Floodam: Modelling Flood Damage functions of buildings. Manual for floodam v1.0.0

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floodam

Modelling Flood Damage functions of buildings

Manual for *floodam* v1.0.0

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Abstract

To estimate the damage due to floods, damage functions can be used. They associate a level of damage to flood parameters and built assets characteristics. In France, a comprehensive effort has been made for a decade to build damage functions at national level for different types of built assets (dwellings, economic activities, public infrastructures). During this process, *floodam*, a computer utility, has been developed. It is based on expert knowledge and used to produce damage functions that relate to specific buildings. The present manual explains the purpose of *floodam* and its principle.

Based on version 1.0.0 of *floodam*, the manual then describes, first at the level of the building components, and then at the building level: 1) how the data used by *floodam* were collected, 2) how the damage to the components or buildings is modelled, 3) how the input data are organized, 4) the outputs, 5) some examples. The last chapters explain how some features of the building models can be modified to produce new damage functions and the development perspectives.

keywords: flood, damage, modelling, building, *floodam*, expert knowledge, sensitivity, reparation

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Contents

Chapter 1

Introduction

1.1 Development context

1.1.1 Cost-Benefit Analysis in the PAPI procedure

Since 2002, a procedure has been implemented in France to obtain funding from the State for flood management projects designed at local levels (Direction Générale de la Prévention des Risques, 2017b). This procedure is embedded in programmes called "PAPIs" (for Programmes d'Actions de Prévention des Inondations), developed by local collectivities in charge of flood management at catchment level. The French State requires that PAPIs address several aspects of flood management, following the direction given by the European Union Flood Directive (UE, 2007). Since 2011, it has also required that actions implying costly investments (mainly those that involve building large infrastructures, such as dykes or dams) be analysed through a Cost-Benefit Analysis (CBA). [1] PAPIs that comply with the specification given by the French State (Direction Générale de la Prévention des Risques, 2017a) are judged by a commission called CMI (for Commission Mixte Inondation), which decides whether each PAPI shall be funded, modified or rejected.

The CBA was only introduced in the specification in 2011 (Direction Générale de la Prévention des Risques, 2011). Before 2011, it was not mandatory to conduct a CBA of costly investments. In fact, Ledoux et al. (2003) brought to light the fact that the French practice of CBA applied to flood management projects was late compared to other countries, such as the United Kingdom (Penning-Rowsell et al., 2003) or the United States of America (USWRC, 1983). Following a seminar held in 2007, which strengthened this observation, the French State created in 2008 a working group called the GT AMC (for Groupe de Travail sur l'Analyse Multi-Critère) composed of representatives from several entities: two departments of the French Ministry in charge of Environment (the DGPR (Direction Générale pour la Prévention des Risques) and the CGDD (Commissariat Général au Développement Durable)), and five external entities, which are the main reinsurance company in France (the CCR for Caisse Centrale de Réassurance), the CEPRI (Centre Européen de Prévention du Risque d'Inondation), the Cerema (Centre d'Etudes et d'expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement), Irstea (Institut de Recherche en Sciences et Techniques pour l'Environnement et l'Agriculture), and the MRN

[1] Since 2014, it has also been mandatory to provide other indicators to assess some projects, such as the expected number of inhabitants they protect by year (Magnier et al., 2014).

(Mission Risques Naturels). The aim of this working group was to develop an unique CBA methodology to be used by local collectivities to analyse their flood management projects.

The GT AMC first identified the aspects that needed improvement to provide a robust CBA methodology, and prioritized them in order to propose an acceptable first version of the CBA methodology. The GT AMC highlighted that one of the main aspects to be improved was the modelling of expected damage (Bournot, 2008). As a first step, the GT AMC proposed to use an adaptation of "old" damage functions to conduct CBAs. These damage functions were developed during the 1980's and 1990's for some specific studies in France (Soubieux-Bournot et al., 2010). This led to the introduction of a mandatory CBA methodology in the PAPI specification in 2011, based on these "old" damage functions (Direction Générale de la Prévention des Risques, 2011). Then, the GT AMC proposed to develop new damage functions, that should all fulfil the following specifications:

- transparency of the methodology used to develop them;
- consistency with the spatial databases that are available for the French territory;
- possibility to be easily updated with new data;
- possibility to be easily transferred to other contexts.

1.1.2 Development of flood damage functions to built assets

floodam is the result of several works within the GT AMC.

First, Irstea developed flood damage functions for the agricultural sector (Agenais et al., 2013). These flood damage functions relate to crops and must be applied at plot level. They were produced based on a formalization of expert knowledge that has been implemented as a computer tool called *floodam*, which is now called *floodam-agri*.

Secondly, the CEPRI started to work on flood damage functions for buildings dedicated to dwellings (CEPRI, 2014). For this purpose, they used an approach comparable to the one used by the FHRC (Penning-Rowsell et al., 2005) and compatible with the one used by Irstea for flood damage functions for the agricultural sector. This approach is based on the decomposition of the building into components, for which elementary damage functions were established based on expert knowledge. To do an inventory of all the components that are present in buildings, the CEPRI used models of real buildings. Nevertheless, the process developed by the CEPRI to do the inventory of the components of a given building was not straightforward and quite time consuming. Thus, it soon appeared very difficult to improve flood damage functions to dwellings by using new representative buildings. In order to partly automate the damage functions development process, Irstea started in 2013 to develop a version of *floodam* for built assets.

Besides, the Cerema and Irstea started in 2012 to work on the development of flood damage functions for buildings dedicated to economic activities. For this purpose, the same approach based on expert knowledge and the breakdown of buildings into components was used.

It soon appeared that *floodam* could be used for any type of building, independently of its destination.

1.2 Model development choices

It has been decided to develop *floodam* as an R package. R is a free and open source language that is widely used in the scientific community. Moreover, R packages can easily be shared and provide a rigorous development framework. This characteristic is convenient since *floodam* will be shared with the members of the GT AMC and then more broadly disseminated.

1.3 Plan

In chapter 2, the manual provides an overview of the underlying model used to develop *floodam*. Then, in chapter 3, it focuses on the building components level and describes 1) how the data used by *floodam* to produce elementary damage functions were collected, 2) how the damage to the components are modelled, 3) how the input data are organized, 4) the outputs, 5) some examples. Chapter 4 follows the same plan but focuses on the building level. Chapter 5 explains how some features of the building models can be modified to produce new damage functions. Finally, chapter 6 lists the perspectives to develop *floodam*.

Chapter 2

floodam and underlying conceptual model

2.1 Quick presentation of floodam

floodam is an utility implemented as an R package (R Core Team, 2018) which produces damage functions at the building level.

floodam has been developed for the purpose of developing the French national damage functions (Rouchon et al., 2018). So far, it has been used to:

- estimate the French national damage functions for activities;
- perform uncertainty analyses of the French national damage functions for dwellings;
- estimate the potential efficacy and efficiency of some measures aimed at reducing the vulnerability of dwellings to flooding;
- appraise a "Plan de Prévention des Risques d'Inondation" (PPRI)[1].

2.1.1 Code availability

floodam is developed as an R package. It is available upon request through a git repository maintained by Irstea, and under certain conditions.

2.1.2 Data availability

Data at building levels used within *floodam* are available upon request through a git repository maintained by Irstea, and under certain conditions.

[1]PPRI are the French tool to impose land use regulations within floodplain areas.

2.2 Conceptual model

2.2.1 Elementary components level

floodam relies on a decomposition of a building in elementary components. For each elementary component, the damage process is modelled as follows:

1. Before a flood, the elementary component is assumed to be in a normal state (i.e. non altered). An elementary component that is in a normal state is not necessarily new. As a result, its replacement value can depend on its level of dilapidation.
2. When a flood occurs, the elementary component can be altered (i.e. it can switch to an altered state, for instance moist, dirty, damaged, destroyed, depending on the water depth and submersion duration). This step reflects the elementary component sensitivity to flooding, which has been defined based on expert knowledge.
3. To go back to normal state, it is necessary to take one or several actions.
4. The sum of the costs of these actions is considered to be the damage to the elementary component.

For each elementary component, the damage process is modelled for all possible combinations of flood parameters (water depth and submersion duration in *floodam* v1.0.0). Thus, the domain of definition of the elementary damage functions produced by *floodam* is the set of all possible combinations of flood parameters. In other words, for each elementary component:

$$d_e = f(h, d) \tag{2.1}$$

where:

d_e is the level of damage suffered by the elementary component

h is the water depth in centimetres, which is comprised between $-\infty$ and $+\infty$

d is the flood duration in hours, which is comprised between $-\infty$ and $+\infty$

2.2.2 Building level

Buildings are described precisely in terms of geometry, composition, and contents, which enables *floodam* to make an inventory of the elementary components and to locate them within a building. More specifically, for each elementary component that is present in a building, *floodam* identifies the storey and room in which it is located, but also the height at which it is located, relative to the ground. Combining this inventory with elementary damage functions leads to a damage function at the building level, which can be adjusted by information on potential flood protective devices. Damage functions at the building level can be either absolute (directly in €) or relative to a summary statistic of the corresponding building (surface, value of contents for instance.)

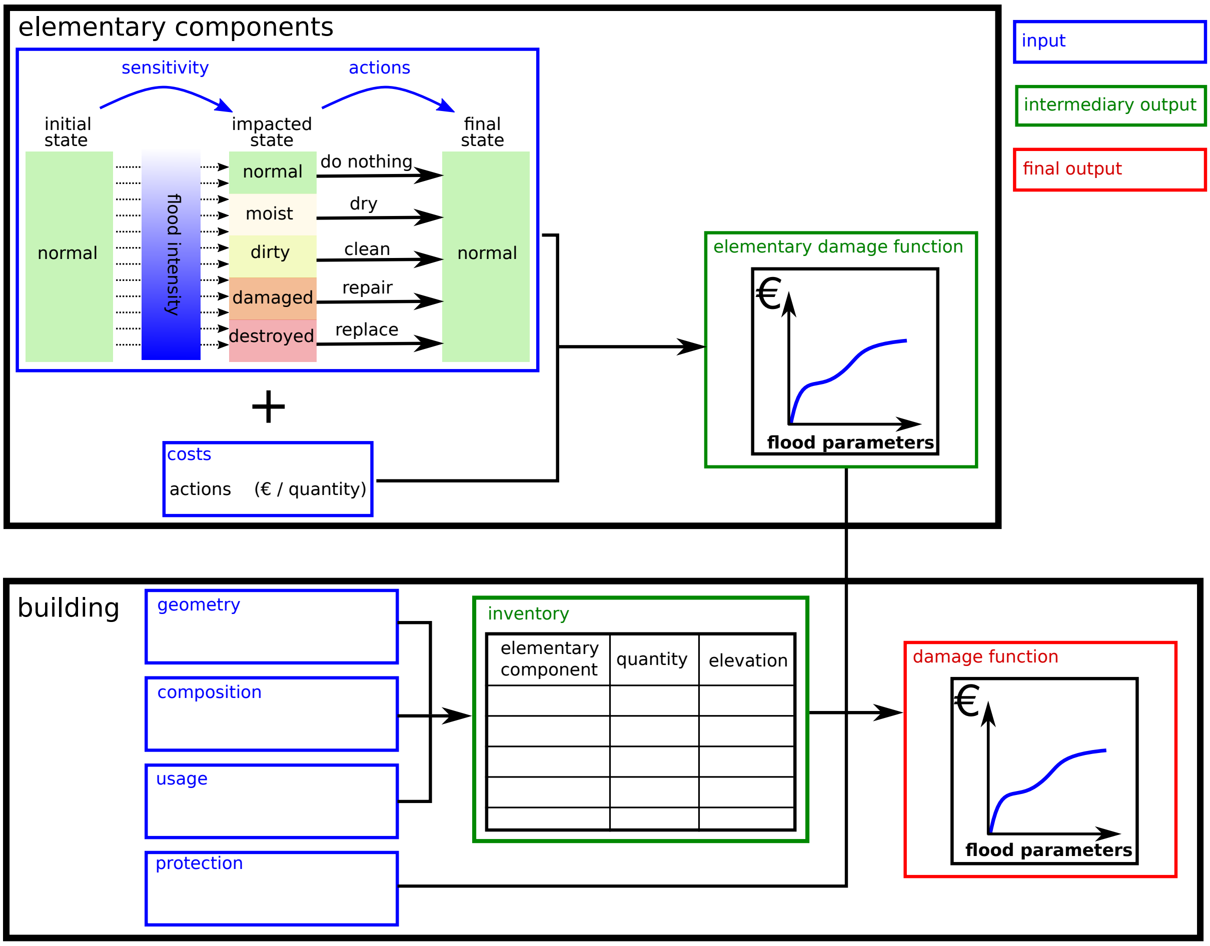

Figure 2.1: Overview of *floodam*

2.3 Overview of *floodam* implementation

Figure 2.1 gives a general overview of how *floodam* is designed, making emphasis on data, intermediary outputs, and final output. In the following chapters some details are given on how elementary components and buildings are modelled, on how data are formalized.

Given the geometry of a building, *floodam* also provides a way to easily change its other characteristics (composition, contents, protection), which enables:

- uncertainty analyses;
- the estimation of the efficacy and efficiency of adaptation measures at building level.

Chapter 3

Damage modelling at elementary level

As shown in Figure 2.1, elementary damage functions are intermediary outputs of *floodam*. In this section, we first describe the way we collected the data we used to produce these elementary damage functions. Then, we explain how we model the sensitivity of the elementary components. In the third part, we present the way *floodam* estimates damage functions at the elementary component level. We describe the way the data used to estimate the elementary damage functions are organized in a fourth part. Finally, we describe the outputs produced by *floodam* at elementary level and provide some examples.

3.1 Data collection, modelling validation

3.1.1 Survey of damage experts

floodam relies on the modelling of expert knowledge. Two types of experts who have an experience of how buildings are affected by flooding have been surveyed :

insurance adjuster Expert in charge of assessing claims after the occurrence of a flood. This expert is mandated by insurance companies to record damage, to estimate what type of actions are needed (reparation or replacement), and to estimate theirs costs.

building expert Expert in charge of inspecting buildings to check their integrity. This expert may be mandated by insurance companies when buildings display defaults compared to the norm of construction.

These experts have been surveyed on their knowledge on the damage processes and actions needed when damage occurs. We asked them:

- to validate how we model damage processes in general in comparison with their experience (the fact that we consider the total damage as the sum of damage to elementary components, but also the fact that we define the damage as the sum of the costs of the actions to be taken when elementary components are altered, and the fact that we relate the probability of alteration to some flood parameters);

- to specify as precisely as possible the damage mechanisms, and their relationship to the hazard parameters.

We surveyed 14 insurance adjusters and one building expert. We took into account both their speciality (buildings, types of equipment, types of furniture, stocks) and the region where they usually work (details are given in table 3.1). The survey was conducted in five steps:

First step It was based on focus groups, where experts were grouped by region. We presented the way we model damage processes, the usage we planned for this model. We asked for any commentary, positive or negative. We also asked the experts information about their speciality and the types of buildings they were the most familiar with (shops, banks, restaurants,...).

Second step It was based on individual interviews. We asked specific questions on damage processes for elementary components within each expert's speciality.

Third step It was based on focus groups, where experts were grouped by speciality. We reported our comprehension and modelling of the second step, showed the implications on damage estimation, and presented the differences between experts, possible inconsistencies or lacks. Experts were asked to made any comments they found useful, and that we should take into account to improve the modelling.

Fourth step It was based on written exchanges. The aim was to validate the feedbacks from the third step.

Fifth step It was based on a focus group. We met insurance adjusters that did not participate in the first four steps and presented them the results of the whole study. Again, the experts were asked to made any comments they found useful, and that we should take into account to improve the modelling. However, at this stage, the experts did not ask for further changes.

3.1.2 Data on costs

The costs of the actions were defined according to lessons learnt during the survey of experts:

- Some costs of repair were directly given by insurance adjusters. This was the case for very frequent repair costs.
- For the costs of repair of specific devices (which may be present in some activities), insurance adjusters explained to us that, in practice, they would ask the manufacturers to assess these values. Nevertheless, they indicated the relative damage to such devices, depending on their nature (mechanical, electrical, electronic).
- For repair costs concerning building components, the building expert gave us estimates based on batriprix (`https://www.batiprix.com/`). Batiprix is a price catalogue specialized in building construction.
- For replacement costs concerning the contents of the building, insurance adjusters advised us to use prices catalogues.

Table 3.1: List of experts surveyed to estimate elementary damage functions

Insurance adjusters (14)					
Region	Expert	Generalist	Building	Equipment	Stock
South-East (6)		1	2	2	2
—	M. Le Goff				■
—	M. Legenne	■			
—	M. Pitoun				■
—	M. Grepilloux			■	
—	M. Dol		■		
—	M. Chauvet		■	■	
Rhône-Alpes (6)			5	4	2
—	M. Crétinon			■	■
—	M. de Castillon		■	■	
—	M. Claisse		■		
—	M. Fernandez		■	■	
—	M. Goguyer Deschaumes		■		
—	M. Roguet		■	■	■
Île-de-France (2)			2		
—	M. Rousseau		■		
—	M. Boussard		■		
Building expert (1)					
Île-de-France (1)			1		
—	M. Jarrault		■		

3.2 Modelling of sensitivity

An elementary component is a material component for which an elementary damage function has been modelled. These elementary damage functions result from the interpretation of the answers given by the surveyed damage experts (see figure 2.1).

We define the sensitivity of an elementary component as its propensity to change state when affected by a flood.

For each elementary component, several states are defined, including at least the "normal" one, and some possible deteriorated states. By default, elementary components are considered to be in the "normal" state, which accounts for their current level of dilapidation. When a flood occurs, elementary components can be impacted, which modifies their state. Two parameters of flood intensity are considered to define the exact conditions in which a state modification occurs: the water depth and the duration of submersion. The exact conditions in which a flood modifies the state of an elementary component are defined relatively to this elementary component, not to the whole building. For instance, an electronic component is "destroyed" if the relative water depth is positive, "wet" if in presence of water that does not touch it. For some elementary components, the damage experts explained that the change of state is not certain and they defined it as a stochastic variable. For some elementary components, the damage experts also indicated a relation between the flood intensity (defined by the combination of water depth and duration of submersion) and either the probability of a change of state or the intensity of the change of state. The intensity of the change of state refers to the difference between the normal state and the deteriorated state. It is a coefficient comprised between 0 and 1. For instance, some elementary components with mechanical, electrical or electronic pieces can be slightly to highly damaged depending on the water depth.

For a given elementary component, each deteriorated state is associated to an action necessary to come back to the "normal" state. This action has some characteristics that may depend on the nature of the elementary component:

- a cost
- a quantity of elementary components on which the action must be performed, if the elementary component can be divided into smaller parts. For instance, a quantity is indicated for the actions associated to the walls or wall coatings.

The coefficients that describe the intensity of a change of state are used to adjust the costs of the actions that need to be done to go back to the normal state by taking into account the severity of deterioration.

Elementary components that have the same sensitivity to floods but for which the costs of the actions can differ are grouped in what we call a category of vulnerability. This categorization was given by the experts. It enables the addition of elementary components on which the experts were not specifically interviewed. For instance, all electronic devices belong to the same category of vulnerability. Thus, we only need to know the replacement cost of any electronic device to produce its elementary damage function.

3.3 Estimation of damage functions at the elementary component level

For a given combination of water depth and flood duration, we define the damage to an elementary component as the expected value of the cost of the actions that are necessary to go back from the state induced by the flood to the normal state. Thus, for a given elementary component the damage resulting from a flood is given by the following equation:

$$d_e(h,d) = \sum_{s \in S} p_s(h,d) \times i_s(h,d) \times c_{a_s} \times h_{a_s}(h,d) \tag{3.1}$$

where:

e refers to the elementary component

h refers to the water depth relative to e. h may be negative, to take into account impact of humidity.

d refers to the duration of submersion relative to e. d has to be strictly positive for a submersion to occur.

S refers to the set of all admissible states s for e.

$p_s(h,d)$ refers to the probability that a submersion of characteristics h and d brings e into the state s.

$i_s(h,d)$ refers to the intensity in which a submersion of characteristics h and d brings e into the state s.

c_{a_s} refers to the cost of the action a that is necessary to bring back e from the state s to the normal one.

$h_{a_s}(h,d)$ refers to the height up to which it is necessary to perform the action a for a submersion of characteristics h and d. If e is indivisible, $h_a(h,d)$ is constant and equal to the height of the elementary component.

Examples are given in section 3.6 to illustrate the elements of equation 3.1.

3.4 Input organization at elementary level

The data concerning the elementary components are organized as a database with the following tables:

component.elementary contains information at the component elementary level on the characteristics of the components

component.elementary.action contains information at the component elementary level on the characteristics of the changes of state and associated actions necessary to go back to the normal state.

category.vulnerability contains information at the category of vulnerability level

category.vulnerability.complex contains complementary information at the category level on some actions for which p_s or i_s depends on the flood parameters.

The detail of each table is given in appendix A.

3.5 Outputs at elementary level

At elementary level, the *floodam* outputs are the elementary damage functions. In this section, we describe the characteristics of these elementary damage functions and indicate how they can be represented.

3.5.1 Elementary damage function

The elementary damage function of an elementary component e is an array of damage with 3 dimensions:

h the water depth relative to e. The user can define its range and the interval between its consecutive values. By default, its range is $[-110, 500]$ (cm) and it is defined for values that increase with a step of 10cm.

d the duration of submersion relative to e. The user can define its range and the interval between its consecutive values. By default, its range is $[0, 144]$ (h) and it is defined for values that increase with a step of 12h.

action the name of the action that produces damage.

completed by the following information for each action:

h.action refers to the height at which it is necessary to perform the action.

dilapidation is a boolean indicating whether or not dilapidation should be considered for this action.

support refers to the characteristic that should be taken into account to compute the quantity of elementary components considered for this action. It can take values such as *unit* if the elementary component is indivisible, or *length* or *surface* if the elementary component is divisible.

value indicates whether the maximum cost of the action should be defined at action level, independently of the replacement value of the elementary component, or should be estimated as the replacement value of the elementary component. The maximum cost of the action is the replacement value if the action that needs to be done to go back to the normal state consists in replacing the elementary component.

and the following meta-information at elementary component level:

v gives the range of default admissible values of the elementary component, in Euros.

component.elementary gives the names of the elementary component.

3.5.2 Representation of elementary damage functions

An elementary damage function can be represented in different ways:

map In this representation, total damage values of all actions are represented for all combinations of defined h and d.

total.h In this representation, total damage values of all actions are represented as a function of h for some selected d.

action.h In this representation, damage values for a specified d are represented as a function of h, for each action.

3.6 Commented examples

3.6.1 Simple example, one action, quantity fixed

Figure 3.1 shows the elementary damage function of an air conditioner. If this elementary component is affected by a flood with a positive water depth and a positive water duration, it needs to be replaced. Hence, the damage is constant over all combinations of positive water depth and flood duration.

In this example, the values taken by the components of equation 3.1 are the following:

- e refers to an air conditioner
- S comprises 2 states:
  - ▷ s_1: normal state (no action needed)
  - ▷ s_2: destroyed (needs to be replaced)
- $p_{s_1}(h, d)$ is equal to 1 if the water depth is negative or null or if the flood duration is null and to 0 otherwise.
- $p_{s_2}(h, d)$ is equal to 1 if the water depth and flood duration are strictly positive and to 0 otherwise.
- $i_{s_1}(h, d)$ and $i_{s_2}(h, d)$ are always equal to 1
- $c_{a_{s_1}}$ is equal to 0 because no action needs to be done when the component is already in the normal state.
- $c_{a_{s_2}}$ is equal to €1950
- $h_{a_{s_1}}$ and $h_{a_{s_2}}$ are equal to the height of the air conditioner

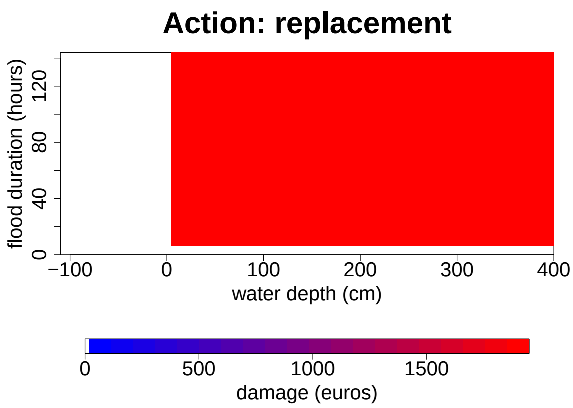

Figure 3.1: Elementary damage function of an air conditioner

3.6.2 Example, several actions, quantity fixed

For some elementary components, different actions need to be performed depending on the flood parameters. For instance, Figure 3.2 shows the elementary damage function of a vending machine. It is the sum of the costs of two actions: cleaning and replacement. For all flood durations, if the vending machine is affected by a water depth between 0 and 19 cm, it must be cleaned. The cost of this action does not depend on the flood parameters. If the water depth is higher than 19 cm, the vending machine must be replaced. Again, the cost of this action does not depend on the flood parameters.

In this example, the values taken by the components of equation 3.1 are the following:

- e refers to a vending machine
- S comprises 3 states:
  - ▷ s_1: normal state (no action needed)
  - ▷ s_2: dirty state (needs to be cleaned)
  - ▷ s_3: destroyed (needs to be replaced)
- $p_{s_1}(h,d)$ is equal to 1 if the water depth is negative or null or if the flood duration is null and to 0 otherwise.
- $p_{s_2}(h,d)$ is equal to 1 if the flood duration is strictly positive and the water depth positive and below 20 cm and to 0 otherwise.
- $p_{s_3}(h,d)$ is equal to 1 if the flood duration is strictly positive and the water depth higher than 20 cm and to 0 otherwise.
- $i_{s_1}(h,d)$, $i_{s_2}(h,d)$, $i_{s_3}(h,d)$ are always equal to 1
- $c_{a_{s_1}}$ is equal to 0 because no action needs to be done when the component is already in the normal state.
- $c_{a_{s_2}}$ is equal to €50
- $c_{a_{s_3}}$ is equal to €3000

- $h_{a_{s_1}}$, $h_{a_{s_2}}$, and $h_{a_{s_3}}$ are equal to the height of the vending machine

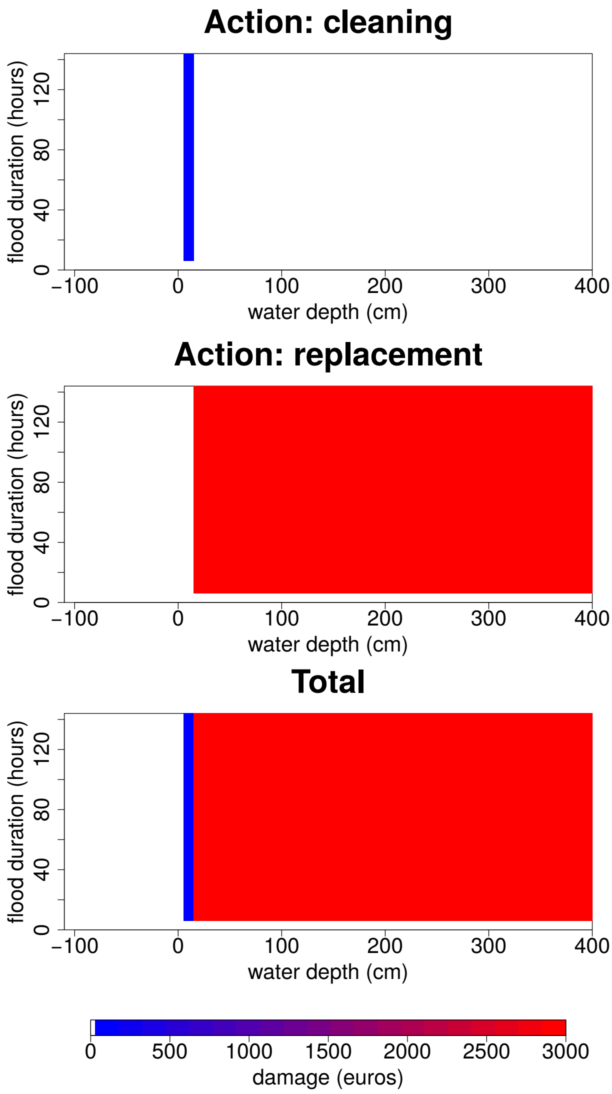

Figure 3.2: Elementary damage function of a vending machine

3.6.3 Example, complex actions

For some elementary components, the probability that an action has to be performed after a flood can be strictly positive but lower than 1 and depend on the flood parameters. For instance, Figure 3.3 shows the elementary damage function of a gas-operated boiler. For all flood positive flood durations and for water depths equal or higher than 20 cm, the probability that this elementary component has to be replaced is strictly positive:

- for water depths comprised between 20 cm and 100 cm, this probability is equal to 0.1
- for water depths comprised between 100 cm and 150 cm, this probability is equal to 0.6
- for water depths higher than 150 cm, this probability is equal to 1

For a given combination of water depth and flood duration, the damage to a gas-operated boiler is equal to the replacement cost of this elementary component multiplied by the probability that the component has to be replaced.

In this example, the values taken by the components of equation 3.1 are the following:

- e refers to a gas-operated boiler
- S comprises 2 states:
  - ▷ s_1: normal state (no action needed)
  - ▷ s_2: destroyed (needs to be replaced)
- $p_{s_1}(h, d)$ and $p_{s_2}(h, d)$ are respectively equal to:
  - ▷ 1 and 0 if the water depth is below 20 cm and the flood duration negative or null
  - ▷ 0.9 and 0.1 if the flood duration is strictly positive and the water depth between 20 cm and 100 cm
  - ▷ 0.4 and 0.6 if the flood duration is strictly positive and the water between 100 cm and 150 cm
  - ▷ 0 and 1 if the flood duration is strictly positive and the water depth higher than 150 cm
- $i_{s_1}(h, d)$ and $i_{s_2}(h, d)$ are always equal to 1
- $c_{a_{s_1}}$ is equal to 0 because no action needs to be done when the component is already in the normal state.
- $c_{a_{s_2}}$ is equal to €5300
- $h_{a_{s_1}}$ and $h_{a_{s_2}}$ are equal to the height of the boiler

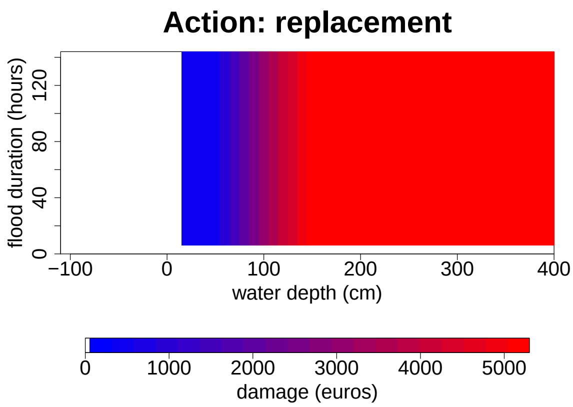

Figure 3.3: Elementary damage function of a gas-operated boiler

3.6.4 Example, role of humidity

Some elementary components can be damaged by a flood, event if they are not immersed. That is the case for elementary components that are moisture-sensitive. For instance, Figure 3.4

shows the elementary damage function of a computer. If the room in which the computer is located is flooded, but the water does not reach the computer, the computer needs to be dried. That is why the damage is positive for negative water depths (relative to the computer). If the computer is immersed, it needs to be replaced.

In this example, the values taken by the components of equation 3.1 are the following:

- e refers to a computer
- S comprises 3 states:
  - ▷ s_1: normal (no action needed)
  - ▷ s_2: moist (needs to be dried)
  - ▷ s_3: destroyed (needs to be replaced)
- $p_{s_1}(h, d)$ is equal to 1 the the flood duration is negative or null and to 0 otherwise
- $p_{s_2}(h, d)$ is equal to 1 if the water depth is negative and the flood duration strictly positive and to 0 otherwise
- $p_{s_3}(h, d)$ is equal to 1 if the water depth and the flood duration are strictly positive
- $i_{s_1}(h, d)$, $i_{s_2}(h, d)$, and $i_{s_3}(h, d)$ are always equal to 1
- $c_{a_{s_1}}$ is equal to 0
- $c_{a_{s_2}}$ is equal to €120
- $c_{a_{s_3}}$ is equal to €5300
- $h_{a_{s_1}}$, $h_{a_{s_2}}$, and $h_{a_{s_3}}$ are equal to the height of the computer

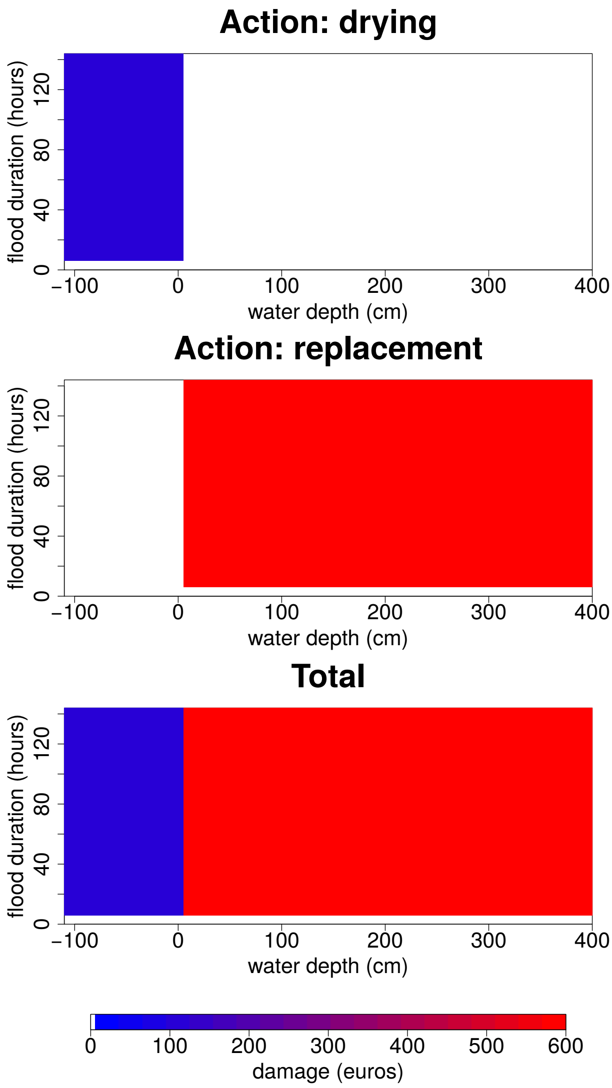

Figure 3.4: Elementary damage function of a computer

3.6.5 Example, quantity to be fixed

The damage functions of some elementary components depend on their geometry (e.g. the walls, the floors). Figure 3.5 shows the damage functions of 2 rectangular partition walls in masonry that have a length of 19 m but different heights: 1 has a height of 0.5 m and the other has a height of 5 m. Both walls need to be:

- repaired if they are affected by a flood that lasts less than 71 h
- replaced if they are affected by a flood that lasts at least 71 h

For flood durations below 71 h, only the portion of the wall that was in contact with water needs to be repaired. For flood durations of at least 71 h, the entire wall has to be replaced. Since the repair cost is proportional to the surface of the wall that needs to be repaired, it increases with the water depth up to the wall height. The replacement cost does not depend on the flood parameters but depends on the wall surface. As a result, for a given combination of flood duration and water depth, the damage that affects a wall increases with the wall surface.

In the example of the partition wall that has a length of 19 m and a height of 5 m, the values taken be the components of equation 3.1 are the following

- e refers to a partition wall in masonry that has a length of 19 m and a height of 5 m
- S comprises 3 states:
  - ▷ s_1: normal (no action needed)
  - ▷ s_2: damaged (needs to be repaired)
  - ▷ s_3: destroyed (needs to be replaced)
- $p_{s_1}(h, d)$ is equal to 1 the the flood duration and the water depth are negative or null and to 0 otherwise
- $p_{s_2}(h, d)$ is equal to 1 if the water depth is strictly positive and the flood duration positive and below 71 h and to 0 otherwise
- $p_{s_3}(h, d)$ is equal to 1 if the water depth is strictly positive and the flood duration is at least 71 h and to 0 otherwise
- $i_{s_1}(h, d)$, $i_{s_2}(h, d)$, and $i_{s_3}(h, d)$ are always equal to 1
- $c_{a_{s_1}}$ is equal to 0
- $c_{a_{s_2}}$ is equal to €22.5 by square meter that needs to be replaced
- $c_{a_{s_3}}$ is equal to €7365.5
- $h_{a_{s_1}}$ and $h_{a_{s_3}}$ are equal to the height of the partition wall
- $h_{a_{s_2}}$ is equal to the height of the portion of the wall that was in contact with water

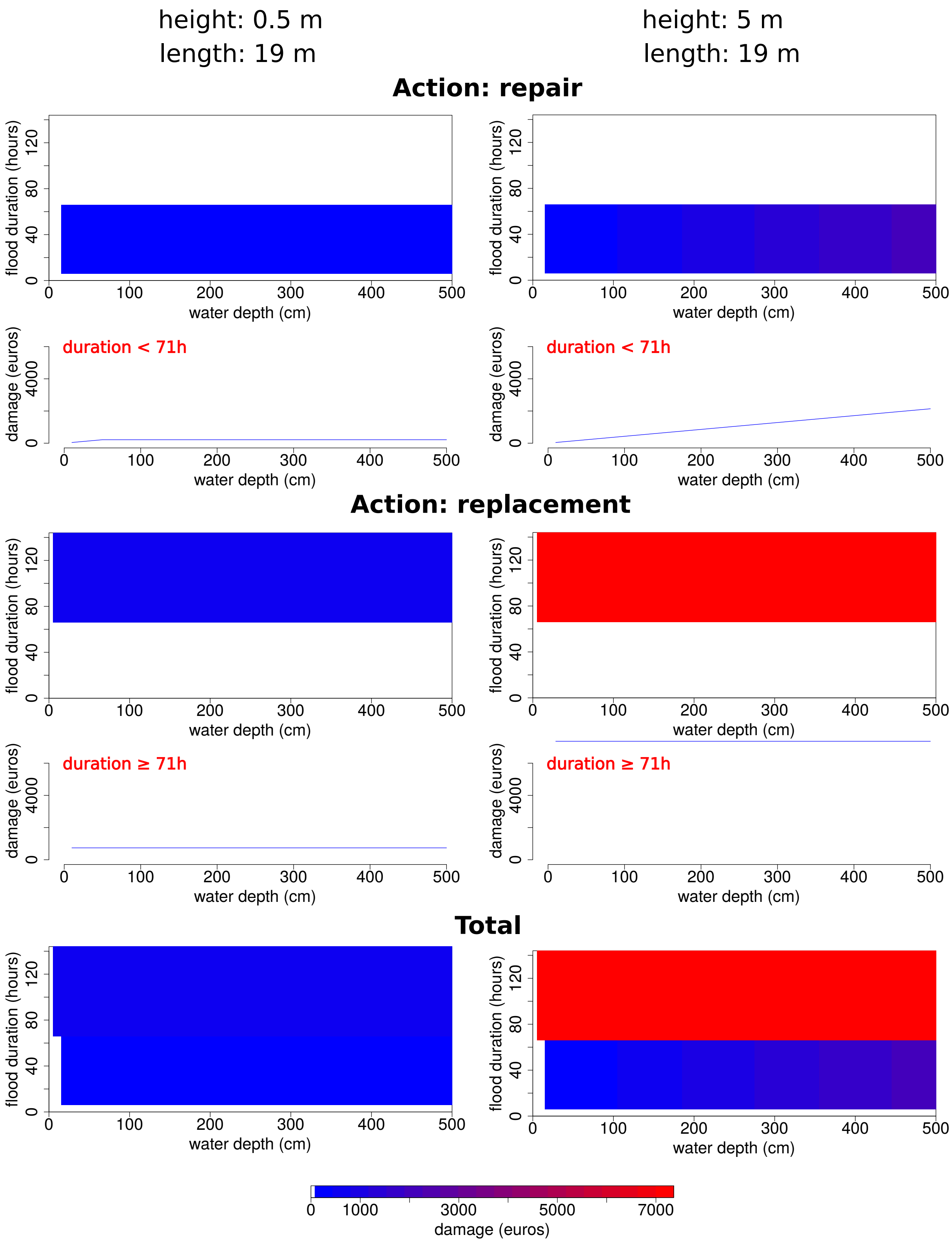

Figure 3.5: Elementary damage functions of 2 rectangular partition walls in masonry: 1 with a length of 19 m and a height of 0.5 m, and 1 with a length of 19 m and a height of 5 m

Chapter 4

Damage modelling at building level

To produce the damage function of a given building, *floodam* combines the elementary damage functions of the elementary components that form the building by using information on the building characteristics. In this section, we first present the options available to collect the necessary data regarding the building characteristics. In a second part, we explain how the buildings are modelled using these data. In a third part, we indicate how *floodam* computes the damage at the level of a building model. Then, we describe the files in which the building models are defined. We finally describe the outputs produced by *floodam* at the level of the building and provide some commented examples.

4.1 Data collection

Modelling a building for the purpose of producing its damage function with *floodam* requires to collect data on its geometry, its building material, and its contents. To do so, 3 different strategies can be implemented:

real building survey It consists in visiting a real building in order to establish its plan, make a list of its contents and locate each item. If a plan of the building is readily available, it can be used directly. Moreover, it is not necessary to collect data on the roof and, if the building contains dwellings, on perishable goods. Realistic models of building can be produced using this strategy. However, it is time consuming. Furthermore, for the purpose of producing damage functions that are representative of the buildings of a specific area, it is better to model real buildings whose features are typical. But it can be difficult to find people who both own a typical building and accept having it visited. Besides, without the proper expertise, it can sometimes be difficult to identify all the building materials.

real building plan It consists in using the plan of a real building. This strategy is easier to implement than real building surveys. However, realistic assumptions regarding the building materials and contents need to be made in order to obtain a realistic building model.

hypothetical building It consists in making assumptions on the building plan, materials, and contents by using several real building plans and information on the materials and contents of the type of buildings that are to be modelled. This information can come from existing

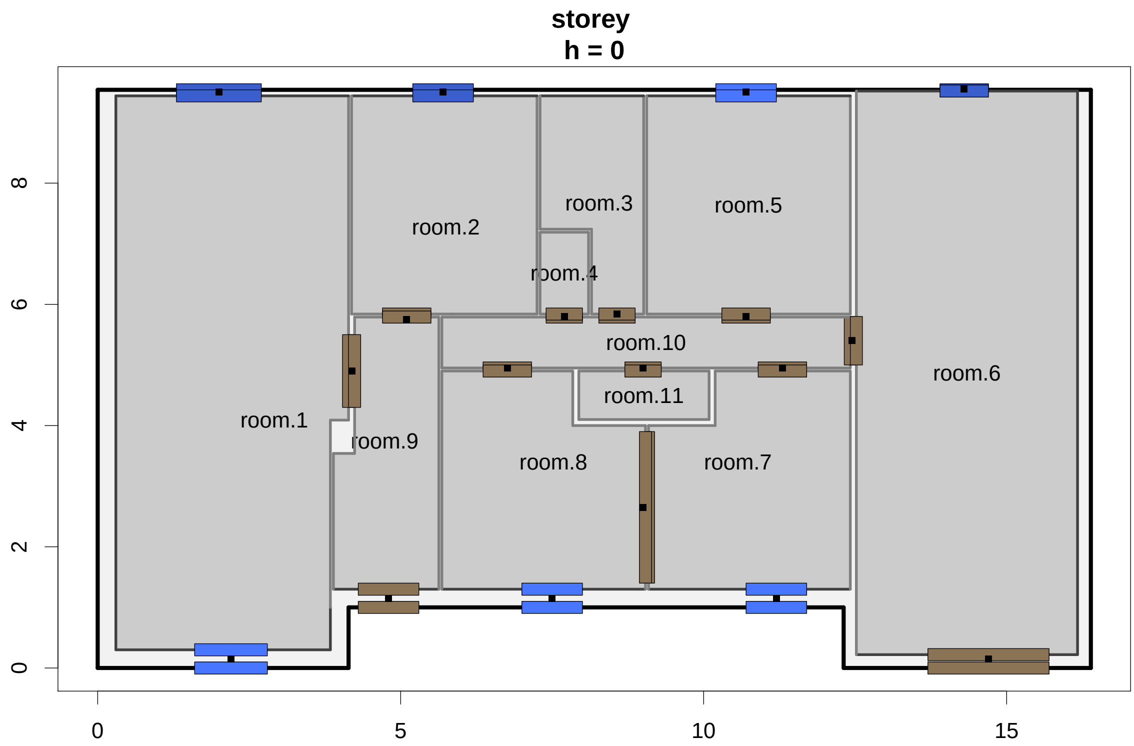

Figure 4.1: Top view of a model of dwelling processed by *floodam*

databases, technical reports, or interviews with experts. This strategy can be used to model buildings that are representative of an area. However, it can only be implemented if the characteristics of the buildings of the studied area are well known.

4.2 Building model

A building model describes all the characteristics that are necessary to determine the quantity and disposition of the elementary components present in the building:

- the geometry of the building, which is a description in three dimensions of its shape, including all its openings;
- the composition of the building, which refers to the building materials;
- the contents of the building, which refers to the nature and location of the equipment and stocks located in the building.

Figure 4.1 shows an example of a building model which represents a dwelling.

4.2.1 Geometry of the building

The geometry of a building is described as follows:

- The elevation of the building is given.
- The building is divided into storeys, made up of rooms.
- Each storey is defined by the following characteristics:
  - ▷ its elevation, which is relative to the one of the building
  - ▷ external walls, which define the external contour of the storey.
  - ▷ rooms, which make up the storey.
- Each room is defined by the following characteristics:
  - ▷ its elevation, which is relative to the one of the storey. This elevation is used to locate the floor of the room.
  - ▷ the height of the ceiling. This height, combined with the elevation of the room, is used to locate the ceiling of the room.
  - ▷ the walls that define the contour of the room.
- Each wall is defined by the following characteristics:
  - ▷ its elevation, which is relative to the one of room. It is only used for external walls if they are below or above the floor.
  - ▷ the positions of the starting and ending points of the wall. They are used to precisely locate the wall and to calculate the surface of the wall and related components.
  - ▷ the openings that are present on this wall (may be empty)
  - ▷ its coating (may be empty)
- Each opening is defined by the following characteristics:
  - ▷ its elevation, which is relative to the one of the wall where the opening is located.
  - ▷ its height and width.
  - ▷ its position of its middle point. This is used to check that openings are well positioned (an opening should not protrude from the wall on which it is located).
- Each coating is defined by the following characteristics:
  - ▷ its elevation, relative to the wall where it is located
  - ▷ its height. This is not a characteristic given by the user but computed depending on the other coatings that are present or on the height of the wall.

4.2.2 Composition of the building

The composition of the building refers to the elementary components that make up the built part of the building. These elementary components belong to the following types:[1]

baseboard It is defined by its constituent material. It is optional to include a baseboard.

[1]If it is not specified that a type of component is optional, it is mandatory to include it to produce a model of building.

ceiling Three kinds of elementary components are associated to ceilings: the ceiling itself, the ceiling insulation, the ceiling coating. They are all defined by their constituent material. The ceiling insulation and coating are optional.

coverstrip It is defined by its constituent material. It is optional to include a coverstrip.

floor Three kinds of elementary components are associated to floors: the floor itself, the floor insulation, the floor coating. They are all defined by their constituent material. The floor insulation and coating are optional.

opening It is defined by its constituent material and its subtype (door, window, french window). It is optional to include an opening.

wall Three kinds of elementary components are associated to walls: the wall itself, the wall render, and the wall insulation. The wall is defined by its constituent material and its subtype (load bearing wall, partition, or lining). The wall render and insulation are defined by their constituent material.

coating It refers to the wall coatings and it is defined by its constituent material. Wall coatings are defined separately because they do not always share the geometry of their supporting wall.

4.2.3 Contents of the building

The contents of the building refers to the elementary components that compose:

- the equipment and stocks located in the building, if the building is used as an economic activity.
- the furniture of the building, if the building is used as a dwelling.

Each elementary component that is part of the contents is defined by the following characteristics:

- its name
- the name of the room in which it is located
- the name of wall on which it is located (optional)
- its elevation, which is relative to the one of the room in which it is located
- the dilapidation that must be applied to take its age into account when calculating its value. The default value for the dilapidation is 50%.
- the quantity in which it is present in the building
- its minimum and maximum replacement values
- some details on its nature (optional)

4.2.4 Protection of the building

A building model can include a protective device to limit the damage due to floods. If present, this protective device is defined at the building level and has the following characteristics:

type indicates whether the device is external (protecting both the interior and the exterior of the building, as flood barriers may do) or internal (protecting only the interior of the building, and openings, as slot-in flood barriers may do)

elevation indicates the relative water depth for which the device is designed

duration indicates the flood duration for which the device is designed

reliability indicates the reliability of the protective device.

4.3 Damage computation procedure at building level

For a given combination of water depth and flood duration, the damage to a building model is the sum of the damage suffered by its constituent elementary components. Thus, it is given by the following equation:

$$d_b(h, d) = \sum_{e \in E} d_e(h - h_e, d) * q_e \tag{4.1}$$

where:

b refers to the building

h refers to the water depth relative to the ground.

d refers to the duration of submersion relative to b. d has to be strictly positive for a submersion to occur.

E refers to the set of all elementary components e that make up b.

d_e refers to the damage to e. It is defined in equation 3.1.

h_e refers to the elevation of e relative to the ground.

q_e refers to the quantity of e.

4.4 Input organization at building level

The data used to describe a building are organized into two different formats:

building This is a xml file. It defines the geometry and composition of the building. It is divided in three parts:

- **general** This part gives the following general information about the building, such as its type (dwelling, economics activity), its height, the dilapidation that is used as default value for the elementary components that make up the building, the version of *floodam* that is compatible with the way the file is organized, and the level of protection of the building.
- **element** This part is used to define the elementary components that make up the built part of the building and their characteristics.
- **building** This part is used to define the geometry of the building and to indicate the location of the elementary components defined in the element part of the file.

furniture This is a table that allows the inventory and the location of elementary components that are not necessary for the definition of the geometry of the building.

The detail of each format is given in appendix B.

4.5 Outputs at building level

At the level of a building model, *floodam* produces four types of outputs:

- an inventory of the elementary components that make up the building
- summary statistics of the characteristics of the building model
- absolute damage functions
- relative damage functions

In this section, these types of outputs are successively described.

4.5.1 Inventory of elementary components

floodam produces tables that list and give the characteristics of the elementary components that make up:

the walls For each wall:

- the characteristics given as inputs are reminded
- additional characteristics that are computed by *floodam* from the input data are given: the wall length and surface

the openings For each opening:

- the characteristics given as inputs are reminded.
- additional characteristics that are computed by *floodam* from the input data are given: the opening surface and its elevation relative to the ground.

the contents For each element of the contents:

- the characteristics given as inputs are reminded.
- the value of the characteristic is given. It is computed by *floodam*. It is the mean between the maximum and minimum replacement value, multiplied by the dilapidation. It is used to estimate the damage if the element is destroyed.

the wall coatings For each wall coating:

- the characteristics given as inputs are reminded.
- additional characteristics that are computed by *floodam* from the input data are given: its elevation relative to the ground, its height, its width, its surface.

4.5.2 Summary of the building modelled

floodam produces some characteristics that summarize the building modelled.

area *floodam* computes different types of areas:

- the total internal area of the building (considered as the sum of the areas of all internal rooms);
- the internal floor area of the building (considered as the maximum of all internal areas calculated at storey level);
- the external floor area of the building (considered as the maximum of all external areas calculated at storey level; external walls are used to compute external areas).

value *floodam* computes the total value of the contents. This value may be categorized according to the type of contents items. For instance when a building is a dwelling, all the items that make up the contents are considered as furniture. When a building is an activity, the items that make up the contents are classified into equipment and stock categories.

4.5.3 Absolute damage function

floodam produces absolute damage functions that pertain to:

- the whole building
- the built part of the building
- the furniture contained in the building, if the building contains a dwelling
- the equipment contained in the building, if the building contains an economic activity
- the stocks contained in the building, if the building contains an economic activity

Absolute damage functions indicate, for the defined combinations of water depth and flood duration, the total damage to the considered part of the building or to the whole building.

Figure 4.2 shows the total absolute damage function of the dwelling represented in Figure 4.1.

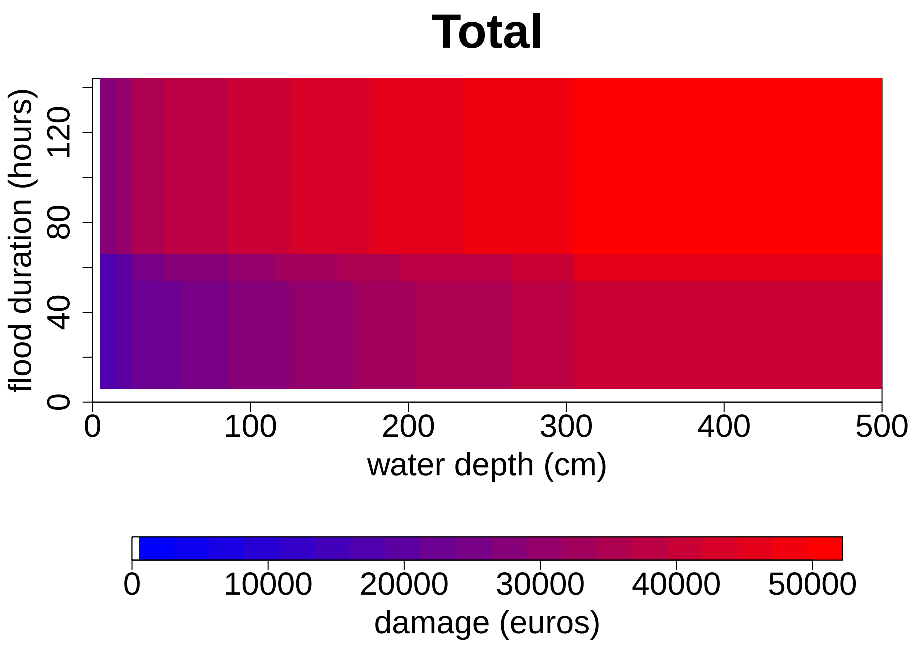

Figure 4.2: Total absolute damage function of the dwelling represented in Figure 4.1

4.5.4 Relative damage function

floodam produces relative damage functions by dividing the absolute damage functions by some statistics at the building level. For instance, *floodam* produces:

- relative damage functions related to the built part of the building by dividing the corresponding absolute damage function by the internal floor area of the building;
- for dwellings, relative damage functions related to the furniture by dividing the corresponding absolute damage function by the total value of the furniture;
- for activities, relative damage functions to the equipment by dividing the corresponding absolute damage function by the total value of equipment;
- for activities, relative damage functions to the stocks by dividing the corresponding absolute damage function by the total value of the stocks;

4.6 Commented examples

4.6.1 Adaptation of elementary damage functions in model context

4.6.1.1 Simple example, one action, quantity fixed

Figure 4.3 shows the damage function of an air conditioner located in the model presented in Figure 4.1. This damage function is different from the one of a decontextualized air conditioner presented in Figure 3.1 in two aspects:

- This air conditioner is located at 200 cm above the ground floor. Thus it needs to be replaced only from a water depth of 200 cm.
- Moreover, it is associated to a dilapidation of 50%. Thus, its replacement value is half that of the decontextualized air conditioner, which is associated by default to a dilapidation of 0%.

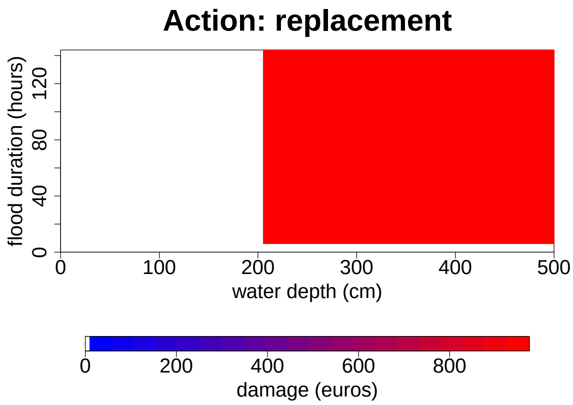

Figure 4.3: Damage function of an air conditioner located in the model presented in Figure 4.1

4.6.1.2 Example, several actions, quantity fixed

Figure 4.4 shows the damage function of a vending machine located in the model presented in Figure 4.1. It differs from the damage function of the vending machine presented in Figure 3.2 in the replacement value. Indeed, the new purchase value of the contextualized vending machine is given in the furniture file of the model. It is equal to €4 000, whereas the new purchase value taken into account to produce the decontextualized elementary damage function is equal to €3 000. This is due to the fact that the first value is the new purchase value of the specific vending machine considered, whereas the second is a default value, defined as the mean between the minimum and maximum new purchase values found in price catalogues or given by the experts. Moreover, the contextualized vending machine is associated to a dilapidation of 50%, whereas the decontextualized one has a dilapidation of 0%.

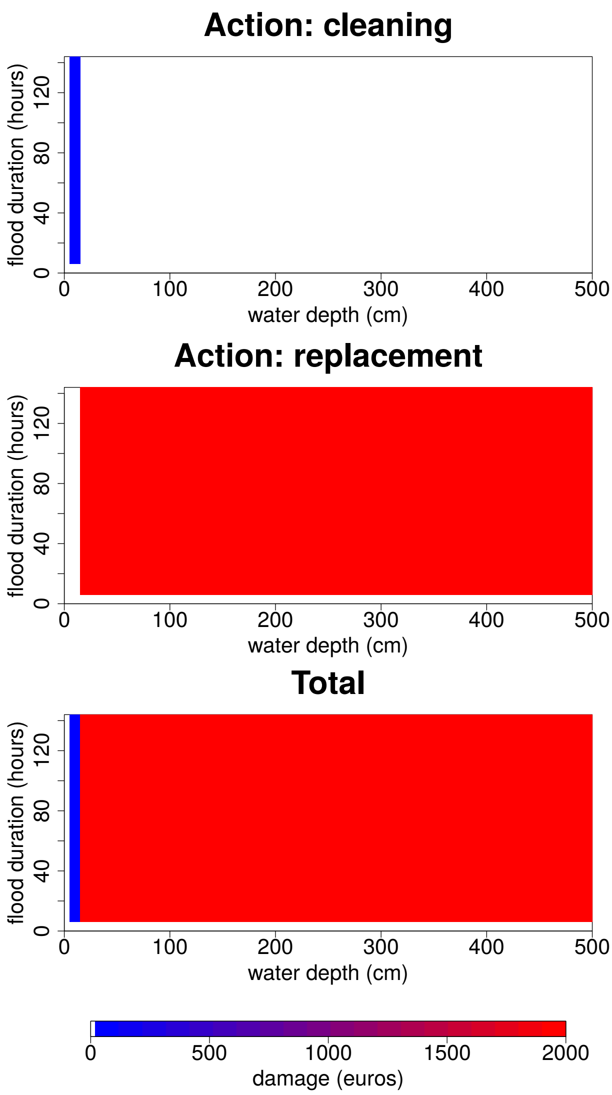

Figure 4.4: Damage function of a vending machine located in the model presented in Figure 4.1

4.6.1.3 Example, complex actions

Figure 4.5 shows the damage function of a gas-operated boiler located in the model presented in Figure 4.1. Compared to the damage function of a decontextualized boiler, presented in Figure 3.3, it differs in two aspects:

- The contextualized boiler is located 10 cm above the ground floor. Thus, the probability for it to be replaced is strictly positive only from a water depth of 10 cm.
- It is associated to a dilapidation of 50%. Thus, its replacement value is half that of the decontextualized boiler.

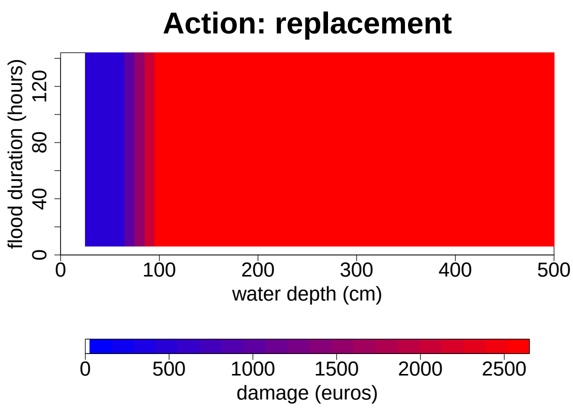

Figure 4.5: Damage function of a gas-operated boiler located in the model presented in Figure 4.1

4.6.1.4 Example, role of humidity

Figure 4.6 shows the damage function of a computer located in the model presented in Figure 4.1. It differs from the damage function of a decontextualized computer presented in Figure 3.4 in 2 aspects:

- Since the computer is located at 100 cm above the ground floor, it needs to be dried for water depths comprised between 0 and 100 cm and it needs to be replaced for higher water depths.
- The computer is associated to a dilapidation of 50%. Thus, its replacement value is half that of the decontextualized computer.

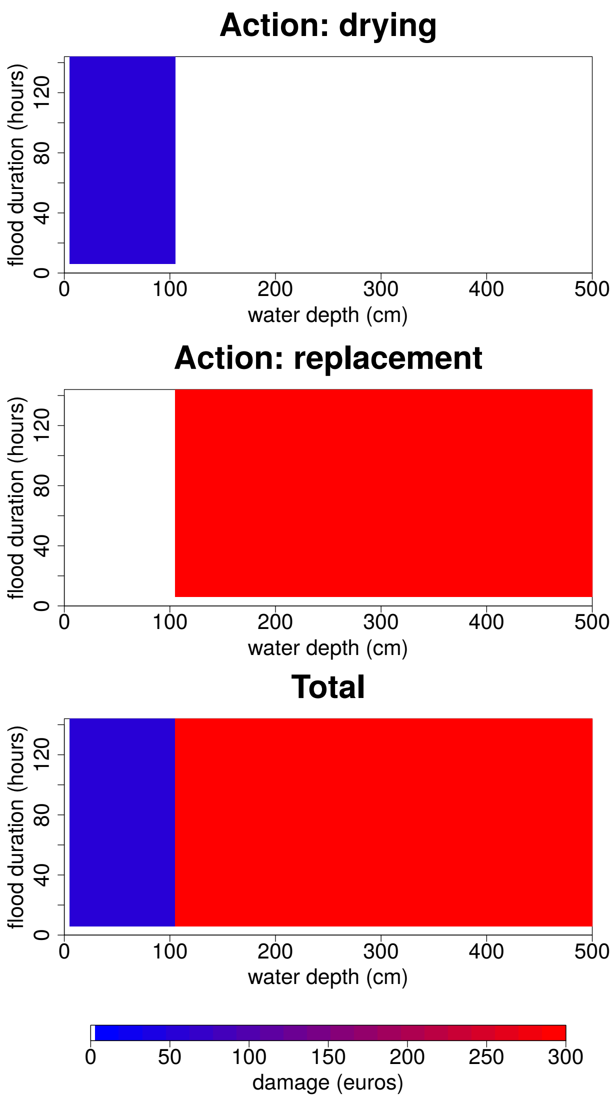

Figure 4.6: Damage function of a computer located in the model presented in Figure 4.1

4.6.1.5 Example, quantity to be fixed

Figure 4.7 shows the damage function of a wall in masonry located in the model presented in Figure 4.1. This wall has a total length of 2.7 m and a height of 3 m. It supports a door with a width of 2.5 m and a height of 2 m. As a result, between 0 and 2 m from the floor, the portion of the wall made up of masonry is only 0.2 m. Thus, when it is affected by floods that last less than 71 h, the surface that needs to be repaired is equal to:

- $0.2\ m * WaterDepth$ if the water depth is below 2 m.
- $0.2\ m * 2\ m + 2.7\ m * (WaterDepth - 2\ m)$ if the water depth is higher than 2 m.

When it is affected by floods that last at least 71 h, the replacement cost is equal to the replacement cost by square meter multiplied by the surface of the wall ($0.2m * 2m + 2.7m * 1m = 3.1m^2$)

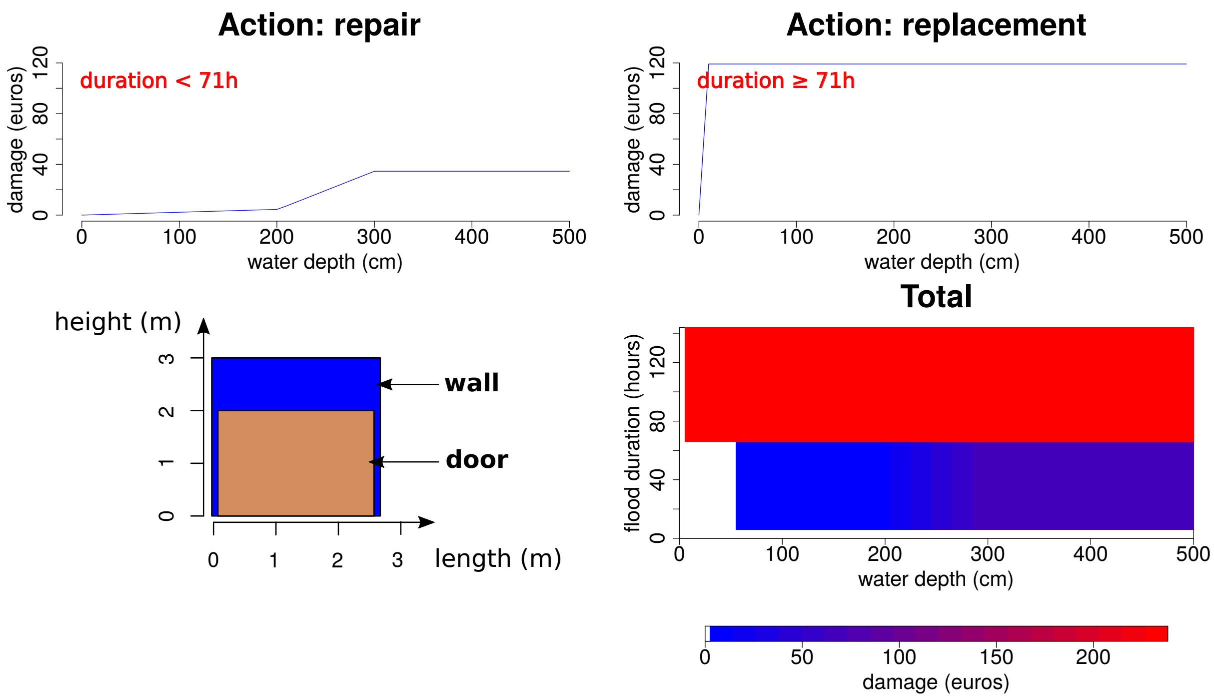

Figure 4.7: Damage function of the wall presented in the bottom left quarter, which is located in the model presented in Figure 4.1. N.B.: The damage scale differs between the 2 actions in order to highlight the relationship between the cost of the repair action and the water depth.

4.6.2 Single storey, uniform height

Figure 4.8 shows the damage function of the single storey house represented in Figure 4.1.

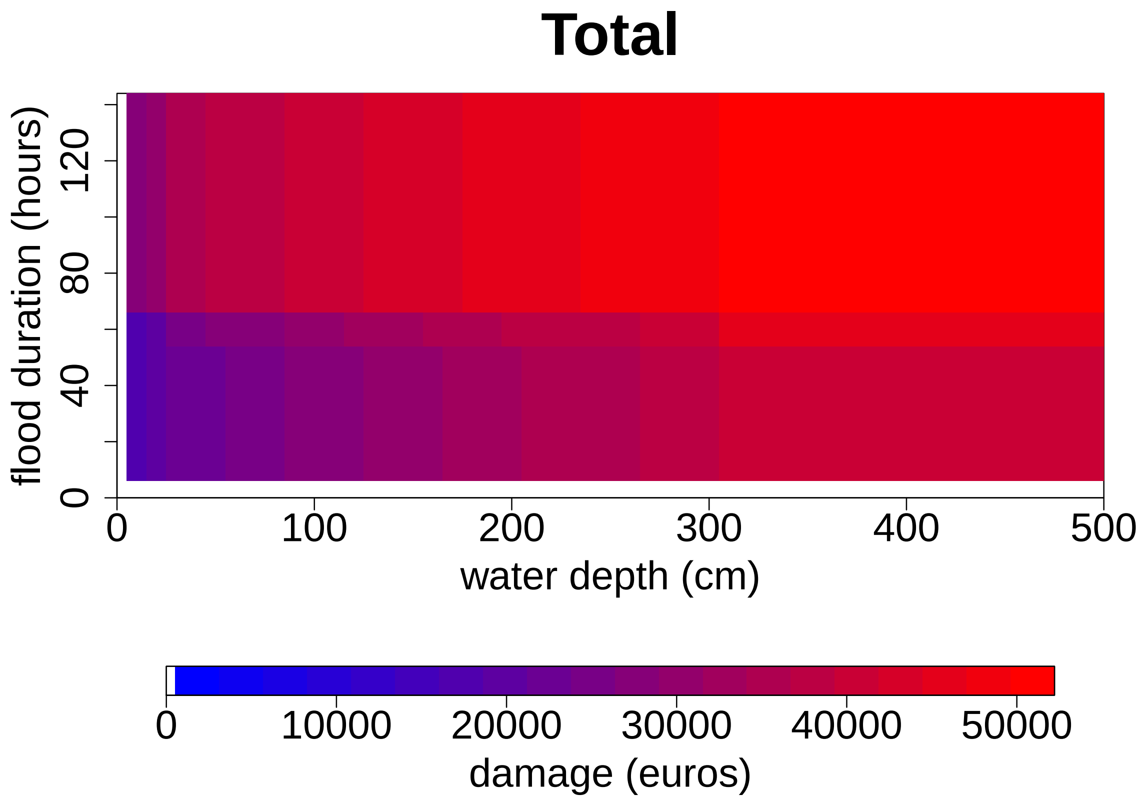

Figure 4.8: Damage function of a single storey house with a uniform height relative to the ground

4.6.3 Single storey, different heights

Figure 4.9 compares the damage function of the single storey house represented in Figure 4.1, which is on the ground level, with the damage function of a similar house that has a varying elevation relative to the ground. The first damage function is always higher than the second one, but this difference decreases with the water depth.

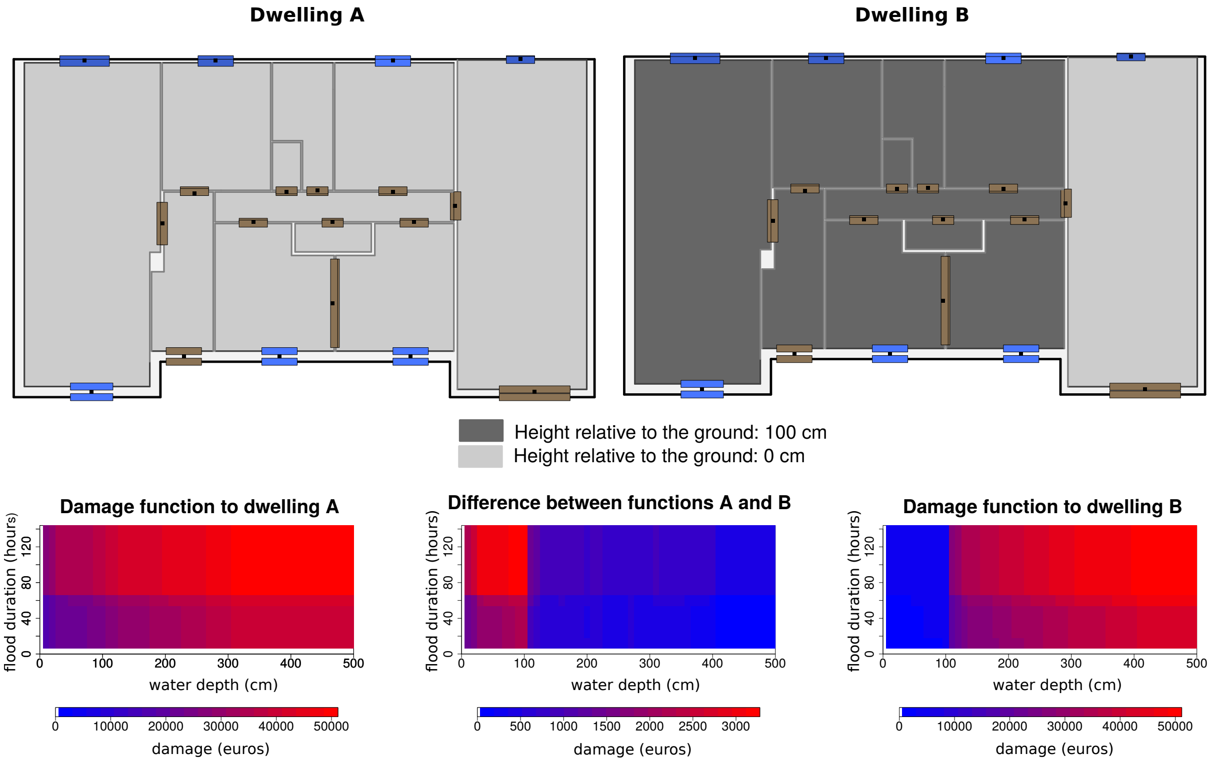

Figure 4.9: Damage function of a single storey house with a uniform height relative to the ground (dwelling A), a varying height relative to the ground (dwelling B), and difference between the 2 damage functions

4.6.4 Several storeys

Figure 4.10 shows the damage function of a double storey house. Compared to the damage function of the single storey house (cf. Figure 4.8), the highest value of the damage is higher because the total surface of the double storey house is bigger. Moreover, we observe a threshold between the first and the second floor.

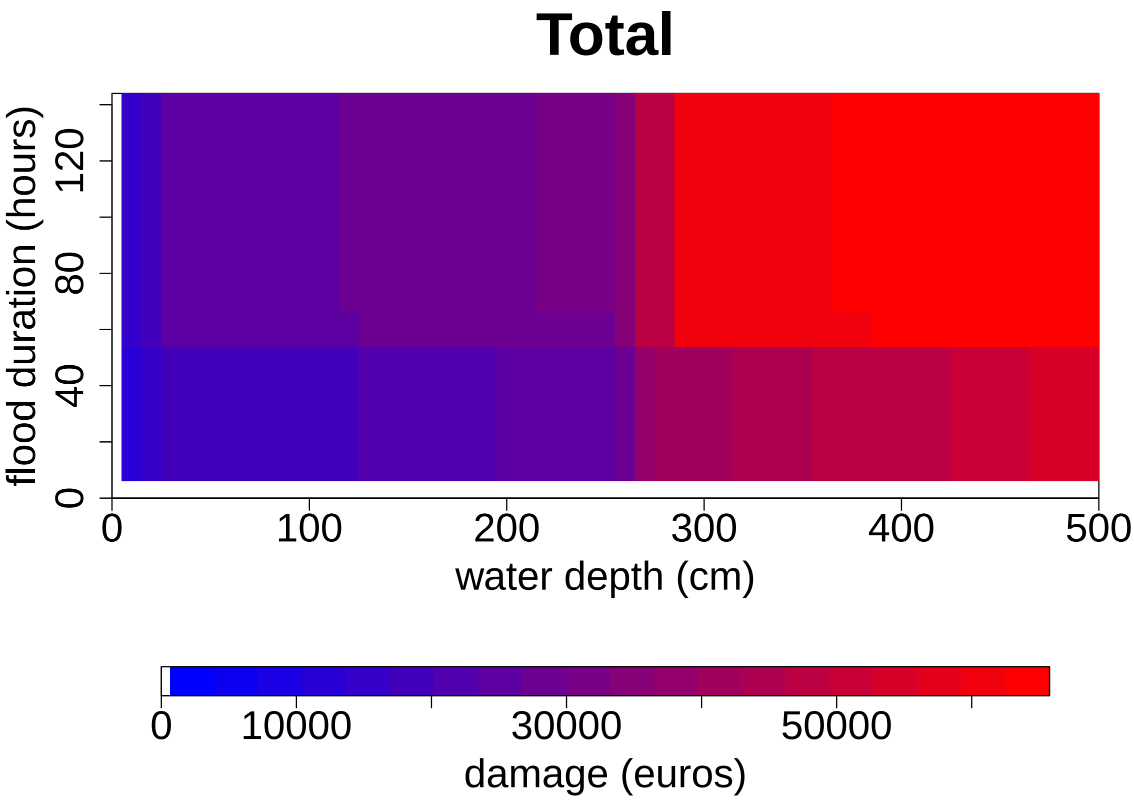

Figure 4.10: Damage function of a double storey house

Chapter 5

Declensions of models

5.1 Definition and possible uses

Several features of a model of built asset can be easily modified, either automatically or manually. Changing these features produces variants of the initial model that have the same geometry. The features that can be modified are:

- the building materials
- the contents
- the protection

At the time of writing, the building materials can be modified using *floodam*, whereas the contents and protection must be changed manually.

A set of model variants can be used to explore the influence of the varying features on damage, but also to better represent real built assets, and thus better estimate their vulnerability to floods.

5.2 Data collection

Data that describe real built assets are needed to produce model variants that represent them, and ultimately to build damage functions that accurately depict their vulnerability.

floodam was initially developed to build damage functions at the national level in France. To do so, we thus need to collect data on built assets at the level of France. At the time of writing, we already have model variants that represent the French dwellings in terms of building materials. However, we still need to collect the necessary data to obtain representative models of French dwellings in terms of contents and protection, and to produce representative models of other built assets.

5.2.1 Building materials representative of the French dwellings

To produce model variants that better represent the dwellings in France, we used the information contained in two reports: a report produced by the Agence Qualité Construction (AQC, 2009)[1] and another one produced by Pouget consultants (Pouget Consultants, 2017).[2]

The first report indicates the share of different building materials in dwellings for which a building permit was issued in France in 2004, 2005, and 2006. The second report classifies the French dwellings depending on their type (house or apartment) and their period of construction. For each type of dwelling, it indicates the most common building materials.

5.3 Modifying the building materials

Modifying the building materials consists in replacing the original elementary components that form the building by others. The components that form the building are the baseboards, the ceilings, the coverstrips, the floors, the openings, the walls, and the coatings.

In practice, to modify the building materials, we must indicate the name of the original component that we want to replace and the name of the replacement component. Then, *floodam* replaces the original component in the element part of the building.xml file.

5.4 Modifying contents

Five aspects of the contents items can be easily modified by changing the furniture.csv file of the model:

quantity It can be modified in the quantity field.

disposition Two aspects of the disposition of a contents item can be modified: the room in which it is located and the relative height at which it is located.

value The minimum and maximum values of each contents item can be modified.

nature The nature of a contents item can be changed by modifying its identification name.

dilapidation It can be modified in the dilapidation field.

5.5 Modifying protections

The protections can be changed by modifying the building part of the building.xml file.

[1] The AQC is an association of professional organizations of the construction industry that works on preventing damage and improving the quality of the buildings.

[2] Pouget Consultant is an engineering and consultancy office specialized in the construction industry.

5.6 Modifying dilapidation

The dilapidation of the building materials can be changed by modifying the general part of the building.xml file. For each contents item, it has to be changed by modifying the furniture.csv part.

Chapter 6

Past and future evolutions

In this chapter, the planned evolution of both the current manual and of *floodam* is presented.

6.1 Evolution of the manual

6.1.1 Changes compared to version 1.0.0.a

In this section we included remarks from Reine Tarrit:

- State "broken" is now described as "damaged" to better represent what we mean.
- More precisions are given on how we collected data from experts.
- Some planned evolutions of the manual has been added.

6.1.2 Planned evolution

The projected developments of the manual do not depend on the development of *floodam*. We plan to:

- Take into account possible remarks from contributors that did not participate in the writing of the current version.
- Better explain how we modelled protective devices
- Provide examples of uncertainty analyses
- Include examples in chapter 5
- Add a new chapter on the production of damage functions that relate to activities (in particular, we will explain how the typology is managed).

- Add a new chapter on the production of damage functions that relate to dwellings (in particular, we will explain how the typology is managed).
- Add a new chapter on *floodam-agri*.
- Add a new part to explain how to use *floodam*, which will contain:
  - ▷ a description of the main functions
  - ▷ guidelines to produce a building model
  - ▷ guidelines to produce variants of a building model

6.2 Evolution of *floodam*

6.2.1 Changes compared to version 1.0.0.a

There is no last version: this is the very first version of *floodam*.

6.2.2 Planned evolution

Cost of protection *floodam* is able to calculate the cost of implementation of some protective devices at building levels. However, this functionality has not been thoroughly tested yet. Thus, it is not included in the current version of *floodam*.

Multi-building It is planned to develop *floodam* to enable the estimation of damage functions of built assets composed of several buildings.

Enhance the robustness of the modelling of damage processes Some actions related to some elementary components depend on other actions that relate to other elementary components. In the current version, this is not taken into account in *floodam*, which may lead to inconsistencies.

Uncertainty analysis It is planned to develop *floodam* to enable the production of uncertainty curves for all damage functions based on the uncertainty related to the following parameters:

- the building materials
- the costs of the actions (or values of the elementary components)

Stochastic damage model As experts indicated stochastic processes to model the sensitivity to flooding of some elementary components, it is planned to also represent the sensitivity of buildings in a stochastic way.

Appendix A

Detail of data organization for elementary components

A.1 component.elementary

This table contains information at the level of the elementary components. In this table, each row corresponds to an elementary component. For each elementary component, the following features are given:

component.elementary identification (name) of the elementary component (e.g. coffee.machine).

category.vulnerability identification (name) of the category of the elementary component (e.g. small.household.appliances). It is used to describe its sensitivity to flooding.

v.min min default value of replacement. The mean between v.min and v.max is used if no other value of replacement is provided in the furniture.csv file.

v.max max default value of replacement. The mean between v.min and v.max is used if no other value of replacement is provided in the furniture.csv file.

v.unit unit used for the expression of v.min and v.max (€/unit, €/m^2, €/m, ...).

v.support support used for the calculation of v.min and v.max. It can be one of the following modalities: unit, length, surface.

A.2 category.vulnerability

This table contains information at the level of the categories of vulnerability. Each category of vulnerability is made up of elementary components that have the same sensitivity to floods. In other words, all the elementary components that belong to a same category of vulnerability:

- have the same admissible states (e.g. normal and destroyed)

- present the same relationships between the flood parameters and the probability to be in the different admissible states
- require the same action when they are in a given state

In the category.vulnerability table, each row corresponds to an unique combination of a category of vulnerability and an action that needs to be done to bring the elementary components of the considered category back from a given state to the normal state. For each couple of category of vulnerability and action, the following characteristics are given:

category.vulnerability identification of the category of elementary components concerned by the action.

action identification (name) of the action.

version version of the category.vulnerability table in which the action has been defined.

expert name of the experts involved in the current definition of the action or identification of the meeting in which the current definition of the action was provided.

h.min min water depth for which the probability that the action needs to be done is strictly positive. If h.min is $-\infty$, the probability that the action needs to be done is strictly positive for all water depths below h.max.

h.max max water depth for which the probability that the action needs to be done is strictly positive. If h.max is $+\infty$, the probability that the action needs to be done is strictly positive for all water depths over h.min.

d.min min submersion duration for which the probability that the action needs to be done is strictly positive. If d.min is $-\infty$, the probability that the action needs to be done is strictly positive for all water depths below d.max.

d.max max submersion duration for which the probability that the action needs to be done is strictly positive. If d.max is $+\infty$, the probability that the action needs to be done is strictly positive for all water depths over d.min.

p.action probability that the action needs to be done for water depths between h.min and h.max and for submersion durations between d.min and d.max. It is either a constant real number comprised between 0 and 1 (included), or a real number that varies depending on the water depth and flood duration. In the latter case, the value of p.action is "complex" in category.vulnerability and defined in the category.vulnerability.complex table. In equation 3.1, p.action is called $p_s(h, d)$.

h.action height up to which it is necessary to perform the action. If the action needs to be done on the whole elementary component, it takes the value "h.component". Otherwise, it indicates the height up to which it is necessary to perform the action as a function of the water depth. For instance, h.action takes the value "h.alea + 30" if it is necessary to perform the action up to 30 cm above the part of the elementary component that has been immersed. In equation 3.1, h.action is called $h_{a_s}(h, d)$.

i.action intensity in which a submersion with a water depth between h.min and h.max and a duration between d.min and d.max brings to elementary component into the state where the action is needed. Thus, i.action also refers to the intensity in which the action needs to be done. It is either a constant real number comprised between 0 and 1 (included), or a real number that varies depending on the water depth and flood duration. In the latter case, the value of i.action is "complex" in category.vulnerability and defined in the category.vulnerability.complex table. In equation 3.1, i.action is called $i_s(h,d)$.

dilapidation boolean. If true, the level of dilapidation must be taken into account to compute the value of replacement of the elementary component.

A.3 category.vulnerability.complex

This table contains information at the level of the categories of vulnerability. It provides additional information regarding the actions for which the value of i.action or p.action in category.vulnerability is "complex". More specifically, it indicates the value taken by i.action or p.action depending on the water depth and flood duration. In this table, there is at least one row by couple of category of vulnerability and action. A couple of category of vulnerability and action can be associated to more than one row if p.action or i.action can take several strictly positive values for a same water depth, depending on the submersion duration (for instance, if p.action is 0.5 for water depths between 10 and 50 cm and flood durations below 48 h, and 0.9 for the same water depths and flood durations higher than 48 h). If p.action or i.action can at most take one strictly positive value for each water depth, no matter the submersion duration, the couple of category of vulnerability and action is associated to only one row. For each row, the following characteristics are given:

category.vulnerability identification of the category of elementary components concerned by the action.

action identification (name) of the action.

type indicates the field of the category.vulnerability table which takes the value "complex". It can be either "i.action" or "p.action".

version version in which the action has been defined.

h.min min water depth for which the probability that the action needs to be done is strictly positive. If h.min is $-\infty$, the probability that the action needs to be done is strictly positive for all water depths below h.max.

h.max max water depth for which the probability that the action needs to be done is strictly positive. If h.max is $+\infty$, the probability that the action needs to be done is strictly positive for all water depths over h.min.

d.min min submersion duration for which the probability that the action needs to be done is strictly positive. If d.min is $-\infty$, the probability that the action needs to be done is strictly positive for all water depths below d.max.

d.max max submersion duration for which the probability that the action needs to be done is strictly positive. If d.max is $+\infty$, the probability that the action needs to be done is strictly positive for all water depths over d.min.

h.XXX value taken by the variable in **type** for a water depth of XXX cm and a submersion duration between d.min and d.max.

A.4 component.elementary.action

This table contains information at the level of the elementary components. Each row corresponds to an action associated to an elementary component. For each action, the following characteristics are given:

component.elementary identification (name) of the elementary component.

action identification (name) of the action.

v.min min cost of the action.

v.max max cost of the action.

v.unit unit used for the expression of v.min and v.max.

v.support support used for the calculation of v.min and v.max (€/unit, €/m^2, €/m, ...). It can be one of the following modalities: unit, length, surface.

value boolean. If true, the value of replacement of the elementary component is the mean between the values given in the fields **v.min** and **v.max** in the component.elementary table.

Appendix B

Detail of data organization for buildings

B.1 building

The data used to model a building is contained in an xml file that gives information on the composition and the geometry of the building. The xml file is divided in three parts:

B.1.1 general

This part gives general information at the level of the building:

type type of building (dwelling or activity)

H height above the ground

height height of the building

dilapidation default dilapidation factor to be used for the elementary components

version version of the xml file used

B.1.2 element

This part gives information on the elementary components used at the level of the building:

baseboard This is the list (optional) of the types of baseboard present in the building. Each type of baseboard is defined by the following characteristics:

- **material** material used for the baseboard.
- **width** width of the baseboard.

ceiling This is the list of the types of ceilings present in the building. Each type is defined by the following characteristics:

material material used for the ceiling.

insulating material used to insulate this type of ceiling. It is optional.

coating material used for the coating of this type of ceiling. It is optional.

H height at which the ceiling is located (relative to the floor of the room in which the ceiling is located).

coating This is the list (optional) of the types of wall coatings present in the building. Each type is defined by the following characteristic:

material material used for the coating.

coverstrip This is the list (optional) of the types of coverstrips present in the building. Each type is defined by the following characteristic:

material material used for the coverstrip.

floor This is the list of the types of floors present in the building. Each type is defined by the following characteristics:

material material used for the floor.

insulating material used to insulate this type of floor. It is optional.

coating material used for the coating of this type of floor. It is optional.

opening This is the list of the types of openings present in the building. Each type is defined by the following characteristics:

opening.type type of opening (door, french.window, window or empty).

material material used for the opening.

shutter material used for the shutter with this type of opening. It is optional.

height height of the opening.

width width of the opening.

wall This is the list of the types of walls present in the building. Each type is defined by the following characteristics:

wall.type type of wall (load.bearing.wall, lining, partition or empty).

material material used for the wall.

insulating material used to insulate this type of wall. It is optional.

render material used for the render with this type of wall. It is optional.

B.1.3 building

This part gives information on the geometry of the building, and on the way the elements defined in the previous part are used. It is organized as a list of storeys.

storey Each storey has the following characteristics:

name name of the storey.

H height at which the storey is located (relative to the ground)

height height of the storey. This value is used as the default height of the walls, if this information is missing.

Each storey is made up of a list of two types of rooms:

external Type of room that refers to the external part of the storey. It has the same characteristics as a room.

room Each room has the following characteristics:

- **name** name of the room.
- **baseboard** if present, type of baseboard used in the room.
- **ceiling** if present, type of ceiling used in the room.
- **floor** if present, type of floor used in the room.
- **H** height at which the room is located (relative to the base of the storey in which the room is located).

  Each room is made up of a list of walls:

- **wall** Each wall has the following characteristics:
  - **coordinates** coordinates of the starting point of the wall. The coordinates of the ending point of the wall are given by the coordinates of the starting point of the next wall.
  - **type** type of wall.
  - **H** height at which the wall is located (relative to the floor of the room in which the wall is located).
  - **height** height of the wall.

    Each wall is made up of a list of coatings (can be empty):

  - **coating** Each coating has the following characteristics:
    - **type** type of coating.
    - **H** height at which the coating starts (relative to the base of the wall on which the coating is located). The height at which the coating ends is given either by the height at which the next coating starts or by the height of the wall on which the coating is located.

    Each wall is also made up of a list of openings (can be empty):

  - **opening** Each opening has the following characteristics:
    - **type** type of opening.
    - **coordinates** coordinates of the center of the opening.
    - **coverstrip** if present, type of coverstrip used.
    - **H** height at which the opening is located (relative to base of the wall on which the opening is located).

B.2 furniture

The furniture.csv file contains a table that provides information on the contents items. These latter are not described in the xml file. The furniture.csv file contains the following fields:

component.elementary identification (name) of the type of elementary component (e.g. coffee.machine).

room.name identification (name) of the room in which the elementary component is located.

relative.height height at which the elementary component is located, relative to the floor of the room in which the component is located.

dilapidation own dilapidation factor to be used for the elementary component (overwrites the one defined at the level of the building).

quantity quantity in which the elementary component is present.

v.min own min value of replacement (overwrites the one defined by default for the type of elementary component).

v.max own max value of replacement (overwrites the one defined by default for the type of elementary component).

Appendix C

Contributions in the development of *floodam*

manual Frédéric Grelot and Claire Richert wrote this manual. Bénédicte Meurisse and Reine Tarrit reviewed this manual.

***floodam* implementation** Frédéric Grelot developed *floodam* with contributions from Florence Gontrand, Hélène Boisgontier, Claire Richert, and Cédric Gaillard.

data organization Frédéric Grelot developed the organization of data used in *floodam* with contributions from Hélène Boisgontier, Pauline Brémond, Cédric Gaillard, Loetitia Gamard, Florence Gontrand, Céline Looten, Amanda Macquart, Anthony Payet, Reine Tarrit.

data collection Hélène Boisgontier, Pauline Brémond, Cédric Gaillard, Loetitia Gamard, Florence Gontrand, Frédéric Grelot, Céline Looten, Amanda Macquart, Anthony Payet and Reine Tarrit contributed to data collection.

Most of the people mentioned above contributed to the development of *floodam* while working at Irstea. Reine Tarrit contributed to the data collection and organization steps while working at the Cerema.

Bibliography

Anne-Laure Agenais, Frédéric Grelot, Pauline Brémond, and Katrin Erdlenbruch. Dommages des inondations au secteur agricole. guide méthodologique et fonctions nationales. Groupe de travail national acb inondation, IRSTEA, 8 novembre 2013 2013.

AQC. L'évolution des parts de marché des produits et matériaux de construction. Technical report, Agence Qualité Construction, Paris, France, 2009. Coordonné par Godlive Bonfanti.

Anne Bournot. Évaluation de la pertinence des mesures de gestion du risque d'inondation. manuel des pratiques existantes. Technical report, CEPRI, 06 2008.

CEPRI. Évaluation des dommages liés aux inondations sur les logements. Technical report, CEPRI, Orléans, France, Août 2014.

Direction Générale de la Prévention des Risques. Programmes d'action de prévention des inondations (papi). de la stratégie aux programmes d'action. cahier des charges. Technical report, Ministère de l'Écologie, du Développement durable, des Transports et du Logement, 2011.

Direction Générale de la Prévention des Risques. Cahier des charges « papi 3 ». Technical report, Ministère de l'environnement, de l'énergie et de la mer, 9 mars 2017 2017a.

Direction Générale de la Prévention des Risques. Programmes d'actions de prévention des inondations (papi). cahier des charges « papi 3 » - guide méthodologique. de l'intention à la labellisation : Constituer mon dossier papi. Technical report, Ministère de la transition écologique et solidaire, Octobre 2017b.

Bruno Ledoux, Frédéric Grelot, and Claire Reliant. Synthèse des évaluations socio-économiques des instruments de prévention des inondations. Technical report, Ministère de l'Écologie et du Développement Durable – Direction des Études Économiques et de l'Évaluation Environnementale, Paris, France, 2003.

Cécile Magnier, Natacha Christin, and Cédric Peinturier. Analyse multicritères des projets de prévention des inondations. guide méthodologique 2014. Théma - balises, Ministère de la Transition Écologique et Solidaire, Commissariat général au développement durable, Paris, France, July 2014.

Edmund C. Penning-Rowsell, Clare L. Johnson, Sylvia M. Tunstall, Sue M. Tapsell, Joe Morris, John Chatterton, Annabel M. Coker, and Colin H. Green. *The benefits of flood and coastal defence: Techniques and data for 2003.* Flood Hazard Research Centre, Middlesex University, Enfield, England, 2003.

Edmund C. Penning-Rowsell, Clare L. Johnson, Sylvia M. Tunstall, Sue M. Tapsell, Joe Morris, John Chatterton, and Colin H. Green. *The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques.* Flood Hazard Research Centre, Middlesex University Press, 12 2005. ISBN 1 904750 51 6.

Pouget Consultants. Analyse détaillée du parc résidentiel existant. Rapport Version 2.0, Programme d'Action pour la qualité de la Construction et la Transition Energétique, Juillet 2017.

R Core Team. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria, 2018. URL `http://www.R-project.org/`.

Delphine Rouchon, Natacha Christin, Cédric Peinturier, and Doris Nicklaus. Analyse multicritères des projets de prévention des inondations. guide méthodologique 2018. Théma - balises, Ministère de la Transition Écologique et Solidaire, Commissariat général au développement durable, Paris, France, Mars 2018.

Anne Soubieux-Bournot, Chloé Auffret, Magali Dupont, Frédéric Grelot, Régis Morvan, Alice Néron, Cédric Peinturier, and Marie Renne. Analyse coût bénéfice. annexes techniques. Technical report, CEPRI pour le compte du Ministère de l'Écologie, du Développement durable, des Transports et du Logement, Décembre 2010.

UE. Directive européenne 2007/60/ce du parlement européen et du conseil du 23 octobre 2007 relative à l'évaluation et à la gestion des risques d'inondation. Journal officiel de l'union européenne, Parlement Européen - Conseil, FRANCE, 11 2007.

USWRC. Principles and guidelines for water and related land resources implementation studies. Technical report, U.S. Water Resources Council, 1983.