This discussion paper on Flood Risk (the paper) was prepared by the Resource and Environment Working Group (REWG) of the International Actuarial Association (IAA).

The IAA is the worldwide association of professional actuarial associations, with several working groups and special interest sections for individual actuaries. The IAA exists to encourage the development of a global profession, acknowledged as technically competent and professionally reliable, which will ensure that the public interest is served.

The role of the REWG is to identify issues related to global resources and the environment that are of interest to actuaries and to which the actuarial profession, at an international, national, or individual level, can make useful contributions in the public interest.

The paper was prepared by a subgroup of the REWG consisting of Sam Gutterman, its leader, and Jacqueline Friedland, Stuart Mathewson, Rade Musulin, and Mike Smith. After careful review and constructive comment, the REWG and the Scientific Committee of the IAA approved the paper for publication.

The views expressed in this paper do not represent those of the IAA, nor those of the entire REWG. They do not constitute an actuarial standard of practice.
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Executive Summary

Although water is an essential ingredient of life, floods can threaten life and property. The objective of this paper is to inform its readers of the nature of flood risk from an actuarial perspective, including the issues and challenges associated with managing flood risk, which has financial, political, social, and indeed emotional components.

After a formal definition of flood and detailed description of the major types of floods and their consequences, this paper describes the components of flood risk, flood hazard, and flood vulnerability, and identifies the drivers of flood risk.

Losses associated with floods can be extensive. Often, those who are most vulnerable are also those who can least afford the losses. For those who are already poor, floods deepen their poverty, add misery, and strain limited available public or charitable resources.

A risk management process can be applied to flood risk. This process involves multiple steps, including feedback loops, as underlying conditions and expectations are dynamic in nature. Both qualitative and quantitative considerations are needed to address flood risk, including concentration risk, related perils, and stakeholder behaviour. Private and public stakeholders need to be involved in this process, especially as various means of mitigating risks and financing damages are likely to be required. Being prepared for and reacting to disasters in a timely manner can significantly reduce consequential damages.

Insurance, whether offered by the private sector, the government, or a public–private partnership, can address the financial effects of damages following a flood. Key considerations in the design of an insurance program are discussed, including the protection gap, pre- and post-event financing, and the use of subsidies in insurance rating programs.

There are several constraints that affect the development and maintenance of effective flood risk management. This is partly the result of the many stakeholders involved, each with differing risk perceptions influenced by their own interests. These perceptions can represent a difficult concept for individuals, businesses, and even insurers to grapple with and communicate. Recent enhancements in availability of data and advances in modelling may help overcome some of these obstacles.

Flood risk is a moving target, significantly influenced by human activities and global climate trends. Its dynamic nature poses unique challenges for public policy planners and leads to many difficult social and political questions. Changes may be needed in many areas, especially in how policymakers think about building codes and land-use development.

Due to their experience and skills, actuaries can develop proper analysis and provide practical and sound advice to facilitate appropriate decisions with respect to flood risk management, including the design and pricing of flood insurance products.
Flood Risk

The acquisition of high-quality flood-related data is usually very difficult, as granular data related to many different risk factors are required to accurately estimate the expected losses and distribution of losses for a particular property or area. In addition, conditions, data, and information are constantly changing, leading to uncertainty in the quantification of flood risk. Developing flood premiums is especially difficult given the catastrophic nature of flood losses, where large and infrequent losses, which cannot be projected with precision, tend to cause most of the loss. Currently, catastrophe models are a critical tool in the ratemaking process and will be even more so as they continue to be enhanced.

Governments need to play a central role in managing flood risk. This role involves managing critical infrastructure and enacting building codes and land-use policies to reduce loss exposure. Governments also create the flood risk management process and flood insurance framework within which private sector and government insurance programs operate. Many countries have built unique programs to finance and manage flood losses suited to their local or regional conditions, examples of which are described in the paper. Nevertheless, they share certain similar features. Understanding the differences in private sector and government insurance programs, as well as the unique drivers for such programs, is critical to actuaries’ ability to provide support to these programs.
1. Introduction

Floods have been a major cause of injury, death, and destruction of property throughout history, while they have also provided a source of rich soil deposits in river basins. Societies have made large investments in flood control and in recent times devised complex frameworks to finance post-event reconstruction. Insurance mechanisms, both private and governmental, have become increasingly important tools to promote both mitigation and recovery.

While information regarding flood risk may have been under-represented in actuarial education, several trends are combining to make it an important topic for actuaries:

- **Technology.** Recent technological advances have significantly improved the ability to measure and model flood exposure. These include tools such as light detection and ranging (LIDAR) to precisely measure elevation, Google Earth to visualize structures at the site level, and geographic information systems to organize location-based information. Combined with exponential improvements in computational power, this technology has enabled the development of powerful modelling tools that allow flood risk to be quantified more effectively and efficiently. Nevertheless, significant uncertainty remains in the estimation of flood losses.

- **Financing capacity.** Enabled by better modelling, private insurers, reinsurers, and capital markets are making more capacity available to underwrite flood risk.

- **Scope of actuarial work.** Actuaries have included catastrophe and stochastic modelling in their technical toolkit, as well as in their practice of enterprise risk management. Flood risk offers significant opportunities to apply actuarial skills in new ways and in new applications, for both the private and public sectors.

Although floods represent a major peril causing huge losses around the world, there is limited relevant information in the actuarial literature. This is partly the result of coverage of flood damage by a government program in some countries, so that actuaries involved in the private sector in those countries have not been involved. As flood insurance is becoming more widespread, it is hoped that the information contained in this paper will prove useful to actuaries in many countries.

Flooding have many unique characteristics. For example, flood is one of the few property insurance perils where factors outside the geographic area and control of the insurance exposure, such as the effect of upstream water management and flood control infrastructure, play an important role.

The objective of this paper is to inform its readers of the nature of flood risk from an actuarial perspective, including the issues and challenges associated with managing that risk. Relevant topics include: identification; quantification; prevention, mitigation, and adaptation; relevant land and water management (e.g., land-use policies and building standards); community resilience; and financing of flood risk through private sector and public approaches.

The primary intended audiences for this paper are actuarial associations and actuaries around the world. Other audiences include stakeholders of the flood risk management process, including the insurance industry and its companies, investors, public policymakers, and regulators.
Flood Risk

It is hoped that this paper will encourage further discussion of the issues involved with the management of flood risk and help lead to the development and management of effective approaches by national actuarial associations, individual actuaries and actuarial consultancies, providers of insurance and reinsurance, regulators, financial markets, and policymakers. The paper also illustrates the relevant roles and responsibilities of actuaries in this area.

It is organized in eight sections:

Section 1, “Introduction”, introduces the topic and provides a roadmap to the paper.

Section 2, “What is Flood Risk?”, provides background on flood risk, including definitions of key terms, a description of key types of flooding, and characteristics of floods. The section then summarizes global flood experience, describes drivers of flood risk, and explains how flood damages are classified. It introduces the concept of dynamic flood risk, referring to how flood risk changes over time.

Section 3, “The Flood Risk Management Process”, describes how the risk management process (comparable to an actuarial control cycle) can be applied to flood risk.

Section 4, “The Role of Insurance”, focuses on the financial resources available to address damages following a flood. Insurance, whether offered by the private sector, the government, or a public–private partnership, is a critical element of the flood risk management process. Key considerations in the design of an insurance program are discussed, including the protection gap, pre- and post-event funding, and the use of subsidies.

Section 5, “Constraints”, outlines several constraints that affect the development and maintenance of flood risk management viewed through the lens of risk perception. Flood risk is viewed from the perspective of various stakeholders. The changing nature of flood risk and its dependence on complex flood control infrastructure is discussed. The section closes with a discussion of how actuarial concepts can be applied to building codes and land-use planning.

Section 6, “Actuarial/Cost-Based Pricing”, describes the key components of pricing flood products, including data collection, catastrophes, modelling, and risk loading.

Section 7, “The Role of Government”, discusses the key role the public sector can constructively play in flood risk management. The section begins with a review of non-insurance activities, including data collection, infrastructure construction, and promulgation of building codes and land-use policies. A review of government insurance programs, whether they operate on a local, national, or supranational level, follows, with a discussion of how they differ from those in the private sector in terms of their principles and practices. The section closes with a description of insurance systems from various countries.

Section 8, “The Role of Actuaries”, offers a perspective on the many ways actuaries can contribute to improving societal awareness and resilience in the face of flood risk.
Flood Risk

2. What is Flood Risk?

From the beginning of mankind until today, floods have been one of society’s most threatening natural perils. Floods affect more people than any other type of weather-related disaster and are a leading cause of natural disaster fatalities worldwide.2

While statistics differ greatly by source about the number and severity of floods versus storms, Munich Re reports that globally floods represent roughly one-third of all reported events and economic losses arising from natural catastrophes.3 Floods can have direct humanitarian and financial impacts, as well as indirect consequences to economic growth and societal well-being. In Effective Adaptation to Rising Flood Risk, Brenden Jongman, Disaster Risk Management Specialist at the World Bank, opens with the statement: “Floods are causing increasing havoc in our rapidly urbanizing world, with disproportionately high impacts on the poorest and most vulnerable.”4 It has been estimated5 that the global population in flood-prone areas has more than doubled over the past 30 years. Yet there is limited data available on urban floods outside known floodplains.

2.1 Flood Definitions and Categories

Various definitions of a flood have been used. In the Emergency Event Database (EM-DAT)6 Glossary, the Centre for Research on the Epidemiology of Disasters7 (CRED) defines flood as: “A general term for the overflow of water from a stream channel onto normally dry land in the floodplain (riverine flooding), higher-than-normal levels along the coast and in lakes or reservoirs (coastal flooding) as well as ponding of water at or near the point where the rain fell (flash floods).”8 More generally, a flood is a water event, usually occurring when an area receives water and there is no place for it to go.

A flood can be categorized according to its cause, such as:

- Winter rainfall floods;
- Summer convectional storm floods;
- Snow-melt floods and glacial lake outbursts;
- Sea-surge and tidal floods;
- Earthquakes and tsunamis;
- Rising groundwater floods;
- Urban sewer floods; and
- Dam breaks or reservoir-control floods.9

In addition to its cause, a flood can be characterized by its features, such as water depth, flow velocity, matter fluxes, and temporal and spatial dynamics.10

As referred to in CRED’s definition, floods are frequently classified into three major types: (1) coastal or surge floods, (2) riverine or fluvial floods, and (3) flash, surface, or pluvial floods.11 Sometimes the term “lacustrine” is used to refer to flooding from overflow of lakes; generally, such flooding is considered in the riverine or fluvial category unless the lake is large enough for its shoreline to be considered a coast subject to tidal forces (e.g., the Great Lakes in the United States). In this paper, tsunamis are not addressed in depth, though their potential for devastation of life, health, and property is recognized.
2.1.1 Coastal or surge floods

These floods occur in areas that lie on the coast of a sea, ocean, or other large body of open water. Coastal floods, also known as surge floods, typically result from extreme tidal conditions caused by severe weather and tsunamis, which can result from offshore earthquakes. High winds from tropical cyclones or other storms push water onshore to create a storm surge, which is the leading cause of coastal flooding and represents the greatest threat and damage associated with such storms, which can overwhelm low-lying land. Coastal flooding can be amplified or dampened by tides, both daily and periodic king tides. This flooding are also sensitive to wind and atmospheric pressure.

Much of the disparity in global reporting on the incidence and consequences of weather-related disasters is tied to the categorization of damage due to coastal floods. Some data sources, such as Swiss Re and Munich Re, tend to include damages (financial and fatalities) in flood, while CRED classifies storm surge as storm (i.e., wind events). CRED’s EM-DAT classifies disasters according to the type of hazard that “provokes” them. Thus, in CRED’s reporting, storms include hurricanes, cyclones, and storm surge (defined in the EM-DAT Glossary as “an abnormal rise in sea level generated by a tropical cyclone or other intense storms”).

2.1.2 Riverine or fluvial floods

Riverine floods occur when extreme rainfall over prolonged periods of time results in a river exceeding its capacity. These floods, also known as fluvial floods, can also be due to heavy snow melt, ice jams, or earthquake-induced landslides that block rivers. Damage from a riverine flood can be widespread as overflow can affect rivers downstream, often causing dams and dykes to break and inundate surrounding areas.

Two main types of riverine floods are:

- **Overbank flood**, which occurs when water rises and overflows the edges of a river. This is the most common type of riverine flood and can occur in any size channel, including small streams and large rivers.
- **Fluvial flood**, which is characterized by the high intensity and velocity of water that occurs in an existing river channel. These floods can be extremely dangerous and destructive because of the force of water, the fact that they can occur with little to no notice, and the speed and power at which debris can be swept up in the flow.

Although fluvial floods often affect larger populations and land areas than other types of floods, there are normally fewer fatalities in fluvial floods than in pluvial floods. The lower mortality rates in overbank riverine floods are mostly attributed to slower onset, which usually allows a longer time for warning and evacuation.

2.1.3 Flash, surface, or pluvial floods

Flash floods occur when heavy rainfall creates a flood event independent of the overflow of a body of water. These floods often occur in combination with coastal and fluvial flooding. Although in some cases resulting water only reaches a few centimetres deep, flash floods can cause significant property damage.
Two common types of flash floods occur when:

- Intense rain saturates an urban drainage system. Such rain is sometimes referred to as a microburst or rain bomb, whereby the system becomes overwhelmed and water overflows into streets and nearby structures.
- Runoff or flowing water from rain falls on hillsides that are unable to absorb the water. Flash floods commonly occur on hillsides affected by forest fires and in suburban communities on hillsides.

*Pluvial floods*, also referred to as *surface floods*, occur when an extremely heavy downpour of rain cannot be absorbed by land or drainage systems. A common misconception is that one must be located near a body of water to be at risk of flood damage. In fact, this type of flood can happen in urban areas that are at elevations far above coastal and river floodplains.

In the United Kingdom (U.K.), for example, roughly 2 million people are at risk of flash floods, which represent about one-third of all U.K. floods.

### 2.2 Flood Risk

Some basic flood risk elements and concepts that will be used throughout this paper are discussed in this section.

In *Flood Risk Management – A Basic Framework*, Jochen Schanze describes *flood risk* as arising from a combination of flood hazard and flood vulnerability. The term “hazard” as typically used in an insurance context is a condition that increases the possibility of loss. In contrast, Schanze uses *flood hazard* to represent the probability of occurrence of a potentially damaging flood event. "Potentially damaging" indicates that, while property or lives are exposed to floods, they may not be harmed. He illustrates different types of flood hazard by means of a building in a floodplain that can be threatened by a 50-year flood with a water level of 1 metre and by a 100-year flood with a water level of 1.5 metres. Such events would likely be associated with different recovery needs regarding debris, sediment, and other potentially toxic substances, with varying effects on people and the environment.

The extent of damage arising from flood hazards is dependent on *vulnerability*, which refers to the inherent characteristics of elements at risk that determine their potential to be harmed. Schanze states that vulnerability is a combination of susceptibility and societal value and is expressed by direct and indirect effects, which can be tangible or intangible. Susceptibility is indicative of the process of damage generation, and dependent on the type of flood event as well as the nature of the elements at risk.

Flood risk can be correlated with both climatic and other risks. For example, wind intensity and other characteristics can affect total flood losses. Offshore earthquake risks can result in tsunami risks. These correlations and cause-and-effect relations need to be recognized in the cost-benefit analysis of the risk management process.

Additional characteristics of the three different types of floods are presented in Table 1.
### Table 1 – Characteristics of Major Types of Floods

<table>
<thead>
<tr>
<th>Type</th>
<th>Cause</th>
<th>Threatened Areas</th>
<th>Loss Factors</th>
<th>Damage</th>
<th>Loss Prevention</th>
<th>Effects of Climate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal floods</td>
<td>• High level of water due to wind set-up, high waves • Tsunamis</td>
<td>• Relatively narrow strip of coast</td>
<td>• Salt water • Wave forces</td>
<td>• Low frequency (good protection measures, sea defences) • Very high losses</td>
<td>• Land-use rules • Early warning • Dykes • Evacuation</td>
<td>• Sea level rise • Glacial melt</td>
</tr>
<tr>
<td>Riverine floods</td>
<td>• Prolonged, copious large-scale precipitation (possibly snow melt)</td>
<td>• Recurrently the same areas near rivers</td>
<td>• Prolonged impact of water • Water contamination (e.g., by oil)</td>
<td>• Low frequency • High loss potential</td>
<td>• Land-use rules • Early warning • Structural flood control • Temporary protection of property • Placement of hard-to-move objects somewhere else • Evacuation</td>
<td>• Glacial melt • Increased rainfall</td>
</tr>
<tr>
<td>Flash floods</td>
<td>• Mostly local torrential rain (thunderstorms)</td>
<td>• Practically anywhere, including places far from watercourses</td>
<td>• Mechanical impact of fast-flowing water • Possibly large amounts of sediment</td>
<td>• High frequency (but not at the same place) • Relatively minor losses (in individual events) • Erosion</td>
<td>• Adequate drainage • Effective building construction and maintenance • Quick evacuation</td>
<td>• More intense rainfalls • More intense and stalled cyclones</td>
</tr>
</tbody>
</table>

In summary, flood risk represents the possibility of harm to flood-prone elements with specific vulnerability due to probable flood events with their features. The concepts of flood hazard and flood vulnerability are critical to the catastrophe models that actuaries use to quantify flood risk. Such models are discussed further in Sections 3, 6, and 8 of this paper.
2.3 Global Experience

2.3.1 Difficulty in obtaining global statistics

There is no single source of complete, up-to-date, accurate data on the incidence of and damages associated with floods. As noted previously, there are significant differences in the categorization of some events as either flood or storm; this inconsistency mostly affects coastal floods (i.e., surge floods). In this section of the paper, we primarily rely upon the statistics contained in the report *The Human Cost of Weather-Related Disasters 1995–2015* published in 2016 by CRED and the United Nations International Strategy for Disaster Reduction (CRED/UNISDR). Where other sources are used, they are noted.

On a global level, floods have been consistently ranked as the most frequently occurring natural disaster and as the natural disaster that threatens the largest number of people worldwide. Figures 1 and 2 are from CRED/UNISDR and provide a summary of experience over the past two decades based on the EM-DAT number of occurrences by type of natural disaster and the number of people affected (excluding fatalities) by type of natural disaster, respectively.

*Figure 1 – Percentages of Occurrence of Natural Disasters by Disaster Type (1998–2017)*

Flood Risk

Figure 2 – Number of People Affected by Weather-Related Disasters Excluding Fatalities (1998–2017)

Flood Risk

As noted, it is difficult to obtain data on economic losses associated with floods. In *Global Drivers of Future River Flood Risk*, Hessel C. Winsemium et al. report that between 1980 and 2009, global direct economic losses due to floods exceeded $1 trillion (2013 values).\(^\text{22}\)

### 2.3.2 Global breadth of flood risk as seen through news headlines

This paper uses recent news headlines from around the world to demonstrate the prevalence and severity of flood risk. To provide an indication of the geographical range and high frequency of floods, Table 2 summarizes, by major region, a sample of news headlines from March to August 2018 from [http://floodlist.com/](http://floodlist.com/).

<table>
<thead>
<tr>
<th>Region</th>
<th>Date (2018)</th>
<th>Headline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>21 May</td>
<td>EU Releases €1.5 Million to Help Flood Victims in Kenya in the Wake of a Deadly Dam Burst</td>
</tr>
<tr>
<td></td>
<td>25 May</td>
<td>Uganda – Hundreds Evacuate Floods in Eastern Region</td>
</tr>
<tr>
<td></td>
<td>25 May</td>
<td>Horn of Africa – Major Flooding After Cyclone Sagar Leaves 16 Dead</td>
</tr>
<tr>
<td></td>
<td>20 June</td>
<td>Ghana – Devastating Floods Hit Accra Again</td>
</tr>
<tr>
<td></td>
<td>6 July</td>
<td>Tens of Thousands of Kenyans Go Hungry After Floods – Aid Agencies</td>
</tr>
<tr>
<td></td>
<td>16 July</td>
<td>Côte d’Ivoire – Deadly Floods in Aboisso Department</td>
</tr>
<tr>
<td></td>
<td>17 July</td>
<td>Nigeria – Major Flooding Hits Two States</td>
</tr>
<tr>
<td></td>
<td>23 July</td>
<td>Liberia – Flooding Affects Over 30,000</td>
</tr>
<tr>
<td></td>
<td>8 August</td>
<td>Algeria – Deadly Floods Hit Tamanrasset Province</td>
</tr>
<tr>
<td>Americas</td>
<td>2 July</td>
<td>United States – Deadly Floods in Des Moines, Iowa</td>
</tr>
<tr>
<td></td>
<td>5 July</td>
<td>United States – Floods Prompt 3 Minnesota Counties to Declare Emergency</td>
</tr>
<tr>
<td></td>
<td>11 July</td>
<td>Dominican Republic and Puerto Rico – Evacuations After Storm Beryl Causes Flooding</td>
</tr>
<tr>
<td></td>
<td>19 July</td>
<td>United States – 40 Rescued After Record Rain Causes Flash Floods in Washington DC</td>
</tr>
<tr>
<td></td>
<td>3 August</td>
<td>Grenada – Severe Flooding and Landslides After Torrential Rain</td>
</tr>
<tr>
<td>Date</td>
<td>Region</td>
<td>Event Description</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>15 August</td>
<td>United States</td>
<td>Emergencies Declared After Floods in New York, New Jersey, and Pennsylvania</td>
</tr>
<tr>
<td>16 August</td>
<td>Colombia and Venezuela</td>
<td>Thousands Displaced as Rivers Continue to Rise</td>
</tr>
<tr>
<td>Asia</td>
<td>31 July</td>
<td>Laos – Over 100 Still Missing After Dam Collapse</td>
</tr>
<tr>
<td>Asia</td>
<td>31 July</td>
<td>Myanmar – Floods and Landslides Displace 120,000</td>
</tr>
<tr>
<td>Asia</td>
<td>8 August</td>
<td>Pakistan – Villagers “Living Between Life and Death” as Pakistan’s Glaciers Melt</td>
</tr>
<tr>
<td>Asia</td>
<td>8 August</td>
<td>Laos – Landmine Risk for Thousands Displaced by Floods in Laos</td>
</tr>
<tr>
<td>Asia</td>
<td>9 August</td>
<td>Turkey – Hundreds Rescued After Floods in Ordu Province</td>
</tr>
<tr>
<td>Asia</td>
<td>13 August</td>
<td>Philippines – Thousands Displaced as Deadly Floods Hit Metro Manila</td>
</tr>
<tr>
<td>Asia</td>
<td>14 August</td>
<td>India – 19 Dead After Torrential Rain in Himachal Pradesh</td>
</tr>
<tr>
<td>Asia</td>
<td>15 August</td>
<td>India – Deadly Flash Floods in Jammu and Kashmir</td>
</tr>
<tr>
<td>Asia</td>
<td>15 August</td>
<td>India – More Fatalities as Kerala Floods Continue</td>
</tr>
<tr>
<td>Asia</td>
<td>16 August</td>
<td>India – Deadly Flash Floods in Madhya Pradesh</td>
</tr>
<tr>
<td>Europe</td>
<td>13 June</td>
<td>Europe – Floods in Switzerland, Italy and Germany After 50 mm Rain in 1 Hour</td>
</tr>
<tr>
<td>Europe</td>
<td>29 June</td>
<td>Bulgaria and Romania – Homes Damaged and Roads Closed as Rivers Overflow</td>
</tr>
<tr>
<td>Europe</td>
<td>4 July</td>
<td>Italy – Evacuations After Major Floods in Trentino Province</td>
</tr>
<tr>
<td>Europe</td>
<td>21 July</td>
<td>Slovakia – Hundreds Evacuated After Floods in Tatra Mountains</td>
</tr>
<tr>
<td>Australia, New Zealand, and Oceania</td>
<td>27 March</td>
<td>Australia – More Floods in Queensland After Torrential Rain from Ex Cyclone Nora</td>
</tr>
<tr>
<td>Australia, New Zealand, and Oceania</td>
<td>12 April</td>
<td>Fiji – Thousands Displaced by Tropical Cyclone Keni</td>
</tr>
<tr>
<td>Australia, New Zealand, and Oceania</td>
<td>11 May</td>
<td>Australia – Flash Floods in Hobart After 129 mm of Rain in 24 Hours</td>
</tr>
<tr>
<td>Australia, New Zealand, and Oceania</td>
<td>12 June</td>
<td>New Zealand – Major Floods Hit Gisborne and Hawke’s Bay</td>
</tr>
</tbody>
</table>
2.3.3 Effect of increasing urbanization

In 2013, Swiss Re published a study titled *Mind the Risk: A Global Ranking of Cities under Threat from Natural Disasters*. A significant concern about growing flood risk arises from recent and expected future shifts in population. The study indicated that the United Nations anticipates that by 2050, 6.3 billion people or 68% of the world’s population will live in urban areas, many of whom will be located on a coast or near rivers and lakes.\(^{23}\)

Swiss Re analyzed the most severe natural disasters in 616 of the world’s largest cities. Using catastrophe modelling and its database, Swiss Re analyzed risk exposure in terms of the consequences to human life, as well as economic impact. With respect to the effect on human life across the 616 metropolitan areas, riverine flooding poses a threat to more than 379 million people (compared to more than the 283 million threatened by earthquake and 157 million at risk from winds). In addition, coastal storm surges potentially affect about 33 million urban dwellers, and tsunamis threaten just over 12 million.

Swiss Re’s study concluded that almost all large cities are at danger of flooding to some degree, with cities in China and India subject to the most significant threat. The three areas with the greatest number of persons at risk are the Pearl River Delta (12 million residents), Shanghai (11.7 million residents), and Kolkata (10.5 million residents). They did not find any European metropolitan areas in the top 20 when ranked by affected urban population. The situation changes, however, when ranking according to the economic loss potential.

There are extensive writings about the effect of increased urbanization on the damages resulting from flood. Jongman comments:

> For the first time in history, over half the world’s population now live in cities, many of which are located at rivers, along coastlines, or both. A new study shows that the total urban area exposed to flooding in Europe has increased by 1,000% over the past 150 years. On a global scale, trends in flood zone urbanization have been similarly steep and continue to climb, especially in Africa and Asia. Not only does this mean that ever more human assets are in the way of floods, but urbanization with an increase of non-permeable surfaces and lack of natural drainage creates additional flooding issues that did not previously exist.\(^{24}\)

According to *Underwater: Rising Seas, Chronic Floods, and the Implications for US Coastal Real Estate* by the Union of Concerned Scientists, in the United States alone, by 2045 more than 300,000 existing homes and commercial properties, currently valued at US$135 billion, will be at risk of chronic, disruptive flooding.\(^{25}\) On March 22, 2019, Pitt et al. reported that the U.S. states of Iowa and Nebraska suffered more than US$3 billion worth of damage from the March 2019 Midwest floods (Iowa Governor Kim Reynolds estimated that it would cost Iowans about US$1.6 billion, including US$0.5 billion in home losses, US$0.3 billion in losses to businesses and $0.5 billion to repair levees).\(^{26}\)
2.3.4 Areas of greatest vulnerability

CRED/UNISDR cite the following findings related to flood events:

- Floods strike more often in Asia and Africa, but the danger is also increasing in other continents.
- In South America, from 2005–2014 on average 2.2 million people were affected annually by floods, which compares to an annual average of 560,000 people in the previous decade.
- Deaths are also rising in many parts of the world. In 2007, floods killed 3,300 people in India and Bangladesh; in 2010, 2,100 people in Pakistan and 1,900 in China; and in 2013, 6,500 people in India.\(^{27}\)

Fatalities from weather-related disasters are summarized in Figure 3.\(^{28}\) Note that *storm* as defined by CRED includes hurricanes, cyclones, and storm surges.

**Figure 3 – Number of People Killed by Disaster Type (1998–2017)**

CRED/UNISDR also comment on rural malnutrition and the effects on children exposed to recurrent flooding. These children have been found to be more stunted and underweight than those living in villages that have not been exposed to floods.

The economic value associated with flood losses in developing countries is usually a fraction of the losses associated with flood events in the United States and Europe. However, severe floods in developing countries can be devastating, especially as financial savings and employment opportunities are often extremely limited. Migrants can be especially hard hit when they are housed in otherwise undesirable locations in inadequately built structures.

Jongman writes about the effect of floods on the most vulnerable in society:

> The welfare loss from flood events hits the poorest in society hardest. In many countries, the poorest population groups are relatively overexposed to flooding, as they are often forced to live and work in low-lying areas. In addition, the poorest households are more vulnerable to the resulting impacts to their income and can often be pushed across the poverty line by a single event. As such, natural disasters may effectively increase global poverty.\(^\text{29}\)

### 2.3.5 Some promising developments

While flooding worldwide has been a leading cause of natural disaster-related fatalities, responsible for 6.8 million deaths in the 20\(^{\text{th}}\) century,\(^\text{30}\) the widespread use of effective early warning methods for hydrological events (defined by CRED to include flood, landslide, and wave action) has contributed to declining overall flood mortality.

Jongman writes that economic development, technological progress, and targeted adaptation interventions are reducing the adverse consequences of floods. He states that in Europe, fatalities and normalized losses (relative to GDP) have decreased significantly in recent decades, despite an increase in flooded areas and absolute values of losses.\(^\text{31}\) While losses in Europe may be expected to decrease on a relative basis, the magnitude of the increase in losses is still immense. A 2016 paper prepared by the European Environment Agency titled *Floodplain Management: Reducing Flood Risks and Restoring Healthy Ecosystems* states:

> Annual flood losses [in Europe] can be expected to increase five-fold by 2050 and up to 17-fold by 2080. The major share of this increase (70\%–90\%) is estimated to be attributable to socio-economic development as the economic value of the assets in floodplains increases, and the remainder (10\%–30\%) to climate change.\(^\text{32}\)

Jongman reports that in some low-income countries the relative impact of floods has decreased as per capita income has increased.\(^\text{33}\)
2.4 Drivers of Flood Risk

The factors driving flood risk are diverse, multi-faceted, and interrelated. Factors can be categorized as being associated with:

- Weather;
- Geography;
- Environmental and physical land features; and
- Human actions.

Weather factors include, but are not limited to, heavy or sustained precipitation, snow melt, and storm surge from tropical cyclones (so-called cyclone bombs). Drought is another weather factor, which may initially seem counterintuitive as a driver of flood risk – it can, for example, create soil that is so dry that it will not absorb rainfall or areas that are significantly more susceptible to a wildfire, which in turn can lead to greater flood risk, especially due to resulting mudslides.

Geographical factors refer to the proximity to coastal areas, river basins, and lakeshores, particularly if in a floodplain. Environmental and physical land features include soil type, the presence or absence of vegetation, drainage characteristics, earthquakes, and deforestation that can lead to precipitation runoff and higher risk of flash flooding.

A sometimes overlooked, though critically important, category of drivers of flood risk are those arising from direct human activity, which include:

- Socio-economic and demographic changes, such as rapid and unplanned or haphazardly planned urbanization, especially the proximity of large populations to coastal areas accompanied by weak land use and unsound buildings;\(^{34}\)
- Structural failures such as dams and levees that are designed to reduce flood risk but, in some cases, lead to more construction in flood-prone areas, followed by failure or sub-par performance of measures intended for mitigation;\(^{35}\)
- Alteration of absorptive land cover with impervious surfaces;\(^{36}\)
- Inadequate drainage systems;
- Intentional drainage of aquifers for water use that leads to sinkholes and land subsidence;
- Construction along embankments that interferes with surface-water flow, causing drainage congestion;\(^{37}\) and
- Booming construction that leads to excessive mining of sand and gravel from upstream riverbeds, which during rainy seasons can result in loosened sediments and more flooding downstream.\(^{38}\)

Floods are often due to a combination of human and natural factors, including continuous rainfall and cloudbursts, snow melt and rainfall, glacial lake outbursts, volcano crater lakes, and breaking of dams caused by landslides falling directly into rivers. Flood risk, which was previously described to emerge from a combination of flood hazard and flood vulnerability, is affected by physical infrastructure, economic systems, and human factors. Areas highly modified by human activity tend to suffer greater harmful effects from flooding. For example, significant flood damage in Canada in 2013 (Calgary and Toronto) arose from a combination of extreme rainfall, overwhelmed drainage infrastructure, and building structures in flood-prone areas.
Flood Risk

In some ways, landslide risk, like other environmental risks, can be treated in a manner similar to flood risk. Although in some cases landslides can be caused by floods, the two risks may not share the same drivers. They can be subject to similar risk management and insurance processes, which include risk identification, financing, and pricing functions. The assessment of comprehensive landslide susceptibility, subject to drivers of land rather than water movements, can lead to applicable mitigation and recovery approaches that can be affected by zoning for land-use planning and disaster risk management.

One set of disasters can sequentially result in others. An example is California’s experience in 2016–2017. A very wet winter ended six years of extreme drought in 2016. A three-month deluge led to the wettest winter on record. The following spring and summer saw almost no rainfall, leaving above-average vegetation growth as a source of fuel for wildfires. In September 2017, a near-perfect combination of heat, low humidity, and fuel drove one of the worst wildfire seasons in recorded California history. Floods and mudslides followed in the burnt-out areas. The situation was even worse in 2018, when California wildfires once again broke historical records in terms of the number of fires, hectares burnt, and economic costs. Some of the California areas affected by the 2018 wildfires faced flooding in early 2019.

Another example of multiple drivers of a flood causing significant damage occurred in Thailand in 2011, where the natural factors included:

- A La Niña that increased rainfall and subsequently increased runoff;
- Reservoirs that exceeded threshold storage before large tropical storms hit (seven consecutive months of above-average rainfall); and
- Gentle slopes (topological aspects) that led to heavy flows of water, which broke downstream water gates and levees.

Drivers due to human actions in Thailand included poor land use, where natural waterways and wetlands were replaced with urban structures. Developers in Bangkok, situated in a former floodplain, failed to prepare for the likelihood of persistent and recurring floods, which led to land subsidence. This resulted in many areas being vulnerable even with modest breaches. Finally, poor governance and coordination of national and local governments with competing objectives (such as storing water in dry seasons and minimizing flooding in wet seasons) contributed to weak urban water management under decentralization conditions.

Care is needed when there is human interference with water systems. Where there is an attempt to control water in one area, an unintentional consequence might be to increase potential flood risk in another. For example, a dam may reduce downstream flooding, but can also create flooding from backed-up water upstream or might create a dangerous situation downstream if the dam breaks or is breached. Efforts to channel river flow for river navigation purposes has led to subsidence and higher flood risk downstream. Finally, if a sea wall is built, a surge flood might at the same time be diverting a surge flood to neighbors.
Flood Risk

2.5 Flood Damages

Flood damages can be classified in many different ways. One approach for describing the major types of flood damages is:

- Direct or indirect;
- Property or human;
- Short- or long-term;
- Whether it is possible to price or place a value on the damages;
- Flood vulnerability: (1) social and cultural vulnerability, (2) economic vulnerability, and (3) ecological vulnerability, particularly if in an island environment; and
- Contact with water or as a consequence of flood water (i.e., direct or indirect).

Table 3 presents different aspects of flood damage, along with examples.

<table>
<thead>
<tr>
<th>Type of Damage</th>
<th>Tangible and Priced</th>
<th>Intangible and Unpriced</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct damage</strong></td>
<td>• Residences &lt;br&gt; • Capital assets and inventories &lt;br&gt; • Business interruption (inside the flooded area) and looting &lt;br&gt; • Vehicles &lt;br&gt; • Agricultural land and livestock &lt;br&gt; • Roads, utility and communication infrastructure &lt;br&gt; • Evacuation and rescue operations &lt;br&gt; • Reconstruction of flood defences &lt;br&gt; • Clean-up costs, including debris removal</td>
<td>• Fatalities &lt;br&gt; • Injuries &lt;br&gt; • Inconvenience &lt;br&gt; • Opportunity cost &lt;br&gt; • Utilities and communication &lt;br&gt; • Historical and cultural losses &lt;br&gt; • Environmental losses</td>
</tr>
<tr>
<td><strong>Indirect damage</strong></td>
<td>• Damage for companies outside the flooded area &lt;br&gt; • Adjustments in production and consumption patterns &lt;br&gt; • Temporary housing of evacuees</td>
<td>• Societal disruption &lt;br&gt; • Psychological stress and traumas &lt;br&gt; • Undermined trust in public authorities &lt;br&gt; • Reduction in tax revenue</td>
</tr>
</tbody>
</table>

Source: Masahiko Haraguchi and Upmanu Lall, *Flood Risks and Impacts – Future Research Questions and Implications to Private Investment Decision-Making for Supply Chain Networks*.42

2.5.1 Tangible and priced damages

Direct damage to residences and businesses can include rotting wood, termite damage, undermined building foundations, and consequential mould, in addition to damage to their contents. Agricultural damage often includes crop failure due to rain damage, waterlogged soils, ruined crops in storage, and harvesting delays as well as loss of livestock and fencing.
Public properties (including roads, bridges, dams, levees, utilities, and public buildings) can be vulnerable to damage arising from floods and flood-related perils. Infrastructure damage can affect entire communities and can lead to significant economic damage. Flood events can not only disrupt individual infrastructure systems but can also result in cascading failure across interconnected systems with a wider impact than the original flood footprint. As an example of a cascading failure, 2007 floods in the United Kingdom resulted in 350,000 people losing water for up to 17 days, 42,000 people losing electricity for 24 hours, and over 10,000 people being stuck on a motorway or stranded in trains. Another example is Puerto Rico after Hurricanes Irma and Maria in 2017. A substantial portion of the island’s 3.5 million residents lost water and electricity. Some estimates are that nearly 5,000 people died as a result of the hurricanes and their consequences.

In addition, infrastructure damage can contribute to losses to privately-owned residential or commercial structures and can result in properties with little or no apparent damage becoming uninhabitable due to damage that restricts access to the property, due to, for example, lack of high-quality water or means of transport. Recovery costs include the cost of debris removal and services such as building inspections. Infrastructure damage can also contribute to ongoing health and safety issues in a community. Some damage can have a long-term effect, such as nuclear or chemical contamination if such facilities are affected.

### 2.5.2 Deaths, ill-health, and intangible and unpriced damages

Fatalities can occur directly through causes such as drowning, electric shock, or consequential criminal activity. Fatalities can also occur indirectly by contracting bacterial infections (such as leptospirosis) by walking in heavily polluted waters, or through consequential animal and insect bites, as flood waters can remain for a long time, providing breeding areas for mosquitoes and displacement for animals and reptiles. Epidemics such as diarrheal diseases, cholera, typhoid fever, and hepatitis are common after catastrophic flood events.

Human and animal health can be adversely affected by conditions such as contaminated water quality; waterborne and insect-transmitted diseases, particularly from standing water; food insecurity; water pollution; and contamination related to the mud, bacteria, sewage, and chemical toxins that flood water can contain. According to Rodriguez-Llanes et al. (2016), particularly in low-resource or subsistence-farming rural settings, **children, especially infants, who are exposed to floods suffer the highest levels of chronic malnutrition due to such factors as lost agricultural production and interrupted food supplies.**

While evacuation appears in Table 3 as a tangible and priced damage, there are intangible and unpriced consequences associated with displacement. Evacuation results in the forced removal of people from their homes, which can in turn lead to over-crowding with the potential for adverse physical and mental health implications. Evacuation can adversely affect both short- and long-term quality of life, as well as family and community support. Common long-lasting mental health consequences that can follow a severe flood include post-traumatic stress disorders, depression, anxiety, and victim traumatization.

Governments may suffer indirect damage due to reduced tax revenue. The direct damage caused by a flood may in turn reduce its property tax base and reduce business activity, at the same time as demand for flood-related services increases.
2.5.3 Other damages

Although flood damages are generally expected to be primarily water-related, a flood can also increase the risk of fire due to:

- Improper generator use or maintenance;
- Leaks in above-ground gas lines, containers, and tanks;
- Use of electrical appliances that have been exposed to water;
- Operation of nuclear sites for electricity that need water to be cooled; and
- Improper use of alternative heating devices, or their use near combustible materials.

Floods can also result in significant consequences, favourable and adverse, to the environment. For example:

- Floods can play an important role in maintaining key ecosystem functions and biodiversity – floods link rivers with surrounding lands, recharge groundwater systems, fill wetlands, increase connectivity between aquatic habitats, and move sediment and nutrients into marine environments;
- For many species, floods trigger breeding events, migration, and dispersal – these natural processes tend to be resilient to the effects of all but the largest flood events;
- While cycling of sediments and nutrients is essential to healthy system, too much sediment and nutrient entering a waterway can adversely affect downstream water quality and contribute to dam failure; and
- Floods can cause loss of habitat, dispersal of weed species, release of pollutants, lower fish production, loss of wetlands function, and loss of recreational areas.

2.6 Dynamic Aspect of Flood Risk

Flood risk and its drivers evolve over time. For example, the course and size of rivers change; the population and property exposed to flood risk can increase or decrease; and climate change leads to higher sea levels, extreme weather events (including torrential rain storms), and changing temperatures. All such changes can influence the risk of flood and the associated damages.

Thus, problems can arise even in areas that appeared to have adequate flood controls in place but where the hazard had increased. This is true in countries such as the Netherlands and cities such as New Orleans, which have recently invested significant amounts to fortify their flood defences; time will tell whether the resulting mitigation actions are adequate.

In the Netherlands, given that “nearly 60% of the land, some 70% of the population (total 17 million people) and 70% of the economy (total GDP of €650 billion) are flood prone”, strong water management systems are a top priority. There are approximately 3,800 kilometres of primary flood protection structures in the Netherlands. The Dutch government sets aside €1 billion annually for water defence, which includes maintaining and strengthening dykes, levees, and other water mitigation measures. In addition, as of July 2017, half of the Netherlands’ primary flood protection structures required reinforcement to meet upgraded safety standards.
Flood Risk

Like the Netherlands, much of New Orleans sits below sea level, which makes it vulnerable if its flood protection infrastructure were to fail. Following Hurricane Katrina in 2005, the U.S. federal, state, and local governments spent more than US$20 billion on 350 miles of levees, flood walls, gates, and pumps that now encircle greater metropolitan New Orleans. Even with this investment, some experts question whether the protection is sufficient. John Schwartz and Mark Schleifstein, writing for the New York Times, stated:

The problem, in the argot of flood protection, is that the Army Corps of Engineers designed the new system to protect against the storms that would cause a ‘100-year’ flood – a flood with a 1 percent chance of occurring in any given year. And that, experts say, is simply insufficient for an urban area certain to face more powerful storms.50

In May of 2019 the State of Louisiana released a 1,500-page strategic plan to avoid the anticipated impacts of climate change along the state’s vulnerable southeast coastline.51 It focuses on sea level rise and storm-induced inundation that integrates a planned retreat from certain areas that are becoming unsustainable as sea levels rise. Areas are assigned three risk zones – low, moderate, and high, providing a framework for increasing resiliency in each zone, while helping people and communities in high-risk areas move to higher, less vulnerable ground.

Unfortunately, many developing countries are not able or willing to invest in flood mitigation and adaptation projects similar to those seen in the Netherlands and New Orleans. For many, there is a diminished capacity to anticipate flood risk due to outdated flood maps and deferred investment in maintenance, repair, and replacement of flood control structures such as dams, dykes, and channels. The situation can be further compromised by infrastructure that was designed to meet standards based on historical meteorological data, which may be inadequate to cope with future climatic conditions. Inadequately maintained, damaged, or overwhelmed infrastructure can further contribute to overall damage. Moreover, the traditional focus of flood-prevention programs was primarily on riverine flood, while a growing proportion of flood-related damages in urban areas now stems from sanitary sewer backup, storm water, and groundwater infiltration, which require different solutions.

2.7 Summary

This section introduces the topic of flood risk, including a formal definition of flood and detailed descriptions of the major types of floods and their consequences. The components of flood risk, flood hazard, and flood vulnerability are described and the drivers of flood risk are identified. Losses associated with floods can be extensive. Jongman states:

The impacts of flooding go far beyond direct damages to assets and infrastructure. Economic losses resulting from business disruption, welfare effects and supply chain shocks can often at times equal or exceed direct damages. In extreme cases, such as the shut-down of Wall Street due to Hurricane Sandy, economic ripple effects may be felt across an entire sector around the globe.52

It is often the case that those who are most vulnerable are the population that can least afford the losses. For those who are already poor, floods deepen their poverty and add misery.
3. The Flood Risk Management Process

Proper analysis and effective management of flood risk make use of a comprehensive risk management process, which bears many similarities to the actuarial control cycle. The objective of this section is to discuss this process as applied to the management of flood risk. As shown in Figure 4, a risk management process consists of a dynamic cycle, involving multiple steps or sub-processes, which can also include changes in order and feedback loops that can occur at any of its steps. It is desirable for all countries to develop a flood risk management process, covering the short-, medium-, and long-term planning horizons.

3.1 The Flood Risk Management Process

Although the flood risk management process can incorporate numerous feedback loops and changes in order, as applicable, it can be viewed as consisting of a six-step process, as illustrated in Figure 4 and discussed in the following:

1. Identify risk;
2. Assess risk;
3. Mitigate/adapt to risk;
4. Measure risk;
5. Finance/transfer risk; and

Figure 4 – The Risk Management Process
The European Union (E.U.) Directive on flood risk management (November 2006) exemplifies a similar, systematic approach for the management of flood risk. The E.U. approach incorporates most of the components identified in Figure 4, albeit presented as a three-step, rather than a six-step, approach:

- Member states must undertake a preliminary assessment of flood risk in river basins and coastal zones;
- Where significant risk is identified, flood hazard maps and flood risk maps must be developed; and
- Flood risk management plans must be developed for these zones, including measures that will reduce potential adverse consequences of flooding for human health, the environment, cultural heritage assets, and economic activity. To be effective, their focus should be on prevention, protection, and preparedness.

The following is a description of each major step in the flood risk management process illustrated in Figure 4.

3.1.1 Identify risk

The “identification” step finds the risk-related characteristics involved and the proximity to the location at most risk. In many cases, flood risk is greater the closer a property is to a body of water (e.g., river, lake, and ocean). In some cases, however, a property exposed to excessive rain alone can experience a loss even if not close to a body of water. Regardless, accurate flood risk maps are necessary to identify the extent of the risk and estimate costs associated with flood risk. Flood risk maps can be quite controversial because flood classification can lead to significant construction costs and/or land-use restrictions, as well as availability and affordability issues related to private sector insurance. Due to changing land use, meteorological factors, and structural and land conditions, flood risk maps should be reviewed and updated periodically.

3.1.2 Assess risk

Risk assessment addresses both quantitative and qualitative considerations. This step includes an assessment of the types of flood risk and the extent of possible damages that may be involved, (i.e., susceptibility, as described in Section 2) as well as cost-benefit analysis (developed in steps 2 and 4) of alternative approaches to risk reduction (Step 3) and of risk transfer (Step 5). To do so effectively, relevant and reliable data need to be obtained; in many cases the data need to be local or regional in nature, as risks differ by geographical area as well as by other risk characteristics. Desired achievement of objectives, targets, and timeframes are important to incorporate in the assessment.

Once the initial assessment is conducted, regular reassessments of findings are necessary for the assessment to remain current. The timing for such reassessment depends on the individual situation, including changes in factors such as local infrastructure, land use, and other risk characteristics. It may be appropriate to establish a maximum period (e.g., five years) for which a regular reassessment would be required.
3.1.3 Mitigate/adapt to risk

The obvious “solution” to a flood risk situation (that is, to move everything of value away from an area in which the flood risk exists) is often impractical. Land-use planning and zoning can be used in some jurisdictions to direct people and structures to locations with reduced flood risk exposure. In some cases, however, those responsible for land-use planning neither recognize nor take action in anticipation of flood risk. People or businesses can refuse to leave or, in some cases, continue to move back even after a disaster has struck in the same location. In extreme cases, police action may be needed to remove people, especially if the risk of flood is imminent or extreme.

There are many methods and forms of risk reduction. They can be categorized as mitigation or adaptation. There are several ways of distinguishing between them. The following is one method, focusing on potential immediate action, although efforts to address risk over a long-term period (permanent) are just as important.

- **Mitigation approaches.** Mitigation includes methods and tools used to reduce or eliminate the severity of the underlying risk. For example, to avoid water damage in homes, the Insurance Bureau of Canada recommends the following mitigation techniques:
  
  - Keep all floor drains clear of obstructions;
  - Arrange to have someone check your property if you are away from home for more than three days;
  - Ensure that there is proper grading around your home;
  - Install a sump pump;
  - Install backflow valves or plugs for drains, toilets, and other sewer connections, to prevent sewer water from entering your home;
  - Store important documents and irreplaceable personal objects (such as photographs) where they will not get damaged;
  - During the winter, if you are away for more than three days, drain the plumbing or arrange to have someone come in daily and check that your heat is still on;
  - Elevate furnaces, water heaters, and electrical panels in the basement on masonry or relocate these objects; and

- **Adaptation approaches.** Given that floods will occur, adaptation measures, which can be described as responsive adjustments to an environmental condition, are essential for controlling the extent of flood damage. Diverse approaches include:
  
  - Structural flood protection measures such as levees and dykes, which are used in areas with high populations and asset concentrations;
  - Nature-based solutions such as widening of natural floodplains, protecting and expanding wetlands, and investing in urban green spaces to reduce runoff;
  - Community-based early warning systems, which are especially important in poor rural communities at higher risk; and
  - Structural protection such as cyclone shelters and resistant buildings.

In some cases, managing flood loss requires difficult trade-offs, both prior to flood occurrence, at the time of a flood, and during the recovery period. During Hurricane Harvey (Texas, 2017), a small area was intentionally flooded to avoid damage in a larger area.
A flood management program can be designed to include effective incentives that induce loss-sensitive behaviours. One loss prevention technique prohibits constructing residences in a floodplain where there are many “repetitive loss properties” (i.e., properties that experienced similar flood damage over time). Another example is to require resilience in new and existing buildings as stipulated through building codes, which can also be developed to protect against other perils, including earthquake, mudslide, wind, and wildfire. Both high- and low-tech solutions can provide enhanced preparedness assistance.

Adaptation projects can also lead to significant economic and other benefits, such as improved health care and emergency-response infrastructure.

CRED/UNISDR highlight two key action points related to mitigation and adaptation efforts directed at flood control:

- Improving flood control can be a “low-hanging fruit” in disaster risk reduction policy terms. Affordable and effective technologies already exist or may simply not be widely implemented, including dams, dykes, mobile dykes, and improved early warning systems.
- Flood control is both a development issue and a response to a humanitarian concern. Priority may be better assigned to cost-effective mitigation measures in vulnerable regions with a concentration of poverty at high risk of recurrent flooding, combined with malnutrition programs.\(^{56}\)

### 3.1.4 Measure risk

The measurement (i.e., quantification) of flood risk, including consequential damages, is complex. Expert knowledge is required of geological characteristics and weather conditions of the region, building features, the range and type of economic damages net of mitigation and adaptation measures, and coverage of the damages under the program. Both costs and benefits need to be included in measurement.

Catastrophe models, which often incorporate Monte Carlo simulation, are usually constructed based on historical flood data by geographical area. These stochastic models are often supplemented by sensitivity and scenario analyses. A wide range of scenarios is needed to properly evaluate estimates of flood risk and to be useful for mitigation and adaptation planning.

Considerations taken into account by catastrophe models may include the following:

- **Quantitative and qualitative characteristics.** In addition to the financial costs associated with flood risk, there are also non-financial aspects, many of which are related to the drivers of flood risk and the damages associated with floods. (See Section 2 for further information.)

- **Low-frequency/high-severity events.** Estimating the distribution of possible losses can present significant challenges, particularly given the scarcity of high-quality data. In addition, an estimate is required for the distribution of probable losses based on current conditions given that a flood occurs. The development of reliable estimates is complicated by recent experience that indicates that many recent events have exceeded the traditional 1-in-100-year timeframe that many protection systems were originally designed for. For
example, headlines described Hurricane Harvey as the third 500-year flood in three years. Quantification is also difficult when estimates are based on historical data, especially when the data cover a long period of time, which may not reflect the current conditions, let alone the effects of future drivers including behavioural and climate changes.

- **Keeping current.** Expectations need to be updated on a regular basis due to changing conditions, enhanced knowledge, human behaviours, and risk preferences. Risk factors can change gradually or suddenly. For example, an increase in sea level tends to evolve over decades (and even centuries), while sudden and severe sea surges can result from natural disasters, such as an offshore earthquake or tropical cyclone. The amount, locations, values, and quality of construction are all important variables that can change, thus resulting in the need to keep models current.

- **Scope of damage.** Damages include not only direct costs immediately after the event, but also consequential damages, which can be exacerbated by lack of adequate preparation. For example, inadequate or unresponsive health care and emergency-response infrastructure can begin as a local or short-term problem but may become a long-lasting one. If health professionals, equipment, and supplies are not available on a timely basis, a relatively minor situation can become a major disaster due to epidemics or food and water contamination. Timely response related to building decisions can also affect the scope of damages. Building inspector decisions are required regarding whether buildings can be repaired as-is under original building codes or need to be brought up to more recent building codes. Delays are often due to a lack of available building inspectors, who are typically overwhelmed by the demand for their services.

- **Concentration risk.** A flood often covers a wide geographic and population area, affecting many individuals and businesses simultaneously. In contrast, insurance and other forms of risk transfer take advantage of the spread of independent risks over an extensive geographic area. In the case of flood insurance, however, those who purchase coverage tend to be those in the same area, with a relatively high exposure to flood risk, often resulting in multiple simultaneous losses. Reinsurance can be used to spread flood risk.

- **Granularity.** In some cases, the granularity or specificity of criteria is important. For example, a house could be categorized as being in a floodplain because the edge of the property is next to a river. However, if a house is many metres above the riverbank, the exact elevation of a building structure is more important than its location. As another example, a hotel could be rated based on its front entrance, although the property includes a riverboat casino moored at the back of the property on a river. Thus, closeness to another property or exposure may be less important for flood risk than closeness for, say, windstorm risk, as windstorms almost always impact adjacent properties, while the elevation of buildings next door to each other can differ enough to materially impact potential losses.

- **Correlation and causation.** Floods are often correlated with tropical cyclones or severe convective storms. This type of correlation is considered in both actuarial modelling and public policy decision making. In other words, flood should not be viewed in isolation with respect to risk appetite, given that the triggering peril/event that directly caused a flood may be an extreme event risk, such as a tropical cyclone.
Flood Risk

- **Time.** Where a long timeframe is covered for modelling, considerations related to inflation, present value discounting, uncertainty, and risk preferences can be important. Explicit consideration of the effects of anticipated mitigation, adaptation, and behaviour actions can be necessary. Overall, the longer the time period, the greater the uncertainty in modelled results.

The assignment of the risk of a flood hazard to a particular area is often made in terms of being at either a no-risk or 100% risk of incurring a future flood in a stated period of time (e.g., the next 50 years). In reality, however, such a black-and-white assignment of level of risk is rarely possible. Such risk quantification would be better determined in a more granular manner, possibly through the use of a hazard map. Geographical categories could be assigned to more than two possibilities (e.g., no-risk, low-risk, moderate-risk, and high-risk). Alternatively, the areas could be assigned specific probabilities or as an expected flood event every x number of years (e.g., one-in-50-year likelihood). In any case, it is important to effectively provide useful and actionable information that should not be ignored. For example, it might appear to some that an event that could happen in 50 or 100 years is so distant and so unlikely that there is no need to plan for or worry about it, while an event that has a 10% chance of occurring in the next 10 years might be more likely to lead to warranted action.

3.1.5 **Finance/transfer risk**

There are two general approaches to financing potential flood losses: advanced (also referred to as ex-ante) financing and pay-as-you-go (also referred to as post-event or ex-post) financing. Many factors influence which financing approach to utilize, including resource availability, choice of private sector or public program, program design features, and affordability. Self-insurance, which may differ from no insurance, can also be a viable alternative for financing flood risk, particularly for large businesses.

Depending on the local market, advanced financing can be provided through private sector insurance, public programs, or a hybrid (such as private sector insurance with public subsidies or guarantees). Financing arrangements can include funds from the current year or historical years and can be offered through insurance, community pooling, or subsidies.

Pay-as-you-go financing in all countries can be provided by means of public financial assistance or services. Financing from donors can be obtained especially, but not exclusively, by developing countries. Such financing can, however, be problematic in times of global or national financial stress or austerity and can make advanced planning or short-term emergency funding for disasters difficult.

Repairs and recovery to normal conditions can be made faster and more efficient when damages are insured through the private sector. Collectively, private insurers usually have more immediate financial capacity, with far less need to wait for political decisions or bureaucratic delays.

Claims and contractor repair fraud (including simple exaggeration) are often seen following catastrophic events and can be present in programs with either advanced or pay-as-you-go financing, in either public or public programs. For example, a property may have been damaged due to an unrelated event or condition prior to a flood event; when presented with a claim for damages following the flood event, it can be difficult to distinguish a legitimate flood claim from the damage sustained from an unrelated cause, possibly prior to the flood.
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Where flood risk is highly concentrated and adequate risk-spreading devices are not available over a long timeframe, concerns can arise regarding the sustainability of risk transfer or the institutions providing coverage, particularly when flood protection is provided by private sector insurers.

3.1.6 Monitor risk

To ensure a successful and sustainable risk management process, the amount and types of changing exposures must be monitored and estimates of risks and associated costs should be refreshed regularly. Otherwise, proper coverage and loss prevention and control steps may not be taken. To improve future estimates, modellers learn from the past and routinely incorporate changes in conditions.

3.2 Other Aspects of Flood Risk Management

The mitigation of flood risk drivers can be anticipated independently from flood disaster recovery risk. The underlying drivers of flood will not go away – planning is necessary to prepare for the eventuality of a flood occurring, including the coordination and cooperation of private and public responders. Sharing best practice for both on a regional, national, and global basis can benefit all participants in these risk management processes.

Certainly, one size does not fit all. Significant variations in the programs used to address flood risk exist, as can be seen in the Appendix. Program design depends on historical experience, circumstances, and the attitudes, values, and risk appetite of stakeholders, especially those who are directly affected and those responsible for financing a flood risk program. (See Section 5 for a discussion of risk perception.)

Public provision and planning for floods are usually subject to one or more political processes at the local, national, and even supranational levels. If a major flood has not occurred for some time, there is often limited pressure or urgency to prepare for the next event. Consequently, the level of activity related to flood risk management programs tends to change over time, especially given limited public funds. Where practical, it is effective to assign full-time responsibility for flood risk management to an individual or administrative area.

Communication and awareness of flood risks can be challenging especially to those who, although potentially exposed to flood risk, believe that taking action is inconvenient or seemingly expensive. Key elements of an effective communication program are to localize and personalize the message and to incentivize desirable behavior. The concerns of a range of stakeholders need to be addressed and responses carefully planned. For example, many rivers are shared by multiple countries – each of these countries needs to be involved, and the earlier in the process the better. Feedback is crucial to ensure that the quantitative analysis and overall risk management program are kept current.

3.3 Summary

This section describes how the risk management process can be applied to flood risk. As indicated in Figure 4, the risk management process involves multiple steps, implemented with continuous feedback loops that are dynamic in nature. Both qualitative and quantitative considerations are involved to effectively address flood risk, including concentration risk, related perils, and stakeholder behaviour. Private and public stakeholders need to be involved throughout the flood
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risk management process, especially given that various means of mitigating risks and financing damages are likely required. Being prepared for and reacting to disasters in a timely manner can significantly reduce consequential damages.

4. The Role of Insurance

A range of methods can be used to address damage to homes and businesses arising from floods. As indicated in Section 3, actions can be reactive, with assistance from government or other sources following a flood, or proactive, including floodplain management and mitigation combined with public–private sector insurance partnerships. Insurance serves as a primary source of financial liquidity at times of a disaster, but no funding mechanism completely closes the protection gap.

4.1 The Protection Gap

A protection gap exists when the financial needs of individuals and businesses following a catastrophic event are greater than the funds available from the programs they choose or are mandated to participate in. The protection gap arises because of limited supply of coverage options or virtually non-existent demand. Over time and across multiple jurisdictions, insurers have often been reluctant to offer flood insurance because of the unpredictability of floods and their related perils as well as the significant risk of adverse selection. Individuals and businesses contribute to the protection gap by not educating themselves sufficiently about flood risk and by having an optimistic view that “a flood will not happen here”. In some cases, homeowners and business owners think they have adequate coverage when they have either inadequate amounts of coverage or no coverage at all when they do not understand their overall insurance coverages.

A primary objective of public programs, private sector insurers, and public–private initiatives directed at flood insurance is to minimize the protection gap. In developed countries, lending institutions can help reduce the protection gap by requiring the purchase of flood insurance for mortgaged property in a flood-prone area.

A Munich Re report titled “Asian Floods Overshadowed by Houston Flooding” offers details of the extent of uninsured losses related to 2017 flood events in Asia, which were driven by a monsoon season that was exceptional in terms of duration and impact. Details include:

- From early June through mid-October, more than 40 million people were affected by floods (and landslides) in India, Nepal, and Bangladesh;
- Overall losses were about US$3.5 billion, but the percentage of insured losses was negligible in all three countries;
- While the total value of losses was small in comparison to the 2017 hurricane losses in North America, the losses affected countries where people were already extremely vulnerable;
- In Nepal, 40 million hectares of land flooded and 70,000 domestic and farm animals died, and virtually nothing was insured; and
Based on an October 2017 survey conducted by the United Nations in Nepal, only one-third of respondents indicated that they made any provision to protect against flood losses even though 56% had experienced losses in prior years.\textsuperscript{58}

As evident from the experience in 2017, the protection gap can be considerable, especially in developing countries that have many competing priorities for attention, often with significantly limited resources from which to meet them. Post-disaster financial responsiveness, which can be provided through insurance, is critical on personal, business, social, and political levels.

In the event of a severe flood, the protection gap can create a significant strain on the resources of those in the flooded area. Those displaced from their homes may be forced to seek shelter and a livelihood in their own areas or elsewhere with diminished resources. Governments, while responding to the damage of public properties and infrastructure, must address humanitarian needs. The resulting extraordinary strain can have long-lasting financial, physical, and psychological effects, while at the same time may still be insufficient to meet the needs.

### 4.2 Types of Relevant Insurance

Insurance can address damages resulting from the three major types of flood\textsuperscript{59} and their associated perils.\textsuperscript{60} The most commonly used form of insurance for flood risk is property insurance, via both personal and commercial policies. Property insurance provides risk transfer from the property owner or renter to an insurer. For a premium, which is small relative to the property’s value, financial protection is provided for damage to the structure and its contents up to the policy coverage limits purchased. Policy limits for flood coverage can be lower than policy limits for other perils. Even within the flood peril, policy limits can differ based on the source of water, such as sewer backup versus overland water.

Advantages of insurance at the time of a catastrophic event usually include a quicker and more complete response to damage caused by the flood and less strain on government resources following the event. Implementation of mitigation approaches, such as those described in Section 3, often results in reduced losses and insurance premiums.

Life and health insurance policies can be exposed to flood risk because floods can result in loss of life as well as adverse physical and mental health conditions. In addition, certain accident insurance policies may address damage to or death of a person due to flood. Here again there is very often a protection gap.

There are many challenges associated with insurance for flood risk, including:

- Availability of high-quality data (i.e., data that are sufficient and reliable) for ratemaking, including information from which to define rating territories;
- Changing conditions that make historical data less relevant for the projection of future losses;
- Sensitivity to variations in location due to differences in geographical location and relatively small differences in land and building elevation;
- Low penetration for the coverage, due partly to a lack of awareness of the availability of insurance and to misperceptions about the real risk of flood by individuals and businesses;
- Limited interest in spending money for mitigation and adaptation activities;
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- Adverse selection, whereby only consumers with actual or perceived risk purchase flood insurance; and
- Population growth and over-concentration in areas prone to flooding.

The financial payouts available to insurance policyholders following a flood are evolving. Some insurance policies tie the quantum of claims to a specified amount of rainfall or flood depth and not the specific loss incurred. This is referred to as parameter insurance. Although it has the advantage of being less expensive and facilitates a quick claim payment, such an approach to claims has the problem of basis risk, in that actual losses incurred by a policyholder may not correspond well with the predetermined level of the specified payment trigger. The use of such an approach, although still evolving, has not been widely adopted.

4.3 Public and Private Sector Approaches

Pure public approaches include (1) post-event government assistance, which can incorporate pre-event planning, mitigation, and adaptation and (2) existent and ongoing government agencies that provide flood insurance either directly to consumers or through intermediaries. Private sector approaches include local, national, and international insurers and reinsurers.

The possibility of catastrophic losses should not shut out private coverage. It should be possible to promote a high proportion of private insurance even in an environment in which insurers would not normally provide insurance coverage.

One approach that addresses a public–private design would juxtapose a state guarantee (i.e., public reinsurance) limiting insurers' payouts to amounts that could be insured through affordable premiums. In this approach, sufficient premiums could be collected to cover losses up to an agreed limit, with insurers administering and settling all claims, even those that exceed the limit. Excess amounts would be reimbursed by government or a public entity to the insurers in lieu of direct subsidies paid to victims of a catastrophic event. Otherwise, the state would have to declare an emergency to step in to limit the impact of a disaster.

Private premiums differentiated in a manner consistent with the risk characteristics involved would provide price signals that promote prevention or mitigating behaviors while remaining self-supporting for non-catastrophic losses. The program design could at the same time incorporate subsidies as long as incentives for maintaining appropriate behavior are in some manner included in the program design. Of course, the key to the success of such an approach would be maintaining a high participation rate, which might be obtained through mandatory flood coverage as part of mortgage requirements or other strong incentives in areas where mortgages are not prevalent.

An example of a public–private partnership exists in the United States with "Write-Your-Own" (WYO) insurers, who issue policies and handle claims with expense reimbursement from the National Flood Insurance Program (NFIP). WYO insurers cede 100% of premiums and losses to the NFIP. A partnership that crosses national boundaries is the Caribbean Catastrophic Risk Insurance Facility, which operates a risk pool that compensates a country-participant when a significant qualifying natural disaster occurs, with ready access to capital at that time; such a facility takes a great deal of effort, cooperation, and time to develop into an effective and efficient source of financing.

As alluded to in the discussion of the protection gap, market penetration of flood insurance in many jurisdictions is far from complete, even in flood-prone areas. In the United States flood coverage is
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required to qualify for a federally-guaranteed mortgage. Also, in severe floods, a great deal of damage can arise from properties in areas not designated as flood-prone. For example, there was wide-ranging damage from flooding outside Houston, Texas, due to Hurricane Harvey in 2017. Consequently, in virtually all situations, governments end up providing some disaster assistance following every major flood. This assistance can include taking mitigating action in preparation for future floods, preferably by applying a public–private cooperation approach, by rebuilding in a safer manner (or elsewhere) having applied lessons learned from the past flood. Governments may have to provide assistance or incentives to relocate—possibly including voluntary buyouts into “receiving communities” further inland or into what are safer areas.

Reliance solely on public, post-event assistance can lead to incomplete or inadequate reconstruction of damaged buildings and structures after a flood. Consequently, a community can face greater damage when the next event occurs. Although not a complete solution, insurance can provide an organized process to address property damage caused by a flood, albeit only for covered exposures and to covered limits. Insurance can also address, at least in part, immediate and long-term mortality and morbidity risks, both of which can constitute public health issues.

4.4 Use of Self-Insurance

Self-insurance can take many forms, including large deductibles and self-insured retentions, a self-insurance fund, a pooling program, and a captive insurance company. Although it is beyond the scope of this paper to describe self-insurance in detail, it is important to acknowledge that self-insurance can provide a viable means of financing potential damages associated with flood risk.

A well-managed self-insurance program requires detailed analyses of loss potential and the effectiveness of possible mitigation techniques. All the steps of the flood risk management process that are described in Section 3 are equally applicable to self-insurers. Repercussions can result if self-insurance provisions set aside for flood risk are too small or too large. For example, a self-insurance provision that is too small can result in possible financial exhaustion even with a moderately severe flood, while a self-insurance provision that is too large can be excessive during periods with no floods, causing unnecessary negative financial effects.

4.5 Monoline or Multi-Line Insurance Policies

Flood insurance products can take the form of a stand-alone insurance policy that provides only for flood coverage, or, more often, the coverage can be through an endorsement (also known as a rider) to a standard property or multi-peril insurance policy.

Coordination of flood insurance with other protection is important, as there can be gaps in coverage offered by private sector insurance or a government program. Thus, care is needed in product and program design.

Flood risk is one of numerous natural catastrophe risks facing individuals and businesses. In some cases, provision for flood risk can be more effectively addressed if assessment, loss prevention and loss control, and financing are bundled together with other risks, such as in a multi-peril insurance policy.

“Coverage bundling” of flood and other natural catastrophe hazards has several advantages. First, it can avoid problems associated with denial of a claim if multiple causes might be attributed to a
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specific cause. Second, it can lead to more efficient claims handling and possibly to greater consumer acceptance and reduced complaints since claim adjudication is more straightforward. Third, if other natural disasters, such as earthquakes, are covered, the combination might be more appealing than flood coverage – if so, the take-up rate could be improved. Bundling of flood coverage with fire or other casualty coverage could also constitute a marketing advantage. On the other hand, such bundling could reduce the incentive for loss mitigation that an explicit price for flood coverage could otherwise provide.

For example, damage might be attributed to either a flood or associated wind – if both are covered, coverage disputes will be less likely. In Japan, where there is extensive earthquake exposure, flood risk could be more effectively managed when each step in the risk management process is addressed in a holistic manner if flood and earthquake risks are viewed together. Another example is mudslide risk, which can arise because of a flood.

Although flood insurance or a disaster recovery program might solely address flood risk, it may be more efficient, operationally and financially, to address these risks as a bundle of protection, with the added value of potential diversification of risk.

Grouping multiple perils can also result in a greater spread of risk across a wider population of insureds, which can be viewed favourably by insurers, both private sector and public, although it does not address concerns about anti-selection or high loss concentrations.

4.6 Consequences of Subsidies and Inadequate Insurance Premiums

In general, where a robust market exists, private sector insurance companies tend to match premiums with the corresponding expected losses. The insurer’s goal is for the premium for each policyholder to be appropriate and the total premium collected to be adequate to provide for all losses and expenses and a provision to cover the full cost of risk transfer (profit and charge for risk and uncertainty). In the case of flood insurance, however, in many countries there is no effective market. Thus, various government approaches have arisen to provide coverage for floods. Premiums for government programs do not necessarily reflect expected losses of individuals, nor do such programs always provide a risk margin for funding future large events.

In some flood insurance programs, subsidized premiums, which can take an explicit or implicit form, are accessible by a subset of the insured population. For example, the NFIP in the United States incorporates explicit subsidies that were created by the law establishing the program. The use of subsidies can lead to what may seem to be unfairly high premiums for unsubsidized properties or inadequate revenue in total. To remain sustainable, losses incurred by insurers with inadequate revenue have to be financed by others, possibly by other insurers or reinsurers, other participants through cross-subsidies, reduced payments for other perils covered in bundled policies, or government agencies (which in turn are financed by current or future taxpayers).

Premiums will more likely be reasonable and affordable if insurance is compulsory or if there is a high market penetration. In such cases, premiums will prove to be more sustainable if they are developed to cover the overall expected losses that include a reasonable provision for catastrophic events.
4.7 Importance of Reinsurance and Government Grants to Supplement Private Sector Capacity

The catastrophic nature of flood risk means that flood events are typically low-frequency/high-severity events. It is impossible for an insurer to predict the precise year in which a catastrophic event will occur. Thus, it is impossible for the insurer to collect the “correct” amount of premium in any given year. Although theoretically an insurer can build a sufficient fund to handle the infrequent catastrophic loss, tax laws often discourage doing so. Further, even if insurers could build catastrophe reserves over time, the chance of a shortfall remains, particularly in early years of the build-up.

To address the financial volatility and protect themselves against possible catastrophic losses associated with flood insurance, private sector insurers purchase reinsurance, maintain appropriate levels of capital relative to the risks they underwrite, have access to government grants or backstops, or use a combination of these activities.

Reinsurance enables an insurer to restrict its exposure in the event of a catastrophe while meeting its loss-paying obligations to policyholders, and to remain financially viable. The use of reinsurance varies widely between insurers, with small insurers tending to rely on it more extensively, while larger insurers use it at much greater retention levels.

The reinsurer diversifies its risks by assuming such risks over broad, if not global, locations and over multiple types of perils. Further, reinsurers can retrocede risk to other reinsurers to protect their own financial condition. Reinsurance can be purchased from the private sector market or through public-sponsored programs (such as Flood Re in the United Kingdom (see Section 7.3.4) or a national pool such as the one in France). 61

A challenge in designing reinsurance for flood coverage is the definition of an “event”, something necessary for the design of any insurance contract. As a flood can occur over a wide geographic area and cause loss over many days or even weeks in a major riverine event, the typical “hours clause” may need to be modified. This clause enables direct insurers to aggregate claims over a period of time as a single event to provide coverage under reinsurance contracts, thus driving reinsurance capacity that makes it possible to cover flood risk events by the private insurance market. The use of this clause can differ widely by country and by reinsurance treaty that can significantly impact the loss to the reinsurance cover.

Protection from extreme loss events can also be provided by government programs, such as a pooling arrangement or a backstop (i.e., financial guarantee). Governments can provide backstops in the form of borrowing, as in the United States, or disaster relief where private sector flood insurance is quite limited. See Section 7 for a discussion of government programs.

Some form of financial protection against extreme losses is necessary so that policyholders are guaranteed compensation for their covered losses and the insurer is sustainable after a catastrophe.
4.8 Consequences of Limited Financial Protection

In the Munich Re report “Asian Floods Overshadowed by Houston Flooding” referenced previously, Wolfgang Kron speaks about disparities in flood protection between developed and developing countries. The report is focused on the catastrophic floods that occurred in 2017 in India, Nepal, and Bangladesh, where more than 40 million people were affected and at least 2,670 people died. Very few of the losses were insured, and governments struggled to cope with disaster management. Kron writes:

South Asia is representative for the many poorer regions of the world that were afflicted with flood disasters over the last year. South Thailand, Peru, Colombia, Sierra Leone and the Congo were also affected. In absolute terms, losses are often one or two orders of magnitude smaller than in Europe or North America. Yet the impact on people’s lives and livelihoods in these poorer countries is generally much more dramatic, given the frequent lack of insurance cover that could otherwise cushion the negative consequences.62

4.9 Summary

This section focuses on the financial resources available to address damages following a flood. Insurance, whether offered by the private sector, the government, or a public–private partnership, is a critical element of the flood risk management process. Key considerations in the design of an insurance program are discussed, including the protection gap, pre- and post-event funding, and the use of subsidies.

Kron comments on the tremendous effect of flood insurance. He states:

It has been shown time and again that countries with an effective insurance system against natural hazards are able to return to normal conditions after a disaster much faster than countries without any such protection in place.

Whereas the trail of devastation in the flood regions of Asia and Africa could still be seen weeks and even months after the event, life in Houston had returned to almost normal just a few days after the flooding. Apart from one or two tell-tale signs, it was difficult to find any evidence that large parts of the city had been a metre deep in water a short time before.63
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5. Constraints

Providing accessible and affordable flood cover to individuals and businesses requires overcoming several obstacles. In this section, these obstacles are viewed in the context of risk perceptions held by key stakeholders concerning flood risk. This section also discusses how some of these constraints can be overcome.

There can be situations in which flood risk is uninsurable in the private sector. An insurable risk requires:

- The risk to be subject to a contingent specified event or condition;
- Determinable damages from the occurrence of that event or condition; and
- Spreading, sharing, or transferring of the risk.

If the likelihood of the flood is so large or if a very high percentage of the exposures are subject to the same hazard at the same time, there can be no sustainable private insurance program (i.e., the flood risk becomes uninsurable by private means). In such a case, reimbursement for loss can still be covered under a public program, as long as the public entity is willing to reimburse for such damages incurred.

5.1 Economic Effects of Growth and the Timeframe

A significant issue that is often overlooked in discussions of flood loss potential is the mismatch of risk/reward to various stakeholders over time. For example, building and rebuilding in a location with a 1-in-50-year chance of a devastating flood can offer immediate financial rewards, such as:

- Local councils collect stamp duty, sales tax on building materials, or property taxes;
- Builders focus on short-term construction gain financially; and
- Realtors selling properties receive significant, near-term economic benefits.

These incentives and activities that involve possible short-term gain contrast with the cost of mitigating expected damages over a longer timeframe that includes a probable 50-year event. This is a challenging public policy issue. Another example is the tension expected to arise with a release of flood-related information. In some communities, regulations or legal suits have been used to restrict this release when new flood risk maps indicate higher flood risk.

The tension between short-term economic gain and long-term sustainability and community resilience arises in many situations where large disasters are possible, but is particularly important for flood risk.
5.2 Risk Perception

5.2.1 Explaining risk perception

In addressing the topic of risk perception in *Effective Adaptation to Rising Flood Risk*, Brenden Jongman states:

> The design of such holistic risk management strategies requires an accurate understanding of the level of risk across the various layers of society. One important remaining limitation in our understanding of flood risk is the way individuals perceive and respond to risk.⁶⁴

Risk perception in the context of flood risk refers to the judgements that stakeholders make concerning the characteristics and severity of the risks involved. A first step in creating conditions for a flood insurance framework is for key stakeholders (including consumers, builders, real estate agents, local councils, and state/province and national governments) to recognize and understand the flood risk involved and its potential financial and non-financial consequences for individuals, businesses, communities, and countries.

As noted in Section 2, there are three primary types of flood risk, each with its own implications to risk perception for flood risk. For example,

- **Coastal or surge floods** usually arise from tropical cyclones or large winter storms that occur infrequently. Loss exposure depends on both the frequency and intensity of these storms, plus the bathymetry (underwater topography) of the near-shore region. Areas with a shallow continental shelf, such as the U.S. Gulf Coast, have greater storm surge exposures than areas of similar elevation with a deep continental shelf.

- **Riverine or fluvial floods** are usually thought of as being well understood because of the long historical record of past events. However, changing conditions, such as new dams, deterioration of levees, or upstream deforestation, can contribute to different flood exposure than historical experience would indicate, which complicates risk perception based on current conditions.

- **Flash, surface, or pluvial floods** can be the most difficult from a risk perception standpoint, as they often occur far from coasts or rivers, which are commonly thought to be the primary sources of flood risk. Thus, loss mitigation and insurance take-up are challenging. That said, insurance products from commercial insurers may be more available, because of the random nature of flash flood losses, their relatively smaller size, and wider geographic spread.

5.2.2 High-quality data influences risk perception

In developed countries with high-quality data about flood risk and functioning insurance programs, there is usually significant information available to inform risk perceptions of stakeholders. Many developed countries have long historical records of flood events, which enable creation and maintenance of accurate maps of flood risk. For example:
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- EXCIMAP (The European Exchange Circle on Flood Mapping) produces the Atlas of Flood Maps and a handbook of good practices in flood mapping\(^{65}\);
- Risk Frontiers maintains the Australian PerilAUS database\(^{66}\); and
- The U.S. NFIP produces local flood maps.

These and similar tools can aid stakeholders in assessing and managing flood risk.

Data availability and the ability to manage flood risk have improved immensely in recent years, opening new opportunities for private sector insurers to offer flood insurance. In the past, a combination of poor geographic resolution; insufficient data regarding localized elevation, topography, and building characteristics; and inadequate computational capacity often meant there was information asymmetry between the insured and insurer whereby the insured knew more about a property's flood exposure than the insurer. This was particularly true when insurers set premiums and managed exposures by postal (or zip) code.

Recent improvements related to data and modelling are due to:

- LIDAR, which is an air-based radar mapping approach used to create detailed elevation maps;
- Hydrology studies and other local mapping of flood risk in a growing number of flood-prone areas;
- Google Earth and satellite imagery, both of which allow for a much finer assessment of local hazard and building stock; and
- Computational power that has increased exponentially, allowing complex computer models to simulate floods and provide the advanced analytics insurers need to more accurately price and underwrite flood risk, supplemented with site and area inspections of risk characteristics and understanding area-wide mitigation approaches taken.

As these tools become more widely available, stakeholders’ perception of flood risk improves. However, users of these tools need to be aware of their limitations, particularly as many of the issues discussed later in this section are often difficult to quantify.

5.2.3 Limitations related to risk perception

Risk perception is critical to understanding the constraints facing key stakeholders. Risk perception is dependent on high-quality data, sophisticated modelling tools to interpret the data, and a mechanism that sends accurate economic signals to stakeholders to inform good decision making. Even many economically-advanced countries lack one of these three critical elements for some of their exposures subject to flood risk.

For example, in the United States, the Federal Emergency Management Agency (FEMA) produces NFIP flood maps for properties that apply for federally insured mortgages that show areas with a 100-year flood exposure,\(^{67}\) which are the only areas where flood insurance is mandated in order to qualify for these mortgages. Many people in large parts of the United States inaccurately believe that just because they live outside the 100-year flood “bright line”, they are not exposed to flooding. Recent events, such as Hurricanes Sandy (northeastern United States, 2012), Harvey (Texas, 2017), and Florence (Carolinas, 2018) and the extreme flooding in the Midwest (2019) have exposed the fallacy of such beliefs.
Many developing countries lack not only basic flood information, but also up-to-date access to detailed exposure information (such as specifics of construction). The situation is further complicated in these countries by rapid development, incomplete modelling, and limited insurance coverage. The 2011 floods in Thailand exemplify this situation. Despite widespread availability of flood insurance for large commercial risks in Thailand, the high degree of insured flood losses proved to be a surprise to some. This flood inflicted damage to an industrial zone in which foreign companies owned businesses that were part of global supply chains, which resulted in a relatively low coverage gap. Historically, private sector insurers considered Thailand to be a low priority for investment in the development of catastrophe models. Thus, many insurers incorrectly believed that because the flood risk was not modelled, it did not exist. This points out that insurers need to understand the insurance exposure in the area in which they operate.

5.3 Externalities and Human Intervention

One key differentiator of flood risk (and its perception) is how the risk can change over time due to a combination of human activity and changes in climate. The influence of human activity on flood risk is profound and should not be understated. On this topic, Jongman states:

Even if we manage to model population density and flood inundation with increasing accuracy, assumptions about peoples’ risk reducing behavior, willingness to relocate, and access to information play a key role in the actual level of risk. Neglecting this behavioral component may overestimate actual impacts by a factor of two. Recent innovations in agent-based modeling now allow us to integrate complex human behavior in integrated risk assessments, which will allow us to create much more realistic scenarios of flood impacts and possible adaptation solutions.

Several flood-related metrics, such as the incidence of extreme precipitation events and sea level, are changing, which most scientists attribute to climate change. The changing metrics increase the uncertainty of estimates of flood-related damages, which in turn may potentially affect the financial soundness of flood insurance frameworks. In Section 5.4, a discussion of how rising sea levels may affect building code requirements is used to illustrate the non-stationarity of some flood metrics, which poses a significant challenge to actuaries involved in flood risk management, particularly in the quantification of flood risk.

In recent decades, both ground and satellite observations show a significant decline in ice contained in glaciers and high-latitude ice caps. Observed temperatures have increased significantly in both the Arctic and Antarctic, and have had and are expected to have significant long-term effects on sea levels and coastal flooding in many areas. Even if high-latitude temperatures stabilize at current levels, significant amounts of ice will melt in coming decades. These meteorological and ecological processes will continue to contribute to rising sea levels. Figure 5 shows the annual change in the Sea Level Index from the Actuaries Climate Index for North America, which clearly indicates a significant rise in sea level over the last several decades.
The current scientific consensus is that this trend will continue throughout this century. There are hundreds of millions of people and trillions of dollars in property exposed to coastal flooding across the world. Bangladesh exemplifies this situation as it suffers not only from flooding in its south due to sea level rise but also in its north due to excess ice-melt as glaciers recede more each spring. As discussed in the next section, weather conditions and the long-term effect on the climate pose unique challenges to both private sector insurers and governments in providing flood insurance.

5.4 Social Issues

The likelihood that rising sea levels could threaten large parts of the world’s coasts is an illustration of several possible social questions that drive the discussion of the role of government in flood insurance. The discussion that follows uses rising sea level as an example of a social issue involved in flood risk management.

Consider property located in an area threatened by rising seas. Its insurance premium, if based on historical data or even current conditions, will likely not reflect the increased risk the property will face in the future. This is in large part because insurers use short-term policies (often one year in duration) that can be repriced or even non-renewed each year. As a result, insureds can fail to receive an important economic signal regarding the future cost of their properties. Without an early warning indicator of the risks ahead, there is little or no financial incentive to implement mitigation measures that could control this risk. In addition, insurers can also suffer where their premiums only reflect current conditions, for as discussed in Section 7, governments often intervene when changing conditions warrant increasing premium levels or a shortage in the supply of insurance emerges because of a revised assessment of risk.

Recent studies indicate that property values in several parts of the coastal United States threatened by rising sea levels are already adversely affected and that some mortgage lenders are questioning their risk from 30-year mortgages in such areas.70 According to Bloomberg News:
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Between 2007 and 2017, average home prices in areas facing the lowest risk of flooding, hurricanes and wildfires have far outpaced those with the greatest risk, according to figures compiled for Bloomberg News by ATTOM Data Solutions, a curator of national property data. Homes in areas most exposed to flood and hurricane risk were worth less last year, on average, than a decade earlier. 

Several social questions arise regarding the situation described in Bloomberg News, including:

- Should the burden of high insurance premiums or declining property values fall on insureds, property owners, or society in general?
- Does the property owner in a high-risk area have an obligation to take mitigating actions?
- What is the responsibility of the government entities that adopted building standards that later proved inadequate for greater evolved risk?
- What, if any, responsibility for this economic damage should fall on the entities that contributed to the drivers of rising sea levels (such as emitters of carbon) or should the effect be entirely borne by the insureds and their insurers?

While these questions generally fall outside the actuary’s traditional ratemaking or risk management competencies, they nonetheless affect the environment in which the actuary’s work is used. Actuaries should be aware of these social issues when working in flood risk.

The above discussion illustrates a key question regarding building codes and land-use development in areas where flood risk is changing due to rising sea levels or other environmental factors. To what extent should building codes and land-use policies reflect possible future conditions expected during a building’s design life? To the extent the future is uncertain, how can the costs and benefits of various building code strategies be brought into a coherent flood insurance framework?

Actuaries can extend existing catastrophe and economic capital modelling tools to inform public policy decision making related to flood risk management. While a discussion of how this might be done is outside the scope of this paper, it is important for actuaries to understand that their contribution to solving issues related to flood risk and flood insurance will likely extend beyond their traditional activities.

5.5 Summary

This section discusses several constraints that affect the development and maintenance of flood risk management. There are many stakeholders involved, with differing risk perceptions influenced in part by their own interests (for example, economic and timeframe perspectives). Risk perception can be a difficult concept for individuals, businesses, governments, and insurers to grapple with and communicate. Recent advances in data and modelling offer hope for improvements to overcome some of the obstacles presented.

Flood risk is a moving target, significantly influenced by human activities and global climate patterns. Its changing nature poses unique challenges for public policy planners and leads to many difficult social questions. Major changes may be required in how policymakers think about building code and land-use development in a rapidly changing world. Actuaries should be aware of the environment so that they can properly analyze flood risk and influence decisions on flood risk management, including the design and pricing of flood insurance products.
6. Actuarial/Cost-Based Pricing

The price of any private sector insurance product should adequately provide for all costs associated with the transfer of risk, including losses, expenses, and a reasonable return for the insurer.

Section 7 notes that government programs can operate under somewhat different rules than private sector insurers, and thus, actuarial pricing for flood risk can differ between the private sector and public insurers. For either type of program, actuarial pricing for flood insurance can be quite difficult given the uncertainty of flood losses in the short term and the need for unusually detailed data about a wide range of topics.

This section primarily focuses on property-related flood risks, rather than life and health insurance. There are not as many special issues for the life and health perils as they relate to the effect of floods, although many of the basic principles are similar.

6.1 Importance of Up-to-Date, Granular, High-Quality Data

To produce premiums that are in accordance with actuarial standards and best practices, actuaries need data that is up-to-date, granular, and of high quality.

Flood risk is a function of weather (generating water), other natural disasters such as offshore earthquakes, local topography and bathymetry, soil, drainage, building characteristics, and infrastructure (much of which may be hundreds of miles from the area being examined for flood exposure).

Some of these parameters, which are critical to actuaries quantifying flood risk, can change often and at times dramatically. The shifting parameters can be driven by global effects, such as rising sea levels or increasing temperatures, or by local human activity, such as changing building codes, land-use policies, deteriorating flood control structures, and building in flood-prone areas.

Development of areas near rivers, streams, or seashore changes the topography, adding hard ground cover where water runs off instead of soaking in. This is particularly important when wetlands are paved over, as was the case in the Houston, Texas, area during Hurricane Harvey (2017) and in Toronto, Ontario, during severe flooding in 2013. Miami Beach, Florida, is another example where non-storm flooding has become a regular occurrence partly due to human actions. Deforestation, as in Brazil and Indonesia, can also lead to devastating flash floods. Constructing heavy buildings on soft soil causes land subsidence that exacerbates flooding potential, especially near a coast.

All of the above can cause shifts in assumptions and parameters that actuaries use to estimate flood risk, both for pricing and for planning purposes.

6.2 Effects of Catastrophes

Although many loss-causing flood events are relatively small, catastrophic floods result in the largest share of flood-related losses. After floods in the United States in the late 1920s, private sector insurers effectively refused to write flood insurance, deeming the peril uninsurable. Also,
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after Hurricane Andrew in 1992, many U.S. insurers drastically reduced their writings. The creation of an alternative catastrophe insurance market in Bermuda resulted from this market depression in the United States.

For a ratemaking analysis to produce adequate premiums over time, the long-term catastrophe potential should be considered and appropriately reflected. Catastrophe losses can be estimated based on average annual losses (AAL) that account for the possibility of extreme events using actual historical data or simulated values from a catastrophe model. In addition, given the significant uncertainty in estimating annual expected losses for flood risk, premiums should also contain an appropriate risk loading in the profit provision. (See Section 6.4 for further details.)

6.3 Quantification of Flood Risk

6.3.1 Catastrophe modelling and use of historical data

In quantifying risk for catastrophic perils, the usefulness of historical insurance loss data can be quite limited. The low frequency of catastrophes, particularly on an annual basis, with an associated high severity of losses makes it difficult to amass sufficiently credible data from which to base annual loss projections for a specific property. Further, for small regions or specific properties, the loss experience is rarely useful.

Actuarial Standard of Practice 12 (U.S.), Risk Classification, states that "the actuary should select risk characteristics that are related to expected outcomes". When the experience of an individual risk does not provide a credible basis for estimating costs, as is often the case when projecting premiums for flood insurance, it is appropriate to consider the aggregate experience of similar risks.

Actual loss experience can be used to determine the amount of overall premiums needed for a large geographic area (such as a region, state/province, or a country) if the experience period is long enough to include a reasonable number of large flood events (i.e., an event list). As indicated previously, changing conditions can make the reliance on data over a long timeframe somewhat problematic. Even with adjustments for changing environment and human activity, a catastrophe loading requires significant professional judgement.

The key differentiator in flood ratemaking, quantification of capital charges, and risk assessment (such as in the development of an "Own Risk and Solvency Assessment"), is the modelling involved. A flood model developed or purchased (such as those developed by commercial vendors of catastrophe models) produces various metrics, including the AAL, the maximum probable loss, and applicable risk tolerance, at whatever level of granularity needed. In addition, an event list, which can be used for capital loading to examine concentration charges, is developed.

Beginning with a credible flood model, the ratemaking process is similar to that for tropical cyclone, earthquake, or any other peril where rates are derived from models. This includes assessment of the particular risk characteristics of the insurance exposures and expected mitigation and loss prevention/reduction techniques taken by the insured as well as the design of the insurer's reinsurance program.
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In summary, the resultant AAL at applicable resolution is developed, including loadings for the cost of reinsurance, expenses, risk margin, and overall profit load desired/obtainable. A more detailed discussion of the ratemaking process for flood risk is beyond the scope of this paper.

6.3.2 Advances in modelling capabilities

The use of catastrophe models for flood risk is rapidly becoming the market norm, not only in Europe, Asia and Australia, where such models have been in use for some time, but also in the United States and Canada, where the private sector did not offer flood insurance. Catastrophe models can be used to estimate annual losses at a highly granular level. New versions of these models have improved capabilities for assessment of U.S. and Canadian flood risk as well as for some countries in Asia, Oceania, and South America. Catastrophe models will continue to evolve and become more refined over time, as they incorporate the latest catastrophe events and up-to-date science and modelling techniques.

Catastrophe models use extremely detailed information about exposures to analyze the likelihood of water levels in relation to a specific structure to estimate how much loss might occur during floods of varying sizes, together with a corresponding probability. This is done for an exhaustive library of potential events that can be simulated for a portfolio of insured properties to generate measures of large loss likelihood and AAL. Both measures can be used for ratemaking purposes, with the average annual loss representing the expected loss and the large loss estimates used for a catastrophe loading. The volatility around average values can be used to affect the size of the loading for uncertainty in the profit provision.

Computer modelling for flood losses can be more difficult than for hurricane or earthquake due to the localized character of flood hazard (as there can be dependence on conditions at the site level, e.g., elevation that can vary from house to house or business to business) and the need to consider the effectiveness of sometimes distant infrastructure (e.g., a dam hundreds of miles upstream).

6.4 Loading for Uncertainty (Risk Loading)

A key consideration in any ratemaking process is a risk loading to reflect the uncertainty in the estimation of losses. For properties susceptible to catastrophic losses (i.e., low-frequency/high-severity events), the uncertainty is quite high. The size of the risk loading depends heavily on the concentration of properties that can be damaged by a single event and the insurer’s appetite for risk. For coastal floods, uncertainty also exists due to the effect of tides, as potential damage depends not only on the effect of the tropical cyclone but also on the effect of daily, monthly, or annual tidal forces.

Catastrophe models are useful in estimating the risk loading for ratemaking purposes, as the portfolio of properties under consideration is a key input to the model and statistical measures of concentration. In determining a loading for uncertainty, scenario analysis can also be useful for understanding and quantifying the effect of future floods under different weather and water scenarios. The effect of future floods can differ significantly by location and condition. A key factor involved in the application of catastrophe models to a particular insurer is the extent and design of the reinsurance program used.
6.5 Summary

High-quality data are necessary for the development of actuarial premiums for any type of peril. Acquiring such data is difficult for flood risk, as very granular data related to many different risk factors are required to accurately estimate the expected loss for a particular property. In addition, data and information are constantly changing, leading to even greater uncertainty in the quantification of flood risk. Producing flood premiums is especially difficult given the catastrophic nature of flood losses, where large and infrequent losses, which cannot be projected with precision as to which year they will occur, tend to result in most of the aggregate loss. Currently, catastrophe models are a critical tool in the ratemaking process and will be even more so as they continue to improve.

7. The Role of Government

Governments and the public sector can, and most do, play a significant role in managing flood risk. Activities include engineering (such as construction and maintenance of dams and levees), promulgating building codes, issuing land-use permits, regulating insurance markets, offering "coverage of last resort", and dispensing disaster aid. Governments also manage adaptation strategies and investments in respect of climate change and have to make difficult decisions about protecting or abandoning areas prone to flooding. A detailed discussion of the myriad of ways governments affect flood risk is beyond the scope of this paper. Instead, the focus of this section is on several key activities performed by numerous governments and on significant differences in the operations of private sector and government insurance providers. Five examples of government frameworks are described in this section.

7.1 Non-Insurance Activities that Affect Insurance Markets

Three government activities are particularly important in supporting insurance programs for flood risk: data aggregation, financial investment, and development of land use and construction policies. These activities, described in detail below, tend to be more robust in developed countries.

Many governments, often in concert with the private sector, collect historical records of flood losses, maintain flood databases, and promulgate maps of flood risk, which provide information such as estimated return periods for flooding of certain depths. These types of information are used in many aspects of flood risk management, including formulating or revising building codes, establishing land-use policies, and providing data required for catastrophe modelling. Property records that show the number and types of buildings, elevation, proximity to water, use, value, and construction are also important.

Almost all governments invest resources in flood risk management (including mitigation, adaptation, and disaster response systems). Investment activities include constructing and maintaining dams and levees, managing water resources to protect against droughts and floods, and providing financial and other assistance during and after flood events to expedite recovery.

Governments that anticipate extreme future flood damage can mitigate future loss by helping relocate population and infrastructure, although it may cost a lot to do so. An example is the
movement of capitals to alternative locations. For example, in May 2019 Indonesia announced it will relocate its capital from Jakarta – the decision follows decades of warnings about the city’s catastrophic flood risk due to sinking land and rising seas. Indonesian President Joko Widodo indicated that the move is necessary because the city can no longer support its massive population in the face of environmental threats such as the sinking of the city (during the past 30 years Jakarta sank more than 10 feet), as well as concerns regarding traffic congestion and water shortages. Other coastal cities, such as Bangkok, may similarly be affected.

Finally, most governments promulgate building codes and land-use policies. Key considerations include whether construction of buildings is permitted in high-risk areas, whether reconstruction is allowed after an adverse event, how buildings must be elevation-adjusted and flood-proofed, and what construction techniques must be used or avoided.

Actuaries assessing flood risk and calculating flood premiums should understand all the issues noted above. The types of flood insurance programs found in various countries are influenced by factors such as the quality of available data, the sophistication of flood control mitigation and adaptation approaches, and the effectiveness of building codes and land-use policies. As noted repeatedly in this paper, flood risk changes over time, and thus the responsiveness of government activities to changing conditions is critical.

7.2 **Private Sector and Government Insurance**

In countries with robust private sector insurance markets, governments tend to become involved in offering coverage only where it is perceived that private markets have failed to deliver available and affordable insurance needed by consumers or other stakeholders. An example of an important non-consumer stakeholder relevant to flood risk are mortgage lenders that can face significant losses if borrowers default on loans due to lack of or inadequate financial protection.

Section 4 contains a detailed discussion about the protection gap. Private sector insurance markets have failed to provide adequate financial protection for flood risk in many countries for several reasons, including:

- Historical difficulty in obtaining high-quality data in the required granularity that relate to buildings and other flood risk characteristics;
- Historically limited coverage by catastrophe models of flood risk;
- Significant exposure to large catastrophic events;
- Substantial numbers of risks with very high exposure to loss that raises affordability issues; and
- Many areas with very low risk of flooding, making it difficult to develop a sufficiently wide premium base for what is often a very localized peril.

Governments in many countries have been involved with similar issues with earthquakes, terrorist attacks, and tropical cyclones, and have formed government insurance programs that supplement (or in some cases completely replace) private sector insurance markets. These government programs take many forms, including direct insurance, reinsurance, and microinsurance. The table in the Appendix summarizes various flood insurance frameworks around the world. A review of these frameworks indicates there is wide diversity in how these markets operate, making it difficult
to describe a generalized model of flood markets and government programs. Certain principles and practices, however, underlie the operation of private sector and government insurance programs.

To better understand how government insurance programs operate differently from private ones, it is helpful to review several basic principles and practices. Those applicable to private insurers include:

- Insurers can select the risks that they insure;
- Insurers should have sufficient premium income, reinsurance, and capital prior to a catastrophic event to cover foreseeable claims, including those arising from such an event;
- All costs associated with providing coverage to policyholders should come from policyholders;
- Losses can be spread across space using reinsurance, but not usually across time, as all revenue and costs are accounted for during the policy period;
- Premiums collected from a group of policyholders should cover the full cost of the applicable risk transfer;
- To the extent practical, the amount of premiums charged should reflect the relative risk of policyholders given that cross-subsidies among classes of policyholders are difficult to maintain in a competitive and sustainable market; and
- Policyholders can be provided incentives to mitigate their flood risk through premium differentials and policy conditions, but usually cannot be compelled to act.

These principles and practices often make it difficult for insurers in the private sector to provide flood coverage to all risks in a given market.

Government insurers can operate in a manner inconsistent with the principles and practices of the private sector, which enables them to provide coverage in a different manner. The fundamental reason government insurers can do so is that they possess the sovereign power to compel individuals and businesses to pay taxes (sometimes called assessments, levies, or surcharges) that do not necessarily reflect the value of services provided to a specific individual or business or groups of individuals or businesses.

Public insurers generally adhere to the following principles and practices:

- Governments can supplement premium income from a group of policyholders with financing from external sources (through subsidies), such as general tax revenue;
- Governments can spread losses across both space and time using reinsurance and post-event financing, as a government insurer can run a negative surplus to finance a loss in one period with revenue from a later period;
- Governments can create cross-subsidies within insurance programs by requiring participation and charging premiums that are above or below expected costs, possibly with a goal of enhancing overall affordability; and
- Governments can compel insureds to engage in mitigation through, for example, laws, land-use rules, and building codes.

The ability of government insurers to operate utilizing different principles and practices than private sector insurers is the key reason they often become involved in markets that have experienced private sector desertion or failure.
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The development, design, and maintenance of public programs can also consider possible co-benefits and co-costs. An example is the construction of flood defences that might as a consequence encourage greater investment and higher density settlement in protected areas. If the flood risk subsequently turns out to be worse than anticipated and the defences are breached, the cost to society could then become greater than in the absence of that investment. In addition, enhanced infrastructure can be made both to reduce flood risk and to benefit society and industry in different ways. Additional co-benefits might arise whether or not a flood arises, such as through provision of irrigation, potable water, and hydroelectric power from dams.

Actuarial standards and principles related to insurance ratemaking are generally well understood. For private sector insurers, premiums are developed to include the full cost of risk transfer that includes provision for all expected losses and expenses as well as a profit provision. Expected losses include a catastrophe provision, and the profit provision includes a loading for uncertainty. Generally, ratemaking should provide for the costs of an individual risk transfer so that equity among insureds is maintained (i.e., limited cross-subsidies).

For government entities insuring catastrophe exposures, however, the process for deriving an “actuarial” premium is difficult or impossible to calculate without an explicit understanding of key factors such as:

- How much revenue is expected to come from policyholders?
- How much external or post-event financing is available?
- What degree of cross-subsidization is desired?

Direction on these issues must come from public policy makers to assist the actuary in developing appropriate premiums for a government insurance program. In accordance with actuarial standards, guidance related to the above should be fully documented and communicated with users of actuarial work, as should all other key assumptions in the ratemaking process (for both public and private sector programs).

There is no clear answer to the question of whether private sector or government insurance programs are better. This is reinforced by the wide variety of flood insurance frameworks described in the Appendix. However, several generalizations can be made about the consequences of the different programs, which can be validated by recent flood experience.

Private sector programs tend to:

- Include the ability to select and reject risks;
- Charge premiums reflecting current year risk exposures; and
- Have a refined set of risk classifications.

This approach can lead to premium volatility when catastrophic risk is present (due in large part to the market cost of reinsurance) and can result in problems with availability and affordability for relatively high-risk insureds.
Government insurers tend to:

- Use one or more external sources for financing large losses;
- Take all comers that meet specified conditions;
- Have a less refined risk classification; and
- Spread losses over time such that not all losses are financed from current year revenue.

This approach can lead to large deficits when catastrophes strike but often lower up-front cost. Due to the ability to utilize cross-subsidies, government insurers can also address issues related to availability and affordability for relatively high-risk insureds.

### 7.3 Examples of Flood Insurance Frameworks

Many countries have found that the unique nature of flood risk has led to problems with both effective mitigation incentives and a limited number of insurers that are willing to make affordable private sector insurance available, particularly for personal insurance. As a result, countries have created a variety of flood insurance frameworks to finance flood losses. Five examples are described in this section. A more complete list of country-specific mechanisms is contained in the Appendix.

The following discussion focuses on residential risks, as most government programs are targeted at such risks, with some coverage for small businesses. Generally, large commercial risks are covered by private sector insurance companies, some form of self-insurance, or a combination.

#### 7.3.1 Australia

In Australia, private sector insurers provide almost all of the flood insurance coverage. There is no government flood insurance program, and property insurance premiums are not regulated.

Historically, there was significant public confusion as to the types of floods that were covered by insurance policies, as various companies sold products with a range of coverage on both a bundled and an optional basis. This situation created significant problems during the Queensland floods in 2010 when many policyholders discovered that their coverage excluded riverine flooding, but covered flash flooding. As most of the flooding in Queensland was riverine, numerous coverage disputes arose.

In recent years, the government allowed insurers to develop a common definition of a flood to be used in insurance policies. The common definition, combined with the availability of high-quality data from the National Flood Information Database, allow the private sector to offer flood insurance to a large proportion of risks. Generally, insurance for flash and riverine floods is widely available, while coverage for coastal inundation is often excluded.

There were significant premium increases following the 2010 event for properties deemed to be high risk, although some insurers capped annual increases for existing insureds. Risk-based pricing led to pressure on the government to enact mitigation and adaptation measures that enabled lower premiums.

Australia is an example of a country where the government relies almost exclusively on the private sector to provide flood insurance. This results in premium levels for high-risk properties that would
be considered unaffordable in some countries, but protects taxpayers from large government pool deficits, leads to wide availability of flood insurance, and provides strong incentives for risk mitigation.

7.3.2 France

All comprehensive home insurance policies in France must include coverage for natural catastrophes. The French have a public–private partnership system, providing state-owned government-guaranteed reinsurance through the Caisse Centrale de Réassurance (CCR).

Private sector insurers can voluntarily transfer 50% of their natural catastrophe risks to the CCR, which offers a low reinsurance premium and has an unlimited government guarantee. The government was required to recapitalize the CCR with €450 million following storms in 1999, although by 2013 the CCR had built up reserves of €6.4 billion. In addition, private sector insurers pay the government 12% of premiums received to finance mitigation projects.

France is an example of a government providing a low-cost reinsurance mechanism in exchange for requiring private sector insurers to offer coverage. The broad pool created by the requirement to extend all property (and motor vehicle comprehensive) policies to include natural catastrophe perils can be a significant advantage to promote comprehensive insurance coverage. The low cost of the CCR helps make flood insurance affordable to consumers. The program has built a considerable surplus and requires limited government action. The government supports mitigation efforts through a premium levy.

7.3.3 Thailand

Thailand experienced extreme flooding in 2011 that was estimated by the World Bank to have resulted in US$46.5 billion in economic damages. The event exposed several issues relevant to actuaries’ understanding of flood risk:

- Similar to floods in Queensland, Australia, in 2010, there was considerable controversy regarding government water management practices. Low rainfall during the previous year triggered concern about water shortages, prompting dam operators to build water reserves in 2011. This left dams unable to contain flow caused by very high rainfall in 2011, contributing to severe flooding.
- Thailand was home to many large industrial facilities critical to the global supply chain, most of which were built near rivers to facilitate transport. The floods triggered global problems with supplies, affecting manufacturing activities in locations far removed from the scene of the flooding.
- Prior to the event, Thailand floods were not well covered by commercial catastrophe models. This led to an analytical blind spot for risk managers at many global insurers. When huge losses occurred, it demonstrated that one cannot assume a risk does not exist just because existing catastrophe models do not detect it.

The 2011 event led to significant disruption in insurance markets and left many households with large uninsured losses, with about 28% of economic damages covered by insurance. Following the floods, many business and individuals could not find affordable insurance policies covering flood.
In response, the Thai government created the National Catastrophe Insurance Fund (NCIF) to offer insurance coverage against natural disasters.\(^7^4\)

NCIF coverage is triggered by a government disaster declaration, a total of 5 billion Baht of claims (US$158 million) to the NCIF, an earthquake measured at a magnitude of at least 7, or a tropical storm with winds exceeding 120 kph. NCIF coverage is offered by insurers as an add-on to fire policies. Coverage is available to individuals, small and medium-size enterprises, and the industrial sector for a premium that ranges from 0.5% to 1.25% of the coverage amount.\(^7^5\)

### 7.3.4 United Kingdom

Historically, the U.K. government and insurance industry agreed that no residential property would be refused flood insurance, while the government would make necessary investments in flood defence to protect against extreme losses. Following widespread flooding in 1998 and 2000 when insurers alleged that the government failed to maintain its part of the bargain, a more formalized arrangement known as the Statement of Principles (the Statement) was developed. The Statement incorporated the previous agreement, but specified that the insurance industry would withdraw from providing universal flood cover unless the government improved flood defences.

The Statement was maintained until 2013, when a new flood insurance framework was developed based on a public–private partnership to provide coverage to high-risk properties. Flood Re was established in 2016 with the following characteristics:

- All residential insurance policies include flood cover;
- Insurers have the option to reinsure high-flood-risk properties with Flood Re, with premiums for the reinsurance based on the property’s local Council Tax value, which targets subsidies towards lower-income households;
- Flood Re reinsurance premiums do not vary by individual property flood risk characteristics;
- Reinsurance premiums are supplemented by a levy on insurers based on market share, at a level designed to cover the overall subsidy needed for the high-risk customers;
- Flood Re purchases its own reinsurance in the global market;
- Flood Re’s premiums and levies are to be reviewed every five years, with the program scheduled to expire in 2039; and
- Insurance premiums are not regulated, meaning that the effect of Flood Re subsidies is provided indirectly.

The United Kingdom is an example of a market with a largely private sector approach to affordable flood insurance. The government provides the flood risk management framework for the solution and bears responsibility for identification, implementation, monitoring, and promoting flood defence through mitigation and adaptation measures. Barring an extreme catastrophe, Flood Re should operate without the need for subsidies from the U.K. Treasury. As noted above, Flood Re is designed to promote private market coverage and disappear in 25 years.

### 7.3.5 United States

Unlike many other countries, insurance for any type of rising water in the United States is generally excluded from residential insurance policies. For a variety of historical reasons, U.S. insurers generally do not offer any residential flood coverage, particularly in high-risk areas, deeming the
risk to be too great. The NFIP, which operates under the FEMA, was formed in 1968 to close the protection gap. The NFIP also offers insurance to small businesses.\textsuperscript{76}

The NFIP was designed to encourage mitigation of flood risk, which in the United States requires local governments to enact building codes and land-use policies in flood-prone areas. In exchange for making the NFIP insurance available, often at highly subsidized premiums, local communities agree to enact numerous flood management programs. A key objective of the NFIP is to reduce post-event government disaster-aid payments through a combination of loss prevention and insurance benefits. The NFIP covers all type of floods, including coastal.

The NFIP undertakes detailed hydrological and engineering studies of flood-prone areas and provides detailed maps of flood risk. These maps include a 100-year flood line within which properties are required to purchase flood insurance to qualify for federally-backed mortgages (it has been estimated that 13.3\% of the U.S. population are exposed to at least this level of flood risk\textsuperscript{77}) and where flood management activities are concentrated. While the program offers policies outside these high-risk zones, relatively few consumers purchase these policies. As a result, most U.S. residential risks have no flood coverage, which has exposed many to significant uninsured losses in events such as Hurricane Harvey.

While intended to be self-supporting, the design and process for setting premiums leaves the NFIP unable to cover its costs, largely because of Congressionally-mandated subsidies for certain risks and a lack of a full risk load for catastrophic events. By 2017, the program had about 5.1 million policies in force that generated US$3.31 billion of premium.\textsuperscript{78} At the end of the 2018 hurricane season, the NFIP had accumulated US$20.5 billion of debt, almost all of which was attributable to large coastal storms, such as Hurricanes Katrina, Sandy, and Harvey. In 2017 following several large hurricanes, Congress was forced to forgive US$16 billion of this debt to keep the program below its statutory borrowing limit of about US$30 billion.

The NFIP is authorized with a fixed expiration date to force the U.S. Congress to review its operations at regular intervals. The U.S. Congress has extended the program many times. However, the most recent authorization expired in September 2017, with the NFIP currently (2019) operating under one of several short-term extensions.

The U.S. Congress is currently (2019) considering many reforms to the program, including increasing incentives to grow a private sector flood insurance market. However, given the NFIP's financial results, it is difficult to see how these reforms can simultaneously maintain strong mitigation incentives, keep premiums affordable for high-risk customers, avoid significant premium increases (either through the NFIP or by private sector insurers), maintain current coverage levels, and improve its financial condition. In spite of considerable effort, participation remains disappointingly low, as many people underestimate how vulnerable they are to floods.

### 7.4 Observations on Flood Frameworks

While each of these countries’ frameworks for financing losses from flood is unique, certain general observations can be made:

- Loss mitigation, whether provided through private market incentives, government mandates, or eligibility requirements for participation in government programs, is a key component of managing flood risk.
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- Increased knowledge and the changing nature of flood risk often lead to properties that had previously been thought of as safe becoming recognized as high-risk, with attendant problems of providing available and affordable coverage. This has led many countries to develop government programs that force cross-subsidies.

- The catastrophic nature of flood risk poses challenges for flood risk management. The U.S. NFIP is an example of the financial problems that can arise by providing catastrophic flood cover without sufficient provision for adequate financing.

- A government decision regarding the exact locations (e.g., cities and counties) that will participate in the government program is essential. For example, in France, *arrêtés de catastrophe naturelle* are prescribed by the French government, thus indicating the areas for which flood coverage is required when property insurance is purchased. Sometimes, however, a mismatch occurs between the “official” locations and the damages that arise. In these situations, the funds made available to cope with flood losses can be limited or inappropriately allocated.

### 7.5 Summary

Governments play a central role in managing flood risk. This involves managing critical infrastructure (including an emergency-response program) and enacting building codes and land-use policies to reduce loss exposure. Governments also create the framework within which both private sector and government insurance programs operate. There are significant differences between the principles and practices under which these different programs operate. Understanding the differences is critical to actuaries’ ability to support both types of programs. Various countries have built unique programs suited to their local conditions to finance flood losses, though there are some similar features.

### 8. The Role of Actuaries

Actuaries play an important role in all aspects of insurance and risk management, with respect to both short- and long-term risks faced by individuals, businesses, and governments. Actuaries support both the private and public sectors. They operate in traditional markets that offer standard insurance products and incomplete markets where solutions are often novel and creative. Actuaries routinely determine premiums, perform valuations of insurance liabilities, and participate in each step of the risk management process described in Section 3. Actuaries can also serve in much broader capacities to influence important public policy, such as program design, land-use policies, and building codes.

Actuaries abide by stringent professionalism requirements that govern all aspects of actuarial work, including analyses and communications. Stakeholders can depend on actuaries to identify and gather relevant information and continually refine their analytical tools as they contribute to developing solutions to today’s current problems.
8.1 The Role of the Actuary and the IAA

The IAA describes the many functions the actuary can serve in its 2013 paper *The Role of the Actuary*.

Actuaries fulfill many roles in a broad range of environments, including insurance companies, health organizations, pension plans, risk management, government, regulatory regimes, and in other fields. They have a detailed understanding of economic, financial, demographic and insurance risks and expertise in:

- developing and using statistical and financial models to inform financial decisions;
- pricing, establishing the amount of liabilities, and setting capital requirements for uncertain future events.

Actuaries also provide advice on the adequacy of risk assessment, reinsurance arrangements, investment policies, capital levels and stress testing of the future financial condition of a financial institution. ... One of the key skills of an actuary is the development and application of models to help solve complex financial problems. ... Actuaries add value to the raw output of a software model by using their professional judgement to assess and explain the practical implications of the results and the limitations of the model.79

8.2 Actuaries and the Flood Risk Management Process

In the context of flood risk, actuaries understand that a unique solution does not exist that will satisfy all stakeholders. Thus, stakeholders work collaboratively with a wide range of non-actuarial professionals (such as specialists in meteorology, building construction and land use, geology, geography, and government policies and programs) to foster the dialogue and debate necessary to address the complex issues underlying flood risk.

Given the experience of working in each step of the risk management process, actuaries can offer appropriate and objective feedback, particularly with respect to advantages and disadvantages of specific techniques used to address flood risk. Actuaries recognize that approaches that work for some risks and exposure populations may not work for others.

Referring to Figure 4 in Section 3, actuaries have valuable contributions to offer in the identification and assessment of risk (Steps 1 and 2, respectively), which are closely tied to the identification of data required for measurement (Step 4). In identifying data to assess and measure risk, actuaries recognize that it may not be appropriate for experience taken from one set of conditions to be used for another. For example, property damage depends on the location and the effectiveness of land use, building resilience, and other mitigation techniques.

Actuaries can offer important insight regarding risk reduction and prevention (Step 3) both in terms of how such activities could be incorporated into insurance program design and in how they affect larger societal questions regarding land use and building codes. In an insurance system, program design is intricately linked to risk quantification. The very existence of a program or certain design features can alter the rate of utilization and amount of losses.
Flood Risk

Actuaries are also critical for the measurement of flood risk (Step 4), which typically incorporates the use of catastrophe models. Actuaries recognize the significant uncertainties involved in projecting changing conditions in countless areas with direct implications to flood risk (not the least of which are human behaviour and weather) and doing so over a long timeframe. It is precisely because of these uncertainties that the actuary’s involvement is so valuable.

The design of risk financing and risk transfer mechanisms (Step 5) will depend in large part on risk quantification, and thus actuaries should be involved in this step as well. Actuaries have expertise in quantifying all the components of risk transfer programs including losses (with catastrophe loadings), expenses, and profit provisions (including loadings for uncertainty). The actuary’s involvement in designing a program that incorporates appropriate incentives to reduce losses helps ensure more satisfactory long-term sustainable solutions for all stakeholders of flood risk.

Finally, actuaries should be engaged actively with other participants to monitor (Step 6) the entire flood risk management process on an ongoing basis. As noted in Section 3, there should be continuous feedback loops among the steps of the risk management process. Integrating the latest information applied to local conditions is crucial to the development of a sound, affordable, and sustainable program that properly spreads risk and provides appropriate coverage to participants.

In ongoing monitoring, the actuary would consider actual claims experience and the need for financial protection of the entity itself. Following a flood event, actuaries are frequently involved in the determination of claims liabilities (case liabilities, sometimes referred to as “case reserves”, and incurred but not reported liabilities). Actuaries also play a very important role in the analysis of capital required and reinsurance, particularly for private sector insurers, as these are critical to their financial soundness and sustainability. Actuaries use the results of catastrophe models as well as scenario and sensitivity analyses when evaluating capital and any reinsurance.

The actuary’s involvement in the flood risk management process as described above is necessary not only for the private sector but also for public programs.

8.3 Summary

The actuarial profession has a rich history of addressing complex problems and contributing to forward-looking solutions in the public interest. Actuaries bring healthy scepticism and refined approaches to the analysis of risk, recognizing the importance of dynamic techniques to respond to changing conditions, over both short and long timeframes. Actuaries can play an important role in providing advice regarding both public and private sector flood insurance and the management of flood-related risks.
## Appendix: Government Flood Insurance Mechanisms

<table>
<thead>
<tr>
<th>Country</th>
<th>Coverage Provider</th>
<th>Form of Coverage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Private</td>
<td>Public</td>
<td>Automatic Extension</td>
</tr>
<tr>
<td></td>
<td>Res       Com’l</td>
<td>Res</td>
<td>Com’l</td>
</tr>
<tr>
<td><strong>Australia</strong></td>
<td>X         X</td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Austria</strong></td>
<td>X         X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Belgium</strong></td>
<td>X         X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Canada</strong></td>
<td>X         X</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chile</strong></td>
<td>X         X</td>
<td></td>
<td></td>
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<tr>
<td><strong>Costa Rica</strong></td>
<td>X         X</td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Czech Republic</strong></td>
<td>X         X</td>
<td></td>
<td></td>
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<tr>
<td><strong>Denmark</strong></td>
<td>X         X</td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Estonia</strong></td>
<td>X         X</td>
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<tr>
<td>Country</td>
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<tr>
<td>Finland</td>
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<tr>
<td>France</td>
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<td>X</td>
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<tr>
<td>Germany</td>
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<tr>
<td>Hungary</td>
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<td>Iceland</td>
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<td>Ireland</td>
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<tr>
<td>Israel</td>
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<td>Italy</td>
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<tr>
<td>Japan</td>
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<tr>
<td>Latvia</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Mexico</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Netherlands</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tbody>
</table>
### Flood Risk

<table>
<thead>
<tr>
<th>Country</th>
<th>Coverage for Flood Damage</th>
<th>Coverage for Land Damage</th>
<th>Access Ways Coverage</th>
<th>Public Pool for Natural Disasters</th>
<th>Voluntary Coverage</th>
<th>Natural Peril Pool</th>
<th>Flood Coverage Requirement</th>
<th>Reconstruction Authority</th>
<th>Natural Disaster Coverage for Buildings</th>
<th>Mandatory Natural Disaster Coverage for Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Zealand</td>
<td>X X X X X</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Private insurers provide coverage for flood damage to structures. The public Earthquake Commission provides coverage for damage to land in and near residential properties and access ways.</td>
<td></td>
</tr>
<tr>
<td>Norway</td>
<td>X X</td>
<td>X</td>
<td></td>
<td>The Norwegian Natural Perils Pool has been established to pool natural disaster losses among private insurers.</td>
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<td></td>
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<tr>
<td>Peru</td>
<td>X X X X</td>
<td>X</td>
<td></td>
<td></td>
<td>Insurance coverage for all major natural perils, including flood, is voluntary, provided by most private sector insurers. Flood coverage can require an additional premium. “The Authority for Reconstruction with Changes”, was established in 2017 by the government to lead and implement a comprehensive plan to replace, rebuild and construct quality public infrastructure.</td>
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<tr>
<td>Philippines</td>
<td>X X X X</td>
<td>X X</td>
<td></td>
<td></td>
<td>Some general insurance coverage is provided by publicly-owned insurance companies. These companies are the only providers of flood insurance for high-risk properties.</td>
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</tr>
<tr>
<td>Poland</td>
<td>X X</td>
<td>X</td>
<td></td>
<td>The homeowner’s policy covers flood risk and all other natural perils automatically and is offered by most local private insurers.</td>
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<td></td>
</tr>
<tr>
<td>Portugal</td>
<td>X X</td>
<td>X</td>
<td></td>
<td>Insurance companies may not offer flood coverage, or may stipulate unaffordable tariffs.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>X X</td>
<td>X X</td>
<td></td>
<td>Insurance is not available for structures in flood zones (where in violation of construction permits). Insurance companies may exclude flood coverage in flood-prone areas.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>X X X X X X X X X</td>
<td></td>
<td></td>
<td>The risk is assumed by the Consorcio de Compensación de Seguros (CCS), a public entity attached to the government (provided it is not assumed by the insurer on its own). It is provided through a clause that is required to be included in property, life and personal accident insurance policies, with a mandatory surcharge. The CCS is provided with an unlimited state guarantee in case its resources are exhausted (not used to date).</td>
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<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>X X X X X X</td>
<td></td>
<td></td>
<td>Coverage for natural disaster losses is mandatory for residential and commercial buildings in 22 of 26 cantons. Insurance coverage for buildings is provided by private insurers in seven cantons. In the other 19 cantons, natural disaster insurance coverage for buildings is provided by canton monopoly insurers only. Coverage of contents is provided by private insurers in all cantons. Contents and motor vehicle insurance coverage is not mandatory.</td>
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</tr>
</tbody>
</table>
**Flood Risk**

<table>
<thead>
<tr>
<th>Country</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>The coverage of flood risk is not required as part of standard fire policies although, in practice, most policies are automatically extended to cover flood risk. However, insurance companies may not offer flood coverage in flood-prone areas or may stipulate extra conditions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Private insurers can transfer risks related to their coverage of certain high-risk properties to Flood Re, an industry-established pool, for which the government has agreed to fund relief if the country is hit by an especially costly flood.</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>The NFIP provides flood coverage for residential properties in eligible communities. Private insurers may also provide alternative or excess coverage for amounts above the maximum level of NFIP coverage (excess flood insurance) as well as coverage for additional living expenses (which is not covered by the NFIP).</td>
</tr>
</tbody>
</table>


Res: residential property (mostly all risks; Hungary, the United Kingdom, and the United States are flood only)
Com'l: commercial property (usually covers all risks)
Flood Risk

Glossary

Adaptation. A deliberate effort or adjustment in an ecological, social, or economic system to reduce the bio-physical effects of a possible flood.

Bathymetry. The measurement of depth of water in oceans, seas, or lakes.

Captive insurance company. An insurance company owned and controlled by its insureds, whose primary purpose is to insure the risks of its owners.

Catastrophe model. A comprehensive set of formal structures, data, and components used to capture processes associated with the effects of natural catastrophes.

CRED. The Centre for Research on the Epidemiology of Disaster is a research unit of the Université catholique de Louvain. It is situated at the School of Public Health of the Brussels campus of the university.

Cyclone (see tropical cyclone)

Cyclone bomb. A strong winter storm with high winds and heavy rains.

Dyke (also, dike). A long wall or embankment built to prevent flooding from the sea.

Ex-ante coverage. Pre-financing before an event that causes damages. Also referred to as advanced financing or advanced funding.

Ex-post coverage. Financing of losses after an event that caused damages. Also referred to as pay-as-you go financing.

Flash flood. A sudden local flood, typically due to heavy rain.

Flood. A significant rise of water level in a stream, lake, reservoir, or coastal region, or a temporary covering of land by water outside its normal confines.

Floodplain. An area that, due to its location relative to a body of water, is subject to flood hazard.

Flood hazard. A condition that increases the possibility of loss due to a flood. Alternatively, it can be used to express the probability of occurrence of a potentially damaging flood event.

Flood risk. The possibility of harm, with vulnerability due to a probable flood event.

Flood risk management. The process used to reduce the risks and costs associated with floods.

Flood vulnerability. The expected damage caused by a flood hazard that depends on the vulnerability of exposed elements.

Fluvial. Of or found in a river. (Also see riverine)

Hours clause. In a reinsurance contract, a provision that stipulates a time period during which multiple losses arising from a covered peril can be recovered as a single aggregated loss. Typically, the time period may be fixed at somewhere between 72 or 168 hours.
Flood Risk

Hurricane (see tropical cyclone)

Insurance. An organized program for financial (or equivalent value in goods or services) payments from an insurer to an insured (or designated beneficiary) as a result of an adverse contingent event or condition. It can be provided through the private sector (through a contract), the public sector (through a program established by law or regulation), or hybrid system.

King tide. A colloquial term, referring to the highest astronomical tides of the year, due to the interaction of the earth, moon, and sun in their orbits.

La Niña. A cooling of water in the equatorial Pacific, which occurs at irregular intervals and is associated with widespread changes in weather patterns complementary to those of an El Niño, but less extensive and damaging.

Lacustrine. An adjective related to or associated with lakes.

Landslide. The movement of a mass of rock, debris, or earth down a slope.

Levee. An embankment built to prevent the overflow of a river.

Mitigation. An action or technique that reduces costs or risks.

Premiums. The price an insurer charges for insurance coverage. Also referred to as insurance rates.

Pluvial. Relating to or characterized by rainfall. A pluvial flood, which occurs when an extremely heavy downpour of rain cannot be absorbed by land or drainage systems, is also referred to as a surface flood.

Protection gap. The difference between the needs of consumers and the approaches those consumers choose (or are required) to take to meet their needs.

Repetitive loss properties. Properties that experience similar flood damage over time.

Risk management process. A dynamic cycle, involving multiple steps, sub-processes, and feedback loops that address issues associated with risk and opportunities affecting an individual(s), business(es) or government(s). Sometimes referred to as an actuarial control cycle.

Risk perception. The judgements that a stakeholder makes about the characteristics and severity of a risk.

Riverine. Relating to or situated on a river or riverbank. A riverine flood occurs when excessive rainfall causes a river to exceed its capacity; also referred to as a fluvial flood.

Scenario. An internally consistent set of characteristics of a situation, event or series of situations or events under study. A scenario analysis is an assessment of a particular scenario under a given set of conditions.

Self-insurance. Insurance protection not provided by a third party (i.e., by the individual or business, sometimes through deductibles, co-payments, or lack of externally-provided insurance).

Storm. A violent disturbance of the atmosphere with strong winds and usually rain, thunder, lightning, or snow.
Flood Risk

Subsidence. The process by which an area of land sinks to a lower level than the land surrounding it, or a building sinks into the ground.

Subsidy. The amount of the reduction in the price for a good or service compared with that which would be charged in a competitive market. It can be provided for political reasons, for example, for those who cannot afford the subsidized price. A cross-subsidy arises in a situation in which some participants pay a higher price than the competitive price to offset the income lost due to the subsidy.

Surface flood (see *pluvial flood*)

Tropical cyclone. A generic term for a non-frontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection (i.e., thunderstorm activity) and definite cyclonic surface wind circulation.

Tropical cyclones with maximum sustained surface winds of less than 17 m/s (34 kt, 39 mph) are usually called “tropical depressions”. Once a tropical cyclone reaches winds of at least 17 m/s (34 kt, 39 mph), it is typically called a “tropical storm”, or in Australia a Category 1 cyclone, and is assigned a name. If winds reach 33 m/s (64 kt, 74 mph), then they are called either a:
- “hurricane” (the North Atlantic Ocean, the Northeast Pacific Ocean east of the dateline, or the South Pacific Ocean east of 160°E);
- “typhoon” (the Northwest Pacific Ocean west of the dateline);
- “severe tropical cyclone” or “Category 3 cyclone” and above (the Southwest Pacific Ocean west of 160°E or Southeast Indian Ocean east of 90°E);
- “very severe cyclonic storm” (the North Indian Ocean); and
- “tropical cyclone” (the Southwest Indian Ocean).

Tsunami. A long, high sea wave caused by an earthquake or other disturbance.

UNISDR. Acronym for the United Nations International Strategy for Disaster Reduction. Its mandate is “to serve as the focal point in the United Nations system to ensure coordination and synergies among disaster risk reduction activities of the United Nations system and regional organizations and activities in socio-economic and humanitarian fields”.

Notes

1 This paper intentionally focuses on the management of the potential losses and damages associated with floods, rather than their long-term benefits in some areas, especially in river basins.


3 Munich Re, “Natural Hazards/Hydrological Hazards”.


6 The Centre for Research on the Epidemiology of Disasters maintains the EM-DAT, which “contains the world’s most comprehensive data on the occurrence and effects of more than 21,000 technological and natural disasters from 1900 to the present day”. The EM-DAT was created with the support of the World Health Organization and the Belgian government.

7 CRED describes itself as “the world’s foremost agency for the study of public health during mass emergencies, including the epidemiology of diseases, plus the structural and socio-economic impacts of natural and technological disasters and human conflicts”.


10 Ibid.


12 In the United States, tropical cyclones are referred to as hurricanes, and in parts of Asia as typhoons. In this paper, the terminology “tropical cyclone” is used, except when referring to U.S.-named hurricanes.

13 This is most evident when comparing the fatalities related to the 2004 Indonesia tsunami where in some reports the fatalities, which are estimated to be roughly 280,000, are said to be a result of flood events and in some reports a result of storms.


15 PLOS Currents, *The Human Impact of Floods*.
Material for this section is derived from Schanze, *Flood Risk Management – A Basic Framework*, Chapter 1.

16 Munich Re, "Natural Hazards/Hydrological Hazards".

17 Catastrophe models are used for pricing, short- and long-range planning, and evaluation of liabilities and capital needs.


22 Swiss Re, *Mind the Risk*.


28 Ibid.


30 PLOS Currents, *The Human Impact of Floods*.


34 For example, land subsidence caused by the weight of buildings on soft soil, which lowers the level of buildings relative to existing water. This has been a significant issue in flood risk in Bangkok, for example.

35 This was an issue in the Brisbane flooding in Australia in 2010, where too much water was stored in dams for drought mitigation, rendering them ineffective when sudden rains then led to flooding that the dams were designed to stop.

36 For example, replacing marshland with pavement and buildings can change the land’s ability to absorb a given level of rainfall. This effect was clearly seen in 2017 during Hurricane Harvey in Texas.


Flood Risk


41 Schanze, Flood Risk Management, Chapter 1.

42 Haraguchi and Upmanu, Flood Risks and Impacts.

43 The term “businesses” is used in this paper to refer to for-profit as well as non-profit entities.


49 Ibid.


52 Jongman, Effective Adaptation to Rising Flood Risk.


55 Jongman, Effective Adaptation to Rising Flood Risk.


57 This can take the form of a ground-up (deductible or self-loss limitation) basis or be for losses in excess of an insured maximum amount.


59 The three types of floods are: coastal or surge; riverine or fluvial; and flash, surface, or pluvial. (See Section 2 for further details.)

60 Further perils that can result from a flood include, but are not limited to, mudslide, landslide, subsidence, and loss of or breach to infrastructure.


62 Kron, “Asian Floods Overshadowed by Houston Flooding”.

63 Ibid.

64 Jongman, Effective Adaptation to Rising Flood Risk.


66 https://riskfrontiers.com/major-projects/perilsaus/


68 Jongman, Effective Adaptation to Rising Flood Risk.
The Actuaries Climate Index, at http://actuariesclimateindex.org/home/, covers Canada and the United States. A similar index has been developed covering Australia at www.actuaries.asn.au/microsites/climate-index.


Exceptions include multi-year reinsurance treaties and smaller insurers that may be able to spread losses across time using reinsurance, since a larger reinsurer may be more capable of absorbing volatility across years than a small direct writing insurer. While at the individual insurer level it may appear as though losses are spread over time, across the entire global market, losses are accounted for in the current year under all private sector flood insurance programs.


Flood Risk

References


The Actuaries Climate Index, at actuariesclimateindex.org/home/


Australian Actuaries Climate Index. www.actuaries.asn.au/microsites/climate-index.


Flood Risk


Flood Risk


