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Economical consequences of floods: modelling impacts in urban areas

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Abstract
The analysis of flood impacts is an integral part of the planning and of the local, regional and global evaluation of risks. In the search for sustainability and safety in community development, the analysis of flooding impact is a tool for decision making in every level of government as part of risk management. This study tries to estimate the economic consequences of floods upon households and the city, characterizing the direct and indirect damages, including an assessment of the recovery capacity and time to recover of the exposed population. For this purpose a multisystemic analysis was undertaken, incorporating the hydrographic system, the households, the transportation system and the companies. Monetary fluxes were defined based upon financial exchanges between companies and households. The information was aggregated using a network computational model. In order to verify the relationships between the system and the various regions of a complex urban space a prototype has been devised. In addition, detailed models of vulnerability, threat and exposition were created, to capture the several dimensions related to the risk of flooding.

Keywords: floods, impact assessment, agent based modelling

1 Introduction

This study aims to estimate the economical consequences of floods on households, characterizing the direct and indirect damages. Thereto, besides characterizing each household individually, interactions established among them, and with the environment in which they develop basic functions (such as consumption, education, work and leisure) are also analyzed.

Most of the researches in this field mainly produce estimations for damages resulted from direct contact between goods and flooding waters (Machado, 2005; Torteroto, 1993). Generally, studies that search for capturing indirect effects do it considering specific damages such as those resulted from traffic jams or resulted from the costs of emergency services. There are still approaches that intend to

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catch the value perception of risk reduction on one hand, and of potential damages on the other. They do it through direct interviews (contingent valuation method); or through comparing the real estate market conditions between flood prone areas and areas not prone to flooding (hedonic price method) (Shabman et al., 1998; Brower et al., 2006).

Although these studies bring some advances to the discussion on flooding control benefits, they don’t incorporate aspects which can be brought from analysis which capture the economical relations network. The economical relations are those established between households and economic activities and their alteration in face of the external clash represented by flooding occurrence. Generally, those methodologies work statically, measuring damages in a specific place, or simply they work disregarding the spatial propagation of flood impacts.

On the other hand, macro-economical models, such as the Computable General Balance, need great data volume, which derail their use for more restricted flooding events or for events with limited consequences to the municipality, being more adequate for analyzing disasters of regional or national coverage. Furthermore, these models own limitations for capturing effects of intense and temporary occurrences, such as those resulted from a natural disaster (THE IMPACTS…, 1999).

On the attempt to measure the direct and indirect impacts of floods, a literature review was done focused on three fundamental themes: the structure of intra-urban space, with special emphasis on family consumption relations; the models of microsimulation which were founded in micro-unity analysis; and, in a wide perspective, the studies about damages resulted from natural disasters, specially, flooding. Therefore, this paper intends to join three aspects understood as relevant for the comprehension of flooding impacts: the intra-urban space, the relations among agents at this space, and, as a clash element, the flood. Relevant researches where these three aspects are jointly discussed were not found.

Through the literature review, network analysis, regional models, and multi-agents modeling were considered as efficient methodologies for flooding impact assessment in complex and interconnected systems such as the urban one. From these techniques, elements were taken for elaborating the methodological proposal of this paper.

Figure 1 shows the research line used at the study. The analysis begins with direct damages, because they represent the impact on the event at its first moment, when the waters reache people and the space urban components. The analysis of these damages were made by adapting methodologies already well discussed in the literature (essencially the application of material susceptibility factors, and the use of damages-depth curves).

Indirect damages result from losses caused by the interruption of physical and economical connections in the economy. They incorporate elements of event spatial and temporal propagation. For its analysis, approaches were searched in studies discussing economical relations at the intra-urban space. From network analysis, essencial elements were taken such as the analytical system’s spatial configuration and relations among agents through *links*. It is assumed that, as the urban space organization is formed by a system of interconnections and interdependencies, agents have a strong relational nature, so the impact on each one has a great propagating potencial over other agents.

Analytical microsimulation models allow, from a wide characterization of the microunits and their interactions (and eventually with the use of probability functions applied to each event), the verification of possible behaviors and structures that arise at the macro-economical level. The microsimulation, at its classical form, is made in this research through the transport system in the impacted area, the flooded area and its suroudings. Results of this modelling approach are obtained by the assessment of flood traffic impact on each vehicle individually.

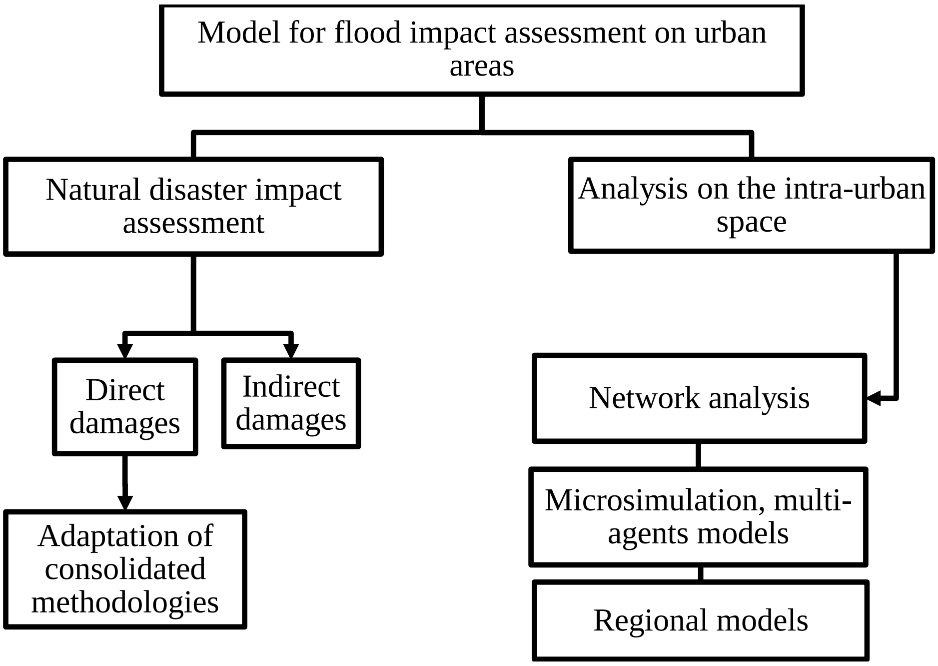


Figure 1: Analytical framework for flood damage assessment in a urban area

To model household behavior and related economical activities, elements of agent based modelling were adopted (ABM). ABM allows agent's representation in their interactions among themselves and with the environment. Each agent is individually differentiated (e.g: sex, age and income) and it interacts with the environment according to behavioral rules which can be adaptative or reactive. Since this is a dynamical model, it's possible to capture temporal and spatial impact propagation.

In the proposed model, a simplified approach of ABM is used, in which households and their inhabitants, behavioral standards of consumption and of work allocation, are atributed to spatial micro units previously defined in the urban area.

Regional models usually adopt representation of geographical areas in zones in which population, goods and capital are exchanged (Benenson, 1999). Each zone is, then, represented by a vector of socioeconomical informations. At the model here proposed, such zoning aproach is adoted for part of the urban area, allowing the aggregation of information at the city level. For the zones directed impacted by floods, the flooded area and close neighbourhoods spatially distributed microunits are used. Therefore, the resulting model is a hybrid model.

2 Material and methods

The research objectives are discussed jointly by means of a multi systemic analysis: 1) river system; 2) household system; 3) mobility system; 4) productive-distributive system (firms). For aggregating all information, a network computational modeling is used.

According to Green (2004), the household is considered the main unit of analysis. The household works as a micro-system where activities are shared aiming the maximum welfare. The productive-distributive and the road system are introduced by their interconnections with the household system. The urban-economical system is represented by means of a network composed by nodes and links. Nodes are the points of economical activity or of residence. Links are formed by fluxes that circulate through nodes, which represent the configured relations among the agents.

A main point is to define which kinds of relation among agents should be discussed in view of the study's goals (economical, religious, etc.). At this research, the point of departure is an economic approach, and the fundamental relation to organize an agent's life (in this case the household) is the consumption relation, in other words, goods, services, knowledge, leisure or work consumption. When the information of all agents in each system is aggregated, the model should be able to show the behaviour of assets stock and goods and services consumption at households, and the consequence on the added value of firms. In the following paragraphs, each system is described.

2.1 The river system

It is composed by river or hydrographic network. In this system, floods represent the external shock to the everyday "normality". In each pixel of the flooding prone area, information are available on depth, flow velocity and flood duration for different return periods.

2.2 The households

This system is represented by the households distributed in the urban area. It contains a great volume of geo-referenced information as much of the own household (e.g.: number of rooms, presence of electricity and sanitation services, existence of durable goods), as of its own inhabitants (e.g.: educational level, individual income, health conditions and age), which allow not only an individualized socio-economical characterization of the community, but also the definition of displacement standards (pendulous and triangular displacement according to daily activities of work, consumption and study).

The goal of the system is the creation of a model with family routines before, during and after flooding. The household behaviour is essentially classified according to three categories: (*i*) consumption of goods and services; (*ii*) education acquisition; and (*iii*) income acquisition. The leisure activities are inserted at the first category.

The system equilibrium occurs when the consumption equals income (Equation 1).

$$C = \sum_{i=1}^{n} (p_i \times q_i) = y \qquad \text{(Eq. 1)}$$

Where:
C = family monthly consumption;
p_i = price of product i;
q_i = quantity consumed of product i;
y = family total monthly income.

The superscript i varies from 1 to n, according to the kind of expenditure.

2.3 Traffic system

At this system, a traffic analysis is done by means of main stretches at the road network in situations with and without flooding occurrences. When part of the network is flooded, the model allows verifying the alternative paths to be chosen by drivers and their capability to bear the additional traffic. The use of new roads may imply an increase at the distance covered and at the time of displacement causing material costs (vehicle detritions, oils and fuel consumption) and additional time. There is still a greater volume of pollutant emissions by vehicles.

2.4 Productive-distributive system

The productive-distributive system is composed by productive activities and by the distributive spots that are spread along the city. This is the system that offers jobs and generates income and also where are located the points of consumption, i.e. the units of distribution for inhabitants' income expenditures. In the system, economic costs due to flooding are evaluated by means of added value variation due to activities disturbance or disruption when they occur. The added value loss represents income loss at the locality.

The system balance occurs when the income equals to the demand (Equation 2):

$$L \; x \; w = \Sigma \, p_i \; x \; q_i \qquad \text{(Eq. 2)}$$

Where:
L = number of workers;
W = wages;
p_i = price of product i;
q_i = quantity consumed of product i.

2.5 System assumptions

The openness of urban economy and the external transactions are presupposed and explain why prices of several goods and the levels of external demand are givens and constants. A defined urban space is modelled and its impact doesn't affect areas beyond its limits. The urban space, therefore, would represent a region furnished with relative independence in relation to other regions. At the case of small cities, these hypotheses are not abided, but for great urban spaces it seems reasonable to use this strategy for impact's assessment.

The subjacent hypothesis suggests that most of economical impacts of a flood take place locally, at the level of affected urban area. In this paper, although the impacts which may occur at extra-urban spheres are not ignored (such as those of regional or even national levels), they are not incorporated at the model due to simulation complexity as well as in reason of its minor relevance in relation to local impacts, which is also a subjacent hypothesis in the system. Therefore, the urban system is closed – neither population nor new structures are added at the city – because the intention is comparing different flood impact scenarios in the same system.

The micro-economical hypothesis is that the household main purpose is to maximize its satisfaction through the consumption of several goods and services, resulting in an increasing household welfare. Its first objective would be, obviously, to guarantee its own survival and from this point, to obtain life quality improvements.

The level of satisfaction is in function of the quantity and quality of goods consumption which depends on income and prices. As the prices in the market have been considered stable, the household income available to consumption and the assets stock accumulated at the household are the measures of welfare for being used at this work.

The difference between consumption and assets before and after the flood event is, therefore, a measure of variation welfare variation. The household recovers the level of welfare when it recovers the level of consumption and assets stock previously to the flood event, or any other event.

2.6 Creation of a prototype

The model prototype searches to represent in a simplified way the main elements of urban space that interfere at the magnitude of flooding impacts. Socioeconomic data, spatial organization and standards of occupation and land use in Belo Horizonte municipality (Brazil) were used for supporting the creation of the prototype.

Three different geographical levels which are interrelated by means of consumption and wage fluxes were created (Figure 2).

- Flooded area – FA: it corresponds to the area flooded by a 100-year return period event. This area will suffer direct impacts in correspondence to the contact of people and goods with flood water, as well indirect impacts. As they are associated to direct damages, the indirect damages in this area tend to be more intense than in the rest of the city. As the urban network gets distant from the flooded area, there is a possible dilution of the total damages.
- Surrounding area – SA: it represents the area around FA. Although it hasn't been directly flooded by the event, it tends to suffer more indirect impacts than the rest of urban area due to its proximity to FA.
- Remaining urban area: it is composed by 74 regions, each one represented by a node at the economical-urban network which aggregates the set of households, inhabitants and economic activities located in each region. It is incorporated to the analysis due to indirect impacts caused by FA.

At FA and SA each household and firm are individualized modelled. But at the nodes, the agents are represented aggregately. SA area was created through the application of a 0.7 km radius over FA borders. This was defined considering Belo Horizonte's districts areas around FA area.

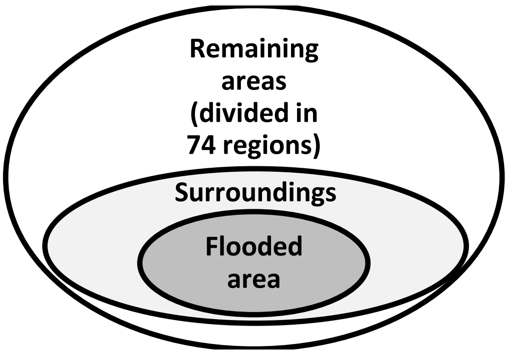


Figure 2 – Prototype regions

The road system is also defined according to two detailing scales. At the region directed impacted and the surroundings, the system is modeled with more detaisl, with the definition of the main road patches and a secondary road system that may serve as alternative routes in the case of floods. The road network at this area has 49.61 km of extension. In a second detailing scale level, only the main city roads are modelled. This allows taking into account their arterial function for the urban network. The use of a two-level detailing approach is justified through the hypothesis that impacts tend to be diluted in space. Modelling with more details the road system at the flooded region would allow capturing great part of flooding impacts on traffic.

Figure 3 presents the spatial configuration of the prototype. The nodes are shown in yellow; the road network is presented in red. The gray spot at the centre of the network refers to the firms and households agglomeration at FA and SA.

Figure 3: Spatial organization of prototype with the road network

In order to capture the several flooding possible effects, FA and SA were intended to be represented as regions of high land occupation, where a great number of households and firms are located. Six subtypes of region zoning were defined and they were differed according to the location of buildings and the economic activity, as one of which representing the economic centre in the city, with the density of 2534 firms by km^2. The region is also relevant as a traffic area, because it connects important city centres of economical activity represented in the prototype.

For defining the number of firms and its distribution at the prototype, information available at the Belo Horizonte Financing Bureau were used, as they contain the number of firms in Belo Horizonte by district and by type of activity, in 2000. Building occupation standards at FA and SA were obtained from the adjustments made considering the number of allotments not occupied by dwellings, resulting in 468 commercial buildings in the whole region. In certain situations, mixed buildings were considered where the first floor was occupied by business activities while the other floors were defined as residences.

The firms are characterized according to their geographical coordinates, to their location or not at the first floor, to their code of activity, to the number of workers, to the wage mass and to their supply capability (possible maximum limit of selling). By means of the activity code, it is known quite precisely which type of good is supplied by the establishment (e.g.: bakery, market, dressing, etc.). A supply vector was built for each firm which allows identifying the existence or not of supply from the 59 groups of goods identified by the National Classification of Economical Activities – NCEA (COMISSÃO NACIONAL DE CLASSIFICAÇÃO – Concla, 2008). The nodes of economic activities have the same information, but shown aggregately and averagely for each NCEA class.

At FA and SA, households represent approximately the household's structure in Belo Horizonte, considering different socio-economical classes and different family typologies. Hence, the model allows assessing flood impacts on households with distinct characteristics.

A sample of 14314 households was obtained in the census micro-data (IBGE, 2000) which represented the income structure and the family typologies found in Belo Horizonte. For each income class and family type, households were randomly located in FA and SA. Tables 1 and 2 present, respectively, the structures of the family typologies and of the social-economical classes present at FA and SA.

Table 1 – Distribution of FA and SA households according to family typologies

Type	Characteristic	% of households
1	Couples without children with keeper of 64 years maximum	8
2	Couples without children with keeper of 65 years or more	2
3	Couple with kids younger than 13 years	34
4	Couples with keeper of 64 years maximum and with all kids in majority	15
5	Couples with keeper of 65 years or more and with all kids in majority	4
6	Single woman of 64 years maximum	4
7	Woman with children	18
8	Woman and others	4
9	Single man of 64 years maximum	4
10	Man and others	2
11	Single elder	2
12	Man with children	2
Total		**100**

Table 2 – Distribution of FA and SA households according to socio-economical classes

Socio-economical classes	% of households
A1	6
A2	8
B1	11
B2	15
C	22
D	21
E	17
Total	**100**

Note: Class A1, the highest income; class E the poorest families.

Each household is represented according to its location (coordinates x and y and location at the first floor or not), family typology, number of inhabitants, property area, building standards, number and quality of the dwelling content (33 types of furniture, equipments and other contents were defined) and household income.

The average monthly expenditures of the household are identified by 59 groups of goods using the same classification defined by the vector of firm's supply. Hence, it becomes possible to cross information about the household consumption goods with the standard of firm's supply.

At the nodes of the prototype, the households were characterized aggregately and in a more simplified way. For each node it was defined the total number of households, the average income and the expenditure structure associated with income.

The model's smallest unit of analysis is the people. They are agents, who displace for pursuing their household's functions as income acquisition, consumption and leisure. At FA and SA, all the residents are differentiated according to their residence location, age and physical and mental capability (capability to listen, to hear, mental handicap, etc.). If the resident is a worker, (s)he is defined by its activity code and the wage received; if (s)he is student, (s)he is defined by its study level.

At the nodes, the inhabitants were not individualized; they were considered as a whole by their household.

The table 3 presents a synthesis of the information composing the prototype:

Table 3 – Synthesis of Prototype information

Indicators	FA and SA	Nodes	Prototype
Total area (km^2)	5.9	326.5	332.4
Flooded Area FA (km^2)	1.3	0.0	1.3
Number of households	14,314	164,379	178,693
Numbers of inhabitants	51,116	588,220	639,336
Total income (Euros)	22,125,344	253,719,404	275,844,749
Household average income (Euros)	1,546	1,544	1,544
Number of firms	5,045	19,084	24,129
Total of received wages (Euros)	51,255,396	253,719,404	271,348,179
Occupied groups	37,474	166,113	203,587
Average salary by worker (Euros)	1,368	1,528	1,333
Average of workers / firms	7	9	8

2.7 River simulation and its incorporation in the prototype

The introduction of flooding in the prototype was made through the hydrological-hydraulic simulation done for a hypothetical river and flood prone area based on simulations performed in the Betim River basin. Although a prototype is a virtual space, a "real" simulation model of river behaviour was chosen, in view of making possible coherence among hydraulic information of depth, speed and flood extension for different return periods. The flood wave propagation was simulated at this study area in 1-D non-permanent flow.

For the hydrological modelling, a model HEC-HSM, version 2.2.2 was utilized (HEC-HSM, 2002. River flow modelling was performed using HEC-RAS, version 4.0 (2003), from US Army Corps of Engineers. Simulations were done for 5, 25 and 100-year return period flood events.

After the hydrologic-hydraulic simulations were performed, flooding maps were created. For this procedure, it is necessary the combination of two data: water level associated to the river sections and the region's topographic map (digital terrain model). For associating these information layers, the program ArcGis 9.2 was utilized.

With the creation of the detailed flooding map, water levels and flow velocities could be estimated for the flood prone area, including FA buildings and road system for the three return period events simulated.

2.8 Traffic simulation

In view of analyzing the flooding impact at the mobility system, the road network traffic which integrates the FA and SA region was modelled. We adopt the hypothesis that the impact on the mobility system due to a flooding in FA is essentially absorbed at FA and SA. Beyond this area, traffic is not impacted. This hypothesis is reasonable if there are alternative routes at the region which are able enough to bear the deviated flux and to absorb the propagation of network disturbance. This is the assumption considered at the model. In a study case, it should be verified which network extension would be probably disturbed, and therefore, which one should be modelled. Ideally, a traffic simulation of the whole road network of a city should be performed. But such procedure involves a high computational cost and a great capacity for data handling which could be not really required in view of the precision of results. Figure 4 shows the road network of the prototype.

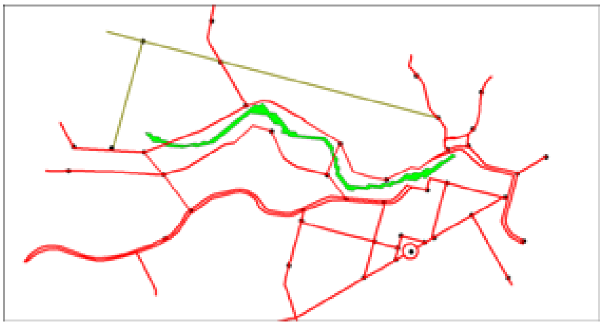


Figure 4: Road network of the prototype – FA region

In view of simulating the flood impact at the road network, traffic micro-simulation was used as an analyzing tool. The modelling was made by means of the software *Integration 5.1* (INTEGRATION…, 2005). The road network has 49.71 km of extension.

The main routes of FA and SA areas were considered regarding vehicle flux and of traffic deviation alternatives in face of flooding occurrence. As there were no information about the origin and the destination of each model agent, the vehicle flux was simulated according to region's characteristics (number of households, firms, occupied groups, number of students which reach the area, estimated number of consumers, possession of vehicles by the households, etc.). Information about road flux from neighbourhoods with similar characteristics in Belo Horizonte were also used for the model parameterization.

For defining if the agent uses the public transportation or the private ones (his/her own car), it was verified in a sample of census micro-data (IBGE, 2000) the percentage of the population above 18 years old who own cars. Since in Belo Horizonte there is no a subway system, only buses were considered as a public intra-urban transport system. The number of cars was multiplied by the factor 1.4 which represents the average of passengers by car in Belo Horizonte (estimation done by the UFMG Department of Transport Engineering, not published). This percentage was, thus, applied to an estimated value of people who attend the FA and SA region, obtaining a estimative of the number of passengers using cars. The remaining people are those users of buses which circulate averagely at the maximum capacity of sit passengers (50 seats, according to Rodrigues *at al.*, 2008).

Figure 5 shows the temporal distribution of vehicle flux at the region as a whole. Three flux peaks are observed: the morning peak, a banking peak and the maximum peak at the end of work journey.

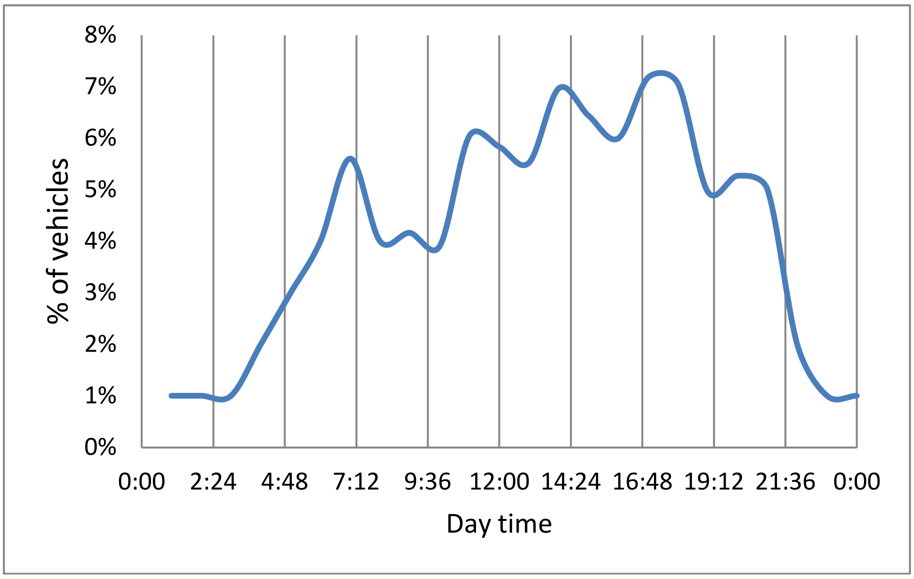


Figure 5: Distribution of vehicle flux during a day

The road capacity was stated for a flux of 700 vehicles/hour for each lane. The speed adopted is 60 km/h for collector roads and 40 km/h for the local ones. These parameters are based on the recommendation of *highway Capacity Manual* – HCM (TRB, 2000). If there is a traffic jam, the speed decreases to its half. At the locals where a very elevated high flux was verified, traffic lights were placed for traffic management.

The simulations were based on four flooding scenarios considering two possible times for the begining of the event, at 10:00 am and at 5:00 pm. The time chosen for the beginning of flooding at 1o:00 am represents an average flux condition. At 17h, the simulaton captures the impacts of floods on heavy traffic conditions (the biggest agents' circulation)..

It the model, if a road is flooding with depth above 15 cm, the flux is interrupted, bellow this level, there is a speed reduction to 20 km/h.

Through traffic simulation, relevant variables are obtained allowting to assess the flood impacts on traffic: time, distance and fuel consumption, polluents emission like CO_2, HC and NO_x. The model contains the following steps to transforming the quantitative indicators into monetary values:

The cost of fuel is obtained according to Equation 3 (IPEA/ANTP, 1997; Nagem, 2008):

$$C_C = (y_C \times p_C \times 0{,}718) \times d_V \qquad \text{(Eq. 3)}$$

Where:
C_c = total fuel cost by vehicle (in Brazilian currency R$, 2000);
Y_c = total quantity consumed by vehicle (1/km);

p_c = price of gas at the pump (in Brazilian currency R$, 2000);
0,718 = factor proposed in Nagem (2008) utilized for compesating the used fuel variation among vehicles;
d_v = distance covered at the study area (in this research, at FA and SA).

The gas price was obtained by current price averages charged by gas stations in the city (obtained by *Internet* search).

For defining the monetary value of time, a formulated adaptation proposed by IPEA/ANTP (1997) was utilized, as (Equation 4):

$$C_T = \left(\frac{w \times ES \times FA \times HP}{y_W}\right) \times t_V \qquad \text{(Eq. 4)}$$

Where:
C_t = cost of the journey time at the atudy area (in Brazilian currency R$, 2000);
w = monthly income given by the agent (in Brazilian currency R$, 2000);
ES = social chargings 95,02% = 1.9502;
FA = Possibility of alternative use of time (0.3);
HP = Percentage of productive use of time (% work journeys + % home / work journeys x 0.75). In case of unavailability, use 0.5;
y_w = number of working hours per month. If not available, use 168 hours;
t_v = time covered by a journey at the study area (in hours).

In Equation 4, wage values and worked hours were obtained for each agent directly from census micro-data (IBGE, 2000). The journey time per vehicle is an outcome of the simulation with *Integration*.

Finally, the pollutant monetization is calculated. For the economic evaluation, the carbon monoxide (CO), hydrocarbons (HC) nitrogen oxide (NO_x) were considered.

The polluents monetization involves studies related to pollution effects over human beings and over the environment which can be very diverse, consideting local environmental conditions (clime, altitude, pollutiant dispersion, wind regimes, relief, etc.), besides considering the effects due to interactions of pollutants. IPEA/ANTP (1997) studies on economic pollutant impacts based on the adaptation of American and European sources the the Brazilian context were here adopted. The final adopted values, in Brazilian currency R$ of 2000, are as follows:

CO = R$ 0,25/kg

HC = R$ 1,50/kg

NOx = R$ 1,48/kg

IPEA / ANTP (1997) considers the impact on health as reference for polluents monetization. The environmental impacts of gas emissions that recently received great attention due to the possible effects that they can cause at the planet (as greenhouse effect, ozone layer destruction, and acid rain) were not incorporated by that study.

2.9 Economic network modelling

An economic network modeling was created with the use of the relational data source previously formed, aiming at creating thre required liks between households and firms. The households do several expenditures at the firms, besides obtaining their income from work places (Figure 6).

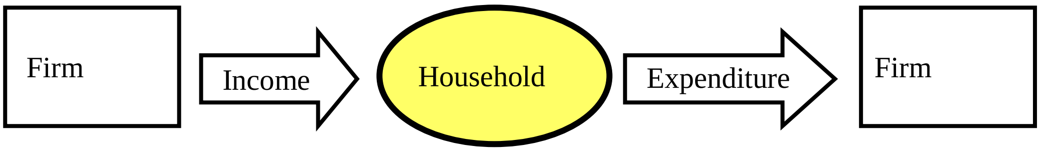


Figure 6: The nodes and the links at the economical net discussed at this study

The spots of origin (households) and destination (firms) are defined according to selected strategies. For defining the agents' work place, a random choice was made among the firms with the same activity code of the workers (worker activity code is a census information). For the choice of the study place, a similar procedure was made, definying randomly the school/college unit attended by the student, according to the intended study level. The firms own a limited labor supply capacity which is determined by the variable "number of workers". In the same way, the teaching units restrain the supply by the maximum limit of allowed students. Both information are model's inputs. In relation to the expenditures done by households, a more detailed allocation strategy was utilized. The 59 types of expenditure were grouped in six typologies which were defined according to criteria of substitutebility and supply distribution (Table 4). The level of substitutebility is refered to the possibility of substituting a good. This criterion enphasizes the rareness or unicity (there is not an alternative for supplying depletion services, for instance), as well as the distinction that could exist among them, in terms of quality, symbolic meaning (e.g.: social status) and sensorial satisfaction (e.g.: beauty, flavor, softness, etc.).

The supply distribution is connected to the location dispersity of city activities or to the existence of ordinary neighbouring activities from household (e.g.: bakeries, pharmacies). Both aspects essentially define if the agent will choose the strategy of postponing the consumption or the one of substituting the supplier, in case of disruption of the purchase link, in other words, in case of a flood at the firm of prefered purchase. Table 5 shows the possible strategies for the agent at the moment of choosing the consumption unit.

The displacement radius represent the edge distance that the agent is inclined to accept for the good acquisition. Beyond this distance, there are transportation and opportunity costs that the agent is not inclined to accept. This radius was determined intuitively, based on the area of the great regions dividing the city of Belo Horizonte. However, the good inside the specific radius is not available, it is considered that the agent felt obliged to search outside this radius, at the nearest supplier.

The definition of each one of these strategies depends on the flood occurrence ont only at the firm of preferable purchase, but also at the consumer household building (building of apartments or house). Three parameters of flooding depth at buildings were considered as relevants for the execution of purchasing functions (Table 6).

The strategy for each household in relation to their expenditures are defined for considering it jointly to access restriction caused by the occurence of flooding at the household or the firm.

Random choice was defined for the expenditures C, D, E and F (strategies 3, 4 and 5) for considering that countless factors, beyond residence proximity, act meaningly at the definition of the good purchase place . However, it is highlighted that the own activities distribution at the prototype already acts as flux directioners.

Table 4: Expenditure typologies

Expenditure group	Examples of expenditure	Substitutebility	Supply distribution
A	Nourishment, medicines, newspapers and magazines	High to medium	Contiguous
B	Toys, appliances, tissues and haberdashery	Medium	Discrete
C	Bank services, personal services	Low to medium	Discrete to highly discrete
D	High education, medical treatment, professional services	Low	Highly discrete
E	Housekeeping, car maintenance	Low to medium	Highly discrete
F	Pensions, private social security	Low to medium	Discrete to highly discrete

Table 5: Agent's strategies for choosing units of purchase

Type	Behavior	Strategy
1	Keeping the expenditure	Purchasing at the nearest firm of the household and substituting the purchasing place in case of link disruption
2	Postponing the expenditure	Purchasing at the nearest firm of the household and not substituting the purchasing place in case of link disruption
3	Keeping the expenditure	Random purchasing in a 3.5 km displacement radius and substituting the purchasing place in case of link disruption
4	Postponing the expenditure	Random purchasing in a 3.5 km displacement radius and not substituting the purchasing place in case of link disruption
5	Keeping the expenditure	Random purchasing at the city and not substituting the purchasing place in case of link disruption

Table 6: Parameters of threat to agent mobility

Flood at household	Mobility Restriction
Absence of flood at household building or flow depth < 0,15cm	Possibility of executing all the functions
Flow depth between 0,15cm and 0,45 cm at the household building	Discouragement for purchasing not essential goods
Flow depth above 0,45cm at household building	Impossibility of executing most of the functions – evacuation

Each firm has its supply capacity defined (established according to the number of occupied groups and the kind of activity), which avoids that a small number of firms become responsible for a high portion of goods supply only due to their strategical location in relation to the agent. It needs to be highlighted that a flood at the work place or at the teaching unit implies, obviously, in a strategy of postponing the activity, because there is not of immediate supply substitution for these goods. If, in turn, the building is smitten for a flood of height superior than 4.5 cm, the household does not execute its function ("work" and "education" functions are inserted at the D expenditure group).

The allocation of labors at firms and students at teaching institutions, as well as the definition of the purchase units chosen by agents, are done with the use of computational language C^{++}. The spatialization of the prototype and the relations were formulated by *NetLogo 4.0.4*, programming plataform of modeling in agents.

Table 7: Agent's strategy according to the flood level at the household building of the resident

Expenditure group	Flood height (y) at the building		
	y < 0,15cm	0,45 cm > y > = 0,15 cm	y > = 0,45 cm
A	1	1	Expenditure not effectuated
B	2	Expenditure not effectuated	Expenditure not effectuated
C	4	Expenditure not effectuated	Expenditure not effectuated
D	5	5	Expenditure not effectuated
E	3	Expenditure not effectuated	Expenditure not effectuated
F	4	4	Expenditure not effectuated

2.10 Evaluation of direct damages

Direct damages were defined to the content of households through the aplication of susceptibility factors to water contact for each one of the 32 types considered (vehicles in exception). The factors were proposed initially for Penning-Rowsell & Chatterton (1977) and they were adapted to Brazilian context by Machado (2005). In its definition, it is considered the type of asset, its quality (defined in three levels) and its probable height in residence, which allow the definition of the value depreciation for each good according to different flooding depths.

Flood susceptibility factor is applied on the value of the good founded in the residence and it is considered to be at its half life, with a 50% average depreciation. Equation 5 shows the total value of household damages for kind of good and Equation 6 shows the total value of damages to the content.

$$DCn_{j,y} = \left(A_j \times P_j\right) \times d_j \times din_{j,y} \qquad \text{(Eq. 5)}$$

$$TDCn_y = \sum_{j=1}^{32} DCn_j \qquad \text{(Eq. 6)}$$

Where:
$DCn_{j,y}$ = total value of damages to good *j* in a depth *y*;
A_j = quantity of good *j*;
P_j = price of good *j*;
d_j = percentage of depreciation at "normal" conditions of good *j*;
din_{jy} = flood susceptibility factor of good *j* in a depth *y*;
$TDCn_y$ = total value of damages to the household content.

Where:

$0\% \leq din_{j,y} \leq 100\%$,
$1 \leq j \leq 32$ e
$y \geq 0$.

The price of goods was obtained by means of a survey made by researchers directly into commercial establishments and through *Internet* (Machado, 2005).

The analysis of value damages to vehicles were done separately, because some additional hypotheses are necessary when a household movable is taken into account. The main difficult is the definition of the number of harmed vehicles. The studies analyzed consider as smitten vehicles those belonging to households exposed to the wind. (Appelbaum, 1985; Nagem 2008; EASTWOOD…, 2009), incorporating eventually a reducing factor (Appelbaum, 1985; EASTWOOD…, 2009). In this study also used the vehicle ownership by households as an indicator of the number of smitten vehicles.

Nevertheless some additional hypotheses were incorporated:

- In the households where there is a vehicle, it is considdered that the workers use ir as a mean of transport to the work place;
- As two flooding moments are used – 10h and 17h – it is estimated that at these time the vehicles used by householdd workers at FA and SA are outside the area of direct impact;
- The smitten vehicles are, therefore, those which are not used by workers who stayed at the household.

When these hypothese are applied to the households from FA and SA, it is verified that 20% of vehicles were kept at residence. A percentage considered proper and near of the 25% defined by the study of EASTWOOD… (2009), are those based on the statistic from the *Australian Bureau of Statistics* about the number of present vehicles at residences at working time.

The possible harms to vehicles and the value for reparing them were established by consultations to specialized ateliers where possible damages to vehicle in different flood depths were simulated. Three kinds of vehicles were utilized at simulations: “popular”, “average” and “luxe”. According to experts, there is water flow into the vehicle in moderate depreciation conditions, in other words, from 40 cm depht. From 40 to 70 cm the costs are, above all, of cleaning, which varies according the vehicle’s value. From 70 cm, the seats are covered and the damages are more relevants. With a height of more than 1m, there is the total lost of the vehicle.

In the analysis of damages to the building, in turn, damages curves were used x depth of submersion – curves DDS – established by Machado (2005).

3 Results

Table 8 presents the impact of flooding according to three flooding scenarios. Regarding the scenario of the biggest impact (flooding with a 100-year-return period), there are 3416 households, 1288 firms and 13 road patches located in the flooded area. The direct damages to households in this area reached about 11 million Euros, 63% representing damages to the content (vehicles not included), 26% to construction and 11% to vehicles of local residents. It needs to be highlighted the great component of the damaging value associated to vehicles, because among the flooded households those which also had the vehicles flooded have shown a raise of 26% at the total value of damages comparing to those simulated considering that they do not have a car or that the car was not flooded.

Table 8: number of households, firms and patches in flooding area according to different return-period scenarios of the event.

Return period (TR)	Absolute number		
	Households	Firms	Road patches
TR = 5 years	1783	624	13
TR = 25 years	2356	865	13
TR = 100 years	3416	1288	13

The same number of road patches was flooded for the three scenarios (Table 8). Of course, extention and depth of flooded roads were higher for higher return periods.

Herewith the damages, a central aspect to be discussed it the household recovering, wich allows incorporating social dimmensions in a strictly financial assessment. Table 9 presents some indicators which auxiliate at this discussion.

Table 9: Household income and recovering time

Attributes	5-year return period	25-year return period	100-year return period
Household median income - monthly (in €, 2010)	1161	1181	1248
Median participation of damages at annual income (in %)	43%	51%	46%
Median number of years necessary for the return to the initial welfare level	3,6	4,2	3,9

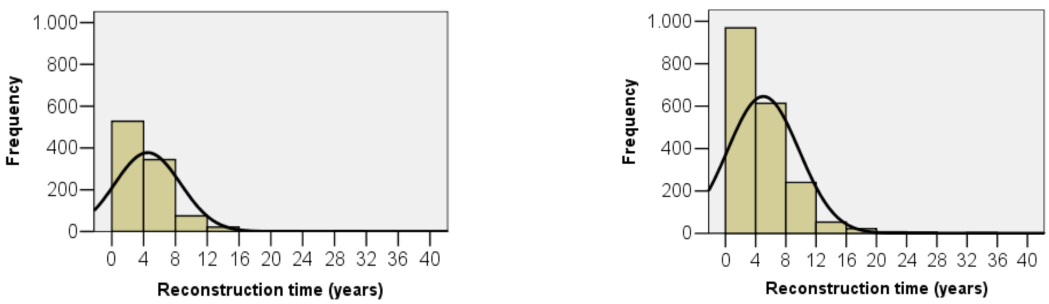
Note 1: includind damages to construction and to the content, including vehicles.

Table 9 shows initially the impact of damages on the annual household income (median values), in percentage. One notes that the part of the median damages on the household median income reduces for the 100-year return period scenario, which is at first grance an unexpected result. This can be explained by the possible incorporation, at this scenario, of new households with hicher income and also by the fact that for the 100-year return period event the flooded area increases, incorporating houses not flooded for lower return period events. This may have several implactions to the sample composition of flooded houses (e.g.: income distribuition, flood depth) resulting in trend changes on the damage part of incomes, in average terms.

Figure 7 shows the required time for the household to reacquire its welfare level previous to flooding. This was estimated considering that the household would allocate all of its income formerly spent in goods classified as luxe, for recomposing itens damaged by flooding and for recovering the construction.

Figure 7 points out that there is a big concentration of households which reconstruction time up to eight years no matter flooding scenarios. However, at the less frequent scenario, there is a bigger proportion of households at the class from 0 to 4 years. Figure 7 ilustrates, as previously commented, that the 100-year-flooding plain incorporates households with higher reconstruction capacity, which could be associated to higher flodding area and with depths, on average less elevated than those observed near to the river, due to topographic reasons.

It is wothwile to highlighted that the analysis of goods recomposition to the same initial conditions previous to flooding, in other words, to the level of average depretiation present before the event, was considered. Nonetheless, many households, for several reasons, possibly will opt for acquiring new goods, which will imply in a longer period of recovery than those shown at Figure 7. On the other hand, households can allocate a bigger part of their income in the recovering process than the one here adopted, the sacrifice of luxury goods. Also, households may possibly count on puclic and private support which are common in case of major floods, such as local tax reduction, donnations, voluntary work, etc. All these factors may contribute to speed up the recovering process. Finally, it is important to point out that in Brazil flood insurance is not available.



(a) Flooding scenario with TR = 5 years (b) Flooding scenario with TR = 100 years

Figure 7: Histogram with the frequency distribution of reconstruction time among flooded households

Households located at very frequently flooded areas may adopt strategies to a quicker recovery aiming at reducing the perspective of being flooded again before total recovery. Supposing that households flooded at a 5-year return period opt for a 3-year recovering horizon, they should commit at about 14% of their average annual income in the recomposition process. And still, they will face a probability of 48% of being flooded in the 3-year recovering spell. This is then a case of permanent precarious welfare conditions. One can suppose that people insist of living in those high flood risk conditions because they cannot afford the costs of moving.

The reconstruction capacity shows in which measure flooded household can manage the situation by their own means, without the need for external aid, becoming less vulnerable (Bollin *at al.*, 2003). However, as mentioned there is a possibility of public and private aid which is of difficult simulation.

Regarding the flood impact propagation in the urban economic network, it can be observed at the scenario of the highest impact that 11461 workers were flooded at their work place, and among those, 75% lived outised FA and SA.

Impacts can also be observed at the structure of expenditures effectuated by households. Figure 8 shows the impact of a 100-year-return period flood on average daily expenditures. The "daily" scenario would represent a day of normality in household expenditures. Expenditures were estimated around 3.8 million Euros, a level which considers an ordinary day of equilibrium in city market. Flooding occurrence represents a shock in the market which forces agents to reorganize their purchasing strategies. According to the kind of expenditure and to the occurrence of floods in households or other usual purchasing units, some consumers decide to postpone their consumption, representing an impact over the global consumption level.

In general terms, the shock representes a "disbalance" of 4% at the consumption level in the simulated urban area. It indicates a potentially lost consumption during one day of flood. The expenditure that more contributed for this performance was expenditure F, resulting in a 5% reduction in relation to the daily scenario. The other types of expenditure also showed a significant reduction, such as in the case expenditures B and D, but since they represent a smaller part of the total household's expenditures, they contributed with less intensity to the global result of consumption value.

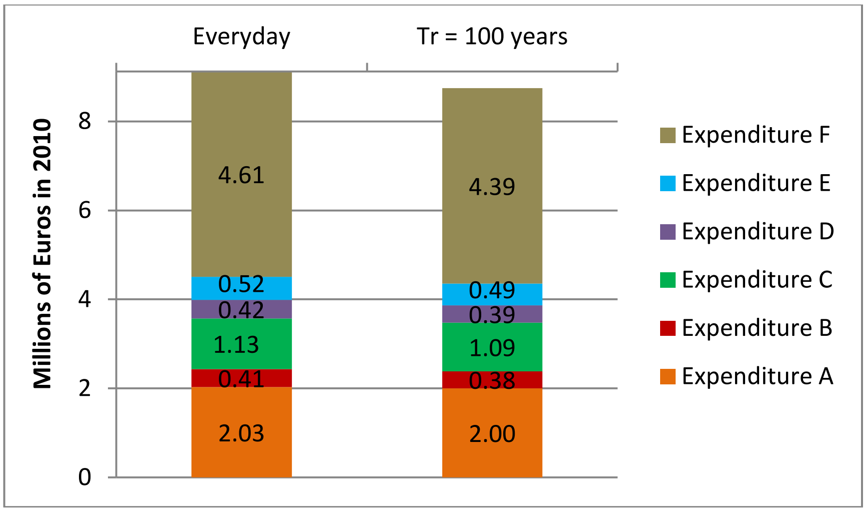


Figure 8: Consumption value of families according to the types of expenditure: daily scenario and 100-year-return period flooding scenario.

In Figure 9 it is illustratited the consumption reduction occurred in expenditure due to the houshold strategies of postponing consumprion, according to the three simulated scenarios. In the Figure XX it could be verified, as expected, that the fall in consumption is concentrated at FA and SA. In these regions, there is a 39% reduction of expenditures in a more restricted scenario in relation to the daily scenario.

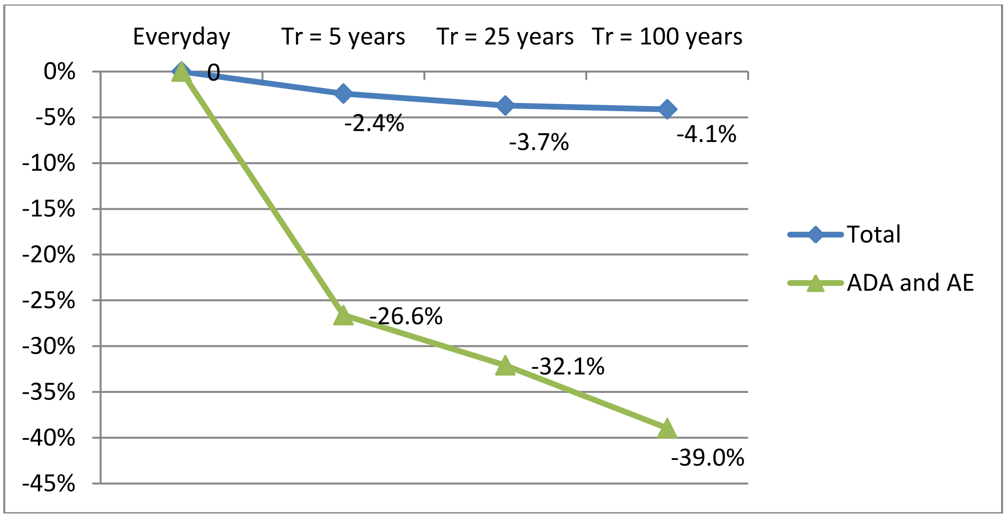


Figure 9: Family consumption variation for the total city area, FA and SA areas according to simulated flooding scenarios.

The consumption variation in families imply, obviously, alteration in sales made by firms which offer final products in the city market. Figure 10 shows a variation at sales value taken place at FA and SA, at the nodes and in all city considering the occurrence of a flood according to the three simulated return period scenarios.

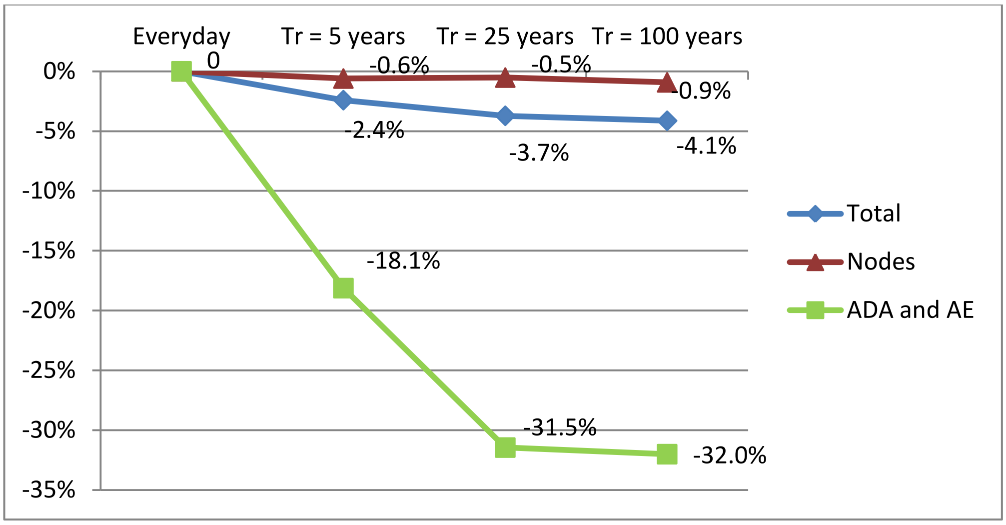


Figure 10: variation at sales value occurred in the prototype at the three flooding scenarios.

As expected, the decrease at the total sales value is coherent with consumption variations (Figure 9). The reduction on sales of firms located at FA and SA are, however, lightly lower than the fall occurred at consumption from households of the region. This difference occurres because flooded households may consume not only on FA and SA but also elsewhere. One can observe that even in the nodes a small reduction on sales occured, possibly due to consumption reductionof households from the FA area.

The simulations of traffic impacts inside FA and SA pointed out the raise on average journey time throught the flooded area from 6 minutes to 23 minutes. The average car velocity, in turn, suffered a reduction from 39 km/h to 10 km/h. In monetary terms, Table 10 shows costs associated to traffic disruption inside FA and SA.

Table 10: Values associated to traffic disruption (in Euros)

Item	Cost (in Euros 2000)	
	Without flood	Flood (TR = 100 years)
Time	100,573	357,558 (256% increase)
Fuel	25,511	52,516 (106% increase)
Pollutants	86	125 (46% increase)

4 Conclusions

The model presented here enabled to show the relations among flooding occurrence, direct damages to households, disturbances on expenditures and income flux, and the disturbances to traffic. These connections could be analyzed not only among those four elements, but also, spatially, among regions in the city area. The aggregation of these dimmensions is not so much common in the literature of flood damage assessment. Other aspects as the lost of value added by firms or the sale and consumption behaviors during the reconstructing period could also be assessed although not clearly incorporated in the present paper (see Cançado, 2009 for more details on these assessments).

The creation of a prototype created a space of simulation and analysis of several natural and social phenomena, which can possibly be beeter understood and parametrized before the empirical application of the method. Besides, this is a flexible method that can be constantly improved by new behavioral routines, data and information.

The methodological and theoretical discussion as well as the evaluation of results obtained with the simulations here performed point out the viability and the potentiality of applying the proposed method for the analysis of environmental impacts in a wide and multidisciplinary perspective, and also considering the relational dimensions which involve the processes. In this sense, it opens perspectives for future studies as the creation of dynamic analysis and the application of the method in case studies.

The agent developed at the prototype is essentialy reactive, presenting a behavioral routine before and other during and after the event. The methodology allows the creation of more complexe agents, with behavioral rules that can change during the simulation and according to their environmental perceptions. The introduction on the model of a network analysis of the network structure and configuration may lead to the assessment of network vulnerability to shocks and to the identification of more vulnerable nodes. Another point to be improved in the model, in the future, is developing a better integration between teh economic and the traffic networks, which would allow verifying more precisely and dinamicly the agent's mobility from the origin to the destination places, and the adoption of alternative roades in case of flood at the road system currently used.

This papers intends to advance on the understanding of complex processes which involve an interaction between nature and society. In a wider context, it searches the opening of ways of reflexion about relevant questions which could guide public policy formulations on flood risk management (economic, social, environmental issuesand which enables a mote harmonious cohexistance between constructed space and "natural" phenomena.

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