Chapter 2

Flood risk in a changing climate

This chapter of the report provides an overview of trends in the occurrence of floods, including the potential for climate change to impact the frequency and intensity of floods. This is followed by an examination of trends in the economic impact of floods, including direct and indirect losses, disruptions to economic activity as well as the impact of insurance in reducing the economic impacts of natural disasters such as floods.

Most floods, defined as "the overflowing of the normal confines of a stream or other body of water or the accumulation of water over areas that are not normally submerged" (IPCC, 2012), can be classified into the following categories:

- Flash flood: Heavy or excessive rainfall in a short period of time that, due to the inability for the ground to absorb a high proportion of the water, produces runoff. A flash flood can occur anywhere (usually in conjunction with a thunderstorm or tropical cyclone) and is the most frequent type of flood.

- Riverine flood: Flooding that results from the overflow of water from a stream or river channel onto normally dry land in the floodplain adjacent to the channel. Riverine flooding may occur seasonally as a result of rainy seasons and/or the melting of snow or could occur as a result of abnormally high levels of precipitation that saturates the soil and leads to an increased proportion of rainfall flowing into water courses.

- Coastal flood/storm surge: An abnormal rise in sea level generated by a tropical cyclone or other intense storm that thrusts sea water onto the coast and/or creates large waves as a result of strong winds.

- Ice jam flood: Where flood waves are created by the break-up of ice that had been obstructing the flow of water. Ice jams tend to develop near river bends and obstructions (e.g., bridges).

- Groundwater flood: In locations where the groundwater level is relatively close to the surface, an abnormal increase in rainfall levels can raise the water table leading to damage by water seepage into basements and the destabilisation of building foundations.

- Dam burst: A failure of a dam, resulting from high levels of precipitation, landslides or engineering defects, could lead to significant downstream flooding.

- Debris flows: Where water transports large amounts of solid matter (soil, sand, gravel, rock and/or other debris), including mudflows (i.e. debris flows consisting of small particles). Debris flows can be a combination of landslide and flood and may occur where heavy rain saturates loose soil on a slope. A special form of mudflow is a lahar where rain washes off volcanic ash.

Flooding may also be caused by a tsunami following the displacement of water by an earthquake, volcanic eruption or landslide. However, from the perspective of insurance coverage, damage resulting from a tsunami is usually treated as part of the consequence of the initial event (earthquake, volcanic eruption) and insured accordingly.

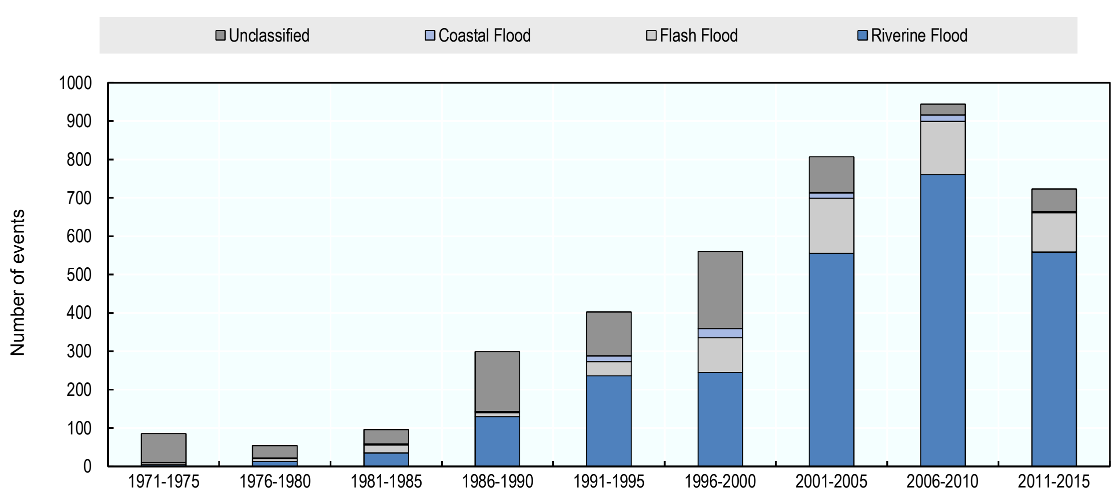
Due to their nature, different types of flood pose different types of dangers. Flooding from the sea and large rivers (including as a result of ice jam or dam burst) is generally less frequent although can impact large areas and cause extensive damage. In the case of riverine floods, flood waters generally remain for longer periods of time leading to greater disruption. Sea surge tends to create significant loss potential due to the high-velocity of water inundation and the damaging impacts of salt water. For example, in the United States, individual claims submitted to the National Flood Insurance Program (NFIP) due to storm surge damage have been found to be 8.0% to 20.5% higher than claims from other types of flooding (Kousky and Michel-Kerjan, 2015). Flash floods can cause significant damage due to the more limited advance warning of their occurrence (and therefore more limited time to put in place protective measures) (Kron, 2015).

The location where floods occur will also have significant implications for the amount of people affected and the level of damage incurred. Most obviously, the inundation of highly-populated areas will increase the likelihood of large damages. The overall level of damage will also vary with the relative value of assets (floods in developed countries with higher-value assets will tend to lead to larger overall losses than floods in lower income countries). In urban areas, flood water can become polluted with sewage leading to additional health risks and potentially higher clean-up costs (Ramsbottom, Sayers and Panzeri, 2012). Also, variations in altitude within the inundated area can have substantial implications. Relatively flat areas may face longer inundation periods while hilly areas could face higher-velocity water flows with greater potential for damage (Kron, 2015).

2.1 Trends in the occurrence and impact of flood events

There has been a substantial increase in the number of flood disasters recorded in recent decades (partly driven by improvements in reporting and data capture). According to data collected by the Centre for Research on the Epidemiology of Disasters (CRED) and included in the EM-DAT database on historical disaster events, close to 62% of the 4 250 flood disasters that have been reported since 1970 have occurred since the year 2000 (see Figure 2.1).[1] The average annual number of reported flood events has increased from under 30 between 1971-80 to approximately 50 between 1981-1990 to over 140 between 2011 and 2015.

Figure 2.1. **Number of flood events by type: 1971-2015**
(total number of events during each 5-year period)

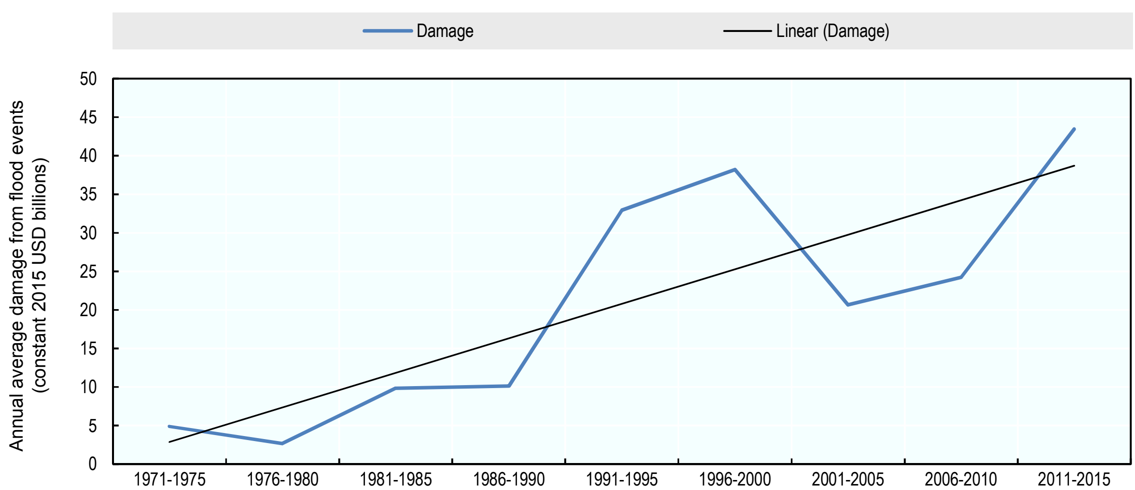


Source: EM-DAT.

Since 2000, floods classified as riverine floods have accounted for approximately 73% of all floods, flash floods for close to 16% and coastal floods for just under 2% (the remaining 9% were not classified). However, many flooding events are difficult to classify as an event may involve more than one type of flooding (e.g. a tropical cyclone may cause coastal flooding as a result of wind-driven sea surge, flash flooding due to heavy precipitation accompanying the cyclone and potentially riverine flooding as the accumulated water enters the river system). In addition, flooding resulting from a tropical cyclone will often be classified as part of the meteorological event rather as a separate hydrological event and therefore not recorded as a flood in the EM-DAT data and other data sets.

Annual average damages from floods reported in the EM-DAT database have increased over time, from less than USD 4 billion per year between 1971-1980 (in constant 2015 dollars) to over USD 40 billion per year between 2011 and 2015 (see Figure 2.2). This is consistent with the finding from Kundzewicz et al. (2014) that fluvial flood losses at the global level have increased from approximately USD 7 billion per year during the 1980s to USD 24 billion per year during 2001-2011 (in constant dollars). As noted above, these figures do not generally include flood damages resulting from tropical cyclones which have also increased significantly (from less than USD 6 billion in recorded damages annually between 1971-1980 to over USD 45 billion between 2001-2010 and just under USD 28 billion between 2011 and 2015, in constant 2015 USD and including both damages from wind and flood).

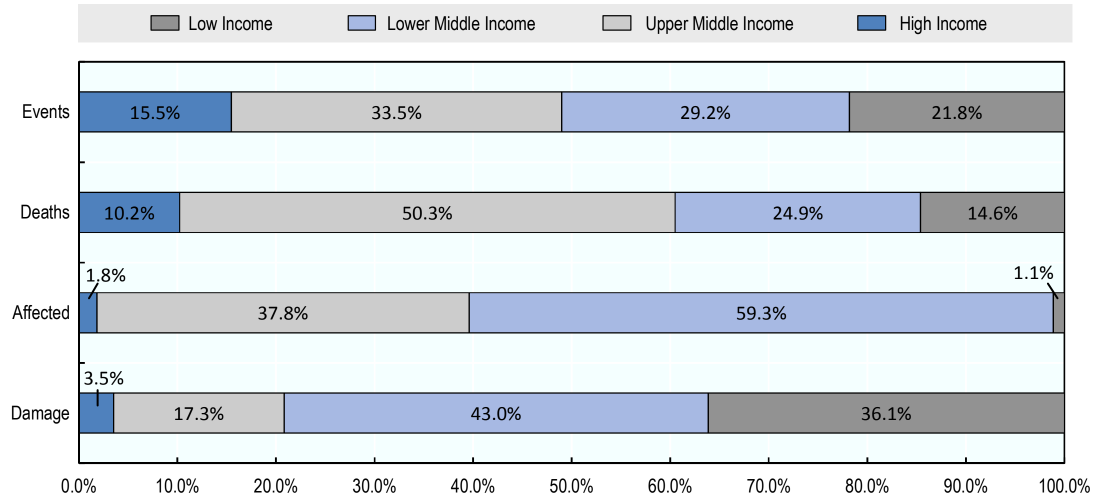
Figure 2.2. **Annual average damage from flood events: 1971-2015**
(average annual damage during each 5-year period)



Source: EM-DAT. The US Bureau of Labor Statistics' *Historical Consumer Price Index for All Urban Consumers (CPI-U)* was used to convert data on damages to constant 2015 USD.

The impact of flooding varies substantially with the level of income of the affected country (which is usually a gauge of the level of a country's resilience against flood risk). Lower income countries tend to face higher deaths from flood events while higher income countries face higher levels of damage. While 49% of flood events recorded in EM-DAT between 1971 and 2015 have occurred in countries considered low income or lower middle income, more than 60% of all deaths have occurred in those countries. High income and upper middle income countries accounted for just under 80% of all reported damages from flood events (see Figure 2.3).

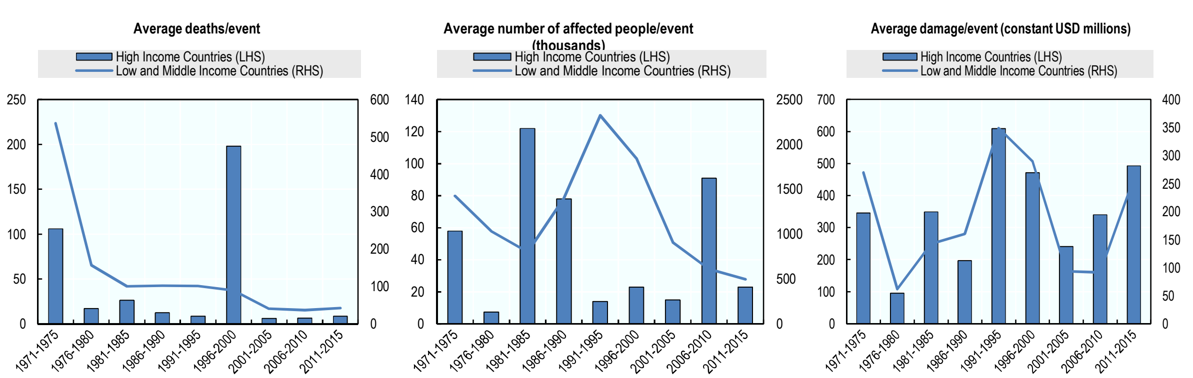
Figure 2.3. **Flood events, deaths, affected people and damage by income classification**



Source: EM-DAT. The categorisation of countries by income level was undertaken based on the World Bank FY2016 country and lending groups.

Despite the significant increase in the number of flood disasters, the average annual number of deaths has not increased significantly in recent decades. On average, close to 5 250 deaths were reported annually as a result of flood disasters between 2011 and 2015, relative to an average of 5 800 between 1971 and 1980 (despite the significant increase in reported events). However, the average annual number of people affected per event, and particularly the average damage per event, generally remained at the same level (with significant year-to-year volatility) over the past four decades (i.e. the number of people affected and the level of damage has increased with the number of recorded events - see Figure 2.4). This suggests more significant achievements in terms of protecting people's lives from floods (likely as a result of improved emergency preparedness and response, and in particular early warning capacity) than protecting settlements and property. As suggested by Figure 2.3 above, the average number of deaths and affected people per event is significantly higher in low and middle income countries while damage per event is significantly higher in high income countries.

Figure 2.4. **Average deaths, affected and damage per flood event: 1971-2015**



Source: EM-DAT. The categorisation of countries by income level was undertaken based on the World Bank FY2016 country and lending groups. The US Bureau of Labor Statistics' *Historical Consumer Price Index for All Urban Consumers (CPI-U)* was used to convert data on damages to constant 2015 USD.

Consistent with the increasing trend in damage from flood events, many of the largest flood events in terms of overall losses have occurred since 1990. There were only three flood events that generated overall losses above USD 2 billion before 1990, relative to six events with overall losses above USD 10 billion in the 1990's, three in the first decade of the 21st century, and three events with overall losses above USD 10 billion between 2010 and 2013 (Kron, 2015) (see Table 2.1). The number of annual flood events with losses above USD 50 million (adjusted for inflation) shows a similar upward trend since the 1980s (Kron, 2015). Historically, reported losses from floods unrelated to cyclones are much smaller than losses from other types of natural disasters. However, losses from some major floods in recent years (such as the 2011 floods in Thailand) have reached levels more commonly associated with earthquakes and cyclones (which involve damage from both strong winds and water penetration).

Table 2.1. **Largest flood events (including cyclone-related flooding) since 2000 (constant 2015 USD billion)**

Event	Estimated overall losses due to flood
Hurricane Katrina (US Gulf Coast) – 2005	100.7***
Hurricane Sandy (US Northeast) – 2012	47.5***
Chao Phraya (Thailand) – 2011	45.3
Elbe/Danube (Central and Southern Europe) – 2002	21.7
Hurricane Ike (Caribbean, US) – 2008	14.3*
Elbe/Danube (Central Europe) – 2013	12.8
Southern Alps (Italy and Switzerland) – 2000	11.7
Midwest/Missouri (US) – 2008	11.0
Indus (Pakistan) – 2010	10.3
Centre, South, East, Northwest (China) – 2003	10.2
Hurricane Ivan (Caribbean, US) – 2004	10.0*
Southwest, Centre, Northwest (China) – 2004	9.8
East, Southeast, South (China) – 2010	8.7
Hurricane Wilma (Caribbean, Mexico, US) – 2005	8.5*
East, Northeast, Southeast (China) – 2012	8.3
Tropical Storm Allison (Houston, US) – 2001	8.0
South, Southwest, East, Centre (China) – 2007	7.8
Monsoon rains (Bangladesh, India, Nepal) – 2004	6.3
Monsoon flash flood (Mumbai, India) – 2005	6.1
West (Calgary, Canada) – 2013	5.8
Hurricane Irene (Northeast, US) – 2011	5.3**
Typhoon Haiyan (Philippines) – 2013	5.1**

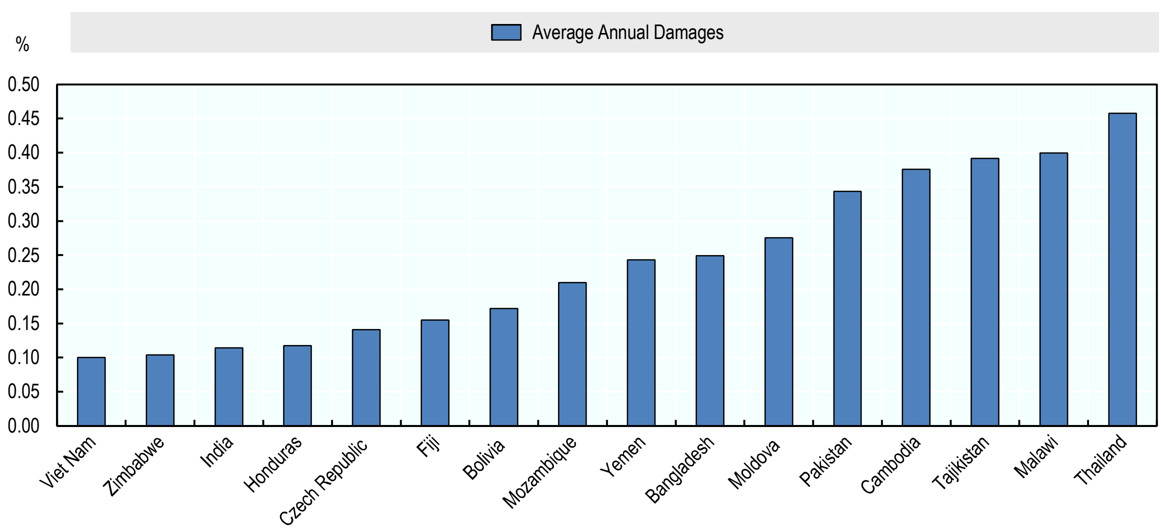
* Indicates that the estimate was based on attributing one-third of the overall damages to flooding.
** Indicates that the estimate was based on attributing one-half of the overall damages to flooding.
*** Indicates that the estimate was based on attributing two-thirds of the overall damages to flooding.

Source: The list of events, including estimates of overall losses at original value and the share of overall damage due to flooding, are taken from Kron (2015) using data from Munich Re's NATCATSERVICE. The US Bureau of Labor Statistics' *Historical Consumer Price Index for All Urban Consumers (CPI-U)* was used to convert data on damages to constant 2015 USD.

2.2 The economic impact of floods

Direct losses from floods are significant for many countries. According to the EM-DAT data, since 1990, 36 countries have faced at least one year of damages to property, crops and livestock of USD 1 billion (in constant 2015 USD) or more from floods while 15 countries experienced at least one year of flood damages exceeding USD 5 billion (including Australia, Bangladesh, Canada, China, Germany, India, Iran, Italy, Japan, North Korea, Pakistan, Poland, Thailand, United Kingdom, and the United States). In some countries, annual average recorded damages have accounted for a material share of GDP (see Figure 2.5). A 100-year event in Central Europe could cause property damages of 2.5% of GDP in the Czech Republic; 3.2% in Poland; 4.6% in Hungary; and 8.5% in the Slovak Republic (Pollner, 2012). In some countries, including the United States, China and India, expected annual damages (EAD) of more than USD 10 billion have been estimated by some analyses (Sadoff et al., 2015).

Figure 2.5. **Annual average damage from flood events as a share of GDP**



Notes: Annual average damage was calculated based on damage reported between 1971 and 2015 and converted to constant 2015 USD based on the US Bureau of Labor Statistics' *Historical Consumer Price Index for All Urban Consumers (CPI-U)*. GDP figures are from the World Bank for the year 2014 (most recent year available) at current USD (*http://data.worldbank.org/indicator/NY.GDP.MKTP.CD*).

Source: EM-DAT.

A key driver of the increasing occurrence and losses from floods and cyclones is the accumulation of assets in flood-prone areas (a flood or cyclone would only be reported as a disaster if it affects a populated area). For example, in the United States, the population in counties along the Atlantic, Pacific, and Gulf Coasts has increased from approximately 47 million in 1960 to 87 million people in 2008 and the number of housing units along the coast has more than doubled from 16.1 million in 1960 to 36.3 million in 2008 (Wilson and Fischetti, 2010).

Based on the accumulation of assets alone (i.e. not taking into account changes in the nature of flood occurrence), exposure to flood risk is expected to increase significantly. While global projections are challenging because of differences in data availability and quality, a number of studies have attempted to project the level of exposure in future years based on asset accumulation:

- Jongman, Ward and Aerts (2012) estimate that the value of global assets exposed to 1-in-100 year river flooding will increase by 200-250% between 2010 and 2050 (depending on the calculation method used) while the value of assets exposed to 1-in-100 year coastal flooding will increase by 182-200%.[2]

- According to estimates by Güneralp et al. (2015) based on urban land-use projections, 13% of urban land will be located in "low-elevation coastal zones"[3] vulnerable to flooding and 40% of urban land will be located in high-frequency flood zones by 2030 (from 11% and 30%, respectively in 2000), with developing countries accounting for an increasing share of that exposure as a result of more rapid urbanisation.

Large flood events can also have significant financial and economic implications for government, business and households through indirect consequences such as business interruption,[4] loss of employment and output, and decreased tax revenues (as well as significant social and environmental consequences):

- Indirect impacts on businesses may occur as a result of disruptions to their supply chains, the infrastructure services they rely on for production (power, water) and/or transport of employees or products, or due to loss of demand for their goods and services. For example, a survey of businesses in regions affected by the flooding in Germany in June 2013 found that close to 60% were affected by staff lateness or absences due to problems reaching work, just under 80% were affected by turnover losses and 88% faced some sort of interruption to their operations, sometimes lasting up to 8 weeks (about 80% had damage to buildings while close to 50% had damage to plant and equipment) (Thieken et al., 2016). These costs will be particularly severe for events such as floods that cause wide-area damage that are likely to also impact local suppliers and clients (The Australian Government the Treasury, 2011).

- Damage to crops can impact food security in a country or region (floods have been responsible for close to 60% of all disaster-related damages to crops). Repetitive flooding could exacerbate food crises over several years and even have an impact on international food markets if a major producer country is affected (FAO, 2012).

- Tourism revenues may also be significantly impacted if the flood event changes perceptions about the attractiveness or safety of a disaster-affected country/city. For example, the 2011 floods in Thailand led to estimated losses in tourism revenue of USD 3 billion (World Bank and Thai Ministry of Finance, 2012).

At the macro-level, government finances could be impacted by the loss of corporate tax revenue due to business interruption and personal income taxes due to lost wages. Governments, both local and national, are also likely to face significant costs related to recovery and reconstruction (often included as an indirect economic cost of disasters). For example, tax revenues in New York City were estimated to have declined by USD 160 million after Hurricane Sandy due to lost business revenue and wages (New York City Recovery, 2015). Governments may also face an adverse impact on balance of payments if exports or capital flows are significantly affected by the disaster event.

While indirect costs are difficult to calculate, a number of pre- and post-event studies have attempted to estimate these costs. For example, an OECD (2014) study assessing the impacts of a major flood event in the Paris region estimated the magnitude of a number of indirect costs as a result of disruptions to critical infrastructure (Box 2.1).

Box 2.1. **Indirect economic impacts: Seine river flood in Île-de-France**

In 2014, the OECD undertook an assessment of the potential economic impacts of a major flood of the Seine river in the greater Paris region. The assessment considered three flood scenarios based on historical occurrences and used business surveys and economic modelling to estimate the potential direct, indirect and overall macro-economic impacts. Based on input from the operators of major power, transport and water utilities, the study estimated the scope of disruption to critical infrastructure services:

- Based on the location of sub-stations, in an extreme scenario (1910 flood levels), approximately 1.5 million households and business customers could face power supply disruptions over an area 50% larger than the area affected directly by floods.
- More than half of the 250 km metro line would be closed, leaving only one of the 14 Paris metro lines operational. A number of suburban public transport lines would also be disrupted along with 3 major train stations in Paris. In addition, the road network would be significantly disrupted, including five motorways, several major highways and all bridge crossing across the Seine River (which winds through Paris and its suburban region).
- The drinking water supply could be disrupted in the outskirts of Paris, with more than 5 million customers potentially facing extended water supply disruptions and 1.3 million customers facing deterioration in water quality.

The impact of these disruptions on businesses' operating losses (particularly as a result of power and transport disruptions) were estimated at EUR 19 billion, or almost 65% of the direct losses of EUR 29.4 billion estimated for the most extreme scenario.

Source: OECD (2014)

The globalisation of supply chains means such disruptions can also have regional or even global impacts. For example, the flooding of several industrial parks in Thailand in 2011 had global/regional impacts in many sectors (including automotive and electronics) as global companies such as Toyota, Honda, Nissan, Ford, Apple, Sony, Canon, and Toshiba faced disruptions to production or facility closures as a result of their linkages to sites located in the flood zone (Chachavalpongpun, 2011). Global industrial production declined by 2.5% as a result of the floods (Schanz and Wang, 2015). The 2015 flooding in Chennai, a major automotive production centre in India, affected an estimated 10-15% of India's automotive production as a result of plant shutdowns and supply chain impacts (Thakkar, 2015).

These direct and indirect losses can have a significant impact on the broader economy. Von Peter, von Dahlen and Saxena (2012), using data from Munich Re's NatCatSERVICE for 2 476 major natural catastrophes in 203 countries between 1960-2011, found that the average natural disaster (of all types, including floods) leads to a fall in growth of 1.0% of GDP upon impact and a cumulative loss to GDP of 2.6%. These impacts are particularly severe for developing countries, and the poorest households within those countries, due to their more limited capacity to manage disaster risks. The Lloyd's City Risk Index: 2015-2025 (2015) also provides an estimate of the economic output at risk from various perils in 301 major cities, including floods. According to Lloyd's, USD 432 billion of economic output is at risk[5] from coastal and riverine flooding in the 301 cities analysed, including more than USD 10 billion in each of the seven most exposed cities (Tokyo, Osaka, Los Angeles, New York, Sao Paulo, Delhi and Chinese Taipei).

2.3 Potential impact of climate change on the intensity and frequency of flood events

While the evidence is far from conclusive, climate change is expected to impact the nature of flood risk going forward as a result of changes to: i) the frequency of heavy precipitation events; ii) the range and intensity of cyclones; and iii) the rise in sea-levels. Specifically, in their special report on *Managing the risks of extreme events and disasters to advance climate change adaptation* (2012),[6] the Inter-Governmental Panel on Climate Change (IPCC) found evidence of a number of likely impacts of climate change on the nature of flood events (although subject to significant regional variation and various levels of uncertainty), including:

- the frequency of heavy precipitation or the proportion of total rainfall from heavy rainfalls will likely increase over many areas of the globe as higher air temperatures allow the atmosphere to retain more water;
- the average tropical cyclone maximum wind speed will likely increase in some ocean basins;
- there may be a projected poleward shift of extratropical storm tracks;
- the mean sea level rise will very likely contribute to upward trends in extreme coastal high water levels; and
- changes in heat waves, glacial retreat, and/or permafrost degradation will affect high mountain phenomena such as slope instabilities, movements of mass, and glacial lake outburst floods.

Among these potential impacts, the IPCC places more confidence in the predicted impact on rainfall intensities than other natural disasters (IPCC, 2012). An increase in the occurrence of heavy precipitation events could increase the frequency of flash floods, riverine floods and groundwater floods. Increasing levels of urbanisation, which will generally reduce the water absorption capacity of land by converting natural terrain to urban use, will likely exacerbate these climate change impacts and increase the level of resulting damage (Wilby and Keenan, 2012).

While there is significant uncertainty in assessing the potential implications of climate change on flood risk, a number of studies have analysed this issue. For example, an assessment of likely changes in river flooding return periods (Arnell et al., 2014) found that the frequency of river flooding will likely double (or more) by 2050 (relative to the period 1961-1990) in Central and Eastern Europe, Central America, Brazil and some parts of Western and Central Africa – while decreases in frequency can be expected in some parts of Asia. Based on the projections of numerous climate models, the return periods for what are currently considered 1-in-100 year floods is expected to decline (i.e. occur more frequently) by 2100 in 22 of the 29 major river basins examined, and decline significantly in a number of basins including the Lena (Northeast Eurasia), Congo (Central Africa), Nile (East Africa), Ganges (South Asia), Mekong (Southeast Asia), and Murray (Australia) (Hirabayashi et al., 2013). Close to 90% of the respondents to an OECD questionnaire on the financial management of flood risk indicated that climate change has increased the level of flood risk in their country, with almost 50% indicating that that impact has already been significant.

A number of studies have used climate change scenarios to model the possible impacts of climate change on flood losses for different regions of the world (for various time periods), using a range of approaches to estimating the damage that could occur as a result of predicted changes in weather patterns. Box 2.2 provides an overview of selected studies that have been undertaken for inland flooding and the range of estimates derived.

Sea-level rise, which is also predicted with a higher-level of confidence, increases the risk of coastal flooding. A study of communities along the US Eastern and Gulf coasts found that, even under a mid-range scenario for future sea level rise, two-thirds of communities could face an increase in the frequency of high-tide flooding (i.e. tidal flooding under normal (non-storm) conditions) of 300% from current levels, with a number of communities facing regular extensive flooding from high-tides alone (Spanger-Siegfried, Fitzpatrick and Dahl, 2014). A study analysing 55 tidal gauges across the United States estimated that the occurrence of what are currently considered 1-in-100 year high water levels could increase to 1-in-10 years in many communities by 2050, and events that are currently considered 1-in-10 year events could occur annually (Tebaldi, Strauss and Zervas, 2012). Depending on the level of sea-level rise, coastal flooding in some vulnerable small island states could become pervasive. The occurrence of coastal flooding could also increase as a result of the higher levels of precipitation that would accompany more intense cyclones (increases of approximately 20% in the precipitation rate within 100 km of the storm centre are generally predicted in higher resolution modelling studies (Knutson et al., 2010)).

Box 2.2. **The potential impact of climate change on losses from inland flooding**

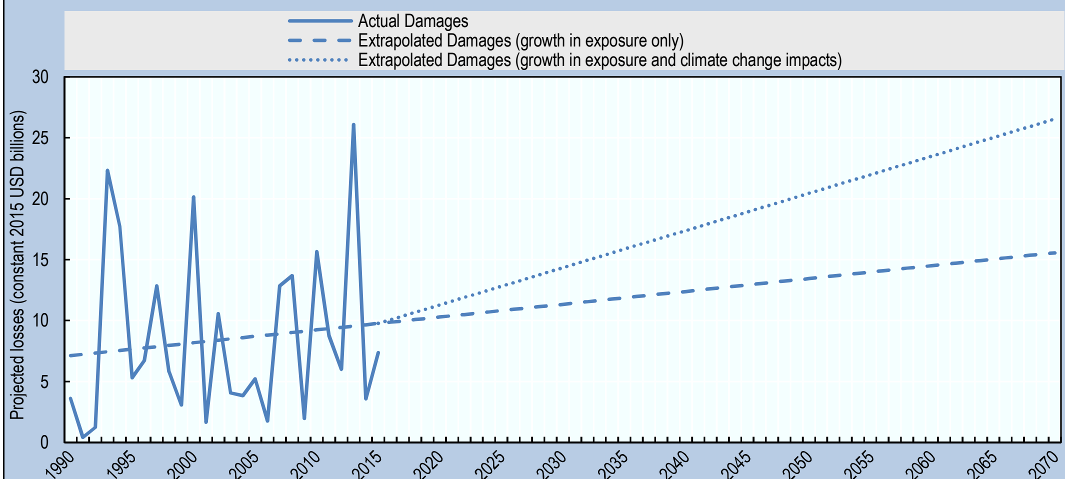
Climate change-related increases in the risk of inland flooding may occur as a result of increased precipitation, more frequent heavy precipitation events, or changes in snowmelt patterns. Inland, these changes could lead to an increase in riverine flooding (as a result of the more frequent or intense precipitation or higher levels of snowmelt) and flash flooding (as a result of heavier precipitation, potentially exacerbated by changes in overall levels of precipitation). Estimates of the potential impact of changes to weather patterns on losses have been undertaken for a number of OECD countries and regions, including the United Kingdom (Dailey et al., 2009), France (Moncoulon and Veysseire, 2015), Germany (GDV, 2011 and Te Linde et al., 2011), Spain (Feyen, Barredo and Dankers, 2009), Australia (Schneider et al., 2000), Netherlands (Bouwer, Bubeck and Aerts, 2010 and Hoes, 2007), Canada (Cheng et al., 2012), Norway (Haug et al., 2011) and Europe (Jongman et al., 2014 and Feyen, Barredo and Dankers, 2009).

While these studies use various climate change scenarios, damage calculations, time periods and loss-types (e.g. insured vs. total damage), the results provide a range of estimates of the magnitude of change in losses that could arise as a result of changes in precipitation and snowmelt patterns across a number of countries.[1] By converting these estimates into estimates of annual increases in damage, a comparable range of estimates of climate-change driven impacts can be calculated in order to derive a rough extrapolation of the magnitude of future losses resulting from changes in climate.

Figure 2.6 uses the derived estimate of the annual increase in losses due to climate change to provide a rough extrapolation of global flash flood and riverine flood losses to 2070. The estimates are derived by calculating the level of losses in each year under two scenarios: i) the increase in losses assuming that the annual average increase in losses that occurred between 1990 and 2015[2] is maintained (which would include both the growth in exposed assets as well as any change in the frequency or intensity of flooding); and ii) the additional increase in average annual losses due to changing climate patterns (based on the range of estimates in the studies noted above). As can be seen in the figure, climate change could have a significant impact on overall level of losses, increasing total losses in 2070 by over USD 10 billion relative to estimated damages based on the current trend in average annual increase in losses.

Box 2.2. **The potential impact of climate change on losses from inland flooding** (cont.)

Figure 2.6. **Projected annual losses from riverine and flash flood in OECD countries: Impact of climate change**



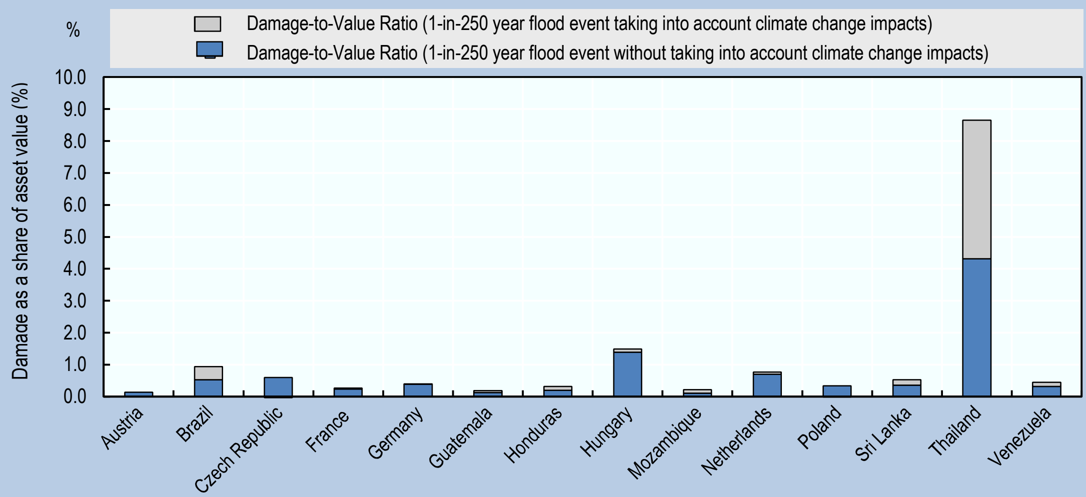
1. While some of the studies' estimates of change include projections of changes in the value of insured assets (or other indicators of socio-economic developments), those that do also provide estimates of the relative share of the change in losses resulting purely from changes in climate.
2. The annual increase in losses from flash floods and riverine floods was calculated based on the increase in losses for both types of flooding in high-income OECD countries as reported in the EM-DAT data since 1990 (approximately 1.5% of 1990 losses or USD 105 million per year in constant 2015 USD). The average annual increase in losses due to climate change impacts was calculated as USD 199 million per year in constant 2015 USD based on the average increase estimated in the studies noted above.
3. The studies used for calculating climate change impacts modelled the following types of flooding: United Kingdom (riverine, coastal and flash flooding in England and Wales and riverine and flash flooding in Scotland and Northern Ireland); France (overland and river runoff flooding in metropolitan France for all river basins); Germany (riverine flooding in 5 major river basins and riverine flooding in the Rhine basin); Spain (riverine flooding in Madrid); Australia (local flooding); Netherlands (riverine flooding and local flooding); Canada (flash flooding in 4 cities in Ontario); Norway (flash flooding in 3 counties); Europe (riverine flooding covering over 1 000 basins and riverine flooding).

Source: OECD calculations based on EM-DAT data and sources identified above on the impact of climate change on losses. The US Bureau of Labor Statistics' *Historical Consumer Price Index for All Urban Consumers (CPI-U)* was used to convert data on damages to constant 2015 USD.

An analysis by Standard and Poor's Rating Services (2015) and Swiss Re of the increase in damage (as a share of asset values) from a 1-in-250 year flood event under climate change (relative to no change in the nature of a 1-in-250 year event) found that, on average, climate change would increase damage-to-value ratio by 25% from such an event in the sampled countries by 2050 with some countries facing a potentially significant increase in damage (see Figure 2.7).

Box 2.2. **The potential impact of climate change on losses from inland flooding** (cont.)

Figure 2.7. **Damage-to-value ratio from a 1-in-250 year flood: Impact of climate change**



Source: Standard and Poor's Ratings Services (2015).

By elevating the base-height of coastal water levels, sea-level rise also increases the possibility of damaging storm surge (RMS and Lloyd's, 2008). When combined with the expectation of higher maximum cyclone wind speeds, the potential for damage is significantly increased. Estimates by RMS (2015) suggest that the probability of events causing at least USD 10 billion in storm surge losses will increase significantly by 2100 as a result of sea-level rise in a number of US coastal cities:

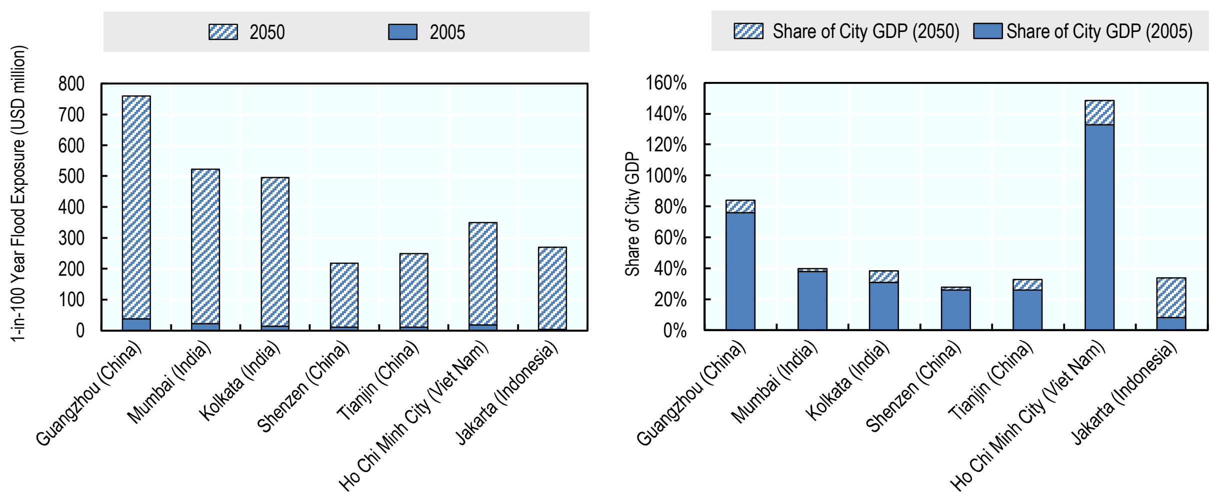
- From 2.22% to 5.26% in Tampa, Florida (1-in-45 years to 1-in-19 years);
- From 1.28% to 5.88% in Miami, Florida (1-in-78 years to 1-in-17 years); and
- From 0.87% to 3.70% in New York, New York (1-in-115 years to 1-in-27 years).

When combined with the expected increase in wind damage, the probability of a USD 10 billion loss event is projected to increase by 1.4 times in Miami and 2.5 times in New York by 2100 (RMS, 2015).

Increases in storm surge losses are also projected for other parts of the world. For example, the IPCC-derived climate change scenario involving a 0.37m sea-level rise in the North Sea could lead to an increase in average annual expected losses from EUR 0.6 billion in 2009 to EUR 2.6 billion in 2100 from storms and sea surges in Northern European countries, with the increase ranging from 100% to 900% (depending on the country) (Swiss Re, 2009). An analysis of the potential impacts of climate change (0.5 m sea-level rise, 10% increase in extreme storm-related water levels and subsidence) as well as asset accumulation in the world's largest port cities projected a more than ten-fold increase in the value of exposed assets, of which approximately 35% of the increase in value was attributable to climate change factors (Hanson et al., 2011).

In Asia, a number of mega-cities are located in coastal areas and are expected to face substantial growth in potential losses as a share of city GDP as a result of population growth and economic development, sea-level rise and subsidence (see Figure 2.8).

Figure 2.8. **One-in-100 Year Flood Exposure in Asian Mega-Cities: 2005 and 2050**



Source: OECD calculations based on Schanz and Wang (2015) and Hallegatte et al. (2013).

Some countries have undertaken comprehensive assessments of the potential impact of climate change on all types of flooding. For example, in the United Kingdom, periodic assessments of various sectors, including coastal erosion and flooding, are undertaken to estimate possible changes in the level of risk (see Box 2.3).

2.4 The potential role of insurance in reducing economic disruption

The level of insurance penetration has been shown to be negatively correlated with the level of impact of disasters on economic output (i.e. countries with higher levels of insurance penetration face more limited negative impacts on economic output). Using data for high and middle-income countries between 1975 and 2008, Melecky and Raddatz (2011) estimate the impact of geological, climatic, and other types of natural disasters on government expenditures and revenues. They found that countries with lower levels of insurance penetration faced larger declines in economic output and more considerable increases in fiscal deficits in response to disasters than countries with higher levels of insurance penetration. Similarly, von Peter, von Dahlen and Saxena (2012) also provide an estimate for the relative impact of disaster events where losses are insured relative to events with no insurance coverage. They estimate separately the impact of disaster-related losses with and without subsequent insurance payout. They find that insured losses have no statistically significant impact on long-term output (i.e. GDP growth does not diverge significantly from its pre-disaster trend) while uninsured losses come with additional macroeconomic costs, amounting to a cumulative output cost over 10 years of 2.3% or more (see Figure 2.9).

Box 2.3. **UK climate change risk assessment**

The United Kingdom undertakes climate change risk assessments every five years. As part of the most recent (2012) Climate Change Risk Assessment (CCRA) process, a comprehensive assessment of the potential impacts of climate change on coastal erosion and flooding was undertaken. The assessment was based on UK climate projections ("UKCP09") which predict increases in: i) the rate of sea-level rise, leading to increased coastal flood risk along the coast and in estuaries; and ii) winter precipitation (increase of 12% to 30%) and storm rainfall intensity (doubling of frequency of heavy rainfall events), which would lead to an increase in riverine and flash flooding. The assessment used future climate scenarios and projections of socio-economic changes (i.e. predictions of changes to the level of exposed assets based on population growth and asset accumulation in zones subject to flood risk) to estimate the change in potential exposure to coastal and river flooding (suitable data for analysis of flash flooding was not available, although the assessment suggested that such an analysis would likely show increasing risk).

The assessment provided estimates of the change in the number of people and properties in England and Wales that could be exposed to a high risk of flooding (more than 1-in-75 year return period or annual probability of 1.3% or higher) in the 2050s and 2080s relative to 2009:

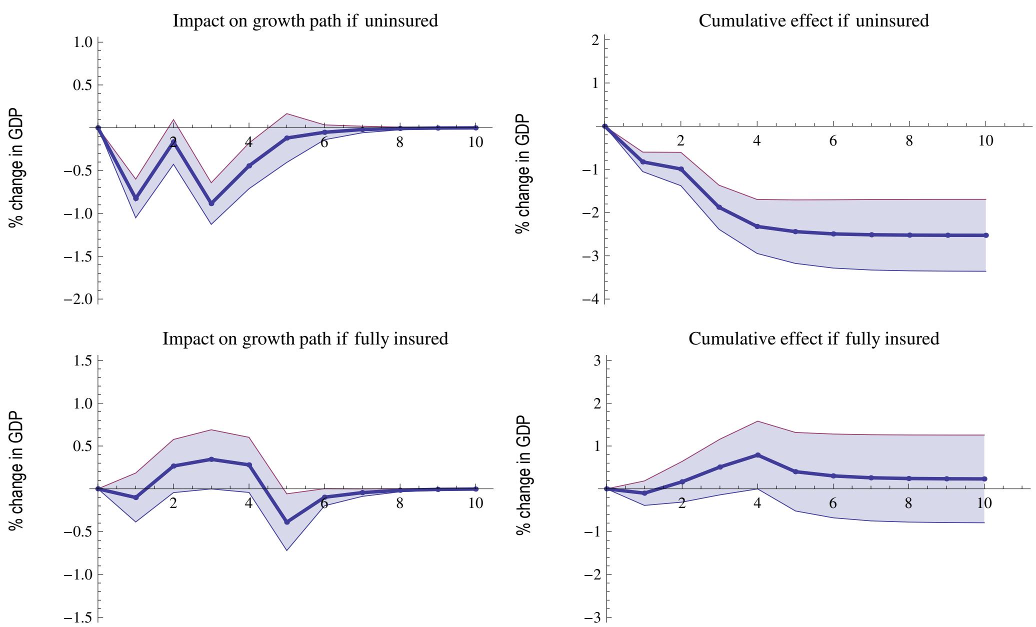
- an increase in the number of people at high risk of flooding from 900 000 in 2009 to between 1.7 million and 5 million in the 2080s
- an increase in the number of properties at high risk of flooding from about 560 000 (370 000 residential and 190 000 non-residential) to between 1.0 million and 2.9 million by the 2080s (of which between 700 000 and 2.1 million are residential properties)
- an increase in the Expected Annual Damage (EAD) to properties from GBP 1.2 billion (of which GBP 640 million is the EAD to residential properties) in 2009 to between GBP 2.1 billion and GBP 12 billion in the 2080s (of which GBP 1.2 billion to GBP 6.5 billion is the EAD to residential properties)
- an increase in average annual business interruption costs from GBP 20 million to GBP 60 million by the 2080s
- an increase in average annual insurance payouts from between GBP 200 million and GBP 300 million in 2009 to between GBP 500 million and GBP 1 billion in the 2080s.

The assessment noted that a higher increase in sea level rise ("a plausible low likelihood high impact scenario") could double the number of properties at high risk of coastal flooding. The authors estimated that approximately 60% of the increase (in EAD) to 2080 resulted from the climate change-related increase in flood risk and 40% was due to socio-economic changes.

Source: Ramsbottom et al. (2012).

Figure 2.9. **Insurance penetration and the economic impact of disasters**

The role of risk transfer



1. The left-side panels show the deviation of real economic growth from its trend due to a typical disaster event for an economy where all losses are uninsured and an economy where all losses are insured. The right-side panels show the cumulative deviation of GDP from trend over 10 years for each type of economy.

Source: von Peter, von Dahlen and Saxena (2012).

While the level of insurance penetration is usually higher in high-income countries (with higher levels of overall resilience), there are a number of ways in which insurance might specifically make a positive contribution to reducing economic disruption. Insurance claim payments can provide a timely source of financing for reconstruction (Keating et al., 2014) – a factor that is beginning to be recognised in credit rating agency assessments of sovereign ratings (Standard and Poor's Ratings Services, 2015). A survey of households affected by Hurricane Katrina found that close to 80% of residences that were insured were rebuilt in subsequent years while less than 50% of uninsured properties were rebuilt (Turnham et al., 2011). Insurance payments also tend to be larger and more quickly disbursed than government assistance (Kousky and Shabman, 2015). After flooding in Germany, Austria and Switzerland in 2005, the average times for a claim to be approved by private insurers in Germany and the (public) cantonal monopole insurers in Switzerland were significantly lower than the amount of time taken to approve a claim through the Austrian public compensation fund (21 and 38 days in Switzerland and Germany vs. 53 days in Austria) (Schwarze et al., 2011).

The global nature of international reinsurance markets also means that a portion of the financing of (reinsured) claims payments is likely to be absorbed by international markets and will therefore reduce the burden on national economies. For example, in New Zealand, where earthquake losses are mostly covered by the Earthquake Commission and private insurers (which are, in turn, reinsured in international markets), the economic impact of the 2011 Canterbury earthquake sequence in New Zealand was minimal despite direct losses approaching 20% of GDP (New Zealand Parliamentary Library, 2014).

Another potential contribution could be the reduced cost to taxpayers in countries with high levels of insurance penetration. A Lloyd's (2012) case study of five disasters (US hurricanes in 2005, UK flooding in 2007, Sichuan earthquake in 2008, Great East Japan Earthquake in 2011 and Thailand floods in 2011) found that a larger share of uninsured losses tended to be correlated with a larger overall cost to taxpayers. This is likely because governments faced with significant uninsured private losses after a disaster will generally face political pressure to compensate those affected, leading to negative impacts on public finances (in cases where that compensation was not previously accounted for in public accounts).

Where new taxes have been imposed to fund reconstruction, there may be negative implications on consumption and therefore economic recovery. In addition, in countries where homeowners or businesses maintain low levels of insurance protection against floods (or alternatively, government compensation for flood losses is low), a significant flood event could lead to an increase in defaults on mortgages, other consumer loans and/or commercial loans if debtors are faced with direct or indirect losses that are beyond their capacity to absorb. If such a scenario were to impact credit conditions, it could also be expected to have negative implications for the broader economy.[7]

Notes

1. The EM-DAT database, maintained by the Centre for Research on the Epidemiology of Disasters, provides data on deaths, affected people, damages and other variables for natural and man-made disasters in all countries since 1900. To be included in the EM-DAT database, a disaster must meet at least one of the following criteria: i) ten or more people reported killed; ii) one hundred or more people reported affected; iii) a declaration of a state of emergency; or iv) a call for international assistance.

2. The authors use a generalised calculation of maximum exposure to damage based on average maximum damage levels per km2 of urban land area (land-use method) and as a function of population (population method). The resulting levels of estimated exposure to damage differ substantially between the two methods although the calculated levels of growth are relatively consistent.

3. For the purposes of the analysis, low-elevation coastal zones (LECZ) are defined as ''the contiguous area along the coast that is less than 10 m above sea level'' (based on (McGranahan, Balk and Anderson, 2007).

4. Business interruption that occurs as a result of direct damages to structures or equipment involved in production is generally considered part of the direct economic losses of a disaster event.

5. To calculate economic output at risk (or "GDP at risk"), the analysis looks at the potential in lost output over a five-year period after a flood event relative to the baseline (no event) (Cambridge Centre for Risk Studies, 2015).

6. The contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change reconfirmed these general findings and provided further detail on the near-term impacts of climate change (IPCC, 2014).

7. This issue was considered as part of the Natural Disaster Insurance Review in Australia and was the subject of a response by the Australian Bankers Association (ABA). The ABA noted that past disasters had not significantly impacted banks' lending books (negligible losses), that banks are protected because most of the property value was related to the land not the building, that government compensation provides additional protection against defaults, and that banks have a number of other options for protecting against underinsurance of natural disaster risks by homeowners and businesses, including mortgage insurance and higher loan-to-value ratios (some banks did in fact reduce their maximum LTVs in flood prone areas after 2011 floods) (The Australian Government the Treasury, 2011).

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