ECONOMIC IMPACT ASSESSMENT OF FUTURE FLOODING IN THE NETHERLANDS

ABN·AMRO

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- This study reports on a first exercise to assess the probability and impact of flooding in the Netherlands in 2050, in the event that global warming continues on its current trajectory (WH-scenario).

- Moderate flooding (50 cm) and severe flooding (>200 cm) would have a GDP impact of -1.5 to -3% in the year of the flood.

- The impact of moderate flooding is mainly driven by a change in risk perception amongst home buyers.

- The impact of severe flooding is mainly driven by a one-month standstill of economic activity (-2% GDP) and a housing price shock of -30%, which work through the economy.

- While impactful, the probabilities of flooding are very to extremely small but are nevertheless rising.

- These results are a part of our first climate stress test, in which we estimate the impact of the physical risks from climate change to the mortgage portfolio of our bank.

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Introduction

In the early hours of 26 August 2003, Wilnis, a small town near Utrecht (the Netherlands), flooded as a regional dike broke during a summer heat wave. The flooding ended within four hours but the cost of the direct physical damage was EUR 16 million[a], mainly due to infrastructure damage. The economic damage - operational losses to firms and households during the flood and its aftermath - are not included in this figure and could be significantly higher.

The Wilnis example shows that weather conditions can interplay in surprising ways to cause a flood. In this case, it was the heat and drought that caused the dike to lose strength and integrity, and eventually break. Inland dikes like the one in Wilnis, which protect the country against river floods, are abundant in the Netherlands. Furthermore, the Netherlands is protected against sea water through its primary barriers.

Dutch flood protection systems are renowned globally for their high safety standards and sheer scale. However, in extreme conditions barriers can fail. The probability of severe floods is currently extremely small but it is increasing as a result of climate change. Climate change scenarios – as developed by the intergovernmental panel on climate change (IPCC) – are surrounded by considerable uncertainty. Current indications suggest that the actual probability is more likely on the high end of existing estimations. Assessing future flood probabilities is complex and makes the probability per location harder to estimate. The calculated probability of a dike breach and resultant flood is kept stable however by strengthening dikes in accordance with set safety standards as climate changes increases the risk of an extreme event. Climate change introduces more uncertainty around extremes and speed of change however. We have therefore chosen to separate our assessment of the macro-economic impact of a flood from the probability of floods occurring. The impact of a flood (even with an unchanging probability) increases with increases in population and the value of their possessions.

This study is part of the wider effort toward understanding and disclosure of the climate related risk for ABN AMRO bank and toward a climate resilient financial system. Together with a group of international banks ABN AMRO joined a Task Force on Climate-related Financial Disclosures (TCFD, where insights and methodologies are exchanged on how the calculate the impact of climate change on a bank's portfolio.

OUR FOCUS

In our analysis we focus on the Randstad area, which is interesting for two reasons. Firstly, it is the economic heart of the Dutch economy and if the primary flood defences are breached, the major part of the Randstad area could be inundated by at least 200 cm of water. This is a flood severe enough to generate an economic shock. Secondly, even moderate flooding of around 50 cm in the Randstad would be significant, mainly because of the societal disruption caused by failure of vital services like power, transport and communications, and a potential effect of a sudden increase in risk perception.

Our analysis presents initial steps in analysing the economic impact of floods in the Netherlands. While we made various simplifying assumptions, we believe that these more likely understate than overstate the impact as the housing price shock alone is driving most of our results. In reality, risk premiums on all assets would rise, which would directly reduce investment and severely tighten financial conditions. Power outages could also occur, causing significant damage to the economy. All these effects have not been taken into account. Therefore, this report is mainly intended to start the debate on the impact of climate change events. We feel it is important to take some first, albeit preliminary steps, because they will alert policymakers and private organisations to the costs of failing to act to prevent climate change.

A LOVE-HATE RELATIONSHIP WITH WATER

The Netherlands has had a love-hate relationship with water for centuries. The country is geographically located on a river delta and its economic hub – comprised of Amsterdam, The Hague and Rotterdam, collectively referred to as the Randstad or historically as Holland – is located close to the ocean and international shipping routes. This enabled economic growth to flourish. But it also means the country is vulnerable to flooding due to both river overflows following higher-than-expected precipitation and/or seawater intrusion during storm surges. Centuries of responding to this water threat have created a flood protection system that is internationally renowned and acclaimed. The 13 famous Delta Works are shown here.

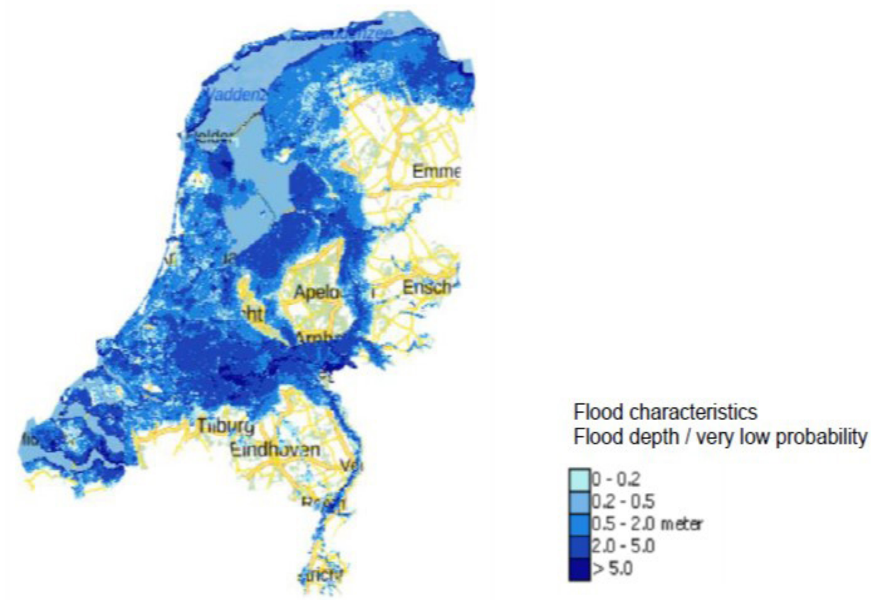


Figure 1: Extremely small probability (1/3000 -1/30,000) flood depth
Source:www.klimaateffectatlas.nl

The safety standard of the Delta Works is such that the chances of a flood breaching this system is extremely small. The final section was completed following the 1953 “Watersnoodramp”, the only high storm flood in the past 100 years. Prior floods causing significant damage occurred infrequently. In 1717, the Christmas flood claimed 14,000 lives, in 1570 the All Saints flood claimed 20,000 lives and in 1421 the Elizabethan flood obliterated 30 towns. Floods due to storm surges are rare but have high impact events. During the 20th century, economic development in the Netherlands created the means to afford protection as well as a valuable economy to protect.

Today, primary flood defences prevent severe flooding in nearly the entire Randstad area. The figure below shows the flooding depth in an extreme, low probability scenario of a primary flood defence breach.

WEATHER CHANGES UP TO 2050

Continuously rising global CO2 emissions, despite climate mitigation efforts, expose the Netherlands to climate change effects such as increasing rainfall, higher variability in weather patterns, a rise in sea level and dryer, hotter summers. These effects also interact with each other as demonstrated by the Wilnis flood, which was ironically triggered by a lack of precipitation during a hot, dry summer that reduced the strength of the embankment. During dry summer periods, similar conditions are expected to occur more frequently, in combination with sudden heavy rainfall the dry soil cannot absorb fast enough.

The Royal Dutch Meteorological Institute (KNMI) reports an increase in the expected number of days per year with precipitation, as well as an increase in the severity (mm per hour) of the precipitation (see appendix 1[b]). This is presented by Kennisportaal Ruimtelijke Adaptatie (Knowledge Portal Spatial Adaptation)[c], which indicates that the chance of heavy rainfall will double by 2050 compared to current rainfall amounts. The 30-year climate cycle of 1980-2010 already showed a 12% increase in annual rainfall compared to the prior 30-year cycle. The maps below show consecutive days with heavy (>15 mm) and very heavy (>25 mm) rainfall per day for 2020 and 2050, respectively.

Climate estimates for 2050 from the KNMI, which in turn are based on the Intergovernmental Panel on Climate Change (IPCC) scenarios, are the most recent scenario forecasts for the global rise in temperature applied to the Netherlands. The KNMI has identified atmospheric circulation (High and Low) scenarios as an important factor, in addition to the IPCC scenarios for climate variability in the Netherlands, thus creating an additional dimension of future uncertainty[1]. For example, for the 4 degree global scenario combined with a high (WH) or a low (WL) airflow average, annual precipitation in the Netherlands will be 2.5% or 5% higher, respectively, in 2050.

Concerning temperature, the increase in the Netherlands is 1.4 (WH) or 1 (WL) degrees, respectively.

[1] The KNMI depicts four scenarios from a combination of temperature rise (2 degree global warming (G) or 4 degree global warming (W) and airflow high(H) or low (L). the combination of these lead to 4 scenarios: GL, GH, WL and WH.

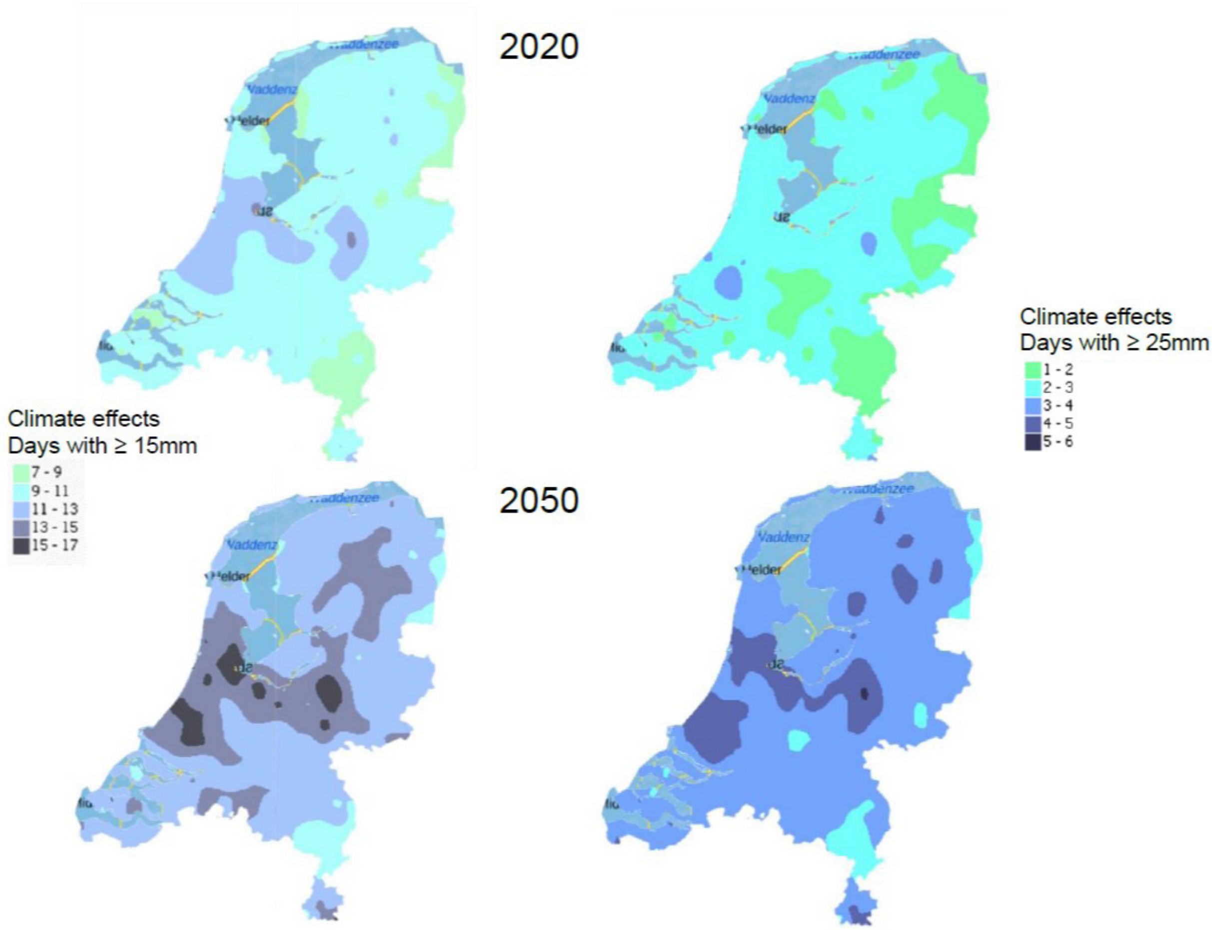


Figure 2: Number of days with heavy (>15 mm) and very heavy (>25mm) rainfall in 2020 and 2050
Source: www.klimaateffectatlas.nl

The full parameter set for the four scenarios are shown in Appendix 1.

In our impact assessment we used the WH scenario – a 4 degree global temperature increase in combination with a high atmospheric circulation pattern. All KNMI scenarios show that both droughts and floods are likely to increase in frequency and severity in the Netherlands.

LOCAL PROBABILITY OF FLOODING BETWEEN 2020-2050: FOCUS ON THE RANDSTAD

Changing weather patterns and rising sea levels represent one side of the discussion, i.e. the probability of a climate event. Another question involves whether specific locations will flood. The so-called encountering probability depends on a number of factors such as local weather changes, the structure of the earth's surface and, of course, the level of protection by infrastructure. For example, flooding risks are not only higher in areas close to rivers or the sea, but also in areas where the surface has a basin structure and a non-absorbent soil type. Similarly, the flood risk is lower in areas with adequate protection measures (dikes) in place. Due to all these factors, regions within the Netherlands vary in terms of the depth, severity and probability of flooding. Every year, the Dutch government invests millions of euros to keep the protection measures up to the required level.

Climate Adaption Services (CAS) has been commissioned by the Dutch Ministry of Infrastructure and Water Management to present the probability of flooding in the Netherlands in 2050, based on the KNMI's WH scenario and the Dutch government's planned investment in protection measures. Interactive graphs with location-based flood probabilities are available on their website (www.klimaateffectatlas.nl). Hereafter is a screenshot of location-based probabilities for moderate (> 50 cm) and severe (>200 cm) flooding. Red areas are mainly areas outside the dikes.

MODERATE (>50 CM) FLOODING IN THE RANDSTAD

Zooming in on the Randstad and selecting the probabilities of a moderate flood exceeding 50 cm, we

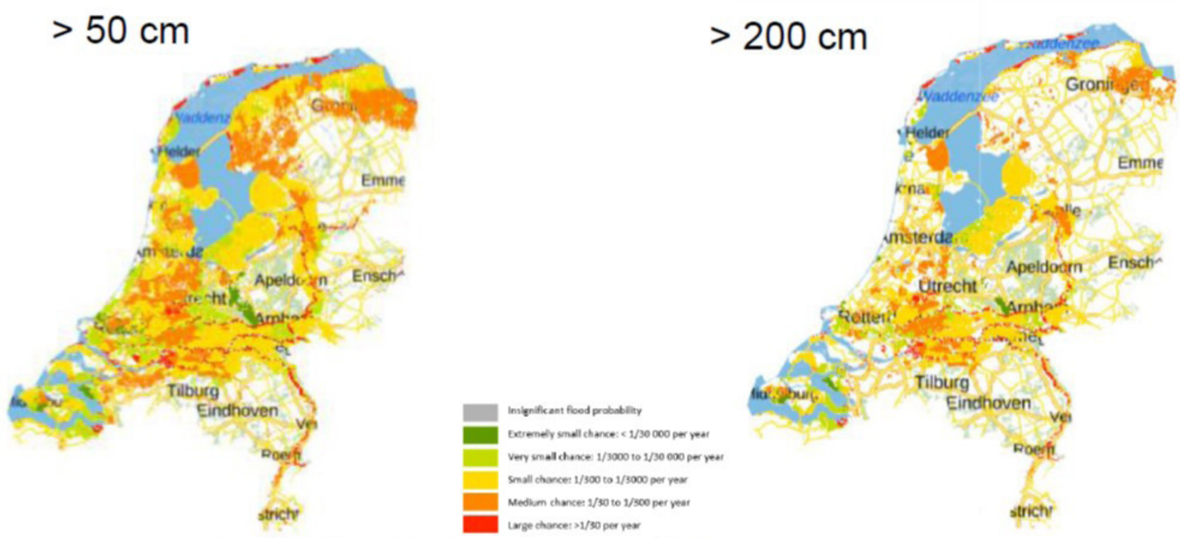


Figure 2: Location-based probabilities of floods exceeding 50 cm and 200 cm
Source: www.klimaateffectatlas.nl

can see that locations along riverbeds and in Gouda have a probability of flooding of up to 1 in 30 per year. This flooding could happen in 30 years or it could happen tomorrow – it is nature's coin toss. For the Randstad area as a whole, we chose to work with the annual probability range from 1/300 to 1/3000 . Areas with a high flood probability are at risk of regional flood defence failure, with associated lower impact – for example Wilnis. Areas with lower flood probability are at risk of primary flood defence failures and associated high impact – more water, terrain and longer duration.

SEVERE FLOODING IN THE RANDSTAD

In the Randstad, some locations have a small (yellow, 1/300 to 1/3000 per year) to medium (orange, 1/30 to 1/300 per year) probability of flooding. The areas close to the sea have no significant flooding probability because they are protected by the primary flood defences. As these barriers adhere to significantly higher safety standards, the probability of flooding is insignificant[2]. Since 2017 new flood protection standards are adopted, which are partly based on a cost benefit analysis., (schade en slachtoffermodule, 2017[3]) This means that additional investment in infrastructure should not outweigh the damage prevented by such investment, which leaves residual risks that are not currently plotted in this map. CAS has local estimations of these residual risks. To be able to make an impact assessment, we consider an average flooding probability of >200 cm to be in the range of 1 in 3000 and 1 in 30,000 years.

[2] Extreme Value Theory (EVT) is the statistical technique used when there is a scarcity of data and for systems where a failure would be very detrimental. EVT models events in the extreme tail (0.05 percentiles) of statistical distributions. For regional defences, a POT (peaks over threshold) method is used because it is a regulated, constant, controlled environment. Damage is also lower for failure. Primary defences failure probability is calculated using a Type 1 EVT Gumbel distribution, because water levels are caused by uncontrolled natural events[a]. Primary defence failure causes significantly more economic damage and loss of life, and therefore has a significantly higher safety standard and lower probabilities for failure than regional defences. This is also visible in the flood map in figure 5, where the area exposed to the ocean has almost no significant flood risk.

[3] https://www.helpdeskwater.nl/onderwerpen/applicaties-modellen/applicaties-per/aanleg-onderhoud/aanleg-onderhoud/schade-slachtoffer/

THE PROBLEM WITH FLOOD PROTECTION AND PROBABILITIES IN THE NETHERLANDS

- Flood peril is not covered in standard Dutch insurance contracts, while elsewhere in the world there is serious discussion about the risk of flood becoming uninsurable. The reason is that a flood has such devastating consequences, that the government rather prevents the flood with barriers financed from tax revenues rather that have households pay insurance premium to cover the damage. There are public funds available to cover flood damage (Wet Tegemoetkoming Schade), but it is generally assumed that this is not enough. In the event of a severe flood, the Dutch public debt would be increased to pay for the damages, which is preferred over an expensive insurance scheme that would hinder consumption, among other things, over a much longer period of time.
- Internationally, (though not specifically in the Netherlands) a growing body of evidence shows that the risk perception of flooding may drive a shift in demand away from living and working in areas that are perceived as risky. This would result in economically harmful price fluctuations, transaction costs and uncertainty. Risk perception could increase in the aftermath of an actual flood, but it could also occur based on a rising global awareness of climate change and increasing extreme weather events.
- A phenomenon in the Netherlands is a perceived safety with technological advancements resulting in risks of flooding being ignored in building and location planning. See here for details.
- There are shortcomings in individual climate models and the way they are aggregated for IPCC scenarios. For instance, the IPCC scenarios do not include feedback from the biosphere.
- In addition to uncertainly about the engineering probabilities, there is also uncertainty about climate projections and exactly how sensitive the earth's system is to climate forcing. It is also unclear, in turn, how much additional pressure this would put on the Dutch flood defence system. In 2015, the Paris agreement targeted warming below 1.5 degrees, which is the bottom range of calculations done by Jules Charney in 1979 giving a range of 1.5 – 4.5 degrees warming for a doubling in atmospheric CO_2 concentration compared to pre-industrial levels. The 2013 IPCC calculations resulted in the same range, and the bottom of this range has widely been used by climate sceptics. Recent research published the Review of Geophysics[d] has concluded a much narrower range of 2.6 – 4.1 degrees, with a central expectation point just above 3 degrees.

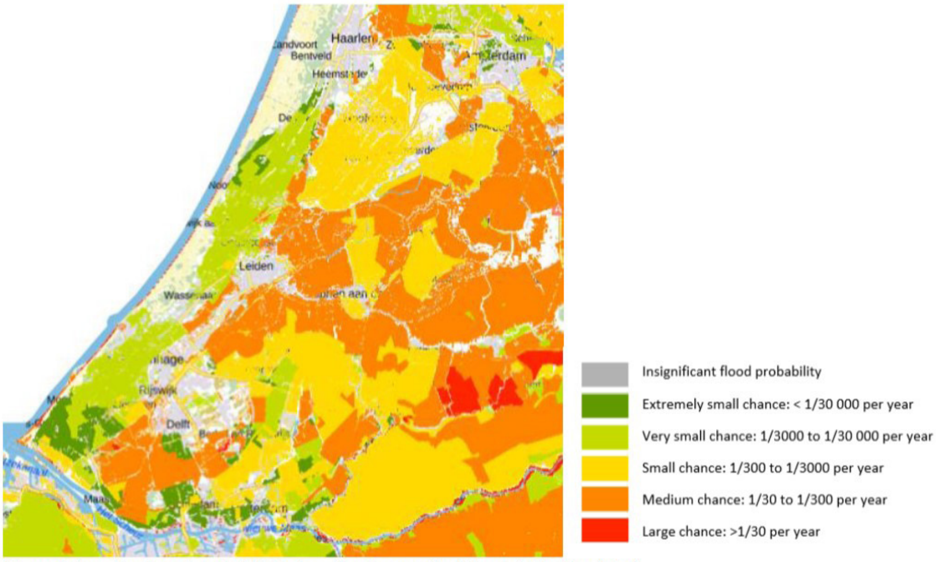


Figure 4: Location based probabilities for a flood exceeding 50 cm in the Randstad
Source:www.klimaateffectatlas.nl

THE IMPACT OF A FLOOD: A CHAIN OF EVENTS

1 DURING THE FLOOD

When an economically active area floods, the initial reaction is an emergency response to get people to safety and reduce the physical damage. Water, sewage and energy - essential utilities - are interrupted, further exacerbating immediate and longer term recovery efforts. If lives are lost or are still at risk, this creates an immediate priority. Non-essential activity comes to a standstill. The effect on company productivity differs depending on the tangibility of the company's assets. More tangible assets imply higher losses[e].

In the event of moderate to severe flooding, schools cannot open, roads and public transport networks are obstructed. People cannot get to shops or to work. Production and non-essential consumption in the inundated area comes to a standstill[4], not least because human lives may have been lost. The initial phase of the inundation can last for several hours to a week in case of a 50 cm flood, and up till 35 days for a severe flood of >200 cm[f]. If polders are inundated it can even take much longer before the water disappears.

In terms of health, flooding can lead to the outbreak of waterborne diseases[g]. The most reported driver of disease outbreaks is heavy rainfall, which leads to cross-connections between water and other environmental systems, leading to the contamination of rivers, lakes, springs and water supplies. In the Netherlands, the damage from pluvial flooding can be estimated by Klimaatschadeschatter[5] (a tool that provides climate risk information for municipal authorities) and is considered low in comparison with physical damage.

2 WHEN THE WATER IS GONE: DIRECT DAMAGE AND RISK PERCEPTION

Once the water has receded, damage to lives, real estate and infrastructure becomes evident. Private dwellings, commercial property and public infrastructure lost, need to be reconstructed or will have lost value. This loss in the stock of physical capital does not in itself affect GDP (Gross Domestic Product - representing the total value of production), however it significantly affects the ability to produce. Both production facilities and labour are lost. Especially in the case of severe flooding, the loss of human lives and the extensive rebuilding programs also results in labour and physical supply shortages, in turn increasing market prices.

Besides the direct physical damage, risk perception can substantially increase after a flood occurs and even if people are worried about future flooding. In flood prone areas, a monetization of the actual damage and the damage to subjective wellbeing shows that risk perception is twice as damaging to people than the actual physical damage[h]. This change in risk perception shifts demand for houses away from flood-

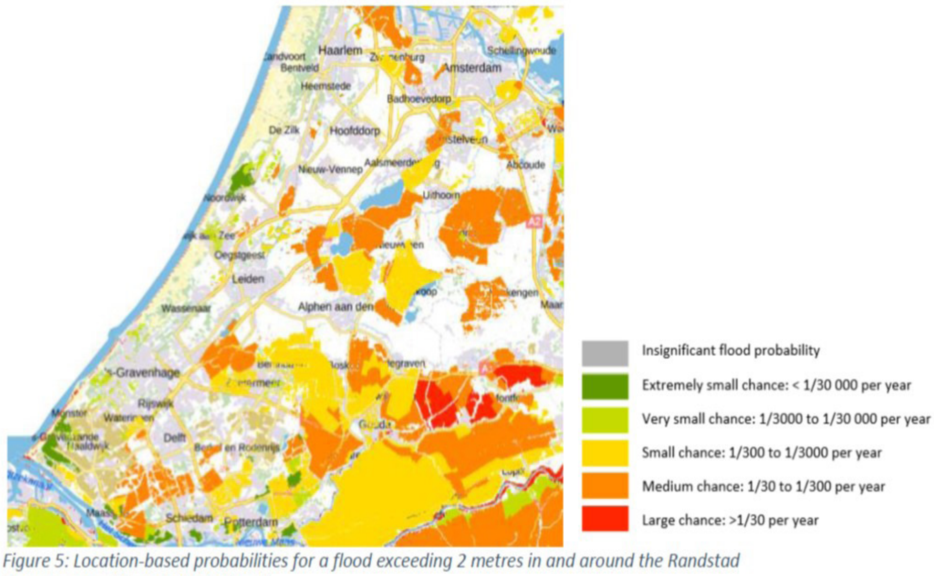


Figure 5: Location-based probabilities for a flood exceeding 2 metres in and around the Randstad
Source: www.klimaateffectatlas.nl

4 It is tempting to compare this to a Covid-19 lock-down, however an important difference is that online consumption cannot substitute for offline consumption during a flood as it did during the lockdown in the second quarter of 2020.
5 www.klimaatschadeschatter.nl

prone areas, thereby changing housing prices. Without an actual flood, these price changes are expected to move gradually (see textbox below). When a flood occurs, the perception of risk can shoot up and rapidly change housing prices[i].

RISK PERCEPTION OF FLOODING

House values can also be affected by the risk perception of households that are looking for a new home. The risks that people perceive can drive down demand for housing and hence lower prices, even without the occurrence of an actual flood. In the US, research at the San Francisco Federal Reserve looks at the price effect of risk perceptions of future floods[i]. Owner-occupied properties will sell at a discount of 5.2% if located in a place that would be flooded if the sea level rises 6 feet (1.80 m) in the year 2100, compared to owner-occupied properties that would not at all be exposed in the event of such a rise. Being exposed is defined as being inundated with a complete loss in value within one 100 years. The study captures the pricing effect through anticipated potential damage.

In the Netherlands, a similar study was conducted on the housing price effect of being located in a flood-prone area[j]. The housing price effect of being exposed to flooding compared to similar houses that are not affected is just 1%. A large part of this price effect is based on risk perception. This study was conducted in 2012 and although the flooding exposure if the dikes broke was already high back then, we believe the risk pricing would be higher today for two reasons. First, much more attention is being paid to climate change and hence flooding probabilities. Second, the 2017 regulation indicates that flood protection is not guaranteed by the government after a certain cost benefit threshold ('remaining risk').

Given our assumption that since 2012 flood risk awareness has grown, we calculate the impact of a perception effect on house prices of 5.2% in our analysis. (this is a temporary effect that occurs after a moderate flooding of 50 cm).

3 ECONOMIC INTERACTIONS

Repair investments, unemployment and crowding out. Damaged assets require repair. Repair investments simultaneously help and hurt the economy[k]. In the short run, repair investments require additional labour, which dampens the rising unemployment. However, in the medium to long term, these repair investments crowd out more productive investments in such areas as innovation, which reduces future economic growth.

Inequality. How and the extent to which households experiencing a flood are able to respond can differ strongly depending on their income and wealth (especially if they have no flood insurance). While high-income households tend to move away from flood risks, low-income households tend to move toward them due to declining housing prices. Various studies document a number of responses that increase inequality. In Arnhem, for example, heavy rainfall flooding not only hit low-income households harder but the response capacity of those households is lower. The effects particularly enhance inequality as municipalities are increasingly shifting the responsibility of 'learning to live with flooding' toward citizens[l].

Consumption. The way households respond to a reduction in the value of their property also hurts the economy. When a mortgage starts exceeding the property value (negative equity), people tend to reduce consumption and step up their mortgage repayment so as to rebalance the loan-to-value ratio. In the aftermath of the financial crisis, property values plummeted, causing a reduction in household spending up to 3% to reduce excessive mortgages. According to this CPB study, the consequence was a double dip in Dutch GDP growth unseen in other European countries without negative equity.

Investments. As a disaster generates uncertainty, investments will shrink and investments in housing and commercial real estate in particular will temporarily be considered too risky[m].

Trade relations shift and production is temporarily reorganised by the government so as to maintain the delivery of essential goods. While production comes to a standstill in the flooded area, other areas take over that role. In large countries, this shift in taking over economic activities can reduce damage substantially. But for the Netherlands, severe flooding of the Randstad would immediately become a national disaster affecting the economy overall with some activities potentially moving to surrounding countries permanently. Exports from the area would be hampered and imports to the area increased[no].

Public debt and interest rates. As the government has to step in with humanitarian and economic aid programs, public dept will increase and so will interest rates. In countries where flood insurance is the norm, insurers will absorb the bulk of the damage to property, while individuals and the state carry the costs in the Netherlands. As described above, this is a choice made in the Netherlands where public debt can be temporarily increased significantly to respond to the flood. In other countries the public budget does not allow for this as easily. In those countries, individuals carry the costs and insurance is very expensive. In some instances, this is solved by a re-insurance scheme (in the UK, for example, this is supported by the government). For European countries in particular, the European Union will assist in dealing with natural disasters, dampening the effect on interest rates.

This distortion of economic activity can lower output for up to two years following a severe flood (although the effects fade). For less severe floods (20-50 cm), production can recover as quickly as within 18 days, according to a flood simulation study of Rotterdam Rijnmond[f].

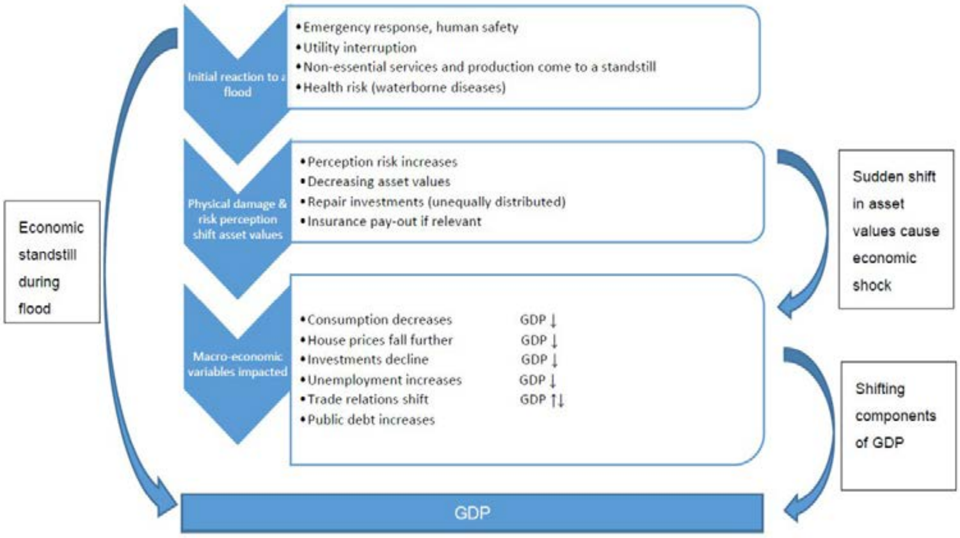


Figure 6: Schematic representation of macro-economic variables

4 RECOVERY

The depth and the speed of recovery mainly depends on the depth, extend and duration of the flood. A meta study from the bank of England that considered numerous empirical studies[p], but supports the hypothesis that both short and long-run GDP is negatively affected by extreme weather events[k]. The permanent loss of GDP ranges from -0.6% to -3.6%. GDP growth does return to trend.

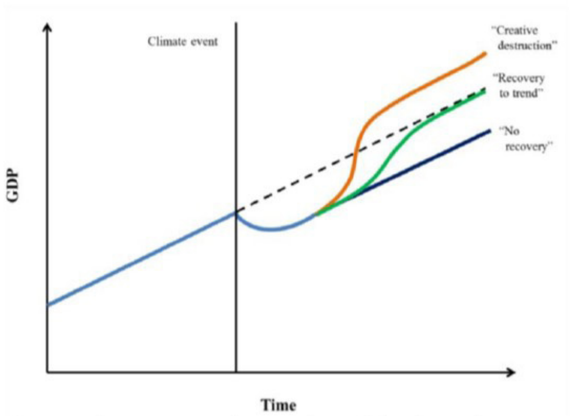


Figure 7: The recovery trajectory of GDP following a climate event
Source: Batten, 2018[j]

The economic impact estimation

A flood of 200 cm would occur if the primary and secondary flood defences were to fail - we assume an instantaneous shock of 2 metres or more in 2020 in the Randstad[6]. This focus on the Randstad area substantially simplifies our impact assessment as we can work with the assumption that a 200 cm flood would essentially inundate all land equally and that housing prices would decline without compensation effects to non-flooded areas (see Figure 1). For the Dutch economy as a whole this would be unrealistic, as demand for housing and commercial activities would eventually shift to the non-flooded areas.

Combining impact assessments of floods from the literature with a macro modelling tool from DNB (Delfi – see page 10), we took a four-step approach to our impact assessment[7].

These four steps have been taken for floods of 200 and of 50 cm, respectively. We determine how the most relevant macro-economic variables change in the 40 years following the flood compared to our baseline projections. In our adverse scenario we assume a flood of 2 metres or more occurs in 2020. In our negative scenario we assume a 50 cm flood in 2020.

STEP 1: INITIAL GDP GROWTH EFFECTS

One of the best documented assessment of flooding damage to the Randstad economy was applied to Rotterdam[f8] Koks simulated flooding of various severities and calculated the economic damage to both the capital stock of Rotterdam (buildings and infrastructure) and the production capacity. Based on flood maps, direct damage was calculated taking into account sector-specific impacts. Next, capital and labour losses were translated into production losses per sector for the inundated period using a Cobb-Douglas production function. Finally an input-output model was used to estimate the economic effects of the recovery period. See Appendix II for a visualisation of this approach.

[6] Based on our projections of 2020 and beyond from Q4 2019. This means Covid-19 is not included in this exercise.

[7] The impact assessment could be improved by taking into account the response capacity of households depending on their income, wealth and mortgage headroom.

[8] We must assume that the loss of production capacity (GDP growth) in the Randstad economies is similar to growth reductions in Rotterdam. In practice, it will differ depending on the underlying sectoral differences.

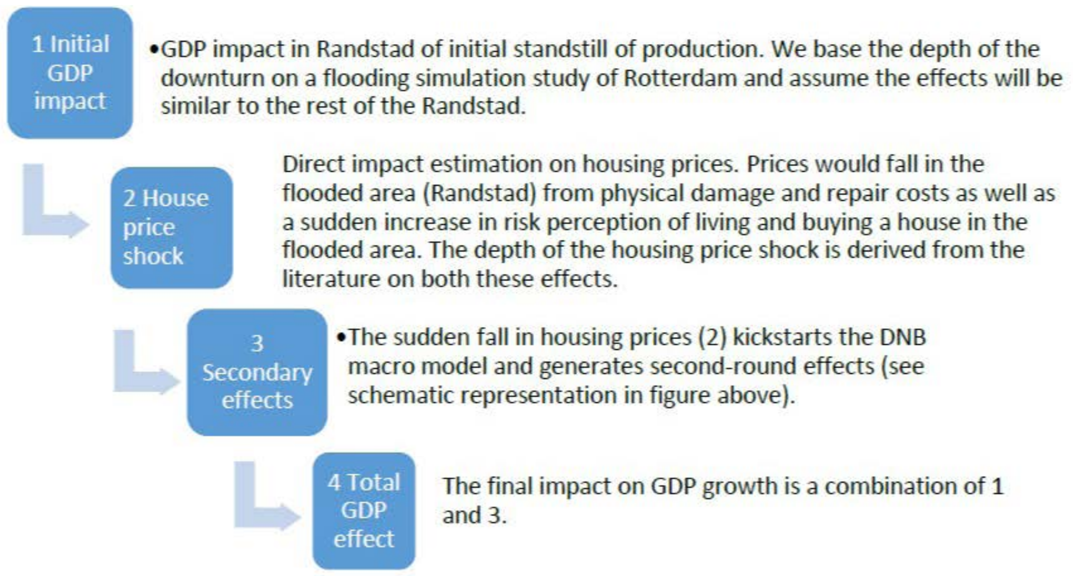


Figure 8: Four-step method to determine overall macro-economic shock, with the house prices as input shock

From the Rotterdam study, we selected two probability scenarios which fall within the interval of a flood exceeding 50 cm, and a flood exceeding 2 metres in the location-based probability map (see Figures 3 to 5).

200 CM FLOOD

For a flood exceeding 2 metres, we have chosen the scenario with a return period of about 1 in 4000 years. The damage leading to a reduction in GDP is calculated for the Rotterdam area at EUR 1.14 billion. In the year of this simulation (2012), the GDP of Rotterdam was EUR 57.2 billion. This means that a 2 metre flood causing EUR 1.14 billion in production damage generates an initial GDP growth effect of -2%. For a 1 in 10,000 year event, the production loss (4.4%) as well as the days to recovery would be roughly double, with a modelled 97.5 percentile loss of up to 12.7%. Selecting the 1/4000 scenario is on the conservative side but considering only small parts of Rotterdam are vulnerable to a flood exceeding 2 metres, we judged this to be a more appropriate input.

50 CM FLOOD

Combining the Klimaatschadeschatter return periods for 50 cm flooding and the impact assessment from the Rotterdam study by Koks, we use the 1 in 1000 year return period for the closest 50 cm flooding probability of the Randstad area (see Table 1). A production loss of EUR 0.61 billion in an economy of EUR 57.2 billion represents an initial GDP impact of -1%. Koks also shows a 1/2000 event impact within the 1/300 to 1/3000 range; we have chosen the lower impact scenario.

STEP 2: HOUSING PRICE EFFECT

200 CM FLOOD

A well-documented study of the sales prices of single-family, owner-occupied properties following a flood in Georgia (USA)[q], shows that low-probability (severe)

Table 1: Flood loss and risk estimates for the Rotterdam Rijnmond area (2012 estimates)

Flood depth	Map range (Figure 3)	Probability per year 1/return period	Loss of capital stock (EUR bn)	Production loss (EUR bn p.a.) Reference values	% of 2012 GDP of EUR 57.2 bn	97.5 percentile model output	Days till back at 99% of initial output
> 50 cm	1/300-1/3000	1/1000	0.76	0.61	1.1%	0.77	173 Days
>200 cm	< 1/3000	1/4000	1.10	1.14	2.0%	1.52	351 Days
Not used		1/10000	1.78	2.51	4.4%	7.28	647 Days

Source: Koks[f], 2015

flood events immediately lower housing prices by 32% on average. However, this effect is short-lived and fades rapidly (5% per year).

Based on this evidence, we assume that our scenario of a flood in excess of 2 metres will have similar distortionary housing price effects. As such, in our scenario housing prices decline 32% in 2020 and then bounce back to -27% in 2021 with 5% increments to the original growth path.

50 CM FLOOD: DAMAGE AND RISK PERCEPTION

We have replicated this approach for a flood of 50 cm. As we do not have any evidence from an actual flood of 50 cm in the available literature, we used the method of Deltaris[9] to estimate the m2 house price change as a result of a 50 cm flood. The damage factor that reduces a house price does not just depend on the severity of the flood. The level of the house (ground floor of higher), the size of the house and the construction type also matters. For a 50 cm flood, we assumed a damage factor of 0.3, which is the average for a single-family, owner-occupied house. This damage factor only reflects physical damage and repair costs. Because we believe that smaller floods in particular could invoke a sudden change in risk perception, we also take into account a market price reduction of 5% immediately after the flood. This percentage is based on literature regarding pricing effects of risk perception (see textbox on page 7) which, if anything, increase over time. To be safe, we assume the risk perception remains at 5%, even as the actual damage from the flood is repaired. The house price change is calculated as:

*Damage factor of 50 cm flood * maximum damage per m2/m2 price Randstad average in 2018 - 0.05 (risk perception). This results in a price change of: (-0.3*EUR 1000)/EUR 2806 - 0.05 = -0.1569.*

STEP 3: SECONDARY IMPACTS[10]

As with any economic shock, an economic shock from a flood will affect many macro-economic variables (see Figure 6: schematic representation of macro-economic variables). These changing variables can also have feedback loops that require a macro model to determine. The housing price change is assumed to be the main driver[11] of change in the other variables, including second-order GDP effects. As housing prices deteriorate, consumption drops. This creates lower demand, more unemployment and more investment, which further lowers GDP growth.

To model macro-economic interactions, we use DNB's Delfi tool. Delfi is an online tool that enables us to give the underlying dynamic model of the Dutch economy an impulse (shock) from housing and GDP growth. The tool provides us with the development of other macro-economic variables over a period of eight years. After that, the model assumes the economy has gone back to its original growth trajectory (see Delfi output in the results section).

STEP 4: THE ADDITION OF INITIAL AND SECOND-ROUND EFFECTS

Finally, we add the initial GDP effect (Step 1) to the GDP effect of the second round (Step 3). The figures below show the development of the main components of GDP from 2020 to 2023.

RESULTS

Should the heart of the Dutch economy (the Randstad) flood following a breach of primary barriers, most urban areas would be inundated by 200 cm of water or more (up to 500 cm). The pace of a flood is crucial for the safety of people and evacuation possibilities, however we focused on the macro-economic effects following the event. As an immediate result, GDP would plummet from growth of 1.4% (this is the long-term average growth as the impact of the pandemic was an unforeseen factor) to a decline of more than 2%. This would be due to a demand and a supply shock changing many components of GDP such as imports and exports, unemployment, investment and all other variables plotted in the figure below. House prices are of particular interest. They not only suffer from the initial physical damage, but as uncertainty drives private and commercial investment decisions, demand for housing and housing investment will drive down housing prices in the affected area for a long period after the flood itself. In addition, general consumption is reduced as house prices remain below the value of their mortgage for some time. From an individual's perspective, reducing consumption to save for repair investments and mortgage reduction makes sense, but on aggregate it initiates revenue losses to firms, which in turn increases unemployment. These effects further suppress the affordability and thus demand for housing.

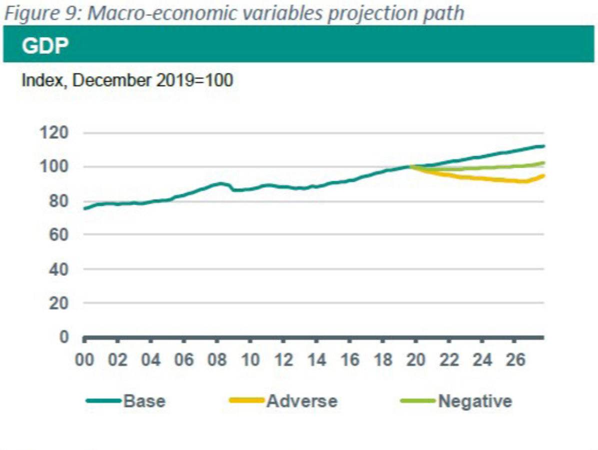
In the event of a 50 cm flood, a similar storyline holds albeit less dramatic. What drives most of the damage in this case is risk perception. To find some evidence of our assumptions we looked at the Wilnis case in 2003, where flooding was around 20-50 cm. We expected housing

9 www.helpdeskwater.nl, 11200580-004-hye-0002-r-standaardmethode_2017_schade_en_slachtoffers_als_gevolg_van_overstroming.pdf

10 We assume that practically all the adverse GDP effects come from a housing price shock. In reality, it is more likely that on top of this, the damage to inventory infrastructure and commercial buildings does not have a -2% impact on GDP only in the year of the flood. We did not find credible GDP component changes for this stock damage effect other than for housing. This could be resolved if we can simulate an investment shock but the Delfi tool does not offer this option.

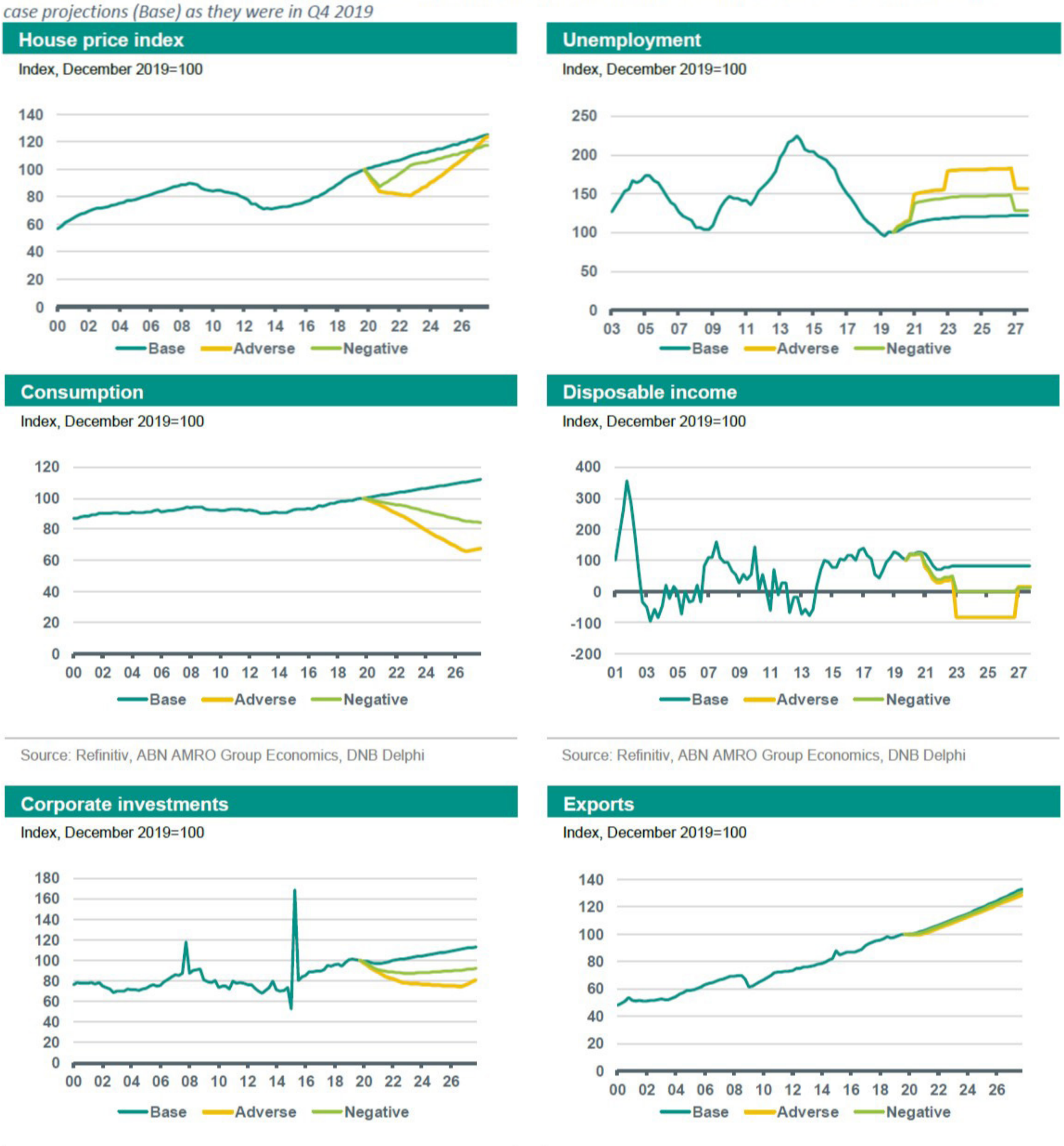
11 This assumption may be understating the actual damage severely. If vital economic infrastructure such as the harbour or power networks disfunction, this may cause much more additional damage. We discuss this at the end of this study.

Figure 9: Macro-economic variables projection path



Source: Refinitiv, ABN AMRO Group Economics, DNB Delphi

Figure 10: Macro-economic variables following a 50 cm flood in 2020 (Negative) and a 200 cm flood (Adverse) compared to base case projections (Base) as they were in Q4 2019



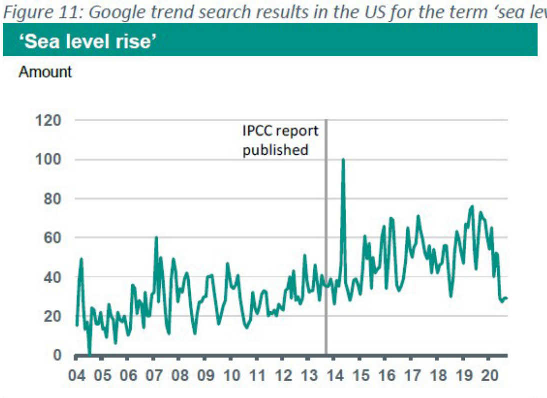
Source: Refinitiv, ABN AMRO Group Economics, DNB Delphi

Source: Refinitiv, ABN AMRO Group Economics, DNB Delphi prices to fall significantly after the flood compared to before the flood and outside the flooded area (using a difference-in-difference approach). No houses were sold for quite a while after the flood, making it hard to assess risk perception changes. The finding that the housing market came to a standstill was, in itself, a strong indication of increased risk perception. The Dutch study by Bosker (2012) on flood risk perception and house price changes would be worth repeating in these times of climate awareness.

CONCLUDING REMARKS AND KEY TAKEAWAYS

In taking our first cautious steps in analysing the macro-economic impact of floods in the Netherlands, we sometimes had to make simplifying assumptions. Notwithstanding these simplifications and numerous uncertainties, we believe that our assumptions more likely understate then overstate the probability and the impact. One reason for this is the fact that our initial GDP shock comes from a simulation study of Rotterdam in 2012. Since then, our economy has become much more productive, and the economic importance of the Randstad as the economic heart of the national economy has grown. In other words, a flood would potentially generate much more damage to production compared to 2012. Another reason is the fact that we 'only' shocked the economy with a house price change, while all infrastructure and commercial real estate would be equally damaged and generate their own effects. The third reason is, of course, the massive uncertainty around the real effects of risk perception. This area in particular requires more research.

Figure 11: Google trend search results in the US for the term 'sea level rise'



Source: Google

RISK PERCEPTION

While the occurrence of floods only impacts house prices, and hence the economy of the affected area, once the flood has occurred risk perception can have an immediate negative impact on property market values as well as an entire economic zone. Risk perception can grow as a result of increasing knowledge and awareness of climate change and the associated risks. An indication of this is the spike in the amount of Google search activity for the term 'sea level rise' just after IPCC published a new report on warning about climate change.

INEQUALITY ALERT

Based on our own mortgage portfolio data, we made more specific calculations of direct damage from floods in different regions. This generated an important insight into the potential increasing inequality effect of a flood that we did not yet take into account in our macro-economic analysis. Even if housing values are reduced by the same absolute amount of damage (which, in practice, they are not) the mere fact that lower income households live in cheaper houses causes a higher relative value reduction. The loan-to-value ratio therefore changes more radically and, at the same time, these households' mortgage headroom to finance repairs is lower due to the generally lower income of occupants of cheaper houses. In addition, we see from an emerging body of literature in the US that higher income households tend to move to safer areas more quickly, while lower income households tend to move into the higher risk areas where prices are lower due to the risk perception effect.

IMPACT ON JOBS

Considering the impact of floods on a company's capital accumulation, in the short run companies in regions hit by a flood show, on average, higher growth of total assets and employment than firms in regions unaffected by flooding. However, the positive effect is unequally distributed. The positive effect prevails for companies with smaller shares of intangible assets while firms with a higher share of intangible assets see a negative impact on productivity[e]. This conclusion by Leiter resembles our current observations from the Covid-19 crisis: blue-collar workers are hampered in performing their jobs much more than white collar service workers who can easily work from home via digital access. This again aggravates existing inequalities as these jobs are held by people living in the higher risk area. One could say they are at a double disadvantage.

THE COSTS OF INACTION

While we have focused on the economic damage from the flood, actions could be taken on various levels to reduce the potential macro-economic impact on the Netherlands. Besides adjustments in terms of flood protection programmes, there is also the option of mitigation. Whilst curbing CO2 emissions is ultimately a global effort, our research shows what costs could be avoided by making the transition to a low-carbon economy. We cannot avoid the economic impact altogether, as global warming is already a fact (globally we are currently already at one degree Celsius above pre-industrial levels) and this process is very hard (if not impossible) to reverse[12].

Still, we can limit global warming, curbing the increasing frequency and intensity of extreme weather, and prevent risk from growing even further. Today, the Netherlands is still able to adapt to climate change. The challenge is to keep it that way.

12 This is the effect of processes that have been set in motion. For example, current warming has caused the defrosting of certain areas, allowing the stronger warming effect of sunlight on defrosted areas to cause even further warming.

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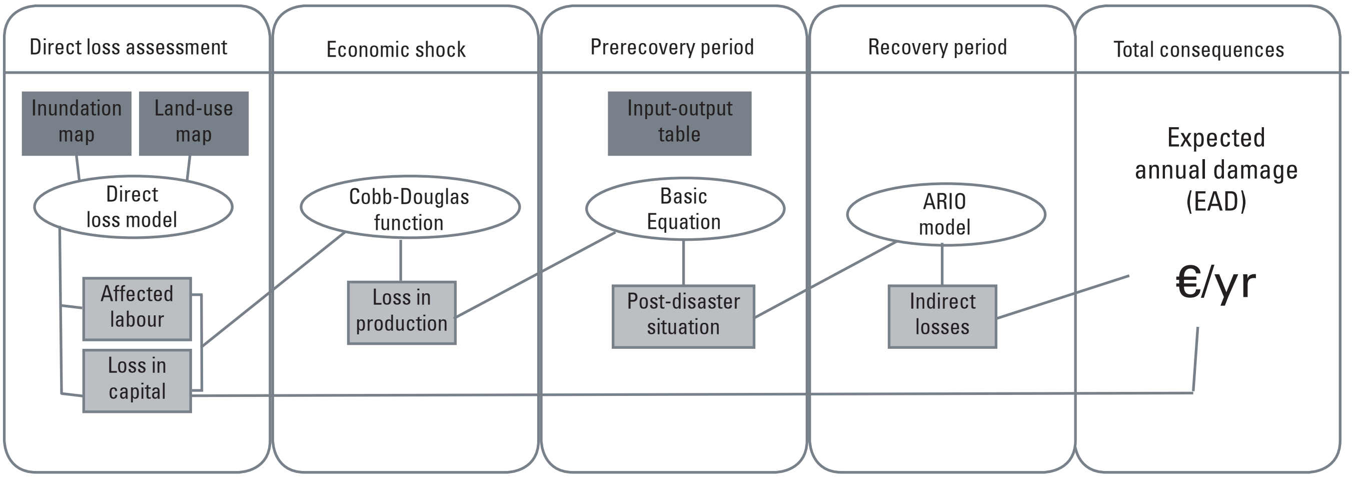
APPENDIX I

Season	Variable	Indicator	Climate 1951-1980	Climate 1981-2010	Scenario changes for the climate around 2050 (2036-2065)			
				=ref.period	G_L	G_H	W_L	W_H
Global temperature rise:					+1 °C	+1 °C	+2 °C	+2 °C
Change of air flow pattern:					Low value	High value	Low Value	High Value
Year	Sea level at the North Sea coast	Absolute level	4 cm below NAP	3 cm above NAP	+15 to +30 cm	+15 to +30 cm	+20 to +40 cm	+20 to +40 cm
		Rate of change	1.2 mm/year	2.0 mm/year	+1 to +5.5 mm/year	+1 to +5.5 mm/year	+3.5 to +7.5 mm/year	+3.5 to +7.5 mm/year
	Temperature	Mean	9.2 °C	10.1 °C	+1.0 °C	+1.4 °C	+2.0 °C	+2.3 °C
	Precipitation	Mean amount	774 mm	851 mm	4%	+2.5%	+5.5%	5%
	Evaporation	Potential evaporation (Makkink)	534 mm	559 mm	3%	5%	4%	7%
Winter	Temperature	Mean	2.4 °C	3.4 °C	+1.1 °C	+1.6 °C	+2.1 °C	+2.7 °C
		Day maximum	5.1 °C	6.1 °C	+1.0 °C	+1.6 °C	+2.0 °C	+2.5 °C
		Day minimum	-0.3 °C	0.5 °C	+1.1 °C	+1.7 °C	+2.2 °C	+2.8 °C
		Coldest winter day per year	-7.5 °C	-5.9 °C	+2.0 °C	+3.6 °C	+3.9 °C	+5.1 °C
		Mildest winter day per year	10.3 °C	11.1 °C	+0.6 °C	+0.9 °C	+1.7 °C	+1.7 °C
		Number of frost days (min temp < 0 °C)	42 days	38 days	-30%	-45%	-50%	-60%
		Number of ice days (max temp < 0 °C)	11 days	7.2 days	-50%	-70%	-70%	-90%
	Rainfall	Mean amount	188 mm	211 mm	3%	8%	8%	17%
		Number of wet days (≥ 0,1 mm)	56 days	55 days	-0.3%	1.4%	-0.4%	2.4%
		Number of days ≥ 10 mm	4.1 days	5.3 days	9.5%	19.0%	20.0%	35.0%
Spring	Temperature	Mean	8.3 °C	9.5 °C	+0.9 °C	+1.1 °C	+1.8 °C	+2.1 °C
	Rainfall	Mean amount	148 mm	173 mm	4.5%	2.3%	11.0%	9.0%
Summer	Temperature	Mean	16.1 °C	17.0 °C	+1.0 °C	+1.4 °C	+1.7 °C	+2.3 °C
		Day maximum	20.7 °C	21.9 °C	+0.9 °C	+1.4 °C	+1.5 °C	+2.3 °C
		Day minimum	11.2	11.9	+1.1 °C	+1.3 °C	+1.9 °C	+2.2 °C
		Coldest winter day per year	10.3 °C	11.1 °C	+0.9 °C	+1.1 °C	+1.6 °C	+2.0 °C
		Hottest summer day per year	23.2 °C	24.7 °C	+1.4 °C	+1.9 °C	+2.3 °C	+3.3 °C
		Number of summer days (max temp ≥ 25 °C)	13 days	21 days	22%	35%	40%	70%
		Number of tropical nights (min temp ≥ 20 °C)	< 0.1 days	0.1 days	0.5%	0.6%	1.4%	2.2%
	Rainfall	Mean amount	224 mm	224 mm	1.2%	-8%	1.4%	-13%
		Maximum hourly rainfall per year	14.9 mm/hour	15.1 mm/hour	+5.5 to +11%	+7 to +14%	+12 to +23%	+13 to +25%
		Number of wet days (≥ 0.1 mm)	45 days	43 days	0.5%	-5.5%	0.7%	-10%
		Number of days ≥ 20 mm	1.6 days	1.7 days	+4.5 to +18%	-4.5 to +10%	+6 to +30%	-8.5 to +14%
	Solar radiation	Solar radiation	149 kJ/cm2F)	153 kJ/cm2	2.1%	5%	1%	6.5%
	Humidity	Relative humidity	78%	77%	-0.6%	-2.0%	0.1%	-2.5%
	Evaporation	Potential evaporation (Makkink)	253 mmF)	266 mm	4%	7%	4%	11%
	Drought	Mean highest precipitation deficit during the growing season	140 mm	144 mm	4.5%	20%	0.7%	30%
Autumn	Temperature	Mean	10.0 °C	10.6 °C	+1.1 °C	+1.3 °C	+2.2 °C	+2.3 °C
	Rainfall	Mean amount	214 mm	245 mm	7%	8%	3%	7.5%

Source: KNMI – 2014 – http://www.climatescenarios.nl/images/Brochure_KNMI14_EN_2015.pdf. For more information about the alternative scenarios, please check the brochure

APPENDIX II: KOKS, 2015 DIRECT & INDIRECT LOSS ASSESSMENT MODEL



Overview of the different components of the framework. The dark gray squared boxes are the inputs, the ellipses are the different models, and the light gray squared boxes are the models outputs.