



**HAL**  
open science

## **Regional hydrological models for distributed flash-floods nowcasting: towards an estimation of potential impacts and damages.**

Guillaume Le Bihan, Olivier Payrastre, Eric Gaume, David Moncoulon, Frederic Pons

### ► **To cite this version:**

Guillaume Le Bihan, Olivier Payrastre, Eric Gaume, David Moncoulon, Frederic Pons. Regional hydrological models for distributed flash-floods nowcasting: towards an estimation of potential impacts and damages.. FLOODrisk 2016, 3rd european conference on flood risk management, Oct 2016, LYON, France. 10p, <10.1051/e3sconf/20160718013>. <hal-01449510>

**HAL Id: hal-01449510**

**<https://hal.science/hal-01449510v1>**

Submitted on 30 Jan 2017

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

# Regional hydrological models for distributed flash-floods nowcasting: towards an estimation of potential impacts and damages.

Guillaume Le Bihan<sup>1</sup>, Olivier Payrastre<sup>1</sup>, Eric Gaume<sup>1</sup>, David Moncoulon<sup>2</sup> and Frederic Pons<sup>3</sup>

<sup>1</sup>LUNAM Université, Ifsttar, Département GERS, Lab. Eau Environnement, Route de Bouaye, CS4, 44844 Bouguenais cedex, France

<sup>2</sup>CCR, 157 boulevard Haussmann 75008 Paris, France

<sup>3</sup>CEREMA DTer Sud Est, Pole d'Activités Les Milles, Avenue Albert Einstein, CS 70499 Aix en Provence Cedex 3, France

**Abstract.** Flash floods monitoring systems developed up to now generally enable a real-time assessment of the potential flash-floods magnitudes based on highly distributed hydrological models and weather radar records. The approach presented here aims to go one step ahead by offering a direct assessment of the potential impacts of flash floods on inhabited areas. This approach is based on an a priori analysis of the considered area in order (1) to evaluate based on a semi-automatic hydraulic approach (Cartino method, Pons et al. 2014) the potentially flooded areas for different discharge levels, and (2) to identify the associated buildings and/or population at risk based on geographic databases. This preliminary analysis enables to build a simplified impact model (discharge-impact curve) for each river reach, which can be used to directly estimate the importance of potentially affected assets based on the outputs of a distributed rainfall-runoff model. This article presents a first case study conducted in the Gard region (south eastern France). The first validation results are presented in terms of (1) accuracy of the delineation of the flooded areas estimated based on the Cartino method and using a high resolution DTM, and (2) relevance and usefulness of the impact model obtained. The impacts estimated at the event scale will now be evaluated in a near future based on insurance claims data provided by CCR (Caisse Centrale de Réassurance).

## 1 Introduction

Hydrometeorological forecasting is an essential component of real-time flood management. The information it provides is crucial for crisis managers to anticipate and quantify the floods which will hit the territories at risk. In the particular case of flash floods which may affect very small watersheds spread over the territory, suitable forecasting systems are still currently under development. {examples et bibliographie à développer: US, UK.} In France, some approaches devoted to flash-flood forecasting have also been developed in a close from operational framework: AIGA system {citep{Lavabre2005, Javelle2014}}, PreDiFlood project {citep{Naulin2013}}. These developments often rely on highly distributed hydrological models and on radar based QPEs or rainfall nowcasts as input information. They provide indications on possible flood magnitudes, but are still rarely designed to directly account for the possible associated impacts on society. The translation of flood magnitude in impacts requires, indeed, a detailed knowledge of the vulnerability of the considered areas, which is generally well developed and shared at a very local scale (local authorities, inhabitants of flood areas,...), but much more difficult to assess and incorporate at the much larger scale at which hydrometeorological forecasting systems are generally

implemented. Considering that these systems are designed to monitor a very large number of small rivers spread over large territories, a large number of simultaneous alarms may be generated in case of a significant rainfall event. Thus, providing directly an information on local vulnerabilities and associated possible impacts would probably be helpful for coordination managers to have a faster evaluation of the situation and to focus their actions on the most problematic situations.

The approach developed in this paper aims to enable a direct evaluation of flash flood impacts on inhabited areas based on an hydrometeorological simulation chain. The question of impact prediction has already been addressed in previous works conducted at IFSTTAR {citep{Versini2010, Naulin2013}}, and were up to now mainly focused on road inundation risks. The aim of the new approach presented herein is now to account for risks of flooding in settlements. The methodology developed is based on an comprehensive analysis of the study area in order to build an impacts model on each river stream incorporated in the hydrometeorological simulation chain. This analysis is based on simplified 1-D hydraulic simulations to evaluate the extent of the flooded areas for different discharge levels. The impacts models are then used to directly translate the discharges

<sup>a</sup> Corresponding author: author@e-mail.org

simulated by the rainfall-runoff model into possible associated impacts.

Even if the approach developed may appear relatively straightforward, its application on a very detailed stream network including small watersheds prone to flash floods, may be too much time consuming to enable an application at a large scale (more than 100000 km<sup>2</sup>). Therefore, the challenge has been here to define a very simplified and automatic procedure for the building of the impacts model, with the objective to limit its implementation time to a reasonable level. This objective of simplification has been considered as a priority, placed before the accuracy of flooded areas and associated impacts evaluated. In other words, a decrease of the quality of the impacts model has been accepted to guaranty its applicability at a large scale including a very detailed stream network. **{Bibliographie à développer sur l'hydraulique appliquée à grande echelle}**

The content of the article presents the application of the method on a preliminary case study, and a first evaluation of the quality of the impacts model obtained, provided the relative large level of simplification of the estimation procedure. The article is organised as follows: the first section presents the application case study and the datasets involved in the study, the next section presents the methodology developed for the fast computation of flood areas and the associated building of impacts model. This section also describes the procedure used for the evaluation the results. The results are presented in section 4 and discussed in section 5. Lastly, section 6 presents conclusions of this work.

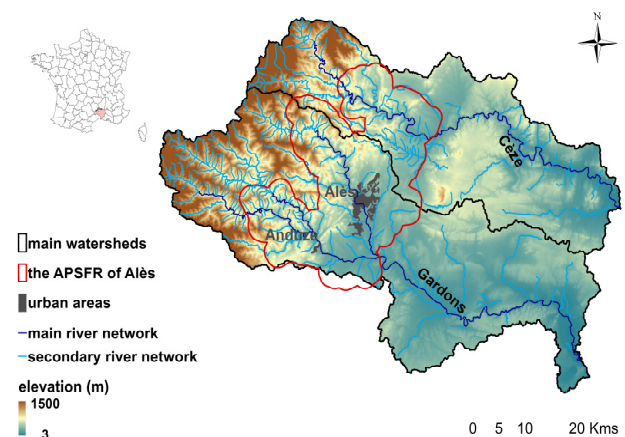
## 2 Presentation of the case study

### 2.1 The region of Alès in the Cévennes area, south eastern France

The study has been focused here on a territory of 1990 km<sup>2</sup> including the town of Alès in south eastern France. This area is located in the core of the Cévennes region, well known to be prone to intense flash floods. Moreover, this area has been identified during the implementation of the EU flood directive as one of the areas having the most significant vulnerability to floods over the whole French territory. For this reason, it was included in the list of Areas with Potential Significant Flood Risk (APSFR) selected for the application of the flood directive. This vulnerability is mainly related to the

presence of the town of Alès, but also to other highly vulnerable small towns such as Anduze (see figure1).

This region is represented on figure 1, showing the exact limits of the APSFR of Alès. This territory is part of two main watersheds: the Gardon d'Alès and the Cèze rivers. These two main rivers have their upstream course in the Cévennes mountains, and reach in their downstream part a plateau zone with limited slopes. The APSFR of Alès is located just in the transition zone between the mountainous and plateau areas. Therefore, this case study includes a large variety of river beds configurations including very steep and narrow valleys, up to relatively flat and wide plains. Some statistics about the river beds characteristics are provided in table 1.



**Figure 1.** Location of the APSFR of Alès territory in the Gardon and Cèze watersheds.

One part of the river network in this territory is already covered by the French national flood forecasting system. However, significant damages associated with flash floods also frequently occur on the secondary river network which is currently not monitored. A detailed analysis of the features the river network, based on a DTM treatment, shows that it includes 400 km of river streams having an up to 5 km<sup>2</sup> upstream catchment surface, divided in 192 river reaches (a river reach being defined as the portion of river located between two confluences), among which only 70 reaches (132 km) are covered by the current flood forecasting system (see main network figure 2). This illustrates both the relevance and the difficulty associated with the implementation of complementary flash flood forecasting systems on the very dense stream networks prone to flash floods. Even if the extent of the case study considered here is not very large, the quantity of rivers courses to be integrated in the

Location	Bed slope (%)		River bed width (m)		Floodplain width (m)	
	average	min - max	average	min - max	average	min - max
Main network	0.48	0.22 - 1	37	16 - 84	470	120 - 1670
Secondary network	3.41	0.17 - 20	7	2 - 34	430	60 - 3130

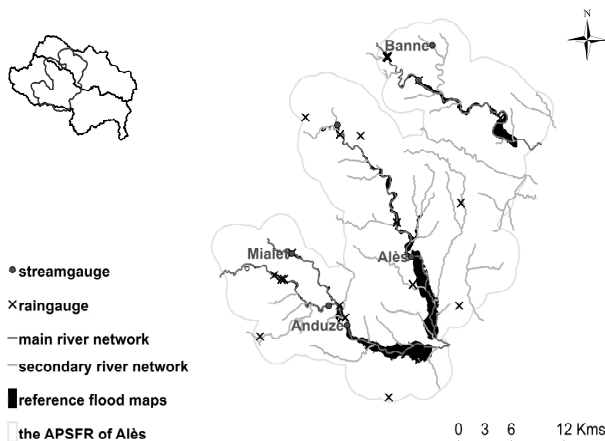
**Table 1.** Characteristics of the river network considered in the case study (extracted from SYRAH database).

models is very significant and may cause difficulties associated with lack of time available to implement and test the models. It is noteworthy that a elementary catchment surface of 5 km<sup>2</sup> is represented here, and that decreasing this surface would lead to highly increase the quantity of river courses to be considered. This finally illustrates the importance to define very simple and efficient approaches for the implementation of flash flood forecasting, as far as the objective is to apply such approaches in areas of relatively large extent (largely exceeding the extent of the case study considered herein). This point is particularly important herein since the main objective is the definition of a flash flood impact model based on hydraulic simulations, which may represented a much time consuming task.

## 2.2 Available data

### 2.1.1 Digital Terrain Model

The implementation of the impacts model has been based on a 20m resolution DTM produced in 2007, which altimetric accuracy is less than 20 cm in clear areas, and less than 1 m in forest areas. This DTM was interpolated on a 5 m resolution grid for the purpose of the study. Therefore, the quality of the terrain information used herein remains relatively limited: the use of a real 5 m resolution DTM obtained fro Lidar measurements would probably lead to results of better accuracy (*{reference a inclure sur les effets de la resolution des MNT}*).



**Figure 2.** River network considered in the APSFR of Alès (5 km<sup>2</sup> upstream catchment surface), coverage of reference flood maps and position of available streamgauges.

### 2.1.2 Rainfall and discharges

The region is equipped with relatively dense streamgauge and raingauge networks, complemented with three hydrological radars. The positions of stream gauges are presented on figure 2. Thanks the OHMCV observatory, this data is carefully checked and can be considered as exceeding conventional quality standards. However, given the limited possibilities to make direct flow measurements during intense flash floods, the rating curves are often extrapolated, with consequently a large

decrease of the quality of estimated discharges for high water levels.

### 2.1.3 Flood quantiles

The regional SHYREG database (*{reference a inclure}*), providing flood quantiles of different return periods (from 2 to 1000 years) on all the river network, has been used herein for the implementation of the impact model. This database relies on the combined regionalization of parameters of a rainfall stochastic generator and of a distributed hydrological model. It has to be noticed here that both the work of regionalization and some specificities of watersheds such as kartsn urban areas, snowmelt, or hydraulic structures (dams) may reduce the reliability of SHYREG data.

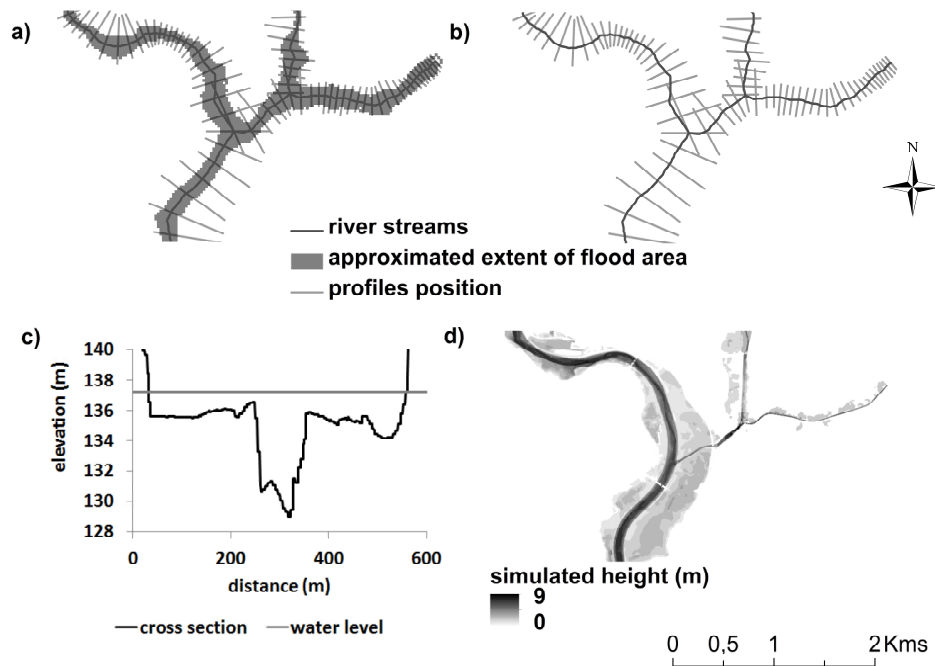
However, the accuracy of information on flow frequency is not crucial herein for the implementation of the impact model (only the discharge values are used and not the information on frequency): it just enables to derive flood maps for discharges values of relatively homogeneous magnitude in all the considered area.

### 2.1.4 Reference flood maps

Thanks to the recent application of the EU flood directive in the considered case study, a great effort was put on flood cartography, enabling to produce detailed maps of probable flood extent for three reference events: a common event (30 year return period), a medium event (300 year return period), and a large event (exceeding a 1000 year return period). Therefore, 3 reference flood maps are available, which have been carefully validated using all the available information (including the extent of the exceptional september 2002 flood). These maps will be used for the validation of the flood areas evaluated for the purpose of the flash flood impacts model implementation. Unfortunately these maps, presented on figure 2, were produced on one part only of the river network considered herein which limits the validation possibilities: the river network covered represents 192 km (among 400 km included in the case study) and includes 101 river reaches (among 192).

## 3 Methodology

As indicated in introduction, the approach developed herein is based on a pre-evaluation of the extent of flooded areas for different discharge levels. This evaluation should be obtained in an as simple and automatic as possible way in order to enable its implementation on a large number of river reaches. Therefore, it has been based on a 1D hydraulic model run in permanent mode, and implemented automatically based on a high resolution DTM. This work has been based on the Cartino software (developed by Cerema), enabling to build the structure and run the model in a iterative way until satisfactory results are obtained. The Cartino parameters have been adapted to the objectives purchased herein, and some additional post treatments



**Figure 3.** Overall principle of the computation of flood maps based on CartinoPC software: a) input information (position of river streams and approximated extent of flood area), b) position of profiles integrated in the 1-D model, c) computation of water levels (1-D hydraulic model), c) map of water heights obtained after post-treatment.

have been added to remove the most identifiable inconsistencies in the outputs.

The whole procedure will be presented hereafter in the following way: first, the overall principles of the Cartino software will be presented; then the implementation details (parameters, etc) will be provided; the additional post treatments introduced will be presented; and lastly, a short discussion about the main remaining sources of errors will be proposed.

### 3.1 The Cartino software

The Cartino software enables to build and run a 1-D hydraulic model on a river network based on a high resolution DTM, to finally obtain a simplified evaluation of potential flooded areas for a considered discharge value. The computation is achieved in 3 main steps presented in figure 3: 1 - a pretreatment module for the definition of the position of cross sections, 2 - a module running the 1-D hydraulic simulation for the computation of water elevations, and 3 - a post treatment for the estimation of the extent of flooded areas and associated water levels.

The first two modules are run in an iterative way to optimize commonly the couple width - distances between cross-sections, with the objective to finally ensure that all cross sections are wide enough for the considered discharge and that no overlapping is present between two successive cross sections. This procedure is initiated based on the position of the river reaches and a first possible extent of the flooded area (provided as input) which is used to estimate a default width of each cross section. The associated distances between profile widths are then defined as a proportion of each profile widths (to be

defined as input parameter). After each run, the width of each profile is checked according to the computed water elevation, and it is enlarged if necessary in a proportion defined as input parameter. Distances between profiles are adapted in consequence. The roughness coefficient is also defined as an input parameter, and the same value is used for all computations.

The choice of the input information (default extent of flooded area, parameters values) have a great impact on the results and on the computation times. For instance, a too large default flood area or a too fast increase of profile widths may lead to incorporate in the model some depressions located nearby the river bed, but not connected to it for the considered discharge (see figure 4): this leads both to simulate flooded areas of too large extent at the considered profiles, and to decrease the altitude of the simulated water level, with a repercussion on the simulations results at the upstream profiles (possible under estimation of water level). On the other hand, a too narrow initial flood area and/or too slow increase of profile width will highly increase the computation times.

To cope with these difficulties, the software offers the opportunity to change the position and/or modify the widths of any profile after a first iterative run.

### 3.2 Specificity of application of Cartino for the purposes of the study

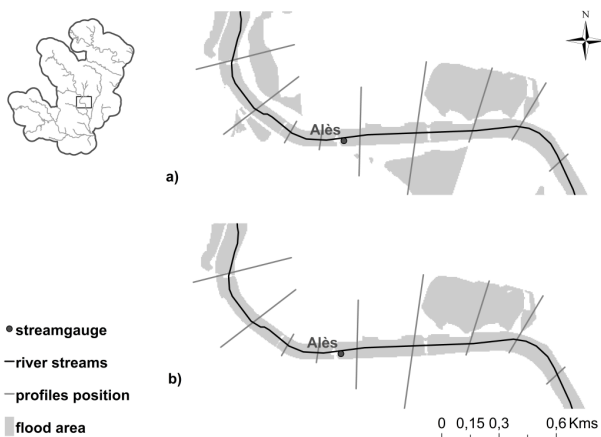
For the purpose of building a comprehensive impact model on detailed river network considered in the case study, the objective is here to obtain a catalogue of flooded areas corresponding to different discharge quantiles. A wide range of quantiles has been selected to

represent the entire panel of possible flood magnitudes: based on the SHYREG database, discharges corresponding to return periods of 2, 5, 10, 20, 50, 100, 200, 500, 1000 years have been selected for each river reach. For a given return period, the flooded areas has been computed for all river reaches in the region.

Depending on the flood quantile, the simulated flooded areas may be limited to the river bed or extend up to the entire floodplain. One crucial aspect is to determine as accurately as possible the discharge level at which the inundation of the floodplain begins. For this purpose, the Cartino software was applied in the following way:

- application first for the smallest discharge values (first run for T=2 years), using a narrow initial river profile widths and progressive increase in profiles widths to be able to estimate as accurately as possible the limits of the flooded river bed.
- application to the next discharge quantile based on the results obtained for the immediately lower discharge as initial river bed width. -

A careful check of the results after each computation also enables to eliminate some errors related to wrong estimations of the shape of some cross sections, mainly associated with the limits of DTM information used as input: bridges still appearing in the DTM, remaining noise due to dense vegetation. This verification was based on the comparison of the wetted area of the successive cross sections, with an automatic removal of cross sections appearing as inconsistent with the immediate downstream and upstream cross-sections..



**Figure 4.** Illustration of additional post treatments applied to the Cartino results: a) initial Cartino results, b) after removal of disconnected areas.

### 3.3 Additional post-treatments

Despite the aforementioned precautions, some evident inconsistencies still remain locally in the computed flooded areas: flooded areas disconnected from the river bed, some areas included in the estimated flood extent for a given discharge and not for the larger one. Thus, a simple post-treatment was applied to the catalogue of flood maps to ensure a better overall consistency of the results. This enabled to:

- systematically remove disconnected flooded areas (see figure 4).
- systematically include each flooded area in the ones computed for larger discharges.

### 3.4 Remaining sources of uncertainty

Although some precautions were taken to enhance the quality of the results, important limits and sources of errors remain, affecting the quality of the results. These remaining errors are mainly related to the limits of the procedure applied herein, which was to guarantee a fast application and to accept the associated unavoidable errors. These errors are mainly due to:

- wrong representation of topology and characteristics of river bed due to the automatic definition of position of profiles and also to the limits of topographic information ,
- absence of representation of friction losses due to bridges and other singularities
- choice of a fixed Manning roughness coefficient, equal to 0.05
- absence of representation of dynamic effects due to the systematic computation in steady state

For these reasons, it is important to keep in mind that the information produced here cannot correspond exactly to the real extent of flooded areas. It represents a simplified estimation giving on order of magnitude of the level of flooding and enabling some comparisons at a regional scale.

### 3.4 Evaluation of the results

#### 3.4.1 Comparison with reference flooded areas

The remaining error levels on flooded areas can be evaluated thanks to the availability of maps produced for the application of the EU flood directive, which were used as reference information.

For this purpose, intermediate inundation maps were added to the catalogue using the same flood discharge values as for the EU directive cartography, corresponding to return periods of respectively 30 years and 300 years. They were then compared with the reference flooded areas on each river reach based on the following procedure: the common surface ( $S_c$ ) between estimated surface ( $ES$ ) and reference surface ( $RS$ ) was first considered (see figure 5), enabling to define the excess ( $Se$ ) and default ( $Sd$ ) surfaces as follows:

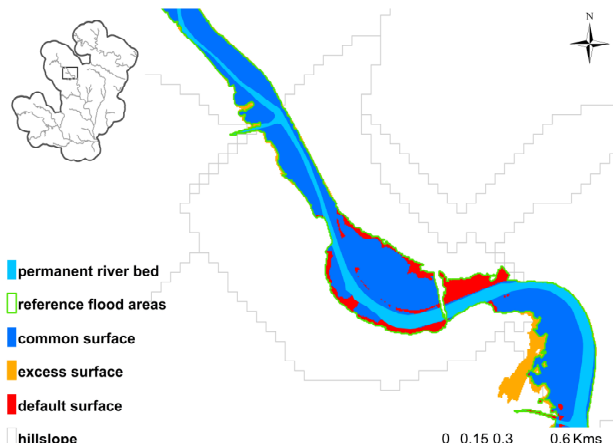
$$ES = S_c + Se \quad (1)$$

$$RS = S_c + S_d \quad (2)$$

A synthetic incoherent surfaces proportion ( $ISP$ ) was then computed, representing the relative proportion of  $Se$  and  $Sd$  if compared to reference surface:

$$ISP = (Se + S_d) / (S_c + S_d) \quad (3)$$

It has here to be noted that the portion of the river bed being permanently wet (represented on figure 5) may increase the value of  $Sc$  when this area is not crucial for flood risks evaluation (absence of vulnerability). For this reason, this area was systematically removed from estimated (ES) and reference (RS) surfaces before the computation of  $Sc$ ,  $Se$ ,  $Sd$ , ISPs, and therefore the evaluation proposed here is strictly limited to non-permanently inundated areas.



**Figure 5.** Illustration of comparison between estimated and reference inundated areas: definition of common surface ( $Sc$ ), excess surface ( $Se$ ), and default surface ( $Sd$ ).

### 3.4.2 Comparison with rating curves established at stream gauges locations

The presence of stream gauge stations with calibrated rating curves offers the opportunity to evaluate the accuracy of stage-discharge relation estimated by the model in the associated cross sections. This comparison was achieved after a careful selection of cross sections which better correspond to the location of the stream gauges. However, considering that the distances between profiles are variable and may reach up to 100 m, a perfect correspondence could not systematically be achieved {alternative: an additional profile was added if necessary at the exact location of the gauging station}.

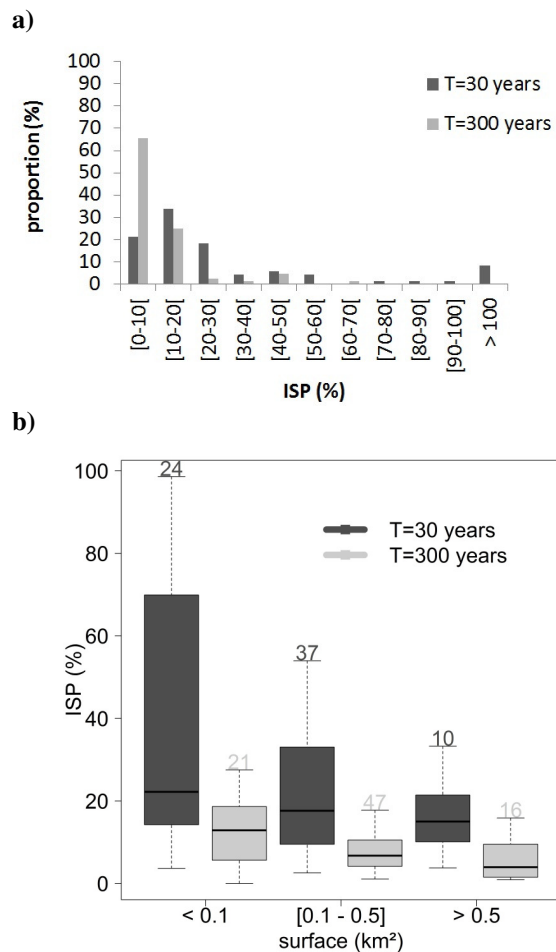
### 3.4.3 Comparison of impacts curves obtained

The last evaluation step was based on the computation and comparison of impact curves based on the inundation map catalogue obtained for each river reach. The impacts curves were computed herein in a simple way by counting the number of buildings present in the estimated flooded areas according to the IGN BDCarto database. These impact curves cannot be directly validated, but they were nevertheless compared between river reaches in order to verify whether the preliminary objective of the methodology developed herein - i.e. providing a hierarchy of possible impacts on a relatively large area - was achieved by obtaining significantly different impact curves depending on the locations of the considered river reaches.

## 4 Results

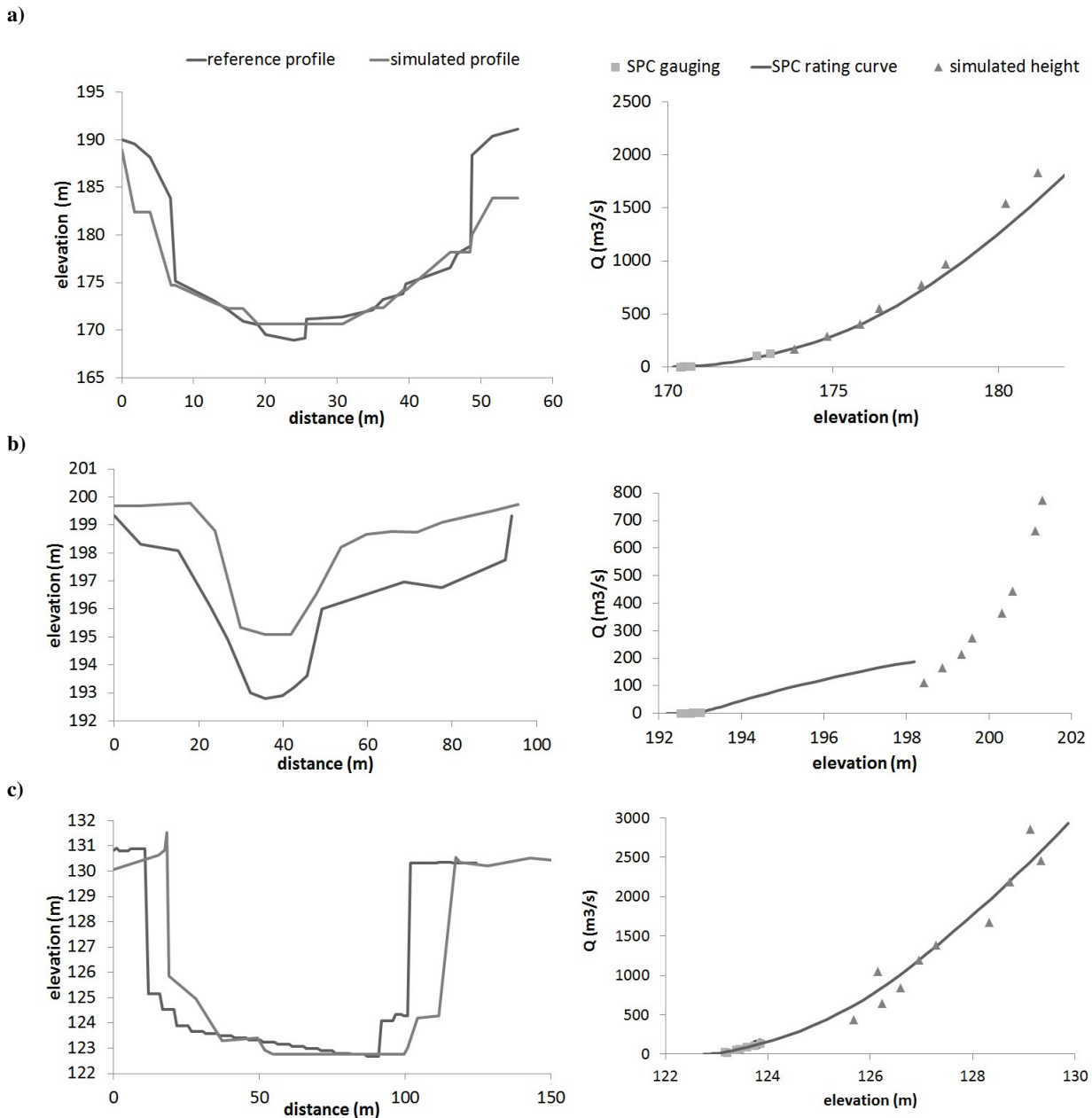
### 4.1 Extent of flooded areas

Figure 6 presents the distributions of ISPs computed for the 101 rivers reaches on which the reference inundation maps are available. This figure illustrates first the limited ISPs values obtained in a large majority of cases: ISPs rarely exceed 30 %. If we notice here that the ISP cumulates both default and excess areas, the real differences of surfaces of the estimated flood areas will be much more limited than the ISPs values: this suggests that the errors in the estimation of impacts will also be limited.



**Figure 6.** Synthesis of ISPs scores computed for the 75 river reaches on which reference inundation areas are available: a) overall distributions, b) repartition in function of reference inundation surfaces.

These figures also illustrate significant differences depending on the magnitude of the simulated floods: the results obtained for the 300 year flood appear much more accurate, with ISPs rarely exceeding 50 %. This can be mainly attributed to the fact that the flood plains are almost entirely flooded for this range of discharges, leading to limit the errors associated with the description of local flow conditions. On the other hand, the 30 year return period flood extent appears much more difficult to appraise, with a significant part of very large errors: ISPs



**Figure 7.** Examples of comparison of cross sections and water levels at three stream gauges: a) Mialet station, b) Banne station, c) Alès station.

exceeding 100 % in almost 10 % of the considered reaches. These large errors are mainly related to the crucial importance of the description of the characteristics of the river bed and of the flow conditions to correctly simulate the beginning of inundation: errors in cross-section widths or position, on roughness values, absence of description of head losses, will all result in large errors in this range of discharges. Therefore it appears completely logical that the simplified procedure used herein leads to results of significantly lower quality for moderate return period floods.

The analysis of repartition of ISPs depending on the surface of the reference flooded area (RS), provided on figure 6b, confirms the same tendency: ISPs are much more important for low RS values, illustrating the difficulty to appraise correctly the beginning of inundation. This tendency is also present for the 300 year

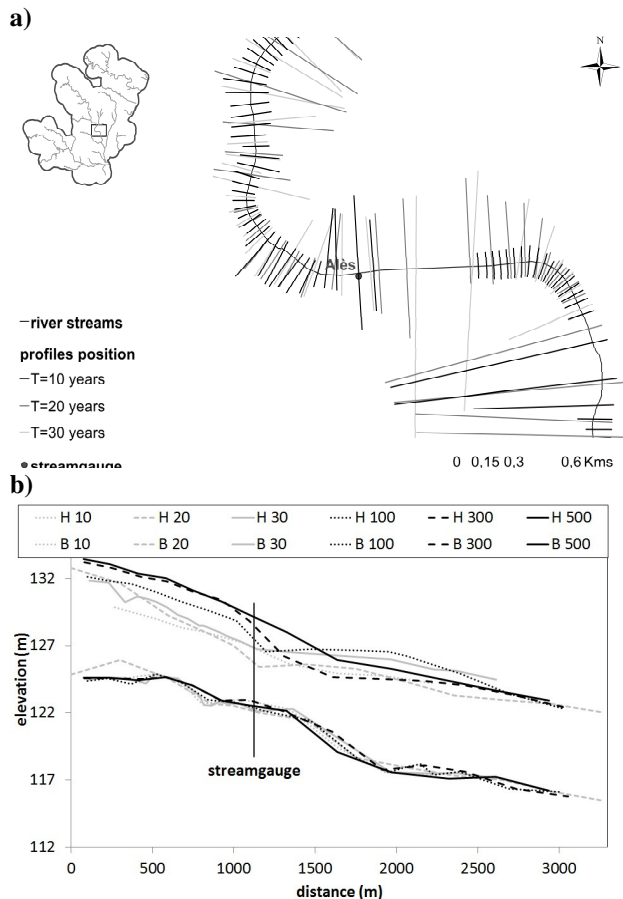
flood but in a much limited extent: in this case, a limited value of the reference surface RS often implies a very deep and narrow river valley, highly limiting the risks of errors.

#### 4.2 Water levels at gauged river sections

The results of comparison of stage discharge relationships are presented on figure 7. This figure illustrates contrasted situations which are detailed hereafter.

The case of the Mialet station appears as an ideal situation, in which the shape of the cross-section is very well represented in Cartino, and the water levels computed don't seem to be significantly affected by other sources of errors (choice of roughness coefficient, width

of considered profiles, etc ..). This may be explained by the simple configuration of the valley (deep and relatively narrow), the limited presence of vegetation in the river bed, and the significant slope. A sensitivity test to the value of roughness coefficient can show in this case that the associated errors are of secondary order, provided that the cross section is well described.



**Figure 8.** Illustration of the impact of profile widths on the simulated water levels nearby the Alès station: a) position of cross sections for different discharge levels, b) longitudinal profiles (B) and computed water levels (H).

The case of the Banne station is much more problematic since the topography of the river cross section is absolutely not well represented in the Cartino model. This may be attributed to local errors in the DTM used, maybe associated with the presence of dense vegetation. However, even if a significant error is made in the estimated elevation of the water level, this error will not necessarily be very problematic for the computation of inundated areas, since the same DTM including the same elevation bias will be used for this purpose.

The case of the Alès station is a more surprising one. Again in this case, the topography of the river bed appears well represented in Cartino. But the shape of the stage discharge relation appears very chaotic if compared to the rating curve of the station. A sudden decrease of water levels is simulated for discharge levels of 20 to 30 years return periods. The configuration of the river bed is different here from the previous cases. The section is

located on the main Gardon d'Alès river, with a wide permanent river bed (about 100 m), and a very flat floodplain including some large depressions. This represents a typical case in which the width of the profiles included in Cartino will have a great impact on the results. Figure 8 illustrates in detail what happens in this case: for limited discharge levels the profiles defined by Cartino ends at the riverbanks, leading to very consistent results; but for the T=20 years discharge, a wide profile is incorporated in the hydraulic model, located just downstream the position of the station (see figure 8a). As a consequence, a wide flooded area (disconnected from the riverbed, see figure 4) is considered by the 1-D model, leading to a significant decrease of simulated water levels in the considered section and also the upstream sections. In such a situation, the use of a 2-D hydraulic model could help in improving the delineation of the flooded areas but at the price of a dramatic increase of computing times.

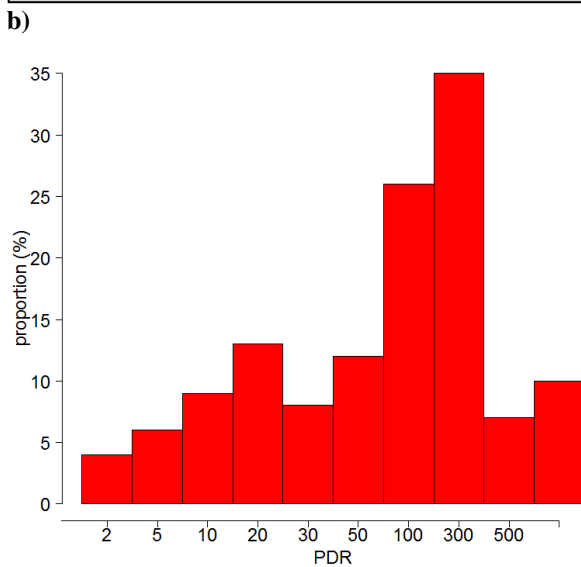
### 4.3 Impacts curves

The characteristics of the impacts curves obtained are summarized on figures 9 and 10. Figure 9 represents the geographical repartition of the maximum impact estimated at each river reach (number of buildings located in the 1000 year estimated flooded area). This figure confirms that the main urban areas, representing the main potential impacts are correctly identified by the model: a limited number of river reaches with very large estimated impacts. In addition, the impacts model also provides an interesting hierarchy of the possible impacts in other locations: figure 10.a shows that the model identifies a large majority of river reaches for which the potential impacts are very limited, and therefore enables to discriminate the more limited number of river reaches for which significant impacts may be observed, even if remaining much more limited than in urban areas. It is likely that this kind of information will be of great help for the interpretation of forecasts provided in real time by distributed hydro-meteorological models.

Moreover, figure 10 also shows that the impact model identifies an interesting hierarchy in the discharge return periods for which a significant part of the exposed assets begin to be affected. The model seems to be able to distinguish river reaches for which the inundation begins for relatively low discharges, or on the other hand for large discharges, providing interesting information about the flood levels (in terms of frequency) leading to the first potential damages. Of course, considering the relatively high uncertainty of estimated flooded areas in the beginning phase of the inundation, this information will probably be less accurate than the previous one (hierarchy of impacts for large discharges), and will probably include significant errors. But it is nevertheless interesting information for the management of floods of intermediate magnitude, for which the location of damages do not necessarily follow the repartition of damages presented on figure 9.



**Figure 9.** Map of the maximum impacts estimated for each river reach (number of buildings in the 1000-year flood area).



**Figure 10.** Main characteristics of the impacts models obtained on the 192 considered river reaches: a) distribution of maximum impacts (1000 year flood area), and b) distribution of discharge return periods leading to 50 % of the maximum impacts.

## 5 Discussion and further validations based on the CCR database

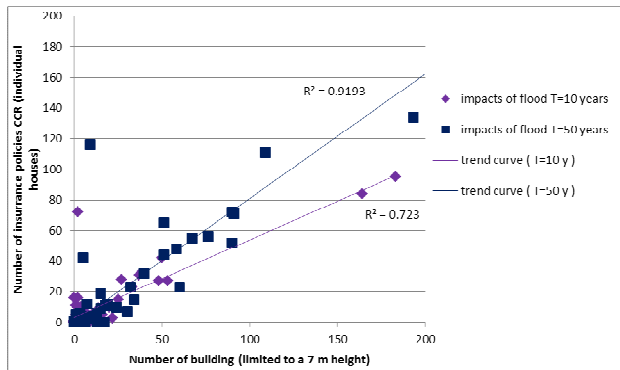
The first validation results presented herein are focused on the accuracy of estimated flooded areas. These results show that if very large errors may be observed in a limited number of cases (typically less than

10% of the river reaches) for which the results should still be improved, in a large majority of cases the errors associated with the important simplifications introduced in the computation procedure remain much more limited (ISPs not exceeding 20 to 30 %). Therefore the procedure applied herein combines the advantage of its computational efficiency, enabling to generate estimated flooded areas on a very detailed river network and for a wide range of discharge levels, and of acceptable error levels considering the objectives of this study: giving a first estimation of the magnitude and hierarchy of impacts at a large regional scale.

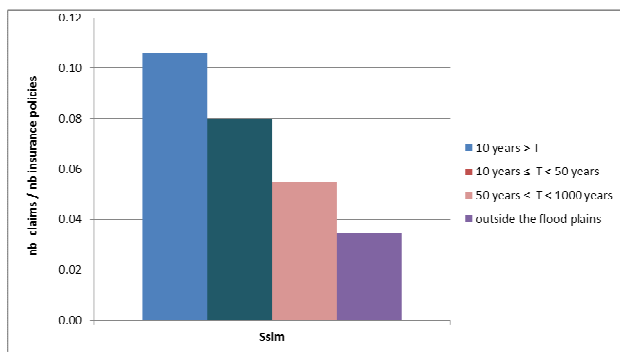
The features of the impact model show that it contains useful information about the location of the vulnerable settlements, and could probably usefully complement the outputs of a rainfall runoff model to support crisis management and rescue operations. However, the combination of this impacts model with a rainfall-runoff model will introduce additional sources of errors such as: errors in discharge estimations, interpolation between two estimated flooded areas for the estimation of the associated impacts. The final accuracy and usefulness of information on possible impacts will highly depend on the combination of these sources of errors. Finally, it clearly appears that this kind of approach still needs further validation to estimate its real efficiency in a close to real world situation. For this purpose, one objective is now to value insurance claims data collated by the CCR in the XXX database. This information, indeed, may provide an interesting synthesis of the location of the main damages to settlements at the event scale (Moncoulon et al. 2014), to be compared with the impacts estimated by our model.

This kind of validation at the event scale is in progress, but we present here some preliminary results showing the overall consistency between the nature and representativeness of information included in the CCR database and our impact model. Figure 11 presents for instance the correspondence between number of buildings identified in the impacts model and the number of insurance policies of individual houses included in the CCR database in 2014 (limited here to the well geocoded policies). This graph shows a good overall consistency of both information sources with proportion policies/buildings of about xxx%.

Figure 12 shows the proportion of insurance claims/policies computed on the whole observation period covered by the CCR database (1995-2014), within the flooded areas used for the definition of the impacts model. This figure shows again a good consistency of information, with a decreasing proportion of claims/policies ratios as the return period of the considered flooded area increases. It can also be noted that the ratios are significantly higher within the identified floodplains than outside.



**Figure 11.** Main characteristics of the impacts models obtained on the 192 considered river reaches: a) distribution of maximum impacts (1000 year flood area), and b) distribution of discharge return periods leading to 50 % of the maximum impacts.



**Figure 12.** Ratios between number of claims and number of policies included in the CCR database within (and outside) estimated flooded. Areas..

Based on these first results, the challenge is now to use the claim data for the validation at the event scale of the entire simulation chain including both hydrological rainfall runoff model and impacts model.

## 6 Conclusions

The case study presented herein aimed to illustrate the potential benefits of a simplified impact model to complement the real time information provided by hydrological models for the monitoring and forecasting of flash floods. The impacts model proposed is based on 1-D hydraulic computations achieved during a pre-analysis phase : important assumptions are made, enabling to derive in a limited computation time a catalog of inundation maps for different discharge quantiles.

The evaluation of this catalogue versus reference flood maps shows that the level of errors, even if significant, remains acceptable for the monitoring and forecasting objectives . Moreover, this catalogue leads to a clear hierarchy of the exposure of the considered territory, including interesting information about the discharge levels above which the assets begin to be significantly affected.

Based on these promising results, the challenge is now to combine this impact model with a hydrological model to assess if the information on impacts obtained at

the event scale can be valuable for crisis management operations. The validation of these results should be possible based on the insurance claims included in the CCR database.

## 5 References

Here are some examples:  
Prévision distribuée

1. Versini P-A., Berrengher M., Corral D. and Sempere-Torres D. (2014). An operational flood warning system for poorly gauged basins : demonstration in the Guadalhorce basin (Spain). *Natural Hazards*, 71, 1355-1378.
2. Rozalis S., Morin E., Yair Y. and Price C. (2010). Flash flood prediction using uncalibrated hydrological model and radar rainfall data in a Mediterranean watershed under changing hydrological condition. *Journal of hydrology*, 394, 245-255.  
Utilisation des impacts pour tester les modèles
3. Javelle P., Demargne J., Defrance D., Pansu J. and Arnaud P. (2014). Evaluating flash-flood warnings at ungauged locations using post-event surveys: a case study with the Aiga warning system. *Hydrological sciences journal*, 59(7), 1390-1402.  
EN intro sur les FFG on peut citer en plus de Geogekakos(2006) et Norbiato (2008) cf liste de l'article de Rozalis cité ci-dessus.
4. Gourley J.J., Flaming Z.L. Hong Y. and Howard K.W. (2014). Evaluating of past, present and future tools for radar-based flash-flood prediction in the USA. *Hydrological sciences journal*, 59(7), 1377-1389.
5. Heffernan J. E. and Tawn J. A. (2004). A conditional approach for multivariate extreme values. *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 66(3), 497-546
6. Alonso E., Degoutte G. and H. Girard (1990). Results of seventeen years of using geomembranes in dams and basins. *Proceedings of the 4th International conference on geotextiles, geomembranes and related products, Vol. 2, The Hague, The Netherlands*, pp. 437-442.
7. Cazzuffi D. (1987). The use of geomembranes in Italian dams, *International Water Power & Dam Construction, Vol. 39, No. 3*, pp. 17-21.
8. Carvajal C., Peyras L., Arnaud, P., Boissier D. and Royet P. (2009). Probabilistic Modeling of Floodwater Level for Dam Reservoirs, *Journal of Hydrologic Engineering*, 14(3), 223-232