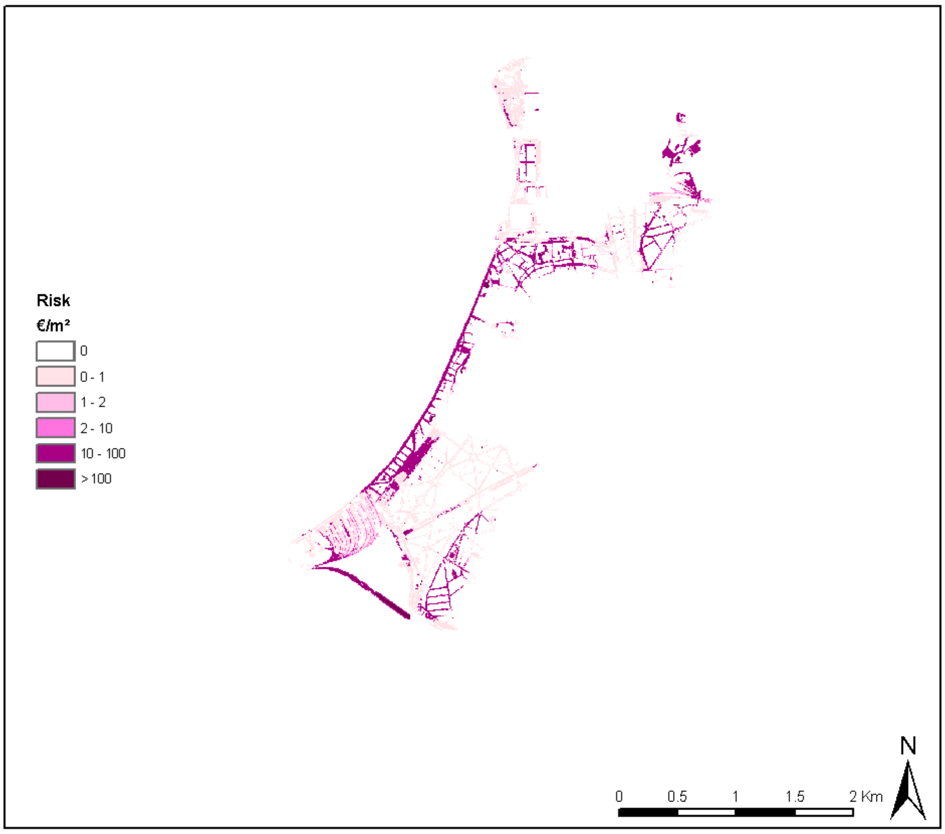

Figure 10: Detailed flood damage map.

When the simplified hydraulic model is used, flood water is spread out evenly over roads, buildings and open spaces. This would be the case when flood depths are sufficiently high for the water to enter the buildings. When the detailed hydraulic model is used instead, buildings can no longer be flooded and will suffer no flood damage. This could be the case when flood depths are limited, allowing the inhabitants to keep the water out with limited means such as sandbags. Flood water is now concentrated in roads and open spaces. As these land use categories are less susceptible to flood damage, the actual flood damage will decrease. Which approach best represents reality, entirely depends on the maximum flood depth. Unfortunately, this depth is usually not known at the start of a flood risk analysis and is likely to vary in space. Therefore, the use of the detailed approach is not necessarily an improvement in all cases.

When the simplified damage model is applied, buildings and their surroundings will be assigned the same average value for maximum damage. In reality, the replacement value of buildings is much higher than the replacement value of their surroundings. This means that the damage to buildings will be underestimated, whereas the damage to the surroundings will be overestimated. Usually, buildings are located on high grounds. In case of flooding, it is very likely that the building surroundings will be affected more than the buildings themselves. As the maximum damage to the surroundings has been overestimated, the total actual damage will also be overestimated. In the detailed damage model, buildings and surroundings are treated separately and this overestimation is automatically corrected. This results in a decrease of the total actual damage. The lower value produced by the detailed damage model is undoubtedly more realistic.

When the detailed hydraulic and damage models are combined, the impacts from both models reinforce each other. Flood water is concentrated in roads and open spaces between buildings. In addition, the open spaces are attributed a lower maximum damage. This combination results in a significant decrease of actual damage and actual risk.

6. CONCLUSIONS

From this case study, we can conclude that the procedures used for dealing with the presence of buildings can be a significant source of uncertainty in urban flood risk analysis. Depending on the procedure chosen, the resulting flood risk may vary by a factor 3.

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