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International approaches to flood risk management: the role of insurance, maps and regulations. Comparing the United States, the European Union and Canada

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ABSTRACT

Flood losses are increasing worldwide because of expanding urbanization in flood-prone lands and flood peaks super-charged by climate change. Across the globe, countries struggle to manage flood risk, drawing upon insurance, structural measures, and land-use regulations. Canada is now creating its first federal flood insurance program while reinventing its flood mapping guidelines after two decades without a federally-supported flood mapping program. Recent changes in the current U.S. administration have put on the table two options for the future of flood risk management in the country: "shutting down" the Federal Emergency Management Agency or a massive reform of the National Flood Insurance Program. While these unprecedented situations have created big uncertainty on the future of flood policy in the United States and Canada, it can also create an opportunity to reimagine flood risk management in the 21st century. What can we learn from international experiences to inform strategies in North America? In this paper we summarize the results of a recent workshop hosted by the University of California Berkeley, where a group of researchers, practitioners and policy-makers from the United States, Canada, and the European Union reviewed the state of the art in flood risk management with emphasis on the interface between insurance, mapping, and land use planning regulations.

Our results show that there is no perfect insurance scheme. Some European countries such as Austria and Spain employ universal multi-peril insurance models. These systems have proven to be more sustainable financially. In contrast, the United States' National Flood Insurance Program, which is characterized by an adverse selection model, has experienced persistent financial deficits since Hurricane Katrina in 2005. The "moral hazard" – the fact that flood insurance can encourage exposure in high hazard zones - is a big challenge in all the countries analyzed. There are no agreed methods on how to assess risk reduction indication. Exposure in high hazard zones is increasing in all these countries. However, land use regulations in these zones are more restringing in Austria, Spain and some regions of Canada (e.g., Quebec) than in the United States. Currently, regulatory flood mapping – "official flood maps"- is more advanced and holistic in Europe, which aims at integrating flood risk management and nature protection (e.g., areas for groundwater recharge, habitat connectivity, etc.), although there are no harmonized European or other international standards for flood mapping.

KEYWORDS: Flood risk management, insurance, mapping, regulations, international approaches.

1 INTRODUCTION

Insurance relies on the law of large numbers — pooling many independent (non-correlated) risks to make losses predictable on average. If risks are "non-correlated", losses occur randomly and independently, what allows the insurer predict total losses more accurately to set fair premiums. Insurance also relies on the principle of "randomness", which refers to the idea that losses should occur by accident or chance, not by intention or certainty (Borch 1967). For example, a fire caused by accident is insurable while arson by the owner is not. Insurance also relies on the principle of "ease to estimate", what means that the amount of potential loss must be measurable or capable of being estimated accurately (Berliner, 1982).

However, if risks are highly correlated, what happens with extreme events, many losses might happen at the same time (e.g., flood disasters) (Jarzabkowski et al., 2023). This increases systemic or catastrophic risk. Catastrophe risk violates these principles for insuring risks: non-correlation, randomness, ease to estimate, etc. Therefore, catastrophe risk has to be insured with specific mechanisms such as "coinsurance", which is the percentage of costs that the policyholder and the insurer share after any deductible has been met, "reinsurance", a financial arrangement where an insurance company (the "ceding company") transfers part of its risk to another insurance company (the "reinsurer") in exchange for a share of the premiums, "Public–Private Partnership" (PPP), which is a structural partnership between public and private sectors to manage disaster risk, or "Insurance-Linked Securities" (ILS), a financial mechanism connecting insurance and capital markets to expand risk-bearing capacity, etc.

Different countries arrange solutions to address catastrophic risk based on their socio-economic and also their cultural contexts. However, the main problem is to conciliate three key issues: *availability*, *affordability* and *risk reduction indication*. Solutions have generally to choose between two of them, as meeting the three at the same time is really complicated. For example, providing subsidized insurance can encourage exposure in high hazard zones because there is a reduced incentive to prevent or minimize flood risk because someone else (like the government or an insurer) will bear the cost of the loss. In economy, this is known as "the moral hazard" (Pauly 1968).

Not meeting these three points – *availability*, *affordability* and *risk reduction indication*- usually conducts to a wider "insurance protection gap", which is the difference between economic losses from disasters and the portion of those losses that are insured. This gap is a matter of particular global concern with current urbanization trends in high hazard zones and climate change exacerbated hazards and therefore, loss. To fill this gap some countries have created what Jarzabkowski et al. call "Protection Gap Entities" (PGE) to cope with uninsurable risk. PGE are public insurance mechanisms that address the gap between the total risk of a disaster and the insurance covered.

In this paper we compare three protection gap entities: the National Flood Insurance Program in the US, the Consorcio de Compensación de Seguros in Spain and the Catastrophe Funds in Austria. We also analyse regulatory flood mapping systems used to inform land use planning decisions in these three countries to understand how each country balance the moral hazard. Our goal is to find insights from international approaches that can inform ongoing policy changes in Canada and the United Stated.

1.1 Methods and study areas

The comparative analysis presented in this paper draws primarily on the outcomes of the workshop *"Managing Flood Risk: The Role of Insurance, Maps, and Regulations—International Approaches,"* organized by the University of California, Berkeley's Center for Catastrophic Risk Management. The workshop, held on the UC Berkeley campus, convened scientists, policy-makers, industry representatives, and officials from state and federal agencies to identify potential directions for flood insurance, mapping, and regulatory frameworks across North America, with particular attention to Canada, which is currently in the process of developing a national flood insurance system.

2 THE ROLE OF INSURANCE, MAPS AND LAND-USE REGULATIONS IN REDUCING FLOOD RISK: COMPARING INTERNATIONAL APPROACHES

2.1 Flood risk management in Spain: the Consorcio de Compensación de Seguros and the EU Floods Directive's Flood Maps

Spain has a bold and comprehensive approach to insuring certain catastrophic perils. The Extraordinary Risk Insurance Scheme has been in place since 1954, and by law, it is compulsory to extend the coverage of most property damage policies (including business interruption) and all personal injury policies sold in the Spanish market to include a list of extraordinary perils. These perils encompass all types of floods (riverine, pluvial, and coastal), as well as windstorms, earthquakes, volcanic eruptions, and other events, including human-made hazards such as terrorism (Sanabria-García and Torres-Sempere, 2025).

To fund this coverage, a surcharge is applied to policies sold by every insurer operating in the Spanish market. The surcharge depends only on the type of line and property insured (taxes vary for dwellings, shops, factories, motor vehicles, or infrastructure) and the sum insured. For instance, for residential properties, the surcharge is 0.07‰ of the insured capital. These surcharges are transferred to a public insurer, the Consorcio de Compensación de Seguros (CCS), which establishes equalization reserve with these funds to indemnify losses caused by extraordinary perils. CCS manages the entire process of claim filing, loss assessment, and compensation as a direct insurer under the same policies issued by private insurers.

This system exemplifies a public-private partnership: nearly all policies in Spain are dual, with one component covered by the private market—responsible for selling policies, selecting risks, and setting premiums freely—and the other by CCS, which charges a flat rate and covers extraordinary perils. In practice, this means the insurance protection gap against events such as flooding is virtually zero in Spain, as all insured properties are covered for flood risks. At a national level, approximately 80% of residences are insured. While insurance itself is not mandatory, extending coverage for extraordinary perils to insured properties is compulsory. This universal approach applies to both privately and publicly owned assets and prevents adverse selection, reduces premiums, and ensures the long-term sustainability of the insurance scheme.

CCS possesses a wealth of data. In the case of flooding, CCS holds all insured flood loss data in the country with high granularity and long-term series. These data are shared with different levels of government and academia to inform risk prevention measures and serve as a baseline for risk reduction and climate change adaptation policies.

For risk reduction and adaptation, both susceptibility reduction and exposure control are essential, with land use planning serving as the key mechanism to implement these measures. In Spain, this is regulated through the national transposition of the EU Floods Directive (2007/60/CE), via Royal Decree 903/2010 on the Assessment and Management of Flood Risks. This decree modifies the Water Act and the Public Water Domain Regulation, defining different areas associated with river courses and their uses. The main areas include the "Floodable Zone" (zona inundable), defined by the 500-year return-period flood, and the "Frequent Discharge Zones" (zona de flujo preferente), affected by the 100-year return-period flood. Within the frequent discharge zones, a more severely affected area—the "Intense Drainage Channel" (vía de intenso desagüe)—is delineated. Most uses, such as schools, hospitals, nursery homes, malls, and potentially polluting industries, are prohibited within the frequent discharge zones. Residential and certain other uses are permitted only with safety measures adapted to cope with 500-year return-period floods. Uses in the rest of the Floodable Zone (between the 100-year and 500-year floods) are allowed provided the design is adapted to flood risk.

Insurance loss data is crucial for calibrating flood models used to create these flood maps, which must be updated every six years as mandated by the EU Floods Directive.

2.2 Flood risk management in the United States: The National Flood Insurance Program

The National Flood Insurance Program (NFIP) was created by the National Flood Insurance Act of 1968, enacted by the U.S. Congress, with the goal of reducing the economic impact of flooding in the United States. It does so by providing affordable (frequently subsidized) insurance, encouraging communities to adopt floodplain management regulations, and reducing the need for post-disaster federal aid. Now administered by the Federal Emergency Management Agency (FEMA), the NFIP operates through a partnership among the federal government, local communities, and private insurers (Congressional Research Service 2025). Its structure combines risk-mitigation policy with an insurance mechanism, to make coverage available to property owners who might otherwise be unable to obtain it.

This link—local compliance with development criteria in exchange for access to federal flood insurance—is central to the program's design. Communities that participate are required to adopt and enforce floodplain management ordinances that meet FEMA standards. These local regulations govern development in high-risk areas, ensuring that new construction and substantial improvements are built in accordance with FEMA's development criteria[1] to withstand specific flooding events. Participation in the NFIP is voluntary, but for participating communities, NFIP flood insurance is available to homeowners, renters, and business owners. When properly implemented, it can help reduce future flood damage, thereby lowering insurance payouts and federal disaster spending.

In parallel with the development criteria established under the NFIP, another influential set of standards in the United States is the American Society of Civil Engineers' (ASCE) "Flood Resistant Design and Construction" standards, known as ASCE 24. ASCE 24 standards set minimum requirements for designing and constructing buildings and structures to resist flood damage. Although the NFIP minimums are an improvement over earlier requirements, they are still far below the standards of ASCE 24-24, the 2024 edition of the ASCE 24.

ASCE 24-24 is anticipated to be adopted into the next International Code Council (ICC) model codes (2027 cycle). ICC develops a set of model codes, including the International Residential Code (IRC) – which apply to small residential buildings-, International Building Code (IBC) - which applies to all other buildings including larger commercial buildings or more complex residential (e.g., apartments, condos), and the International Mechanical, Plumbing, and Energy Codes. These are model codes, meaning they don't have legal force until a state, city, or county officially adopts them. Whether IRC might treat ASCE 24-24 differently from the IBC is still unclear. Historically, the IRC does reference ASCE 24 flood provisions, but often in a more limited way than the IBC. In states such as California, state-adopted provisions such as ASCE 24 flood requirements can take precedence over NFIP development criteria since ASCE24 is often more stringent or detailed than NFIP minimums.

The NFIP produces and maintains Flood Insurance Rate Maps (FIRMs), which delineate "Special Flood Hazard Areas" (SFHAs)—zones with at least a 1% annual chance of flooding (100-year return period flood). While properties with federally backed mortgages in SFHAs are required to carry flood insurance, flood insurance is only encouraged for all other properties both in and out of the SHFA. This results in an overall low insurance take-up rate, particularly in areas outside of the SFHA where the perceived risk is lower.

The low overall take-up rate contributes to a phenomenon known as "adverse selection," where individuals with a higher likelihood of experiencing a loss are more likely to purchase insurance. In flood insurance, those in "official" flood-prone areas are more inclined to buy coverage, leading to an unequal distribution of risk among policyholders. This can result in increased claim costs and financial strain on the insurer and the government (through taxpayers), as evidenced by estimates suggesting that between 2015 and 2019, 40% of all NFIP claims came from outside of the SFHA (Federal Emergency Management

[1] Under FEMA's 44 CFR § 59.1, "development" is defined as: "Any man-made change to improved or unimproved real estate, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation or drilling operations, or storage of equipment or materials."

Agency, 2024). The age of the FEMA maps and the lack of pluvial mapping contributes to adverse selection, as the Flood Insurance Rate Maps may not identify areas of known localized flooding.

Insurance premiums under the NFIP are based on several factors, including property location, building characteristics, elevation relative to the base flood elevation, and flood risk as mapped by FEMA and as identified by commercial catastrophe models. For decades, rates were partially subsidized and did not fully reflect actuarial flood risk, leading to financial instability in the NFIP. The Biggert-Waters Flood Insurance Reform Act of 2012 (BW-12) required FEMA to move the National Flood Insurance Program (NFIP) toward actuarially sound, risk-based rates and to reduce or eliminate long-standing subsidies. Thus, BW-12 created the legal and policy foundation that pushed FEMA to modernize its pricing methodology, called "current pricing approach" (informally known as "Risk Rating 2.0"). Under this system, properties with higher flood risk pay higher rates, while many lower-risk properties benefit from reduced premiums. Although rate changes are capped annually to ease the transition, the shift aims to build long-term financial resilience for the program. However, the lack of gradual implementation and insufficient support mechanisms for affected homeowners whose insurance premiums skyrocket made the policy politically and socially contentious, highlighting the tension between risk-based pricing and affordability in flood insurance.

Claims under the NFIP are paid even when catastrophic events cause widespread damage, because the program has federal backing. However, repeated major disasters have often forced the NFIP to borrow from the U.S. Treasury (over $23 billion as of December 2025), highlighting the tension between individual affordability and the financial sustainability of the insurance scheme. Reforms over the years have aimed to reduce repetitive-loss properties, improve flood mapping technology, and strengthen mitigation grants that help elevate structures, buy out high-risk homes, or enhance community resilience. However, increased exposure in high-hazard zones remains the biggest driver of rising flood risk in the United States (Wing et al. 2022).

Recent changes in the current U.S. administration have raised discussions about potentially abolishing FEMA or drastically reducing its functions (Pinter et al. 2025). As of June 1, 2025, 2,446 FEMA employees have either been dismissed or taken buyout offers since the new administration took office in January, 2025 (U.S. Government Accountability Office, 2025). As a result, the future of the NFIP remains uncertain. Some states are preparing to strengthen their own roles in flood risk management in anticipation of further downsizing of FEMA or major reforms to the NFIP (Pinter et al. 2025).

2.3 Flood risk management in Austria: the catastrophe funds and the flood maps included in the Hazard Zone Plans

Every private property owner in Austria is required to have household insurance that includes coverage for natural hazards. However, this natural hazard coverage is capped, generally in the range of €10,000–15,000. There is also an option for voluntary insurance against additional risks, such as flooding. The premiums for these extra policies are calculated with support from the HORA system (www.hora.gv.at), a public-private partnership between the Austrian Association of Insurance Companies and the Austrian Federal Ministry for Agriculture, Forestry, Climate and Environmental Protection, Regions, and Water Management.

In addition to insurance, damage compensation in Austria follows the "solidarity principle." In the event of a catastrophe—which, depending on the spatial extent of the flood, must be declared by the municipality, district, federal province, or federal government—direct tangible damages are compensated through national catastrophe funds. The compensation rate typically amounts to up to 40% of eligible direct tangible damages, while luxury goods are excluded. For extreme events, such as the 2002 flood along the Danube and its tributaries, compensation rates may be higher.

For the agricultural sector, natural hazard insurance is available, with premiums partially subsidized. In cases of flooding, hail, or similar events, 100% of losses are compensated for insured properties. For industry and trade, individual or facility-specific insurance solutions are available and often mandatory.

To raise awareness and support the insurance sector, Austria provides various tailor-made maps for different target groups and purposes. Austria has approximately 100,000 km of river courses, of which 25,000 km along major urban areas and infrastructures are mapped with Hazard Zone Plans based on 2D hydrodynamic modelling. These maps are also used to implement the EU Floods Directive, which requires preparing flood hazard and risk maps.

These detailed maps are complemented by the HORA system, which provides simplified mapping to cover most areas in Austria and raise public awareness of flood risks. Established in 2005, the HORA system is an open-access tool that allows users to locate hazards by address and includes downloadable PDF reports. A login area for insurers supports the determination of policy premiums.

Two types of maps are available: flood hazard and risk maps according to the EU Floods Directive, and HORA system maps at approximately 1:6,000 scale. For local decision-making, property-level information at 1:2,000 scale is provided by Hazard Zone Plans (Neuhold, 2026). These plans delineate two zones: the "Yellow Zone," based on a 100-year flood scenario, and the "Red Zone," based on flood intensity (a function of water depth and flow velocity), representing areas of higher conveyance within the 100-year flood. These zones serve as advisory assessments for local spatial planning and building regulations. Hazard Zone Plans also define "functional areas" based on a 300-year flood scenario, intended for water retention, conveyance, and the prevention of increased flood risk. Public participation is mandatory in creating Hazard Zone Plans. Thus, these maps also help raise flood risk awareness among citizens.

Zoning restrictions and flood-related building codes for hazard zones and functional areas are defined in national spatial planning laws and local building regulations. New developments are prohibited in "Red Zones," though some exemptions exist for expansions of existing buildings or urban areas under high land-use pressure. In "Yellow Zones," development is discouraged and restricted according to the legal framework; new structures are permitted if elevated at least 50 cm above the 100-year flood level. However, raising terrain by filling is prohibited to prevent adverse effects upstream or downstream. "Functional areas" must remain free of new developments to ensure safe water retention and conveyance during 300-year flood events. Functional areas and related regulations are currently under discussion concerning urban development, pluvial flooding, and zoning. Finally, the "residual flood risk" beyond the 100-year flood prone area, including residual risk behind levees (dikes), is also communicated to the public in these maps by highlighting 300-year flood scenarios.

In summary, Austria uses four types of flood maps to inform flood risk reduction measures at different scales: (1) Hazard Zone Plans (1:2,000): Highest resolution maps including expert judgment, providing recommendations for spatial planning and building regulations at the local level, (2) Flood Conveyance Maps (1:5,000): High-resolution maps based on 2D models, used as a basis for Hazard Zone Plans, (3) Flood Hazard and Risk Maps (EU Floods Directive): Incorporating Hazard Zone Plans and flood conveyance maps, (4) HORA System Maps: Simplified 2D models complementing flood risk information beyond areas covered by Flood Directive maps.

3 CONCLUSION

Our results show that while the United States was ahead of Europe as a whole in floodplain mapping through the 20th century, flood mapping has evolved enormously in Europe since the implementation of the Floods Directive in 2007. However, there are no harmonized European or other international standards for flood mapping. In the US, mapping is only mandatory for communities that want to participate in the NFIP and is generally restricted to the 100-year flood hazard zone, (the Special Flood Hazard Area, SFHA). The SFHA is the area where floodplain management regulations must be enforced and where the mandatory flood insurance purchase requirement applies. Recent federal flood initiatives in Canada include Natural Resources Canada's guidelines and mapping programs, and several major programs at Public Safety Canada focusing on flood risk quantification, Disaster Assistance, Flood Insurance costing, and flood risk communication. However, at the provincial and territorial levels of government, approaches to flood hazard identification and mapping are not consistent.

The EU has a more integrated, holistic and forward-looking flood risk management approach that strengthens coordination and collaboration between different sectors beyond water management, especially civil protection, spatial planning and nature conservation.

Public consultation has become the norm in all EU Member States leading to improved awareness of flood risk by citizens and stakeholders. However, there are still major challenges to be tackled such as the consideration of climate change on a long-term perspective, pluvial flooding as a local process and vulnerability assessment. Flood hazard and risk maps are required in all Member States under the Floods Directive but, unlike the US, flood maps are not systematically linked to the flood insurance system, which can be public, private or a public-private partnership, depending on each country. The increasing uninsurability of flood disasters is a global concern.

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