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Natural catastrophes in 2021: the floodgates are open

02 Executive summary
03 Key takeaways
05 2021: another year of severe weather events
11 Flood: worthy of primary peril status
23 Building flood resilience: roles for re/insurers
28 Concluding remarks
29 Appendix 1: 2021 – the year in review
33 Appendix 2

Executive summary

In 2021, global economic losses from natural catastrophes were USD 270 billion, of which around 40% was covered by insurance.

Natural and man-made disasters resulted in global economic losses of USD 280 billion in 2021, the sixth highest on *sigma* records, and the 16th highest since 1970 after normalising for GDP growth effects. Of the economic losses, USD 270 billion was attributable to natural catastrophes. In addition to a devastating earthquake in Haiti that, sadly, claimed more than 2 000 lives, there were more than 50 severe flood events across the world, as well as tropical cyclones, episodes of extreme cold and heat, and severe convective storms (SCS). Insurance covered USD 119 billion of last year's economic losses, the fourth highest on record, of which USD 111 billion was compensation for damage resulting from natural catastrophes.

Hurricane Ida was the year's biggest loss event, also contributing to the widespread devastation inflicted by severe floods around the world.

Insured losses have been elevated over the last five years due to recurring high-loss secondary peril events such as SCS, floods and wildfire. However, peak perils have also featured prominently, including Hurricane Ida, the costliest industry event of 2021 with insured losses of USD 30–32 billion. Coming after a dip in 2012–2016, however, the higher insured losses of 2017–2021 signal a return to long-term growth trend of 5–7%, rather than a step-change up in claims. While we do not see a new norm of higher loss growth rates, regular occurrence of multi-billion insured loss outcomes from secondary peril events is new. In 2021, two separate secondary perils events – winter storm Uri in the US and devastating floods in central-western Europe in July – each caused losses in excess of USD 10 billion. Traditionally secondary perils have been less well monitored than primary. Recent efforts to change this should be further progressed.

Floods wreak widespread devastation each year, undermining social and economic resilience.

Flood affects more people around the world than any other peril. Losses from flood have been on an upward trend globally and at a significantly faster pace than global GDP. Through 2011 to 2020, at near USD 80 billion, cumulative insured losses from flood events around the world were almost down that of the previous decade. The flood experience of 2021, with insured losses at USD 20 billion, indicates no let up of the upward trend. Historically Asia has suffered the highest economic losses from flood, but it lags in terms of insured losses. There is a large flood protection gap across the world. Insurance has covered just 7% of the aggregate economic losses from flood events in emerging markets in the last 20 years, and 31% in advanced economies.

Flood risk is complex to assess, with many and varied factors shaping the physical and financial loss outcomes.

Flood risk is complex to monitor. Exposure accumulation with economic growth and urbanisation has been the main driver of rising flood-related losses over time. However, many other factors such as aging or lack of flood control infrastructure, "soil sealing" in urban areas, more rainfall from tropical cyclones, and clustering of catastrophe events have also shaped loss outcomes. Changing climate also needs to be considered in present-day and for future risk assessment. For instance, in scenario analysis, we project for 2050 more pronounced increases in UK flood-related losses for high return periods and assuming no adaptation interventions.

Data flow and modelling of flood risks need to be more rigorous.

We believe flood is and will remain insurable. The task is to deepen understanding of the risk by making more active use of existing technology and models. By optimising the large range of granular data sets available today, and continually updating these as conditions change, existing industry models can be adapted to integrate the multiple factors that shape present-day and future flood risk in different parts of the world. To this end, we call on the industry to afford flood risk the same attention as primary perils when it comes to exposure data capturing, sharing and model use, and to enforce the same discipline and adherence to rigorous risk management practices.

More granular understanding will improve flood risk costing and inform local mitigation planning.

Granular understanding will improve the accuracy of flood risk costing and facilitate the development of innovative risk transfer solutions. It can also help inform local mitigation planning and disaster risk management. A core element of adaptation measures are flood defences. As long-term investors in sustainable infrastructure, here too re/insurers can make a significant contribution to making communities more resilient. Indeed, with due attention on different fronts, re/insurers will remain primary agents of economic and social resilience against the ubiquitous risk that is flood.

Key takeaways

2021 in a nutshell

Economic losses

Total
USD 280 billion*

2020: USD 217 bn
10-year average: USD 204 bn

Natural catastophes
USD 270 bn

Man-made
USD 10 bn

0.29%
of global GDP

10-year average: 0.23%

*Ranks 16th in terms of GDP -normalised economic losses from natural catastrophes since 1970

Insured losses

Total
USD 119 billion

2020: USD 99 bn
10-year average: USD 83 bn

Natural catastophes
USD 111 bn

Man-made
USD 8 bn

6% of global property direct premiums written

10-year average: 4.5%

Natural catastrophe insured losses

Total
USD 111 billion

2020: USD 90 bn
10-year average: USD 74 bn

Secondary perils
USD 81 bn (73%)

2020: USD 63 bn

Primary perils
USD 30 bn (27%)

2020: USD 27 bn

Victims

11 881

Catastrophe events

306

Global protection gap

2020
USD 117 bn

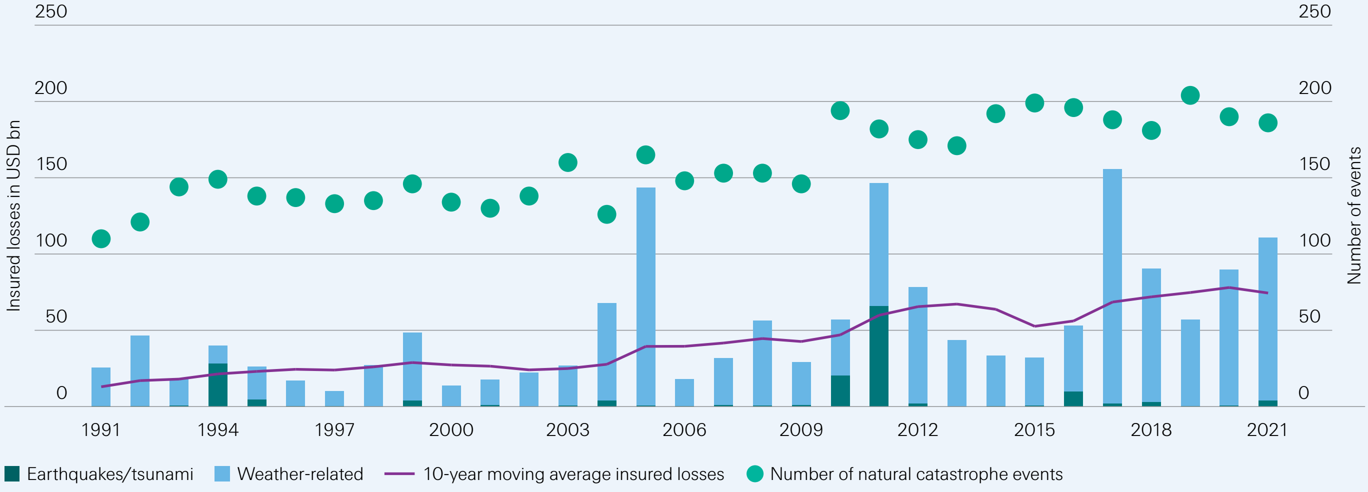
2021
USD 161 bn

10-year average
USD 121 bn

Source: Swiss Re Institute

A return to long-term trend

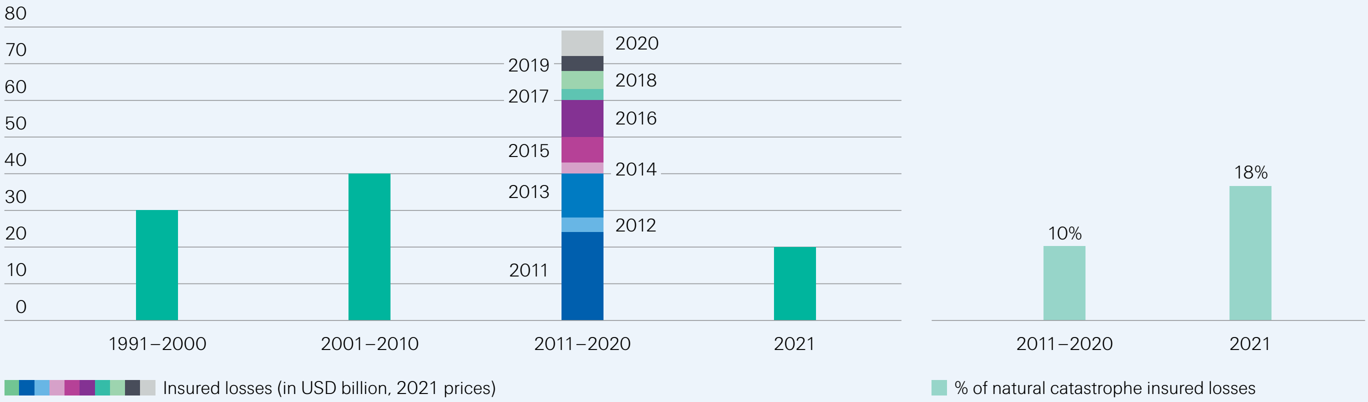
The record of the past five years has been elevated insured losses from natural catastrophes. Question: is this a "new normal"? Answer: not in our view. After a benign phase of lower annual losses in the 2012–2016 period, annual losses have resumed their historically observed long-term growth rate of 5–7% annually, based on 10-year moving averages. Rather than a new normal or a step-change, insured losses have reverted to long-term (and still significant) growth trend.



Source: Swiss Re Institute

Global insured losses from flooding in 1991–2021 (in USD billion, 2021 prices)

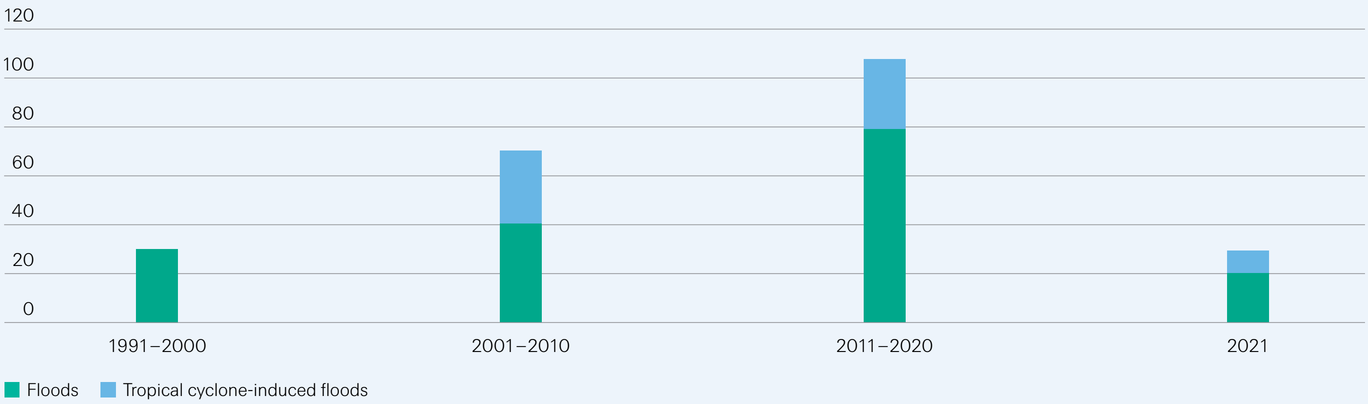
Insured flood losses are on the rise, with most of the global flood insurance losses recorded in the last two decades. Accumulating economic wealth, growing populations, poor defence infrastructures and climate-change effects are driving the increase. Even so, in the last decade flood events counted for just 10% of insured losses from all natural catastrophes. This is a reflection of low flood insurance penetration in both emerging and advanced economies.



Source: Swiss Re Institute

Global insured flood losses, including estimated flood damage due to tropical cyclones (USD billion, 2021 prices)

Floods can be secondary effects of tropical cyclones that spark storm surges and/or heavy rains, leading to large-scale inland flooding. With limited information available, we estimate that over the last 20 years, flooding as a secondary effect of tropical cyclones added around 30% to the global insured losses from pluvial and fluvial flood events.



Source: Swiss Re Institute

Call for action for the re/insurance industry

Make flood risk assessment more rigorous and develop risk transfer solutions.

	Call for action for the industry	The positive trajectory
1	**Data quality, transparency, and flow:** collect and include in submission data accurate flood-related exposure, claims, policy information	Detailed exposure available on building level, including correct coverage coding for flood
2	**Expand model capabilities:** probabilistic models for the different types of flooding and markets	Pluvial and tropical cyclone-induced floods represented along side fluvial and storm surge risk for major markets
3	**Ensure representation of present-day risk:** frequent recalibration and debiasing of models from macro trends	Underwriting using flood models with near-future perspective, instead of experience costing
4	**Ensure representation of future risk:** scenario simulations projecting to 2050–2100 horizons	Regulatory requests for climate change scenarios to inform business strategy
5	**Increase risk awareness and transfer solutions:** private insurance covers and national pool schemes	Flood insurance products available for privates and successful examples of national schemes

Source: Swiss Re Institute

2021: another year of severe weather events

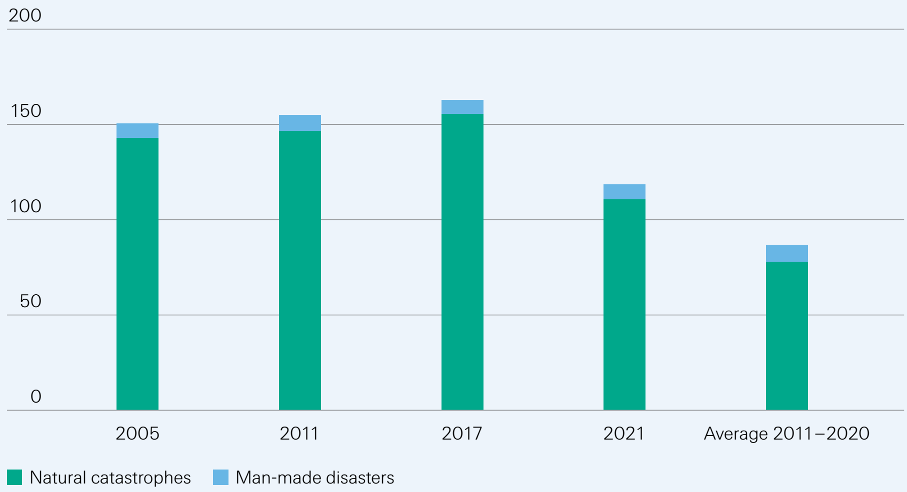
Disaster events resulted in insured losses of USD 119 billion in 2021, the fourth highest on *sigma* records. The year's natural catastrophes reinforced recent observations: namely the huge loss potential of a primary peril, and the significant impact of secondary perils, including flood. Secondary peril events accounted for more than 70% of last year's insured losses and for the first time ever, two separate secondary peril events each resulted in insured losses of more than USD 10 billion. Overall, annual catastrophe insured losses have been above average in the last five years, but a 5–7% long-term growth trend remains intact.

Affirmations

Global insured losses from disaster events in 2021 were USD 119 billion, the fourth highest annual tally on *sigma* records.

2021 was another year of intense catastrophe activity across the world, including episodes of severe rainfall, heat, snow and cold, a massive earthquake in Haiti, hurricanes, wildfires and major tornado outbreaks. In real terms, global economic losses from man-made and natural disasters were USD 280 billion, of which USD 270 billion came from natural catastrophes. The insured loss total was USD 119 billion, the fourth highest for a single year on *sigma* records. The insured total was well above the USD 99 billion registered in 2020 and the 10-year average of USD 87 billion. Natural disasters caused USD 111 billion of last year's total insured losses, also the fourth highest annual count on record.

Figure 1
Top 4 peak insured loss years and past decade annual average, in USD billion (2021 prices)



Source: Swiss Re Institute

Hurricane Ida provides a timely reminder of the huge loss potential of tropical cyclones.

The main loss event of 2021 was Hurricane Ida in the US, which battered the south with category 4 force winds in August before tracking northeast. There, it unleashed intense rainfall resulting in heavy flooding in New York City and surrounding areas. We estimate overall insured losses from Ida at USD 30–32 billion, highlighting the huge losses that can result from a single primary peril event. There were 21 named storms[1] in the 2021 hurricane season, less than the record 30 in 2020. Yet the insured losses from Ida alone surpassed the combined losses of all hurricanes in the previous year.

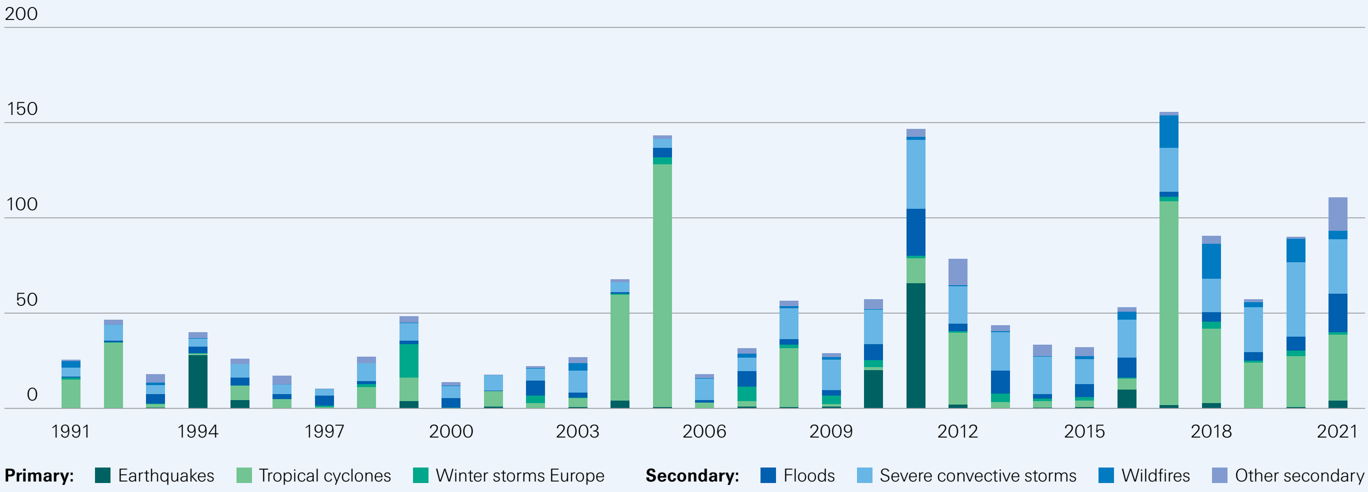
The main secondary peril events in 2021 were floods in Europe and winter storm Uri in the US.

In 2021, natural catastrophe losses were spread across a wide variety of perils. The mix of events affirm the continuing importance of secondary perils such as severe convective storms (SCS) and floods in contributing to both economic and insured losses (see below: *Wildfires in 2021: still burning)*. Secondary perils accounted for 73% of all natural catastrophe insured losses in 2021 (see Figure 2). The main events were winter storm

[1] Tropical cyclones in the North Atlantic basin designated by the US National Weather Service or its divisions, and where a number or name has been applied.

Uri in the US (USD 15 billion in insured losses); and multiple floods in central and central-western Europe in the summer as a result of the same atmospheric event, resulting in record insured losses of an estimated USD 13 billion.

Figure 2
Global insured natural catastrophe losses by peril, in USD billion (2021 prices)



Source: Swiss Re Institute

Primary and secondary perils present a different rigour in industry monitoring.

For the purposes of this research and absent of a standard definition, we categorise natural catastrophes as *primary* and *secondary perils*. A key differentiator for our allocation is the sophistication of insurance industry modelling for different perils with respect to the rigour of data collection, submission and underwriting consideration. Table 1 below shows the distinction.

Table 1
Distinction between primary and secondary perils, according to the event typology and monitoring in the re/insurance market.

	Event type	Re/insurance industry status	Examples
Primary perils	Natural catastrophes that tend to happen less frequently, but with high loss potential.	Traditionally well-monitored and managed risks in developed re/insurance markets.	Tropical cyclones, earthquakes, winter storms in Europe.
Secondary perils	Natural catastrophes that can happen relatively frequently, and *typically* generate low to medium sized losses.	**Independent secondary perils.** Less rigour in industry monitoring and modelling than for primary perils. Weaker exposure data capture and claims tracking.	Severe convective storms (including thunderstorms, hail and tornadoes), floods, droughts, wildfires, landslides, snow, freeze.
		Secondary-effects of primary perils. Not always explicitly modelled alongside the originating primary peril, less rigorous monitoring.	Tropical cyclone-induced inland flooding and storm surge; tsunamis, liquefaction and fire following earthquakes.

Source: Swiss Re Institute

Last year's insured losses from wildfire were below average.

Wildfires in 2021: still burning
At more than USD 4 billion, insured losses from wildfires in 2021 were below the average of the previous five years. Canada, adjacent parts of the US and many parts of the Mediterranean experienced record temperatures. During the last days of June, a "heat dome" set a new all-time Canadian temperature record of nearly 50°C in a village in British Columbia. Temperatures in Death Valley, California reached 54.4°C during one of multiple heatwaves in the southwest.[2] The exceptional heat was often

[2] 2021: Meeting the challenge of extreme weather, *World Meterological Organization*, 28 December 2021.

accompanied by wildfires. However, compared to recent years, fires encroached areas of lower property concentration, triggering below-average claims.

Even so, fire risk remains very real.

Last year's below average losses do not detract from fire being an ever-present hazard in North America, Australia and other parts of the world. Losses are likely to continue to grow in the years to come, mostly driven by rising exposure in areas of wild-urban-interface, a multi-year drought in western US, where most of these losses originate, and often sub-optimal fire management strategies that increase natural biomass fuels on the ground.[3] In California, increases in autumn temperatures alongside decreases in precipitation have more than doubled the number of days per year with high fire risk since the 1980s.[4] Longer fire seasons in an increasingly warmer planet (for instance the Colorado Marshall fires, the costliest wildfire of 2021, occurred in winter at the end of the year) also increase the loss potential.

A return to long-term trend

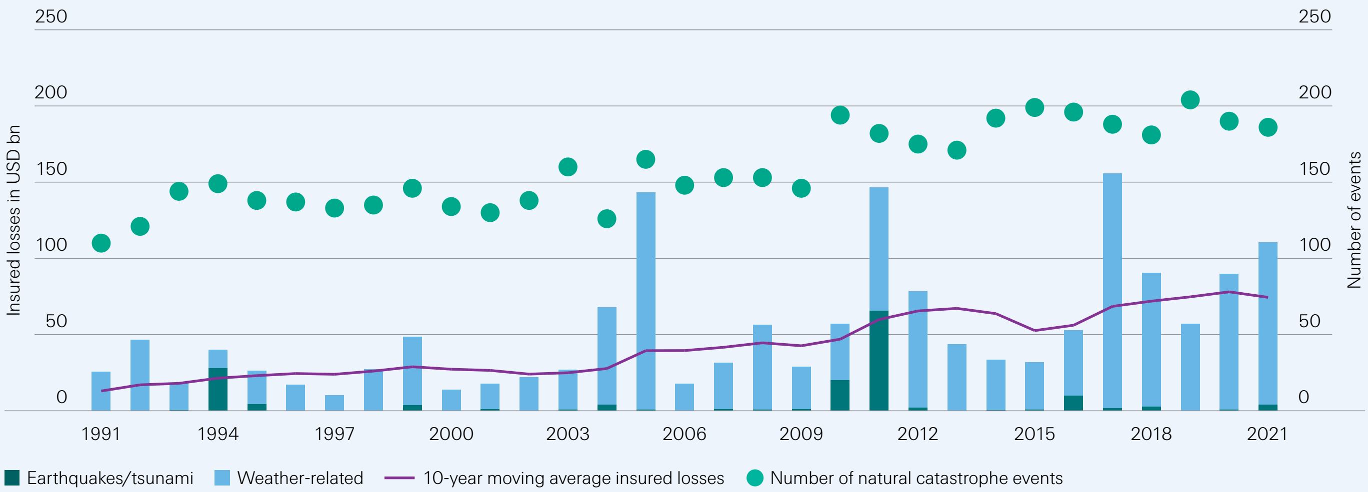
Insured losses from natural disasters have been elevated over the last five years...

The past five years have coincided with heightened insured losses from primary and secondary perils. Over time, the frequency of all large loss-making events has risen. The number of events resulting in insured losses of USD 1 billion or above increased from 6 on average annually from 1991 to 2010, to over 15 annually from 2011 to 2021 (see Figure 5). Two-thirds of the increase is attributable to secondary perils.

...signalling a return to long-term trend growth rather than a step-change in claims.

Average global insured losses from natural catastrophes in 2017–2021 were USD 101 billion, more than double the USD 48 billion in the prior 5-year period. In our view, the increase does *not* represent a step-change in the growth rate of annual insured losses. The past five years have seen some very large disaster events, including Hurricanes Harvey, Irma and Maria in 2017, Typhoon Jebi in 2018, and large-scale wildfires in California and Australia (2017, 2018, 2019 and 2020), all of which have made for dramatic headline losses. Even so, coming after a benign phase for the industry between 2012–2016, the elevated losses of the past five years have brought the rate of increase of insured losses back to the long-term average growth trend of 5–7% (see Figure 3).[5]

Figure 3
Global natural catastrophe insured losses and 10-year average in USD billion (2021 prices) and number of events



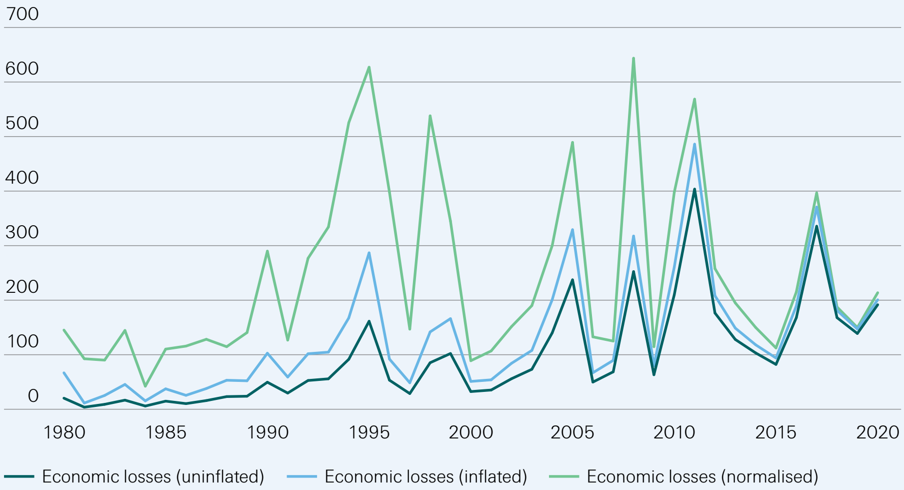
Source: Swiss Re Institute

[3] C. Kolden, "Wildfires: count lives and homes, not hectares burnt", *Nature*, vol. 586, 2020
[4] M. Goss et al., "Climate change is increasing the likelihood of extreme autumn wildfire conditions across California", *Environmental Research Letters*, vol.15. 2020.
[5] From 1991, on a 10 year-moving average basis.

Rising losses over the last 40 years have been mostly driven by economic development and urbanisation.

Rising losses have been mostly driven by socio-economic factors. Economic growth and urbanisation have generated ever-higher values of assets in areas exposed to natural catastrophes. After normalising for GDP growth effects, the average annual growth rate of economic losses between 1980 and 2021 is 0.91%. This shows that an historic event, if it were to occur at same severity today, would result in higher losses based on the accumulation of economic value over the past 40 years alone.

Figure 4
Uninflated, inflated (2021 prices) and normalised economic losses from natural catastrophes, USD billion



Note: normalised by GDP (country real GDP+US inflation); loss-data quality pre 1990 poor.
Source: Swiss Re Institute

In the last two years, inflationary pressures have helped fuel insured losses.

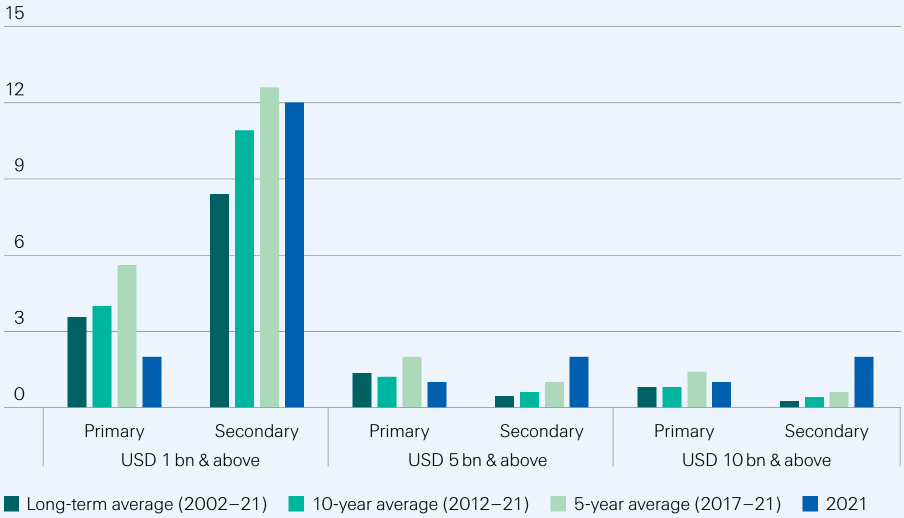
Further, disasters typically trigger a surge in demand for insurance locally. With more households and businesses needing repair work, the price of that work goes up. Of late, broader inflationary pressures have also contributed to higher insured losses. In the past year and for part of 2020, inflation has risen at a rate well-above the surge in demand for insurance attributable to events like Hurricane Ida. The pandemic has disrupted global supply chains and also led to labour shortages, low inventories and an energy crisis, among others. In addition, the scale of fiscal stimulus packages have been unprecedented, leading to overheating in several economies including the US, and fuelling higher inflation; this has amplified the losses resulting from catastrophe events.

Putting the spotlight on the scope of loss drivers

For the first time ever in a single year, two secondary peril events resulted in insured losses of over USD 10 billion.

Whether wildfires, SCS or floods, each of the last five years (except 2019) have seen secondary peril events that have caused insured losses of USD 5 billion or more. Prior to 2011, secondary peril losses of that severity were unheard of (see Figure 5). The development points to the widening scope of events that can generate very large losses. The events in 2021 provide more food for thought. For example, it was the first year ever in which two secondary peril events each generated losses in excess of USD 10 billion (winter storm Uri and the flooding in Europe). The first of many such years? There is no reason *not* to expect repeat occurrences, not least with a warming climate anticipated to trigger more frequent and intense extreme weather events, and with ongoing development of socio-economic conditions leading to more exposure growth.

Figure 5
Average number of natural catastrophe events with insured losses of USD 1bn and above, at 2021 prices



Source: Swiss Re Institute

A confluence of factors contributed to the high losses from specific events...

A confluence of multiple factors contributed to the large loss outcomes from many of the natural catastrophes in 2021. For example, the catastrophic flooding in central-western Europe in July was caused by heavy precipitation over a few days. However, prior events also contributed to the high impact. SCS with heavy rainfall over the region in the previous month had left soils saturated, decreasing their drainage capacity.[6,7]

...including pre-existing infrastructure vulnerabilities.

The losses of some of last year's events were also exacerbated by infrastructure vulnerabilities. In the case of Hurricane Ida, the New York City transport system was inundated by the rains that came in the wake of the storm. The investments in sea barriers and other coastal protections following the storm surge from Hurricane Sandy in 2012 could do nothing against stormwater in the city away from coastal areas. Meanwhile, winter storm Uri exposed the vulnerability of Texas' energy grid. Massive power failures played a big role in the record losses from Uri. Temperatures below zero for two weeks caused much of the equipment to freeze, resulting in widespread blackouts.[8] Owing to the state's grid independence, the authorities could not import energy from neighbouring states, leaving millions of residents without power for several days.[9] Tragically, Uri resulted in an estimated 226 deaths.[10] There were also a very high number of insurance claims to cover for the cost of repairing burst water pipes.

Models need to account for the full range of present-day drivers that can shape catastrophe outcomes.

That different factors contribute to the large losses from catastrophe events is not new knowledge. But the loss experiences of 2021 strengthen the case for broader and more uniform risk costing procedures. This includes expanding the range of perils and the number of countries monitored, and accounting for the full range of risk drivers and contingencies from secondary effects. Historically, re/insurers and the modelling industry have focused more on peak severity perils (earthquakes, tropical cyclones), Secondary perils have received less attention, and so too the increasingly evident effects of global warming, urbanisation, land-use changes, and other socio-economic macro-trends. This has likely led to some underestimation of actual exposures to catastrophe risks. For example, based on the analysis of insurance loss data from Swiss Re's *sigma* database, a recent study by S&P Global estimates that a USD 150 billion insured loss event has an empirical return period of 10 years.[11] Considering the exposures of the top 21 global reinsurers, however, the study also estimates that on average, industry models see losses of such magnitude occurring only once in every 20 to 30 years.

[6] *Naturgefahrenreport 2021*, Gesamtverband der Deutschen Versicherungswirtschaft, 2021.
[7] A. Schäfer, B. Mühr, J, Daniell et al., *CEDIM Forensic Disaster Analysis: Hochwasser Mitteleuropa*, Center for Disaster Management and Risk Reduction Technology, June 2021.
[8] Y. Glazer et al., "Winter Storm Uri: A test of Texas' Water Infrastructure and Water Resource Resilience to Extreme Winter Weather Events", *Journal of Extreme Events*, 31 December 2021.
[9] *The February 2021 Cold Weather Outages in Texas and the South Central United States*, FERC, NERC and Regional Entity Staff Report, 2021.
[10] See "Billion-Dollar Weather and Climate Disasters", *www.ndnc.noaa.gov*
[11] *Global reinsurers grapple with climate change risks*, S&P Global Ratings, 2021.

Flood risk assessment needs to be more rigorous.

More rigorous assessment and modelling of flood risk is specifically pressing. Currently flood is considered a secondary peril. Though there have been improvements over the past decade, flood is still afforded less attention and rigour in exposure data and modelling data provisions than primary peril risks. This is even with flood ubiquitous risk, affecting an estimated 2.2 billion people around the world, more than any other peril.[12] In addition to the flooding in central-western Europe and New York in the wake of Hurricane Ida, last year also brought record seasonal floods in China and India, and after Typhoon Rai in the Philippines. These events confirm that water inundation is one of the most destructive and recurrent perils globally and, further, one that demands closer attention.

[12] *People in Harm's Way: Flood Exposure and Poverty in 189 Countries*, World Bank. 2021.

Flood: worthy of primary peril status

There were more than 50 severe floods across the world in 2021, including the costliest event for Europe on record and a rising number of flash floods in urban environments. The combined economic losses from all flood events were USD 82 billion. Economic growth and the accumulation of exposed asset values have been the main drivers of rising flood-related losses over time. But last year's events confirm that a wide range of drivers contribute to loss outcomes, including urbanisation and aging infrastructure, more extreme rainfall from tropical cyclones, and climate change effects. Given the widespread devastation wreaked by flooding each year, we believe flooding qualifies for primary peril status and should be risk-assessed accordingly.

A ubiquitous peril

Each year, cumulative economic losses from floods are among the highest of all natural perils.

Around 29% of the world's population is exposed to flood risk.[13] *sigma* records show that flood events caused more than a third of natural catastrophe related fatalities since 2011, and that flood is by far the most frequently occurring of all natural perils. For example, in the same period there were three times as many large loss-causing flood events as there were tropical cyclones, and 1.2 times as many floods as SCS. The devastation wreaked by floods reflects in the associated economic losses, which are consistently among the highest of all perils each year, alongside those from tropical cyclones and earthquakes.

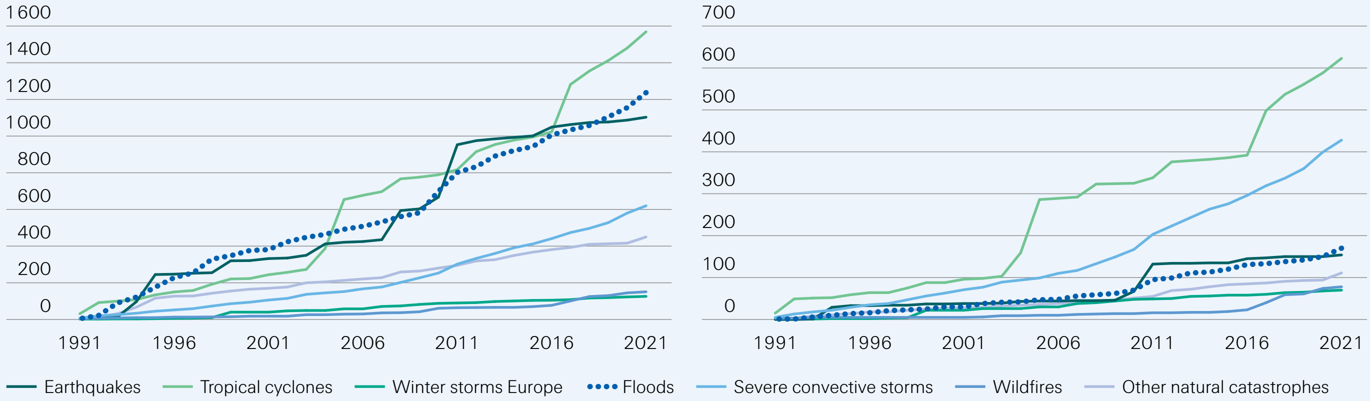
Over the last 30 years, flood events have caused cumulative global economic losses of more than USD 1 200 billion.

Since 1991, global cumulative economic losses from major flood events were more than USD 1 200 billion (see Figure 6). For the purpose of comparison, tropical cyclones caused economic losses of more than USD 1 500 billion over the same period, and earthquakes around USD 1 100 billion. Next highest were the economic losses caused by SCS, much lower at around to USD 600 billion. Note that the flood loss counts *do not* include the losses generated by flooding as a result of tropical cyclones or, in other words, when a flood is a secondary effect of a primary peril, as granular data of this nature is not readily available. Suffice to say, if those were counted, the cumulative economic losses from floods would be much higher.

The associated cumulative insured losses have been much lower.

In terms of insured losses, while those resulting from tropical cyclones and SCS were high in relative terms, those from flood events, were much lower (less than USD 200 billion). We estimate that in the last 10 years specifically, only 5% of flood losses in emerging markets were insured, and just 34% in advanced economies, pointing to the existence of large flood protection gaps across the world. This compares to, for example, tropical cyclones, where insurance covered 11% of losses in emerging markets, rising to 46% in advanced economies over the same period. In the last decade, the largest flood protection gap has been in Asia, with only 7% of economic losses covered by insurance. In contrast, in Europe 34% of flood losses were insured.

Figure 6
Cumulative global economic (left) and insured losses (right) by peril, 1991–2021 (in USD billion, 2021 prices)



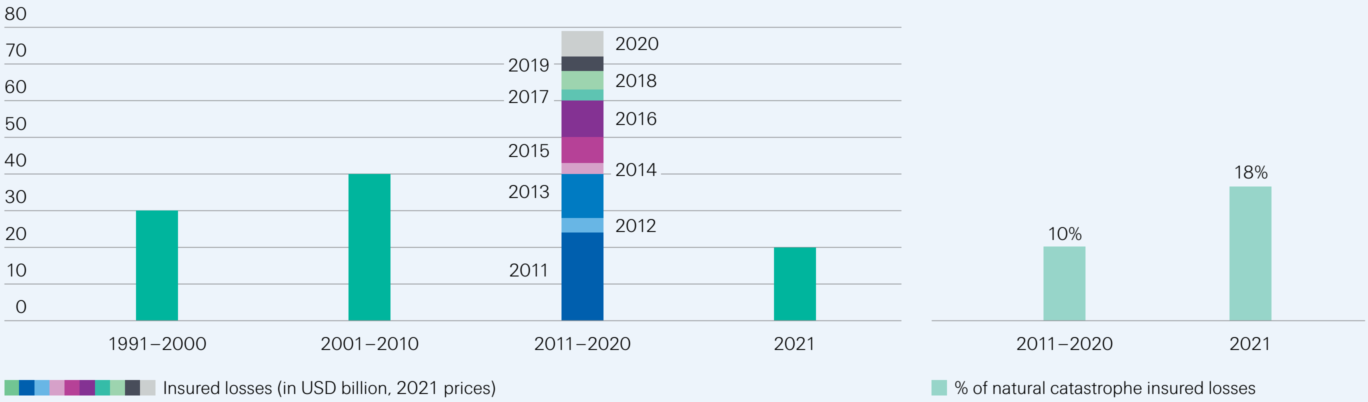
Source: Swiss Re Institute

[13] Ibid.

The damage from floods make up about 10% of insured losses from all natural catastrophes.

There has been an upturn in flood insured losses over the last 20 years, cumulatively amounting to close to USD 140 billion (see Figure 7). The costliest event to date remains the 2011 floods in Thailand, which led to insured losses of USD 18 billion (in 2021 prices). Last year's flooding in central-western Europe in July was only the second time ever that a standalone flood event has resulted in insured losses of more than USD 10 billion. Even with these large amounts, however, flood accounts for around 10% of global insured losses from all natural catastrophes.

Figure 7
Global insured losses from flooding since 1991(in USD billion, 2021 prices, left), and as a % of natural catastrophe insured losses (right)



Source: Swiss Re Institute

In 2021, flood events resulted in economic losses of more than USD 80 billion.

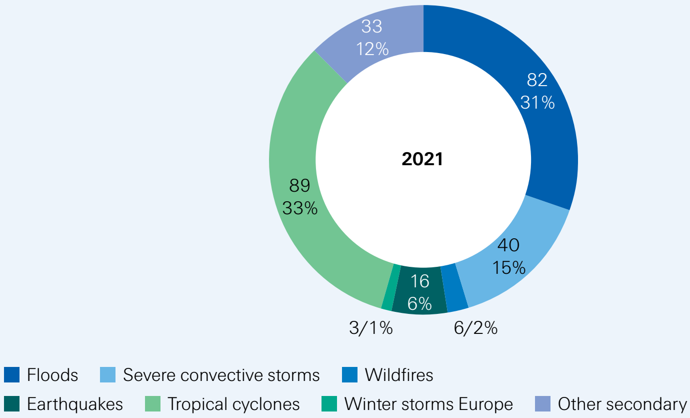
Floods in 2021: record breaking
In 2021, large flood events claimed more than 2 300 victims, the second deadliest peril after earthquakes. Globally, there were more than 50 severe floods, including an increasing number of flash floods in urban environments. Table 2 provide the loss details of the main flood events in 2021. Together, these disasters resulted in economic losses of more than USD 80 billion, among the highest of all perils (see Figure 8). Of those, a quarter were covered by insurance.

Table 2
Top inland flood events in 2021 in terms of economic losses, excluding tropical-induced flooding

Month in 2021	Location	Fatalities	Economic losses (USD billion)	Insured losses (USD billion)
July	Central-western Europe	227	41	13
July	China (Henan region)	302	19	2.3
	China seasonal flooding (excluding Henan)	103	5.8	0.1
November	Canada (southwestern British Columbia)	6	3.4	0.6
	India seasonal flooding	729	2.3	–
March	Australia (New South Wales)	2	1.1	0.4
December	Malaysia	–	1.4	0.7
	All other flood events	**1 157**	**8.8**	**3.1**
	TOTALS	**2 580**	**82**	**20**

Loss total numbers are rounded. Source: Swiss Re Institute

Figure 8
Global economic losses by peril in 2021, in USD billion and % share

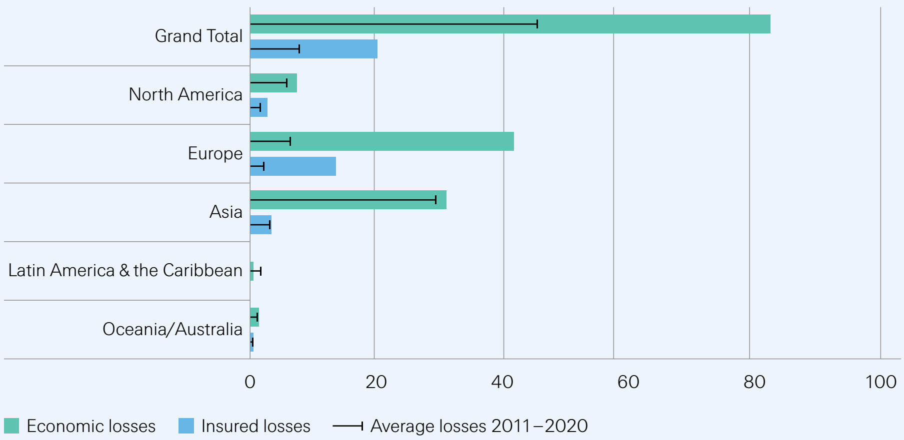


Source: Swiss Re Institute

Insurance covered around USD 20 billion (25%) of last year's flood-driven economic losses

Figure 9 shows global economic and insured flood-related losses in 2021. Europe suffered the highest losses on both fronts. This was on account of the flooding in Germany and neighbouring countries in July, which generated economic losses of more than USD 40 billion and insured losses of USD 13 billion. The event was both the costliest flood event of the year and the costliest natural disaster on record in Germany and Europe ever, when normalising (in this case adjusting for inflation only) past event losses to today. It was the reason for full-year economic losses from floods in Europe being well above the average of the previous 10 years (around USD 10 billion). In Asia and North America, flood-related economic losses in 2021 were much in line with the respective averages from the previous 10 years.

Figure 9
Economic and insured flood losses in 2021 and 10-year averages (USD billion at 2021 prices)



Source: Swiss Re Institute

Countries in Asia suffer the most economic damage from flooding, mostly uninsured.

Historically, Asia has suffered the highest flood-related economic losses. In 2011–2020, economic losses from flood events averaged almost USD 30 billion annually, these including the Thailand flood of 2011. In terms of insurance coverage, though, Asia has lagged Europe and North America. This was the case in 2021 also, when flood-related insured losses were USD 3 billion, or 11% of economic losses. In Europe and North America, the shares of economic losses covered by insurance were 32% and 36%, respectively. There were more than 20 severe floods in Asia last year, once again the highest number of any region. Seasonal floods in China were the most severe in economic loss terms, those rising to USD 23 billion. Henan province was hardest hit. The associated insured losses, however, were just USD 2.3 billion, again indicative of a large flood protection gap.

Understanding the drivers of flood risk

Flooding can take different forms, mainly fluvial, pluvial or as a result of storm surge.

Floods come in varied forms. The most common are fluvial and pluvial floods, and in coastal areas, storm surge floods (see Figure 10). As described earlier, floods can also manifest as secondary effects of primary perils. This is the case for tropical cyclone induced flooding from storm surge and rainfall. For the insurance industry, differentiating between flood types is an important consideration, since different events can produce very different loss patterns.

Figure 10
The three main types of floods

		Sources	Typical causes*	Characteristics	Areas at risk
Inland	**Fluvial flood**	Major and moderate-sized rivers, lakes	Heavy rainfall over days or weeks, but also snow melt, ice jams	▪ Flood wave can build up rapidly (flash flood) or gradually ▪ Often last for long periods	Areas close to rivers, floodplains
Inland	**Pluvial flood**	Surfaces not able to drain and minor rivers	Extreme rainfall in short time. Soil infiltration excess and overwhelmed drainage systems	▪ Sudden and short duration (flash flood) ▪ High flow rates in steep terrain and debris	Anywhere, including urban areas
Coastal	**Storm surge**	Seawater	Storm-force onshore winds pushing water against a coast over hours.	▪ Surge height influenced by storm and coast characteristics ▪ Interaction with tides	Coastal areas

+ Tsunami, reservoir or dam failure, ground-water flooding. sewer flooding, mudflow, lahar.

*Tropical cyclones can cause all the 3 main types of floods

Source: Swiss Re Institute

Flood events are often under-reported; lack of granularity leads to incomplete views.

Flood risk is complex to monitor. Even though they occur frequently, flood events are often under-reported, resulting in incomplete views of the loss drivers. In many markets, claims reports and loss statistics, whether from government agencies, insurers or insurance associations, lack the granularity and historic reference points needed to identify emerging or changing loss patterns.

With many factors involved, the summer floods in central-western Europe in 2021 demonstrate the complexity of flood risk.

Beyond the devastation it wreaked and its record losses, the flood in central-western Europe in July last year demonstrates the importance of granular understanding if lessons are to be learned for future mitigation efforts. The interplay of many factors led to a catastrophic event of this dimension, starting with the formation of a weak and meandering jet stream that allowed a low-pressure system named *Bernd* to hold position over central-western Europe for many days. The resulting very heavy rainfall on soils already saturated by SCS earlier in the season, caused extensive flash fluvial and pluvial floods in Germany, Belgium, Luxembourg and neighbouring countries. The German states of Rhineland-Palatinate and North Rhine-Westphalia, followed by Bavaria, Thuringia, and Saxony, were worst affected, and saw more than 180 fatalities.[14] Of the different contributing factors, the following were key: [15,16,17, 18]

[14] *Naturgefahrenreport 2021* op. cit.
[15] F. Kreienkamp et al., "Rapid attribution of heavy rainfall events leading to the severe flooding in Western Europe during July 2021", *World Weather Attribution*, 2021.
[16] A. Schäfer et. al, June 2021 op. cit.
[17] Thieken, M. Kemter, S. Vorogushyn, L. Berghäuser et. al. *Extreme Hochwasser bleiben trotz integriertem Risikomanagement eine Herausforderung*. Axel, 2021.
[18] A. Fekete, S. Sandholz, "Here Comes the Flood, but Not Failure? Lessons to Learn after the Heavy Rain and Pluvial Floods in Germany 2021", *Water*, 2021.

- Extreme precipitation over many days. Heavy rain events generated by the combination of more available water in the atmosphere and persistence of weather conditions have increased since the 1950s over most land areas. According to the latest IPCC AR6 WG I report, human-induced climate change is likely to be a main driver for these meteorological trends.[19]
- Prior atmospheric events contributed to the high impact. The drainage capacity of soils in the region were compromised after a series of SCS and accompanying heavy rain a month earlier had left the ground saturated.
- The topography of the worst-affected regions with steep river valleys exacerbated the flash intensity of the event in terms of surface runoff.
- Soil erosion due to the heavy flows. Moreover, a drought in 2018 had left mountain forests with fewer trees, allowing a high amount of debris and mud to flow down stream during the rains.
- In some areas, the rapid onset of flooding undermined the effectiveness of alert and emergency systems, leaving property more vulnerable to the fast flow of water and debris.
- Post the event, supply chain disruptions, inflation, increased material costs and labour shortages due to the COVID-19 pandemic, pushed reconstruction costs higher. This in turn fed through to claims inflation and higher insured losses.

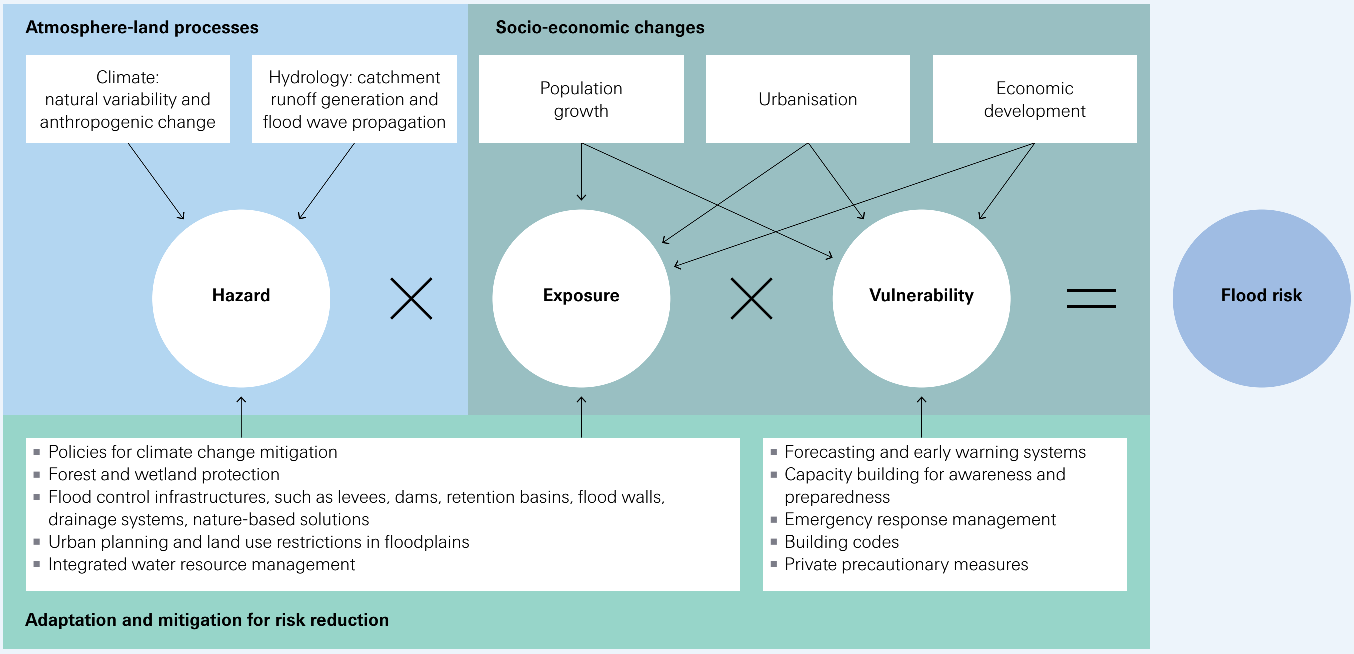
More than water and climate at play

Flood risk outcomes are driven by atmosphere-land processes, and socio-economic changes.

Three main components determine the loss impact of floods: the climate and specific physical characteristics of a flood event; exposure levels, meaning the populations, property and other assets situated in the flood area; and the vulnerability of exposed elements to the hazards. This is both in terms of age and build quality of structures, and the degree of flood preparedness and emergency response in place at the location concerned (see Figure 11). An entire ecosystem of adaptation and mitigation strategies is available today to better manage water resources and emergency response, but the amount and effectiveness of such infrastructure, and the resources available to build and deploy mitigation and adaption measures varies greatly from country to country.

Figure 11

Flood-risk loss drivers



Source: Swiss Re Institute

[19] "Chapter 8: Water cycle changes". *In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2021.

Economic growth, wealth accumulation and urbanisation have driven the trend of rising losses from flood events over many decades.

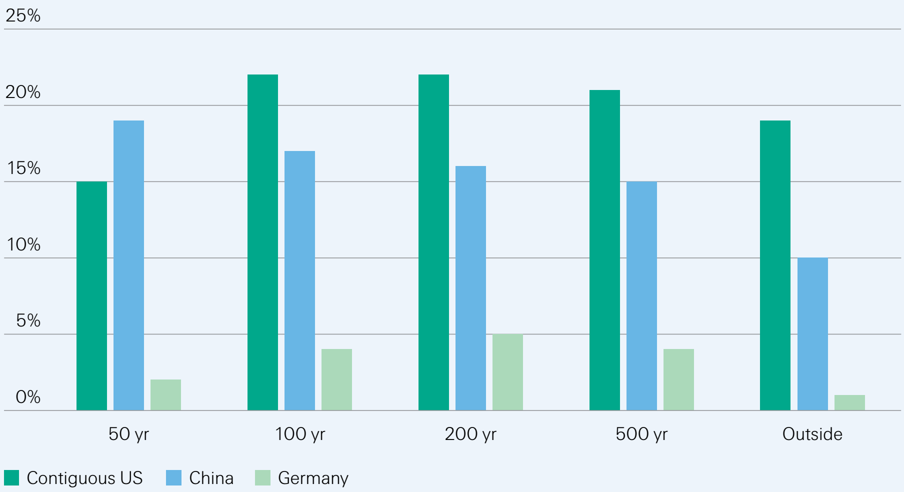
Economic development has been the main driver of the upward trend in losses resulting from floods (and other perils) seen over many decades. Over time, population and economic growth have increased the value of assets at risk. With growth has come urbanisation, which has changed the physical nature of land as well as the "use" of land itself, creating areas of high concentrations of economic (human and property) assets.

Urbanisation in flood plains is a main driver of rising losses.

Urbanisation: a quantifiable flood risk driver

The growth of urban areas is a major driver of the rising losses from weather-related events.[20] With human settlements historically placed in the vicinity of rivers, populations and assets exposed to flood have increased over time, most rapidly in recent decades, and most notably in emerging economies.[21] Figure 12 shows population growth in areas prone to inland flooding in the US, China and Germany during the last 20 years. In US and Germany, the largest growth has occurred in areas exposed to infrequent flooding (return period of 100–200 years). The result can be very large economic losses when a flood event *does* occur in areas not necessarily equipped with suitable defences and other mitigation strategies. Meanwhile, population growth in areas prone to frequent river flooding (return period of 50 years) has been more limited. This is not a universal truth, however. In China, for instance, the highest population growth has occurred in areas exposed to frequent flash flooding (return period of 50 years). This can manifest in a situation of rapid urban sprawl having not been fully offset by water management efforts.[22]

Figure 12
Growth rate of population exposed to inland flooding at different return periods between 2000 and 2020



Source: Swiss Re CatNet®, GHS population grid multitemporal, World Pop

"Soil sealing" in urban areas changes the water absorption capacity of the ground.

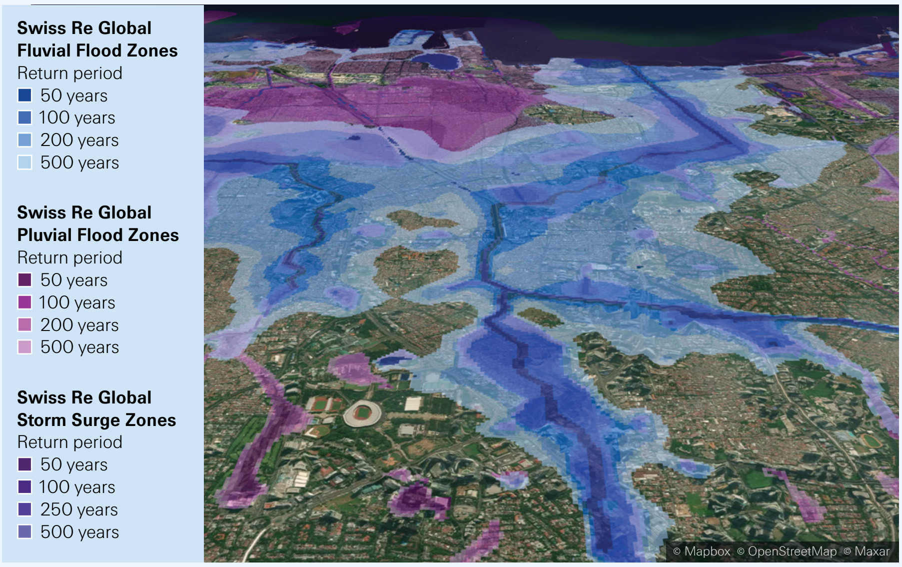
Beside driving exposure growth, urbanisation also transforms the built environment, where natural surfaces are paved to make space for buildings, roads and parking lots. Known as "soil sealing", this affects the water absorption capacity of the ground/soil and generates fast runoff. Soil sealing has been a main driver of the rising number of flash flood events in urban environments.[23] (See also *Urbanisation accentuates tropical cyclone-induced flooding).* While drainage systems are designed to absorb water runoff in urban areas, their capacity can be put at risk by aging and insufficient maintenance.[24] Their failure to function as needed can have negative ripple effects, such as blocking roads and thereby hindering emergency response efforts.

[20] *sigma* 2/2020: Natural catastrohes in times of economic accumulation and climate change, Swiss Re Institute
[21] B. Tellman et al., "Satellite imaging reveals increased proportion of population exposed to floods." *Nature*, 2021.
[22] Y. Jiang et al., "Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy." *Environmental science & policy*, vol 80, 2018.
M. Schiavina, S. Freire, K. MacManu, *GHS population grid multitemporal (1975, 1990, 2000, 2015)*, European Commission, Joint Research Centre, 2019.
[23] A. Blum et al., "Causal effect of impervious cover on annual flood magnitude for the United States", *Geophysical Research Letters*, vol 47, 2020.
[24] *Report Card for America's Infrastructures*, American Society of Civil Engineers, 2021.

Urban sprawl in high-hazard areas is also driving flood losses higher.

Another major threat is the growing urban sprawl in high-hazard regions, such as coastal areas and river deltas. Many of the world's megacities are located in low-lying coastal regions.[25] In cities like Jakarta (see Figure 13), Kolkata, Guangzhou, and Shanghai, the combined effect of urban sprawl into high-hazard areas, land subsidence and sea level rise has accentuated the loss potential from coastal flooding events.[26]

Figure 13
Swiss Re flood hazard maps for Jakarta, capturing fluvial, pluvial, and storm surge risk at different return periods



Source: Swiss Re CatNet®

Modelling needs to consider present-day risk realities rather than rely purely on historical loss information.

To better estimate flood risk, it is crucial that industry modelling techniques move beyond the mere use of historical event and loss data to also include recent, ongoing and anticipated transformations to the built environment. Traditionally, the process of normalisation (or "as-ifing") of historical losses has only considered changes in the exposed value.[27] With human settlement patterns, including urbanisation, sprawl into high-hazard regions and soil sealing producing a growing and material impact on flood losses, it has become clear that these trends need to be incorporated in the normalisation process.

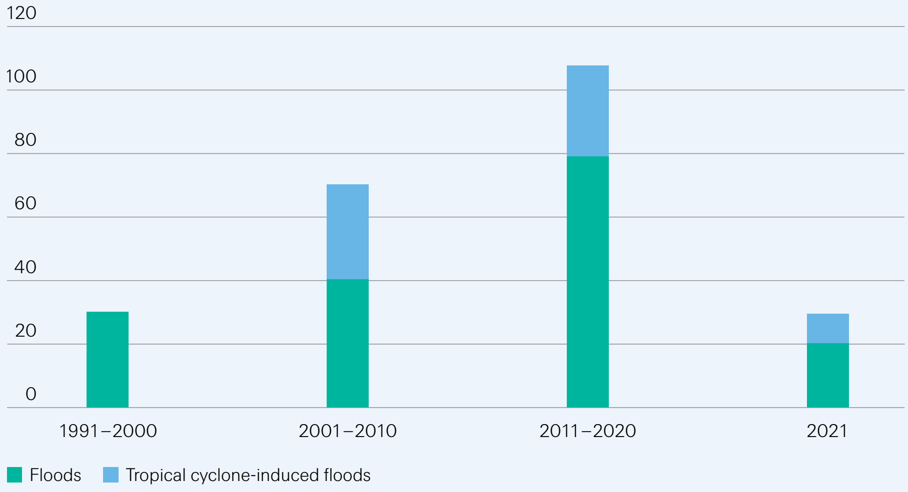
Tropical cyclone-induced flooding: mind the extra risk

Heavy rains and storm surge from tropical cyclones are major drivers of flood losses from the tropics to the mid-latitude.

Tropical cyclones can generate severe floods, not only in the form of storm surge, but also as inland flooding following heavy rainfall.[28] With limited information available, we estimate that over the last 20 years, losses resulting from tropical cyclone-induced floods would add around another 30% to global flood insured losses (see Figure 14).

[25] *World Urbanization Prospects: The 2018 Revision*, UN Department of Economic and Social Affairs, 2018.
[26] R.J. Fuchs "Cities at risk: Asia's coastal cities in an age of climate change." *Analysis from the East-West Center*, No. 96, 2010.
[27] D. Paprotny, A. Sebastian, O. Morales-Nápoles et al., "Trends in flood losses in Europe over the past 150 years," *nature communications*, 29 May 2018.
[28] Tropical cyclones is the umbrella term for what are known as hurricanes in North America, typhoons in far east Asia, and cyclones in the rest of Asia, Australia and Africa.

Figure 14
Global insured losses from floods, and estimated insured losses from tropical cyclone-induced floods (USD billion, 2021 prices)



Source: Swiss Re Institute

Hurricane Harvey in 2017 dropped 30 trillion litres of rainfall over four days.

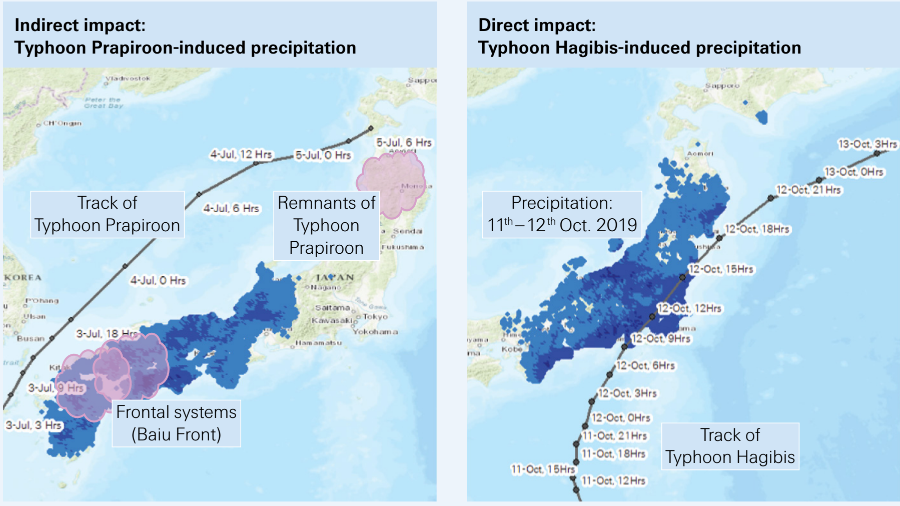
Tropical cyclones are known for the catastrophic damage caused by their wind and wind-driven storm surges. The cyclones owe their power and intensity to the massive transfer of energy and water moisture from the sea surface to the atmosphere. Often this can also lead to release of heavy rainfalls causing, in turn, extensive inland flooding. Of the 10 largest rainfall events in modern US meteorological history (1949-present), five were caused by tropical cyclones.[29] The largest cumulative rainfall event on record, Hurricane Harvey, dropped over 30 trillion litres of water (612 mm over 50 km^2) within a four-day period[30] and was the second costliest hurricane in US history for economic losses, after Hurricane Katrina. Flooding from tropical cyclones is by no means exclusive to North America. For example in Japan, flooding coming as a secondary effect of Typhoon Hagibis in 2018 caused roughly 50% of the typhoon's overall USD 8 billion insured loss count. And in Queensland in Australia, according to *sigma* records roughly 40–50% of the overall USD 1.5 billion in insured losses wreaked by Cyclone Debbie in 2017 came from secondary-effect inland flooding.

Often intense rainfalls occur far away from where the cyclone made landfall, causing inland flooding.

Tropical cyclone-induced inland flooding is distinct from the accumulation risks from wind and storm surge hazard. In the mid-latitudes, the interaction of cyclones with prevalent local weather systems and cold fronts can lead to intense rainfall hundreds or even thousands of kilometres away from the point where a storm initially makes landfall. For example, in 2018 the USD 2 billion in insured losses from Typhoon Prapiroon were nearly all caused by inland flooding in southern Japan far from the storm's track (see Figure 15). The main reason was the influence of the "Baidu" frontal system which pushed the moisture inland from the storm track. Figure 15 also shows the areas of heavy precipitation unleashed by Typhoon Hagibis in 2019. In this case, the areas impacted were much closer to the storm's track.

[29] K. Kunkel, S. Champion, "An Assessment of Rainfall from Hurricanes Harvey and Florence Relative to Other Extremely Wet Storms in the United States", *Geophysical Research Letters*, vol 46, 2019.
[30] Ibid.

Figure 15
Examples of indirect (Prapiroon,right) and direct impact (Hagibis, left) of typhoon-induced precipitation



Background map: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, iPC
Source: Swiss Re Institute, JMA and University of California, Santa Barbara

Tropical cyclone risk assessment should include independent rainfall, wind and storm surge modules.

Hurricane Ida in the US last year was similar to Typhoon Prapiroon. Ida made landfall in Louisiana before moving northeast where it unleashed intense rainfall and flooding. Although Ida was only an extratropical depression at the time, the rainfall was extreme: in New York City, 80 mm of rainfall fell in one hour in Central Park, exceeding the previous record by 50%. And the flooding in the northeast caused more than 60% of the total deaths associated with the storm.[31] Storms like Prapiroon and Ida show that including implicit considerations on wind or storm surge losses to account for extreme rainfall in models is insufficient to accurately understand tropical cyclone risk. Rather, independent rainfall hazard modules must be built alongside wind and surge hazards for every event in a probabilistic tropical cyclone model in order not to miss out on a significant portion of the risk.

We estimate that by ignoring inland floods in tropical cyclone models, insurers underestimate the loss potential in Asia Pacific by 20–25%.

In our view, a change of mindset is needed, one that considers tropical cyclone-induced flooding as a major element of a primary peril. Inland flooding represents a large – and potentially growing – fixed element of tropical cyclone risk. The precipitation from storms like Harvey, Hagibis and Ida have been termed "exceptional", but they are not meteorological aberrations. Sedimentary data from the Chesapeake Bay shows that flood extremes 2 000 years ago can be linked to hurricane activity in the North Atlantic basin.[32] The threat of tropical cyclone-induced flooding may only worsen with time: as the climate warms and urban regions expand, tropical cyclones can drop more moisture on towns and cities with ever shrinking permeable areas. While re/insurance industry risk assessment typically takes into account the presence of storm surge barriers and resilient roof construction as means to mitigate the damage caused by tropical cyclones, models do not always consider the efficacy of local drainage networks, despite the critical role they play in reducing the risk in urban areas (see *Urbanisation exacerbates tropical cyclone-induced flooding*).

Inland flooding represents a large – and potentially growing - fixed component of tropical cyclone risk.

Of the five costliest hurricanes in US history, four (Katrina, Harvey, Sandy, and Ida) can be characterised as "wet", with storm surge and inland flooding comprising a large proportion of the losses. Yet even with this experience and knowledge, the insurance industry continues to approach flood risk stemming from tropical cyclones as an optional consideration in modelling. Exposure data often exclude flood-specific information, and tropical cyclone models often do not account for the inland flooding resulting from a storm's heavy rainfall. On this basis, we estimate industry models may understate the full loss impact of cyclone risk in Asia Pacific, for instance, by 20–25%. This is an understatement that can and should be rectified.

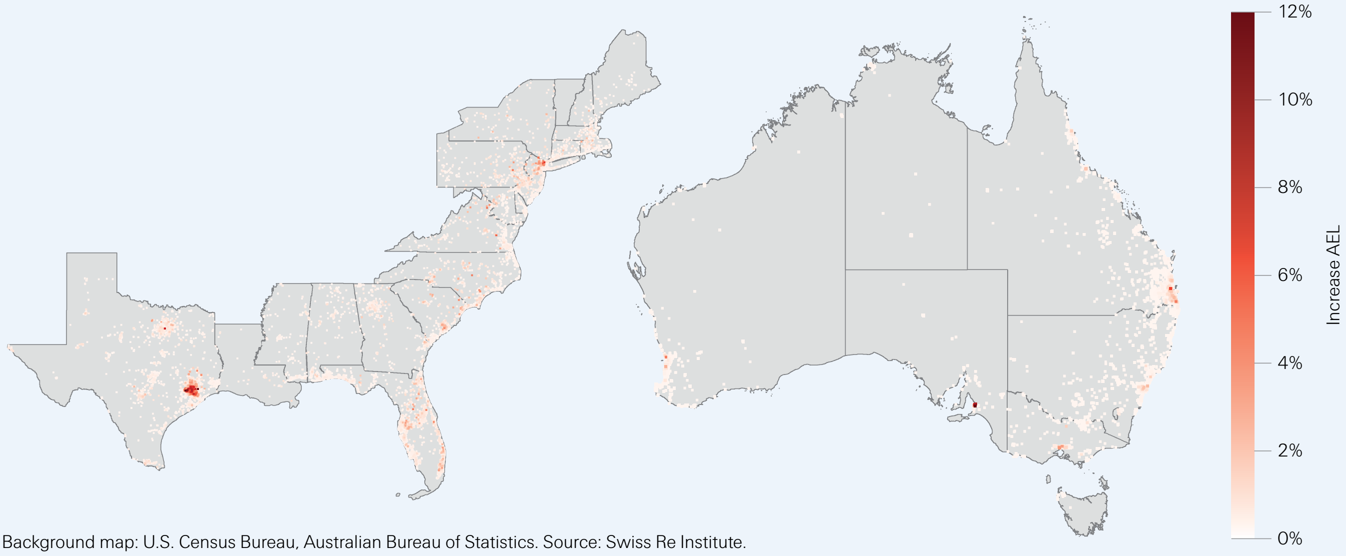
[31] "Notes from the Field: Deaths Related to Hurricane Ida Reported by Media – Nine States, August 29-September 9,2021". in *Morbidity and Mortality Weekly Report*, Centers for Disease Control, 2021.
[32] M. Toomey et al., "The Mighty Susquehanna—Extreme Floods in Eastern North America During the Past Two Millennia". *Geophysical Research Letters*, vol 46, 2019.

Urbanisation exacerbates tropical cyclone-induced flooding

Soil sealing has a significant impact on loss outcomes.

By leveraging high-resolution satellite data,[33] we have quantified the change in the fraction of sealed (impervious) surfaces over the last 20 years in regions exposed to tropical cyclones in the US and Australia. Using Swiss Re's proprietary Nat Cat models for tropical cyclones, we estimated the impact of soil sealing at the river basin and local scales. We also assessed the impact of city-scale differences in stormwater-management performance using data on nature-based solution penetration, flood mitigation incentives and non-levee flood protection measures. Soil sealing is found to have the biggest loss impact in large and fast-growing cities, due to the combined effect of urbanising basins and local imperviousness (see Figure 16). In the US, Houston is the most impacted metropolitan area, with 12% of the increase in (modelled) annual expected losses (AEL) from tropical cyclone-induced flooding over 20 years estimated to be due to soil sealing. The 12% increase is due to the expansion of soil sealed areas over time, net of any growth in exposed value. Other regions significantly affected are large cities in Texas and Florida, parts of South and North Carolina coastlines, and the New York metropolitan area.

Figure 16
Impact of soil sealing on annual expected losses from tropical cyclone-induced inland flooding in the US (left) and Australia (right), 2000–2020



Background map: U.S. Census Bureau, Australian Bureau of Statistics. Source: Swiss Re Institute.

Ageing infrastructures amplifies the impact of soil sealing.

When combining the impact of soil sealing and ageing stormwater infrastructure, expected losses increase significantly, with urban areas more vulnerable to high-frequency events. In our modelling, the border region between the metropolitan areas of New York and Philadelphia shows to be the most exposed urban area. Here, the AEL for the last 20 years increases by up to 35% due to soil sealing and ageing infrastructure effects (net of any growth in exposed value). Other cities showing a large impact are Houston, Jacksonville (Florida) and the Dallas–Fort Worth metroplex.

The impact of soil sealing is less in cities with lower urban growth rates.

The impact of soil sealing in cities in Australia shows to be less severe, due to lower urban growth rates. Locally, modelling shows relatively higher impact in the largest urban areas: Brisbane, Sydney, Melbourne, Victoria, and Perth, with greater Brisbane most affected (annual expected losses up 7% due to soil sealing). When considering the combined impact of soil sealing and aging stormwater infrastructure, the impact is higher with a 12% increase in AEL.

Climate: important today and for the future

Climate influences weather systems.

Population, exposure growth and urbanisation are the main drivers of today's large flood losses. Also important are the physical nature of events, such as rainfall and/or storm surge intensity, which are shaped by climate and weather conditions at the time of occurrence. This is an important consideration today and could be more so in the coming

[33] GHS built-up grid derived from Landsat, multitemporal (1975–1990–2000–2014), R2018A, European Commission Joint Research Centre, 2018.

decades. It is anticipated that warming temperatures will change weather and water load dynamics, and that will have significant implications for flood losses in the future.

Warming climates will change precipitation patterns…

Scientific findings are unambiguous: global climate change is intensifying the hydrological cycle and making extreme events like floods more likely. A warmer climate increases the amount and intensity of rainfall and shifts precipitation patterns, with more precipitation falling as rain rather than snow.[34,35,36] Climate change also impacts cyclonic weather systems and atmospheric rivers, how they are formed, evolve and move, which is crucial for rain/snowfall distribution. Latest scientific research suggests these changes could increase flood risk over the coming decades, especially for pluvial floods, although big regional differences exist.

…and more frequent and intense rainfall events are likely.

Changes in the hydrological cycle have already been observed. The IPCC AR6 WG I report states that the frequency and intensity of heavy precipitation events have increased over most land areas since the 1950s. Changes in monsoon precipitation in Asia and Africa are attributed to anthropogenic changes such as greenhouse gas and aerosol emissions. Attribution studies also link increases in heavy precipitation associated with tropical cyclones (eg, Hurricane Harvey) to anthropogenic warming. The increase in pluvial and fluvial flood risk strongly depends on the region. For example as the climate warms, some regions are experiencing drying soil conditions, which could make heavy flood events less probable. Conversely, the rising risk of coastal inundation due to sea level rise is more equally distributed across the globe.[37,38]

The UK, for example, has become wetter over the last decade.

We use the UK, one of the most exposed countries in Europe to flood risk, as a case study to describe in qualitative terms the potential effect of climate change on precipitation trends (see *Scenario analysis: UK climate and river flood risk by 2050* for a quantitative assessment). The UK Met Office says six of the 10 wettest years from as far back as 1862 have been since 1998, and the last decade was on average 4% wetter than 1981–2010.[39] In recent decades, increasing trends in annual maximum river flows have been observed, changes that are typically attributed to natural variability modes, such as the North Atlantic Oscillation.[40,41]

The changes cannot all be explained by natural variability.

However, there are indications that past flood episodes also bear the mark of anthropogenic warming.[42] The UK's weather is mainly driven by Extratropical Cyclones (ETC), and there is strong confidence that changes in the frequency and intensity of these will lead to more precipitation.[43,44,45,46] However, there is more uncertainty with respect to past and future changes of ETC, such as a shift polewards of storm tracks or changing frequencies. Instead, projections indicate a general increase in precipitation in the UK by mid-century, without a pronounced shift to drier summer and wetter winter months. Studies also project that heavy, shorter-lasting rainfall events during the winter

[34] *Precipitation change in the United States*, US Department of Commerce, 2017.
[35] "Chapter 8: Water cycle changes". IPCC, 2021 op. cit.
[36] S. Chan et al., "Europe-wide precipitation projections at convection permitting scale with the Unified Model", *Climate Dynamics*, vol 55, 2020.
[37] "Summary for Policymakers". In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2021.
[38] "Chapter 8: Water cycle changes" IPCC, 2021 op. cit.
[39] M. Kendon, et al., "State of the UK Climate 2020", *International Journal of Climatology*, 2021.
[40] S. Harrigan, S., et al., "Designation and trend analysis of the updated UK Benchmark Network of river flow stations: the UKBN2 dataset", *Hydrology Research*, 2018.
[41] J. Hannaford, "Climate-driven changes in UK river flows: A review of the evidence", *Progress in Physical Geography: Earth and Environmental*, 2016.
[42] F. Otto, et al., "Climate change increases the probability of heavy rains in Northern England/Southern Scotland like those of storm Desmond – a real-time event attribution revisited", *Environmental Research Letters*, 2018
[43] C. Loureiro et al., "Temporal variability in winter wave conditions and storminess in the northwest of Ireland", *Irish Geography*, vol 51, 2018.
[44] *UKCP18 Science Overview Report*, Met Office, 2018.
[45] H. Gregow , et al., "Review on winds, extratropical cyclones and their impacts in northern Europe and Finland", *Finnish Meteorological Institute*, 2020.
[46] "Chapter 11: Weather and climate extreme events in a changing climate" in *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, 2021.

and summer will become more frequent, intense and widespread.[47,48] Moreover, under a medium emission scenario (SSP2-4.5),[49] it is projected that a record-breaking UK rainfall event such as that of October 2020 could repeat every 30 years by the end of the current century.[50] That would represent a tenfold increase relative to a world with no climate change.[51]

The effect of warming climate on flood-related losses will likely vary by region in the UK.

Scenario analysis: UK climate and fluvial flood risk by 2050

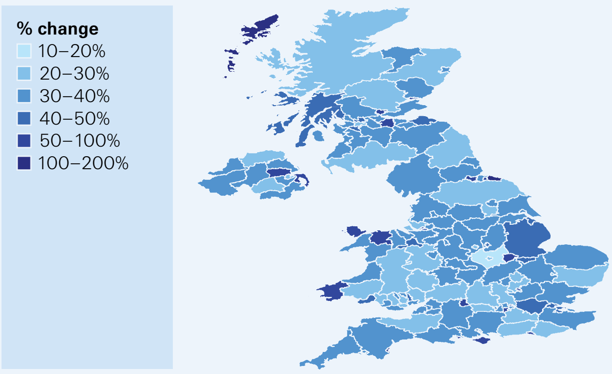
Our analysis focuses on fluvial floods. To represent 2050 climate conditions, we use precipitation projections provided by the UK Met Office. The underlying exposure data is a proxy for a UK insurance portfolio consisting of commercial and residential property. Simulating for many thousands of events through history, the left hand side panel of Figure 17 shows the regional differences in anticipated changes in annual expected losses (AEL) from flood under an RCP 8.5[52] scenario by 2050 relative to baseline (today's risk view = 2021).

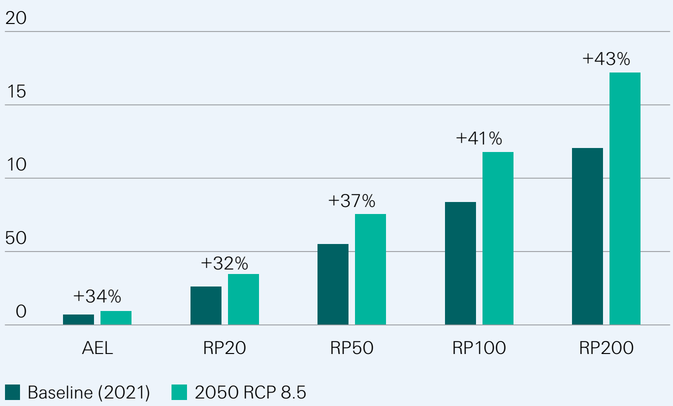
Our model indicates more pronounced increases in UK flood-related losses relative to a baseline in longer return periods.

The chart on the right shows projected changes in absolute baseline and relative AEL and four return periods (RP) by 2050 under RCP 8.5. The results assume the underlying exposure (the proxy property portfolio) remains constant and that no additional adaptation strategies such as flood defences are used to reduce the exposure. If we assume a simple linear change in precipitation and associated flooding, the modelled increase in AEL from the baseline is 34% (around GBP 250 million) by 2050, translating into an approximately 1% increase per annum. For different RPs, however, the results show progressive increases in projected losses relative to baseline, with the increases becoming more pronounced in longer return periods. This reflects the impact climate change could have in terms of exacerbated low-frequency events.

Figure 17

Regional differences in modelled AEL by 2050 relative to baseline (today's risk view = 2021, left); modelled climate change impact on AEL for four different for different Return Periods (RPs, right); both simulations under RCP 8.5 scenario





Source: Swiss Re Institute

The case is clear. To reduce flood risk in the UK today and in the future means more investment in flood defences and strict adherence to land use planning. The UK government is taking heed, with plans to invest several billions into new flood defences over the coming years.[53]

[47] E. J. Kendon et al., "Heavier summer downpours with climate change revealed by weather forecast resolution model", *Nature Climate Change*, 2014.
[48] Y. Chen, et al., "Changing Spatial Structure of Summer Heavy Rainfall, Using Convective-Permitting Ensemble", *Geophysical Research Letters*, 2017.
[49] SSP2-4.5, the middle of the road socio-economic pathway, corresponding approximately to the RCP-4.5 scenario that projects a temperature increase of about 3°C by the end of the century.
[50] The 3rd October 2020 is the wettest day in the UK since records began 1891.
[51] N. Christidies et al., "Record-breaking daily rainfall in the United Kingdom and the role of anthropogenic forcings", *Atmospheric Science Letters*, 2021.
[52] RCP 8.5 represents the high-end of the IPCC scenarios (often referred as "business-as-usual" scenario) where high level of greenhouse gas emissions are projected to increase global surface temperature by the order of 2.4°C by 2050.
[53] *UK Climate Change Risk Assessment 2022*, UK HM Government, 2022.

Building flood resilience: roles for re/insurers

We believe flood risk is insurable. The first step to building resilience against flood risk in a wetter world is to increase understanding of the peril. Today risk assessors use a wide set of tools ranging from sophisticated flood hazard maps to fully probabilistic risk models, but more can be done. Re/insurers can be central players in narrowing still large flood protection gaps around the world, both as long-term investors in sustainable infrastructure and mitigation strategies, and by extending the reach of flood covers, including parametric solutions. For this to happen, flood should be afforded the same attention as primary perils with regard to quality of exposure and claims data. Flood risk assessment and modelling need to be more rigorous.

Role for insurers: make flood risk assessment more rigorous

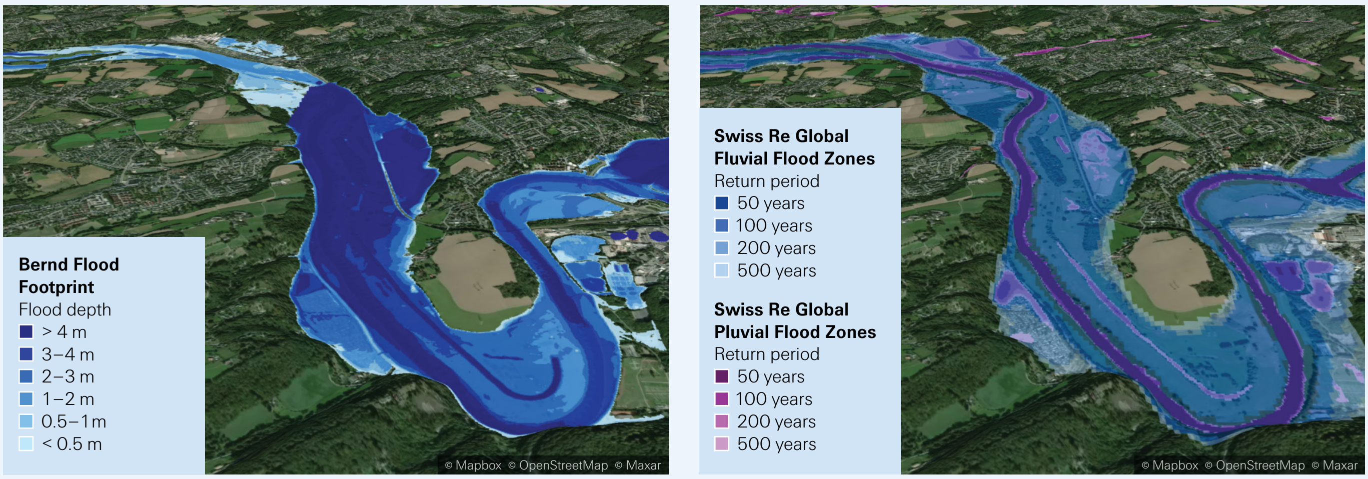
Increased understanding and awareness of flood risk is a first step to building resilience in a wetter world.

To strengthen resilience against flood increased understanding and awareness of the peril is required, similar to that of primary perils. In its many manifestations, flood is a complex peril to model. The influence and interplay of the anthropogenic environment on the physical processes creates additional modelling challenges when compared to other natural catastrophes. In the last decade, the industry has progressed modelling of the multiple drivers of flood risk, capitalising on advances in academic research, computing capabilities and a growing ecosystem of modelling companies.

Flood risk maps have become more sophisticated

An important first step has been the evolution of sophisticated flood risk maps providing granular detail for all major flood types, with high resolution and accuracy. Such as in Figure 18, which compares the actual footprint of the Bernd flood in Germany in July 2021 captured by remote sensing, with the Swiss Re Global Flood Zones for fluvial and pluvial risk. 91% of the entire flood footprint is captured in the Flood Zones, displaying their capabilities for risk selection and land-use decisions.

Figure 18
Remote-sensed Bernd flood footprint (left), compared to Swiss Re Global Flood Zones, fluvial and pluvial (right) in Hattingen region, Germany



Source: ICEYE, Swiss Re CatNet®

Probabilistic risk models have also improved.

Another step forward has been the development of fully probabilistic catastrophe models. These link physical hazards with loss outcomes and encompass the entire range of statistically possible flood events and asset-specific vulnerabilities. A recent improvement has been the incorporation of tropical cyclone-induced flooding in a tropical cyclone model, that can explicitly simulate events like Hurricane Ida in 2021. The increased availability of catastrophe models around secondary perils has been largely driven by smaller modelling companies taking advantage of *Oasis,* an open-source modelling framework that fosters the interoperability of models and model components. This open-source ecosystem facilitates collaboration and knowhow exchange, helping close any local and regional model gaps more rapidly.

Flood should be afforded the same modelling attention as primary perils, especially when it comes to data flow.

Despite the progress made, industry modelling capabilities for flood risk are still less rigorous than for primary perils, in particular with regard to data quality, transparency and flow (see Figure 19). Given the scale of loss potential and its upward trend, we believe flood needs to move up the industry agenda and be afforded the same attention as primary perils. The industry should pursue more granularity by using latest tools and techniques to make use of high-quality and high-resolution data and reproduce the many factors influencing flood risk and associated outcomes. Improving data flow by explicitly capturing and sharing flood specific exposure and policy information is a key first step in this direction. High quality risk information should be a standardised inclusion in the submission data flows where permissible. Monitoring is the second key component by increasing granularity and historic consistency of claims reports and loss statistics.

Modelling tools need to be improved and include forward-looking information.

We believe flooding is and will remain insurable, provided modelling remains abreast of ever-changing conditions with respect to temperature warming, urbanisation, land-use changes and other social and macroeconomic trends. Models need to move away from using past loss experience as a proxy for present-day risks. Optimising the granularity of data sets available today, the models should actively simulate today's dynamic risk scenarios, and continually update inputs as conditions change. Technology and the basic elements are available. Now it is about calibrating the models to the evolving risk. A robust and trusted risk assessment is a key to maintaining and advancing flood insurability, and to avoid surprise losses. The industry should also be more responsive to new insights and scientific evidence when repricing risks. Further there should be more effort to improve communication of the flood risk realities of different locations within the industry, governments and agencies, to help design more effective mitigation plans.

Figure 19
Industry calls to action to maintain insurability of flood risk

	Call for action for the industry	The positive trajectory
1	**Data quality, transparency, and flow:** collect and include in submission data accurate flood-related exposure, claims, policy information	Detailed exposure available on building level, including correct coverage coding for flood
2	**Expand model capabilities:** probabilistic models for the different types of flooding and markets	Pluvial and tropical cyclone-induced floods represented along side fluvial and storm surge risk for major markets
3	**Ensure representation of present-day risk:** frequent recalibration and debiasing of models from macro trends	Underwriting using flood models with near-future perspective, instead of experience costing
4	**Ensure representation of future risk:** scenario simulations projecting to 2050–2100 horizons	Regulatory requests for climate change scenarios to inform business strategy
5	**Increase risk awareness and transfer solutions:** private insurance covers and national pool schemes	Flood insurance products available for privates and successful examples of national schemes

Source: Swiss Re Institute

Role for insurers: help close flood infrastructure gaps

The role of flood infrastructure and the current gap.

A fundamental requirement to mitigate flood risk is the availability of so-called "grey infrastructure", namely flood defences such as levees, dams, retention basins, flood barriers and drainage systems. In advanced markets, much of the existing flood defence infrastructure was built more than 50 years ago, and is now near or beyond end-of-lifetime. Huge investment is needed to keep the structures functional and/or to retrofit them to ensure they remain effective in meeting the challenges of current-day climate and hydrology conditions. Integrated flood risk management solutions that look at the overall water allocation in a river catchment area should also be part of the solution, together with implementing stronger building codes and land-use planning.

Integrated flood risk management solutions are necessary.

As urban populations grow, so do their infrastructure needs. This is an important consideration in ever-growing megacities in emerging markets, where the share of urban population is forecast to increase from 54% in 2020 to 63% in 2040, translating into an additional 1.5 billion urbanites.[54] Grey infrastructure has been the traditional approach to mitigate flood risk. However, current energy, transport, building and water infrastructure make up more than 60% of global greenhouse gas emissions.[55] To achieve the 2030 agenda for global sustainable development, new and existing infrastructure needs fundamental transformation.[56] New nature-based or green infrastructure solutions can reduce flood risk by enhancing infiltration, while also being more sustainable (see *Green infrastructure solutions for flood protection*).

Insurers are instrumental in closing the infrastructure gap.

Closing the infrastructure gap is an opportunity for insurers in their capacity as long-term investors. For example, in the emerging markets, assuming the private sector were to step in and cover 75% of the existing infrastructure gap, and 25% of the total identified spend, we estimate an investment opportunity of close to USD 1 trillion annually over the next 20 years.[57] Insurers are well positioned to offer support as part of their search for investment yields to match their long-term liabilities. Infrastructure projects including flood defences can meet that need, while offering additional benefits of regional and asset class diversification, and opportunities to invest in environmentally and socially-responsible projects. Closing the infrastructure gap offers other upside for insurers also: new infrastructure fosters additional economic and, in turn, premium growth. By underwriting risks inherent in the construction and operational phases of green infrastructure projects, insurers can support the sustainability agenda and gain access to new and emerging risk pools.

Green infrastructure solutions for flood protection

Traditional grey infrastructure protects against the fury of water, but at the expense of biodiversity.

Grey infrastructure solutions (dams, seawalls, roads, pipes, canals, dikes, dredging of waterways etc) remain in use. They fulfill their purpose (eg, building a dam protects the population, creates water reservoirs, and the water can be used to generate electricity), but often overlook conservation of biodiversity and can lead to environmental damage. Further, grey infrastructure development has accelerated the fragmentation of natural habitats, including physical and chemical alteration of ecosystems. Historically, grey infrastructure projects have typically not considered the systemic loss of biodiversity and the economic consequences thereof on, for instance the farming and fishing sectors. Further, solid structures designed to cope with certain flood return periods are not always able to adapt to new flood patterns. This can necessitate often costly retrofits or worse, render the structure obsolete.

Green infrastructure helps restore the natural water retention capacity of the landscape.

In response to these challenges, a variety of sustainable green infrastructure solutions have been developed, tested and proven to be economically viable. These range from hybrid (green-grey) to fully green (nature-based) solutions, and provide multiple additional benefits relative to grey projects. These solutions are more in line with

[54] *World Urbanization Prospects: The 2018 Revision*, Online Edition, UN Department of Economic and Social Affairs, Population Division, 2018.
[55] *Financing Climate Futures: Rethinking Infrastructure Policy Highlights*, OECD/The World Bank/UN/Environment, 2018.
[56] The UN estimates USD 5–7 trillion, see UN Alliance for SDG Finance, UN Global Compact.
[57] *sigma* 3/2020: Power up: investing in infrastructure to drive sustainable growth in emerging markets, Swiss Re Institute

natural processes and can improve and restore the quality of local ecological habitats while limiting erosion.[58]

Belgium and Netherlands are devising a wide range of adaptation measures based on water management and sustainable spatial planning…

The use of green infrastructure for flood protection is garnering more attention from policymakers. Examples include the Sigma Plan developed by the government of the Flemish region of Belgium. This is an integrated river basin management plan to protect the areas surrounding the Scheldt river and its tributaries from flood risk. Another example is the Delta Programme in the Netherlands.[59] Both combine grey infrastructure like dikes and green measures such as creating and using lakes and parks as extra water storage space in times of high river discharge. The plans also aim to increase the retention capacity of urban areas. The idea is to accommodate the river water rather than build ever-higher dikes and discharge the water into the sea as fast as possible. The Sigma Plan is intended to handle the flood risk of more than 20 000 hectares of land with the restoration of around 3 000 ha of natural habitat by 2030. In 2005, the plan was re-evaluated to incorporate climate risks, such as rising sea levels; to develop river nature and recreational facilities; and the economic activities of the Scheldt region, such as shipping and agriculture.

…designed to provide benefits well beyond pure flood protection.

Green infrastructure for flood protection yields economic benefits far beyond risk protection. For instance, engineered flood plains, the sustainable enlargement of riverbanks, the creation of stone walls, the greening of riverbanks, the creation of artificial marshland, and the building of sand dunes all have a positive impact on water supply, agriculture, landscape management, natural habitat, biodiversity and tourism, while also providing a healthier environment for people and species.

The investments give rise to new underwriting opportunities.

Many projects are initiated and funded by the public sector or blended finance. Insurers can be important partners through the entire lifecycle of a project. The construction of green flood protection systems brings risks in both the construction and operational phases. Many of the exposures in the construction phase can be covered by standard property insurance. However, by integrating nature, the operational phase of projects also introduces new risk pool opportunities.

Role for insurers: closing the flood protection gap

Many advanced markets have national flood insurance programmes.

Insurance cover is another key factor in building economic and social resilience to flood risk. Even with the knowledge that flooding can inflict heavy losses, flood insurance penetration remains low. According to *sigma* records, 83% of the global economic losses from flood events over the past 10 years were uninsured. Still, the creation of a flood insurance market is a sustainable opportunity, and it should keep the positive trend seen in some advanced markets, becoming more widely available and affordable while also offering incentives for risk reduction.

In many countries, private sector insurers also provide covers for flood.

In many countries, flood cover is available for purchase from private sector insurers. Many advanced economies also have national property insurance flood programmes, involving the public and private sectors, such as the UK's Flood Re scheme. The specifics of national programmes vary greatly. For instance, in Norway private sector insurers are mandated to offer flood insurance while in Spain, the responsibility lies with the public sector. In both cases, however, purchase of flood insurance is voluntary. In France, by comparison, the purchase of flood insurance, available from the private sector, is mandatory for homeowners. Other countries adopt an approach that lies somewhere between the two, making cover quasi-compulsory, such as when flood insurance is a pre-requisite for a mortgage application. This is the case with the National Flood Insurance Program in the US.

Take up rates for flood insurance that is bundled together with other covers are typically higher.

To add to the range of permutations, in some markets flood insurance is available as a stand-alone product, and in others it is bundled together with cover for other perils. The varied features influence the premiums that homeowners pay and, ultimately, flood

[58] *Financing Sustainable Marine and Freshwater Infrastructure*, International Association of Dredging Companies, 2021. A joint study to explore private financing of green coastal, river and port projects,
[59] Ibid.

insurance penetration rates. Bundled products typically show significantly higher pick-up rates. This accounts for relatively higher penetration rates in Spain, where bundled products are provided by the public sector, and in France where insurance cover is mandatory and bundled products are offered by the private sector.

The industry can design other innovative flood insurance solutions...

Traditional indemnity flood cover is one form of protection that insurers can offer. But the range of solutions is much broader, including parametric reinsurance, micro-insurance and insurance-linked securities. In 2021, for example, the local authorities in the region of Guanajuato in Mexico and the state of Nagaland in India introduced parametric flood insurance to ease the burden on public finances from heavy rainfall disaster relief expenditure. The cover pays out when rainfall exceeds certain levels that in turn can lead to severe flooding. The solution helps the state government cover the emergency expenses incurred as a result of the heavy rainfall, but which are not covered by traditional indemnity programmes (eg, emergency shelters, food and medicine for affected families, immediate infrastructure repairs, etc).

... that are also practical and affordable.

Flood risk can and should be managed using the available large spectrum of physical, social and economic means. Concerted action across the entire risk management chain involving all key stakeholders – government, the insurance industry and consumers – is crucial. Specifically, the insurance industry can assess the risk with sophisticated tools, and help make mitigation infrastructures financially sustainable. That said, even with risk reduction measures in place, residual flood risk remains. Here the role of the industry is to design affordable and practical insurance products in order to transfer the financial risks that flooding presents away from businesses and homeowners.

Concluding remarks

Flood loss events of the magnitude witnessed in 2021 can happen again.

Flood risk deserves the full attention of re/insurers and policymakers alike, not least given the still-large flood protection gaps prevalent in many countries and the many millions of lives impacted by water inundation. Last year marks the second time insured losses from a standalone flood event surpassed the USD 10 billion mark, following the 2011 flood in Thailand. There is no reason not to expect reoccurrence given the increasing frequency and severity of flood events due to warming climates, exposure growth and the inadequacy of flood defence infrastructure in many countries.

Flood losses are already on par with those from primary peril exposures.

Over the last 10 years, the cumulative USD 75 billion in insured losses arising from flood events represents 10% of all natural catastrophe insured losses. Including our loss estimates, based on incomplete information, from flood events that were secondary peril effects of tropical cyclones would add another USD 36 billion to the total. That would make for average annual insured losses from all severe flood events of around USD 11 billion. Irrespective of the tropical-cyclone induced floods, the insured losses resulting from the Thailand flood in 2011 (USD 18 billion in 2021 prices) and also from last year's summer flood in central-western Europe (USD 13 billion), affirm that the loss potential from single flood events today is equal to and can even exceed the losses from primary peril events.

Flood risk is highly susceptible to urbanisation and can be mitigated with robust flood defences.

Given the frequency and scale of flood losses, it is incumbent on the insurance industry to extend the reach of risk transfer solutions and increase the financial resilience of households, businesses and communities around the world. This necessitates better understanding of the risk. Climate and water are not the only drivers of flood losses. Exposure levels, urbanisation, existing flood defences and the efficiency of sewage systems, emergency response mechanisms and many other factors all shape the physical and financial loss outcomes of flood events.

Flood remains insurable…

Flood risk is complex. But it is also insurable. Robust risk assessment in a rapidly changing risk environment is key to maintaining insurability. Progress has been made such as with high-resolution risk-based flood rating models. However, models can be further improved to more holistically account for the multiple factors that shape present and future risk scenarios. This includes, for instance, simulating for climate change effects on the water cycle, and the impact of soil-sealing on ground drainage capacity in urban areas, factors that can now be assessed on a quantitative basis.

…but there is a need for better data quality and more transparency.

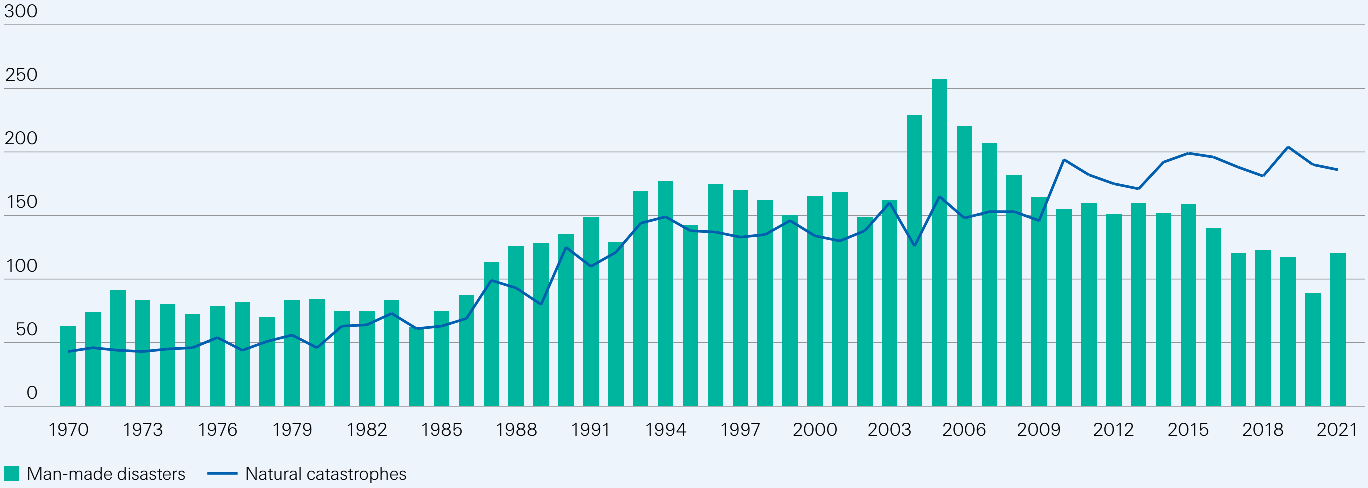
Better understanding is born of greater transparency. Relative to primary peril risks such as hurricane and earthquake with standardised submission flows in terms of exposure and model insights, flood risk has been less closely scrutinised. Optimising the granularity of data sets available today to separate wind and flood covers, and rigorous use of existing flood hazard and modelling techniques to simulate for the wide range of factors driving the physical and financial loss outcomes, will improve pricing and accumulation control. This will in turn facilitate sustainable risk transfer product offerings for both standalone river and pluvial flood exposures, as well as for instances where flood is a secondary outcome of a primary peril event in the case of tropical cyclones.

Appendix 1: 2021 – the year in review

Facts and figures

Number of catastrophic events: 306
In terms of *sigma* criteria, there were 306 catastrophes worldwide in 2021, up from 279 in 2020. There were 186 natural catastrophes (down from 190 in 2020), and 120 man-made disasters (up from 89 in 2020).

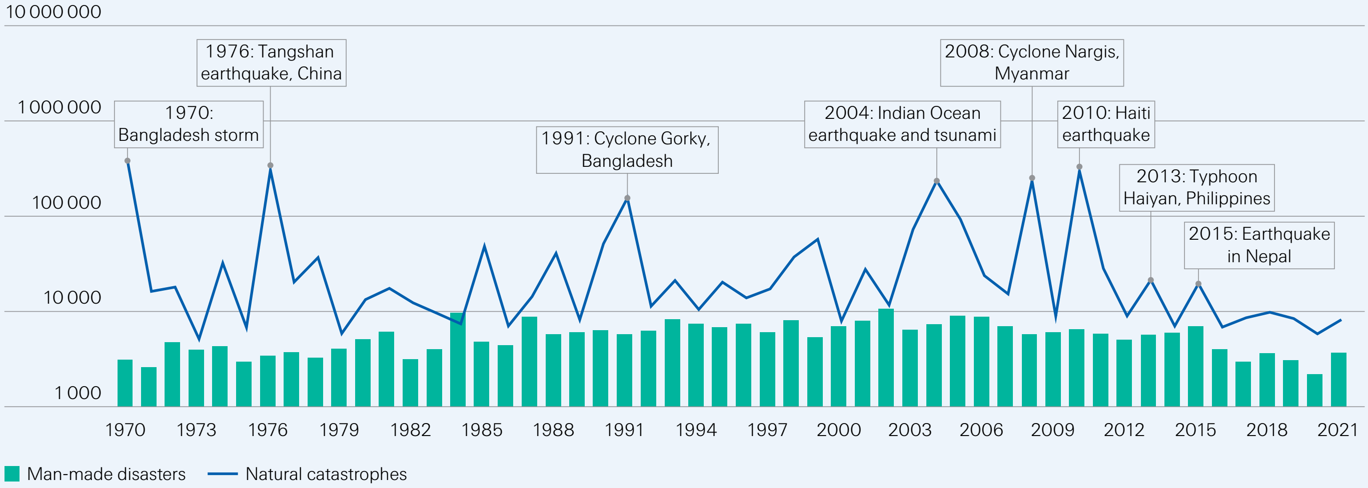
Figure 20
Number of catastrophic events, 1970–2021



Source: Swiss Re Institute

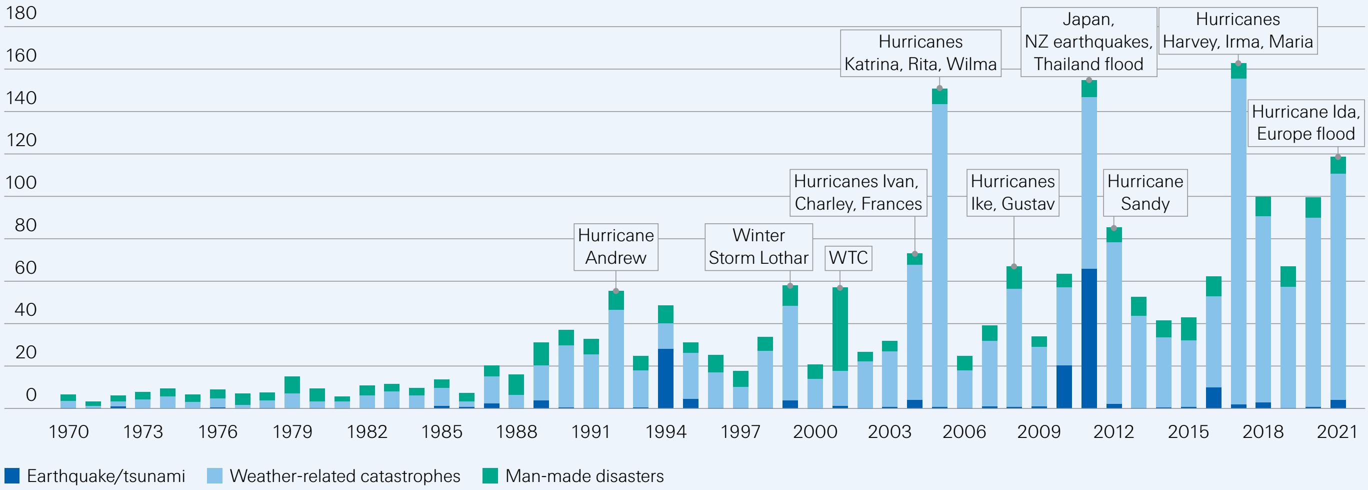
Number of victims: above 11 881
Worldwide, 11 881 people are believed to have died or gone missing in disaster events in 2021. Natural catastrophes claimed roughly 8 200 victims, and man-made disasters over 3 600.

Figure 21
Number of victims, 1970–2021



Note: Scale is logarithmic: the number of victims increases tenfold per band. Source: Swiss Re Institute

Figure 22
Insured catastrophe losses, 1970–2021, in USD billion at 2021 prices



Source: Swiss Re Institute

Total economic losses: USD 280 billion

Total economic losses from disasters across the globe were an estimated USD 280 billion in 2021, up from USD 217 billion in 2020. Around USD 270 billion resulted from natural catastrophes and the remainder from man-made events.

Table 3
Economic losses, in USD billion and as a % of global GDP, 2021

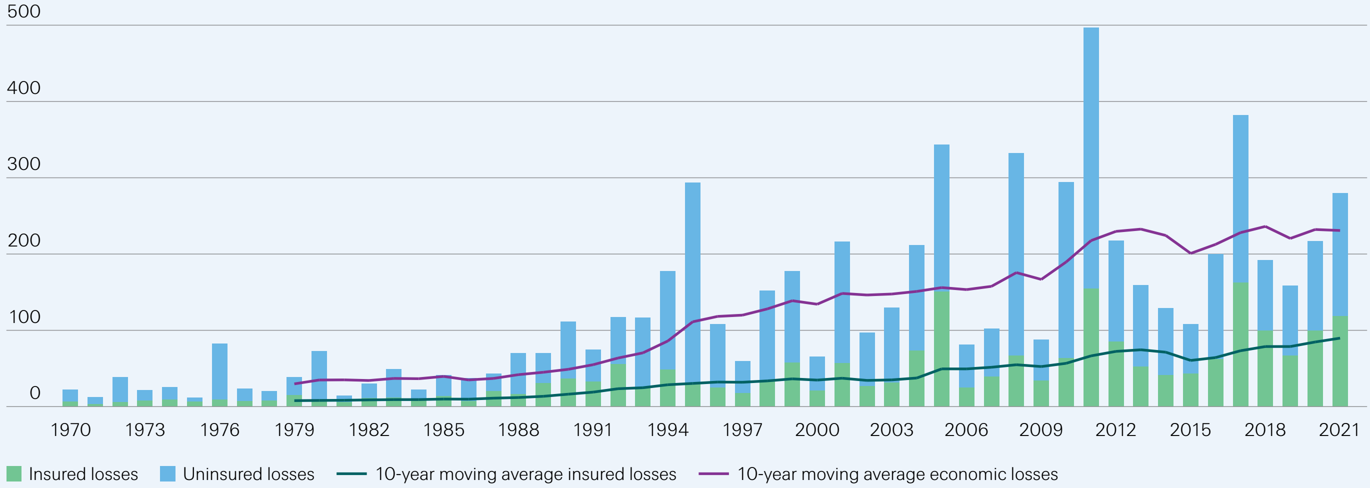
Regions	in USD bn*	in % of GDP
North America	148	0.59%
Latin America & Caribbean	6	0.11%
Europe	59	0.24%
Africa	4	0.14%
Asia	59	0.16%
Oceania/Australia	5	0.24%
Total	**280**	
World total		0.29%
10-year average**	204	0.23%

*rounded numbers, **inflation adjusted. Source: Swiss Re Institute

Global catastrophe protection gap: USD 162 billion

Figure 23 shows global economic and insured losses over time. This highlights the insurance protection gap, ie the financial loss generated by catastrophes not covered by insurance. In 2021, the global protection gap was around USD 162 billion, up from USD 117 billion in 2020 and above the previous 10-year average of USD 139 billion.

Figure 23
Insured vs uninsured losses, 1970–2021, in USD billion at 2021 prices



Economic losses = insured + uninsured losses. Source: Swiss Re Institute

Regional loss overview

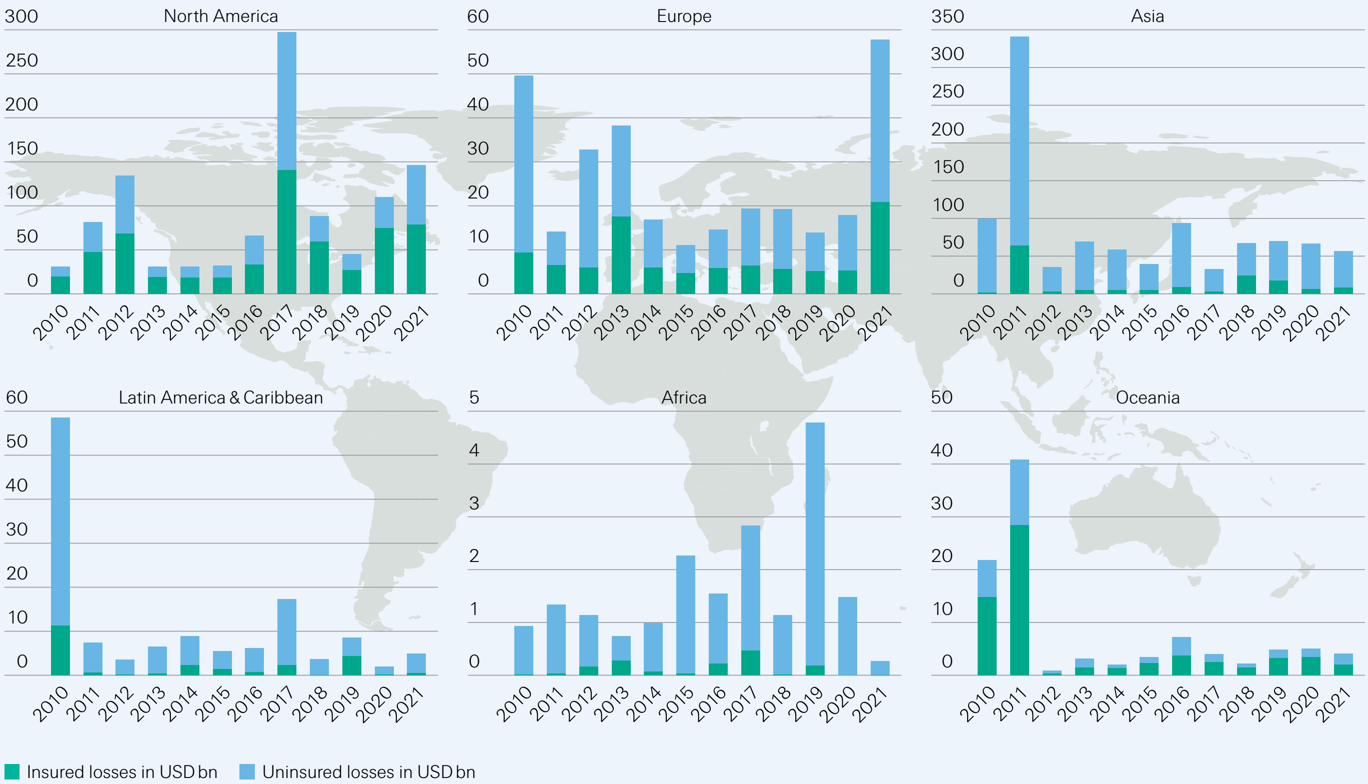
Insured and economic losses were highest in North America.

Table 4
Number of events, victims, economic and insured losses by region, 2021

Region	Events	Victims	in %	Insured losses (USD bn)	in %	Economic losses (USD bn)	in %
North America	87	1 451	12.2%	81.2	68.4%	148.4	53.0%
Latin America & Caribbean	21	2 877	24.2%	0.9	0.8%	5.6	2.0%
Europe	36	633	5.3%	22.1	18.6%	59.1	21.1%
Africa	58	2 554	21.5%	2.3	2.0%	3.7	1.3%
Asia	92	4 094	34.5%	9.6	8.1%	58.5	20.9%
Oceania/Australia	11	272	2.3%	2.3	2.0%	4.5	1.6%
World total	**306**	**11 881**	**100%**	**118.6**	**100.0%**	**280.1**	**100%**

Note: some percentages may not add up to 100 due to rounding. Source: Swiss Re Institute

Figure 24
Natural catastrophes protection gap by region 2010–2021, in USD billion at 2021 prices



Source: Swiss Re Institute

Appendix 2

Definition of terms

Natural catastrophes
The term "natural catastrophe" refers to an event caused by natural forces. Such an event generally results in a large number of individual losses involving many insurance policies. The scale of the losses resulting from a catastrophe depends not only on the severity of the natural forces concerned, but also on man-made factors, such as building design or the efficiency of disaster control in the afflicted region. In this *sigma* study, natural catastrophes are subdivided into the following categories: floods, storms, earthquakes, droughts/forest fires/heat waves, cold waves/frost, hail, tsunamis, and other natural catastrophes.

Man-made disasters
This study categorises major events associated with human activities as "man-made" or "technical" disasters. Generally, a large object in a very limited space is affected, which is covered by a small number of insurance policies. War, civil war, and war-like events are excluded. *sigma* subdivides man-made disasters into the following categories: major fires and explosions, aviation and space disasters, shipping disasters, rail disasters, mining accidents, collapse of buildings/bridges, and miscellaneous (including terrorism).

Economic losses
For the purposes of the present *sigma* study, economic losses are all the financial losses directly attributable to a major event, ie damage to buildings, infrastructure, vehicles etc. The term also includes losses due to business interruption as a direct consequence of the property damage. A figure identified as "total damage" or "economic loss" includes all damage, insured and uninsured. Total loss figures do not include indirect financial losses – ie loss of earnings by suppliers due to disabled businesses, estimated shortfalls in GDP and non-economic losses, such as loss of reputation or impaired quality of life.

Generally, total (or economic) losses are estimated and communicated in very different ways. As a result, they are not directly comparable and should be seen only as an indication of the general order of magnitude.

Insured losses
"Losses" refer to all insured losses except liability. Leaving aside liability losses, on one hand, allows a relatively swift assessment of the insurance year; on the other hand, however, it tends to understate the cost of man-made disasters. Life insurance losses are also not included. Insured losses are gross of any reinsurance, be it provided by commercial or government schemes

Adjustment for inflation
sigma converts all losses for the occurrence year not given in USD into USD using the end-of-year exchange rate. To adjust for inflation, these USD values are extrapolated using the US consumer price index to give current (2021) values.

For the 2021 reporting year, the lower loss thresholds were set as follows:

***sigma* thresholds for 2021**	
Insured losses (threshold in USD m)	
Maritime disasters	22.5
Aviation	45.0
Other losses	55.8
or Total economic losses (threshold in USD m)	111.7
or Casualties	
Dead or missing	20
Injured	50
Homeless	2000

If changes to the loss amounts of previously published events become known, *sigma* takes these into account in its database, but Swiss Re is under no obligation to publicly revise or update this *sigma* study.

Sources
Information is collected from newspapers, direct insurance and reinsurance periodicals, specialist publications (in printed or electronic form) and reports from insurers and reinsurers. In no event shall Swiss Re be liable for any loss or damage arising in connection with the use of this information (see the copyright information on the inside back cover).

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Explore and visualise *sigma* data on natural catastrophes and the world insurance markets at *www.sigma-explorer.com*

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