

## Article

# Flood Damage on Dairy Farms: A What-If Analysis to Assess Economic Losses

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**Abstract:** Although the impact of floods on the agricultural sector is relevant, with potential consequences on food security, in the new EU Common Agricultural Policy (CAP) proposal, agricultural risk management tools have been reinforced and extended. As far as we know, guidelines for the estimation of insurance indemnities related to flooding damage in the European livestock sector have not been proposed yet, unlike what has occurred in extra-European contexts. The present research proposes a model to identify the components of flood damage on dairy farms aimed at categorizing the cost typologies related to flood events by implementing a what-if approach. Our results highlight that collecting data about the vulnerability of a farm is an essential condition to assess the severity of damage from an economic perspective. In fact, even if some of the variables considered cause large economic losses per se, others are mainly related to poor management of issues related to the health of the herd (i.e., mastitis, lameness, other diseases). Such issues can be exacerbated by floods. Herd management, which includes comprehensive data collection, is essential for the calculation of economic losses in a single farm case and is also indispensable for the calculation of indemnity for the recovery of farming activities.

**Keywords:** rural appraisal; natural hazard assessment; flood damage estimation; risk management; livestock; agricultural sector; Italy



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## 1. Introduction

Risk is an intrinsic farming feature. In fact, unlike most other economic sectors, farming is strongly affected by weather and price volatility, natural disasters, pests, and diseases, making farmers' income unstable and unpredictable from year to year [1]. In addition, the climate change that has occurred in the last few decades has led to an increase in the frequency and severity of extreme events, exacerbating the situation and making policy-makers aware of the need to develop targeted risk management strategies.

Among extreme events, floods are the most frequent and damaging natural disasters [2–4] and are expected to increase in frequency in the near future [5–7] due to factors such as the intensification of heavy precipitation events under climate change [8,9], population growth [10], and increasing urbanization [11,12]. Worldwide, between 1995 and 2015, flood events caused approximately more than 25% of economic damage due to natural disasters [2]. However, this official value probably underestimates the real proportion since only 35% of records report information about economic impacts [2]. Flooding is especially common in Europe and the Asia-Pacific region [13].

In Europe, the total area exposed to flooding increased over the past 150 years [14] due to climate change, and from 2000–2012, average annual flood losses reached EUR 4.2 billion on this continent [15]. In addition, annual flood losses can be expected to increase 5-fold by 2050 and 17-fold by 2080 due to socioeconomic development (i.e., the economic value of floodplain assets is expected to increase) and climate change [5].

Among European countries, Italy has the highest percentage of residents (6.7 million, 11.0%) living in flood-exposed areas [5,14] and has had the second-greatest flood-related

total economic losses (behind Germany, followed by France) since the early 1980s [16]. Moreover, according to ISPRA [17], 23% of Italian land is exposed to hydrogeological risk.

The agricultural sector is particularly exposed and vulnerable to flooding since its activities are often concentrated in fertile floodplains and require greater land use compared to other activities [18].

Although the impact of floods on the agricultural sector is relevant and has potential consequences for food security [19], the estimation of the damage has received less stakeholder attention in agriculture compared to other economic sectors (i.e., academics and researchers, private insurance companies, policy makers, etc.) [20,21]. Furthermore, most contributions connected to the agricultural sector focus on the estimation of economic damage to cropping systems. However, what about the quantification of flooding damage to livestock production? As highlighted by Gaviglio et al. [22], a tool for the estimation of economic losses caused by floods is still lacking, not only in the academic literature but also among private insurance companies. In this regard, it is also essential to highlight that under the new Common Agricultural Policy (CAP) proposal, agricultural risk management tools (i.e., insurance support-Reg. (EU) n. 1305/2013, art. 37, mutual funds-Reg. (EU) n. 1305/2013, art. 38, and income stabilization tools) have been reinforced and expanded through a more integrated approach. In this way, the CAP confirms the role of these tools in agricultural sustainability and resilience. In this connection, despite the renewed CAP support, as far as we know, guidelines for the estimation of insurance indemnities related to flooding damage in the European livestock sector have not been proposed yet, unlike what has occurred in extra-European contexts.

The present research proposes a model to identify the components of flood damage on dairy farms: the final aim is to categorize the cost typologies related to flood events by implementing a what-if approach.

The analysis proposed here constitutes the last phase of a broader research project that seeks to provide a technical tool for stakeholders useful for estimating the economic damage of floods experienced by livestock farms. This study follows two previous studies: (i) a first methodological study developed to feature all the damage that a dairy farm may face after a flood event and identifying connections between damage and the different components of a livestock farm (i.e., buildings, herds, machinery, feed, and roads) to provide a systematic framework of overall dynamics; and (ii) a second study expanding on the framework proposed by the first study, focusing on direct damage to herds and proposing a comprehensive methodological framework of damage categories that should be considered when evaluating flooding impacts, developed through an analysis of the available literature on the topic.

Findings from the present research may be useful for private insurance companies, policy makers, farmers, and researchers. First, for the private sector, our results could be relevant for the definition of compensation to be paid to farmers in case of flooding; moreover, our results may be relevant for the design of targeted policy interventions in the livestock sector. On the other hand, the present research could be relevant for scholars since there is a lack of literature that addresses damage related to severe events in complex systems, such as livestock farming systems. More generally, our results could help stakeholders design coping strategies that help farms be resilient in cases of devastating natural disaster contingencies. The remainder of the text is organized as follows. In the next section, we provide a background on agricultural risk management tools in the European context (2.1) and in the extra-European scenario. Section 3 describes the methodological approach implemented in the analysis. The results are presented in Section 4, while in Section 5, an overview of the research, a discussion of the results and some conclusions are provided.

## 2. Risk Management Tools in Agriculture: A Background

### 2.1. The EU Context

The European Union (EU) CAP provides a range of instruments to support farmers in preventing and managing risks to enhance the resilience of the agricultural sector. PAC measures for risk management are provided by Reg. (EU) n. 1305/2013 of the European Parliament and of the Council of 17 December 2013 under the EU's rural development policy. Among the measures proposed by Reg. (EU) n. 1305/2013 to help farmers manage risks they face, we find, for instance, insurance support (Reg. (EU) n. 1305/2013, art. 37), mutual funds (Reg. (EU) n. 1305/2013, art. 38) and income stabilization tools (Reg. (EU) n. 1305/2013, art. 39). Risk management measures are included in rural development in the PAC's second pillar, and according to regulations, they represent voluntary instruments co-financed by the Member States (MSs). Therefore, the decision to adopt these measures is facultative and required for each MS [23]. As a consequence, according to Vigani et al. [24], risk management measures have been implemented in only 14 of more than 100 rural development programs within the EU, allocating only approximately 1.5% of the total budget programmed over the period of 2014–2020. Thus, despite the widely acknowledged importance of risk management in helping farmers face potentially disruptive challenges [25,26], risk management policy is not a priority for MSs.

As widely reported in the literature, farmers' adoption of these risk management tools depends on several factors. In the case of the insurance support tool, these factors are related to their costs, the level of financial contribution, the failures of agricultural insurance markets (i.e., information asymmetries), direct and indirect experiences with insurance, farmers' risk perceptions or risk attitudes, and exposure to environmental risks [26–30].

To prevent and mitigate the impacts of flood events, insurance tools could constitute an effective solution. However, similar to other risk management measures, as pointed out in the European Commission (EC) communication "The Future of Food and Farming" [1], the subscription to agricultural insurance programs is still limited and mainly related to cropping systems rather than livestock production [22]. In contrast to other MSs, Italy allocated a substantial budget for each risk management measure for the period of 2014–2020. However, the adoption of insurance schemes supported by the PAC is limited, involving only certain forms of agricultural production (mainly wine grapes, apples, rice, and corn), and they are not homogeneous across the national territory [29–31].

### 2.2. The Extra-European Scenario

In contrast to the European context, in extra-European countries such as the US and Canada, public agricultural insurance programs and risk management tools are widely used and subsidized [23,26,29]. For instance, in the US, the Agriculture Improvement Act of 2018 (also known as the "2018 Farm Bill") includes a disaster assistance program that involves a set of tools aimed at helping farmers hit by natural disasters, such as drought and flooding, recover. These tools comprise an emergency loan program, which provides aid to help producers recover from production and physical losses, the Emergency Conservation Program (ECP), aimed at repairing damage and developing water conservation methods during periods of severe drought, the Emergency Forest Restoration Program (EFRP), aimed at restoring forests damaged by natural disasters, programs specifically targeted at crop losses caused by natural disasters, and finally, the Livestock Disaster Assistance Programs [32]. Among Livestock Disaster Assistance Programs, there is a program that specifically provides compensation to eligible livestock producers who have suffered grazing losses (the Livestock Forage Disaster Program, LFP), a program that provides benefits to livestock producers for livestock deaths caused by adverse weather (the Livestock Indemnity Program, LIP), a program aimed at providing emergency assistance to eligible producers of livestock, honeybees and farm-raised fish for losses due to adverse weather, disease, or other conditions such as blizzards and wildfires (Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish, ELAP), and finally, a program that provides emergency relief payments to compensate for increases in supplemental feed

costs due to forage losses caused by natural disasters. Additionally, in Canada, business risk management programs (BRMs), disaster financial assistance arrangements (DFAAs), and commercial insurance offer different levels of support for producers. In particular, the Flood Recovery Program for Food Security covers all extraordinary costs caused by floods, including veterinary costs to treat livestock injuries, support for livestock mortality losses, extraordinary costs for livestock feeding, rentals of essential alternate facilities or pasture needed, transportation costs for relocating livestock, available feed, and crop water storage.

Given the above and in light of the current CAP reform, it is urgently necessary to develop EU risk management tools in the livestock sector.

### 3. Methodological Approach

#### 3.1. Conceptual Framework

The current research proposes a tool useful for the estimation of flood damage on dairy farms developed based on the conceptual framework proposed by Gaviglio et al. [4] and Gaviglio et al. [22]. The first part of this framework [4] includes a conceptual model to evaluate flood damage on dairy cattle farms and is composed of four parts: (i) Vulnerability parameters, and thus the internal characteristics of the farm pre-flood, include the state/condition of the herd (e.g., age and condition of animals) and of farm structures (e.g., age and condition of rural buildings and agricultural machinery); (ii) Hazard, and thus external, parameters are essentially the features that characterize every flood event (e.g., the period of the year in which a flood occurs, the duration of an event, and water velocity). Then, the model considers the other two parts: farm components affected by flooding due to the combination of the vulnerability and hazard parameters. These two components are (iii) damage to the herd (which includes direct damage to animals and feed resources) and (iv) damage to the farm structure, which includes damage to rural buildings, agricultural machinery, and roads. Labor is not considered in the model since there is no direct connection to damage to the herd. Moreover, the model does not include direct damage to land, annual crops, land settlements, and hydraulic systems because these damages are already considered in specific models for the estimation of damage to crops (for instance, see Molinari et al. [21]) or do not have a direct impact on herds.

The second part of the model [22] aims to identify variables that can be used to estimate economic damage that livestock farms may experience after flooding, focusing on damage to herds. This framework has been implemented since Gaviglio et al. [4] suggested that poor welfare conditions of dairy cattle directly affect production and thus farm profitability. From this perspective, understanding what may happen and to what extent it happens to a herd when a flood event occurs on dairy farms, especially in terms of damage to livestock, is novel in the estimation of flood damage in agriculture. Damage was identified through a review of the scientific literature focused on flood damage to dairy herds; moreover, literature sources provided information on the magnitude of variation among the identified types of damage.

According to the literature [4,33], flood damage can be direct or indirect and can be further classified as tangible and intangible. Gaviglio et al. [4] and Gaviglio et al. [22] consider only the tangible components of direct and indirect damage in their studies. Tangible damage can be defined as damage that can be easily expressed in monetary terms.

#### 3.2. Assessing Damage: The Estimation Model

Total tangible damage (D) can be assessed as variation in farmers' income in terms of reduced gross saleable product (GSP) and increasing costs (C) and can be computed as reported in Equation (1).

$$D = \Delta GSP + \Delta C = (GSP_{t_2} - GSP_{t_1}) + (C_{t_2} - C_{t_1}) \quad (1)$$

where  $GSP_{t_2} - GSP_{t_1}$  and  $C_{t_2} - C_{t_1}$  represent variation in the gross saleable product and costs at time  $t_1$  pre-flood and at time  $t_2$  post-flood, respectively.

On the one hand, it is possible to compute variation in GSP easily considering the variation in profit (i.e., the decrease in milk production per head and milk discarded due to quality parameters unsuitable for sale); on the other hand, the estimation of the cost’s component, involving several variables, may be more challenging. From this standpoint, the present study proposes a model to identify cost typologies and components related to flood events occurring on dairy farms.

Figure 1 reports the methodological approach and the estimation model presented in Gaviglio et al. [4] and Gaviglio et al. [22] and implemented in the present study.

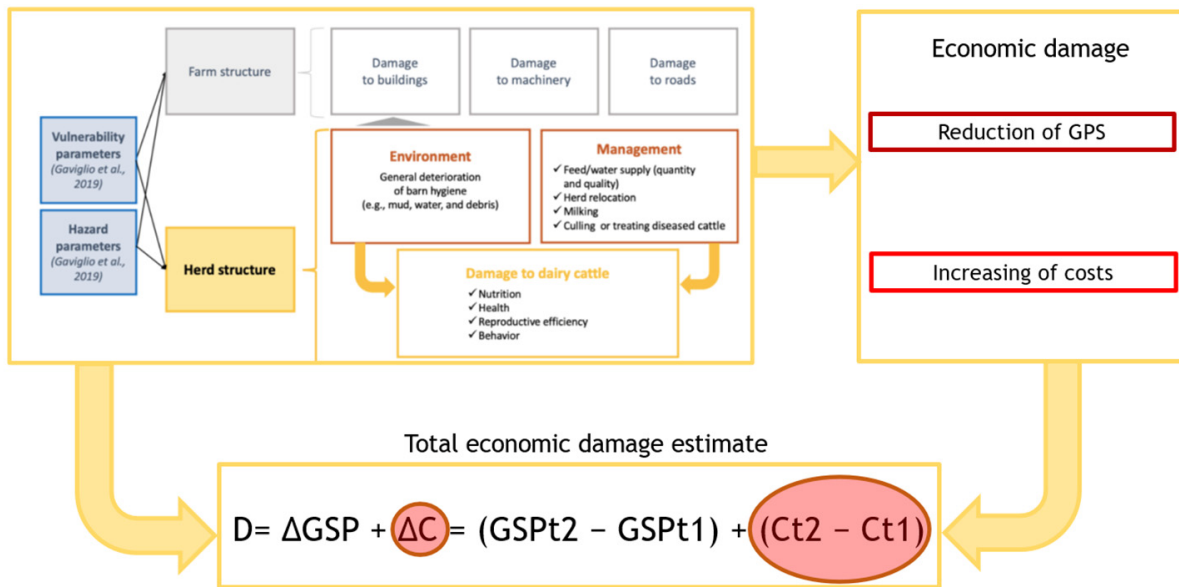


Figure 1. The methodological approach (elaboration from [22]).

### 3.3. The Contribution of the Present Study

Considering the lack of empirical data on flood damage to livestock, as previously mentioned, the present study followed a what-if approach. What-if analysis is a type of predictive analysis based on data collected from interviews and surveys of experts. The method can be defined as the process of changing scenarios or variables to make predictions about effects on the potential final outcome. Unlike other predictive analyses, through the what-if approach, it is possible to conduct a scenario analysis when historical data are not available.

As reported by Marvi [34], this method has been used to assess flood damage to building structures when no data are available, and it is especially used when no flood event has recently occurred in the region of interest, or no flood damage data were collected after recent floods. Since there are no sufficient real damage data available to show the effects of a flood event on livestock, this kind of approach appears appropriate for our research purposes.

The study was organized into two phases. In the first phase, data on potential flood damage to dairy herds were collected through focus groups and in-depth interviews with field experts. The second phase involved the analysis of data collected through interviews to develop hypothetical damage scenarios. In the following sections, the two phases are described in detail.

#### 3.3.1. The First Phase: Interviews with Experts

What if a flood affects the farm? To achieve the study goals, in the first phase, a focus group was organized. The focus group included nine participants who are experts in the field of dairy cattle farming. The focus groups and expert interviews for this study took place in Italy in June 2022, at the University of Milan, specifically in the faculty of veterinary

medicine. Details related to the participants and topics covered during the focus group are synthesized in Table 1.

**Table 1.** Focus group description.

Number of Participants	Focus Group		“What if a flood affects the farm?” Specific Themes Discussed during the Focus Group Session
	Qualification	Professional Skills	
3	Dairy farmer	Farmers specialized in high-production dairy cattle (Holstein) management, one of whom faced flooding on his farm in 2009	General farm and herd management; specific farm and herd management after the flood
1	Dairy herd manager	Professional specialist in dairy herd management	General farm and herd management
1	University researcher	Dairy science researcher	Health-related issue management: focus on mastitis and other diseases
1	Bovine veterinarian	Farm veterinarian specialized in dairy cattle	General farm and herd management; Health issue management: focus on mastitis, lameness and other diseases
1	Podiatrist	Farm consultant and technician specialized in bovine lameness and hoof diseases	General farm and herd management; Health issue management: focus on lameness and hoof diseases
1	Farm consultant	Technical farm consultant specialized in animal health and welfare	Reproduction management; Health- and welfare-related issue management
1	Full Professor in Animal Nutrition	Full professor in animal nutrition, specialist in cattle nutrition	Nutrition management: focus on feed management

Experts were selected considering their expertise in the specific field. Since the studied topic is particularly complex, the interviewees needed to have in-depth knowledge of it; the respondents' high level of involvement with the topic rendered them more inclined to express their opinions and knowledge. Although no time limit was specified for the duration of the session, the session lasted approximately two hours. As suggested by Powell and Single [35], a neutral environment was chosen to conduct the session to avoid positive/negative associations with buildings or specific places; the focus group was held in a university veterinary department meeting room. Participants also provided consent for the audio-recording of the session. Next, due to the specific nature of the topics covered, the two moderators who followed the focus group were two agricultural economists and experts in rural appraisal. The session was organized according to a semistructured scheme: The adopted approach followed the categorization of flood damage types proposed by Gaviglio et al. 2021 [22]. Thus, participants were asked to look at the framework in each separate part and formulate hypotheses on damage that could affect a flooded farm. These hypotheses not only followed categorization according to types of damage retrieved in the literature but also according to the timespan settled by Gaviglio et al. 2019 [4]. Thus, the discussion focused on the question “What would happen if a flood affected a (general)/your dairy cattle farm?” in the aspects of individual damages provided by the categorization. The final question was aimed at revealing further omitted elements. All questions were open-ended: Considerations made by every expert were seen as opportunities for the group discussion to obtain as much multifaceted and precise information on the issues as possible. The session was followed by a debrief by the moderators, which was followed by the analysis of the content recorded.

### 3.3.2. The Second Phase: Building Scenarios

Based on the data collected during the focus group session, the second phase involved the construction of hypothetical damage scenarios referring to two different moments, i.e., the hypothetical preflood scenario (HS1) and the hypothetical postflood scenario (HS2). The scenarios were created taking into consideration the three damage categories, i.e., nutrition (feed and water), health (mastitis, lameness, and other diseases), and reproduction (Figure 2). At this point, it is worth mentioning that the vulnerability parameters are inherent and specific to each individual farm context. We therefore outlined “common hypothetical preflood conditions,” which extend beyond individual business management choices. This consideration forms the basis of the model, and its plausibility was also confirmed by the participants of the focus group session. In fact, even if an increase in costs results from individual (more or less) efficient business management decisions, it is still possible to delineate the general cost components, which can be generalized beyond the individual farm case. Then, given the categories, it was possible for each damage subcategory (identified in Gaviglio et al. [22]) to build hypothetical scenarios with the data collected through the interviews, considering each subcategory singularly. The descriptive status quo and thus the features connected to herd preflood management were provided for each damage subcategory considering a variable number of alternatives depending on the different existing conditions. Thus, this setting allows the identification of costs that affect a farm. In this sense, the results provide a cost characterization, categorizing the cost typologies and components related to flood events.

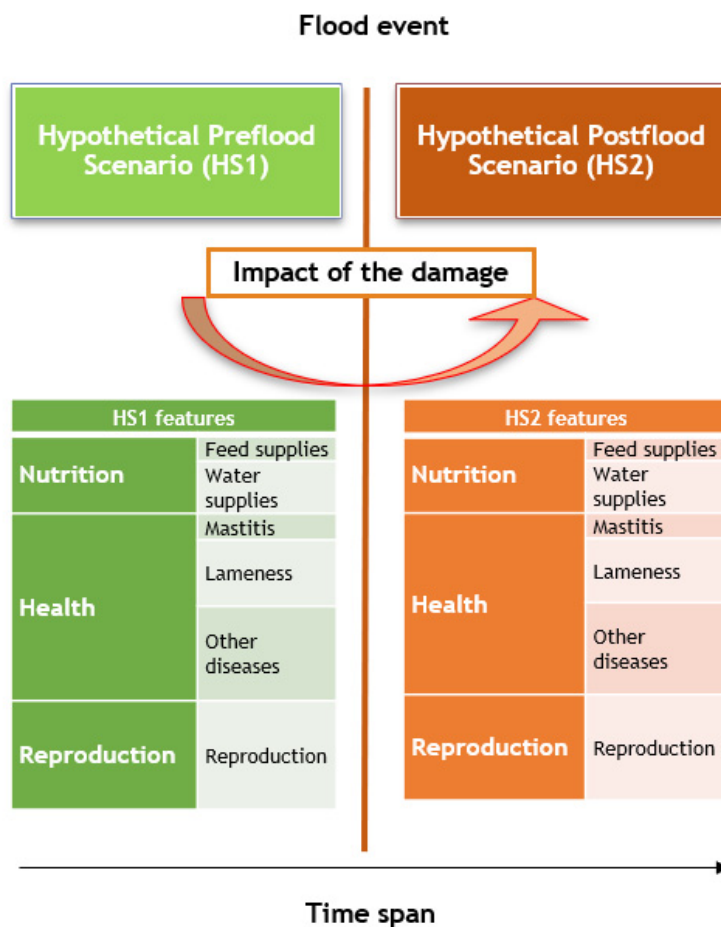


Figure 2. Scenario building method.

#### 4. Results



The results are described and organized as follows. Every subparagraph presents the category of damage presented in paragraph 3.3.2 (i.e., nutrition, health, and reproduction) and describes damage subcategories. Every scenario is characterized by features associated with general farm vulnerability parameters. The characterization of every scenario derives from the identification of flood damage on a dairy farm retrieved from the literature and the results of the focus group with experts. In the context of the focus group, it was possible to observe that all participants, with their individual expertise in the field, interacted harmonically. The combination of different backgrounds of experience was essential to obtain in-depth considerations related to every single aspect investigated. In particular, the focus group results made it possible to (i) confirm the categorization of damages and (ii) specifically describe each individual cost component presented below. Features in this sense constitute the 'starting' conditions of a farm, which are essential for defining the level of risk connected to preflood farm management. Furthermore, two scenario outcomes, namely, the hypothetical preflood scenario (HS<sub>1</sub>) and the hypothetical postflood scenario (HS<sub>2</sub>), are consequently considered for each subcategory. Thus, the impact of damage is identified. Variation in the magnitude of the damage derives from the initial level of vulnerability of the subcategory considered. In addition, the damage description is combined with an indication of the estimation related to the damage recovery timespan for each subcategory.

Table 2 presents an overview of the results. Scenario features are settled for each subcategory. HS<sub>1</sub> and HS<sub>2</sub> represent the impact of the damage at two different moments: preflood ( $t_1$ ) and postflood ( $t_2$ ). The level of risk (HS<sub>1</sub>) and impact of the damage (HS<sub>2</sub>) correspond to different colors. The severity scale was determined through interviews with experts in the field and with the objective severity of the damage components for every single damage category. Additionally, the timespans are provided. In particular, the timespans were confirmed by the results of the focus groups based on timespans previously proposed by Gaviglio et al. 2019 and Gaviglio et al. 2021, where the short-term period corresponds to 3 months and the medium-term period corresponds to 1 year. However, before presenting the damage singularly, two important assumptions need to be made. The first is that all the damage and related costs described in the following paragraph naturally contribute to the reduction of GSP after a flood and thus to a loss of farmer income. The second assumption is that one of the costs of damage not accounted for is related to the loss of animals, which could die during or in the immediate aftermath of a flood. This cost relates to carcass disposal, which is incurred by the farmer him/herself. Clearly, this is flood-related damage, and depending on the number of animals that die, it can be substantial. Thus, even if these can be considered flood damage, they are not listed in the damage checklist, which relates uniquely to damage to livestock that remains alive after a flood.



**Table 2.** Overview of the results.

	Scenario Features	Hypothetical Preflood Scenario (HS1)	Hypothetical Postflood Scenario (HS2)	Post-Flood Cost Constituents	Timespan
		Impact of the Damage			
Nutrition	Damage to feed supplies Before harvesting (F1)	[Grey]	[Yellow]	Feed supplies to replace internal feed production;	s/m
	After harvesting (F2)		[Red]		s/m
	Damage to water supplies	[Grey]	[Red]	Extra water tanks, well refurbishment, water analyses;	s
	Private water well (W1)		[Yellow]		Water analyses;
Connection to water supply (W2)					
Health	Mastitis	[Orange]	[Red]	Veterinary consultation, pharmacological treatments, analyses for the identification of specific microorganisms;	s/m
	High SCC (M1)	[Yellow]	[Orange]		s/m
	Moderate SCC (M2)	[Green]	[Yellow]		s/m
	Lameness				
	High prevalence (L1)	[Orange]	[Red]	Podiatry services, pharmacological treatments;	s/m
	Moderate prevalence (L2)	[Yellow]	[Orange]		s/m
	Low prevalence (L3)	[Green]	[Yellow]	s/m	
Other diseases		NA	Veterinary consultation, specific analysis for the identification of pathogens, pharmacological treatments;	NA	
Reproduction	Reproduction				
	High efficiency	[Orange]	[Red]	Pharmacological treatments, genetic quality of the herd;	s/m
	Moderate efficiency	[Yellow]	[Orange]		m
Low efficiency	[Green]	[Yellow]	s/m		

Legend:  severity scale referring to farm condition;  neutral condition connected to constraints; "s/m" refers to short-/medium-term damage; "s" refers to short-term damage; "m" refers to medium-term damage.

#### 4.1. Nutrition

Nutrition is defined as a category comprising two subcategories of damage: damage to feed supplies and damage to water supplies. These two categories are described in more detail in Sections 4.1.1 and 4.1.2, where definitions of different scenarios and their possible outcomes in terms of cost are provided.

##### 4.1.1. Damage to Feed Supplies

For damage to feed supplies, the main difference that can be seen in scenarios  $F_1$  and  $F_2$  is related to the season in which a flood occurs. It is possible to distinguish between damage for floods occurring before or after the harvesting period (August–September). The motivations behind this are first that feed produced by a farm (forages and energetic feeds, principally corn), mainly in its own fields, forms the basis of the diet of high-production dairy cattle (e.g., the average quantity of corn in the daily feed portion of high-production lactating cattle is nearly 23 kg per day); second, after harvesting, corn is stored in a barn for the whole year in special trenches or silos (maize silage). Since spring and autumn are the two seasons in which the frequency of flood events is most concentrated, we can observe how the extent of damage can affect cattle feeding differently. In this sense, scenario  $F_1$  considers the assumption that if a flood event affects corn stocks in the spring/summer, just before the harvesting season (April–June), the amount of feed destroyed corresponds to the end of the stock, and therefore (unless floods also heavily affect the fields), it might be possible to recuperate feed product from the fields in a short period of time (3 or 4 months maximum).

Conversely, as considered in the scenario labeled  $F_2$ , if a flood affects a farm after the maize harvesting season, the extent of the damage is at least 100%, forcing a farmer to completely change the diet of lactating cattle. This condition would lead to an increase in the cost of replacing diet components with different, nonfarm-produced feedstuffs and therefore of purchases such as a different kind of forage or energetic feed.

##### 4.1.2. Damage to the Water Supplies

Damage to the water supply is considered a subcategory of the damage macro-level category of nutrition. As shown in Table 1, two scenarios, labeled  $W_1$  and  $W_2$ , are considered for water supply:

- The  $W_1$  scenario, under which a farm obtains its water from a private well;
- The  $W_2$  scenario, under which a farm is connected to the main water source.

From the preflood cost composition, under  $W_1$ , costs are connected to routine well maintenance. The procedure may include, e.g., a routine check of components and equipment, a check of the pump, treatment with chlorine, and regular analysis to assess water quality (the presence of contaminants). On the other hand, in the  $W_2$  scenario, preflood costs are related to the connection of the farm to the main water source. After a flood, the variation in costs has different causes under  $W_1$  and  $W_2$ . In  $W_1$ , if the functioning of the well is compromised, extra water tanks to provide fresh water to animals during an emergency could be necessary. In addition, the costs of well refurbishment and detailed analyses of water to exclude the presence of contaminants must be done. In  $W_2$ , no substantial cost increase is expected after a flood related to supply: a small increase in costs may be caused by analyses to assess water quality. Finally, in both scenarios, damage is defined as short-term resolution damage.

#### 4.2. Health

Health is defined as comprising three subcategories of damage labeled mastitis, lameness, and other diseases. These three categories are described in more detail in Sections 4.2.1 and 4.2.2, where definitions of different scenarios and their possible outcomes in terms of cost components are provided.

For this damage subcategory, three scenarios are provided. Scenarios  $M_1$ ,  $M_2$ , and  $M_3$  are characterized by different somatic cell count (SCC) levels in bulk milk. The SCC level

in bulk milk is used as a proxy to determine the udder health of the entire herd. The three scenarios, which consider three different threshold values indicating the vulnerability of a herd, are set as follows:

- Under  $M_1$ , the SCC level is high before a flood, meaning that mastitis infection is strongly present in the herd (SCC before flooding  $>400.000$ );
- Under  $M_2$ , the SCC level is moderate before a flood (SCC before flooding of between  $400.000$ – $200.000$ );
- Under  $M_3$ , the SCC level is low, denoting optimal udder health in the herd, where the SCC level is lower than  $200.000$ .

Amid wet and muddy barn conditions after a flood, environmental mastitis pathogens may proliferate, causing a rise in the number of mastitis cases in a herd. The interview results highlight two main cost components that can be considered in pre-flood and post-flood development under scenarios  $M_1$ ,  $M_2$  and  $M_3$ : (i) costs related to the involvement of a veterinary doctor and (ii) those related to pharmacological treatments required to cure the disease. The only other cost component that can be attributed to the postflood condition is the need for specific analyses to search for mastitis-triggering pathogens not normally present in a herd, but which may be caused by the environment in the postflood period (e.g., bacteria that cause mastitis defined as environmental, especially related to flooded farm conditions). Under normal conditions, however, it is expected that such analyses are done for the selection of the best treatments to deal with the disease.

In this sense, cost variation—and thus, in this case, a possible cost increase—can also be attributable to the possible condition related to the rise in flood-related mastitis cases in a herd. This issue and the associated costs related to its resolution might weigh on a farm's finances for a short to moderate length of time.

#### 4.2.1. Lameness

As described by the literature and confirmed by our interviews with experts, lameness cases could also increase after a flood event: resulting muddy and wet conditions may facilitate interdigital skin and hoof softening. In this sense, it was possible to assign to each of the three scenarios considered different threshold values suggested by experts (the podiatrist and farmers) and confirmed in the literature by a recent review (Afonso et al. 2020). The three scenarios, which consider three different threshold values indicating the vulnerability of a herd, are set as follows:

- $L_1$  involves a high registered frequency of lameness in the herd, which corresponds to a poor management level (greater than 30% prevalence);
- $L_2$  involves a moderate registered frequency of lameness, which corresponds to a moderate management level (less than 30% prevalence);
- $L_3$  involves a low registered frequency of lameness, which corresponds to a high management level (less than 20% prevalence).

It is interesting to note that here again, there are no differences in the composition of pre- and postflood costs. Cost components refer to (i) podiatry services carried out by an expert podiatrist and (ii) pharmacological treatments and thus the purchase of medications to treat the problem. Again, the increase in costs can be attributed to a possible increase in the number of pathological cases in a herd. This is classified as short- to medium-term damage.

#### 4.2.2. Other Diseases

For other diseases, it is very difficult to define scenarios including threshold values that describe the vulnerability level of a farm. In fact, some pathogens are related to flooding, so they are new to a herd. For this motivation, it is impossible to standardize this subcategory with other damage subcategories (see mastitis and lameness). In any case, it is possible to consider cost components that may affect farm finances, such as (i) veterinary interventions for the diagnosis of any new diseases in a herd; (ii) specific

analyses for the identification of pathogens; and (iii) treatments aimed at resolution. Clearly, an increase in costs should be possible, not only with regard to the treatment of new flood-related diseases (the literature reports the risk of infections specifically with *Leptospira* spp.), but also with regard to diseases that lead to the death of the animal in a short time (such as clostridiosis). Additionally, costs can be related to a possible increase in respiratory diseases or dysmetabolic disorders. This can be classified as short- to medium-term damage. In this context, it is also important to bear in mind the negative effect that stress can have on animals. Although it is somewhat impossible to quantify, a stressed animal may have lowered immune defenses and thus greater susceptibility to certain diseases. Such conditions can lead to considerable production losses.

#### 4.3. Reproduction

The last category of damage is labeled reproduction. Regarding this damage category, it was possible to develop scenarios that take into account threshold values relating to the reproductive efficiency of dairy cattle. In this case, the three scenarios, which consider three different threshold values indicating the vulnerability of a herd, are set as follows:

- $R_1$  involves high reproductive efficiency with an optimal pregnancy rate of >30%;
- $R_2$  involves moderate reproductive efficiency with a pregnancy rate of 30–25%;
- $R_3$  involves low reproductive efficiency with a pregnancy rate of lower than 25%.

For the pre-flood condition, cost components are essentially (i) the cost of semen per dose (which varies according to the genetic value of the semen itself); (ii) eventual costs related to treatment for estrus synchronization, which is usually used in highly productive cattle herds; and (iii) the cost related to the involvement of a veterinary doctor for pregnancy diagnosis. Furthermore, after a flood, a farmer may deal with other costs mainly associated with a possible increase in abortions linked either to certain pathologies arising after the flood or to the stress to which the animal is subjected after the emergency, as emerged from interviews with experts. In this scenario, costs related to treatments used for the management of abortions may also increase; finally, it is possible to emphasize how the genetic quality of the herd may affect costs for recovery and thus the resilience of the farm business.

## 5. Discussion and Conclusions

As already highlighted by Gaviglio et al. [4] and Gaviglio et al. [22], flood damage in agriculture has been widely studied, but for the livestock sector, much still needs to be done. Therefore, this study focused on the development of a model aimed at establishing types of flood damage affecting dairy farms and the cost components related specifically to herd damage.

As pointed out by Bermond et al. [20] in their review of economic damage to agriculture, elaborate models to assess flood damage to farms are a complex issue since the combination of hazard characteristics with farm components needs to be considered. In the analysis and identification of damage to livestock farms, several components are involved. Moreover, it is essential to consider that, in the case of live animals, damage persists over long periods of time, whereas crops recover from damage faster. The case of dairy farming is a unique case compared to other types of farming (e.g., swine and poultry farming) that have shorter production cycles and different features. In this respect, as highlighted by Posthumus et al. [36], production losses in the case of floods affecting dairy farms are more important when compared to other livestock farm typologies. Furthermore, such losses are directly related to production, since when a flood affects a dairy farm, milking of dairy cows, which usually happens twice per day, must stop until the herd is relocated and safe.

Our results highlight that collecting data about the vulnerability of a farm, i.e., farm conditions before a flood related to herd management and status (in terms of production and animal welfare), is essential to assessing the severity of damage from an economic perspective. In fact, some of the variables considered cause large economic losses per se and are mainly related to poor management of issues related to herd health, and such

issues can be exacerbated by flooding. Our study identifies these damages, divides them into categories and describes their relative cost components. Specifically, when floods occur before or after the harvesting season, different outcomes for feedstock are expected, and generally, economic losses are linked to the change in diet to guarantee a sustainable production level. For this damage, it is also worth mentioning that the provision of diet components could be affected by the availability and profitability of crops at markets. Moreover, concerning damage to the water supply, our results show that they depend on the water supply system used. The cost related to the restoration of a private well used for water supply appears to be higher than that related to a connection to a main water source. The economic losses related to damage to water supply are therefore related to emergency water supply in the immediate term, the reparation of equipment and the analysis of water quality. Regarding what may concern herd health, mastitis and lameness might represent cases in point. Mastitis's impact on dairy production is well known, and costs related to the management of this disease are documented by the literature on different EU countries [37,38]. Relatedly, it is worth noting that mastitis cases are normally recorded on farms, but this is not always true for lameness cases if the level of farm management is not optimal. Our results certainly highlight the importance of keeping track of cases of these pathologies, the costs of which are difficult to estimate in relation to milk production for different causes, such as the nature and severity of the different types of lameness [39]. Regarding costs associated with other diseases, our results show that although components have been identified, it is imperative to rely on the history of the individual company to determine the importance of the economic damage incurred. As far as costs associated with reproduction are concerned, it is essential to highlight here too that the components have been identified but that the variation depends on the initial level of management.

Considering what has been outlined, some considerations can be made. First, farm resilience after a flood is related to the level of preparedness to deal with uncertainty. Business adaptation to a catastrophic event is relative not only to the magnitude of the disaster that affects a farm but also to prevention measures implemented by the farm. Herd management, which includes comprehensive data collection, is essential for the calculation of economic losses on a single farm and is also indispensable for the calculation of indemnity for the recovery of farming activities. The novelty of the present study is connected to its application of a what-if analysis. To the best of our knowledge, no previous study has used this approach in the estimation of catastrophe-related damage to livestock farms.

Our results provide a helpful tool for different stakeholders, especially those who work on damage assessment and thus calculate compensation for farmers, i.e., insurers and policy makers. This is in line first with the goal set by the European Overview-2nd Preliminary Flood Risk Assessment for the Implementation of the Water Framework Directive (2000/60/EC), the Environmental Quality Standards Directive (2008/105/EC amended by Directive 2013/39/EU), and the Floods Directive (2007/60/EC) and also with the targets and priorities outlined by the UN Sendai Framework for Disaster Risk Reduction. The EU is part of this framework, which delivers guidelines for the evaluation of disaster-related losses and economic impacts and sets a target to reduce such losses by 2030 [40,41]. However, the results of our study may reveal some challenges. First, there is a lack of case history: there are no case studies available. In the Italian context, flood damage data are not detected by public institutions, and a public database related to flood events does not exist. Alternatives to the method applied here need to be explored; the what-if analysis proposed here is certainly not a panacea but an initial attempt intended to stimulate collaborative data collection between institutions. In this sense, our study might also encourage future co-operation between the institutions involved with the creation of tables of experts, such as those implied in the what-if approach, and with the development of a central and well-structured institutional census. Further research should be based on data collected directly from farms to develop empirical models.

Only observations of such contexts could corroborate the application of theoretical frameworks to evaluate the economic damage of floods on dairy farms. Additionally, future

studies should combine farm risk vulnerability data with the flood risk information of each specific geographic area to develop more accurate models and improve the resilience of the agricultural sector [41–43]. In this sense, it is fundamental for further studies to pursue a multidisciplinary approach using data deriving from different study fields. For example, data collected with modern and low-cost technologies implemented recently in flood monitoring, can be taken into account for the future development of risk assessments to identify the most vulnerable areas [44–46]. In this sense, some limitations need to be mentioned. We used a qualitative approach to suggest that a model be applied to real cases, but we are conscious that the use of focus groups and interviews may present certain biases mainly related to the uniqueness and subjectivity of the experiences of the experts involved. However, using focus groups to gather information serves as a first step toward creating estimation models applicable to real cases. Finally, it seems worth mentioning an additional limitation related to the value of the model proposed in this study. This case study is based on the Italian context, which may suggest some difficulties in its application to different scenarios. However, cost components can be considered, if not equal, at least similar in farms not related to the Italian landscape. As already highlighted, an application of this model to real cases can reveal its strengths and weaknesses and test its adaptability to different contexts.

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