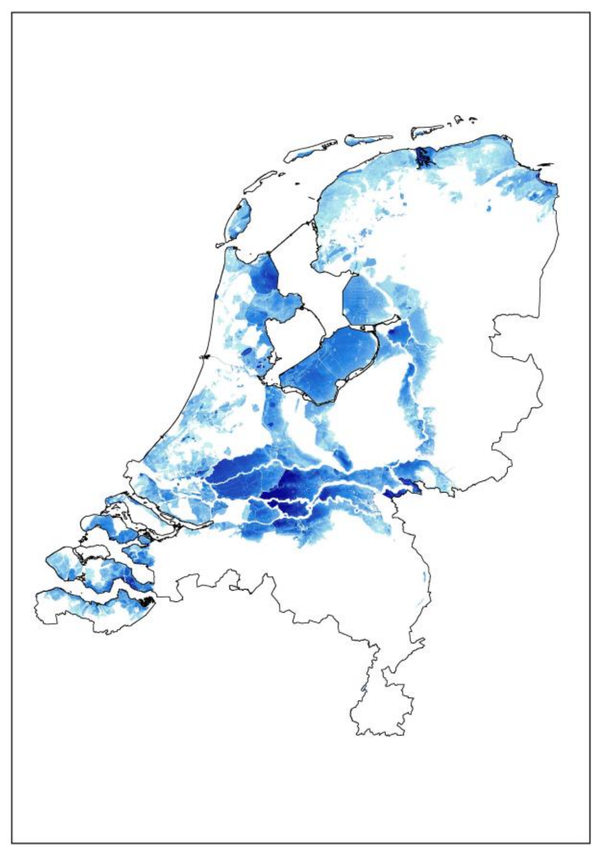
Sustainable spatial planning

An analysis of the costs and benefits of water-robust spatial planning to reduce flood risk in the Netherlands

Annemarijn Plukaard, studentnumber: 1935496
Master thesis earth sciences and economics

March, 2016



Supervisor PBL: Bart Rijken
Supervisor VU: Eric Koomen

Abstract

The Netherlands protect the country with dikes, which lowers the probability that a flood will occur. Lowering the probability will not eliminate it and when a flood occurs, the consequences are enormous. This is due to the fact that the economic value of the Netherlands increased over the last century. Therefore a new approach is needed to reduce damage. The Dutch government already introduced the multi-layer safety concept in order to protect the Netherlands against floods in the future. This concept wants to sustain all aspects of flood risk management. The aspects are the prevention of floods, limiting the consequences through sustainable spatial planning and preparing recovery measures during and after a flood. This research focuses on sustainable spatial planning of multi-layer safety. The costs and benefits of four sustainable spatial planning measures, which are applied on houses, are selected: heightening, dry proof construction, wet proof construction and building on piles. The main effect of applying sustainable spatial planning will be a reduction in damage. The costs are examined to find out what the cheapest measure is to apply. Results show that piles are the cheapest for locations with clay or peat soil. Some locations show heightening as cheapest option, this is predominantly on sandy soils.

The results of sustainable spatial planning are then compared to the costs and benefits of the traditional safety measure, strengthening the dikes, to examine the potentials of sustainable spatial planning to reduce flood risk. This comparison is done on dike ring level. To show which measure is more cost efficient, a ratio between sustainable spatial planning and strengthening of the dikes is calculated by dividing their risk reduction per euro extra costs. This ratio shows that sustainable spatial seems to be the best option to apply when the amount of houses is relatively low, otherwise strengthening the dikes is a better option.

This research is done on behalf of Deltares and the Environmental Assessment Agency who wanted to fill the knowledge gap by examining the costs of sustainable spatial planning to get a first approximation on this subject. I thank Eric Koomen, Bart Rijken and Joost Knoop for the very helpful discussion sessions, advice and comments on drafts of this report. I thank the Environmental Assessment Agency for providing the opportunity, data and workplace. Finally I'd like to thank Bas van Bemmel for his help with ArcGIS.

Index

1. Introduction

The Netherlands is and remains vulnerable to flooding. More than 55% of the Dutch surface is flood-prone, whereas 40% lies below mean sea level, which makes it vulnerable for floods (Klijn et al. 2015). Without the protection of dikes, dunes and storm barriers large parts of the Netherlands will be flooded (Jonkman et al. 2008; Delta programme, 2015; McRobie et al. 2005). The North Sea flood of 1953 is one of the largest floods in the recent Dutch history, which caused approximately 1800 deaths and widespread property damage (Gerritsen, 2005). This flood has been the decisive factor for the development of the Delta works, the coast defence system of the Netherlands and also for the current flood safety policy. Before this flood there was no large-scale protection of the Dutch coast. The Delta works realized heightening of the dikes and constructed dames and flood barriers to prevent the country from another flood (Gerritsen, 2005). This results in the fact that nowadays the Netherlands is the safest delta of the world (Deltacommissie, 2008).

Since the development of the coastal defence system in the 1960s, the population and welfare has increased significantly. The consequences of climate change increases with the dangers of the rising sea level, more extreme rainfall and higher discharges in rivers. These factors ask for extra protection. In 2011 a third of the primary dikes and 20 per cent of the engineering structures did not meet the current standards (PBL, 2012). As stated in the Delta Programme 2015 the current standards are based on a probability of overtopping: 'the risk that a certain water level or wave height is exceeded'. The policy has a strong focus on prevention of floods and has led to limited attention on the probability that it happens (Kolen et al. 2010). It is expected that prevention alone will not be enough, because raising the dykes has limits and needs to be linked to the consequences of a flood. Therefore a new flood safety policy is drafted. It is now a risk-based approach with the focus on a new concept: the multi-layer safety (MLS). This concept wants to sustain all aspects of flood risk management: prevention of floods, limiting the consequences through spatial measures and preparations on recovery measures during and after a flood.
MLS consists of three layers:

1. Prevention as the policy cornerstone
2. Sustainable spatial planning
3. Systematising and sustaining disaster mitigation

Preventive measures (layer 1) will remain the core of the water safety policy and will still be used to limit the risk of a flood (NWP, 2009). Floods can never be completely ruled out and therefore layers 2 and 3 can help by limiting the effects of a potential flood and reduce the risk. Layer 2 focuses on reducing damage caused by floods through adaptations in spatial planning. For example elevation of buildings or floating houses (van Veelen et al. 2013). These spatial planning measures are in particular interesting for new spatial developments and also for some restructuring developments within urban areas show opportunities (NWP, 2009). The third layer wants to create disaster and crisis management of high quality per safety region. In case of a flood a professional plan is needed and the government needs to be able to take over, to prevent or limit that the flood becomes a national disaster (NWP, 2009; Delta programme 2015).

The focus of this research will be on the second layer of MLS and the aim is to examine the potential of applying spatial planning measures by determining their costs and effects. The main effect of applying water-robust measures will be a reduction in damage as has been shown in previous studies (Asselman & Slager, 2013; Oranjewoud & HKV, 2011; Royal Haskoning, 2012). Do these effects outweigh the costs? This question is originated from Deltares and in association with PBL this research tries to fill this knowledge gap by examine the costs to implement these water-robust measures for the whole of the Netherlands and evaluate all costs and benefits associated with limiting flood risk to see which measures are most effective to apply.

The main question of this research will be:

What are the costs and benefits of applying spatial planning measures in the Netherlands and how do they compare to the costs and benefits of only heightening dikes as prevention measure?
The focus of this research is on the benefits in the shape of damage reduction to houses in a worst credible flood situation.

The main question will be supported by several sub questions:
1. *What is the current potential damage in the Netherlands when it will be flooded?*
2. *How will the potential damage be in the future with the current prevention?*
3. *Which spatial planning measures can be applied to reduce damage?*
4. *What are the costs of these spatial planning measures?*
5. *How will these measures reduce flood risk?*
6. *What will the potential future damage be when applying spatial planning measures?*
7. *How does this compare to flood risk reduction with dikes as prevention measure?*

In chapter 2 the method, which is used in this research, will be explained. After the method the results will be discussed. First an analysis is done for the potential damage, in case of a worst credible flood under current conditions and in the future with currently envisaged prevention measures that solely rely on dike heightening. Second the multi-layer safety concept will be explained in more detail. The spatial planning measures that are selected for this research will be introduced, what are the pros, cons and the costs of these measures. Third the potential damage in the future situation with new protection will be examined to show what is cheaper heightening dikes or implementing spatial planning measures. After the results a conclusion will be drawn in chapter 4. At the end of this research the references and appendix are included.

2. Method

This section will explain in more detail the method that has been used to come to the results. For this research the conceptual framework by Van der Pas et al. 2011 is used that is depicted in Figure 1. The main components for this research are exposure and vulnerability. Exposure is the physical feature of a flood in an area, which is in this case the water depth. Vulnerability is the number of people and objects in an area that are potentially affected, in this research the object where the focus will be on are houses. These two components together show the consequences: the damage that results when a flood occurs. The potential damage will be examined in the current situation and future situation. The method will be explained per sub-question. A quick overview of the method can be seen in Figure 2.

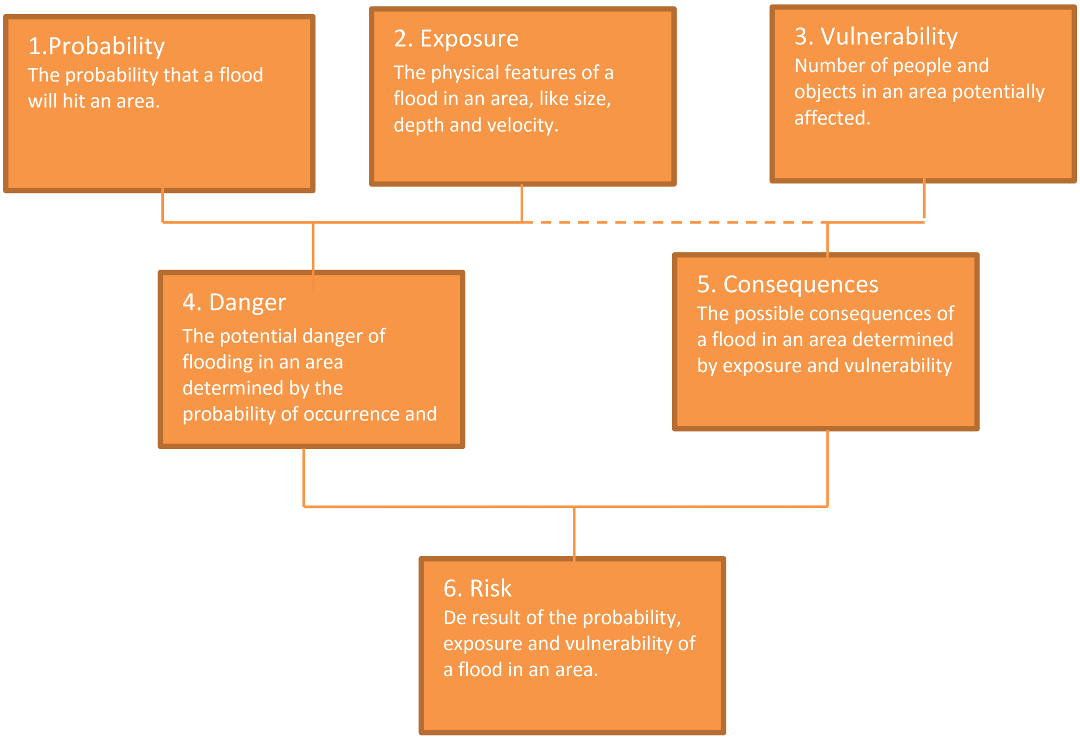


Figure 1: Conceptual framework. Source: van der Pas et al. 2011

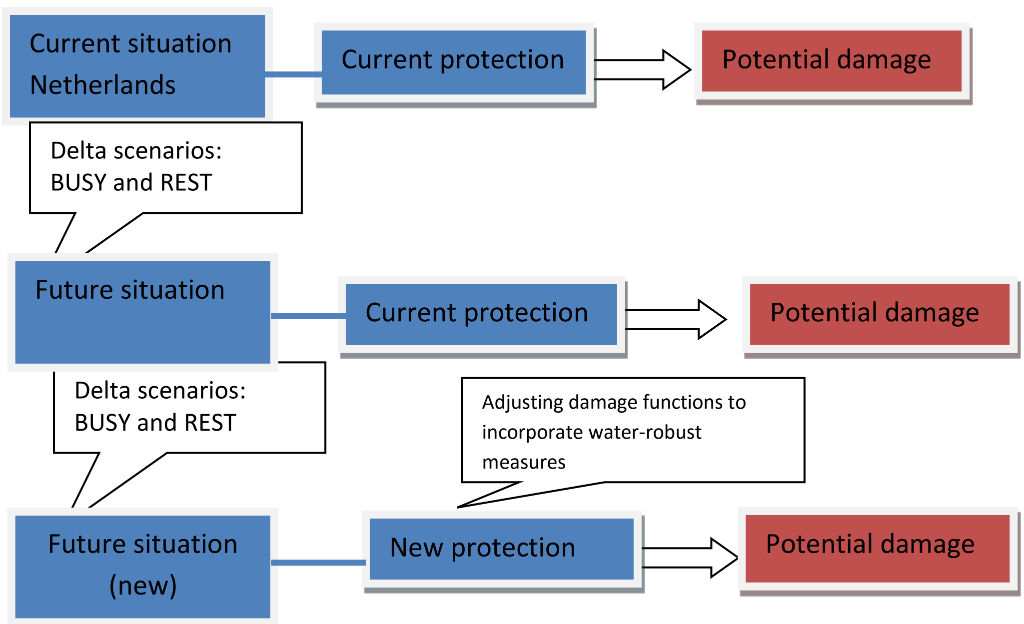


Figure 2: Overview research method

2.1 Potential damage in the current situation

The damage as a result of a potential flood needs to be modelled. The model that will be used to calculate the damage is the damage scanner, which was used in various studies (Klijn et al. 2007; Aerts et al. 2008; de Moel et al. 2011; de Moel et al., 2012). The damage scanner is a meso-scale model, which is developed by De Bruijn (2008) for studying the effect of future land-use and climate change scenarios on flood damage (de Moel, 2012). The damage scanner version that is used in this research is developed by PBL see Figure 3.

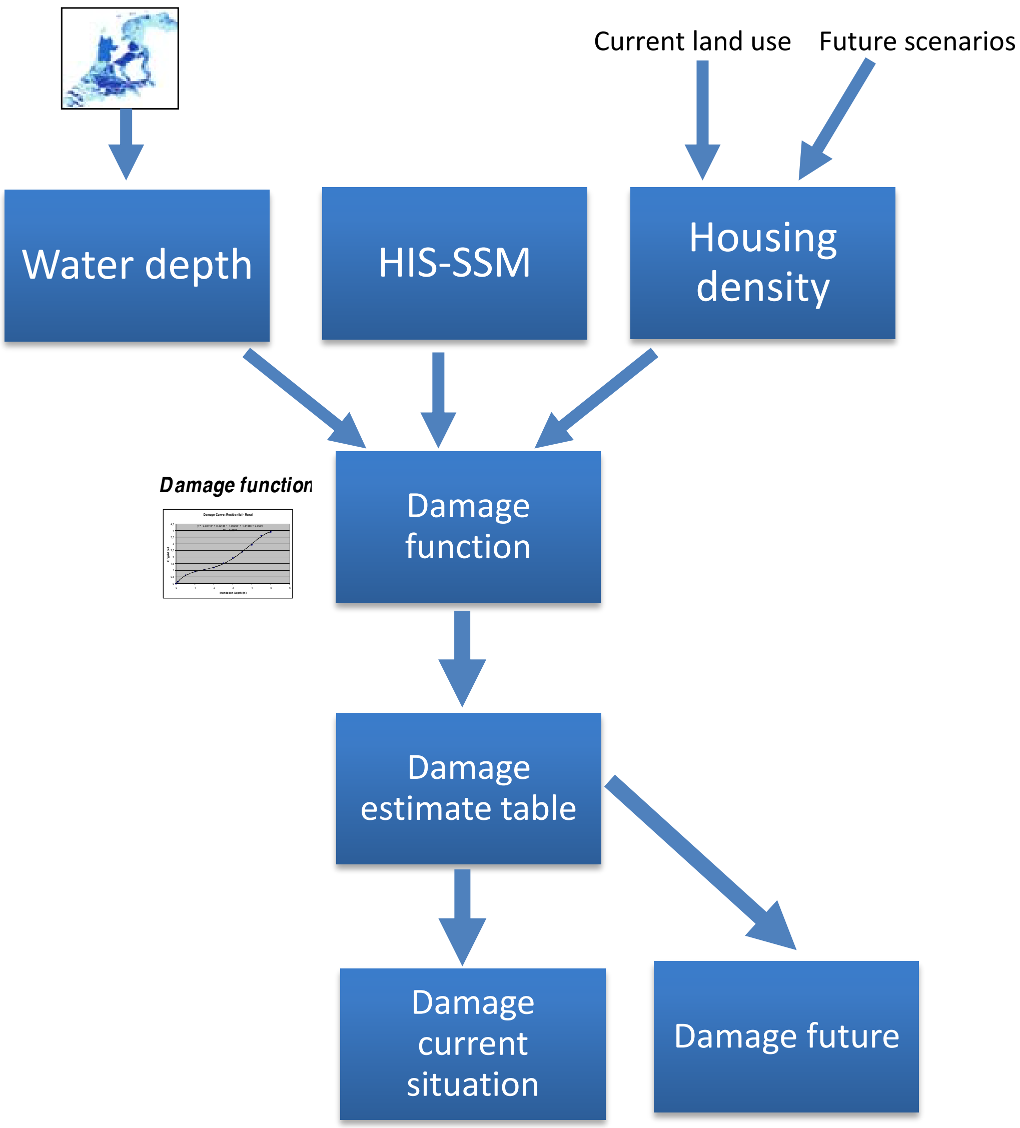


Figure 3: Damage Scanner approach. Source: based on PBL, 2010 and van Leeuwen E., Koomen E., 2012.

The damage scanner calculates the potential damage in euros for the current situation based on water depth and the current land use map. These two components together with the High water Information System Damage and Casualties Module (HIS-SSM) which are used to calculate the expected amount of casualties and damage caused by a flood, are the inputs for the damage function, see Figure 4. This Figure shows an example of a damage function for low-rise houses; it gives the damage factor as function of water depth. The damage factor is a number between 0 and 1, which depends on the water depth and flow rate. Per housing-type there exists a damage function.
There are five housing-types: family, farms, low-, middle- and high-rise houses. The damage function is translated into damage factor-tables per housing type. With these inputs the damage to houses in the Netherlands can be calculated. The focus of this research is not on damage of the five separate housing-types but houses in total. Therefore the individual damage of the five housing-types is added up to one map, which shows the total damage to houses in the Netherlands.
The type of flood that will be used in this research is a worst credible flood. The conditions are considered more extreme than the dikes can withstand (Brinke et al., 2010). These floods provide an upper limit for the flooding scenarios that are still considered realistic and credible by experts (Brinke et al., 2010; Kolen & Helsloot, 2012). Not the whole flood prone part of the Netherlands will be flooded. There are some higher grounds and objects in the areas that prevent some parts of the area to be flooded (Brinke et al., 2010).

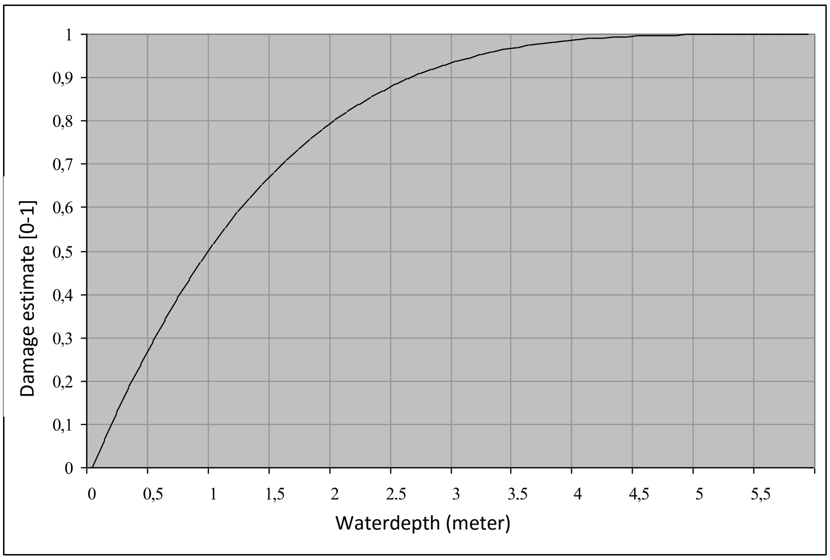


Figure 4: Damage function for housing type low-rise. Source: PBL, 2010

To calculate damage to houses in the future some adjustments to the Damage Scanner need to be made. Water depth from the current situation will be used because it is assumed that climate change has little to no impact on floods, meaning no sea-level rise. The input that will change is the variable housing density in total for the Netherlands again not per housing type. Using the output in the current situation and the output of the future situation can be used to calculate an increase factor. This increase factor will be multiplied with the Best Estimate, the best available estimates of the current potential damage, to calculate the expected damage in the future based on scenarios.

2.2 Potential damage in the future situation with current protection

The damage in the future situation when a flood occurs will be assessed with the current coast defence system. Because land use in the future is not known, scenarios will be used. This research uses the Delta scenarios, which are designed for the Delta program (Bruggeman et al., 2011). The Delta scenarios are a combination of socio-economic scenarios, which are based on the study 'Welfare, prosperity and quality of the living environment '(WLO) (CPB et al., 2006) and climate scenarios based on KNMI'06 scenarios. These two components are seen as most important driving forces for water management (Bruggeman et al. 2011). The climate scenarios are time series of climate records of a possible climate in the future. These scenarios show to what extent temperature, precipitation and wind can change, at a certain worldwide climate change (Bruggeman et al. 2011). The WLO-scenarios show socio-economic developments and their effects on land use in the Netherlands. They describe changes in the environment wherein people work and live. The WLO-scenarios show the future of the Netherlands in 2040 and the Delta scenarios in 2050. As no options of socio-economic scenarios are available it is assumed that the WLO-scenarios are as representative for 2050. There are four Delta scenarios that depend on climate change and socioeconomic growth, depicted in Figure 5.

Two Delta scenarios will be used for this research, the Delta scenarios BUSY and REST (Bruggeman et al. 2011). The variant BUSY has high socioeconomic development and REST has low socioeconomic development. Climate change is expected to be moderate in these scenarios. This results in negligible sea level rise and therefore will not have a large impact on the development of floods. In this research the focus is on socio-economic developments for the year 2050. When climate change will have an impact you need to look even further in the future in the year 2100. However, when using the year 2100 it is difficult to simulate the socioeconomic developments. This is because of the fact that it is too far into the future and it becomes too uncertain to predict these developments. Until the year 2050 the variables population and economic growth can be used with some confidence.

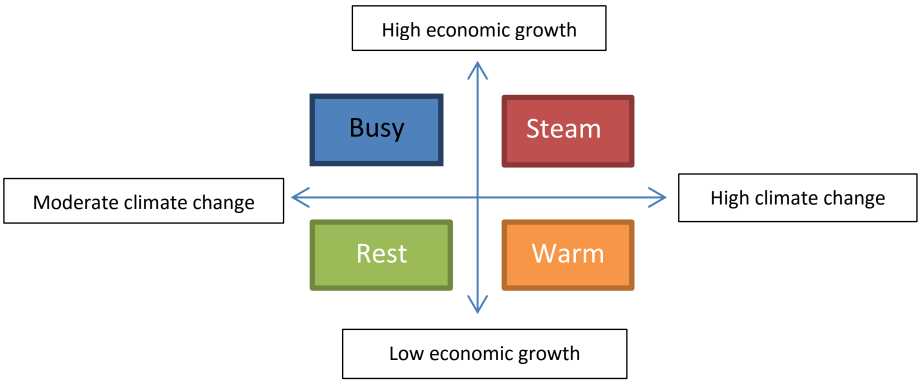


Figure 5: The four Delta scenarios. Source: Bruggeman et al.. 2011

2.2.1 BUSY

This scenario combines high socio-economic growth with moderate climate change. The socio-economic growth leads to scarcity of fossil fuels, which causes energy prices to rise. This scarcity of fossil fuels has as positive influence on the development of energy technology causing a worldwide transition to efficient and low-carbon energy supply. These developments also apply to the Netherlands allowing firms who are specialized in renewable energy, environment- and agriculture technology to growth. Due to the transition to more sustainable activities the demand for sustainable transport increases, therefore the amount of continental transport over water increases.

In the busy scenario more people feel the need to live and work in attractive cities. Sustainable technology makes it possible to create more efficient and economical cities.
The changes in precipitation and river discharge are expected to be limited. But the need for more protection against floods increases, because more people work and live in compact urban areas. These areas are mostly positioned in flood prone area.

2.2.2 REST

This scenario consists of low socio-economic growth in combination with moderate climate change. The low economic growth leads to a decrease in greenhouse gas emissions; therefore less emission reduction is needed. Because of this, worldwide climate agreements are easier to make and give a boost to the development of new energy and environment technology.

Economic growth in the Netherlands is assumed to be lower than in the European Union because the Netherlands cannot cope with the strong competition of other countries. Due to this the population stabilizes at first and after that it even start to decline. The use of fossil fuels declines and will be replaced by the bio-based economy.
Climate change is limited so no adaptation is needed to protect the Netherlands and her population against temperature rises or more precipitation because the population declines and there is almost no economic growth. Therefore the size of the cities declines and building in vulnerable areas is therefore not necessary.

2.3 Sustainable spatial planning

Sustainable spatial planning is a new way of protecting the Netherlands from floods. In this research sustainable spatial planning will be applied on houses. Apart from houses, it can be applied to all kind of buildings like offices, schools or even supermarkets. A literature study will first examine what kinds of water-robust measures are possible to apply. Next the costs and benefits of the selected water-robust measures will be examined. The costs of the water-robust measures will then be compared to the damage reduction these measures achieve.

2.4 Potential damage in the future situation with new protection

The water-robust measures selected in the Section 2.3 will be used to reduce damage for locations in the Netherlands that have to cope with floods. These locations are selected based on where new development projects or restructuring are planned for the future, 2050. The amount of damage reduction that can be achieved through these water-robust measures is calculated comparing damage in the business as usual scenario with the damage when applying water-robust measures. The total amount of data is available in Arc GIS and will be exported into excel© to calculate the corresponding amount of damage reduction per dike ring. Next the costs will be calculated for the locations that are selected to implement water-robust measures. This will be shown on a map for the Netherlands. To answer the research question the benefits and costs of dikes need to be compared to the costs and benefits of sustainable spatial planning. Calculating the risk reduction per euro extra costs will do this, because the purposes of both measures differ. The dikes try to decrease the probability that a flood occurs while sustainable spatial planning tries to reduce the consequences of a flood. The risk will be calculated by multiplying the probability with consequences when a flood occurs. This research focuses on the reduction that can be achieved. For dikes this means reduction in probability multiplied by the consequences, when strengthening the dikes the consequences will stay the same. For sustainable spatial planning the probability stays the same but it will be multiplied with reduced consequences. Still the two applications to reduce risk are not comparable yet. Therefore the risk reduction needs to be divided by the costs, the risk reduction per euro extra costs, this calculates that every euro it costs x risk reduction will be achieved. This will be used to calculate a ratio between dikes and sustainable spatial planning to show the best option to apply, meaning the one that is more efficient to apply per dike ring.

3. Results

This chapter examines the potential damage to houses when a worst credible flood occurs in the Netherlands in the current situation, in the future situation without adjustments to the flood protection system using Delta scenarios and the a future situation when water-robust measures will be applied to reduce potential damage.

3.1 Potential damage in the current situation

Figure 6 shows the flood prone area of the Netherlands and the difference in water depth. The area of Rotterdam will experience much more water when a flood occurs than the area of Leiden. The Netherlands is a low-lying delta located between the rivers the Rhine and the Meuse. The Netherlands is one of the most densely populated countries in the world with 16 million people living in areas protected by flood defences (de Moel et al. 2011; Klijn et al. 2015). There are living so many people in deltas because of the fertile soils, the location of the deltas close to the water, which gives it easy access via waterways and sea ports and the relatively flat surface which makes it easy for the construction of buildings etc. (Klijn et al. 2015).

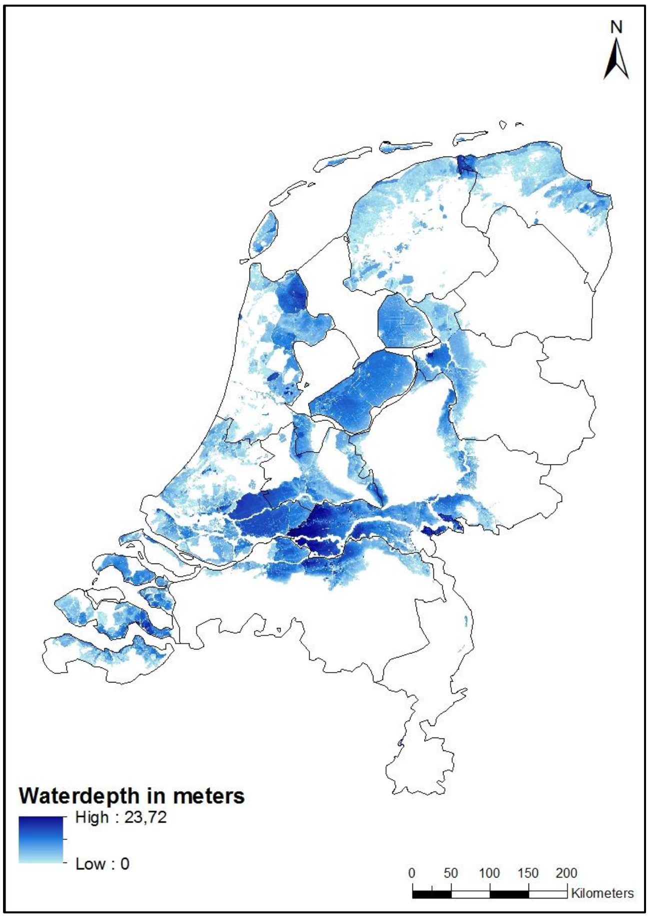


Figure 6: Flood prone area in the Netherlands. Source: PBL

Dikes, which are strong and high enough, are made to protect these highly valued areas to prevent floods that had occurred in the past to happen again (ten Brinke et al. 2010). Their required height is derived from the formula of Van Dantzig, which was made in response to the large flood in 1953. His formula states that a dike has a certain exceedance probability that remains after each investment in a safety structure, i.e. the probability that the water level will not exceed the top of the dike and prevent that it will overflow and flood the land behind the dike (Jonkman et al. 2008; ten Brinke et al. 2010; Vis et al. 2003). The safety standard of Van Dantzig was already accepted in 1960 but is only quite recently translated into a law, the Protection Act of 1996 (Jonkman et al. 2008; ten Brinke et al. 2010).

The safety standard of Van Dantzig was set on a probability of 1:1250 per year, the so-called 'design discharge' meaning that high water levels, that occur with a chance of 6% per human lifetime, must be guaranteed (Vis et al. 2003; ten Brinke et al. 2010). In the Protection Act of 1996 it changed from only one safety standard to five safety levels, which differ per dike ring (Kind, 2014; Klijn et al., 2012). Dike rings are areas in the flood prone part of the Netherlands, which are enclosed and protected by a set of dikes; the Netherlands had 53 dike rings at the time the law got accepted (ten Brinke et al. 2010). There are primary dikes with legal standards and smaller dikes, which are not part of the legal standards because they protect against smaller water bodies (ten Brinke et al. 2010). The dikes with legal standards have to guarantee a certain level of protection. For the provinces North Holland and South Holland these safety standards are set at a probability of 1:10,000 (see Figure 7). Meaning that the probability that a flood may break through or flow over the dike is once in 10,000 years. The probability that a flood will occur the province of Zeeland is 1 in 4000 years. There is a difference between safety levels because North and South Holland have to cope with the threat of the sea, the many inhabitants and the huge amount of capital. A flood in this part of the Netherlands can have major consequences for the country. Zeeland has a similar threat from the sea but the potential damage are lower because the amount of capital and the amount of inhabitants is lower and therefore this province has a lower safety level (Bockarjova et al., 2010)

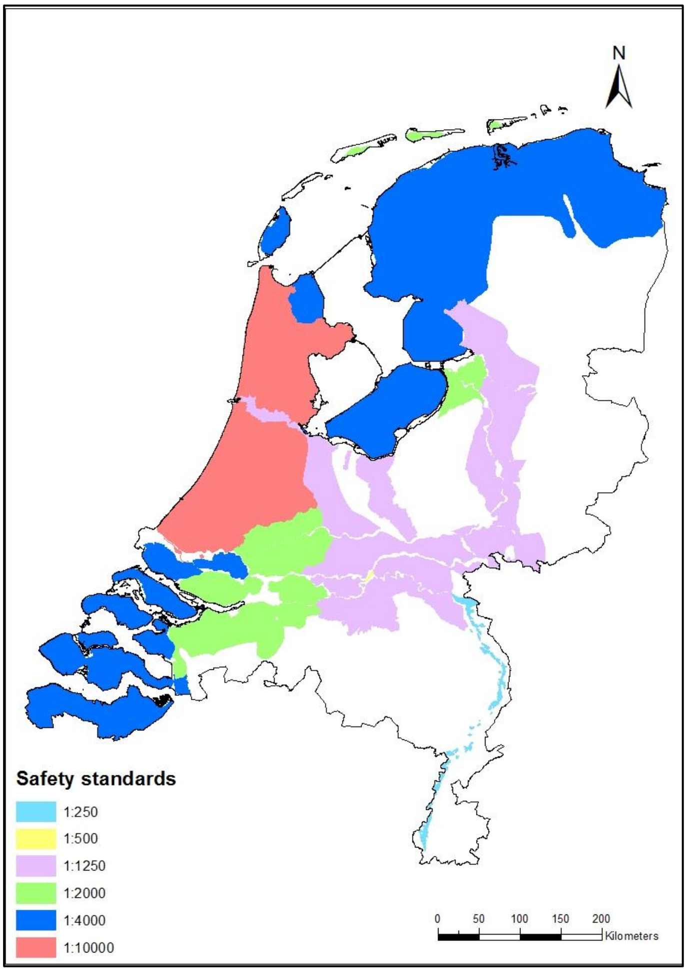


Figure 7: Dike ring areas in the Netherlands divided per safety standard. Source: PBL

Currently the Netherlands has 58 dike rings wherein the risk between the dike rings differ but also within a dike ring the risk differs due to different economic value in an area and the amount of people living in the area. Therefore the dike ring is divided into dike trajectories.
In this research the focus will be on direct damage, in particular on houses. That will result from a worst credible flood that may occur under rare conditions. Figure 8a shows where damage to houses will occur when a worst credible flood happens. Not surprisingly most damage will occur in dike ring 14, South Holland, because it is located in the flood prone part of the Netherlands and most houses are located in this dike ring. See Figure 8b, which shows the damage in million euros per dike ring. In total the potential damage is estimated at 200.000 million euro.

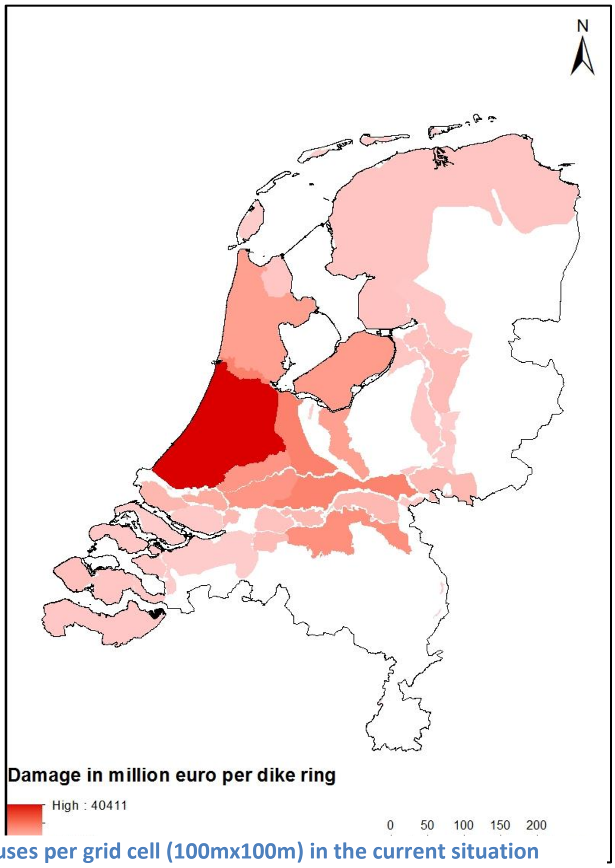


Figure 8a (left): damage resulting from potentially flooded houses per grid cell (100mx100m) in the current situation during a worst credible flood in million euros 8b (right): potential damage to houses added up per dike ring in million euros, source: PBL

3.2 Potential damage in the future situation with current protection

In the current situation seventy percent of the Dutch Gross National Product is earned below sea level. Also the main cities, Amsterdam, Rotterdam and The Hague are located in this area. The amount of people living in flood risk areas is expected to increase as well as the economic developments. The safety standards are being monitored every five years on their capability to prevent floods (Klijn et al. 2012). In the future the economy and demography is expected to change compared to the current situation. Therefore it is stated that the flood defense structures need to adjust. But how will the situation look like in the future, when we do not adjust these defense structures to protect the country from a flood?

In the scenario REST the number of houses will slightly increase and the population will decline, see Table 1. Large cities in the Randstad are not considered more attractive to live in than it was the case in the current situation but now people also like to live at the countryside in the south or east of the Netherlands. This can be seen in Figure 9 the increase in houses is evenly distributed over the Netherlands.

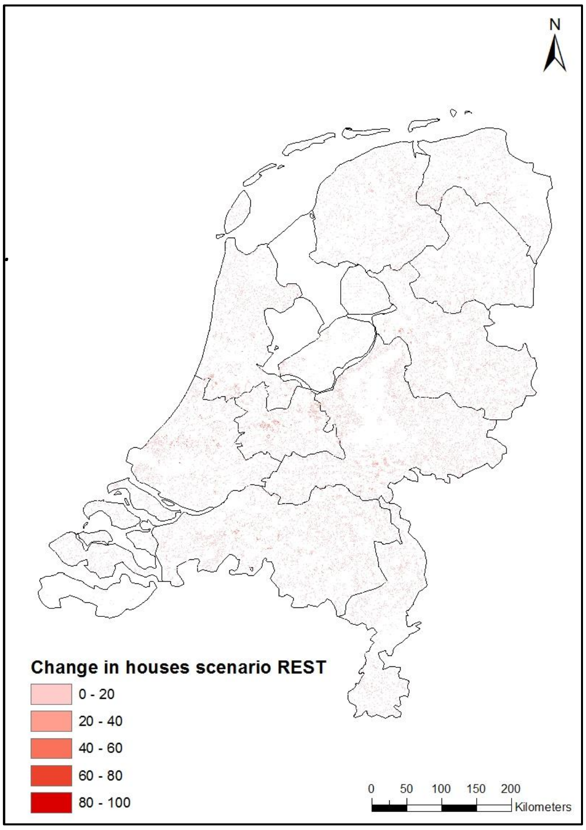
The relocation of houses from the Randstad to other areas in the Netherlands has a positive effect on the amount of potential damage, which will be lower in the scenario REST compared to the current situation (see Table 1). Fewer adjustments on water safety are therefore needed. Figure 10 shows the spots in scenario REST where a flood will cause damage in million euros. Although the Randstad is not the most wanted place to live in any more, still the most damage will be in dike ring 14, which is estimated to be 20,6% of the total damage.

Table 1: Keystatistics data current situation and Delta scenarios. Source: Bruggeman et al., 2011 and statline.nl

Scenario	Base year (2014)	REST (2050)	BUSY (2050)
Economic growth	1,00%	0,70%	2,60%
Population (million)	16	15	20
House units	4942202	4963644	7062053
Damage (million euro)	190473	190394	287353

In the scenario BUSY the population will substantially increase because the Netherlands is attractive to live in. People who already live in the Netherlands will stay and more economic migrants will move to the Netherlands. This can be seen from the number of houses that will be built in this scenario, which shows an increase of 43%.

The socio-economic growth in scenario BUSY increase flood risk. The potential damage to houses when a flood occurs is expected to become much larger when the dikes fail because more houses can be affected. Therefore adjustments to the flood defense structures are needed. Again the largest damage occurs in dike ring 14. Compared to the damage in scenario REST, the damage in dike ring 14 is 40% higher.



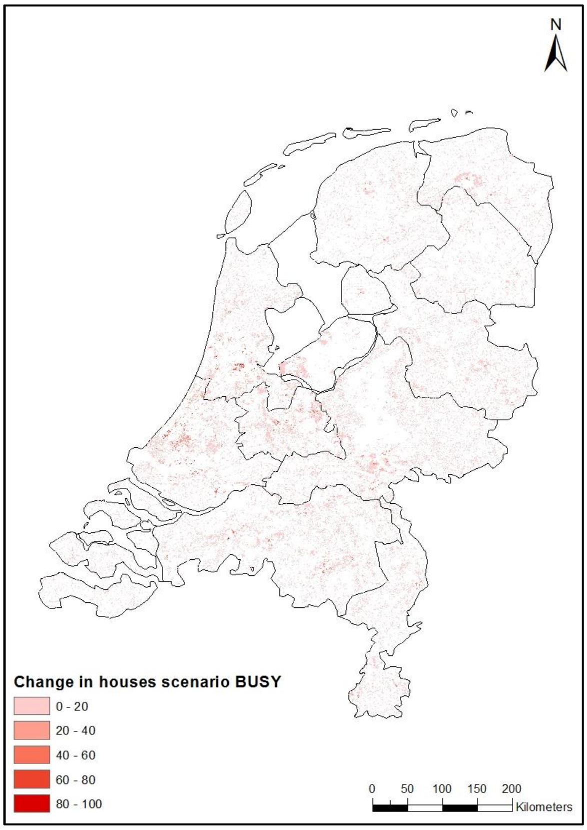


Figure 9: the increase in houses in Delta scenario REST (left) and Delta scenario BUSY (right) between 0 and 100 houses per hectare (100mx100m) the higher amount of houses per hectare is left out to make the two Delta scenarios better comparable

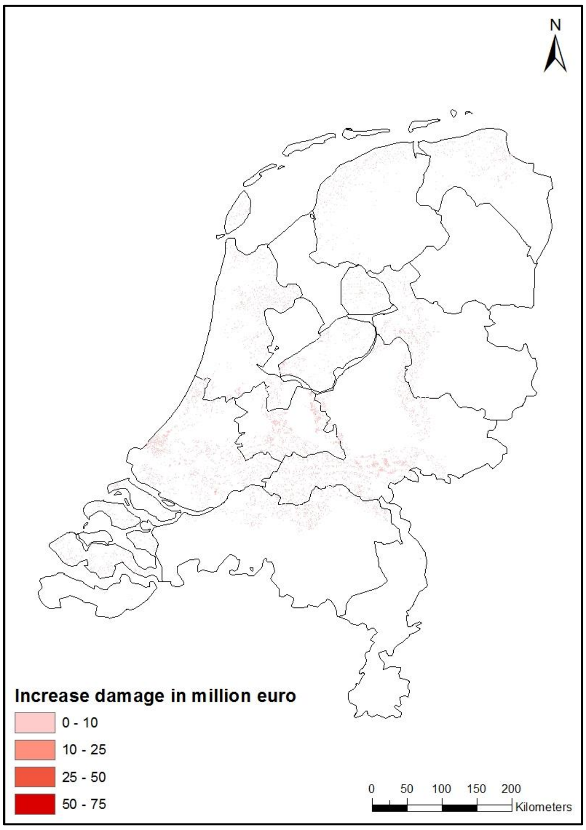


Figure 10: Increase in damage to houses when a flood occurs in million euros for Delta scenario REST (left) and for Delta scenario BUSY (right). Source: PBL

3.3 The multi-layer safety concept

Dikes are the primary form of prevention to protect the Netherlands from a flood. But the vulnerability of the Netherlands increased over the past years and is still increasing due to the developments in the economy, demography and climate, making the flood risk higher. This happens not just in the Netherlands but also in other countries in Europe. Therefore flood management in Europe shifted to an integrated risk management approach (Kreibich et al. 2014; de Moel et al. 2014; Klijn et al. 2015). To adapt to these changes the European Union came up with a framework, the directive on Flood Risk Assessment and Management. This requires all member states to perform risk assessments, create flood maps and develop flood risk management plans to focus also on the potential consequences of a flood. The Netherlands responded to this EU directive with the development of Multi-layer Safety (MLS) in the national policy on flood management (de Moel et al. 2014; Kreibich et al. 2014; Klijn et al. 2015). The MLS is already discussed in short in the introduction of this research but will now be explained more in detail.

The MLS concept consist of three layers

1) Prevention
2) Sustainable spatial planning
3) Systematising and sustaining disaster mitigation

1. Prevention

Prevention focuses on protection of the Netherlands against a flood. This is the only legal binding layer of the MLS concept and therefore remains the most important part of the Dutch flood safety policy (National Water plan, 2009). The current standards will be updated and get the focus on, as stated in the National Waterplan, 'a basic level of safety for every individual, a socially acceptable risk for the risk of large numbers of casualties and an economically optimal level of safety'. Casualty risks will get a more central position in the policy instead of the economy. The flood defence structures are now tested every five years on their hydraulic preconditions. This will change into every six years because this is in line with the European Flood Risk Directive, National Waterplan and the regional water plans. To make sure the flood defence structures remain safe in the future the space along the flood defence structures should be kept open, as in protection zones.

2. Sustainable spatial planning

The second layer is an addition to the first layer of MLS, because probability cannot be excluded entirely and the flood defence structures cannot stop the flood totally. Layer 2 focuses on spatial planning and applies a different way of construction, which is flood proof. By making buildings resistant for flooding the damage can be reduced to a minimum level or even zero. It can be applied to new spatial developments, which makes an area more resistant for the consequences of a flood but also an in existing built-up area, which is the largest part of the Netherlands.

3. Systematising and sustaining disaster and crisis management

The final layer of the MLS concept focuses on the organization to evacuate people when a flood occurs. Therefore the safety regions, which are areas where different organizations, like the fire department work together to ensure the safety, need to be organized professionally and have to know what to do when a flood enters the country. The Cabinet has to put the focus in this third layer on the following points: raising public awareness of crisis management in general; direction and coordination; realizing operational plans; and organizing the 'water column' ('waterkolom') (National Waterplan, 2009). The first three points focus on improvements to crisis control by the safety regions, the provinces and the Ministry of the Interior. The fourth point refers to improvements on crisis management organization concerning the regional water boards and the Ministry of Transport, Public Works and Water Management.

The MLS wants to guarantee a sustainable way of keeping flood risks at a socially acceptable level.

For this research we focus on the second layer of the MLS concept. Flood proof measures that can be applied to houses to make them more resistant to floods. The goal is reducing the consequences, which dikes cannot prevent. There are a lot of measures possible that can be used to make houses flood proof. Some are very creative and innovative others are efficient and easy to apply. A selection of proposed measures was made to keep things manageable. Four measures are chosen for this research: heightening, dry proof construction, wet proof construction and building on piles because these four are most used in the literature (Buitelaar, 2015; de Boer et al., 2008; Asselman & Slager, 2013; Pötz et al., 2014 and Zethof & Kolen, 2015).

The measures will be applied in three different policy options. The first policy option is implementing flood-proof houses within existing urban areas; this is applied to the existing houses that are expected to be replaced in the future following urban and that are located in flood prone area. The second policy option is implementing flood-proof houses in new development areas, here new houses will be built and instead of building traditional houses flood-proof houses will be build. The third and last policy option shows the implementation of flood-proof houses in total, meaning the previous mentioned policy options large combined.

3.4 Sustainable spatial planning – measures

Heightening

The ground where the house is standing on will be heightened with for example one or two meter soil. Heightening ensures that the houses are less vulnerable to flooding. By doing this the inundation depth will be reduced. This can be applied to new constructions and rebuilding (Buitelaar, 2015; Asselman & Slager, 2013; Zethof & Kolen, 2015).

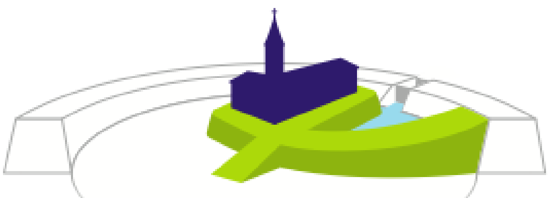


Figure 11: heightening of houses. Source: Stowa, 2014

Dry proof construction

A dry proof construction means that the water cannot enter the house. The floor, façade, walls and windows of the house are water resistant till a height of 0.9 meters. When the flood occurs openings of the house need to be closed manual using water-resistant bulkheads till a height of 0.9 meter above ground level. The house cannot have a subsurface level otherwise the water will enter the house via these levels. Above 0.9 meters the water can damage the house so only applicable with low flood depth. (De Boer et al., 2008 and Asselman & Slager, 2013).

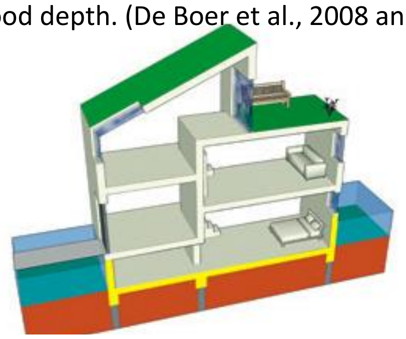


Figure 12: Dry proof construction of houses; keep the water outside the house. Source: Asselman & Slager, 2013

Wet proof construction
A wet proof house is in the initial situation dry but in case of a flood the water can enter the house until a maximum height of 1.5 meter above ground level. The maximum height of 1.5 meter is based on acceptable height for electricity points on the first floor. The damage in the houses will be mostly reduced using water-resistant materials and moving the cupboard to a higher floor (de Boer et al., 2008; Asselman & Slager, 2013). With floods that are higher then 1.5 meter wet proof construction is not a realistic option.

Figure 13: Wet proof construction, lets the water enter the house. Source: de Boer, 2008

Building on piles
This type of measure is comparable with heightening. In this case not the whole ground will be lifted; only the houses will be lifted and put on piles. The piles are placed on the foundation of the house. In the initial situation these houses can be build in wet and dry circumstances. When the initial situation is dry the space under the houses can be used for parking or storage (de Boer et al., 2008; Pötz et al., 2014; Buitelaar, 2015).

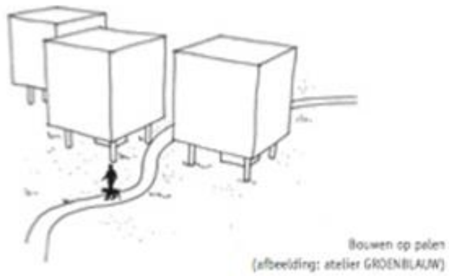


Figure 14: Building on piles. Source: studio GROENBLAUW

Costs and benefits of the measures
The costs of the measures can be seen in Table 2. The costs are extra costs per house to make it flood proof and come on top of the costs for building a traditional house. The type of a house that is used in this research is a traditional house with gross surface area of 145m^2. Heightening and building on piles can be applied on houses for different heights to reduce flood depth. For heightening the costs are specified per soil type, sand, clay and peat for 1m^2 when it will be heighted with 1 meter.

Dry proof en wet proof construction reduces damage with 100% till a height of 0.9 meters for dry proof construction and 1.5 meters for wet proof construction. These two types of measures can be applied to houses that are located in areas that have to cope with shallow flooding. The costs of the dry proof and wet proof construction are much higher than 1 meter heightening or building the houses on piles. The benefit of dry proof and wet proof construction is that it can be applied on existing houses. Heightening and building on piles would be much more costly to apply on existing houses and contaminants remain behind after a flood, which will not happen with dry proof and wet proof construction (Pötz et al., 2014).
For new development projects it would be good to incorporate building on piles as flood proof measure because it will increase the value of the house when it is build near or in the water and the space under the houses can be used for water retention (van de Ven et al. 2009; de Boer et al. 2008;

Buitelaar et al. 2015). A disadvantage will be that, when the area where houses on piles are built is flooded, the people are stuck in their houses. Here the third layer of the MLS concept is required. Heightening will not be affected by this disadvantage with new development projects. Most of the time the whole area will be heightened, meaning that the roads will also be heightened which makes it possible to leave or enter the neighbourhood (van de Ven et al. 2009). This last point is not incorporated in this research since the costs are per house because the data from previous studies that has been used is per house.

Dry proof and wet proof construction are the most expensive options to apply so it will always be cheaper to heighten or build a house on piles. When these houses are build on clay or peat soils it will be cheaper to build these houses on piles. But when houses are build on sand soils it is cheaper to heighten with sand than building on piles. The next section assesses the impact of applying these measures on reducing flood risk.

Table 2: Extra costs per house to apply water robust measures. Source: Kind, 2013; Stowa, 2014; Buitelaar, 2015

Measure	Extra costs per house	Increase in height
Heightening		
Sand	€ 4.350,00	Per 1 meter
Clay	€ 6.380,00	Per 1 meter
Peat	€ 8.555,00	Per 1 meter
Dry proof construction	€ 20.500,00	< 0.9 meter
Wet proof construction	€ 20.500,00	< 1.5 meter
Building on piles	€ 4.930,00	Per 1 meter

3.5 Potential damage in the future situation with new protection

To keep the Netherlands safe from floods in the future the efficiency of sustainable spatial planning measures need to be examined. The costs and benefits will be discussed. The benefits will show if the measures are effective by looking at how much damage will be reduced when implementing them. The costs are defined as extra costs of building a house with flood proof measures.

The first part of this section examines how much damage can be reduced. Locations with plans for redevelopment or new development in flood prone area of the Netherlands are selected to apply measures. The damage at these locations is set to 0 euro, this means 100% damage reduction. The selected locations, meet the criterion that the houses will be flooded during a worst credible flood. The second criterion is that flood depths will not exceed 3 meters. This last criterion is set because houses that are on piles or heightened land of more than 3 meters high do not fit into the current landscape. Damage maps are created for both scenarios and the three policy options.

Results show that damage reduction for Delta scenario REST is lower than for Delta scenario BUSY as can be seen in Figure 15. The red dotted line in Figure 15 shows the difference in damage between the business as usual column on the left side of the Figure and the three policy options.
The damage reduction in scenario REST is not much. This might be due to the lower economic growth, which makes the Netherlands less attractive to live in. As a consequence fewer new flood proof houses will be build, so less damage reduction can be achieved. The difference in damage reduction can also be seen on the damage maps in Figure 16, which shows that flood proof measures will be applied primarily on redevelopment within urban areas. Some damage reduction is achieved in South Holland and Utrecht. The damage reduction in the whole of the Netherlands is in the case of Delta scenario REST only 12%. Figure 17 shows the total damage reduction when applying water-robust measures in new development and redevelopment areas.

Most damage reduction for Delta scenario BUSY can be achieved at new development areas (see Figure 18), especially in the provinces South Holland and Utrecht. In South Holland (dike ring 14) the damage can be reduced with 12% when applying measures on houses in new development areas. The damage reduction for the whole Netherlands will be 25.8% when applying measures in urban areas and at new development locations.

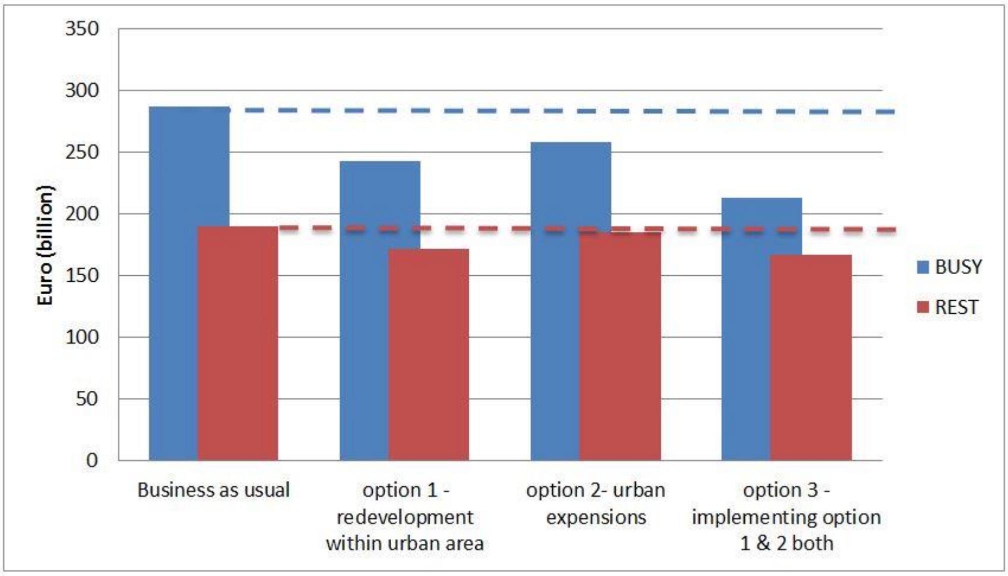
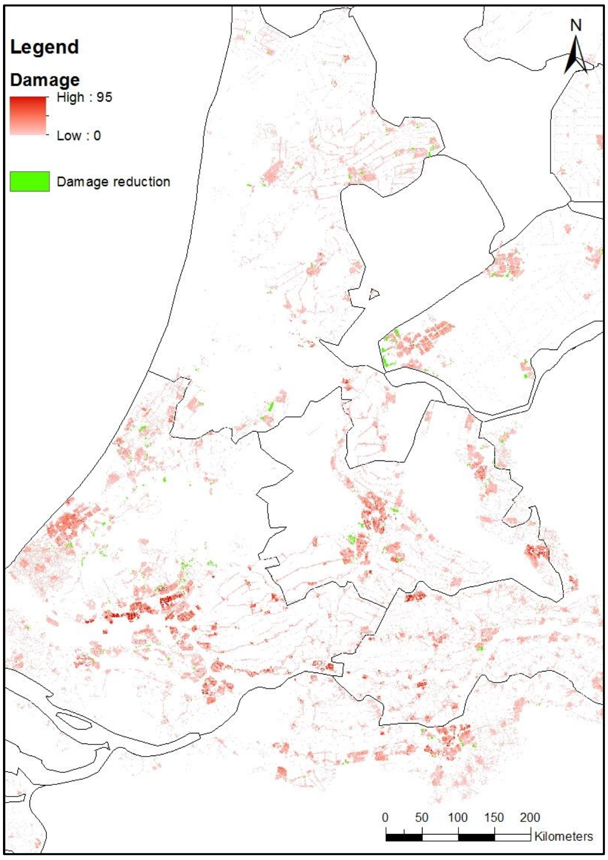


Figure 15: Total damage for the whole of the Netherlands Delta scenarios REST and BUSY per policy option and the business as usual scenario source: PBL



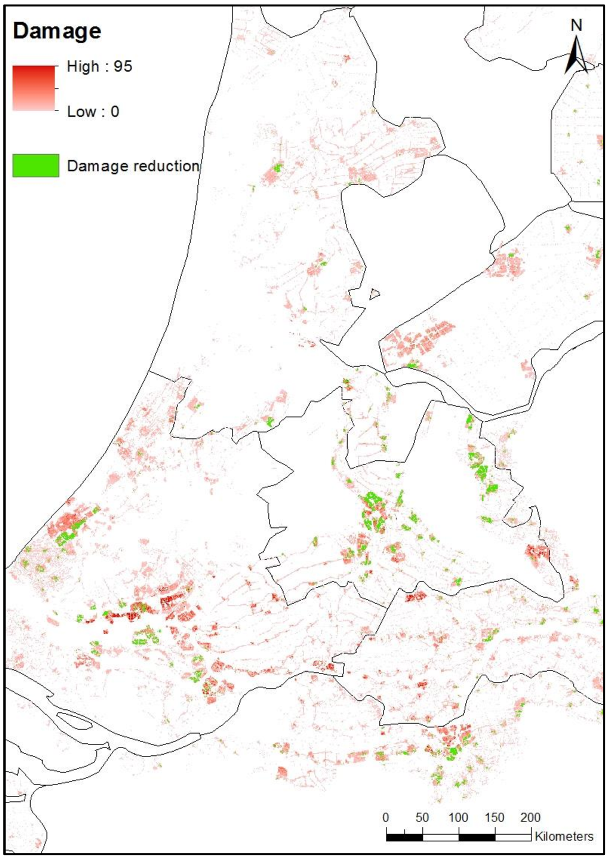


Figure 16a(left): Delta scenario REST in red damage to houses in million euro, new development areas, green areas damage reduction due to water robust measures. 16b (right): Delta scenario REST in red damage to houses in million euro, redevelopment within urban areas, green areas damage reduction due to water robust measures. Source: PBL

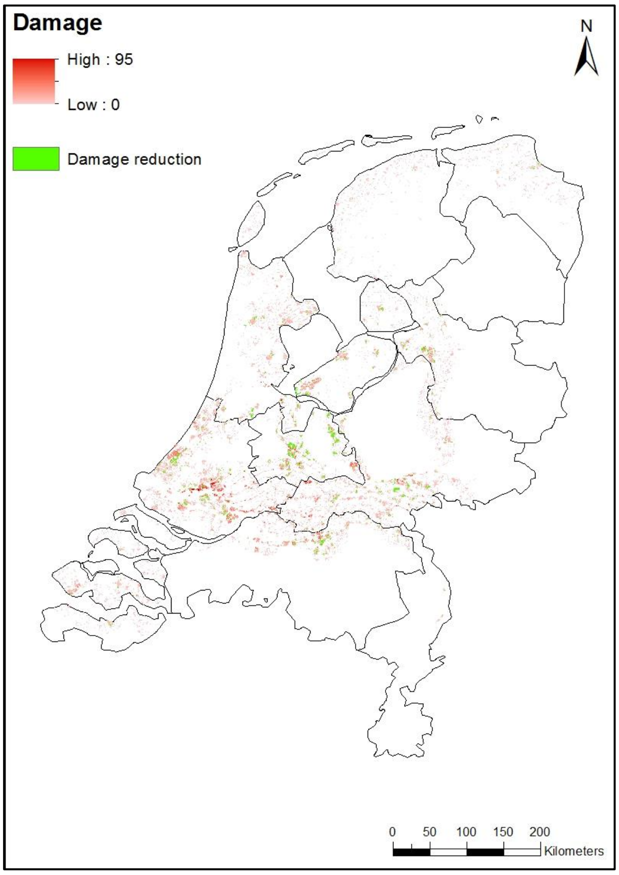


Figure 17: Delta scenario REST in red damage to houses in million euros, new development and redevelopment within urban areas together, in green areas with damage reduction due to water robust measures. Source: PBL

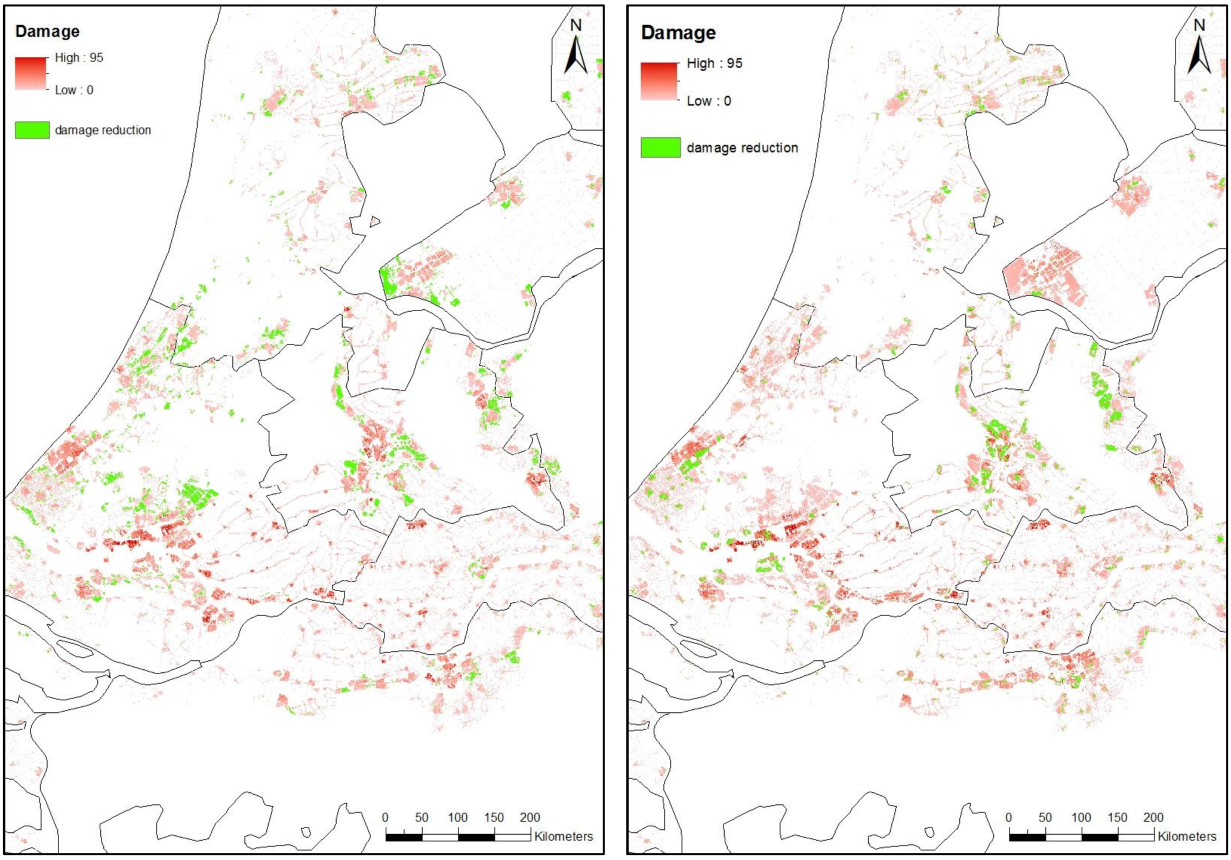


Figure 18a(left): Delta scenario BUSY in red damage to houses in million euro, new development areas, green areas damage reduction due to water robust measures. 18b (right): Delta scenario BUSY in red damage to houses in million euro, redevelopment within urban areas, green areas damage reduction due to water robust measures. Source: PBL

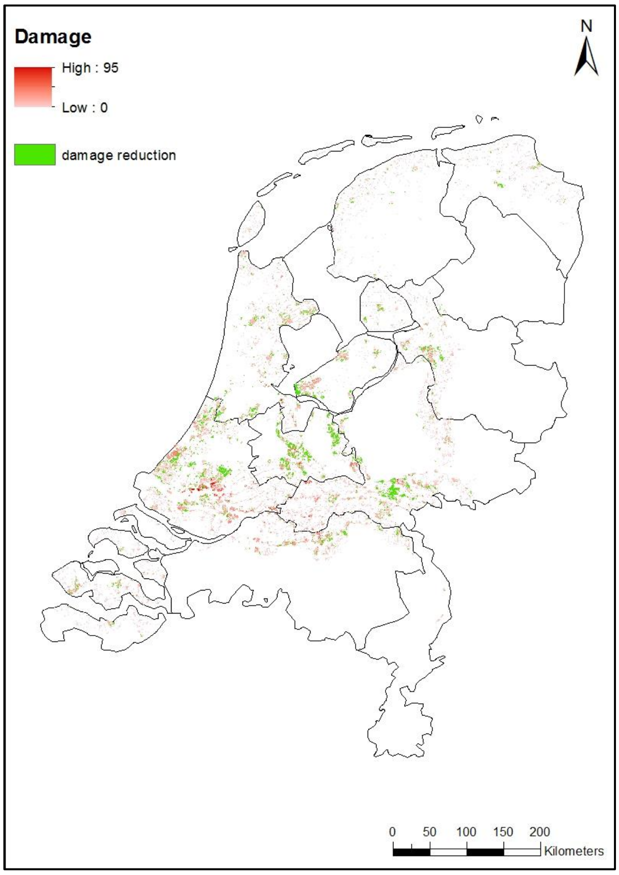


Figure 19: Delta scenario BUSY in red damage to houses in million euro, new development and redevelopment within urban areas together, in green areas with damage reduction due to water robust measures. Source: PBL

The measures that can be applied to reduce damage with 100% are discussed in Section 3.4. The cheapest measure is considered to be the best option for that location. Other criteria could also be used but that is too detailed for this research and needs to be examined at the local scale. This research provides a first insight into the costs of flood-proof measures. The costs of flood proof measures per dike ring are added up to show the total costs. In scenario BUSY this is €13354 million, whereby the highest costs can be found in dike ring 14. In the scenario REST the total costs are €2222 million, much lower compared to the costs of Delta scenario BUSY. This can be explained by the lower attractiveness of the Netherlands to live and work in, in the Delta scenario REST, meaning fewer replacements of houses or construction of new houses. Figure 20 shows the cheapest measures to apply on the selected locations. This figure will be the same for scenario REST only fewer spots. Figure 20 shows that piles are the most used measure. Piles are the cheapest for locations with clay or peat soil. Some locations show heightening, this will only be done on predominantly sandy soils.

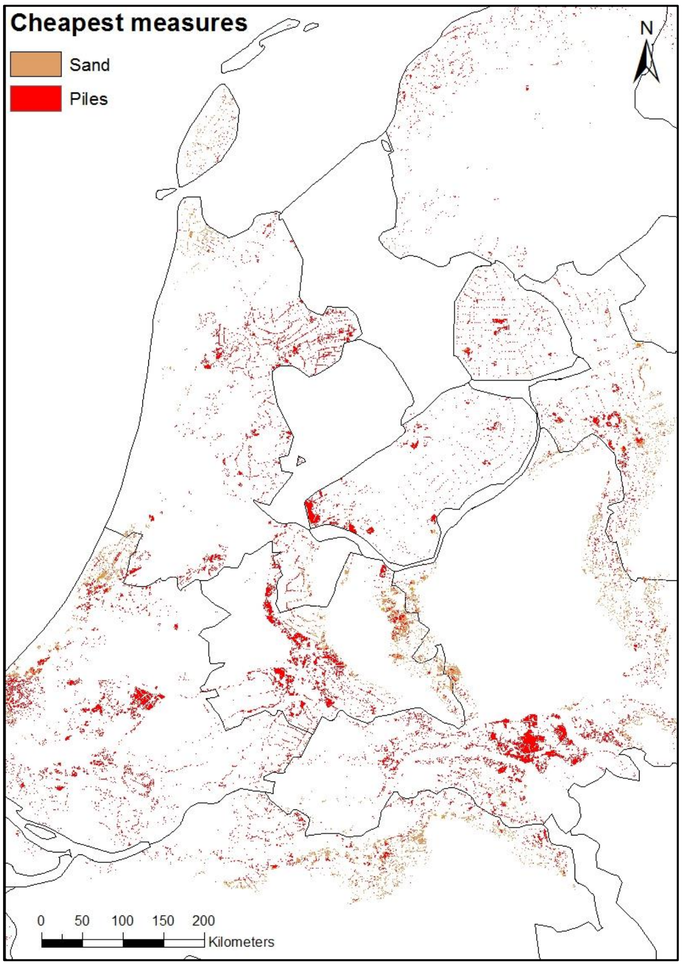


Figure 20: Cheapest measures to apply on redevelopment within urban areas and new development areas Delta scenario BUSY. Source: PBL

To compare sustainable spatial planning with strengthening of dikes we need to know the costs of strengthening the dikes first. The cost-benefit analysis of Kind et al., 2013 is used. This report shows the costs to lower the probability of flooding with a factor ten per dike ring section. Because they use dike sections, the smaller parts of dike rings, the costs are added up per dike ring. The costs are the total costs to strengthening the dikes, meaning investments costs and the extra yearly costs for maintenance (Kind et al., 2013). The costs are the highest for dike ring 16 (Albasserwaard and Vijfheerenlanden) due to the length of this dike ring (86 km) in combination with the high average costs per kilometre (Kind et al., 2013).

Risk

The damage can be combined with the safety standards, which means the probability that a flood will occur, to come to the flood risk (see Figure 4). The definition of risk in this research is in terms of damage per year and calculated by multiplying the total damage per dike ring by its safety standards.

The risk is highest in dike ring 43, Betuwe, Tieler- and Culemborgerwaarden for both the scenarios when looking at the business as usual scenario (see appendix 1). This is because the probability (1:1250) is relatively low and the damage is relatively high (BUSY: 25806 million REST: 15861 million). This risk remains the highest when applying spatial planning measures but the risk is reduced with 33% compared with the business as usual situation. When looking at dike ring 14 where the damage is highest (BUSY: 55356 million REST: 39283 million) the risk is not that high. This is because the probability that the flood will occur (1:10,000) is extremely low.

Risk reduction

Risk reduction, done by strengthening the dikes, can be calculated by multiplying the reduced probability by the damage from the business as usual situation (see Figure 21). The probability is reduced with a factor ten; meaning when the probability was 1:2000 the new probability will be 1:20,000. To calculate the reduced probability these two are subtracted. Risk reductions for sustainable spatial planning can be calculated by multiplying the reduced damage by the probabilities from the business as usual situation (see Figure 21). The damage reduction is in terms of million euros per year. It is calculated by subtracting damage in the business as usual situation, without the spatial planning measures, by damage when applying sustainable spatial planning.
Although the study of Kind etal. 2013 expresses the impact of safety measures by decreased probability, this study expresses it with damage reduction. The reduction in flood risk makes the outcome of both studies comparable.

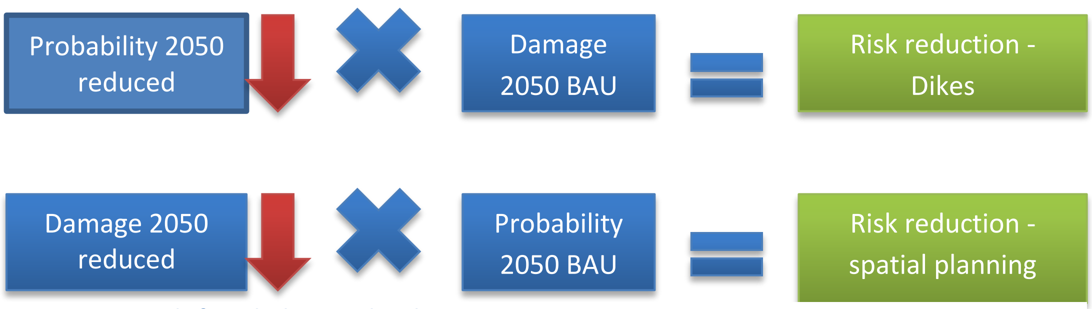


Figure 21: Formula for calculating risk reduction in euro per year.

Risk reduction per euro extra costs

To compare the effectiveness of both approaches their benefits (reduced risk in euro per year) are divided by their costs. By doing this the risk reduction per euro extra costs are calculated, meaning per euro it is will cost a certain or ‘x’ risk reduction can be reached.

Efficiency dikes and sustainable spatial planning

For every dike ring the risk reduction per euro extra costs is calculated for dike strengthening and sustainable spatial planning. These outcomes can be used to find the most efficient option for every dike ring. To show the efficiency per dike ring a ratio is calculated by dividing the risk reduction per euro extra costs of dikes by the risk reduction per euro extra costs of sustainable spatial planning. The results of this ratio can be seen in Figure 22.

If the ratio is 1 the approaches are break even and none of them is more efficient than the other. When the ratio is above 1 then sustainable spatial planning is the best option to apply. If the ratio is below 1 strengthening the dikes is the best option to apply. Also the higher the ratio the better it is to apply this option, the darker the colour on the map. In 37 of the 55 dike rings for scenario BUSY strengthening dikes should be applied, while in the scenario REST most dike rings show that sustainable spatial planning is the best option to apply. Also between dike rings per scenario there are differences to notice. For example in dike ring 39 (Alem) dikes are the best option for scenario BUSY while in scenario REST sustainable spatial planning the best option is for dike ring 39. This might be explained by the fact that in BUSY no new houses will be build or replaced while in scenario REST the dike ring will be used to build or replace houses. The costs of building these flood proof houses are lower than the costs of strengthening dikes.

Another example is dike ring 42 (Ooij en Millingen), here the best option in the scenario BUSY is strengthening dikes and in scenario REST sustainable spatial planning. In both scenarios houses will be build or replaced, but the flood in this dike ring is relatively deep. This makes it expensive to apply flood proof measures in scenario BUSY because more houses will be build and the costs exceed the costs of strengthening dikes. This is not the case for scenario REST because fewer houses will be built or replaced and makes that the costs stay below the costs of strengthening dikes. In general dikes heightening seems to be the best option when the damage is relatively high.

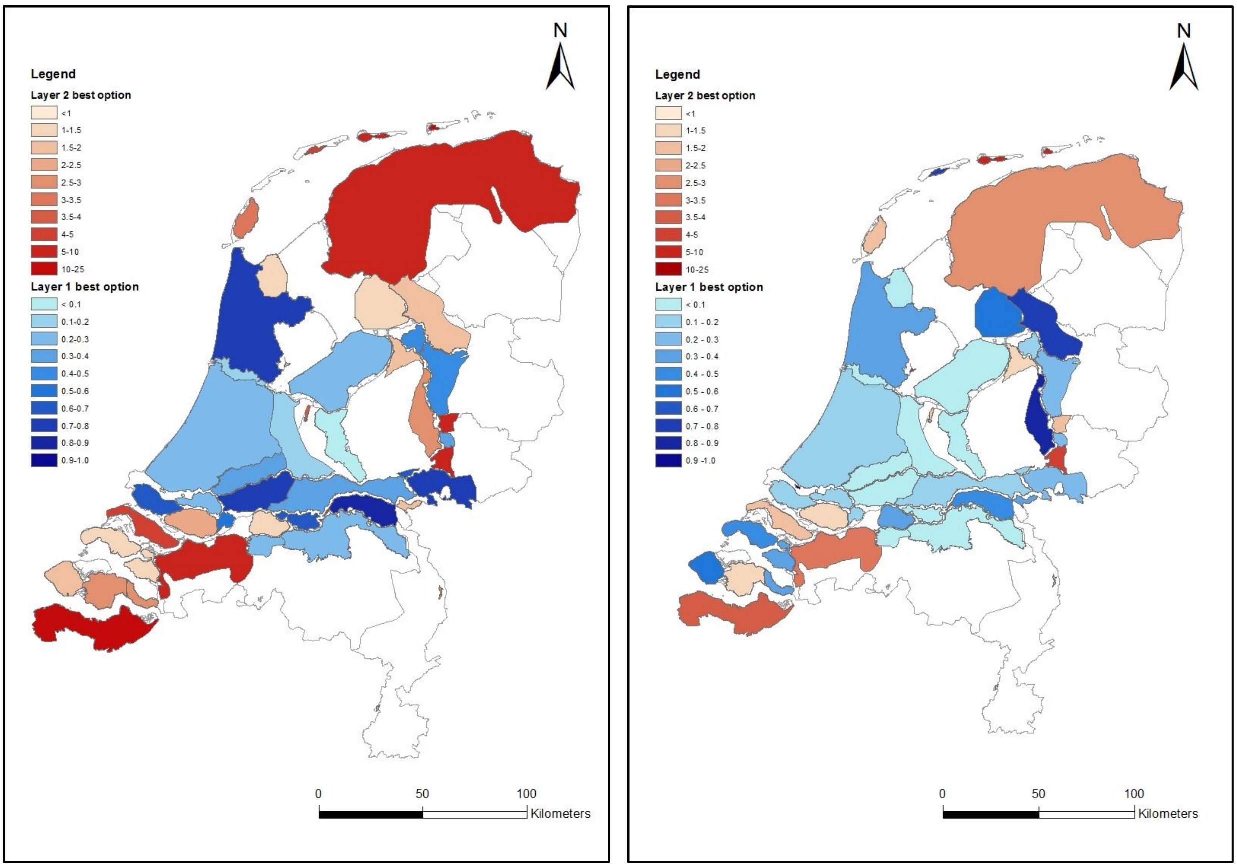


Figure 22: Ratio expressing relatively performance (in reduced risk per euro spent) of sustainable spatial planning versus strengthens dikes for REST (left) and BUSY scenario (right). Red denotes sustainable spatial planning best option. Blue denotes strengthen dikes as best option. Source: PBL

4. Conclusion

The goal of this research was to develop more knowledge, in terms of costs and benefits, on different options to reduce flood risk in the Netherlands in the future. This is done with the research question: *What are the costs and benefits of applying spatial planning measures in the Netherlands and how do they compare to the costs and benefits of only heightening dikes as prevention measure?*
The focus will be on the benefits in the form of damage reduction to houses in a worst credible flood situation.

In this research the focus is on sustainable spatial planning, layer 2 of the MLS concept. Four measures are selected:

- Heightening
- Dry proof construction
- Wet proof construction
- Building on piles

The criterion for applying a measure is the costs: the cheapest measure will be used. The cheapest measures to apply are heightening and building of piles. When heightening takes place on peat or clay soils, building on piles will be cheaper, but on the other hand heightening on sandy soils is cheaper than building houses on piles.
Next the benefits of sustainable spatial planning are examined. In Delta scenario REST most damage reduction can be achieved by redevelopment within urban areas. An explanation is the lower amounts of new houses that will be build especially in the flood prone area.
In Delta scenario BUSY most damage reduction can be achieved in new development areas. This is the result of urban expansion in the popular, but flood prone part of the country.

An alternative to sustainable spatial planning is to strengthen the dikes. The costs to do this are the investments costs and the yearly costs for maintenance for dikes per dike ring. The benefits are ten times lower probability on flooding.

A comparison was made between sustainable spatial planning and the use of higher dikes to see which one is more cost efficient to apply. The ratio of risk reduction per euro extra costs between sustainable spatial planning and strengthening of dikes indicated that in Delta scenario REST sustainable spatial planning is the best option to apply in a majority of the dike rings.
This could be explained by the attractiveness of the Randstad that decreases, people will go to or stay in the east of the Netherlands, these areas mostly do not have to cope with flood risk. Result is that fewer new houses are built in the flood prone area. This makes it more efficient to apply sustainable spatial planning because it will be cheaper to make a 'few' houses flood proof instead of strengthening the whole dike ring for these 'few' houses which is more expensive.

In Delta scenario BUSY the option to strengthening dikes, is in most of the dike rings the best option.
An explanation is the impact of locations with larger water depth, which will be used in the BUSY scenario for new development projects. Due to the economic growth and the attractiveness of the Randstad in BUSY, there is need for houses in the Randstad. Second, a lot of new houses will be build and houses will be replaced making it cheaper to strengthening the dikes for a particular dike ring instead of apply water robust measures to all individual houses within that dike ring.

The difference between Delta scenario REST and BUSY could be explained by the influence of different house types on the amount of damage. A flat will experience less damage when a flood occurs because it is built into height, so most of the apartments stay dry while with a bungalow or villa the whole house will possibly experience more damage. In the scenario BUSY more flats will be built because there is a large need for houses. This might not the case for REST; in this scenario more terraced houses will be build. This makes it more efficient to apply sustainable spatial planning in the

Delta scenario REST because more damage reduction can be achieved. These possible explanations are suggestions for further research.

There are large differences between dike rings, also within the Delta scenarios. Therefore sustainable spatial planning should not be applied on a national level. It is better to apply on the local or dike ring level as extra protection together with the dikes. Because dikes only lower probability but this cannot be excluded entirely, making sustainable spatial planning a good addition for flood safety policy. Case studies are needed to examine if sustainable spatial planning is an option for an area or region. Other studies also show the need for extra protection besides dikes Koomen and van Leeuwen, 2012 conclude that dikes alone is not enough and additional protection such as retention areas becoming more important. Kreibich et al., 2015 expect that damage-reducing measures (layer 2 measures) become more important and should complement the dike structures. The study of de Moel et al. 2014 found for the case study in the unembanked larger Rotterdam area that damage reducing measures help reducing flood risk. Overall the general conclusion is that sustainable spatial planning is a viable solution in a future situation to secure that the Netherlands is safe from floods.

The results presented here are a first approximation on the costs of sustainable spatial planning. People are unfamiliar with water robust construction, which prevents people to use this new way of thinking about making a country flood proof.

The housing size in this research was set on 145 m^2, which afterwards not seems realistic. Most houses are much smaller. Future research the size of the house should be set smaller which makes the costs of sustainable planning lower, so that in some cases flood proof construction might become a good alternative.

In this research four types of flood proof measures were selected. But there are of course all types of measures possible to apply, for example amphibious or floating houses. The problem with these measures is that there is too little information available on their costs and benefits. In particular the costs of amphibious houses could not be found in the time frame of this research. Setting the costs equal to the costs of floating houses was not possible because the costs of amphibious houses vary with the water depths. Floating houses could not be mapped since this type of measure can only be applied on water bodies. In the Delta scenarios it is not incorporated that in the future there will be build on water bodies, which makes it impossible for this research to use these types of flood proof measures. For future research the costs need to be clear and water bodies should be incorporated in scenarios as possible areas for the construction of houses.

Another type of flood proof measure that is not used in this research is building elsewhere instead of building differently. Some locations are not suited for applying flood proof measures because their flood water levels exceeded the 3-meter that was set as maximum likely value for heightening. In this case building elsewhere is an option to incorporate in research. Another reason to apply building elsewhere is when building flood proof houses is so expensive that it will be cheaper to move the houses to another location that is less vulnerable to floods. To do so the land value of both locations should be known to show if it is profitable to move the houses to another location.

In this research the focus was on reducing damage to houses when a flood occurs. This is not the only goal that can be reached by applying sustainable spatial planning. The reduction of damage is related to reducing casualties, because when a house survives a flood and stays intact the people who are living in that house will not get injured. Compared to houses people are mobile, which makes them more difficult to examine. Due to the time frame of this research impacts on casualties were not incorporated and should be examined in future research.

In theory it sounds simple to implement sustainable spatial planning in the future to reduce damage. But in practice a lot of institutions are involved in water safety policy, which makes it difficult to implement flood proof measures. For future research it is necessary to examine the relations between the different institutions and their impacts on water safety policy.

5. References

Aerts, J.C.H.J., Sprong T. and Bannink, B. (2008). Leven met Water, Klimaat voor Ruimte, DG Water. Reportnumber: 009/2008.

Asselman, N. and Slager, K. (2013). *Kansrijkdomkaarten meerlaagsveiligheid.* Deltaresrapport: 1206176-012, Delft.

Boer, S. de, et al. (2008) *Richtlijnen voor bouwen in natte gebieden.* Hoofddorp: Dura Vermeer.

ten Brinke, W.B.M., Kolen, B., Dolle, A., van Waveren, H. and Wouters, K. (2010). *Contingency Planning for Large Scale Floods in the Netherlands.* Journal of Contingencies of Crisis Management 18: 55 - 69

Bruggeman, W., Hommes, S., Haasnoot, M., Te Linde, A., van der Brugge, R., (2011). *Deltascenario's: Scenario's voor robuustheidanalyse van maatregelen voor zoetwatervoorziening en waterveiligheid*. Technical Report. Deltares, Delft.

De Bruijn, K. M. (2008). *Bepalen van schade ten gevolge van overstromingen voor verschillende scenario's en bij verschillende beleidsopties.* Delft Hydraulics, Delft.

Buitelaar, M. (2015). *Inspiratieboek: Ruimte voor water.* Hoogheemraadschap de Stichtse Rijnlanden.

CPB, MNP and RPB (2006) Welvaart en Leefomgeving. Een scenariostudie voor Nederland in 2040. Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau, Den Haag.

Deltacommissie (2008). *Samen werken met water: een land dat leeft, bouwt aan zijn toekomst.* The Hague.

Gerritsen, H., (2005). *What happened in 1953? The big flood in the Netherlands in retrospect.* Philosophical transactions of the royal society (2005): 1271-1291

Jonkman, S.N., Kok, M. and Vrijling J.K. (2008*). Flood risk assessment in the Netherlands: A case study for dike ring South Holland.* Risk Analysis (2008): Vol.26, No. 5.

Kind, J.M. (2013). *Proeve Plangebied Deltaprogramma Rivieren: Quick scan methode, opgave en strategieën voor waterveiligheid.* Deltaresrapport: 1207829-000-VEB-0011, Delft.

Kind, J.M. (2014). *Economically efficient flood protection standards for the Netherlands.* Journal of Flood Risk Management: 103-117.

Klijn, F., Baan, P. J. A., De Bruijn, K. M., and Kwadijk, J. (2007). *Overstromingsrisico's in Nederland in een veranderend klimaat,* delft hydraulics, Delft, Netherlands, 2007

Klijn, F., Knoop, J.M., Ligtvoet, W. and Mens, M.J.P. (2012). *In search of robust flood risk management alternatives for the Netherlands.* Nat. Hazards Earth Syst. Sci. 12: 1469-1479.

Klijn, F., Kreibich, H. and de Moel, H. (2015). *Adaptive flood risk management planning based on a comprehensive flood risk conceptualisation*. Mitig Adapt Strateg Glob Change 20: 845-864

Kolen B. and Helsloot I. (2012). *Time needed to evacuate the Netherlands in the event of large-scale flooding: strategies and consequences.* Disasters 36(4): 700–722.

Kolen B., Maaskant, B. and Hoss, F. (2010). *Meerlaagsveiligheid: Zonder normen geen kans.* HKV lijn in water: Lelystad.

Kreibich, H., Bubeck, P., van Vliet, M. and de Moel, H. (2015). *A review of damage-reducing measures to manage fluvial flood risks in a changing climate.* Mitig Adapt Strateg Glob Change 20: 967-989.

McRobie, A., Spencer, T. and Gerritsen H. (2005). *The Big Flood: North Sea storm surge.* Philosophical transactions of the royal society (2005): 1263-1270.

Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs (2015). *Delta programme 2015: Working on the Delta, the decisions to keep the Netherlands safe and liveable.* The Hague.

Ministry of Transport, Public Works and Water management, Ministry of Housing, Spatial planning and the Environment and the ministry of Agriculture, Nature and Food Quality. *National Water Plan 2009 – 2015.* www.nationaalwaterplan.nl

de Moel, H., Aerts, J. C. J. H., and Koomen, E. (2011*). Development of flood exposure in the Netherlands during the 20th and 21st century.* Glob. Environ. Chang., 21: 620–627

de Moel H (2012). *Uncertainty in flood risk*. PhD dissertation thesis, VU University Amsterdam.

de Moel H., Asselman, N.E.M. and Aerts J.C.H.J. (2012). *Uncertainty and sensitivity analysis of coastal flood damage estimates in the west of the Netherlands.* Nat Hazards Earth Syst Sci 12:1045–1058

de Moel, H., Jongeman, B., Kreibich, H., Merz, B., Penning-Roswell, E. and Ward, P.J. (2015). *Flood risk assessments at different spatial scales.* Mitig Adapt Strateg Glob Change 20: 865-890.

Oranjewoud and HKV water in lijn (2011). *Syntheserapport gebiedspilots meerlaagsveiligheid.* Oranjewoud & HKV : 2011.

PBL (2012). *Balans van de leefomgeving 2012.* The Hague/ Bilthoven: PBL Netherlands Environmental Assessment Agency.

Pötz, H., Anholts, T and de Koning M. (2014). *Meerlaagsveiligheid: Waterrobuust bouwen in stedelijk gebied.* Stichting Toegepast Onderzoek Waterbeheer, Amersfoort.

Royal Haskoning DHV (2012). *Analyse waterrobuuste inrichting. Voor nieuwbouw en vitale & kwetsbare functies versie 2.1.*

van Veelen, P.C. (2013). *Adaptive strategies for the Rotterdam unembanked area.* Knowledge for Climate

van der Pas, B., Slager, K., de Bruijn, K. and Klijn, F. (2011). *Overstromingsrisicozonering. Fase 1: Methode voor het identificeren van overstromingsgevaarzones.* Deltaresrapport: 1204144-019.

van de Ven, F., Luyendijk, E., de Gunst, M., Tromp, E., Schilt, M., Krol, L., Gersonius, B., Vlaming, C., Valkenburg, L. and Peeters, R. (2009). *Waterrobuust bouwen: De kracht van kwetsbaarheid in een duurzaam ontwerp.* Beter Bouw- en Woonrijp maken/SBR, Rotterdam.

Vis, M., Klijn, F., de Bruijn, K.M. and van Buuren M. (2003). *Resilience strategies for flood risk management in the Netherlands.* International Journal of River Basin Management 1: 22-40.

Zethof, M. and Kolen, B. (2015). *Kansen voor MLV: Verkenning voor 5 normtrajecten waar de eis aan de kering wordt bepaald door basisveiligheid door enkele dominante buurten.* Stichting Toegepast Onderzoek Waterbeheer.

Appendices

This chapter includes the used tables in this research.

Appendix A: Risk, safety standards and damage per dike ring business as usual Delta scenarios REST and BUSY

	Dike ring	Safety standard	Damages business as usual		Risk business as usual	
			REST	BUSY	REST	BUSY
1	Schiermonnikoog	1:2000	14	17	0.01	0.01
2	Ameland	1:2000	54	73	0.03	0.04
3	Terschelling	1:2000	58	67	0.03	0.03
4	Vlieland	1:2000	8	13	0.00	0.01
5	Texel	1:4000	166	265	0.04	0.07
6	Friesland en Groningen	1:4000	1504	2221	0.38	0.56
7	Noordoostpolder	1:4000	1221	2406	0.31	0.60
8	Flevoland	1:4000	12505	22243	3.13	5.56
9	Vollenhove	1:1250	725	1096	0.58	0.88
10	Mastenbroek	1:2000	2366	2963	1.18	1.48
11	IJsseldelta	1:2000	1173	1478	0.59	0.74
12	Wieringen	1:4000	806	2255	0.20	0.56
13	Noord-Holland	1:10000	8613	12797	0.86	1.28
14	Zuid-Holland	1:10000	39283	55356	3.93	5.54
15	Lopiker- en Krimpenerwaard	1:2000	11615	16198	5.81	8.10
16	Alblasserwaard en de Vijfheerenlanden	1:2000	9579	17037	4.79	8.52
17	IJsselmonde	1:4000	5898	8550	1.47	2.14
18	Pernis	1:10000	369	391	0.04	0.04
19	Rozenburg	1:10000	236	239	0.02	0.02
20	Voorne-Putten	1:4000	2842	5931	0.71	1.48
21	Hoekse Waard	1:2000	707	1046	0.35	0.52
22	Eiland van Dordrecht	1:2000	3736	5750	1.87	2.88
24	Land van Altena	1:2000	1666	2208	0.83	1.10
25	Goeree-Overflakkee	1:4000	169	299	0.04	0.07
26	Schouwen Duivenland	1:4000	565	924	0.14	0.23
27	Tholen en St. Philipsland	1:4000	649	793	0.16	0.20
29	Walcheren	1:4000	1447	2971	0.36	0.74
30	Zuid-Beveland west	1:4000	938	1565	0.23	0.39
31	Zuid-Beveland oost	1:4000	790	1242	0.20	0.31
32	Zeeuwsch Vlaanderen	1:4000	509	885	0.13	0.22
34	West-Brabant	1:2000	231	301	0.12	0.15
35	Donge	1:2000	3492	4542	1.75	2.27
36	Land van Heusden/de Maaskant	1:1250	13154	19893	10.52	15.91
37	Nederhemert	1:1250	2	4	0.00	0.00
38	Bommelerwaard	1:1250	4071	5232	3.26	4.19
39	Alem	1:1250	22	31	0.02	0.02
40	Heerewaarden	1:500	65	87	0.13	0.17
41	Land van Maas en Waal	1:1250	4160	5065	3.33	4.05
42	Ooij en Millingen	1:1250	1102	1171	0.88	0.94

43	Betuwe, Tieler- en Culemborgerwaarden	1:1250	15861	25806	12.69	20.64
44	Kromme Rijn	1:1250	15655	24499	12.52	19.60
45	Gelderse Vallei	1:1250	10274	14741	8.22	11.79
46	Eempolder	1:1250	204	350	0.16	0.28
47	Arnhemse- en Velpsebroek	1:1250	1409	2085	1.13	1.67
48	Rijn en IJssel	1:1250	3983	5236	3.19	4.19
49	IJsselland	1:1250	100	148	0.08	0.12
50	Zutphen	1:1250	1116	1389	0.89	1.11
51	Gorssel	1:1250	107	214	0.09	0.17
52	Oost Veluwe	1:1250	779	1134	0.62	0.91
53	Salland	1:1250	3844	5452	3.08	4.36
65	Arcen	1:250	50	64	0.20	0.25
13-b	Marken	1:1250	39	43	0.03	0.03
34-a	Geertruidenberg	1:2000	254	291	0.13	0.15
36-a	Keent	1:1250	5	8	0.00	0.01
68rvg	Venlo-Velden Zuid	1:250	150	185	0.60	0.74
86+87	Meers_Maasband	1:250	55	104	0.22	0.42

Appendix B: Costs of strengthening the dikes, spatial planning and cost/benefit ratio

	Costs (million euro)			BUSY		REST	
Dike number	Dikes	BUSY	REST	Ratio layer 1/ layer 2	Ratio layer 2/ layer1	Ratio layer 1 / layer 2	Ratio layer 2/ layer 1
1	16	0.45	0.03	0.18	5.65	0.09	11.38
2	62	2.79	0.01	0.16	6.11	0.12	8.25
3	43	2.02	0.21	1.31	0.76	0.21	4.88
4	6	1.43	0.12	0.34	2.98	0.15	6.48
5	78	12.40	0.64	0.65	1.53	0.32	3.08
6	1023	112.31	7.77	0.34	2.93	0.17	5.85
7	165	143.50	9.38	1.79	0.56	0.72	1.39
8	377	1666.58	161.07	22.02	0.05	3.74	0.27
9	84	39.02	7.43	1.38	0.72	0.58	1.72
10	109	161.12	45.71	7.48	0.13	2.02	0.49
11	171	51.22	20.00	0.99	1.01	0.58	1.72
12	86	173.21	1.55	12.06	0.08	0.88	1.13
13	668	649.29	98.98	2.62	0.38	1.38	0.72
14	719	1808.81	282.71	8.21	0.12	4.15	0.24
15	332	784.21	117.65	11.03	0.09	2.90	0.34
16	663	945.91	18.55	19.52	0.05	1.32	0.76
17	191	499.17	86.37	7.77	0.13	3.55	0.28
18	48	3.59	0.00	0.00	0.00	2.00	0.00
19	84	0.37	0.00	1.02	0.98	2.00	0.00
20	184	224.37	17.29	7.01	0.14	1.61	0.62
21	165	39.80	10.08	0.98	1.02	0.43	2.30
22	242	130.91	8.60	7.17	0.14	1.77	0.56
24	156	47.30	0.31	2.96	0.34	0.85	1.17
25	67	9.77	0.70	0.51	1.96	0.21	4.81
26	76	33.76	2.68	2.18	0.46	0.79	1.26
27	70	16.48	0.15	3.12	0.32	0.89	1.12
29	235	142.47	12.11	1.98	0.50	0.65	1.54
30	287	67.89	5.22	0.96	1.04	0.34	2.94
31	217	48.88	0.45	3.12	0.32	0.35	2.87
32	696	35.11	2.99	0.28	3.59	0.09	11.34
34	118	8.59	2.17	0.31	3.18	0.15	6.62
35	77	144.50	22.57	10.21	0.10	3.87	0.26
36	213	746.85	172.62	18.71	0.05	4.53	0.22
37	4	0.17	0.00	2.00	0.00	2.00	0.00
38	215	146.50	4.33	46.36	0.02	1.48	0.67
39	16	0.93	0.19	2.00	0.00	0.07	15.17
40	37	2.91	1.00	0.35	2.85	0.14	7.12
41	335	195.24	26.32	2.35	0.43	1.17	0.86
42	190	47.77	0.20	3.21	0.31	0.51	1.97
43	584	1487.95	261.03	6.85	0.15	2.56	0.39

44	136	1163.29	384.70	15.85	0.06	8.34	0.12
45	82	802.72	233.84	19.76	0.05	10.08	0.10
46	38	9.40	1.08	0.56	1.77	0.28	3.52
47	94	124.64	14.71	9.43	0.11	1.63	0.61
48	313	254.16	59.14	3.40	0.29	1.43	0.70
49	82	3.99	0.15	0.23	4.43	0.12	8.51
50	32	37.77	23.46	4.13	0.24	2.92	0.34
51	37	7.40	0.17	0.60	1.68	0.16	6.33
52	173	41.41	5.07	1.19	0.84	0.34	2.97
53	164	249.66	84.89	3.63	0.28	2.27	0.44
65	15	2.30	0.33	0.54	1.84	0.37	2.72
13-b	22	0.85	0.00	0.19	5.34	2.00	0.00
34-a	31	7.89	4.28	0.77	1.30	0.62	1.61
36-a	7	0.39	0.00	2.00	0.00	2.00	0.00
68rvg		5.57	1.32	0.10	0	2.00	0
86+87	16	7.23	0.00	2.00	0	2	0