Comprehensive flood economic losses: review of the potential damage and implementation of an agricultural impact model

Gwladys Mao[1, 2,a], Thomas Onfroy[2], David Moncoulon[2], Antoine Quantin[2] and Christian Robert[1]

[1]*Université Claude Bernard Lyon 1, Laboratoire de Sciences Actuarielle et Financière, 50 Avenue Tony Garnier, 69007 Lyon, France*
[2]*Caisse Centrale de Réassurance, 157 boulevard Haussmann, 75008 Paris, France*

Abstract. With an annual loss averaging 580 M€ between 1990 and 2014, floods are the main natural catastrophe (Nat Cat) risk for the French Nat Cat compensation scheme. As part of its role in this scheme, the Caisse Centrale de Réassurance (CCR) offers state guaranteed reinsurance programs and has been modelling the risk of flooding since 2003. This model is based on the traditional valuation approach of direct tangible costs which pairs a physical model with exposure through damage curves. CCR wishes now to widen the studied damage scope to insured and non-insured economic costs and has been collaborating with the SAF research laboratory from the Institute of Financial and Insurance Sciences (ISFA) since 2014. CCR's model has been used to estimate the insured direct damage to residential and non-residential properties and it is now being developed to include damage to vehicles, agriculture and network infrastructures. Research is also being carried out to take into account business interruptions and indirect losses using an Input-Output model. This article describes the undergoing work on model development to estimate the damage to agriculture.

1 Introduction

Floods are with windstorms the most disastrous climatic hazard in France. This peril can cause not only human but also heavy economic losses [1]. The financial compensations for the victims of such natural disasters are supervised by the national Natural Catastrophes compensation scheme (hereinafter referred to as "Nat Cat system"). This system involves CCR (Caisse Centrale de Réassurance), a State owned reinsurance company, through an unlimited guarantee via the non-compulsory public reinsurance.

Agriculture risk transfer solutions against climate risks fall into the private sector for insurable risks and public compensations for non-insurable hazards via the National Fund for Agricultural Risks Management (FNGRA) whose accounting and financial management is entrusted to CCR. The FNGRA derives its funding from a State budgetary allowance and from farmers through an additional compulsory contribution on the premium of their insurance contracts covering liability risks and damage to equipment and buildings. After a decree from the ministry acknowledging that the event is an agricultural disaster, the FNGRA compensates the affected farms. According to the Ministry of Agriculture, Agri-Food and Forestry, these compensations cover in average 30% of the damage. Alternatively, a subsidy is given to farmers who have subscribed to a multi-risk climate insurance covering their crops. This subsidy aims at encouraging farmers to undertake climate risk management measures on their farm. Indeed, crop insurances allow farmers to benefit from a better risk coverage than the FNGRA's system. The subsidy consists in the State covering 65% of the premiums for these contracts. In 2010, they concerned almost 27% of the Utilised Agricultural Land.

In order to estimate insurance related losses, CCR has developed a flood physical model for the valuation of its exposure to floods and losses associated with events [2]. This model covers direct damage to residential and professional goods and induced business interruptions but it does not cover agricultural losses apart from the agricultural buildings damage.

However, agricultural losses are of major concern as they represent on average 11% of floods direct damage, knowing that 25% concerns individuals, 37 % companies and 26% networks (Table 1).

Numerous methodologies have been developed to estimate agricultural damage caused by flooding [3]. Several countries have well-established methodologies to estimate flood damage to agriculture. It is the case in the UK with the Multi-coloured Manual [4] and in the US with the model HAZUS-MH [5] which pays close attention to both agricultural direct and indirect economic costs of floods. Other comprehensive models have also built methodologies and damage curves for agricultural damage [6-10].

Brémond et al. [3] made an inventory and analysis of works completed on this subject in France. Several studies have been carried out by agricultural technical

[a] Corresponding author: gmao@ccr.fr

institutes to represent the interest of farmers for example, in the implementation of flood risk management projects [11-15]. However, the damage curves developed are very specific to the context and the region and they cannot be generalized.

The studies realized by research institutes have the general objective to improve the estimation of the flood damage [16-20]. They are dedicated to the development of a method for the valuation of the flood damage to agriculture.

The scope of this paper is to present a model that allows a quick estimation of the damage to crops due to any flood in mainland France by the implementation of the methodology and the damage curves developed by Agenais et al. [19] within the framework of CCR's model.

2 Review of flood economic potential damage

CCR has been modelling the risk of flooding since 2003. CCR's flood model is based on the traditional valuation approach of direct tangible costs which pairs a physical modelling with exposure through damage curves. It has been used to estimate the insured direct damage to residential and non-residential properties and the resulting business interruptions.

Now, CCR wishes to widen the scope of the damage studied to insured and non-insured economic costs and has been collaborating with the SAF research laboratory from the Institute of Financial and Insurance Sciences (ISFA) through a PhD since September 2014.

To understand the relative importance of each direct damage category, it is useful to study the experience feedbacks undertook after natural hazard events. From detailed information about 11 flood events [21-26], we obtain the overall distribution in Table 1. This table shows the potential magnitude of the damage to agriculture and networks which are not modelled today by CCR.

Event (M€ 2015)	Individuals	Companies	Agriculture	Networks
France 1977-78 [21]	23 *18%*	25 *19%*	39 *30%*	43 *33%*
Vaucluse 1992 [21]	26 *19%*	26 *19%*	27 *20%*	57 *42%*
Orb 1995-96 [21]	13 *26%*	14 *28%*	3 *7%*	19 *40%*
Meuse 1993-95 [21]	168 *41%*	199 *48%*	17 *4%*	28 *7%*
Nîmes 1998 [21]	179 *25%*	279 *38%*	0 *0%*	269 *37%*
Aude 1999 [21]	191 *34%*	98 *18%*	59 *11%*	207 *37%*
Bretagne 2000 & 2001 [22]	81 *41%*	54 *28%*	6 *3%*	54 *28%*
Somme 2001 [23]	38 *28%*	12 *9%*	9 *6%*	75 *56%*
Gard 2002 [24]	122 *12%*	389 *38%*	259 *25%*	261 *25%*
Rhône 2003 [25]	200 *17%*	628 *54%*	90 *8%*	248 *21%*
Var 2010 [26]	326 *39%*	290 *34%*	73 *9%*	155 *18%*
Overall distribution	25%	37%	11%	26%

Table 1. Direct damage distribution listed in the experience feedbacks adjusted on the inflation basis

CCR's model is now being developed to include damage to crops, vehicles and network infrastructures. CCR's goal is to use this model to evaluate the different damage categories amounts systematically and efficiently when a flood event occurs. It would allow CCR to study each category relative weight and the differential between insured and non-insured costs.

Research is also being carried out to take into account operating losses and indirect losses using an Input-Output model. Indeed, even if direct damage are often considered to be a first indicator of an event scale, they are insufficient and inadequate because indirect impacts may be significant and there is no linear relation between direct damage and indirect losses, as illustrated in Figure 1 [27].

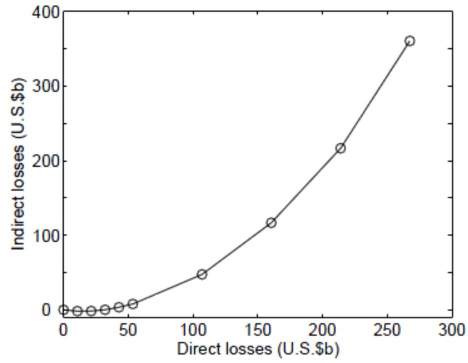

Figure 1. Indirect economic losses, in terms of value added losses, as a function of direct losses [27].

Even if the uncertainties of models developed so far are important, they help to "gauge individual and community vulnerability, evaluate the worthiness of mitigation, determine the appropriate level of disaster assistance, improve recovery decisions, and inform insurers of their potential liability" [28].

Table 2 summarizes the damage classification as defined in this study. This paper focuses on the development of an exposure and a damage model for agriculture.

3 Typology of damage to agriculture

Brémond et al. [3] identified and classified the main categories of damage to agriculture (Table 3).

The direct instantaneous damage are due to the contact with flood water during the event. When trying to estimate the direct instantaneous damage to plant production, it is important to identify the main hazard parameters impacting the plants.

Based on experience feedbacks in France, Agenais et al. [19] identified several key parameters, namely:

- The date of the flood occurrence: due to the plant production seasonality, it is important to situate the event in the cropping calendar. Brémond [18] also took into account the season of occurrence in the estimation of the damage to the stocks ;
- The water level ;
- The duration of the submersion : this parameter can be related to a vulnerability parameter on the soil texture so as to estimate the soil drying duration ;

	Direct	Operating losses	Indirect
Tangible	- Private individual: *Real properties*[1], *movables*[1] *and vehicules*[1] - Businesses: *Real properties*[1], *stocks*[1], *manufacturing tools*[1], *vehicules*[1] - Agriculture: *Real properties*[1], *stocks*[1], *manufacturing tools*[1], *vehicules*[1], *livestock indoors*[1], *harvested crops*[1], *not harvested crops*[2], *crops*[2], *soils*[2], *livestock outdoors*[2] - Transportation infrastructures: *- Road infrastructures: highways, roads, civil engineering works* *- Other transportation infrastructures: rail networks, urban networks (tramway, subway...), river system, port installations, airport infrastructures* - Technical networks: *- Drinking water supply and distribution* *- Sewage facilities* *- Electricity & energy networks (EDF, GDF, nuclear plants, power plants)* *- Telecom networks* *- District heating networks* - Tourist installations: *Campsites*[1], *hotels*[1], *other*[1] - Public buildings: *Public assets*[1], *administrative buildings, school buildings, medico-social buildings, museums, other* - Other: *Life insurance settlement*	- Business interruption of a flooded site[1] - Business interruption due to direct damage[1] - Business interruption due to network disruption: *road access interruption (passenger & goods traffic diversion or disruption), utility network failure* - Business interruption of a site located outside the affected area: *supply shortages, clients deficiencies, interruption or slowing down upstream or downstream the production chain*	- Private individual: *temporary relocation, loss of property value, loss of capital assets* - Businesses: *loss of markets, temporary or permanent relocation, loss of property value, loss of capital assets* - Agriculture: *loss of property value, lower productivity, loss of value of the farm* - Transportation infrastructures: *loss of markets (operators, carriers and their clients)* - Tourism: *temporary closure of equipment and touristic sites, loss of markets* - Public buildings*: temporary or permanent relocation* - Cost of the emergency response: *evacuation, emergency services* - Macroeconomic impacts : *loss of tax revenue due to companies delocalization resulting from the flood, households and governments debt level, trade imbalance, reconstruction, technological improvements, economic recovery*
Intangible	- Loss of human lives - Injuries - Psychological distress - Historic heritage : *buildings, artwork, parks and gardens* - Ecological impact : *watercourses, wetlands, forests*	X	- Public buildings : *duration of the service interruption* - Health effects - Psychological impacts: *trauma, loss of memories, loss of confidence in public authorities* - Negative impacts on ecosystems: *dispersion of harmful substances, agricultural production losses due to soil erosion, impacts on tourist numbers*

[1]: insured through the Nat Cat system
[2]: compensated by the National Fund for Agricultural Risks Management or by a multi-risk climate insurance

Table 2. Flood impact classification

- The flow: especially in the case of flash floods, the flow can tear the crops and the plant material. It can also have long term effects on soil erosion ;
- The type of the flood: in the case of fluvial flooding, the farmer may have enough time to undertake adaptation measures, an early harvest for instance ;
- The silt loading, soils pollution and salinity in the case of coastal flooding: these three parameters can have significant long term impacts on yield.

Bauduceau [29] highlighted that future yield losses may continue for several years after the flood when the perennial plants (ex: vineyard) are destroyed. Bauduceau [29] also reported the possible rise in production costs (i.e. additional inputs to limit the losses). When direct damage are not entirely repaired (soil erosion, soil contamination for instance), it can lead to some restrictions of the soil use such as forbidding some crop cultivations.

Some adaptation measures can also change the initial damage. For example, an anticipated harvest can be undertaken to reduce the yield loss, reseed the same crop or a new one depending on the cropping calendar can reduce the loss of value added. To include these actions involves taking into account the savings made, and the expected new returns. These risk reduction strategies also generate new expenses which have to be estimated.

Floods can also disrupt the farm activities. For instance, the overwhelming increase of work due to the recovery tasks can cause delays in the harvesting of not impacted fields. The work can be increased tenfold when the manufacturing tools are unavailable, and the farm activities can also be very disturbed if there are too many tasks to do in the same time [30-32]. Finally, the impacts of a flood may continue over years due to the change in the crop rotation through the impossibility to prepare the affected soils in time for the next crop reseeding.

Qualitative studies on indirect losses note the possible impacts of the flood on agricultural activities not located in the hazard area [30, 33]. For example, farmers that are not directly impacted may suffer from a defaulting supplier (including stored forage) if these activities are impacted.

Finally, economic sectors highly dependent on the agricultural sector can also be affected: if the harvests are destroyed, the agrifood industry may suffer shortages of agricultural inputs depending on its ability to find substitutes to the lost harvest on the market. If many farms go bankrupt, the agrifood industry may have to reorganize itself to adapt to the new situation.

The scope of this paper is the direct damage. However, a broader indirect flood losses model in which agricultural indirect losses are taken into account is under development at CCR.

	Instantaneous (during of just after flooding)	Induced (later after flooding)
Direct (due to flood exposure)	- crop loss and yield reduction - livestock fatalities - loss of livestock products (e.g. milk) - damage to perennial plant material - damage to soil - damage to buildings - damage to machinery - damage to stored inputs - damage to infrastructure (e.g. roads)	- loss of added value due to the loss of yield in the first years after replanting perennial plant material (orchard, vineyard) or reseeding grass - loss of added value due to unavailability of production factors (machinery, inputs etc…) - cost of relocation or premature sales of livestock - cost of additional food for livestock - reduction of herd size
Indirect (not directly due to flood exposure)	- increase in travel time due to damage to infrastructure - delay or cancellation of supply from the flooded area (inputs, machinery, etc…)	- loss of added value outside the flooded area due to business interruption of assets in the flooded area - loss of added value outside the flooded area due to damage to infrastructure

Table 3. Agricultural damage classification [3]

4 Methodology for the implementation of an agricultural impact model

In the insurance industry, two approaches for the estimation of Nat Cat direct damage dominate: on the one hand, the statistical methods based on historic data (regressions or frequency/severity methods) and on the other hand, methodologies which pair a physical modelling with exposure through damage curves. We are interested in the latter methodologies in this article. They are made of three models:

- The hazard model: it generates a catalogue of occurred or stochastic events set (characterised by a probability of occurrence) and data on the hazard characteristics (water depth, flow, duration, type of flood or time of occurrence);
- The exposure model : it lists the risks in the hazard area with their precise location, their characteristics and values ;
- The damage model: it combines the hazard and exposure models outputs to get the hazard information of each risk and estimate the amount of damage through damage curves.

Damage curves describe the relation between one or several hazard characteristics and the level of direct damage for a risk type or use [4, 5, 8].

The model presented in this paper is based on the hazard model developed at CCR and national damage curves for crops built by the Cost-Benefit Analysis (CBA) working group [19].

4.1 The hazard model

The components of CCR's deterministic flood model are [2]: the hydrological model (physical simulation of rainfall, surface water runoff and river overflow) and the exposure and damage model (destruction rate and frequency curves).

For this study, the hazard model of CCR's flood model has been linked with a specific agricultural exposure and damage model.

A flood event for CCR is defined as the occurrence of significant flood damage to the Nat Cat insurance market (exceeding an arbitrary threshold of 10 million €) due to heavy rainfall or river overflow. The flood event is defined by a geographical location corresponding to a rectangular area characterized by bottom left and upper right coordinates. The event duration is determined by two characteristic time limits: 24 hours before the first significant rainfall recorded by Météo-France and 24 hours after the last significant rain. Thus, each event has a minimum duration of 48 hours. The average duration is 72 hours.

The event database, defined for Nat Cat major events, has been used for agricultural simulations, assuming that there is a strong relationship between Nat Cat and agricultural damage.

Flood hazard model is a rainfall-runoff model distributed on a 25m grid, coupled with a river discharge model. The rainfall/runoff model is a water balance that estimates the water level noted h (m) and the soil water content θ (% of soil capacity) at each time step t for the entire flood event duration. The digital elevation model (Intermap 25m) is used to define a regular grid of 25 x 25m over the entire French territory. The DEM is merged with a river database (BD Carthage) to create river segments. A simple 1-D hydrological river routing method is used to determine river flow, water level and overflow areas in the floodplain. The river is considered as a succession of river segments which are individually homogeneous in terms of section shape, width and slope.

The river flow at time t is compared with a threshold defined for each section by the higher value between the 10 years return period flow and the return period that characterizes the efficiency of the protections against flood for that section, if there are any. The flood protection database used for this study has been developed at CCR and is not exhaustive. The flood protection overflow is taken into account when the information exists but the breach risk is not modelled in details. The river overflows if maximum river flow exceeds the threshold at a given segment.

DOI: 10.1051/e3sconf/20160705003

4.2 Development of an agricultural exposure model

Three data sources on agricultural land use exist for mainland France.

Corine Land Cover, which was last updated in 2012, is a biophysical land use database provided by the European Environment Agency and the European Commission.

The Agreste database is developed by the bureau for statistics of the French Ministry of Agriculture. The data is based on the main type of farming for each town. The last version is based on the 2010 agricultural census.

The Graphic Parcel Register (GPR) was set up in the context of the Common Agricultural Policy when a European Union regulation decrees that member States have to locate and identify their agricultural parcel. Every year, farmers have to declare their farmed agricultural land to the French administration. It includes the crop islets boundaries in the GIS shapefile format, with attribute information on the main crop cultivated on each islet. The available data is based on the 2012 declarations.

Table 4 compares the three data sources:

Data	Precision	Classification	Completeness compared to the UAL*
Corine Land Cover 2012	Resolution : 1/100000 scale (250m meshes)	9 crop categories	100%
Agreste 2010	Communal scale	Main type of farming : 16 categories of growing crops and raising livestock	100%
Graphic Parcel Register 2012	Resolution : 1/5000 scale (vector format)	26 crop categories	98%

Table 4. Comparison of the sources of geographic data on agriculture

* *The Utilised Agricultural Land (UAL) is a standardized notion in the European agricultural statistic. It includes arable crops (including pasture and meadow, fallows, indoor cultivation, kitchen gardens, etc...), grassland areas and permanent crops (vines, orchards...). This table presents a comparison of the metropolitan French territory UAL in 2013 (source: INSEE) and the identified agricultural areas in the databases in order to estimate of their completeness.*

The GPR 2012 was chosen for this study. Indeed, this database gives the most detailed classification of the plant productions. Moreover, the Chambers of Agriculture encourage farmers to better declare their crops in order to improve the territory coverage rate of the database. Hence, it will keep on improving over the years.

The map of Figure 2 presents the typology of the data provided by the GPR:

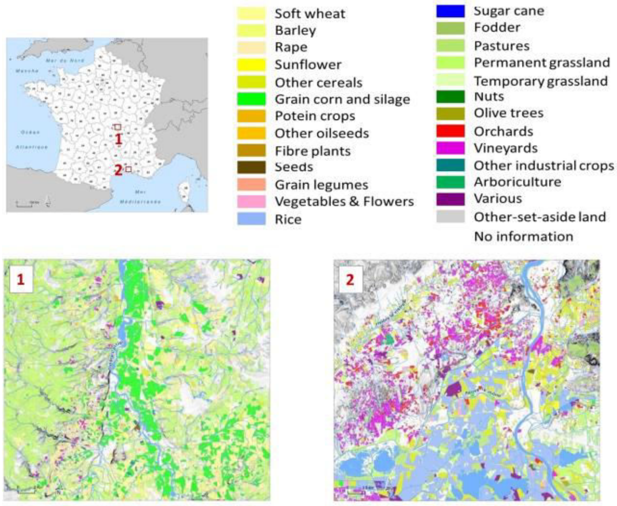

Figure 2. Example of Graphic Parcel Register (GPR) data on two different locations in France

The modelling sought by CCR for agriculture damage imposes several constraints:

- The model must be usable on any flood occurring in mainland France.
- The estimation has to be given within few days after the occurrence of the event.

The wide geographical perimeter of CCR's modelling and the operational effectiveness required make it necessary to reduce the precision of the vectorised GPR data. Hence, the GPR vector data has been converted into a 500m resolution grid using GIS tools. For each grid, the information on the occupied area by each of the 26 crop categories is calculated. The method, adapted from [36] is presented in Figure 3.

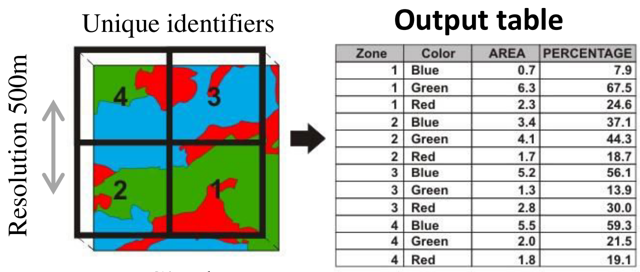

Figure 3. GPR data GIS geoprocessing

The size of the chosen mesh has an impact on the model results: the larger the mesh is, the more we will lose accuracy, as illustrated in Figure 4.

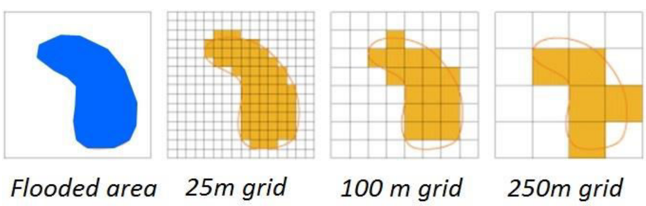

Figure 4. Schematic view of the link between hazard and exposure for different mesh size

However, a too fine mesh can be counterproductive in terms of processing time and modelling accuracy. Indeed, the flood model shows uncertainties on the flooded areas and on the hazard characteristics. The use of larger meshes can mitigate the hazard model uncertainties even if it involves losing accuracy on the exposure model. An impact study of the size of the mesh on the exposure uncertainty will be carried out, and the mesh resolution that will allow reducing as far as possible the flood hazard uncertainties will be retained.

4.3 Link between exposure and damage

The first step of the damage model is to combine data from the hazard and the exposure models and to automate this process. Figure 5 illustrates this step with the example of the vineyards exposure to the 1999 flood in Pyrénées-Orientales.

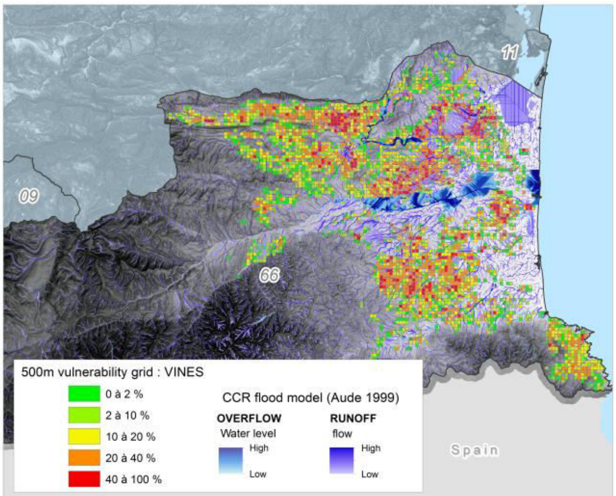

Figure 5. Overlapping of the vineyards exposure and the hazard data, November 1999 flood in Pyrénées-Orientales (66)

For each 25m hazard mesh, the flood hazard model simulates the water depth, the current velocity and the flow. For each 500m exposure mesh, we have information of the area of the mesh covered by each type of crop.

The approach consists in associating the data of the exposure mesh to the hazard meshes it contains. We obtain a grid of 25m meshes with the following information:

- Water depth,
- Flow,
- Current velocity,
- The portion of the mesh covered by each crop type.

The second step of the damage model is to implement the damage curves to the meshes.

Based on the works of Brémond [34] and Agenais [17] and on a sound knowledge of the state of art [3], the Cost-Benefit Analysis (CBA) working group has realized a study on the damage of floods on agriculture. It has surveyed agronomic experts and collected data enabling to build national damage curves for 14 crop types described in a methodological guide [19].

The crop types addressed in this study are: soft wheat, corn (grain and silage), barley, other cereals, rape, sunflower, other oilseeds, other industrial crops, arboriculture & orchards, vineyard, vegetables & flowers, fodder, permanent grassland and temporary grassland.

The hazard parameters taken into account in the damage curves are:

- Water depth,
- Current velocity,
- Season,
- Duration of the flood.

Figure 6 shows the damage curve developed for damage caused by water depth on soft wheat.

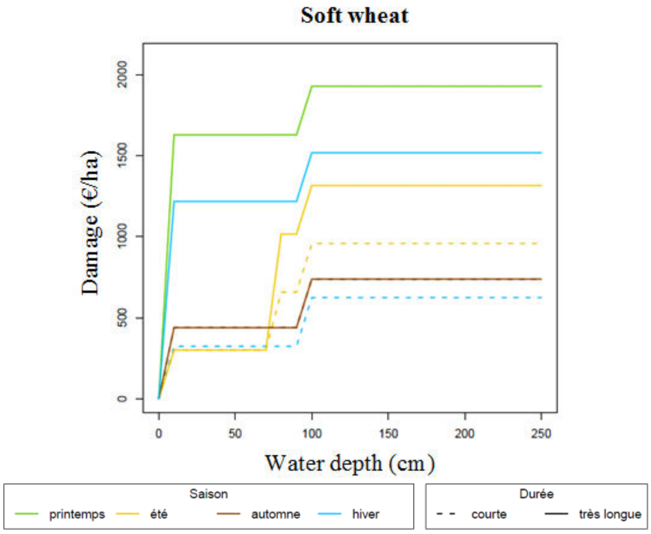

Figure 6. Soft wheat damage curves for metropolitan France [19]

Nevertheless, the GPR and the CBA crop classes do not match and 14 GPR crop types don't have associated damage curves. Three of them are not present in mainland France (frozen surfaces without production, non-food production and sugar cane). Following the advices of the CBA's methodological guide, it has been decided to handle the crops without associated damage curves as follows (Table 5).

GPR Categories	Associated damage curves
Other non-production surfaces	Surfaces little sensitive to floods: no damage
Pastures	
No information	Damage curve corresponding to the weighted average by surfaces of the GPR plant categories having a dedicated damage curve
Various	
Rice	Soft wheat damage curve
Seeds	
Nuts	Arboriculture & orchards damage curve
Olive trees	
Protein crops	Rape damage curve
Grain legumes	
Fibre plants	

Table 5. Damage curves associated to GPR plant categories without dedicated damage curve (from CBA)

Thanks to this methodology, when an event occurs, the model is able to estimate the flood impact: the surface of each crop type affected and the related damage (Figure 7).

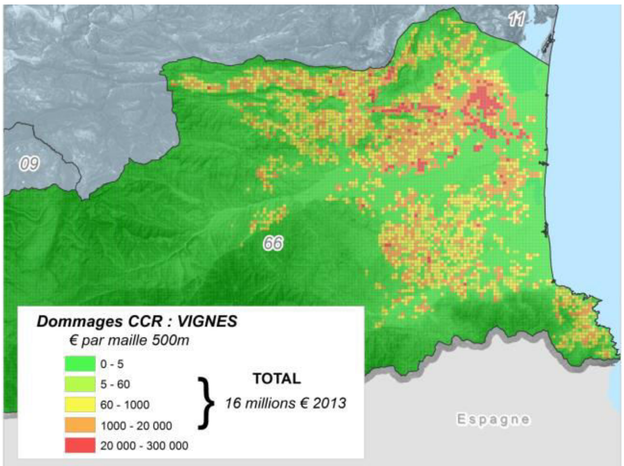

Figure 7. Modelled damage to vineyards, November 1999 flood in Pyrénées-Orientales (66)

5 First results and discussion

5.1. Estimation of the impacted areas

The estimation of the affected surfaces represents the first step for damage modelling. Indeed, the hazard model tends to simulate surface water runoff everywhere if the infiltration capacity of the soil is exceeded (Figure 8).

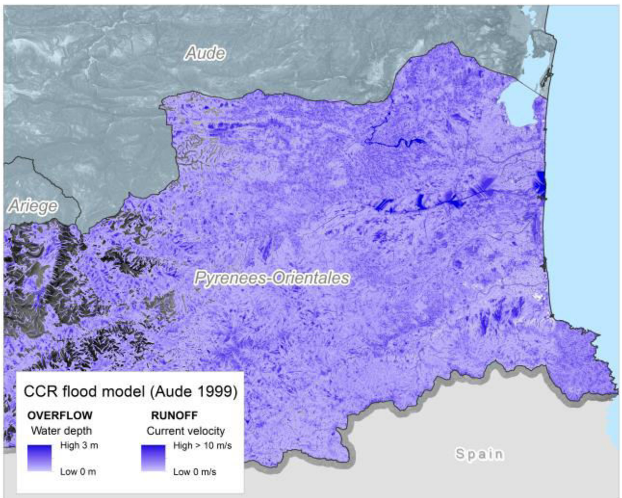

Figure 8. Surface affected estimated by the hazard model without calibration, November 1999 flood in Pyrénées-Orientales (66)

It has been decided to define a current velocity threshold under which it is considered that the mesh is not impacted by the flood.

During the 1999 flood in the Aude and Pyrénées-Orientales departments, vineyards accounted for more than 80% of the claims and 73% of the amount of damage [35]. It has been decided to calibrate the impacted areas on the data about affected vineyards during this event.

Several thresholds have been tested to find the one that matches the best with the real data (Figure 9). This threshold has been set at 0.342m.s^{-1}.

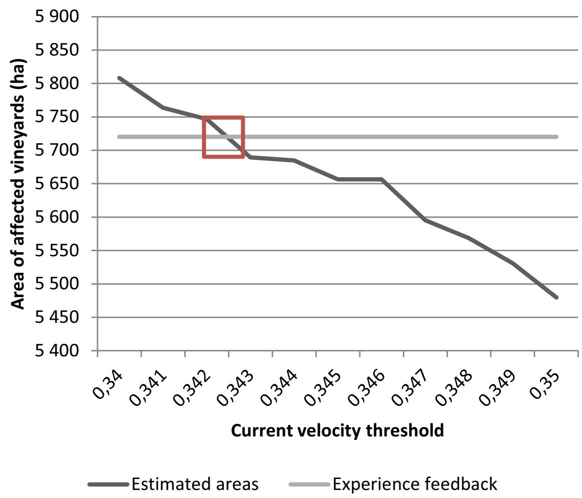

Figure 9. Impacted vineyards estimated by the model given different current velocity thresholds, November 1999 flood in Aude (11) and Pyrénées-Orientales (66)

When applying this threshold to the November 1999 flood in Pyrénées-Orientales, we obtain the following hazard map (Figure 10):

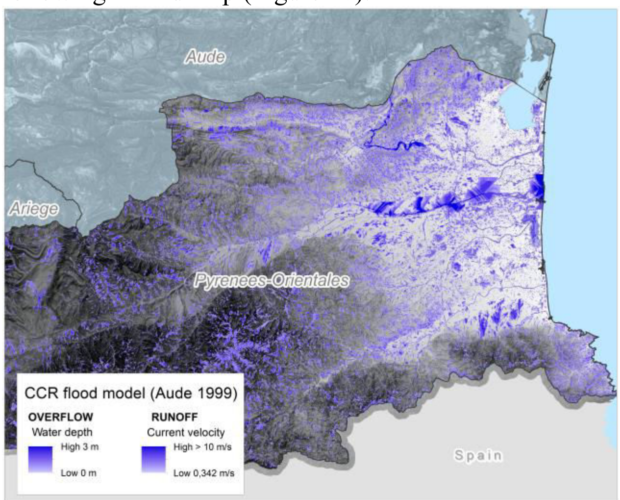

Figure 10. Affected area estimated by the hazard model after calibration, November 1999 flood in Pyrénées-Orientales (66)

After this calibration process, we obtain the following estimation of the vineyard impacted area (Figure 11):

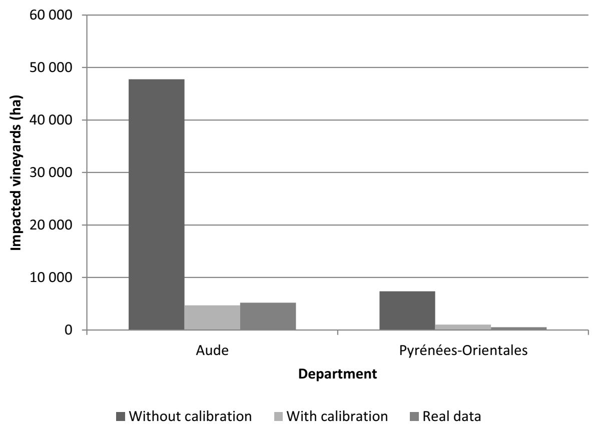

Figure 11. Impacted vineyards estimated by the model before and after calibration compared with real data, November 1999 flood

The same calibration has been used for the entire event set but is not published here since the real impacted surfaces were not available in the experience feedbacks. A different calibration should perhaps be studied for other climatic regions (for example Brittany or North of France).

5.2. Estimation of damage

Following the estimation of the impacted areas, the next step is to link the hazard level to the damage per hectare for each different class of plant production. The easiest method has been tried in the first place to determine a first order of magnitude for the damage.

On the 1999 flood in Aude and Pyrénées-Orientales, given data on vineyards affected areas and damage amount, we can estimate an average cost of 7 547 €/ha with a high variability between the two regions: 6 477 €/ha for Aude (11) and 18 246 for Pyrénées-Orientales (66).

We applied the CBA's damage curves for vineyard on the modelled hazard surfaces, without calibrating the hazard thresholds (Figure 12).

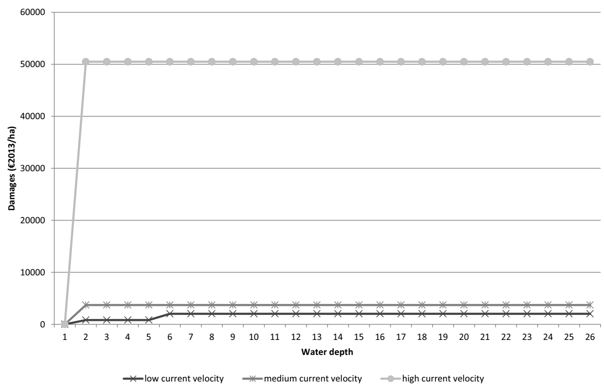

Figure 12. CBA's vineyards damage curves for short events happening in autumn

The damage curves presented in Figure 12 show that, except for high current velocity, the damage value per hectare will not exceed the average cost of 3 700 € which is nearly 50% lower than the experience feedback average cost. Nevertheless, the CBA's curves has been developed for the entire French territory, and especially for vineyards, the economic value per hectare shows a volatility of the added value depending on the location and the quality of production.

The high current velocity curve shows the threshold effect due to the fact that vine plants have been teared. This important threshold effect has to be calibrated on a more important historical database and for other vegetal productions. Indeed, the CBA working group specifies in their study that the hazard parameters classes of the damage curves must be defined according to the hydrological model.

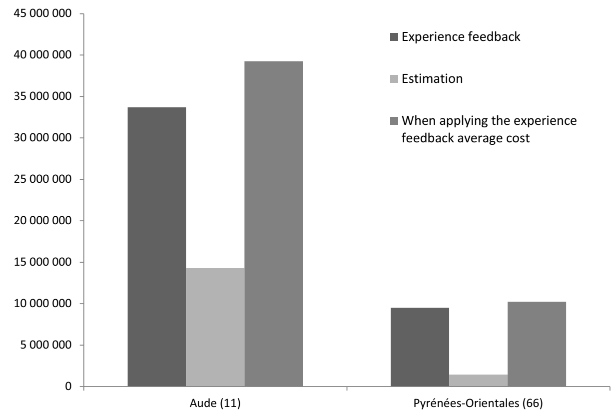

Figure 13. Damage to vineyards estimated with the average cost and the CBA's damage curves on the modelled hazard areas, November 1999 flood

Based on these first results, it clearly appears that the need for further calibration work on vineyards and, more generally, on other vegetal productions will be the next steps of this PhD works. The use of FNGRA data on agricultural disaster damage declared by farmers will constitute a robust historical basis on which determine the link between CCR's flood model and CBA's damage curves.

6 Conclusion: improvement prospects

6.1. Exposure model

A first uncertainty source comes from the use of the GPR for agricultural land use in regions where non-subsidised crops account for a large portion of the agricultural land use (especially vineyards). The coverage rate may not be sufficient enough to obtain satisfying results.

Moreover, we use the GPR 2012 to estimate the exposure but, apart from some plant productions which are quite consistent over time (vineyards or orchards), exposure has evolved between the year of the event and 2012.

Finally, as stated in the paragraph 4.2, the size of the exposure mesh has an impact on the precision of the model. Hence, it would be interesting to test its impacts on an event to find an optimal size of mesh.

However, the more a cultivated area is homogeneous and wide, the more the size of the mesh can be large. The objective of improvement is to work on a homogeneity indicator of the plant production in order to create an exposure model with varying size of meshes [36].

6.2. Damage model

For the same plant production and the same hazard characteristics, the damage can be different depending on the geographic location. In fact, the following agro-economic characteristics can differ:

- Cropping calendars,
- Yields,
- Selling price of the production : there may be high value-added local plant productions,
- Composition inside a category of plant production,

- Agricultural rotations.

Using damage curves may then bring to under or overestimate the damage.

The current objective is to collect data on regional yields and cropping calendars in order to adapt the national damage curves to regional specificities.

As seen in the paragraph 4.3, several GPR categories of plant productions do not have associated damage curves. The objective is to collect agro-economic data to better adapt their associated damage curves.

Finally, more data on past events about flooded agricultural areas and associated damage will be collected to better calibrate the model.

7 References

1. Association Française de l'Assurance (2015). Risques climatiques : quel impact sur l'assurance contre les aléas naturels à l'horizon 2040 ?
2. Moncoulon D., Labat D., Ardon J., Onfroy T., Leblois E., Poulard C., Aji S., Rémy A., Quantin A. (2013) Analysis of the French insurance market exposure to floods : a stochastic model combining river overflow and surface runoff
3. Brémond P., Grelot F., and Agenais A.-L. (2013). Review Article: Economic evaluation of flood damage to agriculture – review and analysis of existing methods *Nat. Hazards Earth Syst. Sci.*, 13, 2493–2512
4. Penning-Rowsell E., Priest S., Parker D., Morris J., Tunstall S., Viavattene C., Chatterton J., Owen D. (2013). Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal, Flood Hazard Research Centre, London: Routledge
5. FEMA (2011). Hazus®-mh mr5. Flood model, Federal Emergency Management Agency, Technical manual
6. Thieken A. H., Ackermann V., Elmer F., Kreibich H., Kuhlmann B., Kunert U., Maiwald H., Merz B., Müller M., Piroth K., Schwarz J., Schwarze R., Seifert I., and Seifert J. (2008). Methods for the evaluation of direct and indirect flood losses, *4th International Symposium on Flood Defence: Managing Flood Risk, Reliability and Vulnerability Toronto, Ontario, Canada, 6–8 May, Institute fo Catastrophic Loss Reduction*
7. Bubeck P., de Moel H., Bouwer L. M., and Aerts J. C. J. H. (2011) How reliable are projections of future flood damage? *Nat. Hazards Earth Syst. Sci.*, 11, 3293–3306
8. Kok M., Huizinga H. J., Vrouwenfelder, A. C. W. M., and Barendregt, A. (2004). Standard Method 2004. Damage and Casualties caused by Flooding, Client: Highway and Hydraulic Engineering Department, 66 pp.
9. Hoes O. and Schuurmans W. (2006). Flood standards or risk analyses for polder management in the Netherlands, Irrigation Drainage, 55, S113–S119
10. Jonkman S. N., Bockarjova M., Kok M., and Bernardini P. (2008). Integrated hydrodynamic and economic modelling of flood damage in the Netherlands, *Ecol. Econom.*, 66, 77–90
11. Pierson F., Barneoud C., Vinatier J.-M., Amiet Y., Hermant A., Grandidier I., de la Rocque T., Kockmann F., Villard A., Matt J.-P., Chrétien J., and Dupont B. (1994). Étude de l'agriculture dans les champs d'inondation de la vallée de la Saône. Aptitudes agronomiques, Tech. rep., Chambre Régionale d'Agriculture de Bourgogne pour le compte du Syndicat Mixte d'étude pour l'Aménagement du Bassin de la Saône et du Doubs, Quétigny, France, 184 pp.
12. Dury, B. and Didier, C. (2006). Activité économique agricole, foncier et environnement écologique du casier d'inondation de Saint-Maurice en Rivière à Allériot, Phase II : chiffrage des impacts agricoles, Tech. rep., Chambre d'Agriculture 71 pour le compte du Syndicat Mixte Saône-Doubs, Mâcon, France
13. Devaux-Ros, C. (2000). Évaluation des enjeux et des dommages potentiels liés aux inondations de la Loire moyenne, Méthodes et principaux résultats, Tech. rep., Équipe pluridisciplinaire Plan Loire Grandeur Nature
14. SIEE, EDATER, AScA, and TTI (2003). Étude globale pour une stratégie de réduction des risques dus aux crues du Rhône, Lot 4 : Analyse de l'occupation des sols., Tech. Rep. Rapport d'étape no 3, Identification des enjeux exposés aux crues et définition et analyse des casiers stratégiques, Territoire Rhône
15. CA30 (2009) Étude des enjeux agricoles sur la plaine de Bellegarde/Fourques et couloir de Saint-Gille dans le cadre de l'étude de renforcement de la digue du Rhône rive droite entre Beaucaire et Fourques, Tech. rep., Chambre d'Agriculture du Gard pour le compte du SYMADREM, Nîmes, France, 148 pp.,
16. Torterotot, J.-P. (1993). Le coût des dommages dus aux inondations: Estimation et analyse des incertitudes, Thèse de doctorat, spécialité sciences et techniques de l'environnement, École Nationale des Ponts et Chaussées, Paris
17. Agenais, A.-L. (2010). Évaluation économique des dommages liés à la submersion marine sur l'agriculture. Construction d'un modèle et application au Languedoc-Roussillon, Mémoire de fin d'études présenté pour l'obtention du diplôme d'ingénieur agronome, spécialisation territoires et ressources: Politiques publiques et acteurs, Montpellier Sup'Agro, Montpellier, France
18. Brémond, P. (2011). Caractérisation et évaluation économique de la vulnérabilité des exploitations agricoles aux inondations, Thèse de doctorat, spécialité sciences Économiques, Université de Montpellier 1, Montpellier, France
19. Agenais A.-L., Grelot F., Brémond P., Erdlenbruch K. (2013). Dommages des inondations au secteur agricole. Guided méthodologique et fonctions nationales. Groupe de travail national Analyse Coûts-Bénéfices Inondation.
20. Blanc C., Brémond P., and Grelot F. (2010). Projet EVA Évaluation de la Vulnérabilité Agricole,

Rapport pour la mission rhône, DREAL Rhône-Alpes, Cemagref, 267 pp.,
21. Lamothe A.-N., Neveu G., Görlach B., Interwies E., (2005). Evaluation of the impact of floods and associated protestion policies, Final report, European Commission DG Environment
22. Huet P., Roussel P., Martin X., Bourget B., Varret J., Guellec J., Monadier P., Sauzey P., Teyssier A., (2001) Mission d'expertise sur les crues de décembre 2000 et janvier 2001 en Bretagne
23. Sauzey P., Monadier P., Renoux J.-P., Robert de Saint Vincent E., Lefrou C., Verrel J.-L., Hornus H. (2001). Rapport de la mission d'expertise sur les crues d'avril 2001 du bassin de la Somme, rapport de l'Inspection Générale de l'environnement et de l'équipement
24. Huet p., Martin X., Prime J.-L., Foin P., Laurain C., Cannard P. (2003). Retour d'expérience des crues de septembre 2002 des les départements du Gard, de l'Hérault, du Vaucluse, des Bouches-du-Rhône, de l'Ardèche et de la Drôme, rapport de l'Inspection Générale de l'environnement et de l'équipement
25. Perriez F., Cannard P., Babre S., Arnaud M., Laurain C., Prime J.-L., Martin G., Muller Feuga P. (2003). Les crues des 1er au 5 décembre 2003 dans les régions Auvergne, Bourgogne, Languedoc-Roussillon, Midi-Pyrénnées, Provence-Alpes-Côte-d'Azur et Rhône-Alpes, premières estimations des dommages, rapport de l'Inspection Générale de l'environnement et de l'équipement
26. Association Française de l'Assurance. (2011). Inondations du Var des 15 et 16 juin 2010 Bilan chiffré au 31 mai 2011
27. Hallegatte, S. (2008). An Adaptive Regional Input–Output Model and Its Application to the Assessment of the Economic Cost of Katrina. *Risk Analysis*, 28, 779–799
28. Rose, A. (2004). Economic Principles, Issues, and Research Priorities in Hazard Loss Estimation. In : *Modeling Spatial and Economic Impacts of Disasters Okuyama Y. Chang E.S.* Part I pp 13-36
29. Bauduceau, N. (2001). Éléments d'analyse des répercussions des inondations de novembre 1999 sur les activités agricoles des départements de l'Aude, des Pyrénées Orientales et du Tarn, Tech. rep., Équipe pluridisciplinaire Plan Loire Grandeur Nature
30. Bauduceau, N. (2004). De la caractérisation de la vulnérabilité de l'exploitation agricole face au risque d'inondation à la production d'un outil opérationnel de réduction de la vulnérabilité, Tech. rep., Équipe Pluridisciplinaire Plan Loire Grandeur Nature
31. Posthumus H., Morris J., Hess T. M., Neville D., Philips E., and Baylis A. (2009). Impacts of the summer 2007 floods on agriculture in England, J. Flood Risk Manage., 2, 182–189
32. Morris J. and Brewin P. (2013). The impact of seasonal flooding on agriculture: the spring 2012 floods in Somerset, England, *J. Flood Risk Manage*
33. Brémond P., Bauduceau N., and Grelot F. (2008). Characterizing Agriculture Vulnerability for Economic Appraisal of Flood Management Policies, *4th International Symposium on Flood Defence: Managing Flood Risk, Reliability and Vulnerability, Institute for Catastrophic Loss Reduction, Toronto, Ontario, Canada*
34. Brémond P. and Grelot F. (2010). Comparison of a systemic modelling of farm vulnerability and classical methods to appraise flood damage on agricultural activities, *Advancing Sustainability in a Time of Crisis, 11th biennal conference of the International Society for Ecological Economics, August 22–25, Oldenburg and Bremen, Germany*
35. Lefrou C., Martin X., Labarthe J.-P., Varret J., Maziere B., Tordjeman R., Feunteun R., Les crues des 12, 13 et 14 novembre 1999 dans les départements de l'Aude, de l'Hérault, des Pyrénées-Orientales et du Tarn, rapport du conseil general des ponts et chaussées et de l'inspection générales de l'environnement
36. Millinship I., La Réunion analysis cell generation, JBA Risk Management