Rain flooding in Spanish urban zones: a damage estimation model based on adjustment experience

Eduardo Martínez-Gomariz – Head of resilience projects, Cetaqua, Water Technology Centre (SUEZ Group)
María Guerrero-Hidalgo – Researcher and manager on environmental, economic and social sustainability projects, Cetaqua, Water Technology Centre (SUEZ Group)
Edwar Forero-Ortiz – Resilience researcher, Cetaqua, Water Technology Centre (SUEZ Group)
Salvador Castán – Insurance adjuster, Agencia Pericial (AGPERICIAL)
Marc Velasco Droguet – Coordinator on Europe's RESCCUE project, Aquatec (SUEZ Group)
Ángel Villanueva Blasco – Climate Change and Resilience Manager, Aquatec (SUEZ Group)

Introduction

According to the European Environment Agency (EEA, 2019), total reported economic loss from extreme climate events in Europe for 1980-2017 amounted to approximately 435 billion euros, of which 37 billion was in Spain. The Consorcio de Compensación de Seguros (CCS) estimates that roughly 50 % of the loss caused was insured. An illustrative figure is that the loss caused in Lorca (Spain) in the wake of the 2011 earthquake was estimated to be one billion euros, of which 50 % was insured, meaning that the relevant compensation was paid out (IDEA -Improving Damage assessments to Enhance cost-benefit Analyses- project, 2014).

Economic loss from flooding in urban zones is increasingly substantial in keeping with the socio-economic changes that occur, such as population growth and greater infrastructure density in cites the world over (UN, 2018). Flooding is the most frequent natural hazard, accounting for two thirds of loss driven by natural events in Europe. Warming from climate change is expected to intensify the hydrologic cycle, producing stronger and more frequent floods in many regions and consequently giving rise to economic loss. Even so, as the EEA suggests, the increased loss from flooding in recent decades could be partly attributable to urban development in floodable zones.

If we only look at pay-outs relating to buildings (excluding civil works and vehicles), 2018 spoke for practically 75 % of the total, being concentrated in commercial premises, stores and warehouses, and other risks.

This therefore confirms that commercial premises are the most vulnerable type of property to urban rainwater flooding.

This data highlights the significance of urban flooding from rainfalls and clearly shows a need for tools that help to estimate the damage that they can cause.

There are several different kinds of loss from flooding and they are classed in the literature as tangible and intangible, which can be further subdivided into direct or indirect (Velasco et al., 2016). Assessing the economic loss from floods (tangible loss) is one of the aspects that has traditionally been studied in the greatest depth. In particular, as regards urban zones the most prevalent analysis to date has concerned evaluating property damage.

Against a backdrop of rising flood damage in Europe, Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks was published, which obliges Member States to draw up, pass and implement flood risk management plans. This EU regulation was transposed into Spanish law via Royal

Decree 903/2010 on the assessment and management of flood risks. One of the measures included in the Flood Risk Management Plans (FRMPs) in Spain was the drafting of a "Guide to reducing the vulnerability of buildings to flooding." (CCS, 2017).

This guide was intended to provide a better understanding of the consequences of floods and to encourage a commitment to risk reduction on the part of the public through a focus on decreasing the vulnerability of people and property as well as enhancing the resilience of exposed buildings.

Thus far, management plans have centred on river and coastal floods, which can in fact bring serious consequences for the urban zones reached by the flood. However, all cities are also exposed to pluvial flooding when the rainfall exceeds the designed capacity of their drainage networks on a more or less frequent basis. While it is true that the consequences of pluvial floods in urban zones do not tend to compromise people's lives, addressing them is worthwhile to the extent that they imply economic loss. Moreover, forecasts suggest that rainfalls will be heavier as a result of climate change, with urban zones in particular standing to be worse off (Arnbjerg-Nielsen et al., 2013).

Estimating flood loss using depth-damage curves

There are several different approaches to developing flood damage assessment models. The common thread they have, though, is that they enable analysis of the efficiency of flood damage mitigation measures. Cost-benefit analyses are conducted to compare the cost of taking no action versus the loss avoided under certain adaptation scenarios. The models enable estimation of both the damage which would be caused in these adaptation scenarios and the associated avoided damages.

An essential difference among the various models is the scale they use: while some are based on aggregated uses of land, others focus on specific items (such as buildings or plots of land). The latter type offers greater complexity, since it is on a more detailed scale, whereas the first sort is more straightforward and yields quicker results for more extensive areas. The models on a detailed scale have the advantage of accurately defining the building density in urban zones, which is not the case with land-use models. Models based on Geographic Information Systems (GISs) provide an idea of the spatial distribution of damage in the zone being studied.

So-called depth-damage curves, also known as vulnerability curves, provide the essential basis for many of these models. These are mathematical functions that correlate floodwater depth for a property or given land use (depending on the scale of the study) with the damage caused.

The models are very sensitive to selection of these curves, given their peculiarities. Asset values have to be adjusted to fall in line with regional economic situations and property characteristics. Furthermore, actual damage to properties is not merely a function of floodwater depth alone, but also of other factors, such as the time of year when the flood happens, how long it lasts, water velocity, water-borne debris, and warning time prior to the flood. It is therefore clear that approaches based on depth-damage curves entail intrinsic uncertainty and that other factors beyond depth are influential in producing flood damage. In spite of this, taking floodwater depth to be a key factor in causing damage is very common practice.

These curves can be presented in relative or absolute terms and considering damage as a percentage of total property or expressed in monetary terms respectively. Whereas the first kind can be more easily transferred in space and time, given that they do not depend on the market value of the assets, the absolute damage curves call for regular recalibration to be made to factor in depreciation or inflation. But then again, the curves can be classified according to their construction procedure; specifically into those that are analytical, empirical or synthetic and even combinations of these types. The analytical ones are based on laboratory analysis resulting from monitoring the effects of variables such as water depth, flow velocity or flood duration. The empirical curves are constructed from gathering actual data on damage to properties based on survey campaigns. Then synthetic curves are the fruit of a theoretical study for a standard type of property on the assumption of it being representative of the zone being studied. This last group is mainly used when no actual data on flood damage is available.

These curves are constructed for different types of properties or land uses, depending on the working scale, and they tend to show, on the one hand, the damage to the building structure and, on the other, that to the contents. Damage to the structure relates to the building itself and the components of it that "are not taken away in the event of moving house", such as doors, the boiler, the flooring or the fitted carpet etc. On the other hand, damage to contents (furniture and fittings/equipment, stock, etc.) are the items that would be carried away if a person moved out of the house in question (McBean et al., 1988).

In Spain there are few depth-damage curve models, most being specific to certain regions, while there is only one for national coverage (Figure 1).

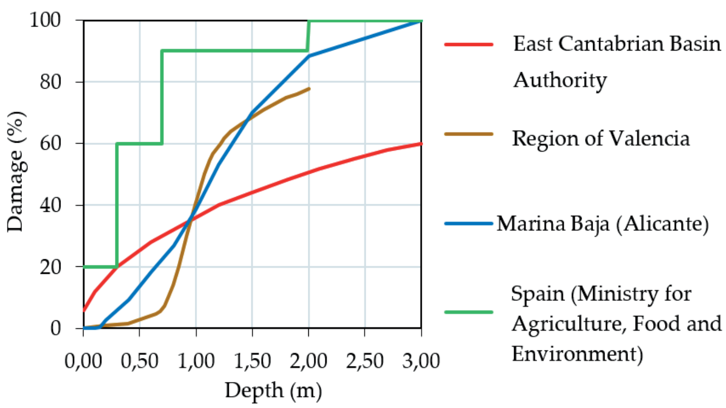


Figure 1. Depth-damage curves for different regions of Spain.

The RESCCUE project and Barcelona as a Spanish case study

The core aim of the H2020 RESCCUE project (http://www.resccue.eu/) (**Res***ilience to cope with* **c***limate* **c***hange in* **u***rban* *ar***e***as – a multisectorial approach focusing on water*) is to develop methodologies and tools to assess and manage urban resilience to climate effects. Three study cases are included where the various tools developed are implemented (Barcelona, Bristol and Lisbon), which have different characteristics and response capabilities according to climate change scenarios.

The RESCCUE project is coordinated by the company AQUATEC (SUEZ Advanced Solutions) and at Cetaqua, the Water Technology Centre (https://www.cetaqua.com/home). We play a major role, since we are the institution with the second biggest contribution. The project has 18 partners, notable among which are the three councils of the case studies, universities, and public and private companies in the urban water cycle and energy sectors. UN-Habitat is also taking part as a partner on the project with the goal of ensuring that implementation of the methodologies developed can be replicated in other contexts beyond those which have been studied in the context of the project.

Among other tasks, at Cetaqua, we carry out studies to assess the risks arising from potential climate effects on the city of Barcelona. One of the most exhaustive analyses is that of risks from rainwater –pluvial– floods, which are increasingly prevalent in metropolitan Barcelona. To illustrate this, here are some of the studies carried out:

- Drawing up mapping of risks to pedestrian and vehicular stability based on stability thresholds determined experimentally at the Institut Flumen (Technical University of Catalonia) (https://www.flumen.upc.edu/en).
- An analysis of the stability of the city's refuse and recycling containers during flood events (Martínez-Gomariz et al., 2020).
- Estimation of vehicle damage (Martínez-Gomariz, Gómez, et al., 2019).
- Development of a model to estimate direct property damage (Martínez-Gomariz, Guerrero-Hidalga, et al., 2019).

Damage caused by floods in Spanish municipalities in the specific case of Barcelona

The record of historical data on compensation paid by the CCS is of great value in managing catastrophe risks in general and flood risk in particular. The analysis of total historical pay-outs for building damage nationwide makes it possible to rank Spanish municipalities from most to least damaged, among other things. Figure 3 shows the 20 municipalities where buildings have had the most flood loss awarded compensation in Spain from 1995 to 2019.

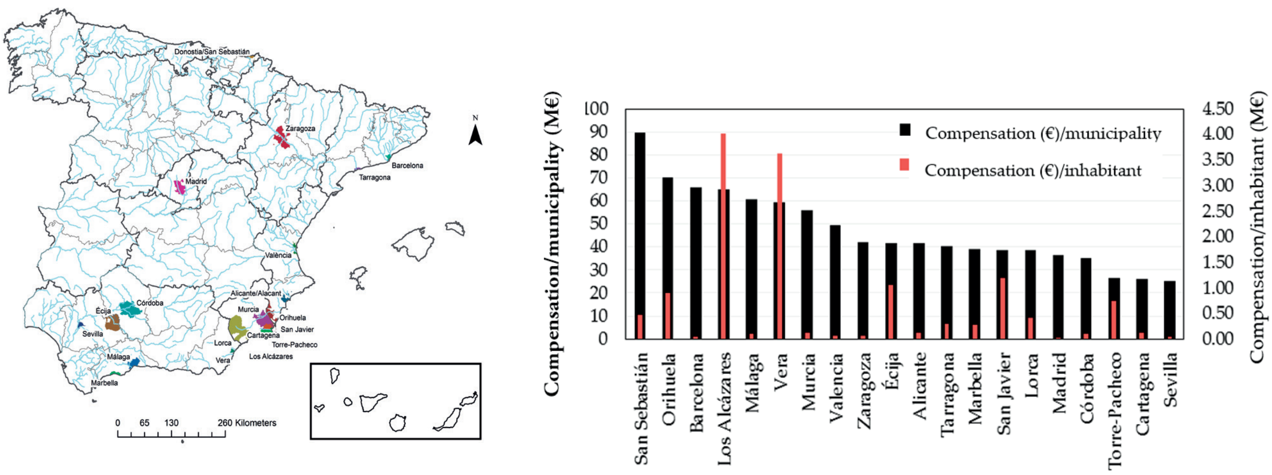


Figure 3. The 20 Spanish municipalities which had the most insured loss on account of floods (pluvial and fluvial) in 1995-2019. The values are for compensation paid out and provisioned by CCS as at 5 February 2020 using prices updated to 2019.

The floods which prompted these pay-outs may have originated from pluvial or fluvial events, since CCS' classification does not make any distinction between them. The geographical illustration clearly shows how the especially vulnerable municipalities are concentrated in the Mediterranean area. With some 75 million euros in compensation over the reference period, San Sebastian (Basque Country) is the most severely affected Spanish municipality with respect to the economic impact of flooding. Nonetheless, if we take average compensation per inhabitant, we could say that Los Alcázares (Murcia) is the municipality most vulnerable to floods.

In the city of Barcelona alone, total compensation paid and provisioned by the CCS as at 31 July 2019 and from 1996 to 2018 accounted for 43 million euros for industries, offices, residential homes and homeowners associations, vehicles and civil works, according to the classification used by CCS (Figure 4). In 2018 there were four episodes of heavy rains which caused significant loss in the city of Barcelona (Figures 4 and 5), with this year marking the third largest economic hit in terms of compensation over 1996-2018. Only 1999 and 2002 outstripped it, although, since then, several actions concerning the city's drainage supported the assumption that the situation had improved considerably.

If we only look at pay-outs relating to buildings (excluding civil works and vehicles), 2018 spoke for practically 75 % of the total, being concentrated in commercial premises, stores and warehouses, and other risks. This pattern is not a one-off and for all major flood events in the years under review over 50 % of total compensation was allocated to this grouping. This therefore confirms that commercial premises are the most vulnerable type of property to urban rainwater flooding.

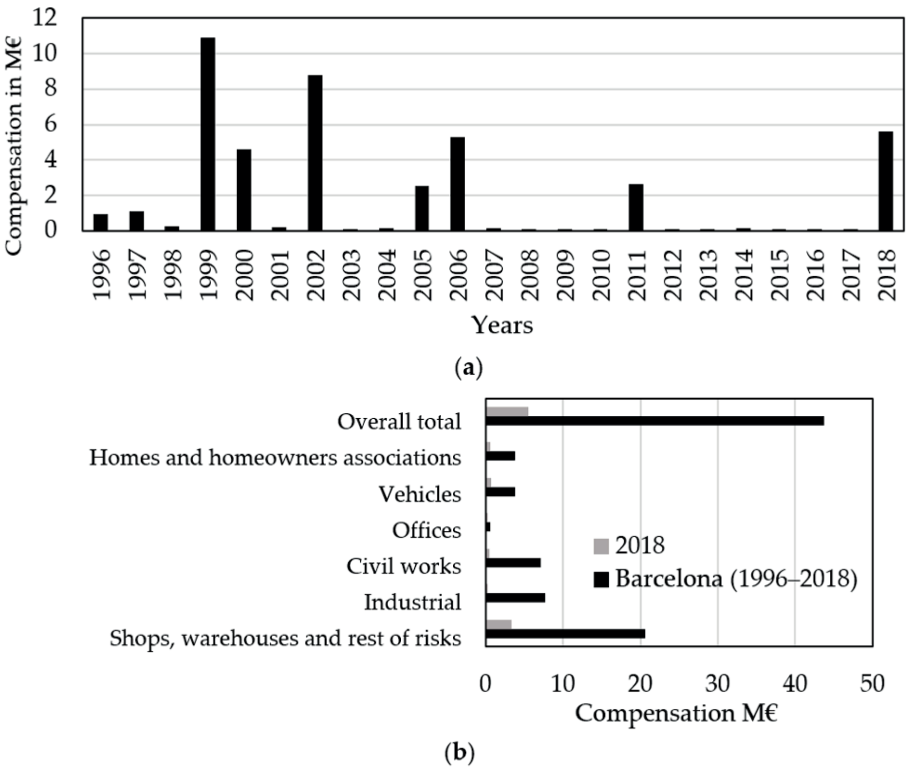


Figure 4. Compensation paid and provisioned by the CCS 31 July 2019 for loss due to pluvial floods in metropolitan Barcelona; a) Annual historical totals (1996 to 2018) and b) Historical totals (23 years) grouped into types of properties. Prices updated as of 2018.

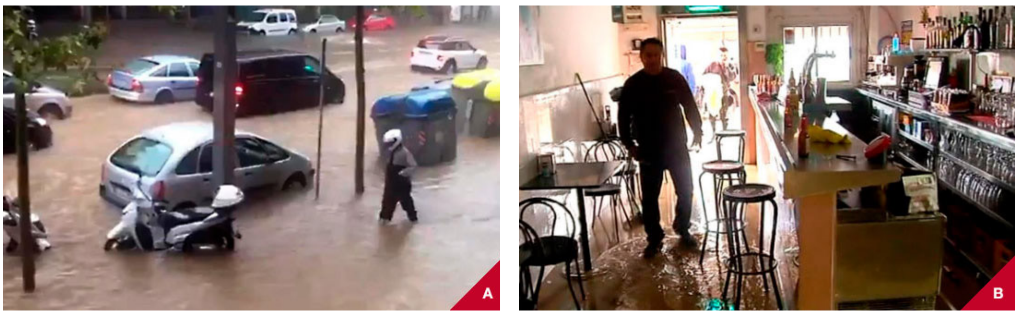


Figure 5. Aftermath of pluvial floods in the city of Barcelona which occurred on a) 9 October and b) 15 November 2018.
Sources: a) https://www.elperiodico.com y b) https://www.telecinco.es.

This data highlights the significance of urban flooding from rainfalls and clearly shows a need for tools that help to estimate the damage that they can cause. Barcelona, which is demonstrably only affected by pluvial flooding, comes third in the ranking of Spanish municipalities hardest hit by floods, classification composed by both riverine and rainfall processes.

How is flood loss estimated in Barcelona?

The economic impact of pluvial floods can now be estimated for the city of Barcelona thanks to tools developed within the RESCCUE project. A loss appraisal model has been devised in collaboration with an insurance adjuster with extensive experience of floods. The construction of this model brings in the expertise accumulated from vast experience in estimating loss from this kind of hazard.

The role of the insurance adjuster in rain floods

The CCS covers so-called "extraordinary risks", which include natural hazards such as flooding that stem from, i.e. rainfalls where these risks are not expressly borne by the original insurer in the insured's policy. Its cover includes losses arising from direct property damage, those from business interruption, costs and losses from housing not being habitable, and personal injury.

When an extraordinary risk event occurs, such as the rain floods in Barcelona on 9 October and 15 November 2018 (Figure 5), the CCS sends out one or more adjusters who are experts in making an initial estimate of the extent of the damage caused. According to conversations with the CCS, these estimates, which are the product of the experience and knowledge of the effects of flooding gained by these professionals, are definitely reliable. Therefore developing tools and methodology that reflects the expertise of these professionals can be extremely valuable when it comes to flood damage assessment in Spain. In relation to this point, the United States Army Corps of Engineers (USACE) already based itself on the opinion of the expert to develop the depth-damage curves for the various states in the country (Gulf Engineers & Consultants [GEC], 2006).

The transfer of water from the streets into the inside of the property

Although flood damage curves are a key element in estimating damage caused, this calls for the depth of water which there might be in the property to be known (or conjectured). It often happens that the depths obtained from hydrodynamic models in the area (i.e. streets) surrounding a property are applied directly, but in the case of flooding from rain it is thought that the depths on the inside of a property are likely to be considerably shallower. On the other hand, in a rain-induced flood event water residence time is thought to be long enough for the levels in the street and within the property to level up. This is what the conceptual model developed (Figure 6) seeks to define to achieve an estimate of the depth indoors that should be used when applying the damage curves.

A key element which limits the depth that comes into contact with the access to the property (y_o, Figure 6) is the height differential at the entrance, which is different for each use. This is in fact a protective element for properties, the more so the higher the differential is. With commercial premises in general there is either no step at the entrance, or else it is very low (Figure 7), to facilitate customer access. A field study in metropolitan Barcelona has managed to obtain average readings for steps (height differentials) that can be associated with the various different kinds of properties being taken into account.

Thus the flood depth in the street, which is normally provided by a hydrodynamic model that takes into account the run-off and network overflows on the surface, is "reduced" by this height differential. The depth left after this reduction is the one which will cause water to enter the property.

The depth inside the property (y_{GF}, Figure 6) is expected to be lower than it is in the street, to a greater or lesser extent depending on the number and type of closable openings. This assumption is based on the fact that with rain floods the water residence time in the streets lasts for only very few hours, or even minutes (Chen et al., 2010).

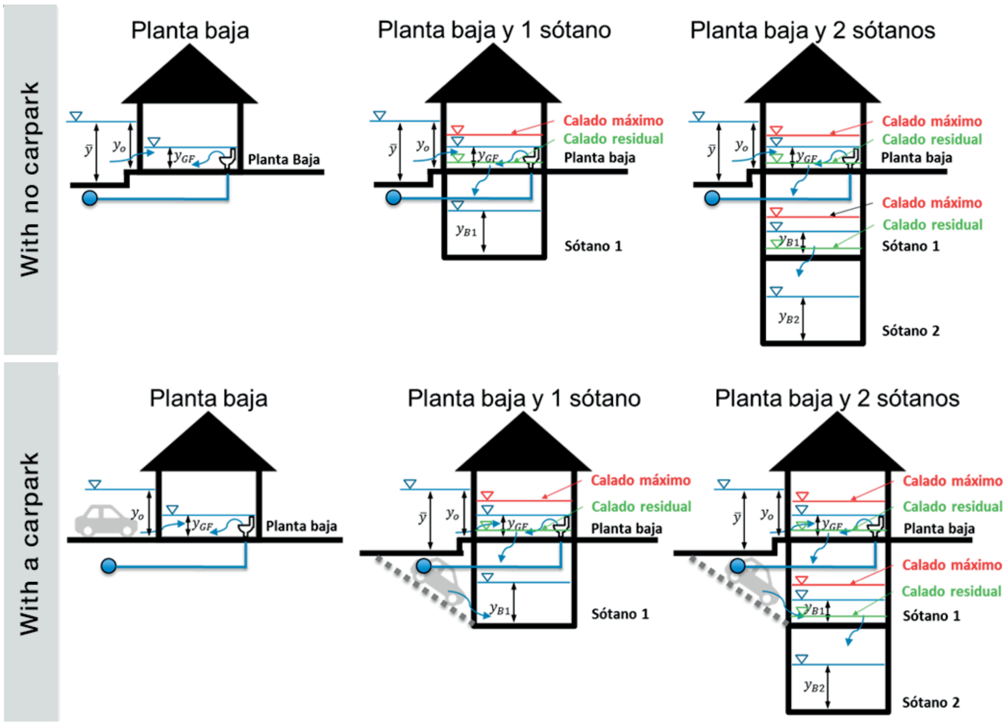


Figure 6. Conceptual model of the transfer of water-level from the streets into the inside of the property.

Figure 7. The entrance doors and almost non-existent steps of two commercial premises in metropolitan Barcelona.

This approach posits a model for the transfer of the depth of water in the street to that inside the property in urban zones which is depicted diagrammatically in Figure 6. This shows different building configurations: 1) only a ground floor, 2) a ground floor and a basement and 3) a ground floor and two basement levels. These three configurations are also considered with a carpark ramp, given that this allows more water to enter. With just a ground floor, the water depth can rise to the level in the street, yet the presence of basements means that a certain maximum depth is not surpassed because the water shifts down to lower levels afforded by the basement/s. A residual level is also accepted, which is that which will remain on the ground floor after the event concludes and is accumulated water that will not increase the depth on lower floors. The damage curves are therefore applied using the depths inside the property (y_{GF}, y_{B1}, y_{B2}, Figure 6) consistent with this approach.

Permeability of properties

Closable openings (doors and windows) are the places through which water moves from the streets into a property in the event of a flood. It is assumed that they are not left open in a flood situation and they can be watertight to a greater or a lesser degree, although it seems evident that the water depth inside properties will be greater than it is outside (Figure 8).

Figure 8. High-water marks following a flood event both inside (49 cm) and outside (110 cm) a property.

As has already been pointed out, the water residence time is a key factor in the ratio of the water depth outside to that inside a property, but in the case of urban rain floods this time is typically not long enough for the two water levels to equal each other. Thus a permeability ratio is proposed to illustrate the relationship between both depths (y_{GF}/y_o), that which can be expected within the property (y_{GF}) and that experienced in the streets (y_o).

There being no available data on flood depths in the streets where buildings stand for which their inside flood depth is known, the permeability ratio has been estimated according to the opinion of the expert flood loss adjuster. These permeability ratios have been initially estimated for several different types of closable openings, as well as drains and syphoning systems. A premise with closable openings just made of glass (sliding doors, for example) and without aluminium metalwork would allow the water in more easily than other premises with frames. These ratios are also expected to vary according to the depth in the streets, given that a greater depth means a longer water residence time. For this reason, they are presented as dependent functions of the street-depth and type of closable opening or drain. In this way, aggregation of curves for closable openings and sanitation systems has enabled a curve of water-tightness ratios to be established for the various kinds of properties taken into account in this study (Figure 9).

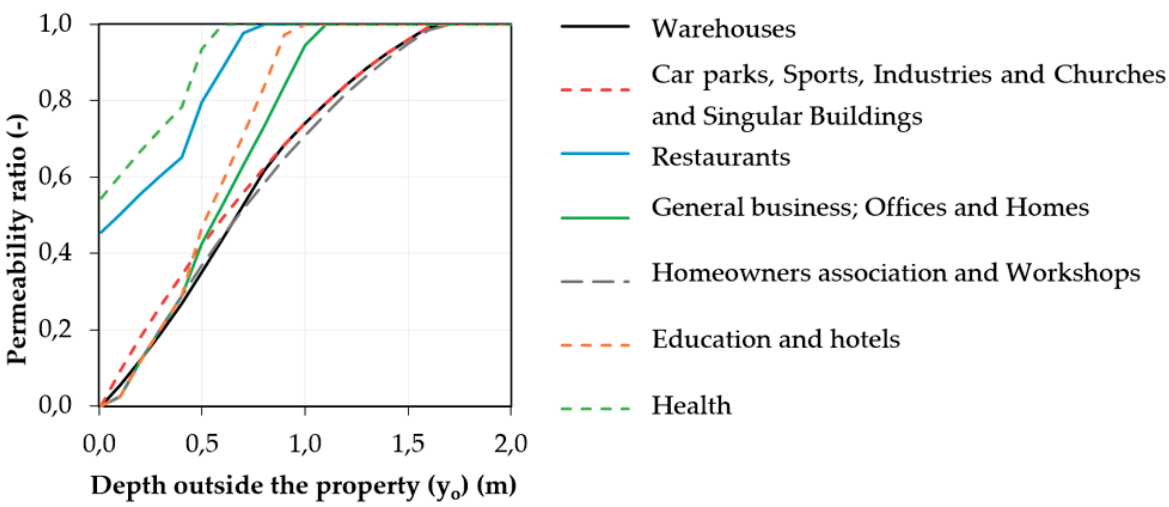


Figure 9. Water-tightness ratio curves for a) types of closable openings and b) kinds of properties.

Potentially floodable areas

On the other hand, the conceptual study presented makes sense for properties with a sufficiently small floorspace because if we consider extensive spaces, we can expect the water that comes into the property not to take up the whole area. In this respect we can draw a distinction between total floorspace and potentially floodable floorspace. Both of these amount to the same in the case of conventional commercial premises (Figure 10a), but they will differ substantially when the flooded street affects a hospital with a large floorspace (Figure 10b) or even a shopping centre, where the water is expected to occupy only a portion of it. Based on experience of performing adjustment for flooded properties, certain functions have been proposed to find out the potentially floodable floorspace as a function of the water-depth in the street (y_o) and overall floorspace (Figure 11).

Figure 10. Entrances to properties with a) small floorspaces (small businesses) and b) large floorspaces (hospital).

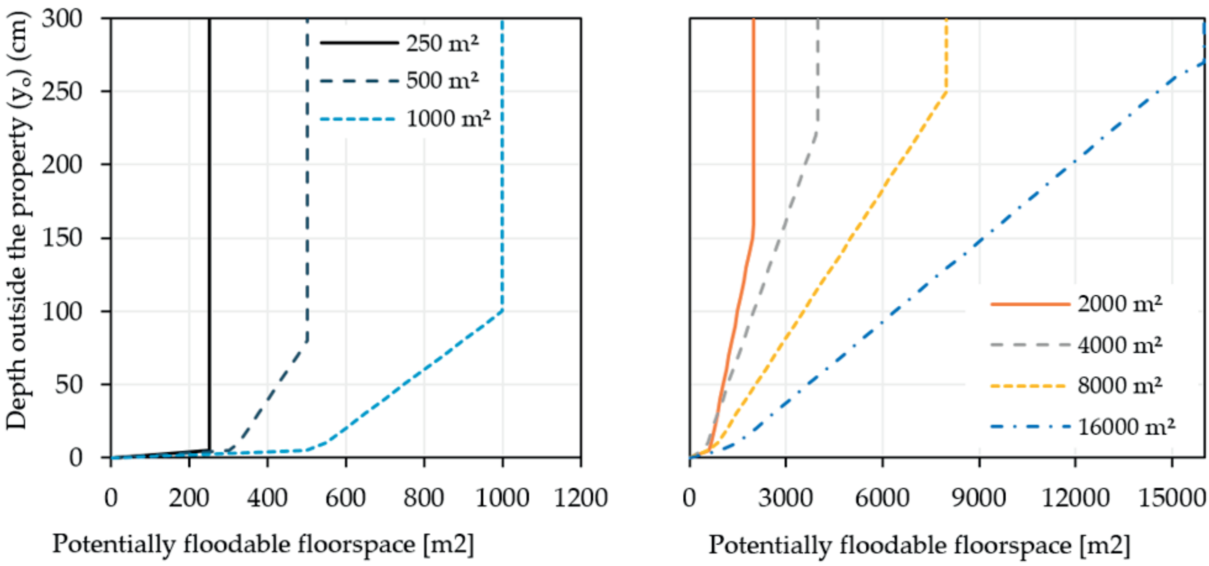


Figure 11. Potentially floodable floorspaces.

Developing damage curves for Barcelona

By way of a last, though essential, element depth-damage curves have been specifically designed for Barcelona. To construct them, a comprehensive analysis has been made of 378 records of flood-hit properties nationwide for which their loss adjustment value, the compensation paid out by CCS and the water-depth inside the property that caused the loss was known. The floods reviewed took place over 2012-2018 and affected Spanish cities with differing economic levels and located in the Mediterranean and Atlantic (Bay of Biscay) areas. These records reflect damage caused by pluvial floods in the Mediterranean zone and fluvial floods in the Atlantic zone. The former relate to damage caused by medium and low depths (up to 50 cm on the ground floor), whereas the latter prompted deep flooding (up to 100 cm) inside properties.

The final results from the depth-damage curves for Barcelona (Figure 12) were obtained after combining linear adjustments according to the relevant data but featuring input from the claims adjuster (semi-empirical curves) on those sections of the functions where there was a paucity of data or the correlation was weak (Martínez-Gomariz et al., 2020).

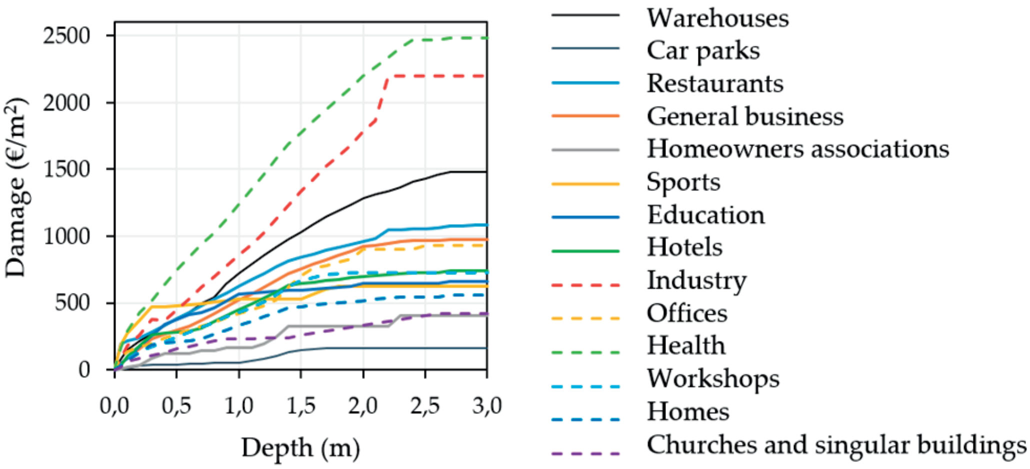


Figure 12. Semi-empirical depth-damage curves for metropolitan Barcelona.

Regional and temporal transfer of the damage curves

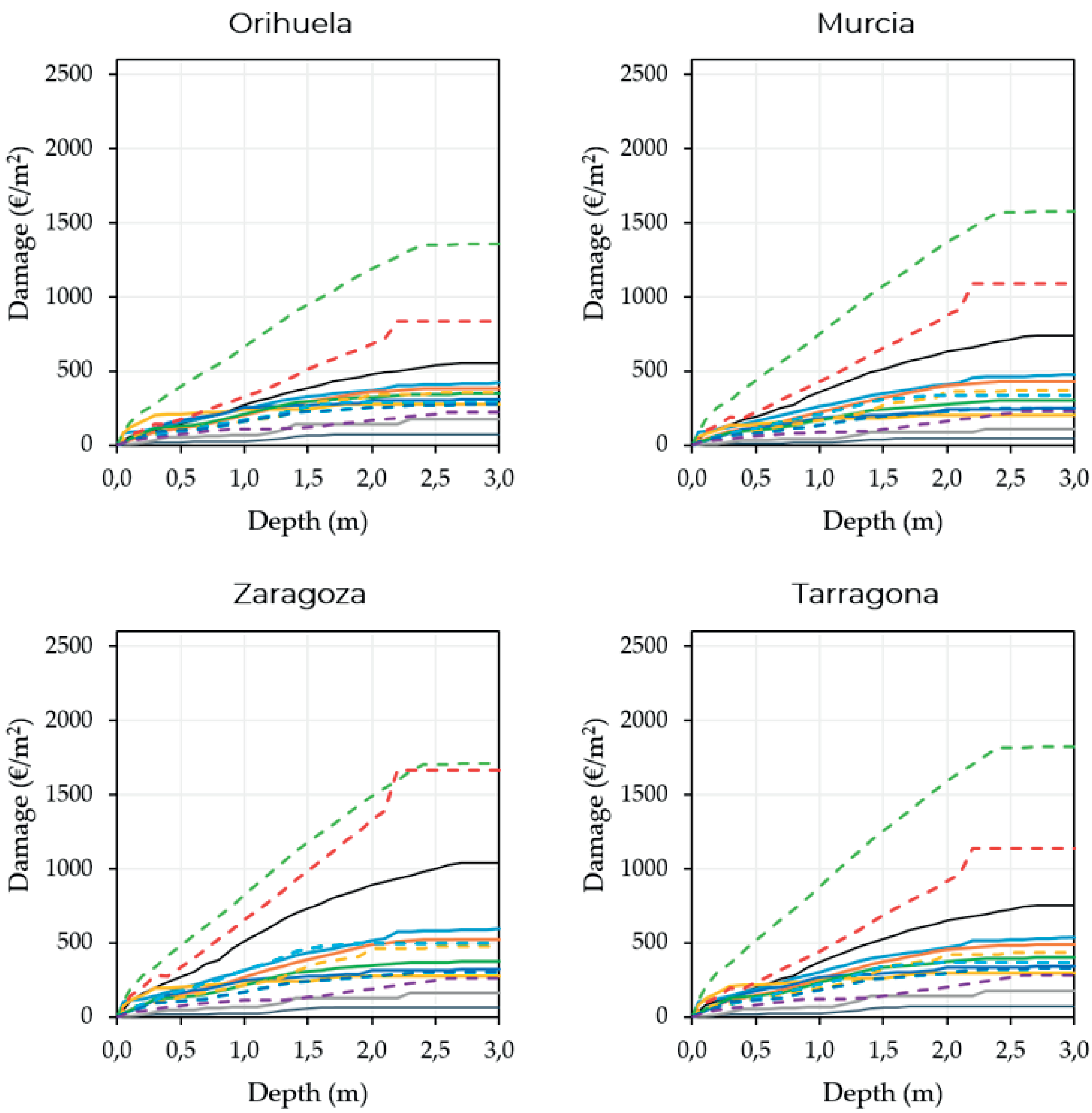
Using the semi-empirical depth-damage curves constructed for metropolitan Barcelona as part of the RESCCUE project as a starting point, we have gone one step further and **developed a methodology to transfer these curves onto other Spanish municipalities. This allows depth-damage curves to be used for flood loss appraisals nationwide by applying curves obtained via a common methodology.**

To transfer the Barcelona curves regionally to a large portion of the 8,131 Spanish municipalities, demographic , economic and geographic factors have been taken into consideration, since they have a bearing on the variability of prices for goods and services in the country (IBI Group, 2015). To do this we have obtained regional adjustment indices which show the proportionate price variation for a curve for Barcelona relative to a different Spanish municipality.

The different types of properties taken into account have been grouped into three broad sectors, namely commercial, industrial and residential, and others. We have assumed that the three property components (the building, furniture and furnishings, and stocks) show differing price variations. For example, we assume that the prices of buildings used for storage vary in the same way as a commercial building, but that on the other hand the remaining components (furniture, furnishings and stocks) exhibit price variability on a par with the industrial sector. After the indices have been obtained for each component, the component curves for Barcelona are adapted to find the curves for each component in the municipality for which depth-damage curves are sought. Aggregation of the component curves gives us the municipality's depth-damage curve for the types of properties taken into account. Figure 12 shows the depth-damage curves constructed for some of the municipalities worst hit by flooding in Spain in recent years.

Temporal transfer of curves is also useful for evaluating future potential flood damage. Temporality indices constructed using the economic scenarios forecast by the OECD up to 2060 (OECD, 2020) can be applied to the depth-damage curves constructed for a municipality.

Details of this study can be found in the article "Depth Damage Curves for Spanish Urban Areas" (Martínez-Gomariz et al., 2020), which was published in the magazine Sustainability.



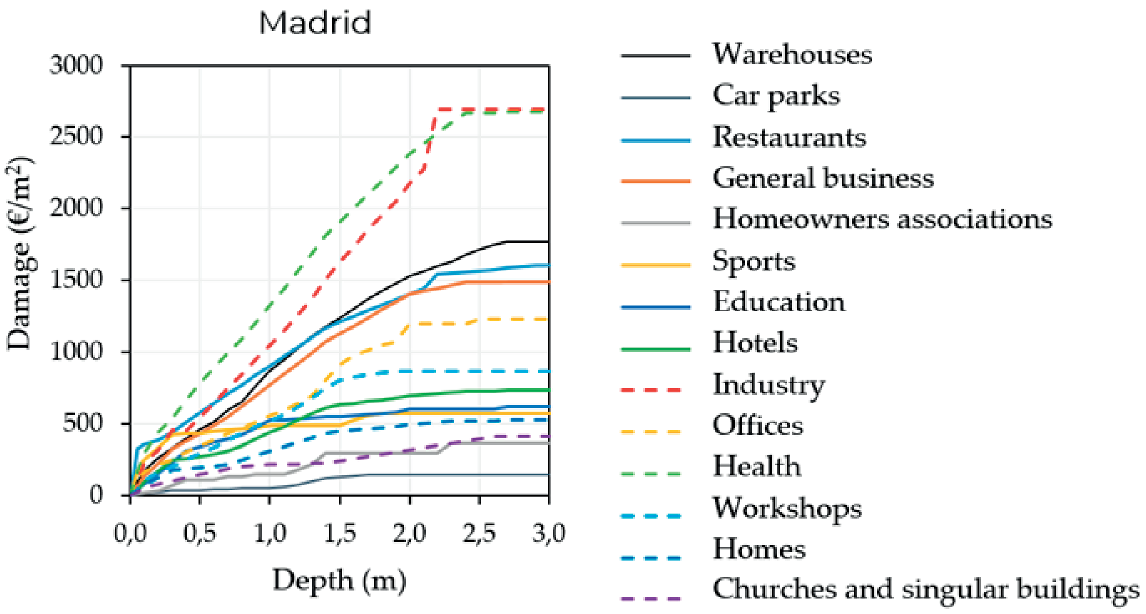


Figure 13. Depth-damage curves for some Spanish cities.

Conclusions

Using depth-damage curves is globally accepted, even while recognising the significance of factors not given consideration, such as water velocity or floodwater residence time. A large number of damage models are based on the depth-damage relationship. One of the biggest limitations of these curves thus far is their regional nature. This means that they are only valid for the place for which they have been constructed and, therefore, cannot be used appropriately elsewhere. Moreover, the need to continually bring prices up to date over time may also be viewed as a drawback when they are absolute curves (€). Even so, when they are relative depth-damage curves (%) there is greater consensus over their usefulness, since their shape remains unaltered over time. The shape of these curves is particularly dependent on the styles and types of construction employed in different regions, which could even be held to be reasonably uniform up to national level.

Barcelona is one of the case studies in the EU's RESCCUE project and is a city for which there has been thorough analysis of its resilience to climate effects. Of those it potentially faces, special attention has been paid to rain floods, which happen with increasing frequency every year. Among the different risks studied, an assessment of potential property damage has been made. To this end a detailed model has been developed that reflects the experience acquired by an expert flood claims adjuster. Due to the lack of depth-damage curves for Barcelona, specific curves have been constructed for the city based on genuine flood records and with the benefit of input of the knowledge built up in the course of adjustment work. These curves cover different uses of properties that are characteristic of highly-developed areas, such as Barcelona.

Furthermore, to extend development of depth-damage curves to the various Spanish municipalities we propose methodology that uses regional indices based on several demographic, economic and geographic indicators. To transfer the curves to future years, we propose a temporal index that allows taking curves up to the year 2060 in line with the economic forecasting which the OECD has estimated.

Both the conceptual model and the curves developed are tools that can be applied nationwide and therefore the results of damage assessment between different municipalities in Spain can become comparable. This work helps toward improving cost/benefit studies, their use being particularly important for pluvial floods, although it is also applicable to fluvial floods. Future revisions of Flood Risk Management Plans (Directive 2007/60/EC and Royal Decree 903/2010) will also pay attention to pluvial floods and the risks that stem from them, since there are now tools available to conduct studies of this type.

The insurance industry will also benefit from a damage assessment model that would allow it to estimate the order of magnitude of compensation pay-outs to be satisfied in the immediate aftermath of a flood, as well as to keep track of quality and fraud.

References

Arnbjerg-Nielsen, K., Willems, P., Olsson, J., Beecham, S., Pathirana, A., Bülow Gregersen, I., Madsen, H., & Nguyen, V.-T.-V. (2013). Impacts of climate change on rainfall extremes and urban drainage systems: a review. Water Science and Technology, 68(1), 16–28. https://doi.org/10.2166/wst.2013.251

Chen, A. S., Djordjević, S., Leandro, J., & Savić, D. A. (2010). An analysis of the combined consequences of pluvial and fluvial flooding. Water Science and Technology, 62(7), 1491–1498. https://doi.org/10.2166/wst.2010.486

Consorcio de Compensación de Seguros (CCS) (2017). Guía para la reducción de la vulnerabilidad de los edificios frente a las inundaciones. http://www.consorseguros.es/web/documents/10184/48069/guia_inundaciones_completa_22jun.pdf/480edc31-446b-40a5-af5b-2c37daf20a35

European Environment Agency. (2019). Economic losses from climate-related extremes in Europe. https://www.eea.europa.eu/data-and-maps/indicators/direct-losses-from-weather-disasters-3/assessment-2

Gulf Engineers & Consultants (GEC). (2006). Depth-Damage relationships for structures, contents, and vehicles and content-to-structure value ratios (CSVR) in support of the Donaldsonville to the Gulf, Luisiana, Feasibility study. http://www.mvn.usace.army.mil/Portals/56/docs/PD/Donaldsv-Gulf.pdf

IBI Group. (2015). Provincial Flood Damage Assessment Study. Prepared for Government of Alberta. (Issue February). https://open.alberta.ca/dataset/807b9710-0867-453e-8fa7-50c239bcd7d0/resource/f2d0a88c-b04b-4a39-af76-0aa8cd1e880b/download/pfdas-alberta-main.pdf

IDEA (Improving Damage assessments to Enhance cost-benefit Analyses) project. (2014). Earthquake of Lorca in 2011. http://www.ideaproject.polimi.it/?portfolio=floods-in-vall-daran-and-pyrenees

Martínez-Gomariz, E., Forero-Ortiz, E., Guerrero-Hidalga, M., Castán, S., & Gómez, M. (2020). Flood Depth-Damage Curves for Spanish Urban Areas. Sustainability, 12(7), 2666. https://doi.org/10.3390/su12072666

Martínez-Gomariz, E., Gómez, M., Russo, B., Sánchez, P., & Montes, J.-A. (2019). Methodology for the damage assessment of vehicles exposed to flooding in urban areas. Journal of Flood Risk Management, 12(3), e12475. https://doi.org/10.1111/jfr3.12475

Martínez-Gomariz, E., Guerrero-Hidalga, M., Russo, B., Yubero, D., Gómez, M., & Castán, S. (2019). Desarrollo y validación de curvas de daño y estanqueidad para la estimación de daños por inundaciones en zonas urbanas españolas. VI Jornadas de Ingeniería Del Agua JIA2019, 4.

Martínez-Gomariz, E., Russo, B., Gómez, M., & Plumed, A. (2020). An approach to the modelling of stability of waste containers during urban flooding. Journal of Flood Risk Management, 13(S1), jfr3.12558. https://doi.org/10.1111/jfr3.12558

McBean, E. A., Gorrie, J., Fortin, M., Ding, J., & Moulton, R. (1988). Flood Depth—Damage Curves By Interview Survey. Journal of Water Resources Planning and Management, 114(6), 613–634. https://doi.org/10.1061/(ASCE)0733-9496(1988)114:6(613)

OECD. (2020). “Long-term baseline projections, No. 103”, OECD. Economic Outlook: Statistics and Projections (Database). https://doi.org/10.1787/68465614-en

UN. (2018). World Urbanization Prospects: The 2018 Revision. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

Velasco, M., Cabello, À., & Russo, B. (2016). Flood damage assessment in urban areas. Application to the Raval district of Barcelona using synthetic depth damage curves. Urban Water Journal, 13(4), 426–440. https://doi.org/10.1080/1573062X.2014.994005