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Managing residual flood risk behind levees: Comparing USA, France, and Quebec (Canada)

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Abstract

Although hydraulic infrastructure such as levees remain important for flood risk management in the USA, France, and Quebec (Canada), there is increasing emphasis on nonstructural measures, such as regulatory flood maps, to reduce exposure and vulnerability, for example, preventing people from building in high hazard areas. One key concept related to areas protected by levees is that of "residual risk", that is, the risk from floods greater than the design standard of the levees (levee overtopping) and from levee breach. In this article, we review the legislative framework for regulatory flood maps in the USA, France, and Quebec (Canada) and compare how residual risk behind protective structures is taken into account (or not) in regulatory flood maps. We find big differences in how the USA, France and Canada manage residual risk behind the levees. While in France the area behind levees is part of the regulatory flood prone area, and land use restrictions, building codes, emergency measures and risk communication are mandatory, in the USA the area behind levees is only shown as part of the regulatory flood prone area if the levee is not accredited. In Quebec, regulatory flood maps in general follow the French approach with a few exceptions.

KEYWORDS
residual risk, regulatory flood maps, levees, France, USA, Quebec

1 | INTRODUCTION

For many years, structural (protection or defense) measures have been central to flood risk management in the USA and in France, with a focus on reducing the hazard component of risk. Levees are designed to a certain level of protection (which in the USA is 100 years), above which they can breach or overtop. Urban development tends to increase in lands protected by levees and other hydraulic infrastructure because they engender a false sense of security known as the "levee effect" (White et al., 2001). Furthermore, most residents behind levees don't understand their risk (Ludy & Kondolf, 2012). Over time, different dams and levees have shown the limitations of the structural measures approach to managing risks, for example, the 2005 floods in New Orleans during Hurricane Katrina (Burby, 2006), the 2010 floods in La Faute-sur-Mer, France during the storm Xyntia

(Mercier & Chadenas, 2012; Vinet, Lumbroso, Defossez, & Boissier, 2012), and the 2019 floods in Sainte-Marthe-sur-le-Lac in the suburbs of Montreal, Quebec (Alalouf-Hall & Fontan, 2020; Olthof & Svacina, 2020).

Flood risk management behind levees has evolved significantly in the last decades, especially after these events, moving from a more engineering oriented view that focuses on "controlling" the hazard with the use of structural works to a more holistic understanding of the concept of risk, which takes into account the "residual risk" behind the levees. This approach recognizes that the responsibility for flood risk management is shared by different levels of government and the individuals. To this end, there are two kinds of maps that are critical to manage residual risk behind levees. The first are what we call the "regulatory flood maps", which show the area within the floodplain where different flood-related regulations apply (e.g., building codes, flood insurance requirements, emergency strategies, risk communication, etc.). These maps are based on natural flood hazard maps and in the USA, France, and Quebec they regulate land use in the floodplain. These maps are available to the general public since one of the main goals is to promote wise use of floodplains. A second set of maps is focused on the performance of the hydraulic infrastructures (levees, dams, etc.) and show the potential consequences of overtopping or levee breach (Narayan et al., 2012; Sayers, Hall, & Meadowcroft, 2002). In the USA, these maps are developed by the US Army Corps of Engineers (USACE) under the Levee Safety Program (LSP) or local and/or state partner agencies but are not available to the general public for reasons of security. In France, these maps correspond to the maps included in the "Etudes de Dangers" (Hazard Studies) and are public (Deniaux, Ledoux, Colin, Beullac, & Tourment, 2018), although they are not widely and systematically disseminated. The idea of these maps is to complement the information from the regulatory flood maps. These second set of maps are mainly created to help levee owners to prioritize investment for the maintenance of the hydraulic infrastructures or to communicate risk associated to them, including preparation of emergency plans. This article is focused on the first set of maps.

Regulatory flood maps such as the Flood Insurance Rate Maps (FIRMs) in the USA, the Flood Risk Prevention Maps (*Plans de Prévention de Risque d'inondations*) (PPRi) in France, and the Flood Zone Maps (*Cartes des Zones Inondables*) (CZI) in Quebec have become critical tools to manage flood risk behind levees since they directly influence land use management. These regulatory flood maps focus on the reduction of vulnerability, since they can discourage or forbid further development in the floodplain (reducing exposure in high hazard zones) or require building codes for existing and/or new developments located in the regulatory floodplain, which can increase the capacity to cope withstand a flood event. While management of flood risk through regulatory flood maps has been widely discussed in the literature (Barraqué, 2014; Burby, 2001; Tourment & Beullac, 2019; Tourment, Beullac, & Poulain, 2017), less has been published on the implications of these maps in managing residual risk behind levees (Deniaux et al., 2018; Hutton, Tobin, & Montz, 2019). Regulatory flood maps made today can create very different scenarios of exposure and vulnerability that local and national governing agencies will have to face when managing flood risks in the future. The way these maps depict (or not) residual risk behind levees, and the way they are linked to different non-structural measures such as land use planning, flood insurance, emergency management strategies or risk communication can have tremendous implications for residual risk behind levees.

With the goal to compare the effect of the levees on regulatory flood maps, in this article, we apply methods from the USA, France and Quebec to the same area, the city of Jargeau in France, to analyze the implications of the three approaches in different aspects of flood risk management, in particular, land use planning, flood insurance, emergency management and risk communication.

1.1 | Study area: the city of Jargeau

The city of Jargeau is protected by a levee system proving a level of protection greater than the 250-y flood (Figure 1). Jargeau is located in the Loire River Valley around 15 km east of Orléans, France, protected by the 51-km-long Orléans Valley levee system, which protects 160 km^2 of valley bottom 30 km long and 5 km wide, occupied by 70,000 inhabitants, and crossed by the Paris-Toulouse railway line and the A71 motorway. The levees breached in the floods of 1846, 1856, and 1866, but contained the floods of 1907, 1923, and 2003 (Maurin, Boulay, Piney, Le Barbu, & Tourment, 2012). The medieval center of Jargeau is located on a hillock, with maximum elevation of 108 meters, where the church stands. During the 1856 flood the levee protecting the east part of the city failed, flooding farmlands. This part of the levee was converted into a spillway (Figure 1b) and another levee was built to protect the south-east part of the city (Figure 1c); a spillway equipped with fuses limits overflows in the channel until a flood occurrence of the order of 1/250 years. The total length of the crest of the spillway is 700 m and the central part where the lowering is maximum is 570 m.

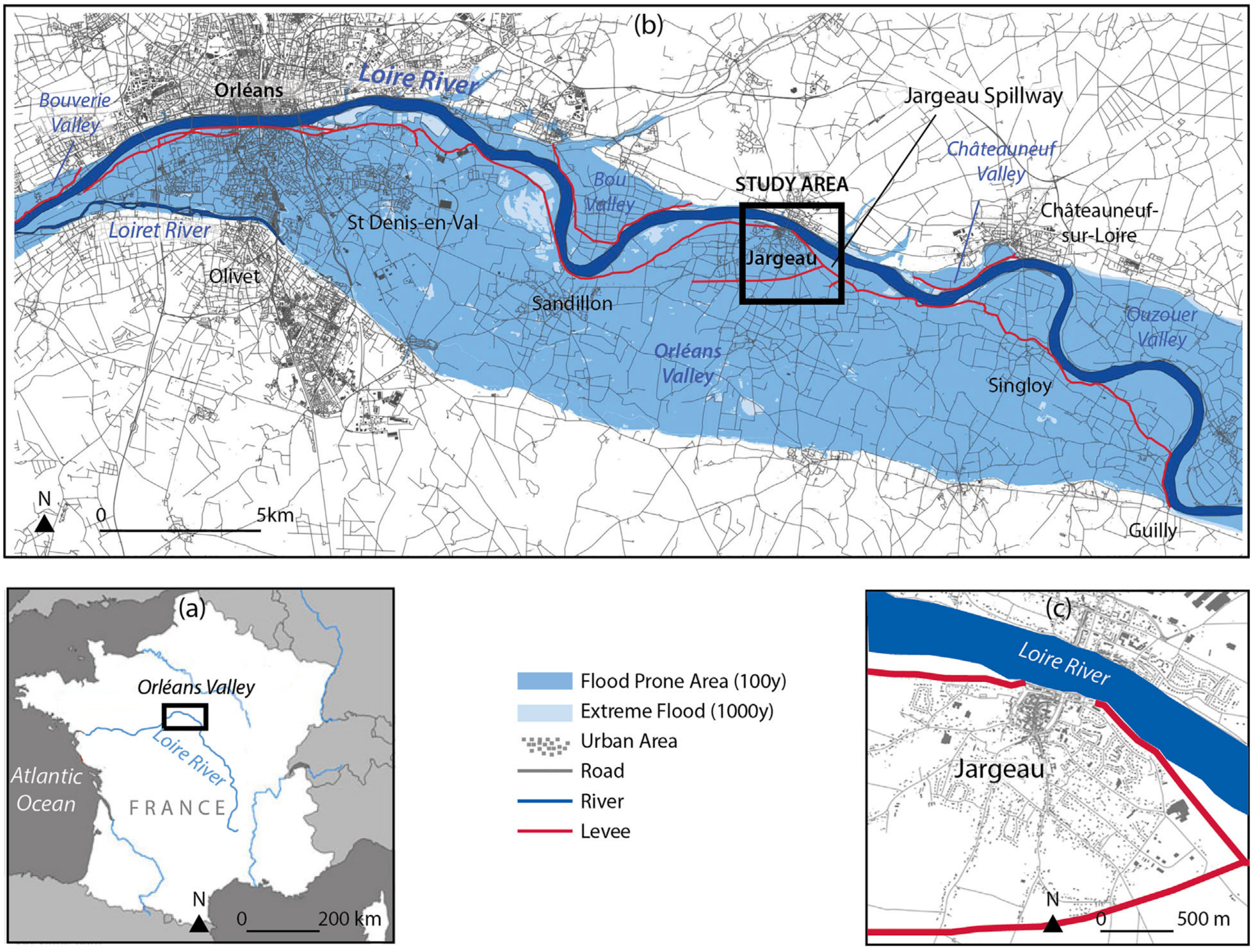

FIGURE 1 Location area of (a) the Orléans valley along the Loir River, (b) the Orléans valley levee system, and (c) the city of Jargeau

1.2 | Methods

We analyzed the legislative framework related to the regulatory flood maps in each country (Section 2). To compare technical aspects of the maps and their implications in different aspects of flood risk management (Section 3), we analyzed grey literature, conducted in person semi-structured interviews with public officials in France and organized a workshop in Berkeley to bring together scientists, and public officials from the USA and Canada. In Jargeau, we met with local floodplain managers and conducted site visit to components of the levee system.

To produce the maps for Jargeau (Section 4), we have used a combination of two GIS data sets: the PPRi GIS dataset provided by the *Direction Départementale des Territoires* (*DDT*) *du Loiret*, and the flood maps produced for the European Floods Directive on the Orléans zone. The only missing layer was the 20 y flood for the Quebec map, which was created approximately using water depths and velocities included in the PPRi dataset. The goal of the maps is not to map precisely each flood scenario but to show how different conception of flood risk management from each country would produce different flood maps.

2 | LEGISLATIVE FRAMEWORKS FOR REGULATORY FLOOD MAPS IN THE USA, FRANCE, AND CANADA: BRIEF SUMMARY

During the late 1960s, the 1970s and the 1980s, major reforms in the flood-related policies in the USA, France, and Canada shifted their national approaches, at that time mainly focused on flood control through hydraulic infrastructures, to a more holistic flood risk management approach that incorporated land use planning as a critical tool to reduce exposure and vulnerability to floods. Flood hazard maps became the cornerstone of these policies—filling a critical gap, as there were hardly any maps at that time (Burby, 2001; Le Bourhis, 2003; Le Bourhis & Bayet, 2000). They were created to discourage developments in hazardous areas or to require building codes such as elevating structures. The USA and France also created insurance systems to allow those affected by floods to recover faster. In the case of the USA, the maps were directly linked to the flood insurance system while in France they were not. In Canada, no national flood insurance system exists (Parliamentary Budget Office, 2016).

2.1 | Legislative framework for regulatory flood maps in the USA: The National Flood Insurance Program (NFIP) (1968)

In the USA, Flood Insurance Rate Maps (FIRMs) are the official regulatory flood maps of a community on which FEMA has delineated both the Special Flood Hazard Area (SFHA), and the risk premium zones applicable to the community. Within the SFHA insurance is obligatory for structures with federally backed mortgages and outside the SFHA insurance is recommended. The FIRMs are produced at a community scale and are a separate document from communities comprehensive/urban plan, although some communities might include the flood hazard area on their comprehensive plans and may create an "overlay" district on their zoning maps. The FIRMs are a key element of the National Flood Insurance Program (NFIP), which was created by Congress in 1968 under the National Flood Insurance Act, and amended significantly in 1969, 1973, and 1994.

The basic idea was that the federal government would provide subsidized flood insurance if local communities agreed to create and enforce a "flood ordinance" that regulates land use within an established flood hazard area, set as the extent of the 100-y (or 1% annual exceedance probability) flood to keep development out of flood-prone areas (Burby, 2001; Eisenstein, Kondolf, & Cain, 2007). The 1% NFIP standard was intended to be a standard for flood insurance rating and not a national standard for flood protection or land use planning (Galloway & Link, 2012). There is no national standard for flood regulation in the USA, per se. The USACE determines the level of protection to be provided by a USACE project (i.e., a levee) based on evolving analysis techniques and since 1965, the urban standard has nominally been the standard project flood, not a statistically derived flood (Baecher and Galloway, 2021). Many USACE projects are designed to protect against a specified nonstatistically derived design flood. To make things more complex, decisions in the floodplain are now caught between old rules and new hydrologic realities. In 2008, hydrologists from the US Geological Survey published an article (Milly et al., 2008) indicating that (hydrologic) stationarity was dead and that procedures that had been used for decades to determine the 100-y flood were no longer appropriate, but new methodologies are still needed to update flood risk assessment and mapping approaches in the context of climate change (Milly et al., 2015).

The NFIP is a voluntary program, which means that if a community decides not to participate in the program, they don't have to adopt the map or ordinance. In that case, they will not be eligible for postdisaster funding or subsidized flood insurance. Because of the voluntary nature of the program, FIRMs do not cover the whole USA territory, and sometimes maps are outdated (Johnson et al., 2020; Lulloff, 2013).

As explained in FEMA (1981) and (1983), FEMA's policy has been to show the residual risk in areas protected by levees in the FIRM. This policy was strengthened in Memorandum 34 (FEMA, 2005) which was issued just days before Hurricane Katrina struck New Orleans in August 2005 (ILPRC, 2006; NAS, 2013). Katrina killed over 2100 people and caused damages exceeding 125 billion dollars (2005$ US). This disaster, caused largely as a result of levee breaches, raised awareness about residual risk behind levees among the general public.

An accredited levee system is a system that the Federal Emergency Management Agency (FEMA) has determined to meet the design, data, and documentation requirements of the Title 44 of the Code of Federal Regulations (44 CFR 65.10) (2020). Many levees in the USA are not "accredited" on a Flood Insurance Rate Map, therefore, in these cases the SFHA (100-y flood), is mapped on the floodplain landward of the levee and the relevant building criteria and insurance requirements apply in communities that participate in the NFIP.

However, if a levee is constructed with a 100-y flood standard of protection (and certified and accredited as providing this protection), the area behind the levee, although still depicted in the map, is then no longer considered to be in the regulatory flood prone area. In the flood hazard area behind an accredited levee, flood insurance, is highly recommended by FEMA but not required and the minimum national NFIP standards for land use do not apply. However, States and communities can enact land use standards and building codes that go above the NFIP minimum standards, but the lack on mandatory standards in some cases has fostered the increase of developments behind levees (Hutton et al., 2019). Regarding emergency measures, evidence of a Flood Warning System (including emergency operations provisions) is required by FEMA (FEMA, 2008) in areas behind a levee.

2.2 | Legislative framework for regulatory flood maps in France: the Cat'Nat' system (1982) and the flood risk prevention maps (PPRi) (1995)

Unlike in the USA, in France regulatory flood maps are not directedly linked to the insurance system. In 1982, the French government passed a law concerning flood risk management (Loi n° 82-600 du 13 juillet, 1982 relative à l'indemnisation des victimes de catastrophes naturelles). Articles 1 and 2 of the law define the Natural Catastrophes System (Catastrophes naturelles), known as the Cat'Nat', which is related to the flood insurance system, while article 5-1 refers to land use planning issues, including the flood hazard maps called Risk Exposure Maps (Plan d'Exposition aux Risques).

On the one hand, the *Cat'Nat'* System was initially created to insure catastrophic floods related to heavy rains (larger than the 10-y return period, to exclude repetitive losses due to ordinary floods) and other natural disasters such as stroms, mudflows, landslides, avalanches, earthquakes or volcanic eruptions (Douvinet, 2006). Since 2003 it also covers damages due to soil subsidence resulting from repeated droughts. The entire French population is covered by this public flood insurance, which is paid by a tax on insurance premiums on homeowners and automobile insurance of 12% and 6%, respectively (Barraqué, 2014).

On the other hand, the exposure prevention part of the law asked for the creation of Risk Exposure Maps, which include regulatory maps for different natural hazards (not only floods). After the 1995 a new law (Loi n° 95-101 du 2 février, 1995 relative au renforcement de la protection de l'environnement) renamed the maps to Natural Risks Prevention Maps, known as PPRN (*Plan de Prévention des Risques Naturels*). In the case of riverine flooding, they are called flood risk prevention maps or PPRi (*Plan de Prévention des Risques d'inondation*) and for coastal flooding they are called PPRl (*Plan de Prévention des Risques littoral*). The main idea in the French approach is that everybody in France is insured for catastrophic natural events under the Cat'Nat' System but on their side, local authorities must restrict developments in hazardous zones (Grislain-Letrémy & Peinturier, 2010).

The 1995 Law also created the Major Natural Hazard Prevention Funds (*Fonds de Prévention des Risques Naturels Majeurs*), also known as the Barnier Fund, which can be used as part of the Cat'Nat' pool for expropriation and amicable acquisitions of buildings in high hazardous zones. The Barnier Fund also covers other type of preventive measures, such as giving financial support to finish the drafting of PPR, and some preventive actions taken to implement the PPR (Barraqué, 2014).

In France, the PPRi are created by the "Préfectures", local representatives of the national government. Although it does not constitute an urban planning document itself, the PPRi is the document that governs urban planning in the floodplains in France since 1995 (MATEMETL, 1999; METL, 2002). These regulatory flood maps are obligatory in flood prone areas. In the PPRi, the area behind levees is part of the regulatory flood prone area, and land use restrictions, building codes, emergency measures and risk communication are mandatory.

2.3 | Legislative framework for regulatory flood maps in Canada and Quebec: The National Flood Damage Reduction Program (1975 to early 2000s) and Quebec's Riverbanks, Riparian Zones and Floodplains Protection Policy (1987)

Canada created the Flood Damage Reduction Program (FDRP) in 1975 with the goal to reduce flood damage and prevent loss of life by discouraging development in areas vulnerable to floods (Millerd, Dufournaud, & Schaefer, 1994). Unlike the USA and France, Canada didn't create a flood insurance system. With a change in government, the FDRP was phased out starting in the early 1990s and the last of the agreements expired in 2000 (de Loë, 2000).

Although there is no longer a federal flood management program, Natural Resources Canada (NRC) (2018) developed flood mapping guidelines to help provinces generate maps. The Guidelines at NRC are actually part of a broader program called the National Disaster Mitigation Program through Public Safety Canada, which also provides funding for flood mapping, risk assessment, and mitigation (Public Safety Canada, 2021). However, these mapping guidelines are not obligatory and provinces like Quebec have their own methods to map the regulatory flood area. Quebec mapping methods are linked to the Riverbanks, Riparian Zones and Floodplains Protection Policy (*PPRLPI, Politique de protection des rives, du littoraux et des plaines inondables*), enacted by the Government of Quebec in 1987 and amended on several occasions since (1996, 2005, 2008, 2015, and 2018) and is now under major revision following the 2017 and 2019 flooding. Among other considerations for the riverine space, the PPRLPI describes the minimal buildings codes and land use restrictions in the regulatory flood prone areas.

The regulatory flood maps in Quebec are called "*Cartes de Zones Inondables*" (CZI) (Flood Zone Maps). The CZI are used by the Regional Municipal County (RMC) and have to be included within the general county planning called "schéma d'aménagement et de développement" (SAD). The RMC is a supralocal entity that includes a group of municipalities and has some legal responsibilities such as creating and implementing the SAD. The SAD is developed with concertation of all municipalities and is implemented within the municipality's urban development planning.

In Quebec, regulatory flood maps generally follow the French approach, showing the area behind levees as part of the regulatory flood prone area. However, a few areas have been exempted from depicting residual risk behind levees.

Individual (i.e., private property) overland flood insurance at reasonable cost currently does not exist in Canada.

Since 2015, insurance companies have begun to offer flood insurance in provinces, and the Insurance Bureau of Canada has recently submitted a report to the federal government about options to insure flood damages across the country. This flood insurance is only available in a few provinces, but not for properties at very high risk; nor is it available at reasonable cost (Parliamentary Budget Office, 2016). In Quebec, as in the rest of Canada, up to 2015, house insurance did not cover natural flood disasters. Home insurance could cover flooding due to sewage backup problems, but not damage due the presence of water from riverine flooding. Damages generated by floods are to be covered in part by federal and/or provincial specific funding programs that are put in place when a significant flood occurs. These programs generally cover only limited items and house types, so usually residents must pay much of the damages. Following the 2017 flood, the Quebec government offers two alternative choices to homeowners whose homes have flooded (Boudreault, 2020). One option is for the government to pay up to a cumulative CA$100,000 for all future flood damages. The second option is for the government to pay CA$ 200,000 to buy the house or CA$250,000 to buy the house and the land. The rationale behind the program is that a homeowner possessing a house in an area that is repetitively flooded is likely to opt for the second choice (Molina, 2019). According to Quebec's public security minister Geneviève Guilbault "We want to avoid people benefiting, year after year, from financial help without a maximum amount" (Adriano, 2019).

3 | IMPLICATION OF THE REGULATORY FLOOD MAPS TO MANAGE RESIDUAL RISK BEHIND LEVEES

Flood hazard maps can be created using different types of information: hydrologic and hydraulic modeling (HHM), information from historical floods, ecological information (e.g., limits of the riparian forest), or geomorphological information based on geomorphic indicators (Figure 2). As explained in Serra-Llobet, Tourment, Montané, and Buffin-Belanger (2021) and shown in Figure 3, the USA, France, and Quebec depict flood hazard information in different ways.

3.1 | Regulatory flood maps in the USA: The FIRM

In the USA, FIRMs are generated by FEMA for riverine and coastal floods following their own mapping standards and guidelines (FEMA, 2021). Many earlier maps were based on expert judgment, but the standard is to base the FIRMs on HHM, mostly one-dimensional (1D) hydraulic models, but with the availability of the two-dimensional (2D) hydraulic model HEC-RAS 2D in the last decade, flood hazard maps are increasingly based on 2D modeling (USACE-HEC, 2021). The maps are prepared at a scale of 1:6000 for the 10-, 50-, 100-, and 500-y floods. The SFHA, is defined for the 100-y flood elevation (also referred to as the Base Flood Elevation, BFE) (Figure 3a). FIRMs are based on existing conditions (not take into account future land-use development, such as urban growth, or climate change), but current FEMA guidelines suggest that flood hazard determinations should consider conditions anticipated within 12 months following completion of the draft Flood Insurance Study (FIS) report such as channel modifications and flood protection projects under construction (FEMA, 2019).

In FIRMs, the SFHA is called Zone A in areas affected by riverine flooding and Zone V in areas affected by coastal flooding. When these zones include information about the elevation, they are called Zone AE (Figure 4a) and Zone VE. When a levee is accredited, the 100-y flood prone area behind the levee (which reflects the "without levee condition") includes a note stating "area with reduced risk due to levee" and is shown as Shaded Zone X in the regulatory flood map, except for areas of residual flooding, such as ponding areas, which are shown as high-risk areas (SFHAs). Flood insurance is not mandatory but recommended in the Shaded Zone X.

To be eligible for subsidized flood insurance communities are expected to enforce flood regulations and to manage land use within the SFHA. Compliance with the model floodplain ordinance, required to be an NFIP participating community, in theory, eliminates development in the SFHA unless certain conditions apply, such as: appropriate elevation, demonstration that the development will not result in an increase to the BFE, permission from all affected properties, etc. In practice, new buildings in the SFHA are commonplace in the USA because developments are not prohibited in the SFHA (Galloway, 2005; Pinter, 2005), in part due to the takings doctrine linked to the property rights (Klein, 2019). This is a fundamental difference between the three approaches: while in the USA developments are not necessarily prohibited throughout the high hazard area (they are only discouraged), in Quebec and France they are.

It is also important to note that the SFHA is regulated based on the elevation of the anticipated flood. Therefore, the term Base Flood Elevation (BFE or 100-y water surface elevation) is critical. If it can be demonstrated that the area shown in the SFHA is actually above the BFE, then the property, or structure is removed from the

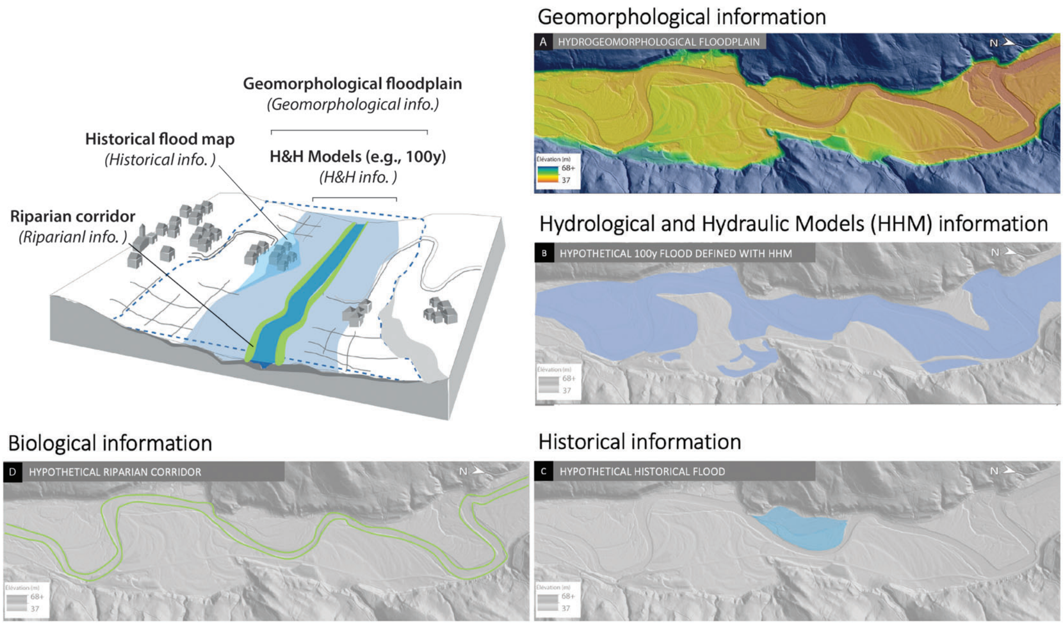

FIGURE 2 Types of information that can be used to create a flood map

SFHA. This is a common practice in the USA. Within the regulatory flood prone area, the maps often show the BFE, and the floodway. The insurance rate will depend on the finished floor elevation of the structure relative to the BFE and if the map was adopted before or after the structure was built. Outside the regulatory flood prone area, the maps also show areas of "moderate and low risk" (although they are hazard areas). The area of moderate hazard (between the 100 and the 500-y flood) is also called "Shaded Zone X", and the "Unshaded Zone X" shows the area of minimal hazard (above the 500-y flood).

3.2 | Regulatory flood maps in France: The PPRi and PPRl

In France, the regulatory flood maps of the PPRi are also based on flood hazard maps (1:5000) and are produced at the level of the "commune" (municipality) or a group of "communes", following the hydraulic logic (watershed scale) rather than administrative logic, by combining different hydraulic parameters depending on the regions of France. They include riverine and coastal flooding and, in some cases, flash flooding (in mountainous areas or in rivers with slopes exceeding 10%), although this is not very common. In France, the hydraulic modeling represents the "crue de référence" (the Reference Flood), which corresponds to a 100-y flood or the largest historical flood known, whichever is higher (MATEMETL, 2002) (Figure 3b). Furthermore, in the north of France, maps are commonly based on a combination of duration of submersion and water depth, while in the south, with a Mediterranean climate, maps are based on velocity and water depth.

As a complementary tool, in France, each regional office of the Environment Ministry (DREAL, Directions Régionales de l'Environnement, de l'Aménagement et du Logement) has elaborated the Atlas des Zones Inondables (AZI) (The Atlas of the Flood Prone Areas) at a 1:25000 scale, which provides information about the geomorphological floodplains of France.

After Storm Xynthia in 2010, France began to take climate change into account more systematically, especially in coastal areas (MTES, 2018a; Serra-Llobet et al., 2021). In 2019, the government defined once and for all the different concepts and principles and integrated them into the Environmental Code, with the 2019 Decree Concerning Risk Prevention Maps for Riverine and Coastal Flooding (MTES, 2019), in the context of the European Floods Directive (2007).

In France, to create the regulatory flood maps, the PPRi or PPRl, the hazard maps are overlaid with an assets or land use (exposure) map (i.e., a land use map showing the urban and the rural areas) (Figure 4b). On the regulatory map, nonurban zones and urban zones with a high hazard level, are depicted as a "red zone", within which new developments are prohibited. Urban zones with medium hazard intensity appear as a "blue zone", which authorizes new buildings with some restrictions. These are the two main basic zones depicted in the final regulatory maps in France. However, each commune/s can create subzones within them according to

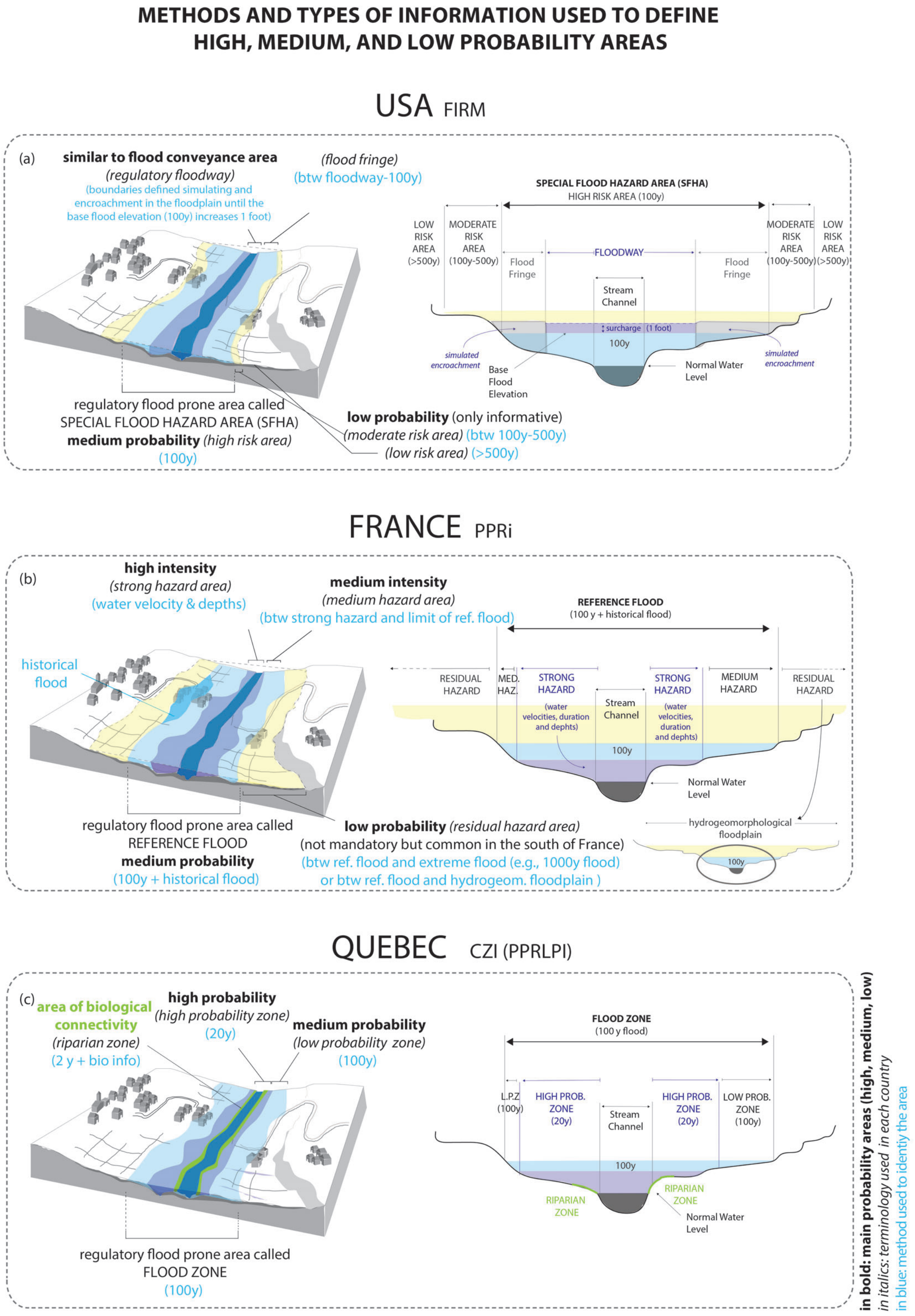

FIGURE 3 Different methods and types of information used to identify the main flood prone areas depicted in regulatory flood maps in (a) the USA, (b) France, and (c) Quebec

different flood characteristics (e.g., water velocities or depths). However, in this article, to simplify, we use the basic zones required in the PPRi guidelines (blue and red) to be able to make it a general example that could be extrapolated to other parts of France. Another interesting zone in the French approach is the "residual hazard zone" (yellow zone in Figures 3b and 4b), but the methodology to delineate this zone changes in different

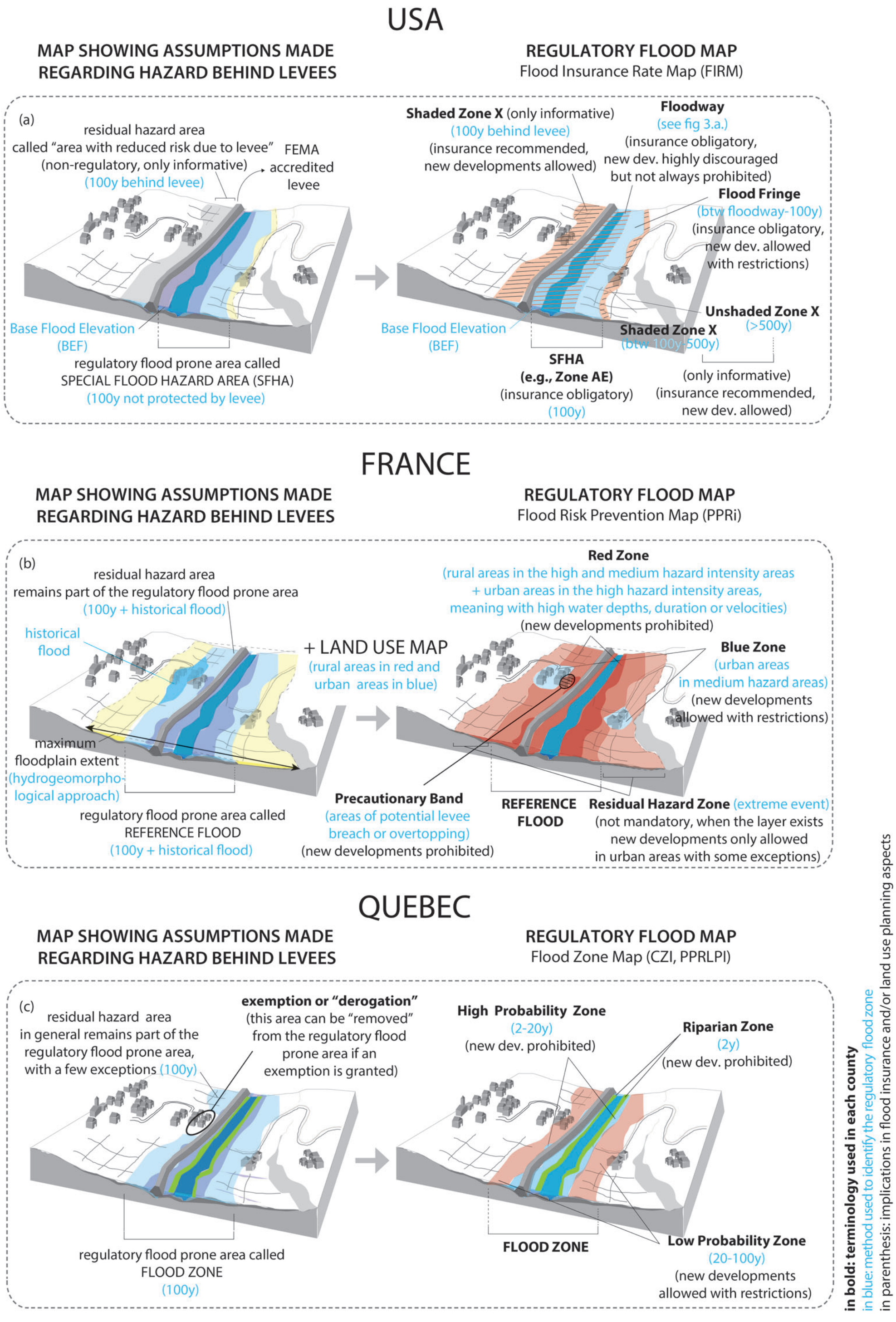

FIGURE 4 Image showing assumptions made regarding hazard behind levees and main zones depicted in regulatory flood maps in (a) the USA, (b) France, and (c) Quebec

regions in France. The residual hazard zone is not mandatory in a PPRi, it depends on the will of each Direction Départementale des Territoires (DDT). There are two main configurations. In the south of France, the residual hazard zone corresponds to the floodplain delineated using a hydrogeomorphological approach. In other regions of France, the residual hazard zone could correspond to exceptional flood scenarios, such as the 200- or 1000-y flood, as it is the case of the Orléans Valley or Lyon. However, the second configuration is very rare in France so it should not be considered as a rule.

PPRis and PPRls are also directly linked to emergency management plans and risk communication. In France, all the communes with a PPRi have to have a local emergency plan (*Plan Communal de Sauvegarde*) (PCS) and have to inform the inhabitants about natural and technological risks with the so-called "Communal information document on major risks" (*Document d'Information Communale sur les Risques Majeurs*) (DICRIM). The DICRIMs have been mandatory since 1987 in all communes with Natural Risk Prevention Maps (PPRN) or a Special Intervention Map (*Plan Particulier d'Intervention*) (PPI) (Dournel, Gralepois, & Douvinet, 2015). The PPI are made for high-risk industrial plants (including also very large dams).

In France regulatory flood maps consider profiles that reflect the "without levee" condition, showing the area behind levees as part of the regulatory flood prone area. In addition to the hazard analysis done in the PPRi/PPRl, in France, the text of the Circular 27/07/11 (MTES, 2011) also retains the "security bands" or "precautionary bands", where the hazard would be highest in case of levee breach or overtopping (Figure 4b). These precautionary bands are calculated for a range of loadings and taking into account the existence of a levee system, the potential of a flood level to exceed the levee crest (protection level) and the potential of levee breach (security level), and the adverse consequences (Sayers et al., 2002). Regarding the zoning plan, the Circular tries to promote a compromise when in certain cases, exceptions could be authorized to the rule and building behind levees with a high level of maintenance and protection can happen, following a new framework related to the management and maintenance of hydraulic structures called GEMAPI (Gestion des Milieux Aquatiques et Prévention des Inondations). The GEMAPI framework gives more responsibility to the municipalities at an intercommunal level to manage levees (MTES, 2018b). Local governments are expected to demonstrate their ability to maintain flood defenses and to integrate consideration of flood risk within urban planning and building regulations. However, these situations are still rare in France (Ledoux, 2017).

3.3 | Regulatory flood maps in Quebec: The CZI

In Canada, the provinces have flexibility to regulate as they choose. Federal guidelines to create flood maps exist (Natural Resources Canada, 2018), but Quebec has its own guidelines, and maps must be approved by the Direction de l'expertise hydrique (DEH), a service within the Environment Ministry at the provincial level. In Quebec, the regulatory flood maps (CZI) are generally defined using HHM for both 20- and 100-y floods at a 1:2000 scale, but they can also include information from historical floods and, more recently, from hydrogeomorphological analyses (Biron et al. 2014). The methodological choice to produce the maps depends on the stakes at risk within the floodplain and on the financial support available to produce the maps. Biological information is also used to define the "zone littoral" (riparian zone) (2-y flood), an area that should be preserved to ensure the connectivity of the river with the immediate floodplain. In Quebec, clear guidelines to account for climate change when defining future flood prone areas have yet to be defined (Serra-Llobet et al., 2021).

The CZIs define two regulatory zones according to the different return periods: the high probability zone (between 2 and 20 y), and the low probability zone (between 20 and 100 y) (Figure 4c). They also show the riparian zone (2 y), where developments are prohibited with the exception of water dependent facilities, such as: boat decks, aquaculture, water extractions facility, river crossing, and cleaning measures. In the high probability zone (between 2 and 20 y), developments are forbidden, except for agricultural activities, modernization of existing building (without increasing the building footprint), underground utilities, septic systems, water extractions facilities, recreational open-air facilities (other than golf), and agricultural drainage. Exemptions may be permitted in this zone with appropriate supporting analyses. Finally, in the low probability zone (between 20 and 100 y), developments are allowed but the structures need to be floodproofed according to specific building codes. The Riverbanks, Riparian Zones and Floodplains Protection Policy (PPRLPI) in Quebec acknowledges the presence of flood prone areas behind levees as part of the regulatory flood prone area, which is called the Flood Zone. In order to ask for an exemption to remove the area behind a levee from the regulatory flood maps is necessary to produce a residual risk analysis, which has to be considered in the SAD (the general county planning).

In Quebec, regulatory flood maps in general follow the French approach (Figure 4c), considering profiles that reflect the "without levee" condition, showing the area behind levees as part of the regulatory flood prone area. However, the areas behind levees can be exempted from being included in the flood prone area when an excemption is approved by the Ministère de l'Environnement et de la Lutte contre les Changements Climatiques. One of these, Sainte-Marthe-sur-le-Lac in the suburbs of Montreal, experienced a levee breach in April 2019, sending more than 6000 residents fleeing to higher ground during devastating floods (Olthof & Svacina, 2020; Radio-Canada, 2019). The 2017 and 2019 floods highlighted the vulnerability of several communities living behind levees within the actual regulatory framework in which exemptions can occur in Quebec.

4 | APPLYING USA, FRANCE, AND QUEBEC METHODS TO THE CITY OF JARGEAU

If we apply methods from the USA, France, and Quebec to the same area, the city of Jargeau in France, we can see big differences in the implications of the different approaches in areas behind levees in terms of flood risk management (Figure 5 and Table 1).

In the USA, there are four possible situations: situation 1, with an accredited levee, situation 2, with a nonaccredited levee, situation 3, if the FIRM is old and doesn't incorporate the note on residual risk, situation 4, if there is no map because the community decides not to join the NFIP. If the levee was accredited (situation 1) (Figure 5a) people from Jargeau would be in a Shaded Zone X where the minimum national NFIP land use standards would not apply, but flood insurance would be highly recommended, and evidence of a flood warning system (including emergency operations provisions) would be required by FEMA (FEMA, 2008). Risk communication would be voluntary in this case. If the levee was not certified (situation 2) (Figure 5b) Jargeau would be in SFHA, flood insurance would be required for all structures with a federally backed mortgage, land use planning and building codes requirements would apply to meet FEMA minimum standards and risk communication would be voluntary. However, when flood insurance is mandatory there is usually some level of risk communication associated with that requirement. If Jargeau had an old FIRM that did not have the note on residual risk, the area behind the levee might not be shown on a map as having any associated hazard (Figure 5c). The same would happen if the community decided not to participate in the NFIP (also Figure 5c). In this case, although still recommended, there are no requirements in terms of flood insurance and minimum national NFIP standards for land use, and emergency preparedness measures and risk communication would depend on the community.

In France, the areas behind levees would be included in the regulatory floodplain (Figure 5d). In the red zone, developments would be prohibited and in the blue zone would be allowed with some restrictions (e.g., building codes). Subzones could be created according to water velocities and depths characteristics. Furthermore, a local emergency plan and risk communication would be mandatory, and all citizens of Jargeau would be covered by the public flood insurance. In the precautionary band (areas at potential risk for levee overtopping or levee breach), no developments would be allowed.

Finally, if Jargeau was in Quebec (Figure 5e), developments would not be allowed in the high probability

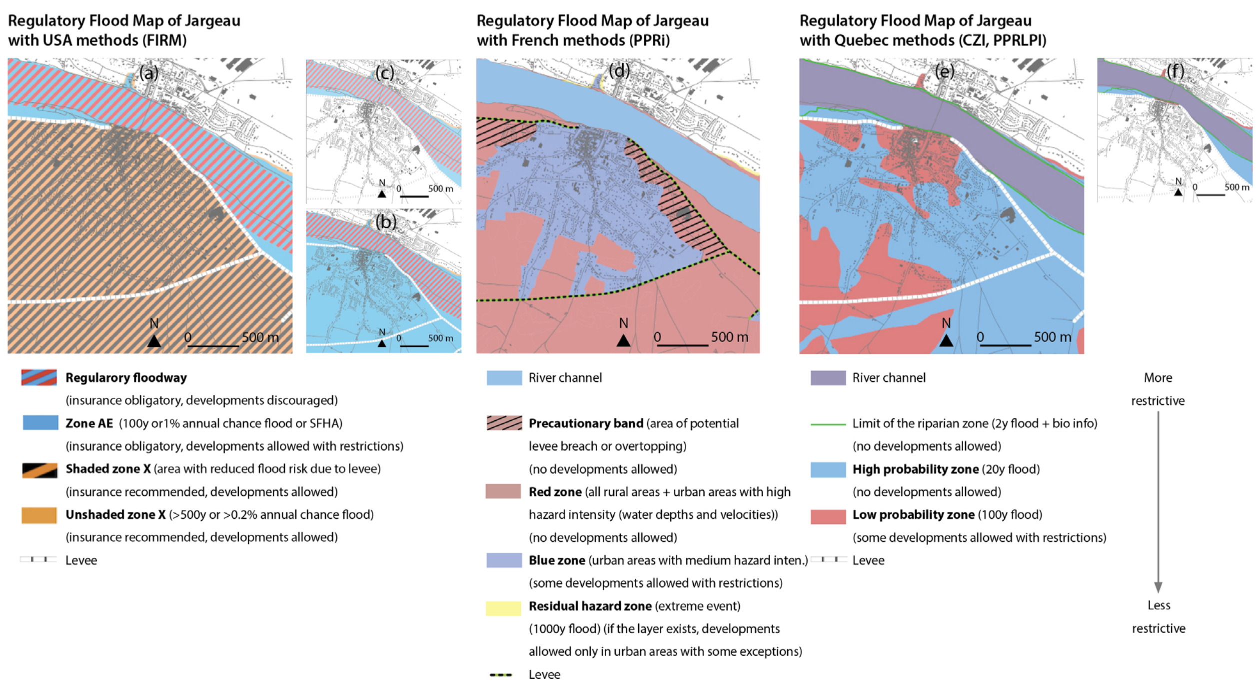

FIGURE 5 Regulatory Flood Map of Jargeau using USA methods (a–c), French methods (d), and Quebec methods (e, f). Four different situations exist for USA methods: (a) if the city is behind an accredited levee, (b) if the city is behind a nonaccredited levee, (c) if the map is old and does not depict the hazard area behind the levee, or if there is no map because the community decides not to join the NFIP (also c). In France, the area behind the levees is part of the regulatory flood prone area (d). Quebec follows the French example (e). However, in some occasions an exemption can be granted (f)

TABLE 1 Implications of the regulatory flood map in different aspects of flood risk management regarding to areas behind levees

	Flood risk management tools linked to regulatory flood maps regarding areas behind levees					
	USA				**France**	**Quebec**
	Flood insurance rate maps (FIRM)					
	Situation 1 (certified/ accredited levee Figure 5a)	**Situation 2 (noncertified/ nonaccredited levee Figure 5b)**	**Situation 3 (FIRM without note on residual risk Figure 5c)**	**Situation 4 (no FIRM Figure 5c)**	**Flood risk prevention maps (*Plans de Prévention de Risque d'Inondations*) (PPRi) (Figure 5d)**	**Flood zone maps (*Cartes de Zones Inondables*) (CZI, PPRLPI) (Figure 5e)**
Flood insurance	Flood insurance linked to the FIRM. Recommended by FEMA in the Shaded Zone X	Flood insurance linked to the FIRM. Mandatory for houses within the SFHA with federally backed mortgage	Recommended by FEMA in areas behind levees without a note of residual risk	Recommended by FEMA in areas behind levees without a FIRM	Universal flood insurance covers all French citizens (flood insurance is not linked to the PPRi)	Public financial programs. No national flood insurance exists in Canada
Land use restrictions	Minimum national NFIP standards not required by FEMA[a]	Minimum national NFIP standards required by FEMA[a]	Minimum national NFIP standards not required by FEMA[a]	Minimum national NFIP standards not required by FEMA[a]	Mandatory	Mandatory
Building codes requirements	Minimum national NFIP standards not required by FEMA[a]	Minimum national NFIP standards required by FEMA[a]	Minimum national NFIP standards not required by FEMA[a]	Minimum national NFIP standards not required by FEMA[a]	Mandatory	Mandatory
Emergency preparedness tools	Flood warning system (including emergency operations provisions) required by FEMA	Flood warning system (including emergency operations provisions) not required by FEMA[b]	Flood warning system (including emergency operations provisions) not required by FEMA[b]	Flood warning system (including emergency operations provisions) not required by FEMA[b]	Local emergency management plan mandatory	Local emergency management plan mandatory
Risk communication to citizens	Voluntary	Voluntary	Voluntary	Voluntary	Risk communication report for the citizens mandatory	Mandatory

[a]However, states and communities can enact land use standard and building codes above national NFIP standards.

[b]On the FIRMs, FEMA shows the existence of levees and indicates whether they provide protection or not. If the levee is certified (by a professional engineer, the US Army Corps of Engineers, or other authority) and accredited by FEMA, it is required to have a flood warning system. However, FEMA does not have authority over levees in the USA, and cannot require maintenance or other activities, which may be under the purview of other governmental authorities at the federal, state, or local level. If a levee is not accredited by FEMA, FEMA cannot require a flood warning system, but it does not mean it does not exist.

zone (20 y), and in the low probability zone (between 20 and 100 y) developments would be allowed but the structures would need to be floodproofed according to specific building codes. If Jargeau received an excemption from the government, the area behind the levee would be removed from the flood prone area and developments would be allowed. However, there would be no clear guidance as to who is responsible for maintaining the infrastructure. According to the *Plan d'action en matière de sécurite civile relative aux inondations* (Gouvernement du Québec, 2018) local emergency plans and risk communication is mandatory and has to be defined by the municipalities. In case of a flood, a new compensation system in place since 2019 would pay up to a cumulative CA$100,000 for all future flood damages or offer to pay to buy or move the house.

5 | CONCLUSIONS: KEY DIFFERENCES AMONG THE THREE APPROACHES

In recent decades, the USA, France, and Quebec have all experienced severe floods that have both challenged and strengthened their approaches to managing floods. All three share a similar general approach to deal with flood risk: the use of regulatory maps to reduce exposure and vulnerability to flood hazard. However, because of their geographic, demographic, governance, and cultural differences, the implementation of this concept ends up being very different among the three countries. In their written flood-related policies, there is a clear focus on the use of nonstructural measures linked to mitigation such as land use planning, building codes, flood insurance, emergency measures, or risk communication.

In the USA, most attention has been paid to managing the "design flood" (the 100-y flood). However, areas behind levees are still subject to the *residual risk* of levee breach or overtopping (low probability high consequences). In the USA, FEMA is aware of the challenges of managing residual risk behind levees, challenges related in part to the mapping system. While trying to evolve its approach, FEMA can only display information about residual risk. In the end, it comes down to how local communities choose to manage residual risk. Furthermore, in the USA the area behind levees is shown as part of the regulatory flood prone area only if the levee is not accredited. Behind FEMA accredited levees this area appears as "Shaded Zone X", where national minimum NFIP land use standards are not mandatory, which, in many cases has created incentives to increase developments in these areas. Recognizing the critical importance of managing these areas, FEMA and the USACE now recommend increased risk communication, emergency preparedness measures, and flood insurance in these areas. However, is up to the local governments to recognize residual risk behind protection structures such as levees and to take steps to control development there.

In contrast, France has a more top-down approach, and designates the area behind levees as part of the regulatory flood prone area, with mandatory land-use restrictions, building codes, emergency measures and risk communication. In France, flood insurance is not linked to the regulatory maps. All French citizens are covered for catastrophic floods with a universal, publicly funded flood insurance.

In Quebec, regulatory flood maps generally follow the French approach and show the area behind levees as part of the regulatory flood prone area, with mandatory land-use restrictions and building codes. However, a few areas have been exempted from depicting residual risk behind levees. One of these, Sainte-Marthe-sur-le-Lac (Montreal) flooded from a levee breach in April 2019, bringing the policy again into public scrutiny. This event has reopened the debate in Quebec about whether and how to acknowledge residual flood risk behind levees. Similarly, the July 2021, a levee breach along the Meuse in Limburg, Netherlands, raised awareness of residual flood risk across Europe (Plevier & van den Berg, 2021). One month later, several small towns in the southern half of Jefferson Parish (next to New Orleans), were inundated when levees surrounding the towns overtopped during Hurricane Ida, "sending several hundred people who were there riding out the storm into attics and onto roofs" (Jiménez, Taylor, & Robertson, 2021).

The same event that caused the levee breach in the Netherlands took 184 lives in Germany and caused over 30 billion Euro in damages. This event was estimated to have been intensified by a factor of 1.2 to 9 due to climate change (Kreienkamp et al., 2021). The increasing number of such extreme events argues for a shift in our management approaches of residual flood risk, which now rely on maps showing statistical values such as 100-y flooding frequencies that may no longer hold true. However, today there is no consensus in a substitute methodology (Milly et al., 2015).

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DATA AVAILABILITY STATEMENT

The article is based on review of prior published research (openly available) and GIS data layers available from the Direction Départementale des Territoires (DDT) du Loiret, and the flood maps produced for the European Floods Directive on the Orléans zone (https://www.loiret.gouv.fr).

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