ABSTRACT
The present paper describes the main results of an on-going research aiming to develop standard flood damage data in the form of generic flood-damage curves. This type of curve allows estimating flood damages from the depth of inundation. Although the research project encompasses flood damages on different urban land use activities (residential, commercial, services and industrial land uses), the paper focus on residential flood damage information. The empirical data used on this research was obtained from systematic surveys performed in the city of Itajubá, a town with 85,000 inhabitants located in the Sapucaí river valley in the South-eastern region of Brazil, during the year of 2002. The survey consisted in interviewing residents in the Itajubá flood prone urban area in order to develop a data base characterizing the social class, the building fabric, the contents (inventory items) and the damages caused to dwellings by a reference flood event, the 2000 flood event. During this event, the town had more than 70% of its urban area flooded for three days and, in some densely urbanised areas, the depth of water was superior to three meters. The FDC curves obtained show relatively high damage according to the submersion depth considering the Brazilian context. This issue suggests that inhabitants can rarely recover, in the short time, from all the harm caused by flooding.

KEYWORDS
Flood damage; flood control; flood-damage curves

INTRODUCTION
Implementation and operation of flood control solutions require high investments. Fixed costs on implementation are quite elevated and marginal costs are almost near zero. This can result on a long term return of the invested capital. Therefore, investments applied on this sector are, usually, public. Theoretical and empirical researches have been done focusing on promoting the development and application of economical efficiency principles. They should be capable of guiding the decision of public sector about the interest of the investment, as well as becoming a support for choosing the most effective alternative on flood control, which will bring better benefits. In Brazil, evaluation and decision of the investment alternatives which involve those objectives are, most of the time, done without a detailed economic-financial analysis. This is mainly due to the lack of systematic information about flood damages (Salgado, 1995).
The present paper reports and discusses the results of a study on the development of a methodology to get flood damage curves translated into monetary values, based on the depth of flood (damage curves vs. depth of inundation), considering the different kinds of urban land-use classified by sectors: residential, commercial, for services, industrial and that providing infrastructure for public services. Curves such as those can be of great value in evaluation studies on flood control alternatives which have financial and economic analysis as reference. They can provide, as well, an important synthesis of the information on the potential flood damages. Based on this, the use of these curves can be quite wide in areas such as urban planning, elaboration of flood emergency plans, and local protection of vulnerable areas, among others.

In this article, the main point is focused on the development of damage curves vs. flood depth for the residential sector. The empirical data used on this research was obtained from systematic surveys performed in the city of Itajubá, in the Sapucaí river valley in the Southeastern region of Brazil, during the year of 2002. The flood event which happened in the same city in January, 2000, was used as the flood reference event for the survey.

FLOOD DAMAGE TYPOLOGY
Flood damages are usually divided, in a primary level of classification, in tangible and intangible and in a secondary level, in direct and indirect. The distinction between tangible and intangible is related with the difficulty in establishing a cost evaluation procedure of the damage. The harm associated to physical damage caused over a construction which has been flooded can be estimated, for example, by means of evaluating the cost of restoring it to the state it had before flooding (tangible damage). On the other hand, stress or anxiety conditions caused by flooding events or by expecting them to happen are damage examples which are hard to evaluate economically and are usually classified as intangible.

Direct damage result from direct contact of flood waters with commodities and therefore being related to the physical deterioration of such commodities. Indirect damage is originated by inconveniences caused in the production system as a consequence of flooding events. This can lead to the reduction of the economic activities, as well as the lost of tax income, costs of emergency services and civil defence, cleaning costs of the affected areas, properties value loss, raise of insurance costs whenever they exist to cover the damages caused by the flooding, unemployment or wage reduction, among others.

The evaluation of indirect damage requires special attention over the fact that some losses can be circumstantial once happening, eventually, compensations among economic agents during the crisis period created by the flooding or for just one agent along the time. On the other hand, indirect damage can spread over bigger areas than the ones directly affected by the flood. Such is the case of eventual perturbations over the production processes in industries established in other areas and even in other countries when dependence on the products from the affected areas by the flood exists.

EVALUATION OF FLOOD SOCIO-ECONOMIC IMPACTS
The evaluation of socioeconomic impacts from floods can be done according to three different methodological procedures known as conceptual methods, determinist methods or direct evaluation and, vulnerability analysis (Hubert & Ledoux, 1999)
Conceptual methods, usually based on the concept of the consumer surplus, incorporate economic analysis techniques developed to value environmental goods or the harm caused by environmental pollution, such as the methods of contingent and hedonic evaluation. The market is supposedly capable of incorporating flood risk and one may devise adequate procedures in order to obtain estimates of the value attached to that kind of risk. One of the main vantages attributed to such methods is their capability to incorporate an estimation of the damages caused by floods, either tangible or intangible. Nevertheless, due to the difficulty on the implementation and the uncertainties associated, this kind of studies has been developed more frequently on an academic context.

Vulnerability analysis intent to establish relationships between the randomness of the hydrologic event (hydrologic risk), the exposed commodities, the potential damage resulting from the occurrence of a hydrologic event of certain magnitude and the available resources to face the risk (planned anticipated actions, physical skills of exposed individuals, financial means to recover affected areas, insurance coverage,...). Vulnerability analysis is usually done based on the use of indicators. Some examples of indicators frequently used can be found in Hubert et Ledoux (1999); examples of procedures to analyze vulnerability can be found in Agence de l’Eau e Ministère de l’Amenagement du Territoire et de l’Environnement (1998).

Direct evaluation methods are based on the statement of a detailed and precise description of the set of impacts generated by flooding, considering the inventory of damage in affected zones (a posteriori evaluation) or the construction of damage scenarios starting from the detailed definition of pathologies caused by flooding (a priori evaluation). Functional relations between flood damage and hydraulic variables associated to submersion depth were established, such as depth, runoff velocity and duration. Direct evaluation can comprehend direct damage as well as indirect, even though substantial methodological progress has happened mainly in the case of direct damage.

The construction of damage curves vs. submersion depth (FDC) is quite difficult when it is considered the variability of the exposed damage, even for just one sector such as the residential one. One of the most detailed construction works of such kind of function was carried out for England and Wales (Penning-Rowsell and Chattrton, 1977) for the residential, commercial, services, industrial and agriculture sectors, based on the a priori analysis of damages. Another more recent example is the work of Dutta, Herath and Musiake (2003).

**DEVELOPMENT OF THE METHODOLOGY**

As mentioned before, two main approaches can be adopted for the construction of the damage curves vs. submersion depth (FDC curves): (i) they can be developed from data synthesis over real damage obtained by sampling on devastated areas (e.g.: Torterotot, 1993), or (ii) by the estimation of hypothetical damage, a priori established, with base on expertise over the potential effects of floods on the construction and their content (e.g.: Penning-Rowsell & Chatterton, 1977).

The methodology presented in this paper tries to combine both views, considering, on the one hand, the statement of an empirical reference for the construction of the curves and, on the other hand, the search of generalizations which can allow, in the future, the use of similar curves in different contexts. In order to get there, there was made the identification of the damage occurred in an affected area, caused by a reference flooding event, through the
application of questionnaires, aiming to obtain a representative sampling of the different reported submersion depths and of the different types of land use present in the area.

In the residential sector, flood damage are related, among other factors, to the quality of the building, the constructed area, the state of the building and its content, characterized by the quantity, kind, quality and age of durable exposed commodities such as furniture, electric and ornamental devises. Considering that these factors are related to the living standards of the inhabitants it is expected that FDC curves present a certain dependency of this variable. It turns out to be relevant to search the possible functional associations between FDC curves and the factors mentioned before, which are potentially linked to flood damage.

In the present paper, the survey was done based on the obtained data through the application of questionnaires. The social status of the inhabitants, which was obtained through the application of the Criterio Brasil (ABIPEME, 2003) was used as an indirect indicator of welfare status. This criterion (Criterio Brasil) adopts five socio-economic classes (A, B, C, D, E) in a decreasing order of welfare and living standards based on information related to comfort household items (durable commodities), to the education level of the of the adults in the family.

In the present research, questionnaires were conceived in order to allow a detailed description of damage caused by floods on dwellings and their content. Each questionnaire is associated to one household, which is characterized by the building standard, flood depth and socio-economic class of their inhabitants.

The damage on buildings is estimated from repairing costs of damage caused by floods in the form of a restoration budget. With the Brazilian norm NBR71721 as a base 4 different levels of building standards were established: high, normal, low and laboring class. The building standard is classified considering the nine more important items: type of indoor and outdoor wall covering, kitchen and bathrooms building material, kitchen and bathrooms accessories and the main material on windows and doors.

The evaluation of the damages on the content of the households is entirely based on a priori analysis. For each social class, a typical dwelling project was defined based on Brazilian standard projects of dwelling units for different income rates, as well as on empirical data of the distribution of built areas for each social class obtained by the survey. Content standards (furniture, electric appliances, ornamental items, etc.) were defined on the base of social class inventories standards as well as on a systematic research on market price distributions for different household furniture and equipments. The empirical data obtained by the application of the questionnaires allowed evaluating the adequacy of the established standards, correcting them out when needed. The estimate of damage to the content according to different submersion depths was based in flood susceptibility curves proposed by Penning-Rowsell and Chatterton (1977). The residual values of the inventory items were established taking into account their life cycle and residual values which were also related to the social classes.

APPLICATION OF THE METHODOLOGY IN THE CITY OF ITAJUBA
Itajubá presents a high vulnerability to inundations since most of its urban area is located on the Sapucaí river flood plain. It is estimated that almost 30,000 inhabitants of a total population of 84,135 inhabitants are living in areas which are frequently flooded (Lima,
2003). During the last 128 years thirteen severe inundations were registered in its urban area (IGAM, 1999). At Itajubá, the Sapucaí River Basin has a surface of 800 km².

During the peak discharge of the January, 2000 event, of which the resulting flooding serves here as a reference, more than 70% of the urban area was flooded. Flood depths reached more than 3 meters, in certain area, and the flood duration was greater than 3 days (Figure 1). Four deaths were reported and at about 20,000 people were left homeless. According to Vianna et al, 2001, this event has a return period of 100 years.

Figure 1. Itajubá: view of the central area during the 2000 flood.

The city of Itajubá was chosen for the application of the methodology, already described, taking into account its development level, the diversity of its urban land use and the characteristics of the 2000 inundation.

In August of 2002, 469 questionnaires were applied for the residential sector and around 200 for the commercial, services and industrial sectors, all of them conceived and carried out according to the methodology here described. A preliminary analysis of the distribution of the constructed area as function of the social class (Figure 2) indicates the existence of a correlation between those variables. Similar analyses were performed for the building quality criteria and social classes, leading to similar associations. These results seem to allow the use of social classes as a reference to estimate flood damage.

Based on those results the construction of the curves were done with the damages expressed in R$/ m² (R$: Brazilian currency “Real”, R$ 3.50 = 1 euro) for the constructed area of the dwelling expressed in m². A FDC was constructed for each social class. Statistical analyses (hypothesis tests, variance analysis) were carried on in order to verify if the four curves obtained for social classes A, B, C and D were statistically different. These analyses led to gathering together the damages related to classes A and B in one curve as well as C and D in another curve (Figure 3 and 4).
Curves shown in Figure 3 and 4 turned out to be a mixture of empirical data (damage on constructions) and of theoretical models (damage on content). Even having a priori components the dispersion shown by data is rather high, illustrating uncertainties associated to this kind of methodology.

![Figure 2](https://iwaponline.com/wpt/article-pdf/1/1/wpt2006022/383459/22.pdf)

**Figure 2.** Itajubá: empirical distribution of dwelling area for social classes A and C.

Regression analysis allowed defining equations for both curves. In the case of curve associated to social classes A and B, fitted equation, with a correlation coefficient $r = 0.88$, became:

$$D = 130.9 + 56.3\ln(y)$$

where:

- $D$: estimated damage per unit of area, in R$/m^2$;
- $y$: local depth of inundation, in m.

For social classes C and D, the fitted equation, with a correlation coefficient $r = 0.61$, is:

$$D = 68.6 + 21.6\ln(y).$$

Tanking into account average revenues in Brazil, the obtained FDC curves show relatively high damage according to the submersion depth. For example, for a flood depth of 1.0 m considering a household with 100 m$^2$ constructed area the total direct damage (building and content) would reach R$ 13,100.00 (3,750.00 euros) in the case of A and B social classes or of R$ 6,900.00 (1,970.00 euros) for social classes C and D. Average revenues for social classes A and B, in monthly terms, are 1,000 euros (class B) and 4,500 euros (class A). The same figures regarding social classes C and D are, respectively, 530 and 242 euros.
These results suggest subsequent questions that are still to be better evaluated in this research:

- Confronting results based on the FDC to the damage declared by the inhabitants during the application of the questionnaires;
- Investigating the hypothesis which states that inhabitants can rarely recover, in the short time, from all the harm caused by flooding.

Another relevant aspect of costs due to inundation regards indirect or intangible damage. These kinds of damage which may constitute a significant part of total damage caused by flooding are not addressed by the methodology here described. It is, therefore, clear that estimations only centred in direct damages may lead to underestimation of total costs due to flooding. For practical purposes, there are some rules of thumb consisting of majoring direct
costs by a percentage which is arbitrarily stated in order to include indirect or intangible damage. These very and highly uncertain methods reveal the need of further research, particularly in the Brazilian context, where few research works have been done on the subject.

CONCLUSIONS

Among the evaluation methodologies for the social-economic impacts due to inundation there are the FDC, an instrument well adapted to the economic-financial estimation of resulting costs of direct damage from inundations. This kind of curve is typically employed in cost-benefit analysis of different flooding control measures. Besides, the kind of information obtained all through its application can contribute, in a significant way, to the use of other instruments and politics aiming flood control the reduction of the related impacts, such as:

- the improvement of urban management instruments considering flooding risks, such as the urban master plans and land use directives which should incorporate flooding risk;
- the improvement of instruments for crisis management through the elaboration of emergency plans;
- the improvement of methodologies to analyze risk and vulnerability to floods.

In this article, a methodology to develop FDC curves was presented as well as some of the results of its application in a case study in the city of Itajubá, Brazil. Afterward applications of those curves to evaluate some alternatives for flood control for the city of Itajubá case should, in the near future, supply elements to achieve a more accurate discussion on the benefits and limitations of this kind of study.

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Flood-damage curves: Methodological development for the Brazilian context