Contribution to improve modelling and observation of flood impacts on agricultural assets (MOOM-agri)

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Scientific report

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Acronyms

EAIP : Approximate Envelope of Potential Flooding (Enveloppe Approchée des Inondations Potentielles)

LPIS : Land-Parcel Identification System

NDVI : Normalized Difference Vegetation Index

OT : Observation Task

RPG : Registre Parcellaire Graphique

so-ii : system of flood impacts observation

Glossary

Impacts : any effects a hazard may have on the system.

Damage : negative impacts.

Cost : evaluation of damage in monetized terms.

System : set of components in relation with one another (interaction, dependency).

Loss : damage that results in decreasing or disappearance of some component of the system.

Tangible damage : negative impact that can be quantified.

Intangible damage : Uneasy or impossible to quantify whether it is monetary or else (ex : environmental damage, aesthetic, psychology, health).

Direct damage : damage limited to the hazard areas (spatial scale) and physical contact.

Indirect damage : damage that occurs outside the flooded areas (spatial scale) and has an impact on the production chain (i.e. added value)

Instantaneous damage : damage that happens during or immediately after the hazard

Induced or deferred damage : occurs later in time (up to the end of the current cropping season and in the years that follow)

Farm component : elements that compose the farm (i.e. plots, buildings, crops, machinery, etc.).

Vulnerability : level of exposition to damage, capacity of crisis gestion and to recover from hazard's impacts

Resilience : the capacity of a system to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure.

Adaptation : capacity of finding and setting changes in order to resolve an issue

Damaging process : processes that occur in the considered system and which generate flood impacts

Short term effect : impact that occurs shortly after the hazard (< 6 months).

Mid term effect : impact that occurs between 6 months and 1 year and after the hazard.

Long term effect : impact that occurs more than 1 year after the hazard.

Abstract

In the context of climate change, farms are expected to face more frequent extreme events such as heat peaks, droughts, frost, hail or floods.

In order to comprehend and compile data on these subjects, observation through on field surveys is essential. Nevertheless, this method is time consuming and costly which is why modelling has been developed to help predict or evaluate farm vulnerability linked with climate change.

The so-ii observatory studies two watersheds (Lez-Mosson and Or) near the city of Montpellier. Subject to a Mediterranean climate, the types of flood hazards it faces are multiple (runoff, overflow, marine submersion or rising water tables). The flooding hazard is the natural hazard that generates the most damage in the world. This observatory focuses on floods but faces many other climatic challenges such as high temperatures and water stress.

Short term-damage is often well covered but the evaluation of long-term damage, resilience and vulnerability of farms facing extreme events is less studied as it is difficult to collect data and understand the mechanisms behind these issues. Observation on the long-term will be facilitated with the observatory and setting up networks of flood observers.

In this report, we propose a methodology that we are currently implementing to jointly and recursively improve the observation and modelling of flood impacts on agricultural systems. In particular, we wish to define more precisely the diversity of flood impacts and long-term damage on farms by taking into account the development trajectory of farms. To this end, we combine two complementary approaches: observation and modelling.

Chapter 1

Context and objectives

1.1 Context

The adaptation of the agricultural sector to global changes appears to be a leitmotiv both in terms of public policies and research questions. However, the tools for rigorously qualifying this issue have yet to be developed. Most of the analyses carried out consist of characterising the state of adaptation of farms to future changes, according to an interpretation framework defined a priori, or of analysing retrospectively the actions undertaken as possible adaptations. In the following, we distinguish between two scientific approaches which we believe can be mutually supportive in characterising the vulnerability, resilience and adaptation of agricultural issues to global change: modelling and observation.

1.2 Research questions and objectives

The work we have carried out aims to develop a methodology for observing, over a long period of time, the trajectories of agricultural activities subject to a 'climatic' regime composed of extremes (floods, marine submersions, droughts), which is potentially changing, by also integrating other so-called 'global' changes (economic conditions, regulations, etc.) in order to better qualify them.

In particular, we wanted to be able to define the characteristics necessary to qualify vulnerability and resilience (exposure to hazards, work organisation, solidarity, etc.) as well as the adaptation strategies implemented (e.g. choice of crops, varieties, transformation processes, cooperative organisation, etc.).

The method is based on tools for modelling the vulnerability of agricultural assets to flooding, in particular those developed within our team. The interest of relying on these tools is twofold, it allows

1. a framework for observation,
2. the production of indicators of vulnerability (e.g. estimation of potential damage to the activity in the event of an extreme event) and resilience (e.g. risk of failure of the activity in the event of an extreme event).

The questions we have addressed in this work are the following:

- What observation methods exist? What types of data can they produce?
- What modelling methods exist? Which components do they address? What indicators can they produce?
- What method(s) should be used to characterise in detail the processes underway (impacts, adaptations) and feed the models over the long term?

1.3 Methodology

In the framework of the project, we implemented the following method:

- literature review of methods for observing the impacts of flooding on agricultural assets;
- literature review of methods for modelling the impacts of flooding on agricultural assets;

- proposal of a methodological framework for the qualification of the impacts, vulnerability and adapation of farms over the long term;
- application of the methodological framework on a case for two types of farms (market gardenning and vineyard).

The points of vigilance that we kept in mind during the implementation of the different stages of the project were the following:

- to qualify the actors' strategies by taking into account :
  - adaptive management of disorders, from a short-term perspective (such as calling in a service provider to carry out tasks normally done in-house);
  - more structural adaptations, which can take place at the time of the management of disorders (e.g. modified replanting of uprooted plants), or afterwards (e.g. modification of the direction of the rows during an already planned replanting, a change of supplier, a change of production process, etc);
- take into account the spatial arrangement of the 'material' components of these activities (plots, buildings, equipment, stocks);
- take account of their organisation (internal and external with, in particular, the downstream and upstream sectors and financial partners);
- qualify the "material" impacts of climatic disturbances (in terms of yield losses, repair needs, unavailability of equipment, etc.);
- monitor, in a temporal way, the induced effects linked to the organisation of activities (modification of the organisation, increase in charges, possible loss of contracts, etc.);
- to qualify the evolution over time of the activities monitored in terms of 'vulnerability' or 'resilience', taking into account the impacts suffered, possible transformations of the activity, and changes in its more 'global' environment.

1.4 Case study : the observation system so-ii

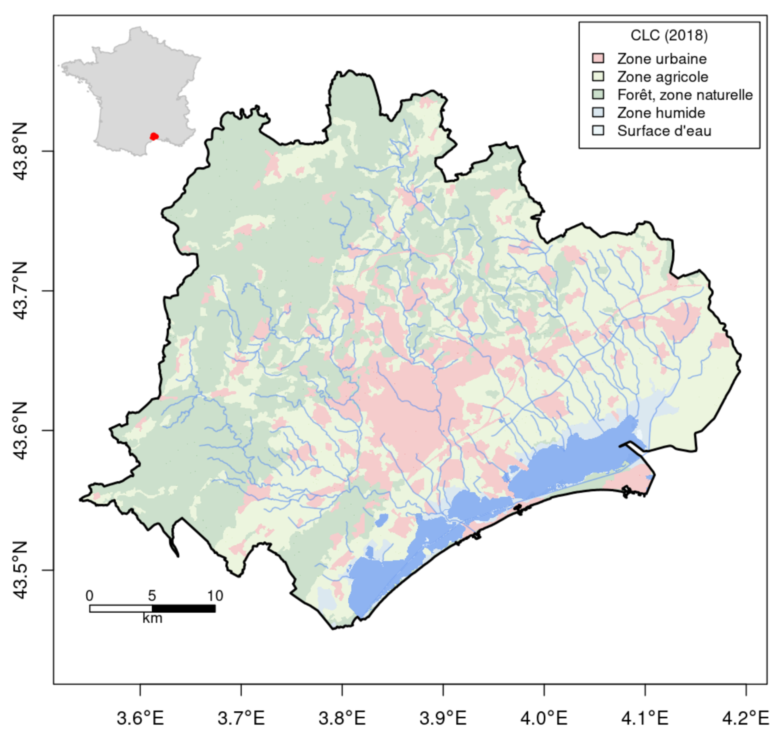

Figure 1.1: Territory of the observation system so-ii

The project was implemented in the framework of the Flood Impacts Observation System (so-ii), recognised as an observation service of the OSU Oreme since 2019. In particular, it contributed to feeding two observation tasks

(OT) in terms of methodological development and data collection, namely the OT REX (Post-Flood Experience Feedback) and the OT ROI (Flood Impact Observers Networks).

The so-ii territory is composed of two watersheds (Lez and Or) as well as their coastlines (figure 1.1). The so-ii observatory is particularly adapted for our study as it faces different types of hazards, including flood risk : floods due to runoff at the head of a basin, plain floods, floods due to marine submersions.

In agricultural terms, a first characterization of the exposure of agricultural issues to flooding on so-ii has been performed (Modjeska et al., 2022). This analysis highlighted that the territory has an important agricultural activity which is exposed to flood risk or submersion in a consequent way. In this work, the exposure was qualified from the Approximate Envelope of Potential Flooding (EAIP : Enveloppe Approchée des Inondations Potentielles).

Indeed, on the so-ii's territory (130 529 ha), 27.05% are agricultural surfaces (37 786 ha) of which 37% are in the EAIP. In particular, the analysis of the Land-parcel identification system (LPIS), locally known as "Registre Parcellaire Graphique" (RPG), by group of crops has shown that the crops mostly impacted are cereals, vineyards but also meadows and market gardening (table 1.1). More than 30% of the vineyards (2 470 ha) could be affected by flooding and more than 80% for market gardening (1 018 ha). This initial assessment justified our choice to test the proposed methodological framework primarily on farms of these two technical orientations.

Table 1.1: Agricultural areas and proportion of areas in the EAIP on the so-ii territory.

	Area (ha)		
Crop	**so-ii**	**EAIP**	**% EAIP**
Other cereals	4085	2705	66.2
Vineyards	7399	2338	31.6
Meadows and moors	13594	2287	16.8
Permanent grasslands	1659	1028	62.0
Vegetables or flowers	1231	1014	82.4
Fruit trees	912	765	83.9
Fodder	1232	721	58.5
Miscellaneous	1833	597	32.6
Grain legumes	1014	593	58.5
Temporary grasslands	903	486	53.8
Set-aside (areas set aside without production)	924	409	44.3
Sunflower	208	189	90.9
Barley	257	161	62.6
Wheat	199	98	55.4
Grain corn and silage	101	93	92.1
Olive trees	293	66	22.5
Other industrial crops	49	48	98.0
Protein crops	40	29	72.5
Canola	34	22	64.7
Nuts	2	1	50.0
Other oilseeds	0	0	NA
Total	35969	13650	NA

so-ii is a territory with stakes particularly linked with the population and urbanization increase. Often considered, a priori, as less vulnerable than urban issues to floods, a rigorous characterization of the vulnerability of agricultural issues and its adaptation capacities is necessary to consider appropriate territorial management policies.

1.5 Scientific valorization

The results of this work were presented at two conferences in 2022:

- Modjeska, M., Brémond, P., Grelot, F., Hossard, L., and Graveline, N.: Methodology for assessing flood damage to farms: observation and modelling, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-3834, https://doi.org/10.5194/egusphere-egu22-3834, 2022.

- Brémond, P., Balzergue P., Grelot F., Marry V., Modjeska M., Nortes Martinez D.: Contribution of a systematic and long-term observation method to improve the understanding of flood impacts, IAHS 2022, Montpellier, 30 May-4 June 2022.

Chapter 2

Conceptual framework and definitions

2.1 Data collection

2.1.1 Types of data to collect

Different types of data can be collected to improve the understanding and enhance modelling of complex processes. Hox and Boeije (2005) proposes the following definitions:

- primary data: original data collected for a specific research goal
- secondary data: data originally collected for a different purpose and reused for another research question
- qualitative data: data involving understandings of the complexity, detail and context of the research subject, often consisting of texts, such as interview transcripts and field notes or audiovisual material
- quantitative data: data that can be described numerically in terms of objects, variables, and their values.

2.1.2 Types of existing methods

In order to collect data and understand or identify impacts, different quantitative or qualitative methods can be used. Each has its advantages and disadvantages. These methods can be separated in different categories.

Data can be collected by questioning experts or people who have experience in the matter. This can be done with interviews, surveys or focus groups (Morgan, 2005). These methods can be declined in several ways depending on the desired data (qualitative or quantitative), the available resources (financial, temporal, etc.) for carrying out the work and the scale of the study.

Data can also be collected by observing impacts without soliciting people who have experienced floods. This can be done by observation (on-field or remote-sensing) and measurements, such as soil sampling, following an event.

Finally the collection of secondary data (when available) can me mentioned as a method for the identification of impacts.

In the field of research on health impacts, quantitative and qualitative approaches are seen as complementary to improve the understanding of impacts. In particular, qualitative research helps to highlight complex issues such as human behavior (Isaacs, 2014). The way the individuals are involved in data collection and their use to produce knowledge and decision making can be more or less participatory (Wehn et al., 2015).

2.2 Flood impacts on farms

2.2.1 Study at the farm scale

Before reviewing observation methods for flood damage assessment on farms it is important to define the system we desire to focus on. Indeed, the farming system is complex and must be defined as it can be viewed as a production system (crop and livestock productivity) or as a whole by considering other aspects such as infrastructures, buildings and social aspects. In our study, we consider the farming system as a whole and made out of these different components that are related with each other and characterized by their functionality that is essential in the case of flood vulnerability :

- plots : crop production, feed for animals;
- livestock : food production;
- buildings : storage for equipment, machinery, supplies and transformed goods;
- infrastructures (e.g. roads, paths) : access to buildings and plots;
- workforce : farmer and his employees;
- farm financial resources : farm capacity to financially cover additional costs due to flood;
- external relations (e.g. suppliers, resellers) : farm's dependency to external partners;
- farmers' coping strategies.

2.2.2 Flood damage classification

For flood damage classification, we will use the definitions pointed out by Brémond et al. (2013) in order to be clear on the distinctions between terms such as "impact", "damage", "costs" and "benefit". Flood impacts are any effects a flood may have on the farming system. Flood damage can be opposed to flood benefit where damage refers to negative impacts (e.g. soil erosion, crop destruction) while benefit refers to positive impacts (e.g. fertility gain due to organic matter deposits or increase of available water). Flood costs refer to the evaluation of damage or benefit in monetized terms.

2.2.3 Types of flood damage on farms

Flood damage can be categorized into four different types according to which scale it corresponds (economic, spatial and/or temporal) :

For the temporal scale, a difference is made between instantaneous damage (damage that occurs during or immediately after the flood event) and induced or differed damage (damage that occurs later in time). At the economic scale, damage can be either tangible (quantified) or intangible (difficult or impossible to be quantified). Finally, at the spatial scale damage can be direct (which appears right after the flood due to contact with the flood) or indirect (which occurs in a area that has not been exposed to flooding). Which leads to having either direct tangible, direct intangible, indirect tangible or indirect intangible damage. The sum of tangible costs and intangible costs is the total cost of flood damage. (Calatrava et al., 2018)

The types of flood damage on farms are detailed on plots (table 2.1), buildings (table 2.2) and other farm components such as roads, livestock, stored goods and human (table 2.3). As we are making a focus on two types of farming systems (winegrowing and market gardening), we will not go in detail on flood damage to livestock. The studies on impacts of floods on livestock have focused their attention mainly on dairy farms. For detailed information, see Gaviglio et al. (2021) and Morris and Brewin (2014).

Table 2.1: Flood impacts on plots

Impact	Effect	Action	Consequence	Economic estimation
Soil				
Available Water Capacity	Filling of the available water capacity	-	Yield gain	Change of added value
Erosion	Loss of organic matter	Fertilizing or organic matter input	Yield loss	Change of added value
Erosion	Loss of culture medium	Soil input	Yield loss	Change of added value
Erosion	Inaccessibility	Repair or leveling	Repair costs	Change of added value
Deposits of solid matter	Inaccessibility	Cleaning	Cleaning costs	Change of added value
Deposits of organic matter	Enrichment in organic matter	-	Yield gain	Change of added value
Pollution	Crop contamination	-	Intangible	Intangible
Salinization	Loss of vigor or mortality	Gypsum input or irrigation	Yield loss	Change of added value
Perennial plant material				
Damage	Loss of vigor or mortality	Restoration	Yield loss (year N and N>1)	Change of added value
Destruction	Mortality	Replacement or change of production	Yield loss (year N and N>1)	Change of added value
Disease	Loss of vigor or mortality	Treatments: mainly fungal	Yield loss (year N and N>1)	Change of added value
Annual plant material or intermediate crop				
Damage	Loss of vigor	-	Yield loss	Change of added value
Destruction	Mortality	Replacement or over-seeding	Yield loss	Change of added value
Disease	Loss of vigor or mortality	Treatments: mainly fungal	Yield loss	Change of added value
Market gardening plant material				
Damage	Loss of vigor	-	Yield loss	Change of added value
Destruction	Mortality	Replacement or offset of following crop	Yield loss	Change of added value
Disease	Loss of vigor or mortality	Treatments (mainly fungal) or crop-rotation change	Yield loss	Change of added value
Harvested product				
Damage or fouling	Quality loss	Cleaning	Yield loss	Change of added value

Table 2.1: Flood impacts on plots *(continued)*

Impact	Effect	Action	Consequence	Economic estimation
Destruction	Destruction	-	Yield loss	Change of added value
Equipment				
Fences: damage or destruction	Total or partial destruction	Replacement or repair	Repair or repurchase costs	Change of added value
Fences: fouling	Logjam or power loss (electric fences)	Cleaning	Cleaning costs	Change of added value
Greenhouse: damage or destruction	Impossible to intervene	Replacement or repair	Repair or repurchase costs	Change of added value
Greenhouse: fouling	Malfunction	Cleaning	Cleaning costs	Change of added value
Irrigation equipment: damage or destruction	Total or partial destruction	Replacement or repair	Repair or repurchase costs	Change of added value
Irrigation equipment: fouling	Malfunction	Cleaning	Cleaning costs	Change of added value
Machinery: damage or destruction	Impossible to intervene	Replacement, repair or service provider	Repair or repurchase costs	Change of added value
Machinery: fouling	Malfunction	Cleaning	Cleaning costs	Change of added value
Trellis: damage or destruction	Total or partial destruction	Replacement or repair	Repair or repurchase costs	Change of added value
Trellis: fouling	Logjam or power loss (electric fences)	Cleaning	Cleaning costs	Change of added value
Tools: damage or destruction	Impossible to intervene	Replacement or repair	Repair or repurchase costs	Change of added value
Tools: fouling	Malfunction	Cleaning	Cleaning costs	Change of added value

Table 2.2: Flood impacts on buildings

Impact	Effect	Action	Consequence	Economic estimation
Equipment				
Inaccessibility	Impossible to intervene	Work to resume accessibility	Work costs	Change of added value
Fouling	Wear and tear	Cleaning	Cleaning costs	Change of added value
Machinery: damage or destruction	Impossible to intervene	Replacement, repair or service provider	Repair or replacement costs	Change of added value
Machinery: fouling	Malfunction	Cleaning	Cleaning costs	Change of added value
Tools: damage or destruction	Impossible to intervene	Replacement or repair	Repair or replacement costs	Change of added value
Tools: fouling	Malfunction	Cleaning	Cleaning costs	Change of added value
Structure				
Destruction	Impossible to intervene	Repair or rebuilding	Repair or rebuilding costs	Change of added value

Table 2.3: Flood impacts on other components

Impact	Effect	Action	Consequence	Economic estimation
Roads or paths				
Destruction or erosion	Plot or building inaccessibility	Repair or leveling	Work costs	Change of added value
Obstruction	Plot or building inaccessibility	Cleaning	Cleaning costs	Change of added value
Livestock				
Drowning or accident	Death	Replacement	Production loss and livestock renewing cost (year N and N>1)	Change of added value
Relocation	-	Shelter rental or moving	Rental fees or travel expenses	Change of added value
Stress	Productivity loss	-	Production loss	Change of added value
Stored goods: on plots or buildings				
Finished goods: destruction	Destruction	Repurchase for honoring contracts	Repurchase costs	Change of added value
Finished goods: fouling or damage	Quality loss	Cleaning	Cleaning costs	Change of added value
Fodder: destruction	Destruction or lack of livestock feed	Purchase or change of diet	Repurchase costs and production loss	Change of added value
Fodder: quality loss	Quality loss in livestock diet	Purchase or change of diet	Repurchase costs and production loss	Change of added value
Inputs: destruction	Impossible to intervene	Repurchase	Repurchase costs	Change of added value
Human: psychological and physical				
Death	Intangible	Intangible	Intangible	Intangible
Injuries	Intangible	Intangible	Intangible	Intangible
Stress	Intangible	Intangible	Intangible	Intangible

2.2.4 Objectives of observation of flood impacts

Damage observation can be defined as a description of flood damage on land/agriculture using methods to acquire data/information on a territory's response to an event. The objective behind observation of flood impacts to agriculture is to understand, confirm and explore the processes (damage or benefit) that are at stake when a flood hits a territory. This observation leads to :

- collecting data on impacts;
- highlighting poorly explored impacts;
- differentiating territorial specificities;
- conceptualizing models by having more data on specific impacts;
- implementing models with data acquired on the field.

Chapter 3

Review of existing methods to collect data on flood impacts on farms

3.1 Objectives

In this section, we will make a non exhaustive review of literature of existing research that has been carried out on collecting flood impacts on farms (section 3.2) or that we have developed previously in our research team (section 3.3).

3.2 Analytical review of methods

This bibliographical review focuses on 18 studies presenting the means implemented to provide feedback on floods: Paulik et al. (2021), Posthumus et al. (2009), Agenais (2010), Agenais et al. (2013), Bauduceau (2001), Brida and Owiyo (2013), Roberts and Doyle (2017), Thieken et al. (2017), Wehn et al. (2015), Goto et al. (2014), Evans and Jones (2011), Sims and Colloff (2012), Durant et al. (2018), Morris and Brewin (2014), King and Gurtner (2017), Psomiadis et al. (2020), Shrestha et al. (2016), Tapia-Silva et al. (2011).

Data collection, whether it is the characterization of impacts for a feedback or for the conceptualization of predictive models for the estimation of damages to the agricultural sector, can be done by different methods as presented in section 2.1.2.

The methods presented in this section are listed in table 3.1 indicating: the article reference, the study area, the method(s) used, whether is applied to the agricultural sector or not, the spatial scale, the temporal scale, the number of interviews, the type of hazard, and whether or not there was subsequent damage modeling.

Table 3.1: Reviewed bibliographic references for flood impact observation methods and their characteristics.

Reference	Area	Method(s)	Interviewees	Agri	Scope	Scale	Time	Number	Hazard	Modelling
AgenaisAL2010a	France	Semi-structured questionnaires	Experts	TRUE	Region	Plot	-	10	Marine submersion	TRUE
AgenaisAL2013a	France	Semi-structured questionnaires, group interviews	Experts	TRUE	Region	Plot	-	30	Marine submersion, river overflow	TRUE
BeauduceauN2001a	France	Semi-structured questionnaires, secondary data collection	Experts, farmers	TRUE	Region, Farm	Region, Farm	10 days (experts), 1 year (farmers)	15 (experts), 30 (farmers), 3 sources for data collection	Runoff, river overflow	FALSE
BridaAB2013a	Mozambique	Semi-structured questionnaires, focus group discussions	households (farmers), experts (semi-structured questionnaires only)	TRUE	Region	Household, Region (focus group and experts)	-	300 (households), 3 (experts), Not specified (focus group)	Drought, flood	FALSE
CalatravaJ2018a	France	Secondary data collection: claim data	Insurance	FALSE	National	Adress	-	-	Drought, flood	FALSE
DurantD2018a	France	Experimental farm observation, soil sampling		TRUE	Farm	Plot	2 year	-	Salinisation, submersion marine	
EvansJ2011a	England	Walking interview	Individuals	FALSE	Local	GPS location	-	-		
GarciaP2021a	France	Structured questionnaires, interviews, semi-structured interviews	Farmers (structured), experts (semi-structured)	TRUE	Waterbasin	Farm	6 years	11 farmers, 11 experts	River overflow, water runoff	FALSE
GotoK2015a	Japan	Field observations, hearing survey, remote-sensing (NDVI), soil sampling	Town hall personnel	TRUE	Region	30m resolution (remote sensing)	remote sensing (before, 1 day, 2 weeks)	Not specified	Marine submersion	FALSE

Table 3.1: Reviewed bibliographic references for flood impact observation methods and their characteristics. *(continued)*

Reference	Area	Method(s)	Interviewees	Agri	Scope	Scale	Time	Number	Hazard	Modelling
KingD2017a	Australia	Online questionnaires, drop off and pick up, phone surveys	Individuals	FALSE	National	Individual	Not speci-fied	Not specified	Flood	FALSE
MorrisJ2014a	Angleterre	Farm visits, semi-structured interviews	Farmers	TRUE	Farm	Farm	1 month	11	River overflow	application
PaulikR2021a	New-Zealand	Semi-structured interviews, farm walk	Farmers	TRUE	Region	Farm	4 month	5	River overflow	FALSE
PerretN2020a	France	Structured questionnaires, interviews	Farmers	TRUE	Waterbasin	Farm	5 years	10	River overflow, water runoff	FALSE
PosthumusH2009a	England	Structured questionnaires	Farmers	TRUE	Region	Farm	Not speci-fied	78	Runoff, waterlogging, river overflow	application
PouilletA2015a	France	Structured questionnaires, interviews	Farmers	TRUE	Waterbasin	Farm	10-12 months	41	River overflow, water runoff	FALSE
PsomiadisE2020a	Greece	Remote-sensing (mapping)	-	TRUE	Region	10m resolution	15-20 days	-	Flood	FALSE
RobertsS2017a	USA	Crowdsourcing	Individuals	FALSE	Region	multiple (from plot to region)	mitigation, re-sponse, recovery	-	Flood, hurricanes	FALSE
ShresthaBB2016a	Philippines	Remote-sensing (mapping)	-	TRUE	Waterbasin	450m resolution		-	Flood	TRUE
SimsNC2012a	Australia	Remote-sensing (NDVI)		TRUE	Region	500m resolution	13 month	-	Waterlogging	
Tapia-SilvaFP2010a	Germany	Remote-sensing (mapping)	-	TRUE	Region	30m resolution	<1 month	-	Flood	application
ThiekenA2017a	Germany	Telephone surveys	Experts, individuals	FALSE	Region	individual	6-35 month	58 to 1697	Flood	FALSE
WehnU2015a	UK, Italy, Netherlands	Citizen observatories	Citizens	FALSE	Region	individual	-	-	Flood risk management	FALSE

3.2.1 Data collection methods

First of all, **interviews** with local stakeholders (farmers, experts) seem to be the most frequently used. They are generally based on more or less structured questionnaires allowing to address different aspects of the relationship between a system (plot, farm or region) and floods.

In the agricultural sector, these interviews are generally conducted **face-to-face** (Paulik et al. (2021); Posthumus et al. (2009); Agenais (2010); Agenais et al. (2013); Bauduceau (2001); Brida and Owiyo (2013)) and may in some cases be accompanied by **visual observations** (Paulik et al. (2021); Morris and Brewin (2014)) of damage directly on the farm. In the same spirit, **group discussions**, similar to semi-structured interviews, were used to complement individual interviews by Brida and Owiyo (2013) with inhabitants (also farmers) and by Agenais et al. (2013) with experts of the agricultural sector.

We also find **remote sensing** as a means to identify the types of crops (Tapia-Silva et al. (2011)) or flood extent on a territory (Psomiadis et al. (2020)) or to directly assess the damage to crops according to the Normalized Difference Vegetation Index (NDVI) method for example (Goto et al. (2014); Sims and Colloff (2012)).

In the specific case of assessing the impact of salinity on crops, **soil sampling** was also done (Goto et al. (2014); Durant et al. (2018)) to complement other methods (surveys, field observation or NDVI).

On the other hand, **secondary data** can be mobilized, as was the case in the report by Bauduceau (2001) which, in addition to interviews with institutions, relied on data from agricultural disasters, the press, the government and local feedback. The mobilization of these data is also carried out in addition to remote sensing (mapping) in order to evaluate damage amounts to the surfaces affected by flooding in the study area.

In the same way, data from insurance companies can be used to provide information on damage levels. Their access is however conditioned to their obtainment from the insurers or the Central Reinsurance Fund ("Caisse Centrale de Réassurance") and represents a partial view of the damage (Calatrava et al., 2018).

3.2.2 Methods' spatial scale

Different scales can be identified when characterizing impacts: plot, farm or territory (watershed, regional or national).

Interviews and questionnaires

Interviews with farmers are generally conducted at the plot or farm level and, depending on the number or profile of the participants, can reflect impacts at the scale of a whole region. For example, Paulik et al. (2021) selected 5 participants to cover the diversity of impacts representative of the study case while Posthumus et al. (2009) randomly selected a larger number of participants (78). Interviews are typically face-to-face and are sometimes accompanied by post-interview visits to observe persistent damage on affected plots (Paulik et al. (2021); Morris and Brewin (2014)). The post-interview farm visits are similar to the "walking interviews" method detailed in the Evans and Jones (2011) study, which allow the respondent to be put into a situation in order to contextualize his or her words and allow the interviewer to better understand the impacts suffered.

Interviews with experts or territorial managers mainly focus on the regional scales. They can also give detail at a plot scale when describing specific impacts. For example, expert consultation is often used to describe impact processes at smaller scales (plot or farm) in order to put them into models.

Secondary data collection

The spatial scale for secondary data collection is variable. Calatrava et al. (2018) indicates that insurance data can be at the address or street level but is limited because of the protection of individual private life. Claim data can only allow statistical approach at micro-scale and meso-scale (Calatrava et al., 2018).

Bauduceau (2001) describes impacts, acquired from secondary data, at the regional (press), sector of activity (press and local technical reports) and farm or plot level (agricultural disaster data).

Remote sensing

Remote sensing makes it possible to gather information on a plot scale with variable precision depending on the origin of the images. The resolution of images seems to range from 10m to 500m in the reviewed articles (table 3.1). The compilation of the plot level data obtained allows to cover areas ranging from watersheds to larger regions.

3.2.3 Type of data collected

Interviews and questionnaires

Semi-structured interviews carried out by Morris and Brewin (2014), Paulik et al. (2021) and Bauduceau (2001) collected plot and farm level data covering the following themes :

- general description of the flood event;
- actions taken during and after the flood;
- estimation of direct and indirect economic losses;
- production and capital asset damage;
- saved costs;
- challenges and coping strategies for recovery.

Surveys can also be used to collect more qualitative data as in the study conducted by Brida and Owiyo (2013) where surveys focused on the perception and impacts of floods and droughts experienced by households (100% agricultural) in a territory in Mozambique.

Remote sensing

Remote sensing is used to identify crop types and flood extent on a territory (referred as mapping in table 3.1). It can be used to determine agricultural land use as shown in the study by Tapia-Silva et al. (2011) in which three methods are compared, two of which come from Landsat images.

Flood characteristics assessment can be done from satellite images. For example, in addition with locating the extent of a flood with remote sensing, Psomiadis et al. (2020) assesses flood metrics such as flood depth, duration, peak discharge and recurrence interval.

The objective of **flood mapping** via remote sensing is to locate the extent of a flood. It is done by Psomiadis et al. (2020) while Shrestha et al. (2016) and Tapia-Silva et al. (2011) determine flood extent from hydrological data and/or models.

No damage evaluation is done by remote sensing in the studies mentioned previously. Indeed, damage is calculated by applying damage curves to expected yields and associated crop prices. For example, the damage curves applied in Shrestha et al. (2016) originate from a previous work made from the same authors (see Shrestha et al. (2015) in section 4.2)

Nevertheless, remote sensing has been used to determine flood impact on crop productivity by comparing NDVI values pre- and post-flooding (Goto et al. (2014); Sims and Colloff (2012)). In particular, crop productivity was studied to look at the impact of soil salinization (Goto et al. (2014)) and the effect of waterlogging on yields in a semi-arid context (Sims and Colloff (2012)). Goto et al. (2014) was able to show that there is a negative correlation between NDVI ratio and soil salt concentration showing that marine submersion causes crop productivity loss. Sims and Colloff (2012) was able to demonstrate that productivity of plants with water-saturated soils increased in the 13 months following flooding.

Field sample collection

Field sample collection was conducted for the assessment of salinity impact on crops by measuring soil sodium levels (conductivity) (Durant et al. (2018); Goto et al. (2014)).

Secondary data collection

Damage costs can sometimes be accessible with secondary data (Bauduceau (2001); Tapia-Silva et al. (2011)). Bauduceau (2001) collected the amount of damage to crops, soil, equipment, livestock and stored goods thanks to data from the compensation system called “Calamité agricole” in France. Tapia-Silva et al. (2011) collected official data on crop losses to validate the estimations made in their study.

Flooding extent and its characteristics are often obtained from the press, government or local institutions (Goto et al. (2014); Bauduceau (2001))

Agricultural land-use data is also a type of data that is collected in order to determine which productions are concerned by a flood. Psomiadis et al. (2020) obtained this data for Greece from the LPIS european database. Other data on the local agricultural systems can be obtained such as average market prices (Posthumus et al. (2009)), crop yields (Shrestha et al. (2016)) and cropping calendar (Shrestha et al. (2016)).

Claim data correspond to the amount of damages really paid by the insured people and the insurers (Calatrava et al., 2018).

3.2.4 Temporal scale

Considering the temporal scale when comparing data collection methods is essential as it plays a major role in the type of data collected.

Interviews and questionnaires

Indeed, short-term damage is easily assessed provided that the interview does not take place too long after an event. For example, Bauduceau (2001) ensures a "fresh memory" of the respondents within 1 year after the event.

However, conducting surveys quickly after an event, as in the case of Morris and Brewin (2014) (4 weeks), does not provide information on either the medium- and long-term impacts or the recovery actions that farmers may have taken because they are not yet clearly defined. Even with the 1-year post-event interviews, only speculations on long-term impacts (> 1 year) could be made by Bauduceau (2001) at several levels:

- changes in productivity of perennial crops;
- loss of customers;
- sanitary risks on the crops (virus);
- agricultural work (difficulty in maneuvering due to gullying, increased workload).

Similarly, by conducting the interviews 4 months post-event, Paulik et al. (2021) was able to gather speculations from the surveyed farmers regarding the loss of milk productivity in the year of the survey but also for the next 2 to 3 years.

Bauduceau (2001) also mentions that for the study of long-term impacts it would be judicious to carry out another study in a second time to validate or not the hypotheses made. Paulik et al. (2021) also makes this remark by proposing a methodology to assess the evolution of impacts over time by conducting interviews at different intervals (e.g. 3 months, 6 months, 1 year, 2 years, etc.).

Remote sensing

As mentioned earlier, remote sensing was used to evaluate yield losses exclusively in the short (15 days for Psomiadis et al. (2020)) and medium term (13 months for Sims and Colloff (2012)).

Farm monitoring

The experimental station of St-Laurent-de-la-Prée in France (Durant et al., 2018), has allowed to study the long term impact of soil salinization as well as the evolution of the farms' financial capacity over two years until original productivity levels on affected plots was reached. The economic evaluation of the damage was done as for Morris and Brewin (2014) by estimating the direct losses related to crop and livestock production, the additional costs of inputs and machinery and the costs of repair actions.

3.2.5 Advantages and limitations of the different methods

Interviews and questionnaires

Questionnaires have the advantage of being comprehensive and addressing a very wide range of impacts as well as damage evaluation. They have the disadvantage of requiring a great deal of organizational and application time for those that are most complete. As an example, face-to-face interviews with farmers lasted 2 hours for Morris and Brewin (2014) and between 3 and 4 hours for Posthumus et al. (2009).

Secondary data

This type of data is not always available or accessible and is often heterogeneous or limited.
For example, concerning perennial crops, a limitation of the data collected on agricultural disaster damage by Bauduceau (2001) is that future crop losses due to uprooting, replanting and waiting for severely affected plots to come back into production are not accounted for.

Nevertheless, the collection of secondary data can be interesting because of the promptness of acquisition and/or the few means necessary to collect them. When combined with other methods, they give key elements for hazard description and damage assessment. They are also used for validation of estimations made by other methods.

Remote sensing

Remote sensing has the advantage of being able to be carried out without having to travel and/or mobilize a resource person. The main limitation of this method is that it assesses only the loss of yield as an impact based on a calculation and not on an exact measurement. On the other hand, there are several biases to using the NDVI for estimation crop productivity:

- saturation of detection of increased biomass or plant vigor at high biomass levels;
- sensitivity to soil characteristics: color, age, moisture;
- a pixel can have the same NDVI value but have different characteristics at the plant level: 1 plant with a lot of biomass or several plants with little biomass.

Finally, remote sensing, without using the NDVI method, does not allow for an estimate of damage and must resort to an estimate based on modeling tools or speculative calculations.

3.2.6 Other methods for observation of impacts not applied to agriculture

Some types of questionnaires have not been mobilized at the agricultural level but are worth mentioning. Questionnaires for the assessment of impacts following a flood take different forms such as telephone interviews, online questionnaires and drop off and pick up surveys.

In general, telephone interviews and online questionnaires allow for coverage of a large number of individuals (Thieken et al. (2017), King and Gurtner (2017)) due to the rapidity of the interviews. However, these methods have some disadvantages such as a limited number of questions and a short and simple question format. Also, telephone interviews have an increasingly low response rate due to the greater use of cell phones rather than landlines and the increase in advertising solicitations.

King and Gurtner (2017) mentions the use of online questionnaires as an alternative or as a complement to face-to-face interviews. It is also mentioned that when some questions needed more time for answering, drop of and pick up technique was used. This technique simply consists of leaving a questionnaire to be filled and picked up the next day. This allowed for the participant to have more time for answering and eventually giving more completer answers.

Similarly, the mobilization of individuals (crowdsourcing) for data collection following natural disasters is a method detailed, from several examples on hurricanes and floods in the USA, by Roberts and Doyle (2017). This ressembles the work by Wehn et al. (2015) in which are explained the role of citizen observatories in governance policies in link with flood risk management for three locations : Doncaster (UK), Delfland (NL) and Vicenza (Italy).

3.2.7 Conclusive remarks

A large number of methods exist for the observation of the impacts of floods on territories. These methods allow for the most part to cover direct short-term damage.

Few studies are able to evaluate the long-term damage of floods, since the feedback is done between 4 weeks and 1 year after the flood. Only the experimental station has been able to observe some medium-term damage since the farm is continuously monitored (Durant et al., 2018).

On the other hand, the observation of impacts does not systematically imply the monetary evaluation of damages (see table 3.2). The few studies that do quantify the damage have either :

- collected the amounts through surveys;
- estimated the amount of damage by modeling the loss of yield and using general sales prices.

There are only a few studies (i.e. Posthumus et al. (2009), Morris and Brewin (2014)) which explicit the intermediate indicators for damaging processes. Also, few of the collected data is used for the implementation of damage modeling tools.

The development of damage modeling tools appears to be a suitable means of providing estimates of the amount of damage caused by a flood.

Table 3.2 gives a look at whether the method is used for observation of impacts, monetary evaluation or both.

Table 3.2: Reviewed bibliographic references for flood impact observation methods : impact description and monetary evaluation.

				Monetary evaluation	
Reference	Area	Method(s)	Impact description	Survey	Modelling
AgenaisAL2010a	France	Semi-structured questionnaires	yes	-	yes
AgenaisAL2013a	France	Semi-structured questionnaires, group interviews	yes	-	yes
BeauduceauN2001a	France	Semi-structured questionnaires, secondary data collection	yes	yes	-
BridaAB2013a	Mozambique	Semi-structured questionnaires, focus group discussions	yes	-	-
CalatravaJ2018a	France	Secondary data collection: claim data	-	yes	-
DurantD2018a	France	Experimental farm observation, soil sampling	yes	yes	-
EvansJ2011a	England	Walking interview	yes	-	-
GarciaP2021a	France	Structured questionnaires, interviews, semi-structured interviews	yes	-	-
GotoK2015a	Japan	Field observations, hearing survey, remote-sensing (NDVI), soil sampling	yes	-	-
KingD2017a	Australia	Online questionnaires, drop off and pick up, phone surveys	yes	-	-
MorrisJ2014a	Angleterre	Farm visits, semi-structured interviews	yes	yes	yes
PaulikR2021a	New-Zealand	Semi-structured interviews, farm walk	yes	yes	-
PerretN2020a	France	Structured questionnaires, interviews	yes	-	-
PosthumusH2009a	England	Structured questionnaires	yes	yes	yes
PouilletA2015a	France	Structured questionnaires, interviews	yes	yes	-
PsomiadisE2020a	Greece	Remote-sensing (mapping)	yes	-	-
RobertsS2017a	USA	Crowdsourcing	-	-	-
ShresthaBB2016a	Philippines	Remote-sensing (mapping)	yes	-	yes
SimsNC2012a	Australia	Remote-sensing (NDVI)	yes	-	-
Tapia-SilvaFP2010a	Germany	Remote-sensing (mapping)	yes	-	yes
ThiekenA2017a	Germany	Telephone surveys	yes	yes	-
WehnU2015a	UK, Italy, Netherlands	Citizen observatories	-	-	-

3.3 Methods previously developed by our team

3.3.1 Short-term post-flood feedback

3.3.1.1 Context

The first feedback on the so-ii territory was conducted in 2015 by Pouillet (2015) in order to respond to a need to deepen and confirm the knowledge on the impacts of floods on the agricultural sector. The objective of this feedback was to collect data on the damage suffered by farms affected by a major event that took place one year earlier in the Etang de l'Or basin, on September 29, 2014. Heavy rains have taken place in a short period of time in the territory. These rains caused both river overflows and runoff resulting in damage to farms.

3.3.1.2 Methodology

To carry out this forensic analysis, an exhaustive and closed questionnaire was applied during face-to-face interviews with 41 farmers. The productions of the farms surveyed are varied (market gardening, horticulture, viticulture, livestock, arboriculture and a seed producer) but the main ones are market gardening (13) and viticulture (14). The purpose of this questionnaire was to collect the following data :

- brief description of the farm's activities;
- description of the hazard (origin, direction of water, height of water, presence of silt, flow velocity, duration of flooding and recovery time);
- perception of risk and risk management by communities;
- past and future actions to reduce the vulnerability of the operation;
- monetized description of the impacts (crops, soil, plant material, buildings, stocks, farm equipment, animals);
- post-flood actions (restoration, decisions on the cultivation route);
- insurance and compensation issues.

3.3.1.3 Results

Hazard characteristics

The hazard was characterized mainly by river overflow and runoff. The market garden plots experienced around 8 days of water stagnation, while the other sectors experienced a maximum of 2 days of submersion. This can be explained by the fact that market garden plots are generally located in alluvial areas, while other crops are spread over a wider range of topography.

Most farmers (73%) reported that the current was strong. However, the results of the study with respect to the soil and crops are more characteristic of weak to medium currents. The responses around flow rates are quite subjective which makes them difficult to process. The water was loaded with silt in 83% of the cases.

Observed damage

This feedback has highlighted damage on all components of the operation (in % of damage amounts):

- crop losses (48%) outside the wine sector because the harvest had already taken place
- damage to soil and plant material (17%):
  - significant soil damage for the wine and market gardening sectors (erosion, gullying)
  - damage to plant material mainly for horticulture and strawberry growing
- damage to equipment (17%): very important for market gardening, in particular for a hydroponic tomato farm
- damage to buildings (8%): 2 farms affected (market gardening and riding stable)
- stored goods losses (5%): these losses only concern farms whose buildings were affected
- damage to livestock (3%)

In addition, farmers were surveyed regarding the psychological impact of the flooding. Most of them (85%) are not particularly affected psychologically. The others reported stress when heavy rains are expected.

Rehabilitation

The cleaning times reported by Pouillet (2015) are quite variable depending on the farm but seem to be more important for market gardening, viticulture and horticulture. Pouillet (2015) noted that rows of vines planted in the direction of flow will be less prone to cleaning because water can flow easily and there is less debris caught in the trellis. In the same way, the time needed to get the farms back up and running is very important for the market gardening and viticulture sectors, but also for livestock farming.

Loss of activity

As a result of this event, the market gardening and horticultural activities are those that have suffered the greatest loss of activity. Indeed, as the plots were not accessible because of the draining or cleaning to be done, it was difficult for the farms to restart the activity quickly (replanting, tilling or uprooting of the damaged crops).

In the case of viticulture, loss of activity is generally caused by the loss of grapes, which prevents the vinification and consequently sale of wine. However, this was not the case in this event because the harvest had already been completed.

Future planning actions

Slightly more than half of the farmers surveyed intend to implement actions to limit the risk of flooding on their farms. The planned actions are as follows:

- the maintenance of ditches and their repair if they have been destroyed ;
- the creation of small retention basins on their parcels;
- maintenance of banks and watercourses whether they are owners or not;
- the levelling of the land;
- the ripening of the banks of watercourses;
- grassing of vineyards to limit the gullying of the land (but this is far from being the majority of cases for wine growers);
- pruning the lowest branches for arborists to limit crop loss.

3.3.1.4 Discussion

The survey work of Pouillet (2015) highlighted multiple and complex damage mechanisms. Some aspects often omitted in other studies (ie. recovery time, clean-up cost, loss of business, damage to equipment and buildings) could be identified.

This work has captured the short-term damage of this event. Some damage, such as damage to plant material and soil, may weaken the farms in the long term. Taking place 1 year after the event, this feedback could not identify the possible long-term damage of this flood on the farms. Moreover, this event generated high expenses for the restoration of the farms, which may suggest a financial weakening of the farm.

3.3.2 Long-term post-flood feedback

3.3.2.1 Context

For the different reasons mentioned above, two survey campaigns were set up several years after the feedback of Pouillet (2015) with students of the Master Sciences de l'Eau, parcours Eau et Agriculture (Water Science, Water and Agriculture cursus), of Montpellier in order to go back on the affected farms. The objective of these feedbacks was to highlight the long-term impacts of floods on farms. In both campaigns, a focus was made on wine (Perret et al., 2020) and vegetable farms (Garcia et al., 2021) as these were the most exposed to the 2014 flood.

3.3.2.2 Methodology

To meet the defined objective, face-to-face surveys were conducted with affected farmers, 5 (Perret et al., 2020) and 6 (Garcia et al., 2021) years after the event. (Perret et al., 2020) conducted interviews with 10 wine growers. (Garcia et al., 2021) conducted interviews with 8 market gardeners and 3 horticulturists as well as 3 interviews with experts from the Chamber of Agriculture of Hérault to consolidate the questionnaire and give their vision of the impacts.

The established questionnaires allowed to address the following points:

- general context of the farm;
- reminder of short-term damage (crops, soil, equipment);
- long term impacts (yield in the following years, loss of contracts);
- financial needs for this flood;
- psychological impacts;
- time needed to return to normal;
- insurance (compensation amounts, interest);
- measures taken in response to the flood risk.

3.3.2.3 Results: Market gardening and horticulture

Surveys conducted by Garcia et al. (2021) have identified some long-term impacts at the farm level for vegetable and horticultural farms on crops, equipment, but especially on the financial level.

Impacts to plots

In terms of impacts on crops, all farms reported crop losses at the time of the flood. However, no impact on the following crops was observed except on one farm which observed a decrease in the quality of its strawberry production (yellowing) the three following years.

No long-term impacts were observed at the soil level despite the short-term damage experienced by half of the farmers surveyed.

Machinery and equipment

Two long-term material impacts were observed: repair of horticultural and/or market garden greenhouses over several years and damage to vehicles causing malfunctions. The destruction or damage of greenhouses can be a real problem for the resumption of activity as shown by the example of one of the farmers who was not able to resume his entire production before 3 years post-flood due to the repair of a greenhouse.

Financial impact and rehabilitation

At the financial level, it is the time needed to return to a stable cash flow that has the greatest impact. Indeed, it took between 6 months and 4 years for the market gardeners and up to 7 years for the horticulturists to find a stable situation following the loans taken out and/or amounts spent for the resumption of activity. Two horticulturists had still not recovered from this event at the financial level, one of which is in judicial liquidation (the floods having played a role among other aspects).

Psychological impacts

Some of the farmers who had reported being psychologically affected to (Pouillet, 2015) were still affected 5 years later. It is important to note that other weather events (including floods) are included in this stress.

Adaptation measures

One farmer mentioned that he stopped producing asparagus after the flood, having lost all his production. Farmers have been limited in the implementation of protection measures due to lack of knowledge or financial means. Only one farmer put in place protections after the event. All the farmers who have protection are also those who have experienced several floods. The protections mentioned are the following: over-lifting of the equipment, maintenance of the ditches around the farm, installation of protective dikes.

3.3.2.4 Results: Viticulture

Impacts to plots

For winegrowing farms, the only long-term damage reported by some farmers concerns plots affected by runoff and consequently soil erosion. In fact, the soil input for compensating erosion did not allow the soil to regain its original structure, texture and organic matter, thus worsening the re-wetting time in the following years. This may suggest that the soil is more vulnerable to erosion once soil has been added.

The only impact to plant material that would appear to be flood-related is the increase of mildew since 2014. No other long-term damage could be identified at this level.

Financial impact and rehabilitation

The rehabilitation was resolved fairly quickly (within 2 years). No particular indebtedness seems to have been observed. The farmers regained financial stability at the end of the season. This is also explained by the fact that no crop losses were experienced.

Psychological impacts

All farmers declared being psychologically impacted but not necessarily by floods only. The risks of hail, frost and drought play a very important role in this state of stress. It is important to note that the surveyed farmers are not insured for floods, which they consider less important than other risks.

Adaptation measures

Certain adaptation measures in terms of agronomic practices have been implemented to limit soil erosion :

- grassing 1 row out of 2
- reduction of pesticides
- stopping plowing after July
- establishment of hedges

3.3.2.5 Conclusive remarks

The two studies carried out have revealed the presence of several different long-term impacts depending on whether one is interested in market gardening or viticulture systems. The vegetable and horticultural systems seem to be more marked by financial and equipment impacts, while the vineyard systems had long-term impacts on the soil. The impacts common to both systems are psychological impacts.

In general, long-term impacts for both types of systems, apart from the financial impacts, seem to be quite minimal compared to the short-term ones. However, the agricultural sector faces many other climate issues that make it difficult to establish a causal link specific to flooding.

The interest of conducting interviews with farms already surveyed beforehand facilitates the implementation of the interviews and allows for a better understanding of the mechanisms of flood damage and vulnerability of farms. Nevertheless, both studies agree on the importance of a mid-term feedback, as some farmers have difficulties to remember some impacts of the flood 5 to 6 years after the event. Semi-structured interviews seem to be suitable for characterizing long-term impacts because they allow the farmer to provide detailed information.

Chapter 4

Review of existing methods to model flood impacts on farms

4.1 Purpose of the developed models

The interest of flood damage modeling on the agricultural sector is multiple. First, modeling has the advantage of predicting the types and/or amounts of damage in establishing flood scenarios. Moreover, it can be used as a support for local decision-makers during territorial development projects but also in the fields of insurance and compensation.

This literature review included 8 studies presenting 7 approaches to modeling flood damages on agriculture as well as the literature review done by Brémond et al. (2013): Edmund et al.; Molinari et al. (2019); Scorzini et al. (2021); U.S. Army Corps of Engineers (USACE) (1985); Vozinaki et al. (2015); Gould et al. (2020); Li et al. (2016); Agenais (2010). Note that three methods/models presented here (Edmund et al., U.S. Army Corps of Engineers (USACE) (1985) and Agenais (2010)) are also part of the literature review done by Brémond et al. (2013).

In the table 4.1, are summarized the methodologies detailed in this section.

Table 4.1: List of bibliographic references of methods and modeling tools for flood damage estimation on farms.

models	ref	type	data	temporality	spatiality
floodam-agri	AgenaisAL2013a	Process-based	Expert-based		Plot
REVA	BremondP2011a	Process-based	Expert-based		Farm
COOPER	NortesMartinezD2019a	Agent-based	Expert-based	30 years	Cooperative wine-system
FHRC	Penning-Rowsell Edmund et al. Flood and coastal erosion risk management	Process-based / methodology	Expert-based, experiment based	N, mention of N>1	Farm
AGRIDE-C	MolinariD2019a	Process-based	Expert-based	N	Plot
AGRIDE-C	ScorziniAR2021a	Process-based	Expert-based	N, N>1 (for grapevine)	Plot
AGDAM	USACE1985a	Methodology	Not specified	N	Plot
WMCLR	VozinakiAEK2015a	Process-based	Expert-based	N	Plot
GouldJ2020a	GouldJ2020a	Process-based	Expert-based	N+7	Plot
WOFOST and HU	LiS2016a	Process-based	Expert-based	N	Region
AgenaisAL2010a	AgenaisAL2010a	Methodology	Expert-based	N+2	Plot
ShresthaBB2015a	ShresthaBB2015a	Process-based	Expert-based	N	Region

4.2 Types of model

There are different types of models to assess the damage of floods on agriculture. Generally, these models are used in combination with hydraulic models to simulate the extent and characteristics of floods. Brémond et al. (2022) presents the different types of models by separating the modeling methods from the data needed to implement them.

The different types of models identified are: data driven modelling, conceptual modelling, process-based modelling. The types of data used to calibrate the models can be of three different forms:

- damage observation data
  - also mentioned by Shrestha et al. (2016): "Data on past flood events and damage, including their relationships, are important for developing damage functions and to validate calculated results."
- data from expert knowledge
- data from experiments

The **process based models** are the most used for the evaluation of flood damages to agriculture.

In Great Britain, Edmund et al. developed a method which is described in the "Flood and Coastal Erosion Risk Management - Manual for Economic Appraisal". This method covers damage estimation at the farm level by taking into account the change in added value between production losses (crop yields, grass productivity according to the method defined by Morris and Hess (1988), livestock), other damage (buildings, machinery, equipment, debris to be cleaned up, loans, loss of contracts) and additional and / or avoided costs (treatments, avoided harvesting costs, etc.).

Gould et al. (2020) developed a model to estimate the impact of marine flooding on agriculture. For this purpose, a focus is made on the impact of salinity on yields by considering that the loss is total in the year of the flood and that it is reduced in the following years. In addition, seasonality is represented by two periods, a flood in autumn/early winter or in spring, which will impact recovery scenarios causing expenses to vary (e.g. no intervention, change of crop to a more tolerant crop or grassing).

In the United States, the method detailed in U.S. Army Corps of Engineers (USACE) (1985) for the evaluation of damage to annual crops is based on the evaluation of the loss of added value (loss of yield and variation in associated costs) as a function of the duration and seasonality of the flooding. In the detailed methodology for damage estimation, velocity, water height and residue parameters are also mentioned. However, these parameters are not taken into account in the development of crop damage functions.

In France, the model floodam-agri (Agenais et al., 2013) was developed for the evaluation of damage to crops (annual and perennial). Its aim is to evaluate damage at the plot level by estimating the variation in added value resulting from a flood in terms of product loss (yield) and intermediate consumption. This model is explained in detail in section 4.4.1.

In Italy, Molinari et al. (2019) implemented a conceptual model for crop damage estimation that is intended to be transferable to other territories. This model combines two sub-models: one physical and one economic. The physical model takes into account the impacts on the soil (negative and positive effects) as well as crop damage. The economic model is based on yield loss and changes in production-related expenses (soil repair, additional cultivation practices, crop abandonment, soil drainage). The damage functions to crops are transferred from Agenais et al. (2013) model "floodam-agri" (see section 4.4.1). AGRIDE-C therefore takes into account a large number of parameters in the conceptual model. In a second step, Scorzini et al. (2021) completed the AGRIDE-C model by integrating vegetable crops (cabbage, spinach, lettuce and bean) and grapevine. The damage functions to these new crops are also transferred from Agenais et al. (2013) model "floodam-agri".

However, when applying it, some parameters cannot be evaluated, such as damage to soil for example, which is taken into account in a recurrent way through a fixed cost and does not depend on the hazard parameters. This is also the case for pollution and the reduction of soil fertility.

In Greece, Vozinaki et al. (2015) developed damage functions for some annual crops (cereals and vegetables), grasslands and perennial crops (fruit and olive trees) according to seasonality, height and velocity of water in the case of a flash flood. Damage considered is direct yield loss not including soil damage, rehabilitation or long-term damage to plant material of perennial crops. Also, the perennial crops were considered to be all the same age (20 years), thus excluding any young plants which are not productive in the first years after being planted.

In Japan, Shrestha et al. (2015) developed damage functions for damage assessment to agriculture in a case-study located in the Pampanga river basin of the Philippines. Hazards parameters considered are both flood depth and duration. These functions focus on the vegetative stages of rice crops to estimate yield loss.

Finally, in China, Li et al. (2016) implemented a wheat yield estimation model to incorporate the impact of soil waterlogging on wheat development. In this study, daily rainfall is simulated and waterlogging will prevent the proper development of wheat. In order to simulate waterlogging, several parameters are considered: available water capacity, crop species (tolerance to waterlogging), waterlogging duration and seasonality. Only yield losses which do not include losses due to velocity are taken into account.

In France, our team has developed several models, including floodam-agri, which are described and put in perspective with the international literature in the section 4.4. In addition, Agenais (2010) proposed a method to assess the impact of marine submersion on crops by taking into account various components of the farm and necessary rehabilitation works.

4.3 Description of the main characteristics

4.3.1 Flood parameters

Flood parameters affecting the agricultural sector are: seasonality, water height, flooding duration, flow velocity, and deposits of organic matter, pollution, or salinization (table 4.2).

In the review of methods for agricultural damage assessment by Brémond et al. (2013), it was identified that seasonality and flooding duration are the most influential parameters.

Table 4.2: Flood hazard parameters taken into account to evaluate damage in the studies reviewed.

models	ref	seasonality	depth	duration	velocity	salinity	pollution
floodam-agri	AgenaisAL2013a	yes	yes	yes	yes	-	-
REVA	BremondP2011a	yes	yes	yes	yes	-	-
COOPER	NortesMartinezD2019a	yes	-	-	-	-	-
FHRC	Penning-Rowsell Edmund et al. Flood and coastal erosion risk management	yes	yes	yes	-	yes	-
AGRIDE-C	MolinariD2019a	yes	yes	yes	yes	yes	-
AGRIDE-C	ScorziniAR2021a	yes	yes	yes	yes	yes	-
AGDAM	USACE1985a	yes	yes	yes	yes	-	-
WMCLR	VozinakiAEK2015a	yes	yes	-	yes	-	-
GouldJ2020a	GouldJ2020a	yes	-	-	-	yes	-
WOFOST and HU	LiS2016a	yes	-	yes	-	-	-
AgenaisAL2010a	AgenaisAL2010a	yes	-	yes	-	yes	-
ShresthaBB2015a	ShresthaBB2015a	yes	yes	yes	-	-	-

Seasonality

Seasonality was mostly used (23 out of 26 studies) to link a period of the year with damage amounts. This parameter varies strongly from one study to the other. Indeed, seasons are considered on different scales:

- Gould et al. (2020): 2 seasons defined as early flood (Autumn/Winter) and late flood (Spring).
- Edmund et al.: 4 seasons (Spring from March to May, Summer from June to August, Autumn from September to November and Winter from December to February)
- Molinari et al. (2019), U.S. Army Corps of Engineers (USACE) (1985), Vozinaki et al. (2015): Monthly

However, there is a difference between taking into account the periods of the year and the physiological stages of the plants at the moment of the flood. Indeed transferability of models to other regions is important which is why Brémond et al. (2013) recommends to establish damage functions from crop growing cycles. Molinari et al. (2019) has implemented this recommendation and relies on vegetative stages to estimate seasonality damage. Li et al.

(2016) and Shrestha et al. (2015) both consider the sensitivities of the different growth stages (5 distinct phases) of crop development.

Water depth

Water depth is used in a very large majority (20 of 24 studies) of the studies reviewed by Brémond et al. (2013). This parameter is used to evaluate the damage to plant material and sometimes to the soil. In the few cases where methods take into account the damage to buildings and their contents, it is generally the only parameter considered.

As mentioned by Molinari et al. (2019), Edmund et al. and Shrestha et al. (2015) water depth will damage crops depending on seasonality thus depending on the vegetative state of the crop at the time of the flood. On the other hand, Vozinaki et al. (2015) combines water depth with velocity to obtain damage curves.

For the studies that do not consider this parameter, Gould et al. (2020) mentions a lack of data on flood depth impacts. Agenais (2010) mentions that water depth can be neglected in the case of marine submersion and Li et al. (2016) does not mention water depth at all.

Flooding duration

Flooding duration is generally considered as a threshold to damage to crops. It can be attributed according to a classification (Edmund et al.; U.S. Army Corps of Engineers (USACE) (1985); Agenais (2010); Shrestha et al. (2015)) or linearly (Molinari et al. (2019); Li et al. (2016)). For example, Edmund et al. assigns damage when flood duration exceed 1 week. For the U.S. Army Corps of Engineers (USACE) (1985) and Shrestha et al. (2015), a percentage of loss is assigned to flood durations: respectively 0 day, 1 day, 3 days and 14 days duration and 1-2 days, 3-4 days, 5-6 days and 7 days. Agenais (2010) considers two categories for flood duration: short and long

In Molinari et al. (2019) (based on Agenais et al. (2013)) damage increases linearly between the lower threshold (where damage is 0%) to the higher one (where damage is 100%). The thresholds vary according to the vegetative stage of the crop. Focusing on waterlogging, Li et al. (2016) sets the maximum effect of duration of waterlogging to 4 days.

It is important to note that it is difficult to know whether the submersion duration which is considered in the studies contains the soil drying time or not.

For example, Agenais (2010) includes the variations in soil drying time depending on soil texture. This is all the more important when evaluating impact of salinity to crops as the exposition time to salt is the main damage factor to crops. Similarly to estimating soil drying time, Li et al. (2016) includes available water capacity to simulate the duration of waterlogging.

Velocity

The velocity of the current of a flood is less frequently used but remains an important parameter in particular for the “flash floods” (Brémond et al., 2013). Indeed Vozinaki et al. (2015) considers this parameter in their study as their focus is made on this type of flood. In the review by Brémond et al. (2013), 6 methods out of 26 use velocity through qualitative thresholds (low, medium, high velocity). These include models that have constructed damage functions for plant material (uprooting) and for soil (erosion).

U.S. Army Corps of Engineers (USACE) (1985) regroups sediment deposition, erosion and velocity in terms of effect mentioning that these effects are difficult to distinguish from depth and duration. It seems as though it is only mentioned in the conceptual framework and is not considered in the application of the method.

Salinity

In the review made by Brémond et al. (2013), the only study including salinity damage is Agenais (2010) as the focus is made on marine submersion. Agenais (2010), Edmund et al. and Gould et al. (2020) consider that salinity will impact yield losses according to crop type (salinity tolerance or not) depending on the level of salt in the soil. Edmund et al. mentions that damage due to salinity also exists if the crop is sown after the flood as their the soil contains salt. Damage is considered greater when the crop is already sown by the time the flood hits.

It should be noted that salinity is considered to impact for several years after the flood in Gould et al. (2020) (up to 7 years) and Agenais (2010) (up to 2 years).

Molinari et al. (2019) mentions salinity being included in damage assessment to soil and to crops but it is not integrated in the model.

Pollution and silt deposits

Although often mentioned, soil contamination by pollution as well as silt deposits are never modeled because the damage processes related to these phenomena are not well understood (Brémond et al., 2013). Edmund et al. and Molinari et al. (2019) mention this pollution in their conceptual models without being able to quantify it. As mentioned before in the section on flood velocity, U.S. Army Corps of Engineers (USACE) (1985) includes silt deposits in its methodology.

Combination of hazard parameters

According to the review in Brémond et al. (2013), most studies use a combination of hazard parameters to create damage functions. Generally two to three parameters are considered as it is also the case for Vozinaki et al. (2015), Gould et al. (2020), Li et al. (2016), Agenais (2010) and Shrestha et al. (2015). Note that U.S. Army Corps of Engineers (USACE) (1985) combines 5 parameters but did not define crop damage functions.

4.3.2 Flood damage indicators

Table 4.3: Farm components taken into account for the evaluation of damage in the studies reviewed.

models	crop	crop_type	livestock	building	machinery	equipments	soil	stock	plant material	indicator
floodam-agri	yes	alfalfa, barley, canola, fruit trees, grassland, maize, sunflower, vegetables, grapevine, wheat	-	-	-	-	yes	-	yes	Net margin adjusted with variable costs
REVA	yes	cereals, fruit trees, grapevine, vegetables	-	yes	yes	yes	yes	yes	yes	Net margin adjusted with variable costs
COOPER	yes	grapevine	-	yes	yes	yes	yes	yes	yes	Net margin adjusted with variable costs
FHRC	yes	beet, beans, cereals (spring and winter), grass, horticulture, roots, oilseed rape, spring peas, potatoes	yes	yes	yes	yes	yes	yes	-	Net margin adjusted with variable costs
AGRIDE-C	yes	barley, grassland, maize, wheat	-	-	-	-	yes	-	-	Net margin adjusted with variable costs
AGRIDE-C	yes	annual vegetable (bean, cabbage, lettuce,spinach), grapevine	-	-	-	-	yes	-	yes	Net margin adjusted with variable costs
AGDAM	yes	not specified	-	-	-	-	-	-	-	Variable
WMCLR	yes	fruit trees, olive trees, tomatoes, vegetables	-	-	-	-	-	-	-	Yield loss
GouldJ2020a	yes	barley (spring and winter), beet, beans, grass, maize, oilseed rape, other brassica, potatoes, wheat (spring and winter)	-	-	-	-	-	-	-	Gross margin (and gross added value)
WOFOST and HU	yes	wheat	-	-	-	-	-	-	-	Yield loss
AgenaisAL2010a	yes	annual crops (barley, sunflower, maize, wheat, etc.), fruit trees, grassland, vegetables, grapevine	-	-	-	yes	yes	-	yes	Gross margin
ShresthaBB2015a	yes	rice	-	-	-	-	-	-	-	Yield loss or cost of input

4.3.2.1 Flood damage to crops and livestock

According to the review by Brémond et al. (2013), all damage assessment methods consider crop damage. This is also the case for the studies we have added in the current review.

Most of the studies include several types of crops and a minority are simplified by considering one or two types of crops (Brémond et al., 2013). Note that one of the studies focuses on impact to livestock which is why only pastures are considered (Morris and Hess, 1988). 6 studies (including Agenais (2010)), which include perennial crops (grapevines, arboriculture and sugarcane) integrate damage to plant material (Brémond et al., 2013). For the perennial crops, only a few studies include long-term damage (Scorzini et al. (2021), AgenaisAL2010a, Gould et al. (2020)). It should be noted that the age of perennial crops in the application of AGRIDE-C (Scorzini et al., 2021) has been set to 17 years for all vineyards on the territory subsequently excluding young plants.

In the studies presented in table 4.1, Li et al. (2016) and ShresthaBB2015a focus on one type of crop, respectively wheat and rice, while the other studies include more than 4 crop types.

Damage to livestock is addressed by 3 studies in the review of Brémond et al. (2013) that incorporate direct damage from loss of livestock and indirect loss of productivity following flood. Furthermore, Morris and Hess (1988) method also incorporates the increased feed costs associated with the loss of grass productivity and temporary housing of animals.

Induced damage is rarely integrated because it is mostly assessable at the farm level (Brémond et al., 2013), yet very few studies are conducted at the farm level. Agenais (2010) includes loss of yield of perennial crops in susbsequent years due to replanting and time before full productivity is reached again. Similarly, in the extension of the Agride-C model (Scorzini et al., 2021), induced damage is considered, in the case of damage to grapevine plant material (based on Agenais et al. (2013) presented in section 4.4.1), by estimating the productivity loss in the following years after replanting. In the consideration of saline damage to crops, Gould et al. (2020) and Agenais (2010) include induced damage to crops in the years following the initial damage. Gould et al. (2020) offers the possibility of applying yield penalties up to 7 years post-flood due to saline residues in the soil while it goes up to 2 years post-flood for Agenais (2010).

4.3.2.2 Damage indicators for the other farm components

Regarding methods that include damage to buildings, Brémond et al. (2013) identified 9 methods that take it into account. Out of these methods, 5 use damage functions created for residential buildings while 4 have damage functions specific to agricultural buildings. A minority of methods include damage to machinery and stored goods. Among the studies shown in table 4.1, only Penning-Rowsell et al. (2013) include damage to buildings in its evaluation. However the estimated damage is not transposable to another territory as it results from an adjustment of damage costs from a previous flood by taking into account inflation and not damage functions with described processes.

4 studies (including Agenais (2010)) integrate damage to soil by considering the costs of restoration due to erosion and cleaning due to deposition (Brémond et al., 2013). For Agenais (2010), soil restoration is evaluated by the time necessary for cleaning and plowing of the plot, the hourly cost of labour, the quantity of amendment (gypsum or organic matter), the amendment cost and the cost of green manure.

The AGRIDE-C model (Molinari et al. (2019); Scorzini et al. (2021)) includes the cost of damage to soils and was evaluated by consulting experts to set a restoration cost of soil. In the method presented in Edmund et al., restoration of “land” (removing damaged crops, adding cultivations or treatments) is considered but does not seem to include direct damage to soil (e.g. erosion) and does not give an explicit method to evaluate the cost of these actions. However the restoration of land includes the cost of gypsum application to ameliorate soil conditions in the case of saline floods.

Concerning indirect damage assessment, Brémond et al. (2013) mentions that very few studies describe and assess this type of damage. Only the method of Du Plessis and Viljoen (1999) addresses indirect damage through an input-output model by considering that direct damage to property and crop products will affect “transactions and jobs in the agricultural and commercial sectors” (Brémond et al., 2013). Similarly, Gould et al. (2020) evaluates the number of jobs at risk for farming business and supplier network.

4.3.3 Flood damage evaluation

The assessment of crop damage is measured by an assessment of loss of added value, which corresponds to the loss of yield minus the variation in production costs. However, in the methods reviewed by Brémond et al. (2013), the loss of added value is only very slightly addressed. It the review, it is mentioned that the Lacewell and Eidman (1972) methodology incorporated the increased production costs associated with additional treatments or operations following a flood in its methodology for damage estimation.

Evaluation is generally done by assessing the variation of: yield only, gross revenue, gross margin or net margin (Brémond et al., 2013). Some studies have simply estimated yield loss (Li et al. (2016)), but the majority estimate gross revenue variation by multiplying yield loss with crop selling prices (Brémond et al. (2013); Shrestha et al. (2015)).

Vozinaki et al. (2015) evaluates damage from the loss of yield and replacement costs, excluding harvesting costs or other expenses. For Shrestha et al. (2015), damage assessment is either based on the loss of yield or cost of input depending on the vegetative state of the crop. Loss of yield is used for reproductive, maturing and ripening (and maybe vegetative stage, it is not clear in the paper) stages while for seedling and newly stages it is the cost of input.

For Gould et al. (2020) and Agenais (2010) damage is expressed by the gross margin. Molinari et al. (2019), Scorzini et al. (2021) and Penning-Rowsell et al. (2013) use the net margin adjusted with variable costs. Molinari et al. (2019) and Scorzini et al. (2021) also express damage in relative terms by dividing the absolute damage by the net margin of the no flood scenario. The relative damage evaluation allows a more robust comparison with other case studies.

4.4 Focus on models developed by our team

The need for tools to estimate flood damage on farms has led our team to develop modeling tools over the years. Thus, four modeling tools have been developed, each with different levels of application:

- floodam-agri (plot scale)
- AVA (farm scale)
- COOPER (cooperative winery system)
- floodam-building (building scale)

In this section we will describe the mechanisms, uses and shortcomings of each model in order to adapt them.

4.4.1 floodam-agri

This tool allows the estimation of flood damage at the plot level (Agenais et al., 2013). It is also based on modeling of yield losses and short-term management strategies based on expert knowledge (agricultural experts involved in the Calamité Agricole system). It estimates the damage as a variation in added value resulting from a flood in terms of product loss (yield) and intermediate consumption. It was set up for the construction of damage functions on a national scale in France as part of cost-benefit analyses for the evaluation of flood management projects which is made mandatory since 2010. It has been fully described by Brémond et al. (2022).

Physical components

The modeled component is the plot. The elements considered for each plot are as follows:

- plant material of perennial crops (yield)
- crop production (yield, selling price, expenses, crop calendars)
- soil (erosion, deposits)
- equipment (irrigation equipment, fences, trellises and greenhouses)

Immaterial components

Beyond the physical components, the farmer's decisions are modeled in the form of recovery actions and on the continuation of the crop management sequence. Indeed, decision rules for each crop were simplified based on yield loss and flood dates. For example, in the case of an annual crop, there is the possibility of reseeding, the same crop or another, depending on whether or not the date of the flooding allows it.

Hazard parameters

The following parameters are considered in floodam-agri: water height, flood duration, speed and seasonality.

Temporality

The model focuses on 1 production cycle. In terms of flood time steps, damage functions are constructed on the basis of weeks of the year and on the day scale for flooding durations.

Damage estimation and added value

To estimate the amount of damage, the model is based on the added-value principle. Depending on the extent of the damage, the above-mentioned decision rules will be applied and the expenses will vary, resulting in a variation of the added value. Damage occurs within the parameters of the hazard creating yield losses.

For grapevines, the model takes into account the root and/or bud asphyxiation, disease and/or decay development, stump removal and/or lying down of vines, bursting of the grape and over-ripeness.

Long-term damages related to replanting, implying a decrease in production in the first years of development, are directly integrated in the variation of added value. Therefore, the shortfalls are not spread over time but applied directly at the time of the flood.

In terms of market gardening, the crops taken into account are presented in table 4.4.

Regarding their damage, the model takes into account: uprooting and asphyxiation (asparagus exclusively).

In terms of soil damage, erosion is a function of water velocity and deposition is a function of water height. The costs associated with these impacts are repair and cleanup costs, respectively. Impacts are limited to the year of the flood.

Advantage

This model leaves room for the adaptation of damage functions at a local scale. Indeed, the following parameters can be modified:

- "economic": selling price, cost of shares
- "climatic": vegetative cycle, yield
- "agronomic": costs linked to crop management

The consideration of plant physiological stages in the damage functions rather than time of year alone is an important asset for the transferability of the model to other geographical contexts.

Limitations

This model uses several simplifications to establish the damage functions. The elements not considered in the model are listed below:

- damage to buildings and their content (inputs, equipment and stocks);
- damage to tools, equipment or machinery;
- inability to do certain tasks in the technical itinerary due to unavailability of tools or inputs;
- links to other plots, buildings, suppliers or roads;
- the availability of labour that can be mobilized by the farm;
- the availability of financial capital for the recovery (notion of indebtedness);
- long-term damage to plant material is taken into account but is not spread over time. This creates a bias in the estimation of the damage in the production year;
- the long-term impacts on the soil are not taken into account;
- salinity;
- possible adaptations by the farmer (change of culture);
- the multi-annual aspect of crop rotations (impossibility of planting the following crop for example);
- livestock.

However, the study by Agenais et al. (2013) presents an in-depth damage evaluation of each of the farm's components even if they are not included in the model.

4.4.2 AVA

This tool relies on the characterization of the farm in terms of spatial and organizational layout to produce from the material consequences, the impacts at the farm scale (Brémond, 2011). It allows for the consideration of induced effects within the farm (such as the impacts of the non-availability of key equipment, inability to access plots, etc.).

Table 4.4: Vegetable crops typology in floodam-agri.

Category	Detail
Asparagus	Asparagus
Salad	Salad
Open field tomato	Open field tomato
Greenhouse tomato	Greenhouse tomato
Vegetables	Cantaloupe Carrot Cauliflower Endive Green beans Green peas Onion Potato Early potato
Trellised vegetables	Cucumber Eggplant Pepper
Trellised greenhouse vegetables	Greenhouse cucumber

It allows a follow-up in terms of damage (variation of added value), but also on other indicators (like cash flow, debt, etc.).

Physical components

The model defines several objects that interact with each other. Two objects are defined and each contains several components:

- territory
  - flooding;
  - spatial elements.
- farm
  - buildings (input stock, products, technical farm equipment);
  - plots (plant material, crop production, soil);
  - crop management (composed of tasks);
  - tasks (production and rehabilitation);
  - the farmer;
  - mobilizable external resources.

Hazard parameters

The following are considered in AVA: water height, flood duration, velocity and seasonality.

Temporality

Like floodam-agri, this model simulates a production cycle. The particularity of this model is that it simulates a sequence of tasks related to the crop management of the farmer. Normally, these tasks are performed when the related equipment, plots or buildings are accessible. When a flood occurs, each spatial component changes from the normal state to another state:

- damaged, destroyed, being repaired or bought back (unusable)
- soiled or being cleaned (usable)

Note that each spatial component can also be inaccessible (because of another component in a state that makes it unusable), in which case it becomes unusable.

When a task cannot be performed, it is suspended. All suspended tasks are shifted and added to the to-do list which will increase the working time.

Principle of damage and added value

The damage at the farm level, is done at two levels:

- costs of restoration of physical components (building, equipment, inputs, soil and plant material on plots)
- yield losses due to uncompleted tasks or direct damage.

The ability of farms to finance restoration is also taken into account by the presence of farmer "profiles." Three profiles have been established:

- profile 1: no solidarity, no cash flow and no possibility of borrowing;
- profile 2: strong personal cash flow and possibility of borrowing;
- profile 3: benefits from solidarity.

From these profiles, the tasks (restoration or production) can be carried out in three different ways:

- internal: with the equipment and labour available on the farm;
- supply: external services for the employment of labour, the rental of equipment;
- solidarity: loan of equipment and solidarity labor.

Advantage

This model has the advantage of taking into account the farm as a whole and the interactions between its components. It makes it possible to assess the vulnerability of farms through the output of vulnerability indicators:

- timeline of usability of physical components
- disruption of the work organization by evaluating the manpower needs in time
- monetary damages :
  - direct damage to physical components (cost of returning to normal state and/or loss of production)
  - damage induced on the activity by the disruption of the tasks
  - total damage

Limitations

Items not considered in the model are listed below:

- loss of production quality (only yield is considered for loss of production)
- the multi-annual aspect of crop rotations (impossibility of planting the following crop for example)
- interactions with the "outside world" (suppliers, other farmers, service providers) which may also be impacted
- livestock
- salinity

Also, loss of yield, damage to building and soil are rough estimations.

4.4.3 COOPER

This modeling tool is a multi-agent model based on the interactions between cooperators (farmers) and a wine cooperative. In this model, the farms produce grapes and the cooperative transforms the grapes into wine. This model allows a characterization of the consequences at the scale of a wine cooperative system, both in terms of damage (variation in added value) but also on other indicators (such as cash flow, debt, etc.).

Physical components

The COOPER model is based on three basic components:

- plots (soil, plant material and equipment)
- farm (building and equipment)
- wine cooperative (building, equipment and stock)

These three components are the foundations of the two agents of the model: the farm (plots and farm buildings) and the cooperative (cooperative buildings). The farm produces grapes on its plots and stores the material necessary to carry out the tasks of the technical itinerary in its building. The cooperative transforms the grapes into wine, takes care of the sale and then shares the income and the production costs with its cooperators.

Temporality

The simulations in the model are spread over 30 years. Each year is divided into four periods corresponding to the four seasons. The interactions between the components of the model take place according to these seasons.

At the plot level, an age is associated with each plot to determine the productivity of the plant material and its level of depreciation in relation to its total life span. As not all plots have the same age, this implies the replanting of some plots that have reached the end of production age (fixed at 30 years) during the simulation.

Principle of damage

To characterize the flooding state of the farm and cooperative, four states are possible for plots and buildings:

- flooded
- not flooded
- destroyed
- not destroyed

Each element (plots, buildings) is exposed to flooding from its distance from the river.

Plot damage is assessed by yield loss depending on the season of occurrence and whether their is plant material destruction or not. If the plants are not destroyed, the production is unchanged in winter, 50% lost in spring and completely lost in summer and fall. If they are destroyed, there is no loss of production in winter but there is a total loss of production in spring, summer or fall. When plants are destroyed, replanting is automatic, implying a lower yield for the first 5 years of production. This long-term damage will be reflected both in the income of the farmers and the cooperative.

When harvest products are lost, production costs are saved.

Regarding soil damage, the model considers a systematic post-flood soil repair.

Flooding of farm buildings automatically implies damage to equipment. Two outcomes are described:

- restoration costs
- inability to perform all production tasks
  - external resources to perform tasks (increase of production costs)
  - internal resources (50% savings in production costs but associated loss of yield depending on the season)

The flooding of the buildings of the cooperative automatically implies damage to equipment. The impact of flooding is the non-fulfillment of tasks according to the season (wine production, sale or collection of grapes).

Advantage

The major interest of this model is the possibility of creating long-term interactions between the components of the system. It is also interesting to be able to address the notion of indebtedness and the risk of bankruptcy of farms thanks to the financial observation of individualized cash flows over a longer period of time.

Limitations

- soil restoration is systematic;
- simulation of a maximum of one flood per year.
- the decision rules are quite radical (e.g. no wine production if the cooperative is affected in winter; loss of yield for all farmers)
- the seasons are very long (3 months) which means that some of the associated decision rules may need to be reviewed (e.g. total loss of grapes when a plot is affected in autumn even if the flood is in November)

4.4.4 floodam-building

In general, tools for assessing the impacts of flooding on the agricultural sector do not take into account damage to buildings or equipment stored there. This tool allows the estimation of flood damages on buildings outside of the agricultural sector. The adaptation of floodam-building to the agricultural sector could allow the integration of the building component in the assessment of flood impacts on farms.

More detailed information is available on floodam-building at the following address: https://www.floodam.org/floodam.building/index.html

4.5 Conclusive remarks

For this conclusion we will expose the main limitations of the reviewed models, both from the international literature and from our team.

In the international literature, the focus is mainly made on crops and the loss of yield. The crops considered are, for the majority, annual crops. For the few studies that consider perennial plants, long term-damage is either simplified or inexistant. When it is evaluated, long-term damage focuses on the loss of productivity of young plants after being replanted or by the impact of salt remaining in the soil. However, loss of vigor due to partial damage of plants is never considered.

A few studies include damage to soil but in a simplified way (fixed restoration costs). An effort is made in floodam-agri and AVA to evaluate soil damage as a function of flood velocity with explicit thresholds.

Most of the models evaluate damage at the plot scale neglecting damage to other physical farm components (buildings, equipment, stocks, etc.), immaterial farm components (financial capacity, indebtedness, etc.) or damages to elements outside the farm's scope (e.g. supplier, external services). AVA and COOPER both consider the farm as a whole and therefore have a more complex definition of tasks to be done. COOPER goes even further by modeling the interactions between farms an a winery cooperative system.

In term of evaluation of damage to crops, a few studies use yield loss exclusively while the majority take at least into account the cost of crop management (inputs, plowing, harvesting, etc.) expressed in gross or net variation. Simplifications are often made when considering the costs included. The most exhaustive models include variation costs due to farmer decisions concerning crop management post-flood (e.g. resowing, plowing, green manure, gypsum application, etc.). Indirect and induced damage are still undervalued as there is generally no interaction at the farm level or with external elements. AVA and COOPER do include indirect and induced damage through the inability to perform tasks in case of inaccessibility or damaged equipment. Two studies also approach induced impacts by evaluating the effect of flood damage in terms of number of jobs.

We can see from this review that every model has shortcomings. But each of the models have their specificities and underline important aspects of flood damage evaluation to agriculture making them complementary with one another.

The next step in this work is to propose a framework for data collection based on the review of observation methods (section 3) and data needed to implement models based on the literature review discussed previously (section 4.1). This framework for data collection is presented in the following section (section 5).

Chapter 5

Methodological framework for observing the impacts of floods on farms

5.1 General view of the framework

Based on the literature and our own experience in collecting impact data after a flood events at different time scale as well as our experience in modelling flood impacts on farms, we propose a methodological framework for observing the impacts of floods on agricultural assets in order to have the most exhaustive view possible of the impacts and to capture the long-term effects and trajectory adaptations. This framework is based on the combination of different methods.

The proposed framework (figure 5.1) consists of two combined approaches that we are implementing at different time steps on the so-ii observation system. The first one, called "REX" for forensic analysis, consists in carrying out systematic post-flood surveys regardless of the intensity of the flood event. The second one, called "ROI" for Network of Flood Impacts Observers, consists of long-term monitoring of farmers by combining qualitative monitoring, modelling and participatory animation methods. The objective is to monitor over the long term (15 years) a group of farmers concerned by floods. The detailed methodologies used for the forensic analysis and the network of observers are developed in section 5.2 and 5.3 respectively.

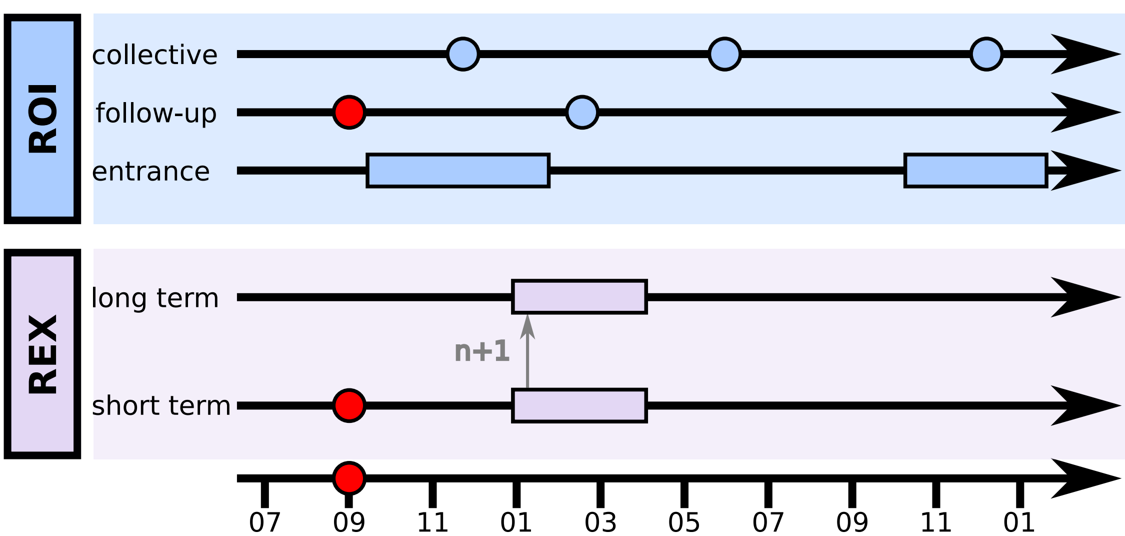

Figure 5.1: General framework proposed to capture flood impacts and adaptations

Other data sources are being considered such as secondary data collection and drone images for impact observation. Indeed, the idea of taking drone pictures of plots that are subject to floods is emerging as part of our observatory tasks in order to evaluate long-term damage and farm trajectories. The method is still in construction. The detailed methodologies used for secondary data collection and drone images are developed in section 5.4 and 5.5

5.2 Detailed methodology for forensic analysis

5.2.1 Implementation over time

As shown on the figure 5.1, the forensic analysis we propose consists in a first survey called short term survey which is implemented a few months after the flood represented by a red dot. If during this first survey, it is found that recovery is not complete, our methodology provides for follow-up over time until full recovery is achieved. In addition, it is planned that a second round of longer-term surveys of respondents will be carried out to capture any delayed effects that may have occurred in the longer term.

5.2.2 Types of flood impacts observed

The questionnaire used for the forensic analysis was established thanks to our experience of previous work done both on observing and modelling farm vulnerability to flood risk (Brémond, 2011; Brémond et al., 2013; Agenais et al., 2013; Pouillet, 2015; Perret et al., 2020; Garcia et al., 2021; Brémond et al., 2022). Based on this, we have chosen to develop questionnaires that make it possible to identify both biophysical impacts, elements of decision making and behavior of farmers for recovery. The purpose of is to collect thorough data on the impacts of flooding at the plot and farm building level. This questionnaire is intended to be used regardless of flood intensity, geographic area or type of production. It is designed with closed-ended and exhaustive questions and has been implemented through the Limesurvey tool.

The major themes of the questionnaire are:

- presentation of the farmer and his farm: identity of the farmer, description of his farm, definition of the workshops affected by the flood;
- characterization of the local hazard: description of the flood, measurements of height, duration of submersion, type of deposits;
- impacts (material, human, animal): description of impacts for each plot (plant material, soil, equipment and stocks) and building (structure, equipment, machinery, stocks) affected;
- private insurances: description of the insurances contracted by the farmer, possible declarations following the disaster, amounts concerned, of the intervention of experts;
- "calamité agricole": description of any declarations made to the "Fonds National de Gestion des Risques en Agriculture" (FNGRA), amounts involved, intervention of experts;
- restoration: repair actions, cleaning, damage amounts;
- situation after the event: implementation of protections, change of practices, various adaptations.

5.3 Detailed methodology for Network of Flood Impacts Observers

5.3.1 Implementation over time

The network of flood impact observers is a completely original monitoring approach that we have chosen to implement within the framework of the so-ii observatory in order to try to capture the long-term impacts of floods and possible adaptations. The implementation of a network of flood impact observers (ROI) with farmers was launched in 2021 with the goals of:

- consolidating knowledge on:
  - the impacts of flooding on farms and their temporal dynamics;
  - recovery strategies;
  - adaptations implemented after the floods.
- promoting the sharing of experience between the farmers concerned;
- disseminate the knowledge acquired to other institutional actors.

For this, the objective is to monitor the trajectory of farmers over the long term (15 years) with an approach that combines qualitative monitoring and vulnerability modeling using models developed within our team (see section 4.4). In addition to individual follow-up, our method includes group sessions.

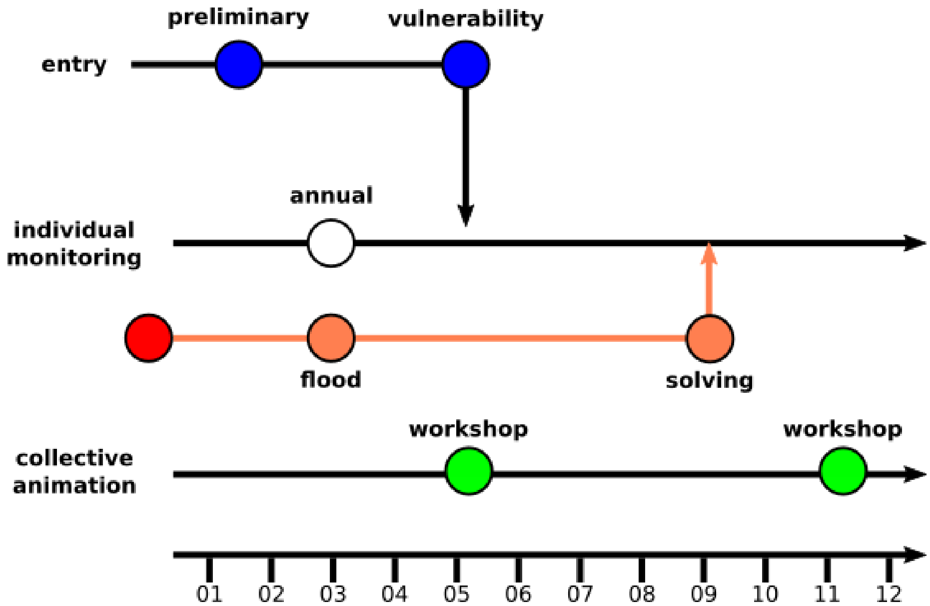

Figure 5.2: Method of entry and monitoring of ROI members.

The methodological steps summarized in the figure 5.2 are described in three parts : the entry in the network, the individual monitoring and the collective animation.

5.3.2 The entry

To contact the farmers several methods are tested on the so-ii territory:

- through the partners of the so-ii observatory (in particular the Chamber of Agriculture, the collectivities in charge of flood management, associations, town halls,. . .);
- by contacting farmers located in flood-prone areas on the territory (door to door);
- following the completion of a forensic analysis interview;
- by snow ball effect following an interview.

Two interviews are conducted in the entry phase of the network:

- the so-called preliminary interview, which is a semi-structured interview (qualitative approach);
- the following interview is called an in-depth characterisation of the farm's vulnerability (modelling approach).

These interviews take place in person generally at the farmer's farm or home and can be accompanied by visits to the affected plots (depending on the farmer's desire and time).

The **preliminary** interview aims to have a first characterization of the farmer and his farm, of his exposure to floods and to probe his interest to participate in the ROI. It addresses the following topics:

- presentation of the farmer: identity, age and background;
- trajectory of the farm: history of the farm, its fate and its link to flooding;
- presentation of the farm: UAA, workforce, agricultural production, sales strategies, description of the building and plots;
- floods and the farm: dates of floods experienced, type of hazard, damage observed on the components of the farm (plots, buildings, livestock, stocks) and/or losses of activities;
- post-flood recovery: time for restoration, support (financial, solidarity), mobilization of internal or external resources to repair the damage caused;
- adaptations: changes or reflections on the implementation of flood protections;
- perception of the risk, of flood prevention/management tools: the farmer's feelings about flood prevention and management measures (feeling of constraint/support. . .), interaction with other actors on this topic, position of the flood risk in relation to the other natural risks encountered on the farm;
- invitation to join the network: explanation of the ROI approach, interest and expectations of the farmer towards the network, request for contacts of farmers concerned by flooding.

Subsequently, for those farmers who agree to join the ROI network, a second interview is conducted to further characterize the vulnerability of the farm.

The **fine characterization of vulnerability** interview aims to provide a comprehensive description of the physical components of the farm in order to model the farm to assess its vulnerability to flooding. This description is intended to collect farm-level data for each plot and building:

- spatial: location of plots, buildings, equipment and stocks (forage, inputs and finished products)
- technical :
  - plot: type of crop, cultivation calendar (tasks to be carried out and inputs/materials mobilized), crop rotation, work time, selling price;
  - building: types of materials, detailed plan of the building;
  - inputs: quantity, purchase costs;
  - equipment/machinery: age, quantity, purchase price;
  - finished goods inventory: quantity, selling price.

In a first step, these collected data are to be put in the models we have previously developped: **floodam.agri** (Grelot, 2022) and **floodam.building** (Grelot et al., 2022).

The ultimate goal of the modeling stage is to produce new data at farm level:

- map the farms (plots and buildings);
- produce damage functions specific to the farms interviewed;
- estimate flood damage for several flood scenario;
- estimate the effects of the implementation of adaptations.

5.3.3 The individualized follow-up phase of members

It is planned to monitor members on an annual basis. If it has not been flooded, it is an annual individualized follow-up and assessment that aims to identify new projects carried out or planned. If a flood occurs, a semi-directive face-to-face interview called "flood" and a second one called "solving" are conducted. They allow the collection of data on the resolution of disorders and decisions made concerning repairs or abandonment of plots, equipment or buildings. In the event that a forensic analysis (as presented in section 5.2) is launched on the flood event, the members of the network are asked to respond (instead of the "flood" interview). The method for these interviews ("flood" and "solving") is still under construction and has not been applied yet.

5.3.4 The collective animation

It is planned to organize on a regular basis collective moments that allow exchanges between:

- farmers members;
- farmers members and researchers;
- farmers members, partners of so-ii and researchers.

During these collective moments, one or several themes are discussed by the different participants in order to produce, share or bring up (e.g. to the governance organizations) information.

5.4 Detailed methodology for secondary data collection

5.4.1 Implementation over time

The collection of secondary data can be separated in two : collecting information to prepare a forensic analysis and collecting third-party datasets to obtain data at the territory level.

5.4.2 Collecting data for a forensic analysis

After a flood, we make contact with the Hérault Chamber of Agriculture to see if they have information on impacted farmers or areas. When an event is qualified as and agricultural disaster, agents from the Chamber of Agriculture make observations on the field which they are able to send us.

As an example, for the REX of the rainy episode of September 2020 in Saint Mathieu de Tréviers, we were able to obtain the contacts of the farmers who started the compensation procedures of the FNGRA as well as a partial vision of the damages suffered from the observations of the Chamber of Agriculture.

The extent of the data transmitted is as follows (note that the information is very heterogeneous from one farm to the other):

- the affected components (plots, building, plant material, equipment, soil);
- the extent of the damage (surfaces concerned, length of fences, quantity of vegetables. . .);
- the types of damage (deposits, uprooting, destruction of the production. . .);
- the height of the water;
- the location.

Mobilizing these data before the field surveys allows to have a first vision of the extent of the damage and the type of hazard faced. It also provides a gateway to contact farmers. Second, access to these data provides information (though heterogeneous) about the damage on farms not surveyed by our team. Also, we are looking into closer collaboration with the Chamber of Agriculture for post-flood damage observation that can be coupled with drone imaging.

5.4.3 Collecting third-party data

On the other hand, we mobilize the Land Parcel Identification System (LPIS) to know the types of crops located in flood-prone areas by crossing this database with flood extension data. This allows us to locate crops that are subject to floods and reach out to the concerned farmers.

The flood extension data either originates from regional hydraulic modelling or from national datasets such as the Approximate Envelopes of Potential Flooding (EAIP) available for France.

5.5 Detailed methodology for capturing drone images

Two types of field campaigns are considered differentiating different timescales :

- pictures taken rapidly after a flood;
- pictures taken periodically on plots where damage was caused.

These two timescales could help understand how plots characteristics evolve directly and years after a flood. By doing this we make the hypothesis that we can observe certain impacts due to floods such as : erosion, vigor loss, organic matter loss,general health of a crop, evolution in crop rotation.

Chapter 6

Application and results

6.1 Forensic analysis of the 19th September flood

The first application was made following the flood of September 19th 2020 which impacted the territory north of so-ii (around the Pic-Saint-Loup).
The damage was considered quite significant although restricted geographically.

7 interviews were conducted face to face with wine growers and took place from June 27, 2021 to November 09, 2021, that is to say between 9 months and 1 year after the flood. They lasted between 30 minutes for the least exposed farms and 2 hours for the most exposed ones.

The questionnaire allowed us to collect information on the characteristics of the hazard and gave us a partial vision of the municipalities concerned. As a result, we were able to identify water heights, submersion times and re-watering times by plot. Since the event took place during the night, the height of water was observed by the farmers from traces of debris on the trellis the next day.

The hazard was characterized by stream overflow and runoff. The majority of farms experienced both types of hazards at the whole farm level. At the plot level, the majority of plots are affected by river overflow and some plots are affected by both types of hazard.

6.1.1 Observed impacts - flood perimeter

The surveys collected detailed data on 19.1 ha for a total of 31 plots involved. The farms, of varying size (from 12 to 147 ha), were on average affected on 7.3% of their useful agricultural area (UAA), i.e. 2.7 ha (table 6.1).

Table 6.1: Affected areas, number of plots and buildings affected.

	Area			Number	
Farm	**UAA (ha)**	**Impacted (ha)**	**% of UAA**	**Plots**	**Buildings**
1	20	0.6	2.8	2	
2	82	2.4	2.9	2	
3	14	0.6	4.3	3	
4	147	3.8	2.6	14	3
5	60	8.1	13.5	2	
6	38	0.9	2.4	4	
7	12	2.7	22.5	4	
Mean	53	2.7	7.3	4	3
Total	373	19.1	50.9	31	3

6.1.2 Impacts to plots

The questionnaire allowed us to address the impacts on the plots at different levels, namely: soil, plant material, equipment (fences, trellis, irrigation equipment) and harvested products

For all the farmers surveyed, impacts on the plots have been identified and are related to the soil, plant material and equipment. No impact to crop products was mentioned as the majority of the harvest was already completed.

Soil

All but one of the affected plots are subject to soil damage. In 90% of the cases (28 plots), erosion was mentioned (see figure 6.1b). After discussion with the farmers, erosion was generally assimilated to the loss of land by gullying.

There were also deposits of green waste on 20 plots, solid deposits on 18 plots and no deposits of pollution or remains. Among the solid deposits, we can mention the presence of large stones in the rows of vines of a plot following the rupture of a dike located upstream. It should be noted that the farmer who had this dike failure did not mention at first that he had had solid deposits in one of his plots and it was when he showed us a photo (see figure 6.1a) of the dike failure that we saw the rocks in the vineyards.

Also, it can be noted that one of the farmers who planted an inter-row cover crop shortly before the flood had a total loss of the seedlings. This impact is interesting because the loss of intermediate crops hasn't been mentioned in the literature.

(a) Rock deposits (dike failure) (b) Soil erosion and damage to fence. (c) Deposits on grape harvester (d) Uprooting

Figure 6.1: Illustrations of the impacts due to the flood.

Plant material

Plant material was affected in just over half of the plots (18). The types of impacts caused were mainly downed plants (72%) but also in some cases uprooted plants (27%) and/or uprooted plants which could be saved (16%). (see figure 6.1d)

Equipment

The equipment considered at the plot level are irrigation equipment, fences, trellises and production tunnels. The fences and trellises were damaged quite badly while irrigation equipment, which is only slightly used in this area, has not been affected. None of the farmers surveyed has a tunnel.

Induced impacts to plots

We asked farmers to describe the consequences of these direct impacts (soil, plant material) on the plant material. Loss of vigor was noted in 12 plots that had damage to plant material. In addition, 2 out of the 3 farmers met post-harvest 2021, noted a loss of yield induced by the flood, on the harvest of 2021.

Despite the removal of plants by the flood on some plots (5), farmers did not mention having observed any mortality on these plots except on one. However, they mentioned that they replaced the destroyed plants afterwards. Finally, the flooding did not cause any diseases on the vines. The answers are presented in table 6.2.

The crop itinerary was not impacted given the physiological stage of the vines at the time of the flooding.

Table 6.2: Types of damage on plant material according to the observed impacts (number of plots).

Impacts	Diseases	Vigor loss	Mortality	None
Uprooted	0	2	1	2
Saved uprooted	0	1	0	2
Downed	0	12	0	1
Root asphyxia	0	0	0	0
Number of plots	0	12	1	4

6.1.3 Impacts to buildings

Only one farmer had buildings flooded. This resulted in the destruction of feed stocks and small electrical equipment. In addition, deposits of silt and green waste were noted on the ground and a grape harvester (see figure 6.1c).

6.1.4 Actions for post-flood recovery

On the soil, the necessary actions consisted of:

- cleaning to remove plant debris and/or solid matter
- mechanical operations carried out on 97% of the plots, such as leveling, soil lifting or adding soil to the vines rows or paths.

For plant material, the actions carried out for its rehabilitation vary according to the intensity of the impacts impacts according to three levels:

1. for downed plants, soil lifting operations on 11 plots out of the 12 concerned;
2. for uprooted plants, the replacement of destroyed plants on 4 plots among the 5 concerned;
3. for saved uprooted plants, the addition of soil on the three plots concerned.

One plot was completely removed out to be replaced by forage production because uprooting was too important.

Equipment, fences and trellises had to be cleaned and/or repaired. In one case, the trellis had to be bought new, as did the damaged power tools in the buildings.

For ditches, dredging operations have been mentioned.

Time needed for restoration

The average restoration times for plots, roads and ditches are 571 h, 173 h and 119 h respectively. The maximum times for plots, roads and ditches are 1600 h, 280 h and 200 h respectively, while the minimum times are 40 h.

Means mobilized

For the rehabilitation of the farms, the farmers mobilized :

1. **labour**, which can be employees of the farm (2), of external service (2) or both (2). One farmer carried out the rehabilitation alone and another farmer mentioned having family help.

2. **tools (machinery)** to carry out mechanical operations (leveling, earth raising or ditch cleaning). Some farmers have had to find an external solution such as using a service provider (3), renting equipment (1), buying tools (1).

3. **financial means and compensation**. Five farmers had recourse to the agricultural disaster procedure ("calamité agricole") for damage to their property. All the farms were able to finance the work by using the cash flow of the farm.

4. **the private insurance** which concerned only the farmer having undergone damage to the buildings and stocks.

Returning to normality

At the time of the interview, 6/7 farmers had returned to a "normal" situation, meaning they had completed the rehabilitation work. This does not mean that the initial state is restored: the lack of vigor, the uprooting and replacement of plants, the amounts involved are all elements that do not allow a return to the initial state. On the other hand, 2 farmers (1 of whom said he had returned to a "normal" situation) still had work to do on some plots and/or roads.

6.1.5 Individual adaptations

By adaptation we consider any change, initiated following the flood, related to agricultural practices, to crop rotation and to the farm in general.

The adaptations mentioned are the following: change of crop following the uprooting of the whole plot (1), change of soil working technique (1), purchase of a mechanical shovel foreseeing other types of work (1), further reflection on grass cover-cropping on inter-rows (1) and on the installation of cofferdams and elevation of the shelves (1).

Most farmers mentioned that the adaptations made on the farm were due to a combination of factors (frost, water stress, biodiversity, practicality) and not just this flooding event.

6.1.6 Conclusive remarks

In spite of the minor nature of the event and the limited number of interviews, the feedback that we have carried out highlights significant impacts on the farms in terms of direct impacts on the soil, equipment and/or plant material, as well as the costs incurred for the restoration (plots, ditches and paths). We have also been able to observe significant restoration times that occurred at a crucial period when time must be freed up for vinification.

Being conducted one year after the event, this survey also showed that some farms have not yet completed all of their rehabilitation work. The questionnaire developed made it possible to address certain themes that are not often mentioned in the literature, such as the time required for restoration work, the time required to return to normality and the adaptations implemented and/or planned. Also, this survey allowed us to strengthen our knowledge of the impacts of a flood on the viticultural sector in this part of our observatory. Several elements are recurrently affected: fences protecting from wild boars, the soil (gullying) and the deposit of solid matter (green waste). On the other hand, the survey highlighted other less frequent impacts such as the loss of green manure seeds following its sowing on inter-rows or the rupture of a dike causing the deposit of important rocks.

The use of the Limesurvey tool to conduct the interviews and enter the questionnaire responses proved to be very suitable because of the possibility of conditional display of the questions. This made the interview quite fluid despite the number and precision of the questions.

One of the difficulties encountered in the interviews was detailing the amounts of damage per affected component. Indeed, farmers generally had a good idea of the total amounts disbursed but not necessarily the details for each component. Moreover, the evaluation of damage to fences should be indicated in terms of linear distance.

6.2 Implementation of the Network of flood Impacts Observers

6.2.1 Overall progress

In 2021, the development of the ROI was mainly conducted within the framework of a master's internship carried out by Coline Marguet from April to September 2021. It was during this internship that the preliminary interviews were conducted. This internship was the subject of a report (Marguet, 2021).

6.2.2 Preliminary interviews

A total of 175 farmers were contacted. The map 6.2 shows the distribution on the territory so-ii.

A total of ten interviews were conducted with farms (figure 6.3) of which 7 showed interest in joining the ROI.

Description of surveyed farms

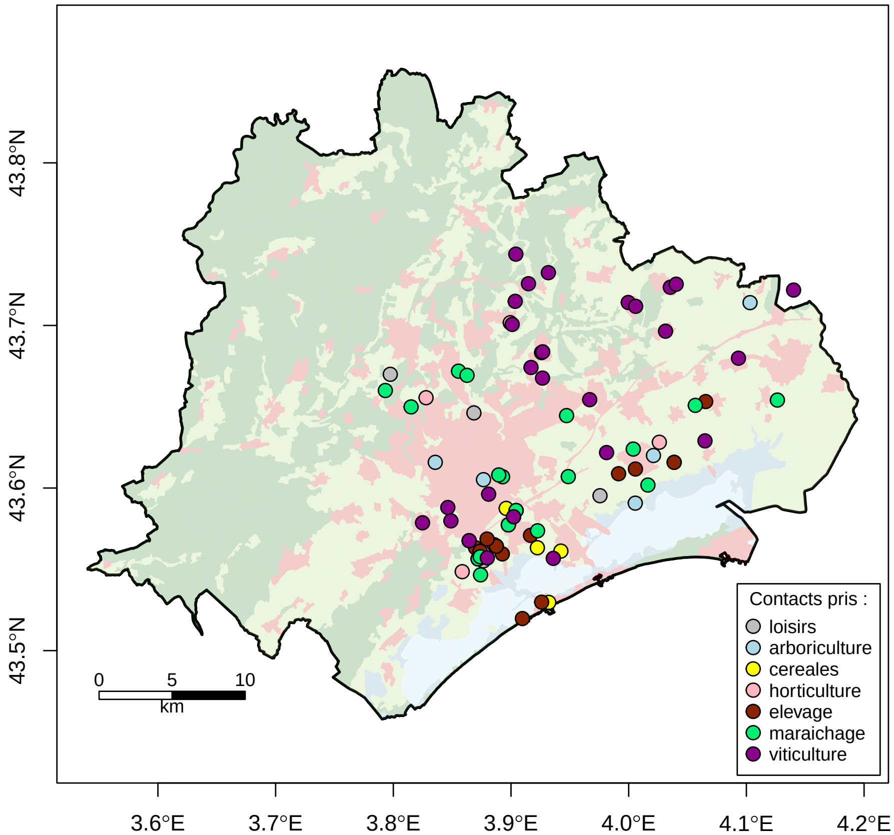

Figure 6.2: Map of the people contacted on the so-ii territory according to their agricultural production.

These farms are specialized in viticulture (including one with a livestock activity) and market gardening or horticulture, which corresponds to the crops mostly impacted on the territory. Farm size varies from 0.88 to 1200 ha. Overall, the farms we met have few or no permanent employees except for one which has 25 permanent employees. The farms are all located in a peri-urban area and two are located within the urban area.

Types of hazards experienced

The farms encountered are mainly concerned by the hazard of river overflow. Two are affected by runoff phenomena. One farm is also affected by brackish water flooding in addition to the overflow phenomenon.

Types of impacts

During the interviews, the following impacts emerged:

damage to plots

- Soil erosion: loss of soil and organic matter (10/10 farmers);
- deposits of silt, green waste (4/10 farmers) and household waste and/or plastic (2/10 farmers);
- crop losses due to destruction or loss of quality (10/10 farmers). For the vines, this is due to the appearance of rot on the grapes (loss of quantity), or to the swelling of these (loss of quality with the dilution of sugars), and depends on the moment of occurrence of the flood (before or after the grape harvest);
- stock losses (4/10 farmers);
- damage to plant material:
  - uprooting of vine rows (laid down, destroyed and/or washed away), concerning three winegrowers;
  - loss of vigor during 3 years after the flood for some affected vines;
- damage to fences, concerning three winegrowers;

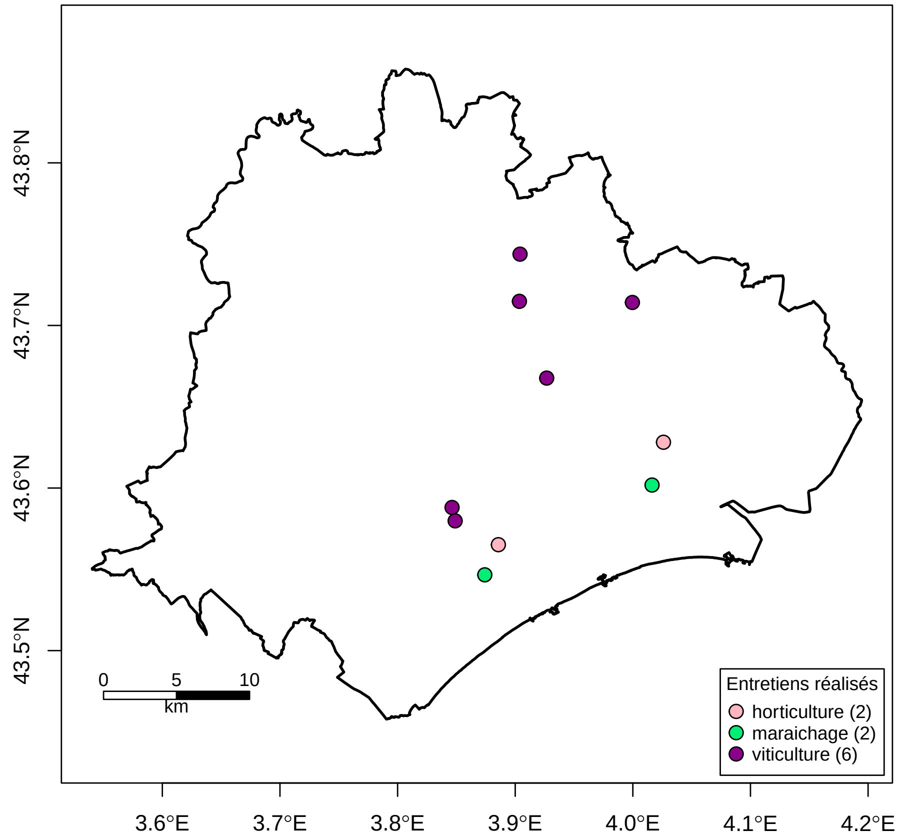

Figure 6.3: Map of the farmers met on the territory of the so-ii according to their agricultural production.

- destruction of a protective stone wall on the periphery of the plot, bringing stones into the vineyards (1/10 farmer).

damage to buildings

- very important deposits of silt and mud, for six farmers;
- damage to agricultural equipment, sometimes to the point of complete loss (impossible to repair), sometimes in a recoverable manner, concerning two farmers;
- damage to office equipment, including computers, for one farmer;
- very important damage in the house of a farmer.

damages to livestock

- drowning of animals.

other damage

- damage to roads, paths and fences, sometimes to the point of them being swept away.

The interviews highlighted impacts that were not included in the models, such as: loss of organic matter that could affect the yield of subsequent crops or future harvests; damage to equipment; deposits on the plots that would require cleaning.

Post-flood recovery

The actions carried out following the floods consist essentially of the addition of soil to the plots, sometimes specifically a contribution of organic matter, and clean-up work (logjams, waste, silt). For wine growers, post-flood work often consists of straightening and repairing the trellis. Some farmers also curate existing ditches that have

Table 6.3: Agricultural areas and proportion located in potentially flooded areas (EAIP) in the territory of so-ii.

ID	production_01	production_02	livestock	area (ha)	workforce	zone
EA01	vineyard	NC	NC	12.00	1	peri-urban
EA02	vineyard	livestock	1000	1200.00		peri-urban
EA03	market gardening	NC	NC	4.00	2	peri-urban
EA04	vineyard	NC	NC	7.00	1	peri-urban
EA05	vineyard	NC	NC	21.00	1	peri-urban
EA06	market gardening	NC	NC	2.00	1	peri-urban
EA07	vineyard	NC	NC	8.50	1	urban
EA08	vineyard	NC	NC	25.00	2	urban
EA09	plant nursery	NC	NC	0.88	1	peri-urban
EA10	plant nursery	NC	NC	7.00	25	peri-urban

been filled in by flooding or tinker with machinery to resolve momentary issues.

For the majority of farmers, the recovery phase is carried out alone, sometimes with the help of a family member. Solidarity mechanisms were observed among three farmers; they consisted of a visit from the mayor, mutual aid linked to the religious community or mutual aid from other farmers practicing the same production and knowing the farmer concerned. People show moral solidarity (town hall), labor to clean and save the remaining stocks (religious community) as well as donations of stocks (farmers practicing the same production).

Individual adaptations

Following the floods, all the farmers have implemented adaptations at the farm level. They are presented in the following categories:

- **plant material and crops**: change the orientation of the vine rows in the direction of the slope; change the grape variety to an early-maturing one that allows harvesting before the periods of higher flood risk; replace the vineyards with grassland on the plots; adapt the timing and location of the vegetable rotations; change the crop to one that is less vulnerable to flooding or abandon the plots and change them;
- **soil management**: establish a grass cover; adapt soil work to the seasons; to bad weather and to the exposure of the plots. Overall, it is important to do very little tillage in winter and never plow the plots along a watercourse.
- **configuration of the farm**: buy slightly elevated plots not far from the farm or on the contrary sell the most exposed plots; move the greenhouses to the less exposed plots; storing farm equipment in a mobile home or container;raising the electrical outlets; raising the height of buildings;
- **construction of individual protections**: create mounds between plots and watercourses; ditches in strategic places to drain the plots; a protective tree slope; a small retention basin; build protective walls in front of greenhouses; put in place buried concrete slabs along the farm and waterproof the gate.
- **cleaning and maintenance of ditches, dikes and watercourses** around the farm by grazing of livestock.
- **placement of drainage material**, on the perimeter of a winery or on the plots.
- **preparation to flood**: increased monitoring of stream levels during inclement weather, keeping a reserve of soil on the farm to backfill more effectively in the event of flooding, and purchasing a backhoe for this purpose.

In addition, one farmer mentions a planned adaptation that he was unable to implement. It is a question of controlled grassing of the vines, finally impossible because of the absence of irrigation on the plots and thus of a too strong hydric competition between vines and grass.

Summary of the interviews conducted

Preliminary interviews were used to establish initial contact with farmers and to set up the ROI. The themes covered by these interviews also make it possible to draw up an overview of the issues surrounding flooding in the territory at several levels:

- history of flooding on the territory
- vulnerability of farms to risk
- capacity of farms to adapt
- perception of territorial flood management

6.2.3 Vulnerability characterization interviews

Two vulnerability characterization interviews were conducted within the framework of MOOM-Agri with a wine grower and a market gardener who had each conducted a preliminary interview.

Wine grower

One of the stakes at the viticultural level was to differentiate the cultural calendar for each of the grape varieties in production. Indeed, 10 different grape varieties are grown on the surveyed farm. During the interview we were able to define, for each grape variety, the selling prices and the expected yields which turned out to be very variable from one grape variety to another. We were able to assign a variety to each plot and differentiate the types of grassing (2 types of inter-row seeding and natural grassing).

Subsequently, the farmer gave us access to his Computerized Vineyard Record (known as Casier Viticole Informatisé in french) which allowed to gather the following information for each plot:

- inter-row distance
- distance between stumps
- age of the vines
- proportion of each grape variety

Moreover, we defined the physiological stages of the vineyard for each variety by classifying them from the earliest to the latest (table 6.4) expressed in week numbers. For this, we based ourselves on the physiological stages of the vineyard identified in floodam-agri (first row of table). It is interesting to note that the physiological stages given by the farmer, being in a temperate climate, differ from the default ones in floodam-agri (values on a national scale). Indeed, the defoliation and vegetative rest are take place later than the default values while stages that take place after pre-ripening seem to take place earlier than at the national scale. This highlights the importance of adapting to local conditions when modeling crop damage.

Table 6.4: Physiological stages by grape variety obtained during the vulnerability characterization interview.

ID_crop	block	defoliation	vegetative rest		start budburst	blooming	berry development	pre ripening	ripening	maturity	harvest	harvest 2021
			start	end								
ref_floodam		42	47	6	14	20	25	30	31	34	38	38
sauvignon b	4	45	50	6	14	21	24	27	28	30	32	27/08/2021
sauvignon b	8	45	50	6	14	21	24	27	28	30	32	14/08/2021
sauvignon b	9	45	50	6	14	21	24	27	28	30	32	27/08/2021
muscat petits grains b	1	45	50	6	14	21	24	27	28	30	32	27/08/2021
merlot n	7	45	50	6	14	21	24	27	28	30	32	25/08/2021
merlot n	12	45	50	6	14	21	24	27	28	30	32	25/08/2021
pinot noir n	5	45	50	6	14	22	25	28	29	30	32	27/08/2021
alicante henri bouschet	9	45	50	6	14	22	25	28	29	30	32	-
marselan n	1	45	50	6	14	22	25	28	29	30	32	27/08/2021
grenache n	6	46	51	8	16	23	26	29	30	35	37	01/09/2021
grenache n	8	46	51	8	16	23	26	29	30	35	37	01/09/2021
syrah n	6	46	51	8	16	23	26	29	30	35	37	27/08/2021
cabernet sauvignon n	2	46	51	8	16	23	26	29	30	36	38	14/09/2021
cabernet sauvignon n	3	46	51	8	16	23	26	29	30	36	38	08/09/2021
cabernet sauvignon n	9	46	51	8	16	23	26	29	30	36	38	13/09/2021
carignan n	3	46	51	8	16	23	26	29	30	37	39	15/09/2021
carignan n	9	46	51	8	16	23	26	29	30	37	39	16/09/2021
carignan n	11	46	51	8	16	23	26	29	30	37	39	15/09/2021

As for the agricultural work done on the vineyard, the tasks to be carried out are the same for all the grape varieties. Only the starting dates of the treatments vary according to the sensitivity of each variety. It should be noted that some tasks are necessary for certain grape varieties while they can be neglected for others without too much impact on the quality or the yield. For example, the pruning of Merlot and Pinot Noir has been described as “essential” because these grape varieties produce more buds than others.

Market gardening

The characterization of the market gardening operation proved to be more complex than for the vineyard operation, given the large variety of productions in a year. Indeed, the farm has 30 vegetable productions under tunnel or in open field.

For each of the productions, we collected the following data for 2021 and 2022:

- variety : quantity;
- implantation : date, location, density;
- sale : quantity, turnover;
- inputs : amendments and treatments (quantity, date).

In a second time, not having the time to detail all the productions, we characterized the cultural calendar of two productions having opposite conducts: tomatoes under tunnel (see table 6.5) and squash full field. For the detailed cultural calendar of these two productions, we have collected, for each task performed, the following additional data:

- date of completion
- working time
- material used
- type and quantity of inputs used

Table 6.5: Crop itinerary of greenhouse tomatoes obtained during the vulnerability characterization interview.

ID_task	start	end	external service	worktime	worktime unit	ID_mat	ID_input	input quantity	input unit
tillage	01/03/22	01/03/22	FALSE	5	h/greenhouse	mat-1, mat-3	plastic	-	-
fertilizer	01/03/22	01/03/22	FALSE	-	-	mat-2	ovinalpes	-	-
biostimulation	10/03/22	10/03/22	FALSE	-	-	-	OSIRYL, tapis vert	-	-
planting	10/03/22	10/03/22	FALSE	3	h/400 plants	-	Tomato plant (4 varieties)	400	plant
protection installation	10/03/22	10/04/22	FALSE	0,25	h/greenhouse	mat-15	-	-	-
protection removal	10/04/22	10/04/22	FALSE	0,25	h/greenhouse	mat-15	-	-	-
string staking	10/04/22	10/04/22	FALSE	15	h/400 plants	-	string	-	m
pruning	10/04/22	30/09/22	FALSE	4	h/week	mat-16	mat-22	-	-
leaf removal_1	15/06/22	15/06/22	FALSE	5	h/400 plants	-	-	-	-
leaf removal_2	15/08/22	15/08/22	FALSE	5	h/400 plants	-	-	-	-
harvest	20/05/22	30/09/22	FALSE	4	h/harvest for 2-3 harvest per week	mat-19, mat-20	-	-	-
whitewashing	20/05/22	20/05/22	FALSE	1	h/greenhouse	mat-17	chalk, lime	10	L/year
plant removal	30/09/22	30/09/22	FALSE	15	h/400 plants	-	-	-	-

Shared data collection

For both farms, lists of equipment and inputs and their location on the farm were made.

6.2.4 Conclusive remarks on the interviews

The vulnerability characterization interviews were facilitated by obtaining the farmers' land parcels beforehand. The printing of the plots on paper allowed the farmers to point out directly for each plot which are the grape varieties (viticulture) or the crops present for the year 2021 (market gardening).

On the other hand, these interviews provided an opportunity to hear from the farmers and to discuss their plans for the future. For example, for the vineyard, a project to extend an olive grove (currently for personal consumption) is underway. Also, for the vegetable farm, it is planned to increase the amount of green manure by using plots not currently cultivated. These discussions about the prospects for development within the farms confirm the importance of monitoring the farms over the long term. In the long term, this monitoring could help assess the vulnerability of farms to flooding when considering future projects.

6.2.5 Collective animation

A workshop with the surveyed farmers was conducted on Tuesday, November 9, 2021 in the presence of three farmers and institutional partners (CA34, SYBLE and SYMBO). This workshop allowed:

- to present and discuss
  - the work done during Coline Marguet's internship;
  - the REX (see section 6.1);
- to reflect on the next themes which could be approached for the continuation of the collective workshops.

6.3 Capturing drone images

This method has been tested but not yet carried out at a larger scale on the so-ii territory.

Pictures were taken on several vineyard plots, in Saint Mathieu de Tréviers, which were damaged during the 2020 event (see 6.1). The drone pictures were taken 1 year post-flood on plots that were partially damaged and completely destroyed. On the destroyed plot (to the right left of figure 6.4), we can see lighter spots on the soil which may be due to soil erosion and loss of organic matter. If pictures had been taken before the flood, chances may be that we could observe differences in soil color. Also, we would have seen that one of the plots was completely destroyed and replaced by grassland instead of another vineyard.

6.4 Conclusive remarks on two production systems

The forensic analysis, the network of impact observers and the collection of secondary data has allowed us to identify aspects of farm vulnerability that aren't mentioned in the international literature. For example, interviews during the forensic analysis showed that the time needed for restoration is important to be measured not only for crops and buildings but also paths. One interview in particular also highlighted possible impacts to farms that we didn't consider initially such as the loss of cover-crop seedlings or plants and the impacts to farm animals that are used as tools (tillage, maintenance grazing in between vine-rows. . .) rather than used for production. We have also learned from the farmers that damage to fences can be evaluated easily by considering the length of impacted fences.

In this section, are presented the specific impacts of floods to vine-growing (table 6.6) and market gardening (table 6.7) farms. The information available in both tables do include damage that are related to the plots or are specific of the farm type. Therefore, damage to roads or paths, buildings, machinery and inputs are not included as they can be assigned to either type of farm and generally only impact task completion. Note that when inaccessibility is mentioned, the indirect impact is the non completion of tasks which could lead to missing treatments, harvest delay, etc. Also, when gain of vigor is mentioned, the underlying effect for the crop is possible yield increase.

6.4.1 Flood impacts : Vine-growing

Figure 6.4: Drone photo, dated September 20th 2021, of the vineyard plots affected by a flood on the 29th of September 2020.

Table 6.6: Impacts of flooding on the components of a vine-growing farm.

Component	Impact	Short term (direct)	Mid term (1 year)	long term (>1 year)
soil				
	erosion (loss of organic matter)	loss of vigor or increased amendments	loss of vigor or increased amendments	loss of vigor or increased amendments
	erosion (inaccessibility)	loss of yield; diseases; harvest loss or quality decrease	-	-
	pollution	not quantifiable	not quantifiable	not quantifiable
	deposits of solid matter	cost of restoration	-	-
	deposits of organic matter	gain in vigor	gain in vigor	gain in vigor
	salinization	loss of vigor; mortality; gypsum application	loss of vigor	loss of vigor
	available water capacity	gain in vigor	-	-
plant material				
	uprooting	mortality; restoration costs; cost of replanting	loss of yield if mortality	loss of yield if mortality (5 years until plant is at normal productivity)
	downed plants	restoration costs	-	-
	partial damage	loss of yield	loss of yield	loss of yield
	waterlogging (root asphyxia)	mortality; cost of replanting	loss of yield	loss of yield (5 years until plant is at normal productivity)
	waterlogging (diseases)	loss of yield; additional treatment costs	loss of yield; additional treatment costs	-
	destruction	mortality; cost of replanting	loss of yield	loss of yield (5 years until plant is at normal productivity)
inter-row cover crop				
	destruction; damage	cost of seedlings; increased erosion risk	-	-
harvested product				
	destruction	loss of yield	-	-
	damage	loss of yield; wine quality loss	-	-
	fouling (silt deposits)	loss of yield; wine quality loss	-	-

Table 6.6: Impacts of flooding on the components of a vine-growing farm. *(continued)*

Component	Impact	Short term (direct)	Mid term (1 year)	long term (>1 year)
equipment				
	irrigation equipment (damage; destruction)	loss of vigor (limited)	-	-
	irrigation equipment (fouling)	cleaning costs	-	-
	fences (damage; destruction)	restoration costs; wild boars entry (damage to harvest and plant material)	loss of yield if damage to plant material	loss of yield if damage to plant material
	fences (fouling)	cleaning costs	-	-
	trellis (destruction; damage)	restoration costs; difficulties for motorised harvest	-	-
	trellis (fouling)	cleaning costs	-	-

6.4.2 Flood impacts : Market gardening

Table 6.7: Impacts of flooding on the components of a market gardening farm.

sub component	impact	short term (direct)	mid term (1 year)	long term (>1 year)
soil				
	erosion (loss of organic matter)	loss of vigor or increased amendments	loss of vigor or increased amendments	loss of vigor or increased amendments
	erosion (inaccessibility)	loss of yield, diseases, harvest loss or quality decrease	-	-
	pollution	not quantifiable	not quantifiable	not quantifiable
	deposits of solid matter	cost of restoration	-	-
	deposits of organic matter	gain in vigor	gain in vigor	gain in vigor
	salinization	loss of vigor, mortality, gypsum application	loss of vigor	loss of vigor
	available water capacity	gain in vigor	-	-
plant material				
	uprooting	mortality, cost of replanting	-	-
	partial damage	loss of yield and quality	-	-
	waterlogging (root asphyxia)	mortality, cost of replanting	-	-
	waterlogging (diseases)	loss of yield, additional treatment costs, adaptation of crop rotation to avoid diseases	-	-
	destruction	mortality, cost of replanting	-	-
inter-row cover crop				
	destruction, damage	cost of seedlings, increased erosion risk	-	-
harvested product				
	destruction	loss of yield	-	-
	damage	loss of yield	-	-
	fouling (silt deposits)	loss of yield or loss of added value (quality decrease)	-	-
equipment				

Table 6.7: Impacts of flooding on the components of a market gardening farm. *(continued)*

sub component	impact	short term (direct)	mid term (1 year)	long term (>1 year)
	irrigation equipment (damage, destruction)	loss of vigor (important)	-	-
	irrigation equipment (fouling)	cleaning costs	-	-
	fences (damage, destruction)	restoration costs, wild boars entry (damage to harvest)	-	-
	fences (fouling)	cleaning costs	-	-
	trellis (destruction, damage)	restoration costs	-	-
	trellis (fouling)	cleaning costs	-	-
greenhouses				
	destruction, damage	loss of yield, restoration costs	-	-

Chapter 7

Conclusions and perspectives

The work presented in this report makes several contributions to the question of the impacts of floods on agricultural issues. In particular, we show that there is a cross-fertilisation between impact modelling approaches and impact observation approaches (figure 7.1). The impacts of floods on agricultural issues are complex and are the result of biophysical processes on the different components of a farm but are also linked to farmers' repair and reconstruction decisions (section 2).

A review of methods for observing the impacts of flooding on agricultural issues revealed that there were no directly reusable methods for observing the impacts of flooding on all components of the farm and the effects propagating over time as well as the possibilities of adaptation (section 3). A review of flood impact modelling methods has shown that the models developed must represent biophysical mechanisms, individual operator behaviours and also an organisation (section 4). The work we have carried out within our working group in terms of modelling (development of floodam.agri, AVA and COOPER) as well as the work we have carried out on the observation of impacts (section 3) has enabled us to propose a framework for the observation of impacts.

This framework proposed in section 5 aims at allowing to observe the impacts in a more exhaustive way and to allow in particular to better take into account the actions implemented following flooding events on the short term (repair) but also on the longer term (adaptation). This approach is quite original because it combines qualitative and longitudinal monitoring methods, modelling and quantitative data collection within the so-ii observatory. The first application results (section 6) show that this framework makes it possible to highlight impacts that are not usually highlighted, such as repair times, and to take adaptive behaviour into account.

The continuation of this work, in particular within the framework of the CAFRUA project, will be directed towards the integration of observations into the modelling.

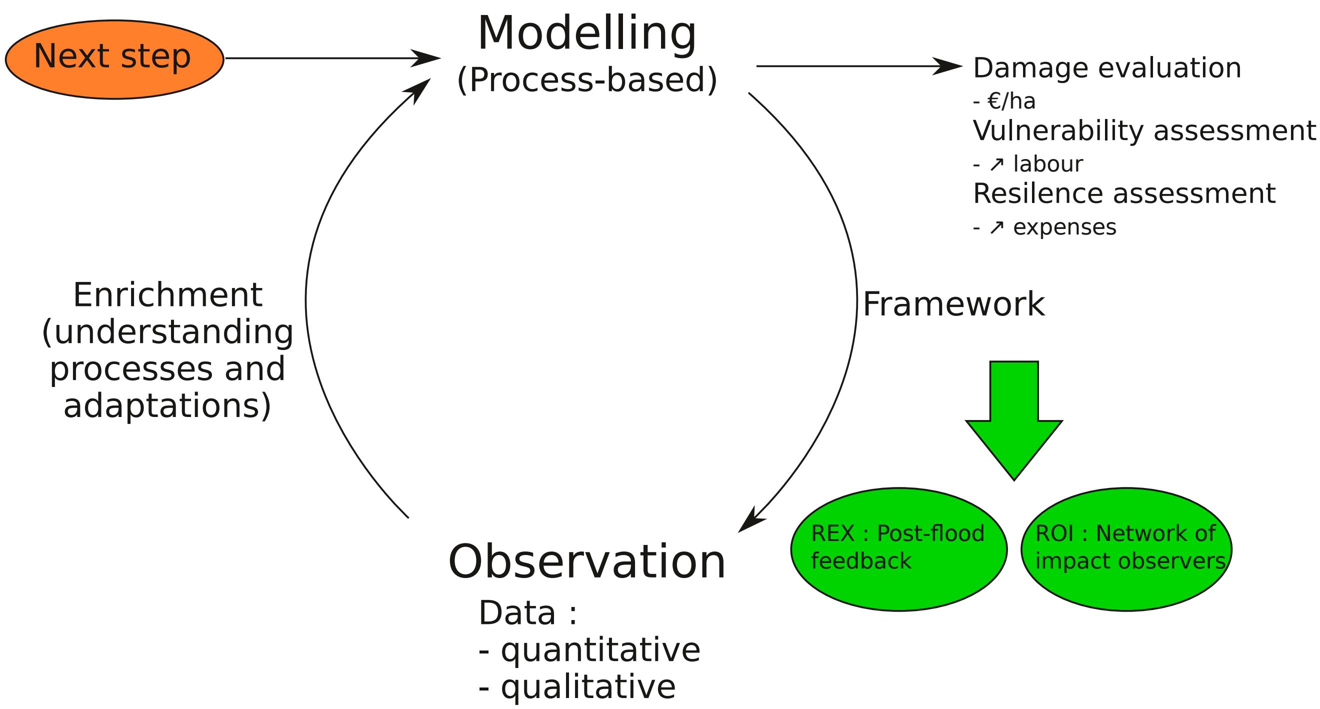

Figure 7.1: Conceptual diagram of the links between modelling and observation approaches to flood impacts

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