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Analyzing future flood risks in Cambodia

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A quantitative approach using Delft-FIAT

Imhoff, R.O.

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Executive Summary

Despite some of the present advantages of the inundations, Cambodia is seen as one of the most hazard-prone countries in Southeast-Asia (UNDP, 2014). With the future socio-economic developments in the Lower Mekong Basin countries and Cambodia in particular, having an economy that is undergoing rapid growth and transformation, flood impacts – such as the historical 2000 and 2011 floods - and their resulting damages will increase. Cambodia is expected to almost double its number of inhabitants towards 2060, resulting in an even further increasing flood exposure for the Cambodian population.
With expected higher peak discharges due to climate change in the future, the effects may be even worse.

So far, many studies have been carried out to model the effect of climate change scenarios with respect to future floods. Climate change has a significant impact on the future floods (Milly *et al.* 2002), but on smaller time scales predominantly socio-economic developments together with its accompanying land use change determine the changing, mostly increasing, flood vulnerability of a country.

In task 3 of the Flood Management and Mitigation Programme (MRC, 2015), three future 2060 scenarios were formulated (A, B and C) for the floodplain of Cambodia. Scenario A and B are so called ‘business as usual’ scenarios within respectively a fast and a moderately growing world economy. In scenario B will, due to the large increase of people, and relatively high number of poor people, the vulnerability at household level be highest. This scenario has the largest absolute number of people exposed to floods and number of vulnerable households, defined as households that are losing a significant part of their assets due to floods. Scenario C on the other hand also takes place in a fast growing world economy – and so does scenario A -, but this scenario distinguishes itself from scenario A and B by its flood adaptation and mitigation.

In this research these scenarios will be used in a quantitative assessment to identify current and future flood impacts for Cambodia with the use of the Delft-FIAT model, predominantly taking into account socio-economic developments in the Mekong floodplain.
The studied socio-economic parameters are: demographic trends, economics, housing and infrastructure. And as a commencement a small assessment was done on both poverty and flood protections.

The results of this research are only intended to be used in relative terms and thus to compare different years and scenarios with each other.

The economic damage as a result of floods has increased in the past years and will do so towards the future. The impacts of the 2000 and the 2011 floods in Cambodia have shown an increasing trend in economic damage and the same trend is visible in the model results between 1998 and 2013. Towards 2060 the economic damage will further rise as a result of socio-economic developments within Cambodia. However, the impact is different for the three scenarios and scenario A reveals by far the highest economic damages. Scenario C results in lower economic damages and so will scenario B.

When looking at the number of affected population, there is an increasing trend in absolute terms. However, in relative terms and when comparing the different scenarios, the percentage

of flood affected people in the 2060 scenarios A and B is not that much deviating from current years, with scenario A and B having just a slightly higher percentage of flood affected people. Scenario C on the other hand results in the lowest percentage of affected people when compared to not only scenario A and B, but also current years.
Combining all of these results, scenario C may be seen as the most beneficial scenario for Cambodia. It is a scenario in an advantageous world economy – so is scenario A too -, which is of course desired, but together with the model results it is made clear that Cambodia is less impacted by future floods than in scenario A and B. Especially when this scenario is implemented together with flood protections, both the number of affected people and the total economic damage will be lower than for scenario A and B.

Moreover, the World Bank (Hallegatte *et al.*, 2016) concluded that on the average more poor people are flood impacted. The expectation that the poorest people are most affected by floods did also result from the model and this may be seen as a fair starting point for further research.

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1 Introduction

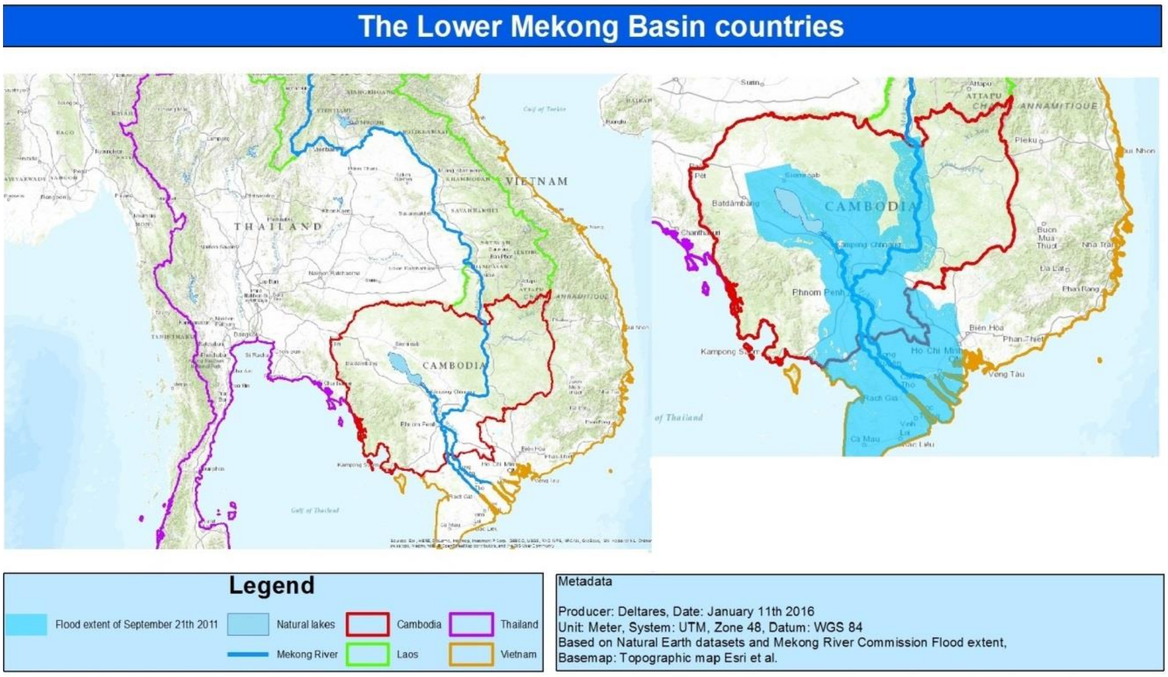
Cambodia has always been used to yearly floods and even benefits from ‘normal’ yearly floods by having an enormous area of rice fields and other crops, and one of the world’s most productive fisheries, located within the system of the Tonle Sap Lake. In 2006, the total harvested rice area was 2.4 million ha, of which 2.1 million ha in the wet season and 0.3 million ha in the dry season (MAFF, 2006). Great parts of these rice fields are flood dependent, particularly floating and recession rice types. The floods serve as a source of moisture and what is left behind after multiple floods is a fertile soil. From the perspective of the fisheries, flooding attributes to the high fish production in the Basin, given that areas flooded during part of the year can produce much more fish than permanent water bodies of the same size (Jensen, 2001). With a GDP share in the agricultural sector of 33.6% (The World Bank, 2015) of which 6.4% is due to the fisheries (They K., 2014), it is clear that Cambodia is dependent on the yearly inundations by the Mekong River.

Located central in Cambodia is the Tonle Sap Lake, which is known for its remarkable connection with the Mekong River. Tonle Sap is connected with the Mekong River through the 120 km Tonle Sap River with the confluence of the two rivers near the Cambodian capital Phnom Penh. In the dry season, the lake releases a major part of its volume to the Mekong River, but in the wet season, from May to October, the high discharge of the Mekong River results in a reverse of the stream in the Tonle Sap River, which is a unique phenomenon for a river of this size (Keskinen *et al*., 2013). This reverse of the river stream in the wet season leads to a rise in the average surface area of the lake from around 3,000 km^2 during the dry season to a maximum of up to 14,500 km^2 in the wet season (MRC/WUP-FIN, 2007). Those natural floods of the Tonle Sap Lake make its environment very suitable for the agricultural sector, with particular rice paddies and fisheries in it.

However, this is a regular situation; a situation with a regular monsoon in Cambodia from May to October and in which the Mekong discharge rises from its lowest value at the end of March, just above 1,000 cubic meters per second, until its maximum around September – October of 12,000 cubic meters per second (MRC, 2009) or even 45,000 cubic meters per second at Phnom Penh (De Bruijn, 2005). Unfortunately this regular situation is unstable, with many years of disastrous floods, such as 2000, 2011 and 2013. These floods cause enormous damages and many people are affected, since the greatest part of the Cambodian population lives in the floodplain of the Mekong River. Between 1996 and 2013 1,087 people died from floods, and flooding is thereby the number-one killer of the natural disasters in Cambodia (NCDM & UNDP, 2014).

With the future socio-economic developments in the Lower Mekong Basin countries (see Figure 1 for a map of the Lower Mekong Basin countries) and Cambodia in particular, having an economy that is undergoing rapid growth and transformation, the flood impacts and their resulting damages will increase. Cambodia is expected to almost double its number of inhabitants towards 2060, making Cambodia much more vulnerable to floods in the future compared to today.
With expected higher peak discharges due to climate change in the future, the effects may be even worse.

Thus, despite some of the present advantages of the inundations, Cambodia is seen as one of the most hazard-prone countries in Southeast-Asia (UNDP, 2014).



Metadata

Producer: Deltares, Date: January 11th 2016
Unit: Meter, System: UTM, Zone 48, Datum: WGS 84
Based on Natural Earth datasets and Mekong River Commission Flood extent,
Basemap: Topographic map Esri et al.

Figure 1: The Lower Mekong Basin countries. Left: overview of the countries. Right: Flood extent of the 2011 flood, source flood extent: Mekong River Commission.

2 Problem definition

So far, many studies have been carried out to model the effect of climate change scenarios with respect to future floods. Climate change has a significant impact on the future floods (Milly *et al.* 2002), but on smaller time scales predominantly socio-economic developments together with its accompanying land use change determine the changing, mostly increasing, flood vulnerability of a country. The impact of the 2000 and 2011 floods in the Lower Mekong Basin are a good example of these rapidly transforming economies and their resulting increase in flood vulnerability. While the flood protection had increased after the 2000 flood, the population and economic growth made the impact in terms of damages and losses still significantly greater in 2011 than in 2000 (see Figure 2 for an example). See also chapter 4 for a more complete analysis of the 2000 en 2011 floods.

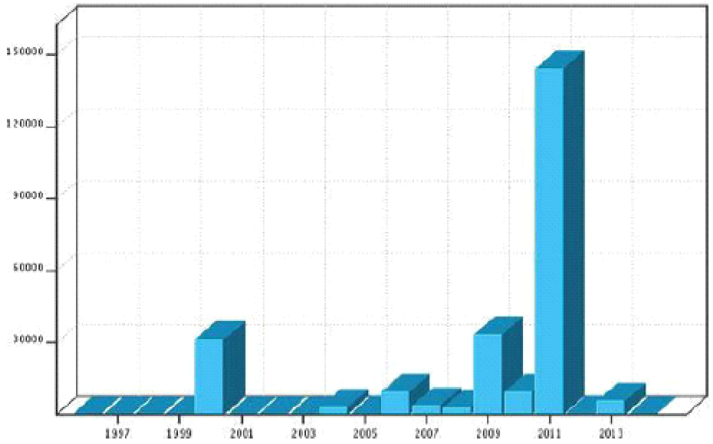


Figure 2: Trend of damage to national/provincial roads due to floods in Cambodia. Source: Mekong River Commission.

Hence in many studies the future flood risks are examined based on climate change scenarios leading to increasing flood hazards. However, in this research the future flood risks are examined based on increasing exposure and vulnerability as a result of future socio-economic developments in Cambodia.

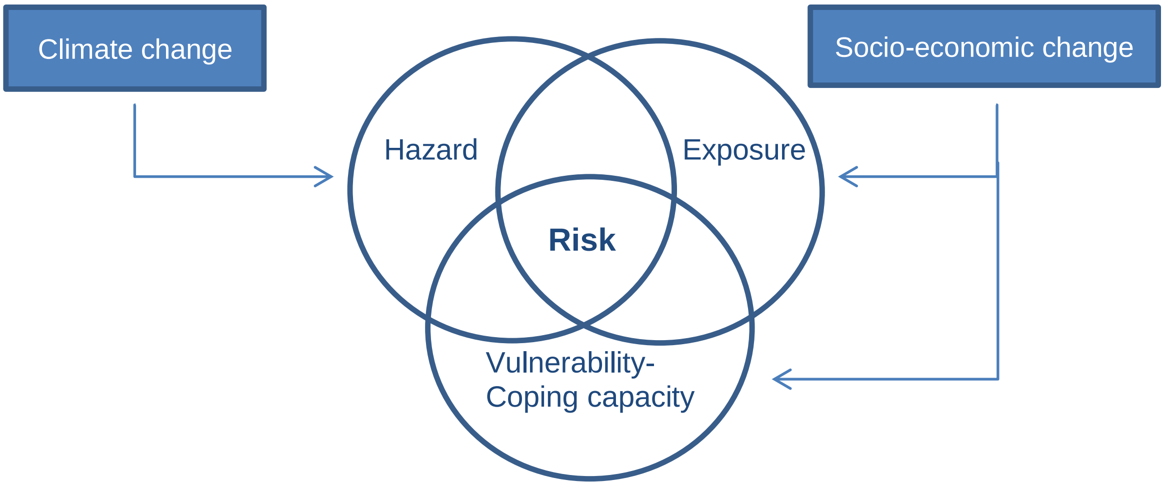


Figure 3: Intersection of hazard, exposure and vulnerability yields the risk. Climate change results in hazards, while socio-economic changes result in increasing exposure and vulnerability. Based on: Reese & Schmidt, 2008.

Figure 3 gives a clear view at the intersection of hazards - leaded by climate change -, exposure and vulnerability – both leaded by socio-economic developments -, that yields the flood risk.

This research is a supplementary assessment of current and future flood impacts in Cambodia taking into account different future floodplain developments until 2060. In task 3 of the Flood Management and Mitigation Programme for the Mekong River Commission, a formulation has been made of future floodplain development scenarios for 2060, encompassing: population growth, increase in standard of living, changes to land use and new floodplain infrastructure developments for different floodplains in Thailand and Lao PDR, as well as for trans boundary floodplain in Cambodia and Viet Nam. For each floodplain, four scenarios were formulated with local experts, scenario A-D (MRC, 2015), see Figure 2.

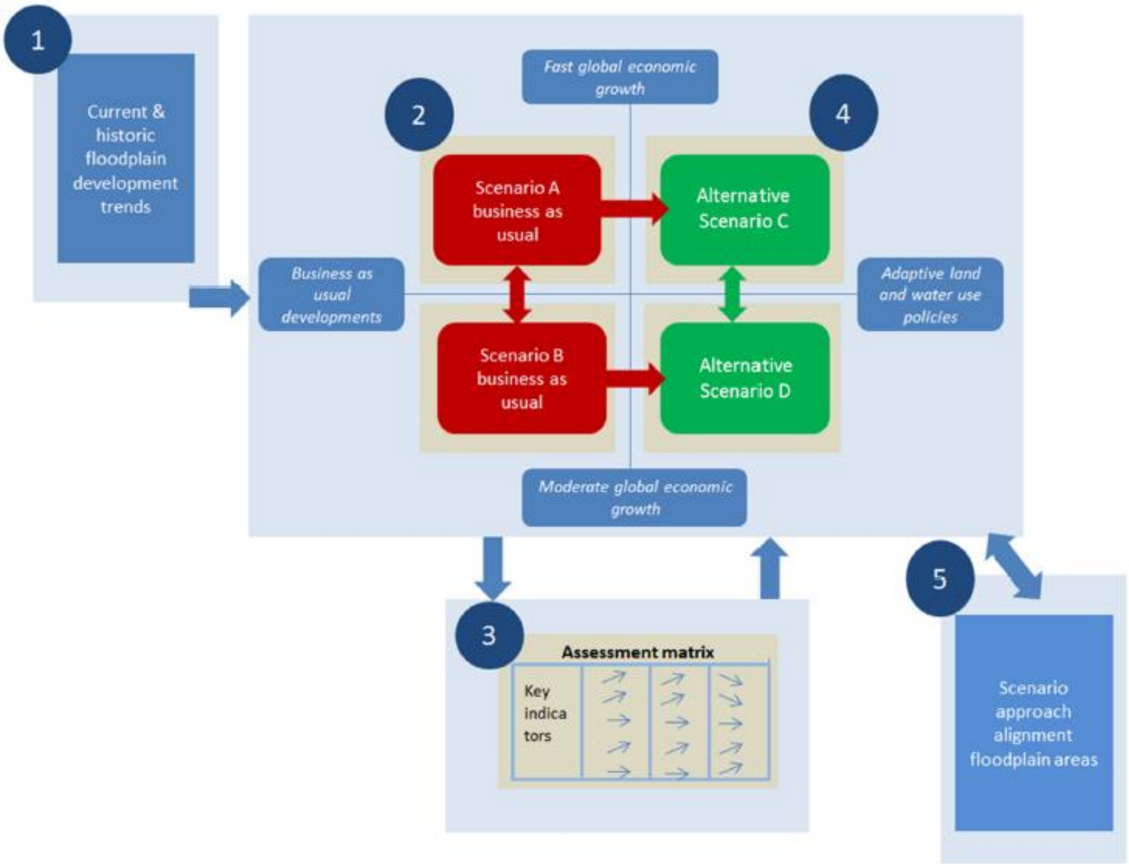


Figure 4: Developed scenarios in task 3 to analyse possible futures in the Lower Mekong Basin. In scenario A and B the development is more or less based on the continuation of the usual policies, 'Business as usual'. Scenarios C and D assume successful implementation of adjusted policies to mitigate negative impacts of A and B and to seize opportunities for a more prosperous development. Source of text and figure: FMMP task 3, MRC, 2015.

The indicated numbers in Figure 4 are briefly explained below with the use of the task 3 description of this figure (MRC, 2015):

1. The current and historic developments in the floodplain are the starting point of the scenarios and thus the future developments.
2. Two scenarios are developed based on the existing trends and developments leading to future development without a radical change in policies. These are scenarios A and B, ‘the business-as-usual scenarios’, which are extreme outcomes of the continuation of

current policies under respectively high and low economic circumstances. Hence, scenario A is the continuation of current policies with high overall global economic growth, while scenario B is based on an overall low global economic advancement. In Table 1 some aspects and assumptions of scenarios A and B are stated:

Table 1: Aspects and assumption of scenario A and B. Source: [1] The World Bank, 2015. [2] Ministry of Planning, 2014. Further assumptions are based on task 3 of the FMMP. See also Appendix 1: Scenario estimations.

	Present	**Scenario A**	**Scenario B**
Population (million people)	15.7[1]	20	28
Urbanization	21%[1]	55%	30%
GDP Growth	7%[1]	4-7%	2-4%
Inequality		Very high inequality: wealthy cities, abandoned rural area	Moderate inequality
Poverty	30,4%[2]	Overall decrease, but high inequality	High

3. After point 1 and 2 a more thorough assessment is done in the assessment matrix, examining the expected future issues and/or opportunities within these scenarios.
4. Based on this assessment, alternative development trajectories (scenarios C and D) are developed. Both scenarios take into account a more adaptive approach of the water system, while dealing with respectively a high and a low economic growth until 2060 (see Table 2).

Table 2: Aspects and assumption of scenario C and D. Source: [1] The World Bank, 2015. [2] Ministry of Planning, 2014. Further assumptions are based on task 3 of the FMMP. See also Appendix 1: Scenario estimations.

	Present	**Scenario C**	**Scenario D**
Population (million people)	15.7[1]	20	28
Urbanization	21%[1]	55%	30%
GDP Growth	7%[1]	4-7%	2-4%
Inequality		High inequality	Moderate inequality
Poverty	30,4%[2]	Overall decrease	Moderate

5. Alignment of the scenario planning methodology of the floodplain areas. A complicated factor here will be the comparison of inter-related development pathways across the four floodplains: e.g. upstream irrigation or hydropower developments may influence downstream floodplains. Hence the pathways need to be established for the four floodplains as a whole in order to have optimal developments across the floodplains, taking into account political boundaries and the national priorities of the Mekong Basin countries.

In task 3, scenarios A, B and C were formulated for the floodplain of Cambodia. Scenario D was not further analysed with the different experts. In this research these scenarios will be used in a quantitative assessment to identify current and future flood impacts for Cambodia.

The goal of this research is: to quantify, with the use of the Delft-FIAT model, possible future flood damages and losses in Cambodia, taking into account the future development scenarios.

As a reference, the 2000 and 2011 floods have been used, because of their severity. The flood extent of 2006 was used as a representative of a more regular flooding in Cambodia. Finally, since this research focusses on the 2060 future scenarios, a possible 2060 flood with climate scenario RCP6 of the ESM2M model as developed by NOAA’s Geophysical Fluid Dynamics Laboratory is used as well.

To quantify the scenarios at district level, data of 1998 and 2013 were used and extrapolated to 2060, taking into account the different scenario assumptions.

3 Flood risk assessment framework

3.1 Key socio-economic sectors included in analysis

Floods can be a threat for the population and the economy, but they can also benefit from it. De Bruijn (2005) stated: *“Regular floods usually bring benefits to riverside communities. In the case of regular normal floods, the local economy and ecology are well adapted to the 'flood pulse'. In regularly flooded inhabited areas agriculture is often important. Agriculture not only uses water but may also benefit from the nutrients in the sediments that are deposited during floods. Furthermore, 'normal’ floods also help preserve areas of floodplain marsh and swamp; they may increase the biodiversity of floodplains and replenish lakes and ponds, which in turn, support irrigation or fish farming. Other possible advantages of floods are the recharge of shallow aquifers that supply households with drinking water and the flushing of salt from the surface of areas thereby increasing soil fertility, e.g. by the forming of good soils or by giving the drainage for rice paddies.”*

With 46% of the Cambodian population living in the floodplain (They K., 2014) there clearly must be interconnectivity between socio-economic factors, land use and floods. This also forms a risk for the country, because those 46% of the population is - besides taking advantage of the floodplain or having at least a reason to live there from a socio-economic perspective - vulnerable to floods. With non-regular, disastrous floods serious damage and losses will take place both in absolute terms, e.g. damage in US $, and in relative terms, e.g. percentage of (poor) people affected.

To quantify the impact of current and future floods in Cambodia socio-economic and land use parameters are, as described below, used together with water depths of flood maps and damage functions, which are combined in Delft-FIAT. A description of the use of Delft-FIAT in the quantification of the flood impact is described at the end of this chapter.
The following socio-economic and land use-related parameters are taken into account: population, economy, households, infrastructure, poverty and current land use (particular agricultural fields). Additional parameters could be considered, however currently fall out of the scope of this assignment, due to time constraints. This would however be interesting to explore in future research, though taking into account that additional parameters can also result in unwanted correlation between the parameters.
Below the different parameters are briefly introduced, including their implementation in Delft-FIAT are described.

In this research other climate related hazards (e.g. droughts) are not taken into account. In particular climate scenarios have great impact on floods (Milly et al. 2002) and that has again its impact on land use and socio-economic factors. However, only the RCP 6.5 climate scenario will be used in this research. It would be interesting to amplify this research with other climate scenarios in future research.
Upstream developments, such as developments of large scaled damns or irrigation projects are not taken into account. Also indirect impacts of floods, such as business disruptions outside the floodplain, are not part of this research, but are recommended for further research.

3.1.1 Demographic trends

Migration trends

Important is the fact that Cambodia currently is the world's fastest urbanizing country with an 8.4% rate of urbanization annually (The World Bank, 2015). While their rate of urbanization is high, their level of urbanization is still low with 21% at this moment (The World Bank, 2016). In the CRUMP project of the Cambodian Ministry of Planning in 2012, destinations of rural migrants in the rural districts of Cambodia were examined, see Figure 5. Most of the migration focuses clearly on the cities, which shows the high urbanization rate of Cambodia. Phnom Penh is by far the most important destination of rural migrants in comparison with the other Cambodian cities. Thus the largest part of the rural migrations may be expected to have Phnom Pehn as their destination. Below, in Figure 6 the ratio urban-rural per province can be found. As can be seen, the province of Phnom Penh has by far the highest urbanization level followed by the province of Preah Sihanouk.

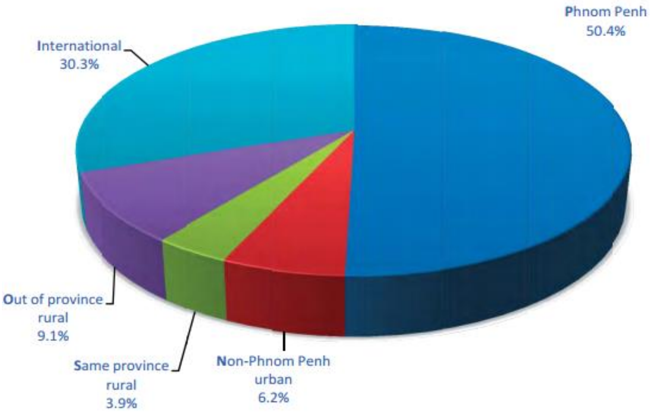


Figure 5: Destination of rural migrants on rural district basis.
Source: The CRUMP project, Ministry of Planning

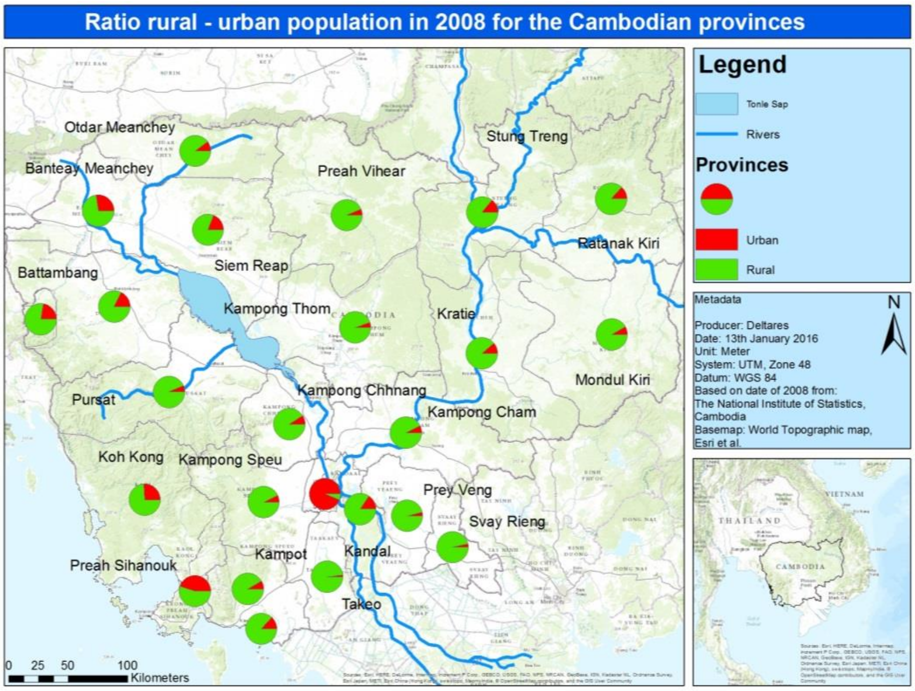


Figure 6: The ratio rural - urban for the 2008 population of the Cambodian provinces.

Demography

Not only in terms of migrations, but also the total population of Cambodia is still rapidly growing (The World Bank, 2015) and is expected to continue growing to 2060 (They K., 2014), although the growth rate will differ, depending on different scenarios. As mentioned previously, the assumptions that were formulated for the Task 3 future floodplain scenarios are used and analysed. Within scenario A and C, it is assumed that Cambodia increases to 20 million people in 2060 (and high urbanization), and to 28 million people by 2060 in scenario B and D. These assumptions are in line with the UN population prospects, which give similar figures for the high and low variant, see also Figure 7.

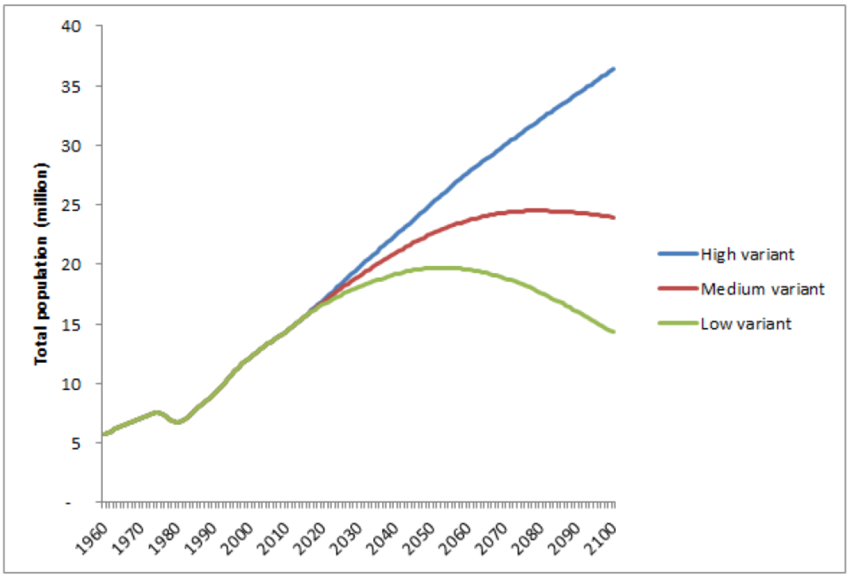


Figure 7: Population prospects until 2100 for Cambodia. Source: MRC, 2015 and UN Population Prospects.

In scenario A, the main growth is expected in and around the Phnom Penh area, as well as in the province of Kandal. This scenario represents a continuation of the ‘business as usual’; in combination with high global economic growth. In scenario B, global economic growth has lagged behind, which has also led to a lower economic growth of Cambodia and inherent slower declining fertility rates. This results in higher population growth compared to scenario A. Due to the slower economic growth, the pace of urbanisation is also lower, leading to a higher spread of the overpopulation in rural areas. In Scenario C, a scenario similar to scenario A, the global economic conditions are favourable; however, more successful adaptation policies have redirected economic developments and population growth outside the floodplain, mostly between Phnom Penh and Sihanoukville. As scenario D was not covered in Task 3, it is not considered in this analysis.

The expected number of inhabitants per district was gathered from the National Institute of Statistics (2014) and the Commune Data Base (2013) for 1998 and 2013, and was extrapolated to 2060, taking into account the scenario assumptions of population growth, urbanization and economic growth for the different 2060 scenarios. The used calculations can be found in Appendix 3: Estimation of the parameters. The amount of inhabitants per district will be used to model the total affected people by a certain flood with Delft-FIAT, but has also an important connection with poverty, GDP, households and land use, which are other model parameters.
In Figure 8 the population densities for 1998, 2013 and the 2060 scenarios are displayed.

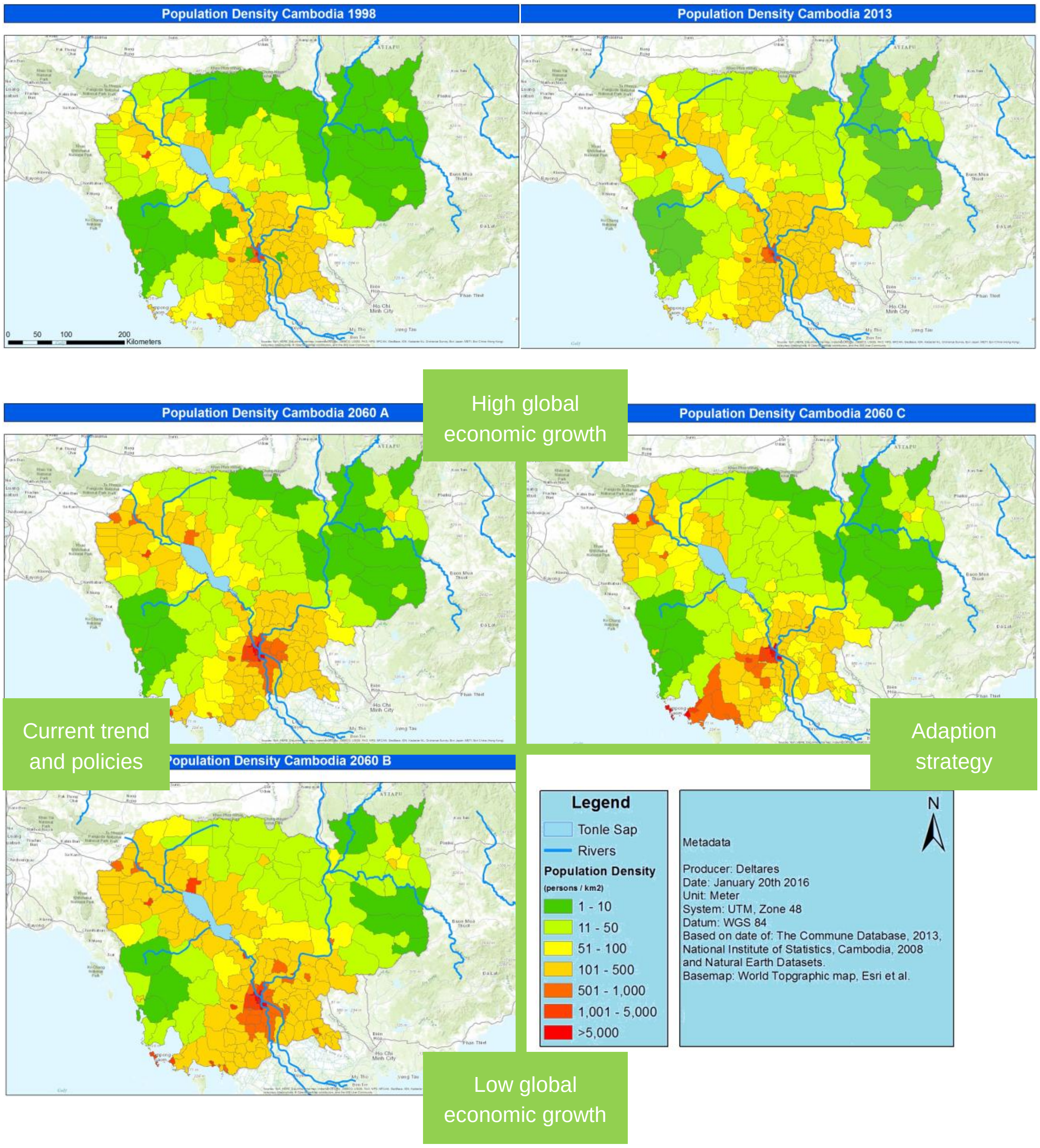


Figure 8: Population densities of Cambodia for 1998, 2013 and the future 2060 scenarios. Source: National Institute of Statistics, 2014 & Commune Database, 2013.

In literature a damage function for the flood affected population is not available. In fact, it is even questionable from of what moment or water depth an inhabitant is affected by a certain flooding. This could depend on the water depth, but is could also depend on the flood duration and the flow velocity.

To make at least an estimation the damage function will be modelled in this research based on a simple damage function, which states that: below 0.30 meter of water depth, there will not be damage to the GDP in a certain grid cell, while at or above 0.30 meter of water depth the damage to the GDP will be maximal for a certain grid cell.

3.1.2 Economics

GDP

An important economic parameter is the Gross Domestic Product (GDP). The IMF (2012) stated: *"GDP measures the monetary value of final goods and services—that is, those that are bought by the final user—produced in a country in a given period of time (say a quarter or a year). It counts all of the output generated within the borders of a country. GDP is composed of goods and services produced for sale in the market and it also includes some nonmarket production, such as defense or education services provided by the government" and "it has become widely used as a reference point for the health of national and global economies".*

GDP can be considered as a good indicator of the total value of certain area. Damage due to floods has an impact on GDP, both direct and indirect: work disruptions of businesses or fabrics, failed harvests, shops are closed, transport is not possible because of damaged (rail)roads, etc. The GDP is thus not only a good measure for the value of a country, but also for its exposure to a flooding.

In Appendix 3: Estimation of the parameters, GDP is calculated per district for 1998, 2013 and the future 2060 scenarios based on the demography per district, the sectorial employment per district and the national current and future GDP together with its sector share. The GDP per district will be implemented in Delft-FIAT and will be used to give a rough estimation of the economic damage in Cambodia due to a certain flood. See Figure 9 for the GDP values per hectare for 1998, 2013 and the 2060 scenarios in constant prices of 2010.

In literature a damage function for the GDP is not available. In this research it will thus be modelled based on a simple damage function, which states that: below 0.30 meter of water depth, there will not be damage to the GDP in a certain grid cell, while at or above 0.30 meter of water depth the damage to the GDP will be maximal for a certain grid cell.

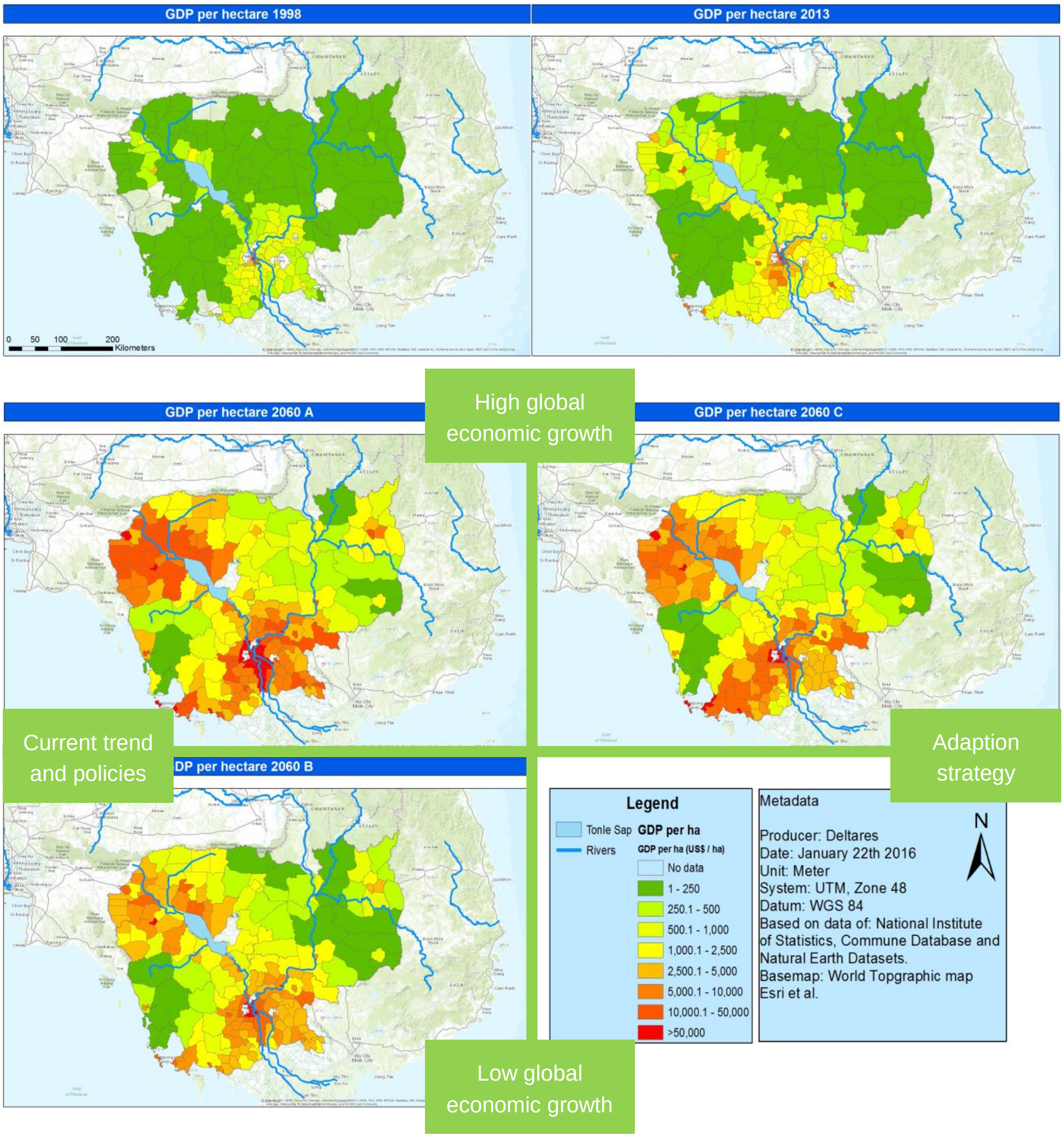


Figure 9: The Gross Domestic Product in US $ at constant 2005 prices of Cambodia per hectare for 1998, 2013 and the future 2060 scenarios. Source: National Institute of Statistics, 2014 & Commune Database, 2013.

3.1.3 Households

While the 2011 flood is currently seen as the flooding leading to the most damage, the 2000 flood was by far the most severe flood for the Cambodian population. By the year of 2000 Cambodia was not at all prepared for a flooding of this proportion, which resulted in around 3.5 million of affected people and many destroyed houses (Shrestra B. B. *et al*. 2013). With improving flood protection, the number of affected people and households will decrease. Nevertheless, the population density is increasing and the housing values are increasing as well lately and probably will continue doing this towards 2060. The damage to houses, absolutely seen, may thus certainly be expected to rise the following years.

According to the method of Sugiura *et al.* (2013) the damage to households can be estimated by using the average household value per capita, see Table 3 for the maximum damages to households measured per capita, together with a damage function as introduced by Sugiura *et al.* (2013). See Figure 10 for a graph of the damage functions. Combining these two with the population density, as described above, and implementing these data in Delft-FIAT will result in an estimation of the damage to households as result of floods. Table 3 shows the estimated maximum damage to households per capita.

Table 3: Maximum damages to households, measured per capita and at constant 2005 prices. For the estimation of the maximum damage values, see Appendix 3: Estimation of the parameters. Source: PFERNA Team Assessment (2013) and The World Bank Dataset (2015).

Year	**Maximum damage to household per capita at constant 2005 prices *(US $ / capita)***
1998	115
2013	373
2060 scenario A	7,198
2060 scenario B	2,077
2060 scenario C	7,198

As can be seen in Figure 10, the damage factor reaches it maximum value of one at a very high water level, because the reason for this is that many of the Cambodian houses in the floodplain of the Mekong are built on stilts and thus elevated.

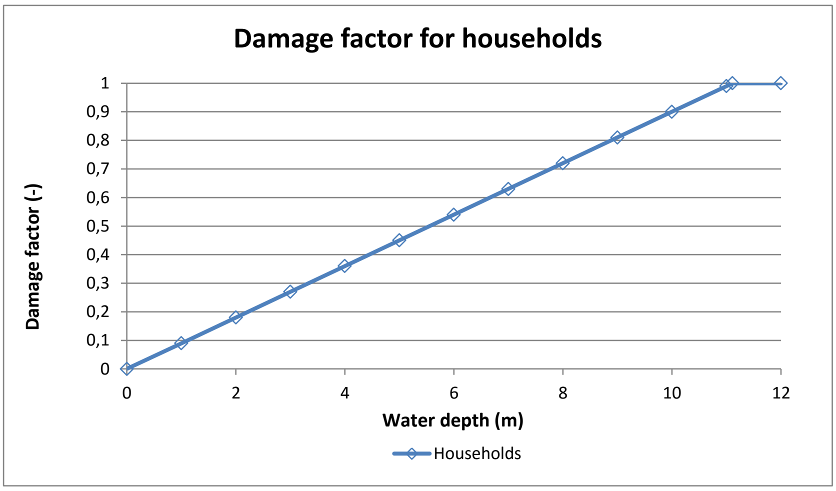


Figure 10: damage factor for households. Source: Sugiura et al., 2013.

3.1.4 Infrastructure

When infrastructure is inundated, which happens during floods, they will be partly damaged. Reparation or renewal of damaged infrastructure is expensive, but that is not the only disadvantage; also the temporary disability of using the infrastructure for transport and business disruptions has an indirect effect on the economy. Furthermore, it is very difficult to give a precise estimation of the damage costs of different infrastructure, as this depends on construction levels, different soil types and so on. The challenge is to give the best estimation possible of the costs after the infrastructure is inundated by a certain water depth.

In Appendix 3: Estimation of the parameters, a derivation of these costs is made by the Asian Development Bank (2012). The 2011 flood was taken as an example for the damage per meter of affected (rail)road. In Table 4, below, the damages and losses to the infrastructure by the 2011 flooding can be found, as well as an indication of the maximum damage to these (rail)roads.

Table 4: The impact to the (rail)roads in Cambodia after the 2011 flooding, including a maximum damage estimation. Source: [1] The Asian Development Bank (2012). [2] De Bruijn, 2005.

Type of infrastructure	**Damaged (km)**	**Total impact (million US $)**	**Maximum damage (US $ / m)**
National/Provincial Roads	363[1]	217.9[1]	600
Rural Roads	1842[1]	126.5[1]	69
Railroads	-	-	1000[2]

The Flood Management and Mitigation Programme report (Khy A., 2015) includes future infrastructural plans. It is assumed that these are all implemented in 2060 in the high growth scenario A. In this 'high growth' scenario, many new primary and secondary roads are constructed and operational, of which most are situated in the floodplain (in line with current trends of economic activities). The same accounts for new railroads that will be constructed. Also most of the existing roads will be upgraded to qualitative better and/or wider roads. See Figure 11 and Figure 12 for a visualisation of these plans.

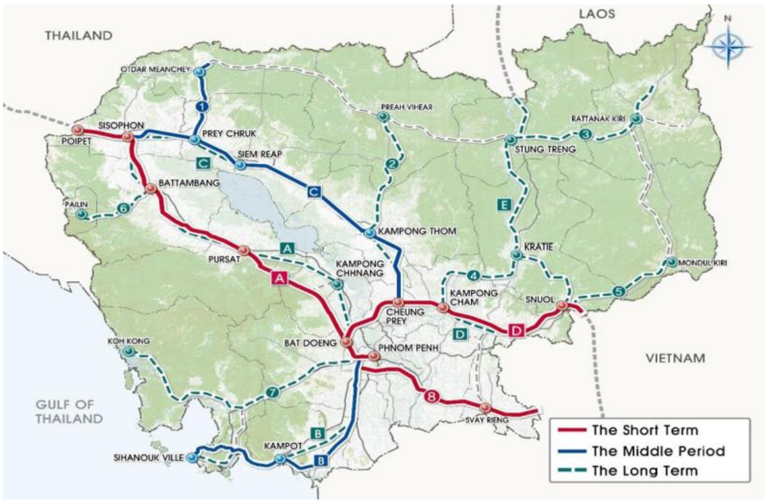


Figure 11: Future railway network plan as stated in the Flood Management and Mitigation Programme of 2015. Source: WWD 2015.

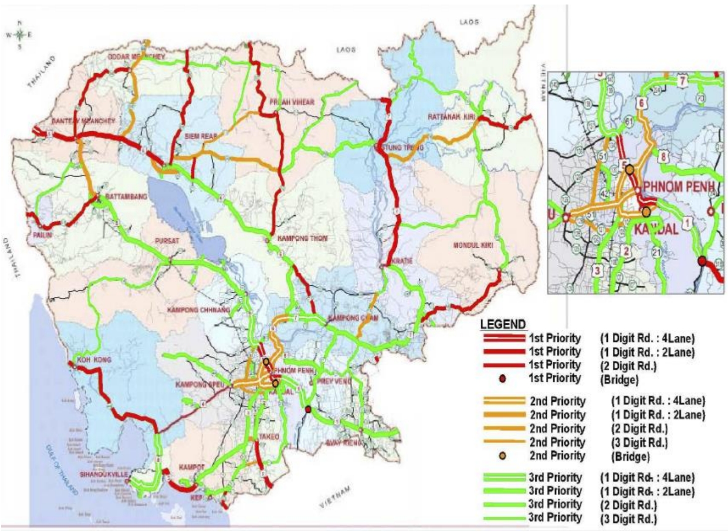


Figure 12: Future highway network plan. Source Khy A., 2015.

In contrast to scenario A, the ‘low growth’ scenario B will have much less infrastructural development. Only a few of the high priority roads will have been upgraded. Also maintenance of the roads will be a serious issue, due to the lack of economic resources. In scenario C, economic activities (and inherent population growth) is better redirected outside the floodplain, in the area between Phnom Penh and Sihanoukville. Inherently, more infrastructure development is focused on the southwest area, outside the floodplain. It is expected that in this part of the country, outside the floodplain, great (rail)road renewal and upgrading projects will take place. In the remaining part of Cambodia – mainly in the floodplain – there will certainly be infrastructural development, e.g. the corridor to Ho Chi Minh City, but not as much infrastructural development as in scenario A.

With the damage function, as introduced by De Bruijn (2005), see Figure 13, the data can be implemented in Delft-FIAT and the possible damages to infrastructure can be estimated for the current and future situation.

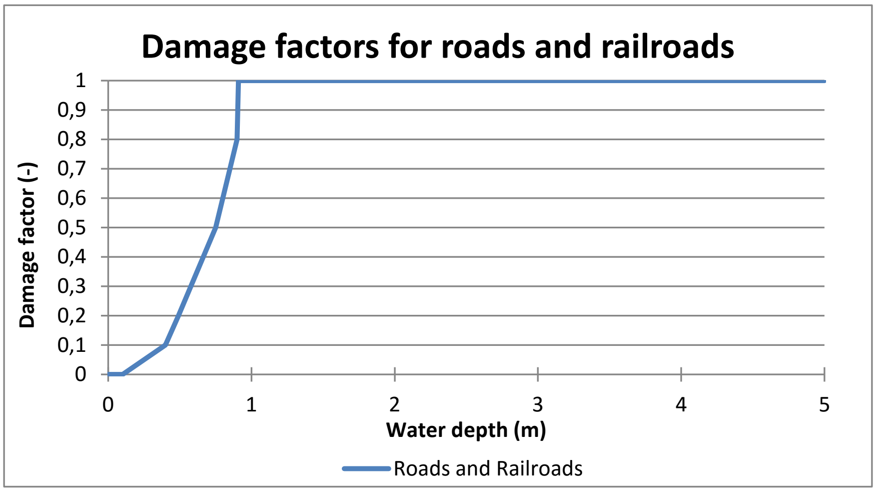


Figure 13: Damage factors for roads and railroads. Source: De Bruijn, 2005.

However, both the damage function and the maximum damages are empirical and thus not completely valid for other years, particularly for the future 2060 scenarios. The infrastructural value and its maximum damages are expected to increase towards the future, while the damage factors may decrease with increasing water depth as a result of flood protections for the infrastructure. Those changes are not taken into account.

As a last remark, the Open Street Maps database did only cover about 10% of the rural roads in Cambodia. The results will thus be multiplied with a factor 10 to correct for this. This, unfortunately, makes the model scale rougher.

3.1.5 Poverty

Quantifying in terms of economic losses is not the only damage that should be examined. With over 30% of the people living below poverty level 1 and 2 (Ministry of Planning *et al.*, 2014), Cambodia gives place to many poor households and many of these poor households are situated in the Mekong floodplain (World Food Programme 2012). The ID Poor report (Ministry of Planning *et al.*, 2014) stated five poverty levels of which level 1 and 2 are the poorest, comparable to the World Bank poverty line.

Poor households do not have a big counterpart in the economics of a country and will therefore not have much influence on absolute impact estimations. However, poor people may, in fact, be most impacted by a flooding since they could lose all their possessions (their house,

agricultural harvests, job, etc.), while they do not have the resources to rebuilt all of this. According to a study of the World Bank (Hallegatte *et al.*, 2016), poor people are above average impacted by floods, and lose a larger share of their annual income due to floods.
So, instead of only analysing possible (future) absolute economic damages, the percentage of poor people affected by a flooding is also analysed. This will be done at commune level and the number of poor people in poor level 1 and the number of poor people in poor level 2 will be used in Delft-FIAT for calculating the number of affected poor people after a flooding.

At this very moment many poor people live in the floodplain of the Mekong River and are in danger of the floods. However, the future developments in Cambodia will lead to certain gradations of poverty as well, depending on the scenario. Scenario A and C are expected to have decreasing poverty as a result of the economic advantages near the future in Cambodia. However, the inequality between the inhabitants of Cambodia will rise, especially for scenario A where much urban poverty – slums – is expected, which has to be taken into account. Scenario C also has urban poverty, though already less than in scenario A.
In Appendix 3: Estimation of the parameters, the derivation of the current and future poverty rates is given on commune scale. Scenario A and C are corrected based on the expected agricultural and industrial employment sector share of a district. Districts, and thus communes, with high agricultural (and industrial) employment shares are expected to have a higher poverty rate than districts with a high service employment share.
In Scenario B, a scenario in which the population of Cambodia doubles in size, with a high share of people depending on an agricultural livelihood, is assumed to have poverty rates corresponding to the current situation. In other words, there will be many more poor people in scenario B and poor communes will become even poorer in absolute terms. In contrast to scenario A and C, most of the poor people will live in rural areas spread over Cambodia and mainly its floodplain. As a result of a lack of resources in scenario B, the flood protection levels are also expected to be low in 2060, making the high number of poor people even more vulnerable to floods.
See Figure 14 for the percentage of poor people in poor level 1 & 2 in Cambodia for 1998, 2013 and extrapolated to the future 2060 scenarios. At the right top the 2013 map is overlaid with the flood extent of the 2011 flood to show the affected communes by the 2011 flood. In particular the poorer communes seem to be affected, while the communes with a lower poverty rate are mostly unaffected by the flood. A further analysis of this situation will be done in chapter 4.

From the Shock Wave report by the World Bank (Hallegatte *et al.*, 2016) affected poor people are tested whether they are more exposed to floods than average or not. This is done using a bias, which is the share of poor people exposed divided by the share of the total population exposed by a flood, subtracted by 1 (Hallegatte *et al.*, 2016). A positive bias then means that poor people are more exposed than average and the other way around for a negative bias. This method will also be used in this research.

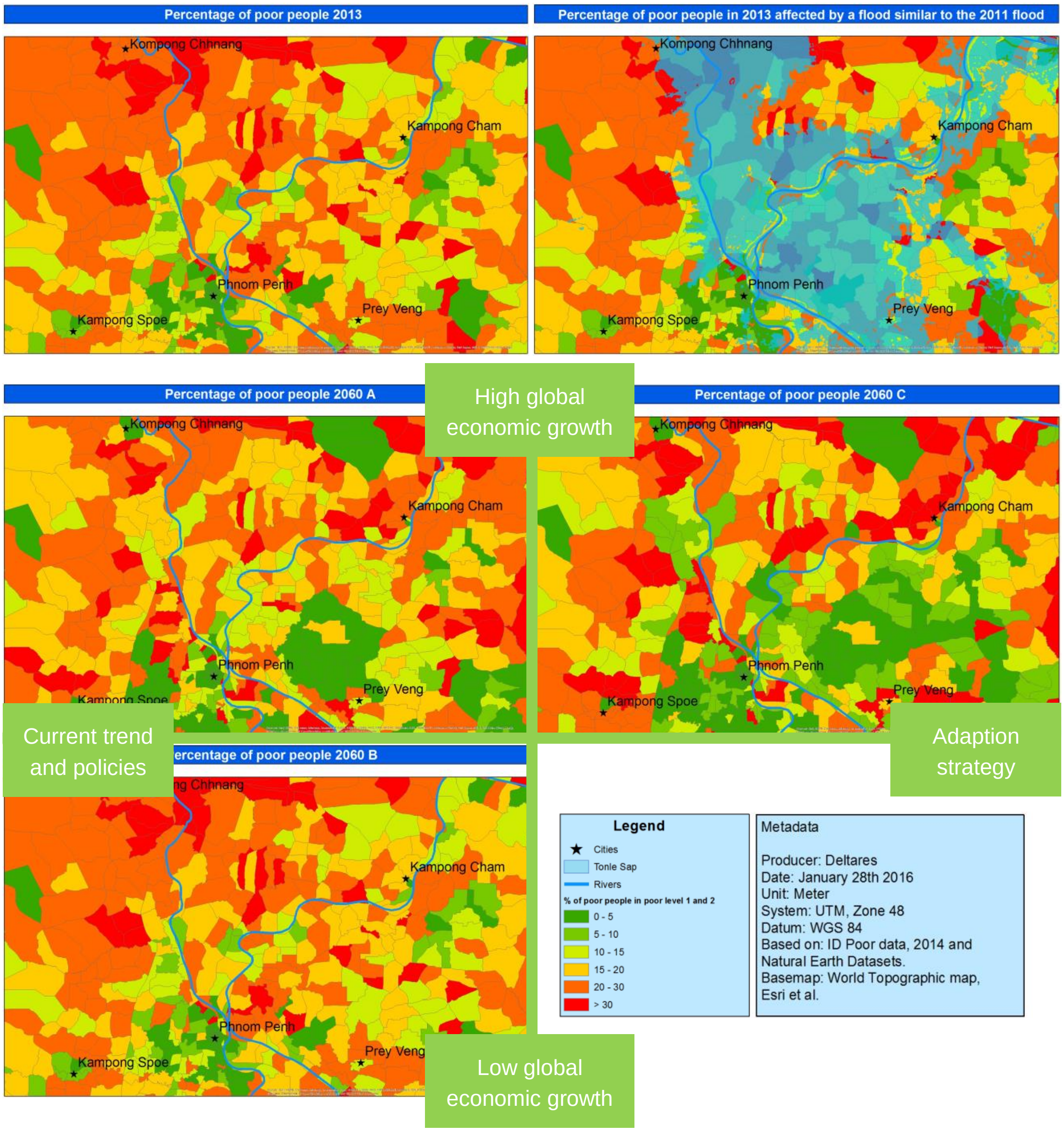


Figure 14: Percentage of poor people in poor level 1 & 2 in Cambodia for 1998, 2013 and the future 2060 scenarios.1998 is not shown, since the map is similar to the 2013 map. The right top image is the map of 2013 overlaid with the flood extent of 2011. The maps are zoomed in on the surrounding areas of Phnom Penh. N.B. in Delft-FIAT absolute values instead of relative ones are used as input. Source: ID Poor Database, 2014.

Box 3-A Land use change and damage to agriculture

Agricultural damage

The economy of Cambodia is at this moment for its major part dependent on the agriculture. Although the sector share in GDP of the agricultural sector is only 33.6%, 48.7% of the employed population is working in this sector (The World Bank, 2014). Central in this sector is rice production, which is mostly grown in the floodplain; see also Figure 15 which is a land cover map of Cambodia in 2010. Not only the majority of the agricultural sector in Cambodia depends directly and indirectly on the success of the rice crop each year, rice production is also a big factor in the national effort of promoting and securing food security (CSIRO *et al.*, 2013).

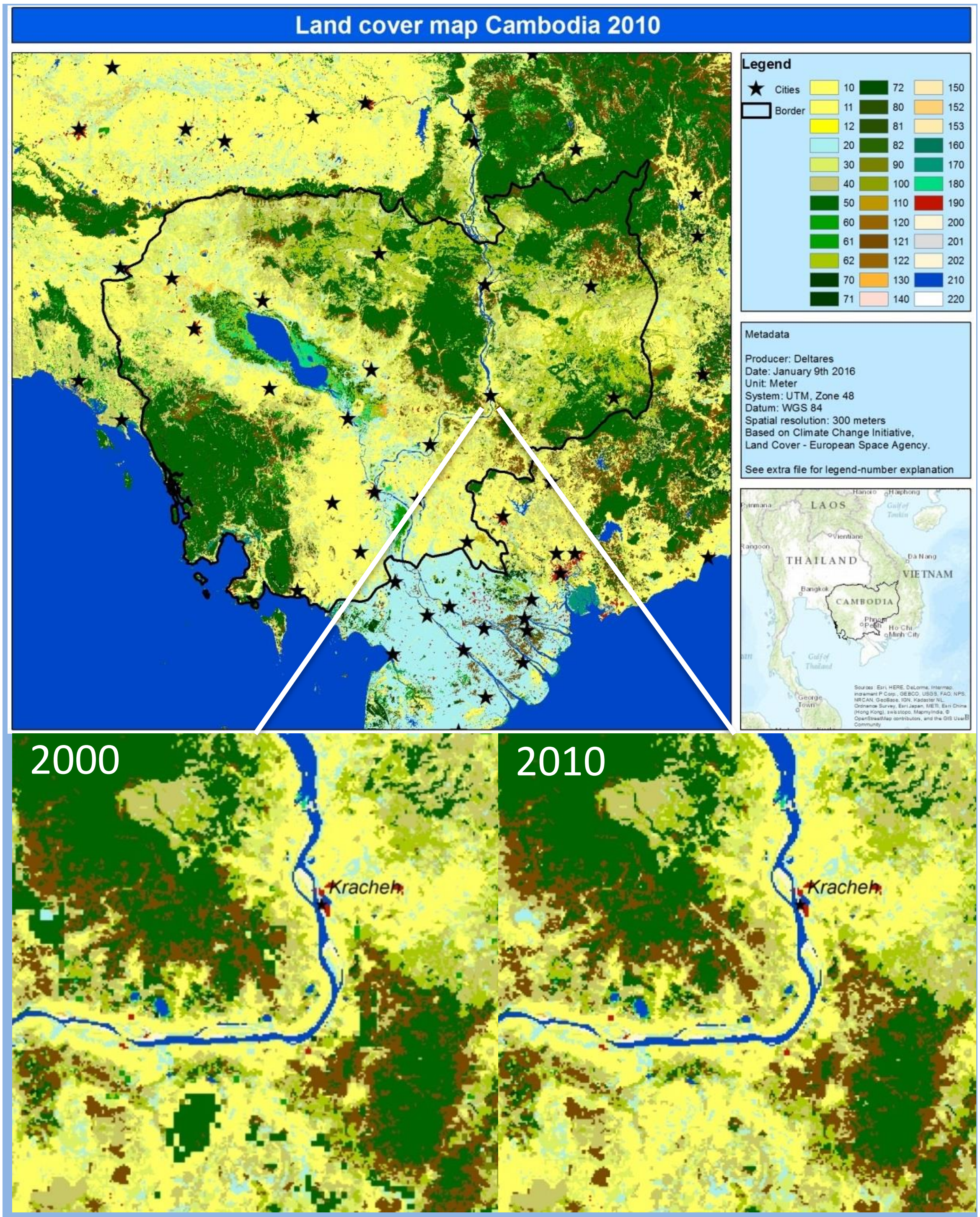
Close to the Mekong River and Tonle Sap, many floating rice paddies can be found (see also Figure 15). Further away, the rice and other crops are rain fed and are only drained during extreme droughts. Though the agricultural sector has many advantages of the floodplain, because of its fertile soil and advantageous drainage in dry periods, a large flood may have an enormous impact on the harvest of that particular year and even the following years in case of heavy floods.

For the years 1998 and 2013 there will be an extra assessment with Delft-FIAT in order to estimate the flood damage to rice fields. This will not be part of the overall damage assessment for those years, since the rice harvest is part of the total GDP, which will result in an overestimation. Nevertheless it may be useful to have an indication of the damage to rice fields in a country having such a high agricultural employment sector.
The locations of the rice fields will be obtained from the ESA land cover maps of the years 2000 and 2010, assuming that 1998 resembles to 2000 and 2013 resembles to 2010. Though this will give a rough estimation of the damage, it is in the scope of this research to do such rough first estimations to quantify the flood damage.

The 2060 scenarios will not have an extra damage assessment for the rice fields, because this would preferably need a future land use map for all the 2060 scenarios. In the 2060 scenarios the agricultural employment share is also expected to further decrease. However, the agricultural productivity is expected to change as a result of technological enhancements, which might result in a reduced rice production and most likely different agricultural products. It is thus difficult to model future flood impacts on the agricultural sector in 2060 and will therefore not be taken into account in this research. Nevertheless, it is worthwhile to explore this subject in further research.

Since there are only land cover maps available, though quite detailed, and no land use maps, some assumptions have to be made:

- Irrigated and flooded cropland, number 20 in the legend of Figure 15, are assumed to consist of only floating rice paddies.
- Rain fed cropland, number 10 in the legend of Figure 15, is assumed to consist of rain fed rice. This could give a slight overestimation.
- The mosaic of cropland and vegetation, number 30 and 40 in the legend of Figure 15, are assumed to consist for 50% of other agricultural crops than rice and for 50% of non-agricultural land cover. So, they do not contain any rice paddies.



Metadata

Producer: Deltares
Date: January 9th 2016
Unit: Meter
System: UTM, Zone 48
Datum: WGS 84
Spatial resolution: 300 meters
Based on Climate Change Initiative,
Land Cover - European Space Agency.

See extra file for legend-number explanation

Figure 15: Land cover map of Cambodia. Shown in the main picture is the land cover map of 2010. Yellow and blue colours are respectively rain fed and flooded/irrigated croplands. Green colours are different types of forests and brown colours are partly forest and partly cropland. For a more detailed legend and an explanation of the legend numbers in the figure, see Appendix 4: Explanation of the land cover legend. Below is an enlargement of the environment near Kracheh to show small land cover changes between 2000 and 2010, which are harder to see on national scale. Between 2000 and 2010 some forest has clearly been replaced by agricultural land. N.B. urban development was not registered in the ESA data. Source: Climate Change Initiative, Land Cover – European Space Agency.

The maximum damage to agriculture was estimated by combining the crop yield data of the Ministry of Agriculture, Forestry and Fisheries with the yearly FAO producer price data for Cambodian crops, see Table 5:

*Table 5: Maximum damages to rice. *Rough assumption: about 0.625 times of the total production yield is produced and sold (De Bruijn, 2005). N.B. the maximum damage depends on the season and the speed of inundation. Sources: FAO (2013), Ministry of Agriculture, Forestry and Fisheries (2014) and The World Bank Dataset (2015).*

Type	Year	Yield (Ton / ha)	Equivalent yield* (Ton / ha)	Maximum damage / Value ($ / ha)	At constant 2005 prices ($ / ha)
Rice	**1998**	**1.66**	**0.83**	**131**	**167**
	2013	**2.83**	**1.42**	**380**	**208**

Together with the damage function, see Figure 16, the data will be implemented in Delft-FIAT and the possible damages can be estimated.

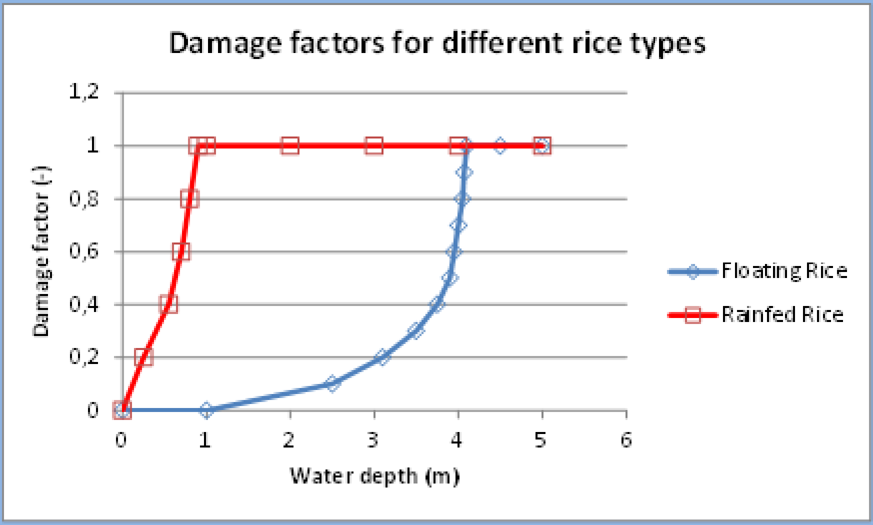


Figure 16: Damage factors for the different rice types. Source: De Bruijn, 2005.

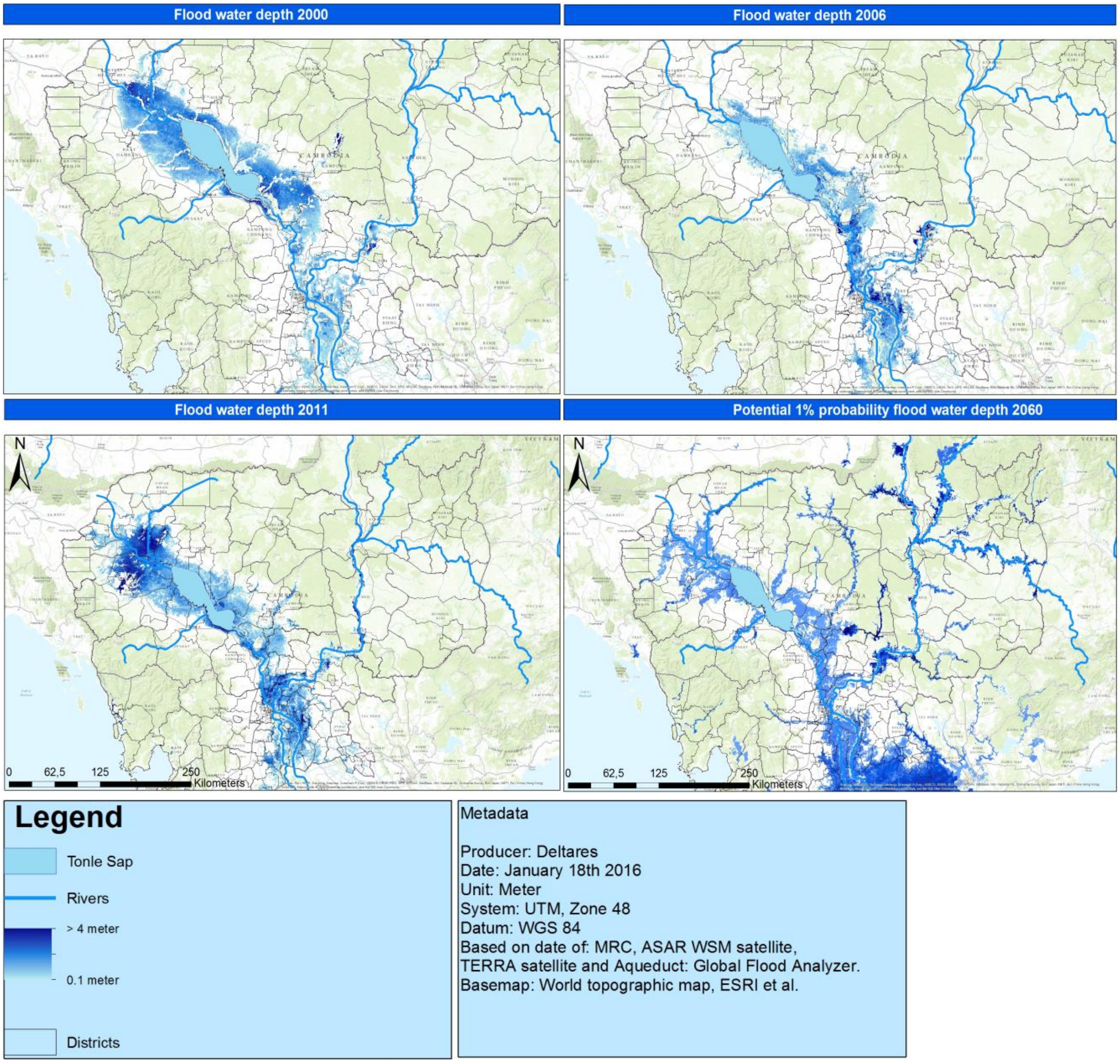
3.1.6 Water depth maps

The in Delft-FIAT used water depth maps were calculated using the flood extents of 2000, 2006, 2011 and the possible 1% probability flood extent of 2060, and the Digital Elevation Model (DEM) of Cambodia. In Appendix 3: Estimation of the parameters, the calculation of the water depth maps is described.

The possible 2060 flood was chosen to have a 1% probability, because the disastrous 2000 and 2011 floods were 1% probability floods. A 1% probability flood is equivalent to a flood that takes place once in a hundred years. However, this still is a probability theory and it may happen more or less often than once in a hundred years. And more than once it was; Cambodia had those floods in 2000, 2011 and 2013. Hence, a 1% probability flood might be a bit underestimated in this case.

In the Aqueduct database, a possible 1% probability 2060 flood is based on future climate scenarios and expected flood protections. The climate scenario RCP6 of the ESM2M model, developed by NOAA’s Geophysical Fluid Dynamics Laboratory, was chosen, since the RCP6 scenario is seen as a moderate/slightly above moderate climate scenario in the range of climate scenarios and assumes an average rise in temperature towards 2065 of 1.3 degrees Celsius (Moss *et al.*, 2008). The choice for the ESM2 model was a result of data availability and it is recommended for further research to run the model with 2060 water depth maps based on other climate scenario models.

At this moment, the extent of the flood in 2000 and 2011 are the largest and both have a quite similar extent. Some differences are present as well between the 2000 and 2011 flood. The 2000 flood peak had a longer duration time than the 2011 peak resulting in a broader flood extent around Tonle Sap (MRC, 2011), but the 2011 flood on the other hand had higher water depths near Phnom Penh and in the direction of the border with Vietnam. This was probably a result of a more intense flood peak with a shorter duration and an increase in flood protections around Tonle Sap. The 2006 flooding was a more regular flood and will be used to show the possible damage of more conventional floods. From Figure 17 one can also see that the possible 2060 flood will be quite disastrous as well, and within this flood extent the effects of the possible future flood protections can be seen around Tonle Sap.



Metadata

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Unit: Meter
System: UTM, Zone 48
Datum: WGS 84
Based on date of: MRC, ASAR WSM satellite,
TERRA satellite and Aqueduct: Global Flood Analyzer.
Basemap: World topographic map, ESRI et al.

Figure 17: Flood water depths of the 2000, 2006, 2011 and a potential 1% probability 2060 floods. For 2000, 2006 and 2011 the flood extents are only shown for Cambodia. The flood extent of 2060 is also displayed for Vietnam. Source: MRC, ASAR WSM satellite, TERRA satellite, UN and Aqueduct: Global Flood Analyzer.

3.1.7 Flood protection

So far this research did not take potential future flood protections into account. As a start in modelling the future flood impacts an assessment will be done including possible future flood protections. However, the results will be rough estimations and the economic feasibility of certain flood protections is not taken into account. This small assessment is thus only meant as a starting point for further research.

Two types of protections will be tested: the first one is an economic based flood protection and the second one is a people based flood protection.

Economic based flood protection

The economic based flood protection focuses on the protection of the wealthier cities in the Mekong floodplain. Scenario A and C are expected to have the opportunities, from an economic point of view, to invest in proper flood protections, while this is not the case for scenario B. So, these types of flood protections are only expected in scenario A and C, where in this assessment the top 10 economically most important cities and their corresponding districts in the floodplain are protected. Those cities with their corresponding districts are:

Table 6: Flood protected cities in scenario A and C.

City	Districts
Battambang	Krong Battambang
Siem Reap	Krong Siem Reap
Pursat	Krong Pursat
Kampong Thum	Krong Stuen Saen
Kampong Chhang	Krong Kampong Chhang
Kampong Cham	Krong Kampong Cham Kampong Siem
Phnom Penh	Chamkar Mon Doun Penh Prampir Meakkakra Tuol Kouk Saensokh Ruessei Kaev
Prey Veng	Krong Prey Veng
Svay Rieng	Krong Svay Rieng

With the use of GIS these cities and their corresponding districts are cut out of the potential 2060 flood water depth map where after the flood impact there is again modelled with Delft-FIAT for both 2060 scenarios.

People based flood protection

Scenario B is assumed to have a lower global - and Cambodian - economic growth whereby the flood protections as stated above are unlikely. Despite that disadvantage, Cambodia could invest in the protection of their poorest inhabitants in scenario B – this is also possible in scenario A and C, but it is unlikely to happen -. The agricultural sector is still assumed to be the most important sector in scenario B, with many agricultural areas in flood prone area populated by many (poor) people. Flood protections would therefore reduce the exposure of the in scenario B still important agricultural areas, the many people and most importantly the poorest people since poverty is still related to the high amount of people working in the agricultural sector.

In this assessment the top 10 districts with the highest amount of poor people are chosen and the districts will be flood protected following the above described method. The protected districts are:

Table 7: Flood protected districts in scenario B.

Province	**Districts**
Battambang	Aek Phnum Krong Battambang Sangkae Svay Pao
Kampong Cham	Krong Kampong Cham Prey Chhor
Kampong Chhang	Krong Kampong Chhang
Kandal	Kandal Stueng Khsach Kandal
Prey Veng	Preah Sdach

The results of both assessments are described in chapter 5, where also the effects of the economic based flood protections and the people based flood protections are compared to see the resulting impact on the poorest people of Cambodia.

Again, the feasibility of these flood protections is not taken into account and is especially for scenario B doubtful, though worthwhile to model.

3.1.8 Framework

As stated in the previous chapter: the goal of this research is to quantify the possible damages and losses in Cambodia as a result of different floods of the Mekong River. These damages and losses are determined by the severity of the flood, but moreover by the socio-economic developments that have taken, and are taking place in the floodplain giving rise to the flood vulnerability in Cambodia. A flowchart of all these processes is shown in
Figure 18 and gives a schematic view of the combination of processes and their interconnectedness leading to possible damages and losses. Socio-economic parameters, such as the population (growth), gross domestic product and poverty, together with present or future situations result in different land uses. It determines not only the land use in the sense of urban and agricultural areas, but also e.g. the infrastructure of the country.

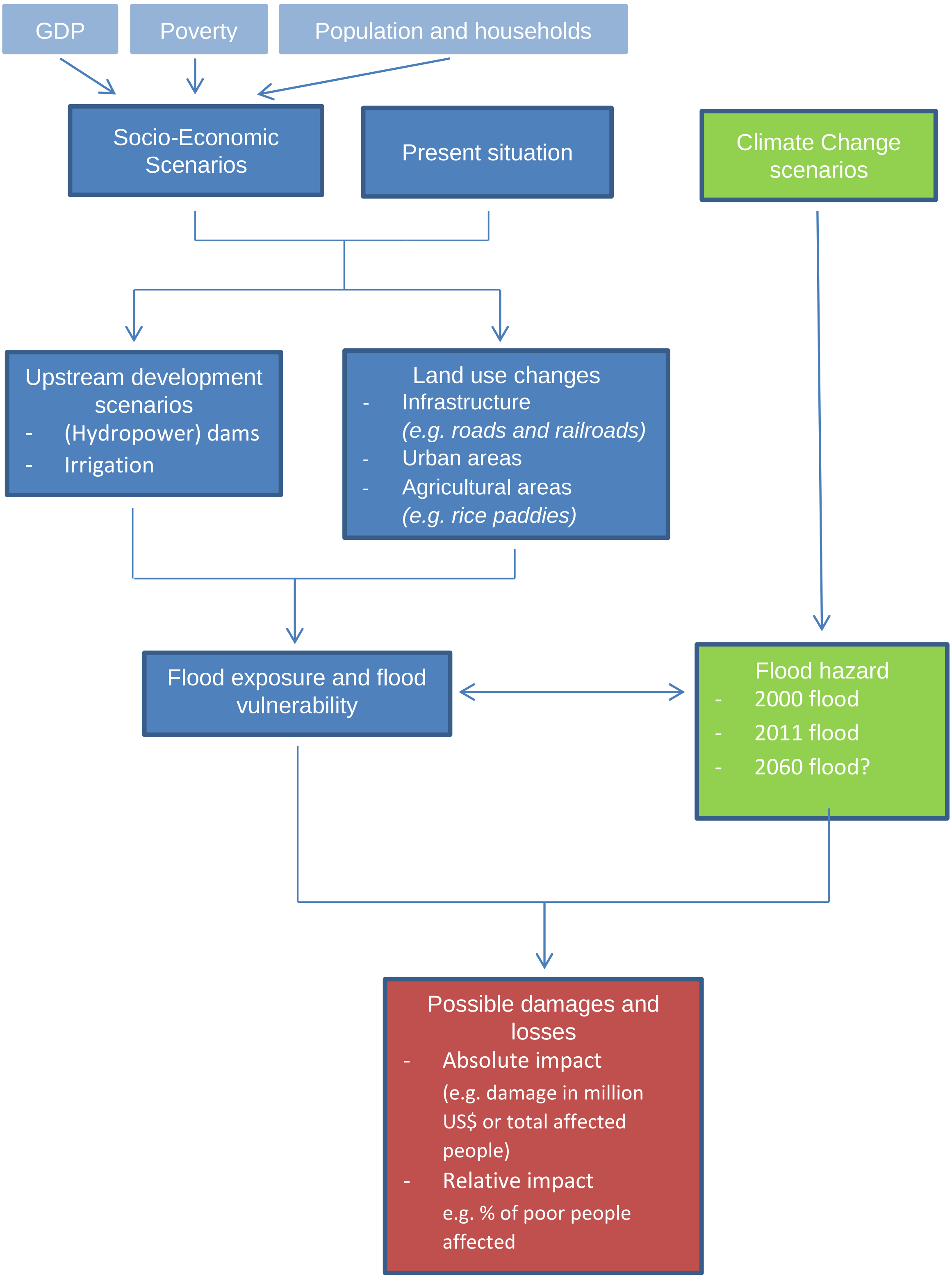


Figure 18: Flowchart of different parameters and processes causing possible damages and losses after hazards and floods. Most of them are connected, causing a more complex system. In this research climate change and other hazards than floods are not taken into account.

3.2 Implementation in Delft-FIAT

Delft-FIAT is in fact a useful Python-script to overlay many ‘object maps’, in this research these are the socio-economic and land use parameters, with water depth maps of flood extents. Delft-FIAT then locates and ‘knows’ the number of affected objects per object map and is able to calculate for every object map the damage based on maximum damages and damage functions. These damage functions and their corresponding maximum damages are defined in advance and they determine the damage to an object (households, agricultural fields, etc.) depending on the object and whether a certain object is flooded, and even more important with what water depth it is flooded, or not. Delft-FIAT then calculates for every scenario the absolute damage in e.g. US $ or number of affected people, which could also be used in a relative sense (e.g. percentage of poor people affected). See also
Figure 19, for a flowchart of the use of Delft-FIAT in this research.

An addition to the model is the possible flood protection. Cambodia is expected to be wealthier in the future scenarios than it is currently and is therefore expected to have flood protections which could reduce flood impacts. In this research a start is made with modelling the future flood impacts with economic based flood protections and people based flood protections, see also the previous paragraph.

In this research Delft-FIAT will be used to calculate the absolute damage in million US $ for 1998, 2013 and the future 2060 scenarios, except for scenario D, based on the available data. Therefore the parameters GDP, households, infrastructure and land use (though land use will only be used for 1998 and 2013) will be used as input for Delft-FIAT. Furthermore the relative damage for 1998, 2013 and the future 2060 scenarios will be modelled with population and poverty as input data for Delft-FIAT. An output of total affected (poor) people will then be given, which can easily be translated into relative amounts (% of (poor) people affected).

Moreover, Deft-FIAT calculates in raster grid cells and the input data – object maps and water depth maps – should have a predefined raster grid which is the same for all input data. It was chosen to use a grid cell size of 100 by 100 meters, a hectare, which isn’t fine scaled, but with most of the data on district or commune level, the cell size is fine enough.

Last, to evaluate the results and have an idea of the sensitivity of certain parameters to small changes, a sensitivity analyses will be executed whereby Delft-FIAT will be run with the maximum damages and damage factors 10% higher and 10% lower. This results in certain bandwidths for the impact estimations as can be seen in chapter 4 and 5.

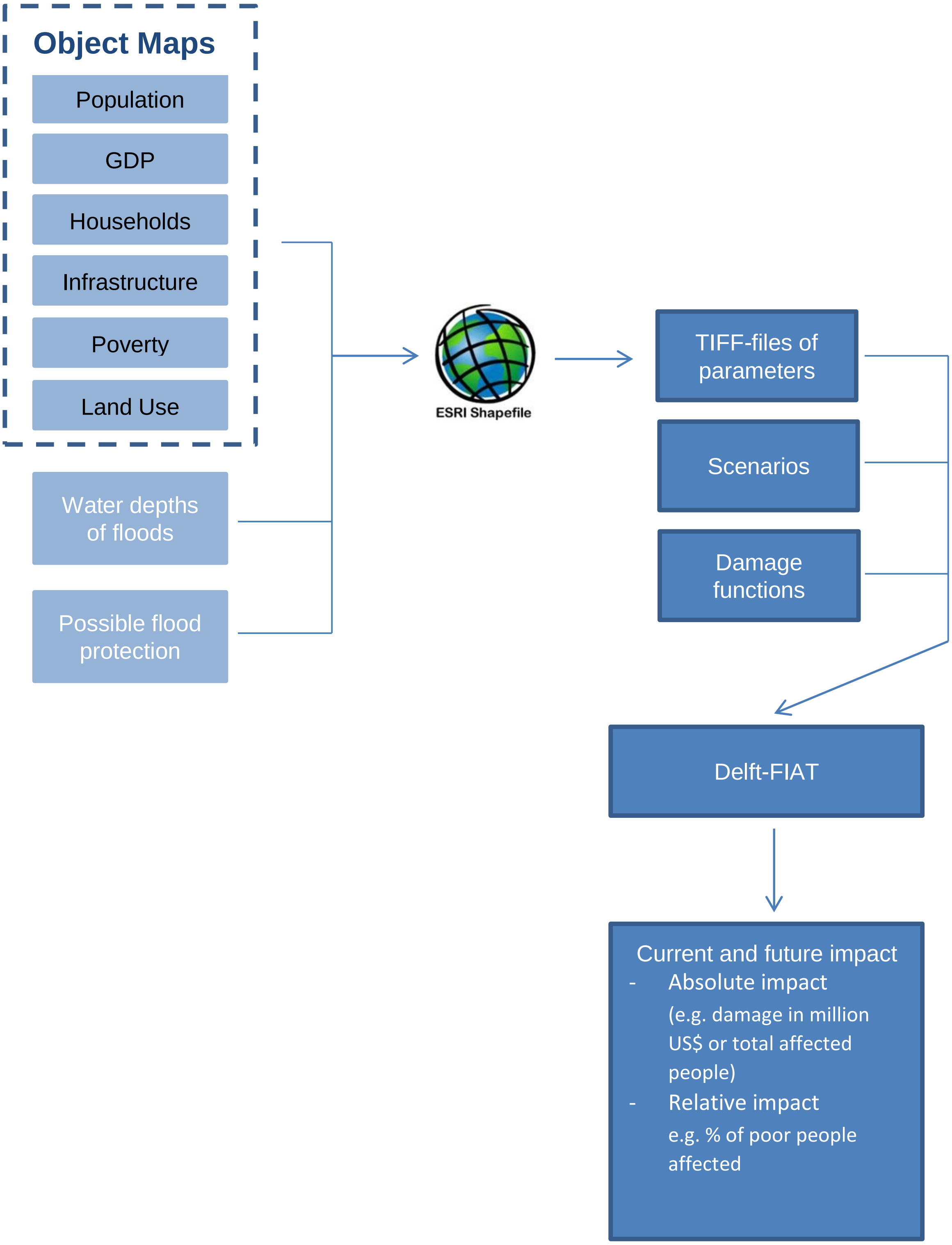


Figure 19: Implementation scheme of the different parameters, water depth maps, flood protections and scenarios in Delft-FIAT. Partly based on Slager et al. (2013).

4 Analysis current situation

This chapter starts with a short analysis of the past 2000 and 2011 floods, before giving the model results of the flood impacts for 1998 and 2013. The results for the future 2060 scenarios are described in the next chapter.

4.1 Past floods

4.1.1 2000 Flood

"Please help Cambodian people in these hard times" were the words of the Cambodian Prime Minister Hun Sen during what is still seen as the worst flood in more than 70 years. Even in Phnom Penh, normally safely situated above the water level, a state of emergency was declared by the authorities, because the capital could inundate in days (BBC, 2000). Fortunately, Phnom Penh remained for its greatest part out of the flooded area.

Less fortunate were the other inhabitants of the Mekong floodplains; according to the Red Cross nearly 800,000 km^2 of land have been deluged by the floods in Cambodia, Laos, Thailand and Vietnam. Table 8 shows some of the impacts due to the 2000 flood in Cambodia:

Table 8: Impact of the 2000 flood in Cambodia. Source: NCDM & UNDP, 2014.

Deaths	**Houses destroyed**	**Houses damaged**	**Schools affected**	**Farming crop damaged *(ha)***	**Rice paddy fields damaged *(ha)***	**Rural roads destroyed *(m)***	**National roads destroyed *(m)***
388	1,305	7,920	23	82,970	491,853	409,330	31,482

The discharge peak, as it started at the end of August that year, was not that exceptional with a recurrence time of only ten years. However, the early flood peak of July had not completely receded yet and the combination of both made the 2000 flood to an extremely destructive flood (De Bruijn, 2005).

In 2000, Cambodia was not at all prepared for floods of these proportions, which made the flood disastrous and it resulted in many affected people and households.

4.1.2 2011 Flood

Only eleven years later another exceptional flood reached Cambodia with a flood extent quite similar to the 2000 flood. Although Cambodia had improved flood protections after the 2000 flood, resulting in less affected and damaged households, the population and economic growth in those years had made Cambodia more vulnerable to floods. Important in this trend is the fact that the 2011 flood had more severe water depths around Phnom Penh, while in the 2000 flood the most severe floods took place around Tonle Sap. Hence the flood resulted in higher damages and losses, especially for the economy and the Cambodian infrastructure (see also Table 9).

Table 9: Impact of the 2011 flood in Cambodia. Source: NCDM & UNDP, 2014.

Deaths	**Houses destroyed**	**Houses damaged**	**Schools affected**	**Farming crop damaged *(ha)***	**Rice paddy fields damaged *(ha)***	**Rural roads destroyed *(m)***	**National roads destroyed *(m)***
458	963	1,838	1,172	26,815	277,379	666,536	144,386

4.2 Results

4.2.1 Impacts on the economy

Special Economic Zones

In 2005, Special Economic Zones (SEZs) were introduced in Cambodia as one of the key government policies to stimulate diversification of the economy (ADB, 2015). The SEZs are meant to attract foreign investors as they provide serviced industrial plots, fiscal incentives, trade and infrastructure facilitation, and offer a secure supply of electricity (ADB, 2015 in FMMP, 2015). Most investments are concentrated in four main zones: Phnom Penh, Manhattan (Bavet), Sihanoukville and Tai Seng, and those investments are predominately of Chinese and Japanese investors (ADB, 2015 in FMMP, 2015).

In this research, the economic value of SEZs is part of the GDP and thus included in the impact estimations. Nevertheless, it is useful to have a look at the current locations of SEZs and the locations of proposed SEZs. Many of them are built, and will be built, inside the Mekong floodplain giving rise to the flood exposure of the Cambodian population. With only 11 of the 33 approved SEZs operational at present accounting for 68,000 jobs in 2014 (ADB, 2015), the SEZs represent only 3.7% of the current industrial sector which is less than 1% of the total employment in Cambodia. So far, the Cambodian SEZs do not have a large counterpart in the flood exposure. However, the exposure to floods is expected to rise as a result of new SEZs being built (in the Mekong floodplain) and an increase in the employment sector share. In Figure 20 the current and future SEZs are displayed.

Meanwhile, the Cambodian garment sector accounts for 600,000 employees, which is about 38% of the industrial employment sector in Cambodia (Asian Development Outlook, 2015). Hence, the garment sector has a significant counterpart in the flood exposure of Cambodia.

With many of the SEZs still being built, it is conceivable that the employment sector share of the SEZs might be brought up to the same level as the garment industry, increasing its economic value. In order to lower the flood exposure, the disposition of new SEZs should be thought-out.

Figure 20: Cambodian Special Economic Zones that are operational or still have to be built. Source: Phnom Penh Post, 2015.

Model results of damages and losses

The economic impact as a result of flooding can be disastrous. To have an idea of this impact, the model results will be shown in this paragraph. Figure 21 displays the economic impact of the four different floods to the economy of 1998 and 2013. The impacts are displayed per flood – 2000, 2006, 2011 and the potential 2060 flood – to not only be able to compare the impacts of the different floods, but more importantly to compare the flood impacts of the different years and scenarios. The impacts should be seen as a possible damage and a result of a flooding comparable to the flood of 2000, 2006, 2011 or 2060.

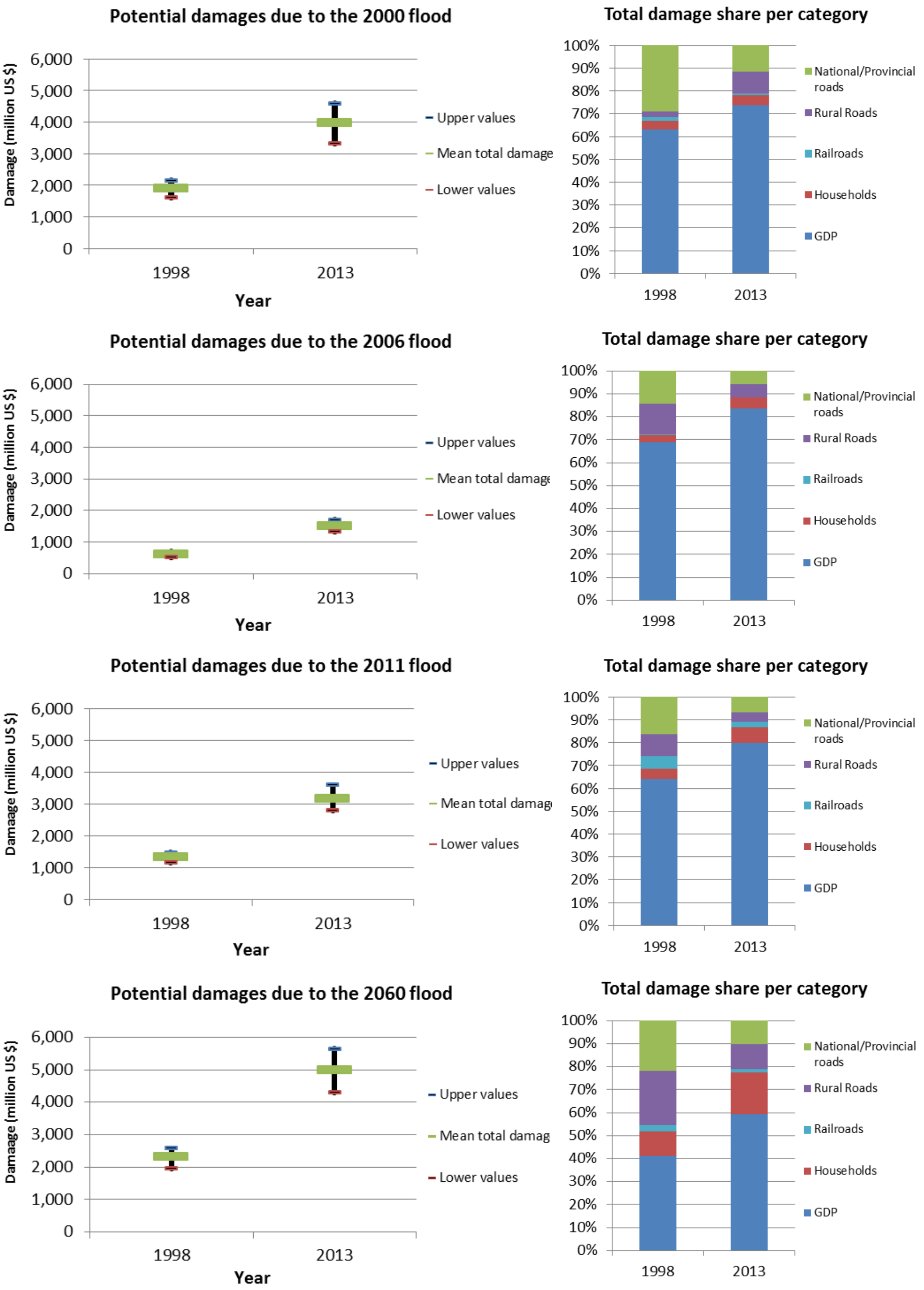


Figure 21: Left: Potential economic impact as a result of the 2000, 2006, 2011 or 2060 flood. Right: total damage share per category for the 2000, 2006, 2011 and 2060 floods.

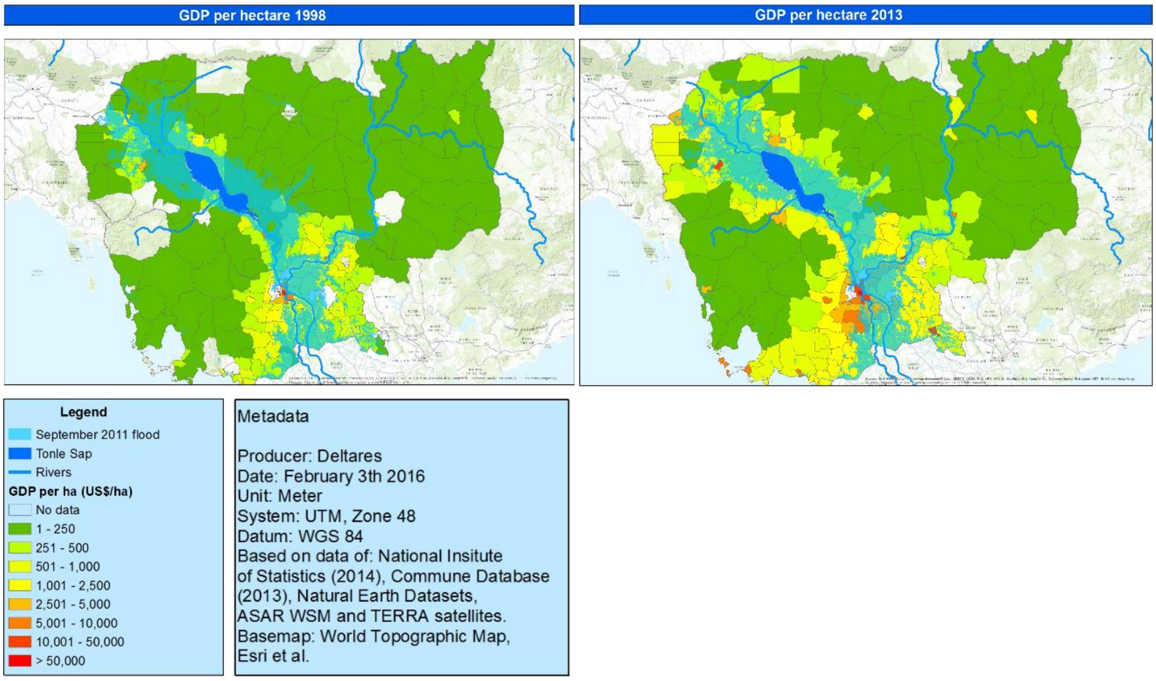


Figure 22: Visualisation of the flooded GDP for 1998 and 2013 as a result of the 2011 flood. Source: The Commune Database (2013), National Institute of Statistics (2014), ASAR WSM and TERRA satellites.

The results for 1998 and 2013, displayed in Figure 21 (a visualisation of the 2011 flood is displayed in Figure 22), give a flood impact between the two years that is significantly higher in 2013 than in 1998 as a result of economic and population growth. Also the four flood events have varying impacts and show a clear ranking in severity. In ascending severity the ranking is as follows: 2006, 2011, 2000 and 2060.

The flood of 2011 could be used as a model reference point, since the damages and losses of this flood were estimated by the Asian Development Bank in 2012, see also Appendix 3: Estimation of the parameters. In their damages and losses estimation, the economic damage in terms of GDP and railroad loss were not included, so only the infrastructural and housing damages can be evaluated.

Table 10: Evaluation of the model results. Source: ADB, 2012.

Category	**Damage [ADB, 2012]** ***(million US $)***	**Modeled damage** ***(million US $)***
National/provincial roads	217.9	215.6 +/- 40
Rural roads	126.5	129.4 +/- 15
Households	11.7	221.3 +/- 200

As can be seen in Table 10 the infrastructural estimations are acceptable, but the housing damages and losses are error prone and clearly overestimated. Estimations in housing damages and their damage functions are always error prone, see also the chapters conclusion and discussion, and will probably give the same error in the future damage estimations as described in chapter 5. Especially small changes in the maximum damage and the damage functions have already a significant impact on the total damage (Wagenaar *et al.*, 2015). A damage function and maximum damage on national level may thus already result in errors of this magnitude. This is a discussable error and will be further discussed in the chapter 'Discussion'.

Since the results of this research are only intended to be used in relative terms, the resulting impact in absolute vales will not be further discussed here.

Box 4A – Flood impacts on the rice paddies

In box 3A the supplementary assessment is described in consisting of the possibility of modelling agricultural damage, in this case rice paddies. See Figure 23 for the results of the possible damage to rice paddies as a result of the four different floods.

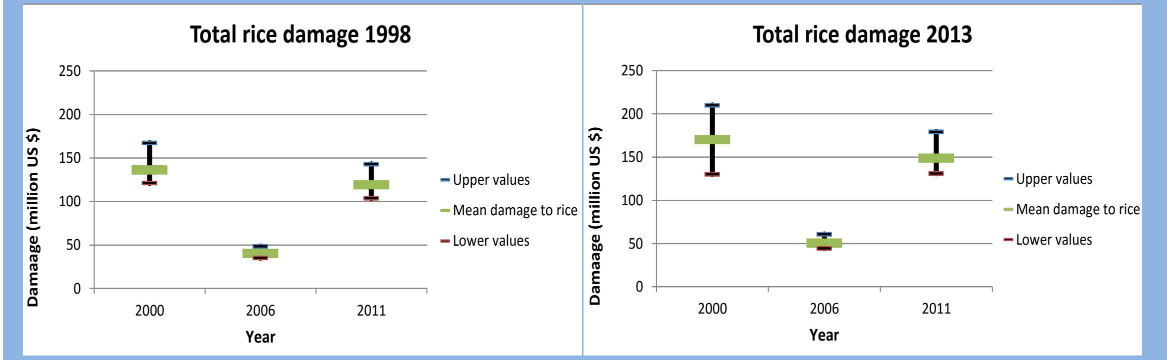


Figure 23: Damage to rice paddies as modelled with the four different floods for 1998 and 2013. The damages are in million US $ based on constant 2005 prices. Left: Damage to floating rice types, right: damage to rainfed rice types.

Both graphs show clearly higher damages to both rice types in 2000 and 2011 than in 2006, and the 2000 flood resulted in even a bit more damage than the 2011 flood.

The Asian Development Bank made an estimation of the damage to the rice paddies and they came up with a damage of $138 million lost paddy production, and $40.8 million of lost planting (ADB, 2012). With the 2013 dataset and the 2011 flooding a damage of around $150 million was calculated.

Comparing 1998 and 2013, the damage increases towards 2013 due to higher rice prices and an increase in agricultural, and thus rice, fields.

Though the 2060 scenarios are not modelled in this box, the current trend is expected to continue towards the future, which will result in an increasing vulnerability near the future. Without additional flood protections, the damage as a result of future floods may continue increasing. Nevertheless, an additional reason to not encompass the 2060 scenarios in this box is the fact the agricultural sector may have significantly changed due to technological enhancements towards 2060.

4.2.2 Impacts on the population

Affected people

As described in paragraph 4.2.1 due to the impact of the 2000 flood, this flood is still seen as the worst flood in the Cambodian history. People were not prepared for such a flood and the same may be expected for 1998. In Figure 25 displays the number of affected people as a percentage of the total number of inhabitants and in this figure the percentage of affected people is higher in 1998 than in 2013. In 1998 people were less prepared to severe floods than they are at this moment, but, more importantly, Cambodia is rapidly urbanizing as a result of which relatively less people live in the flood prone agricultural areas in 2013 than in 1998.

However, this is in relative terms. In absolute terms, the number of inhabitants increased between 1998 and 2013 resulting in a higher number of potential flood affected people in 2013 than in 1998. Moreover, Figure 24 provides a visualisation of an overlay of the population density maps of 1998 and 2013 with the 2011 flood.

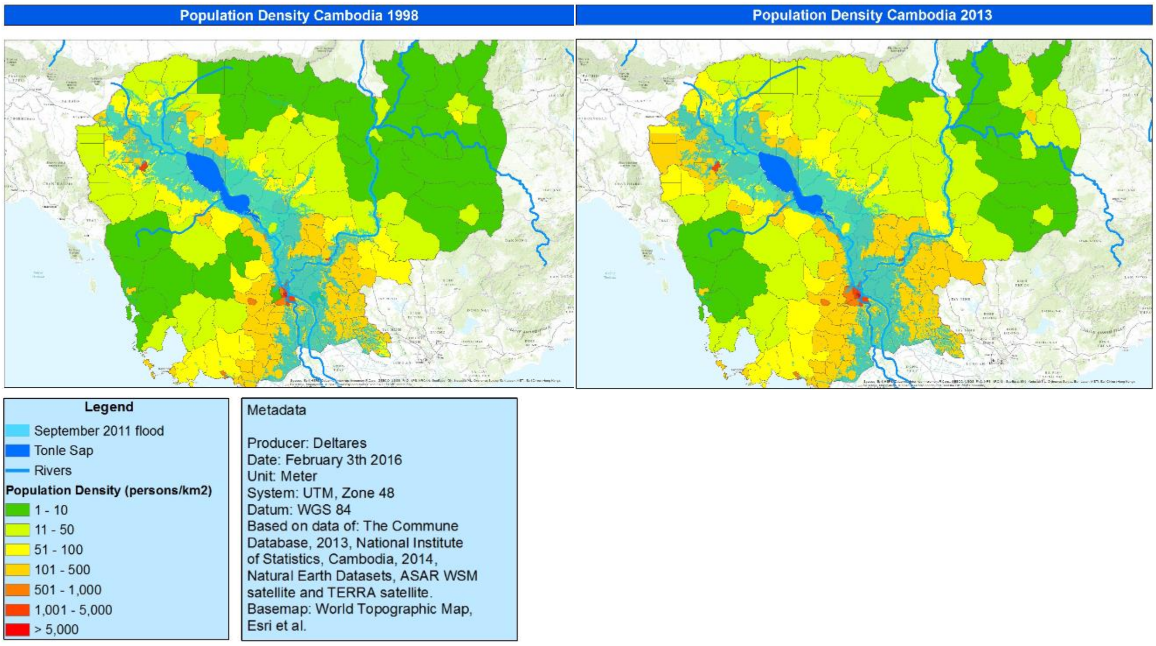


Figure 24: Visualisation of the flood affected people for 1998 and 2013 as a result of the 2011 flood. Source: The Commune Database (2013), National Institute of Statistics (2014), ASAR WSM and TERRA satellites.

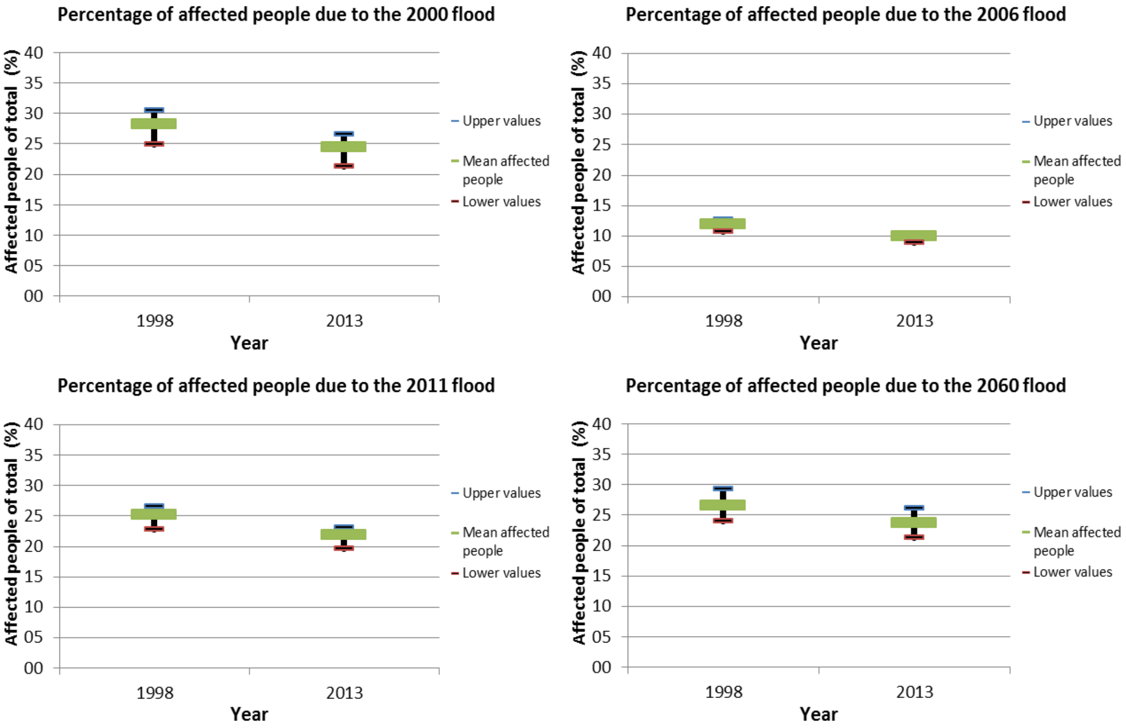


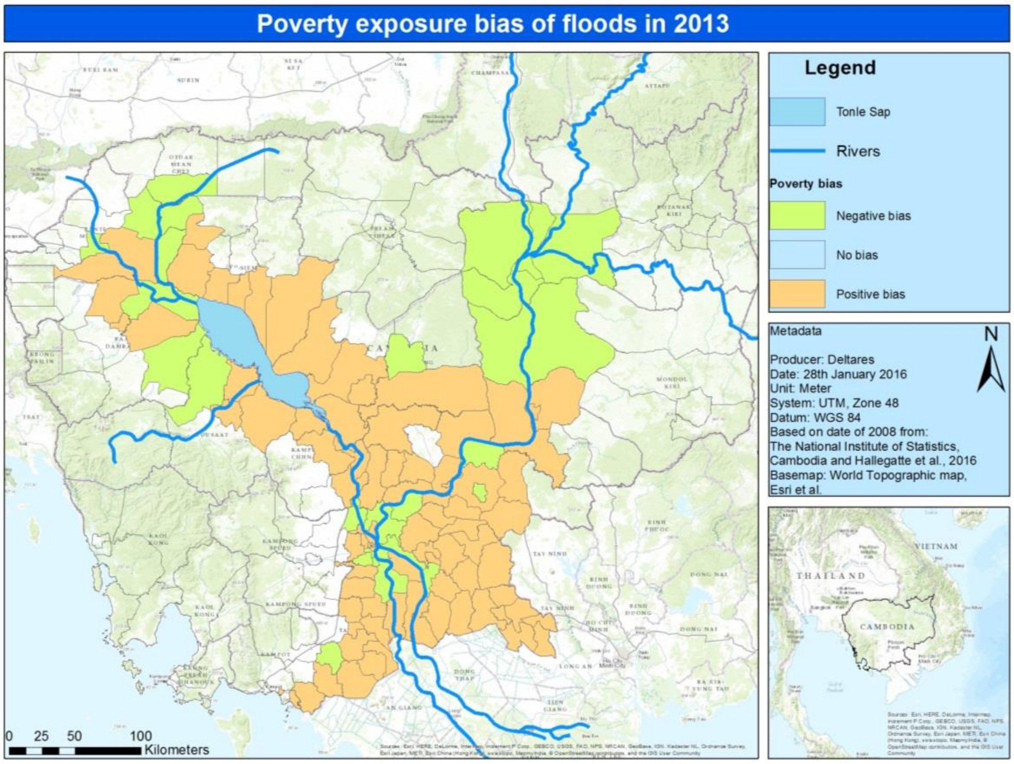
Figure 25: Number of people affected of total number of inhabitants as a result of the 2000, 2006, 2011 and the potential 2060 flood.

Moreover, the 2000, 2011 and potential 2060 flood events result in a higher percentage of affected people than in 2006, but those three flood events are furthermore quite similar in their resulting percentage of affected people.

Affecting the poorest population

With the Shock Wave report method of the World Bank (Hallegatte *et al.*, 2016) the affected poor people are tested whether they are more exposed to floods than average or not. This is done using a bias, as described in the previous chapter, for 2013 with the 2000 flood, but could also be done for 1998 and the 2060 scenarios and/or other floods.

Figure 26 displays the result for 2013 with the 2000 flood. Except for the north-east of Cambodia, the north-west of Tonle Sap and the surroundings of Phnom Penh, there are on average more districts with a positive bias than with a negative bias. This means that on average poor people are more exposed to flood than average. Especially near the south-east of Cambodia, and between Kratie and Kampong Chhang this above average positive bias is clearly visible.



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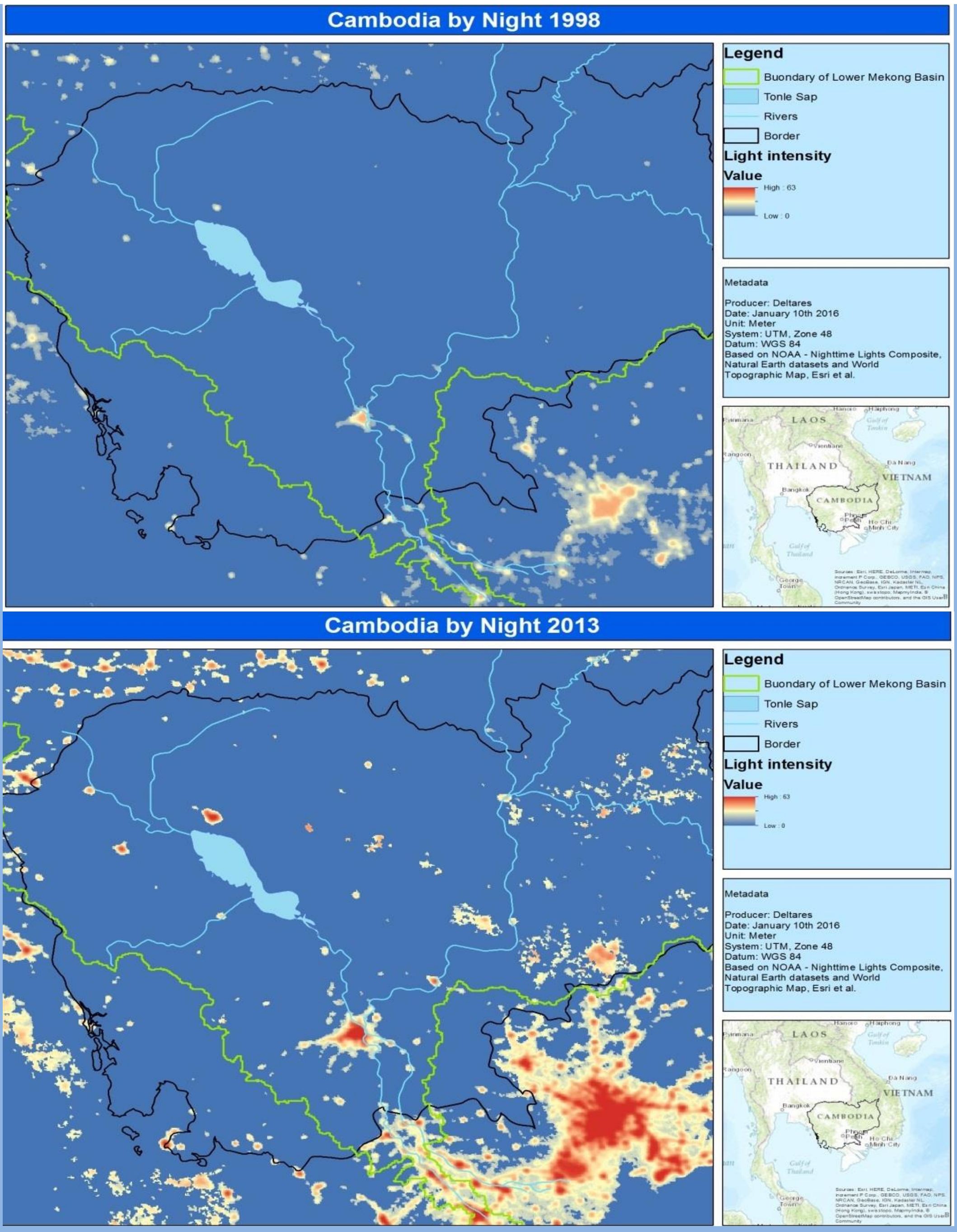
Datum: WGS 84
Based on date of 2008 from:
The National Institute of Statistics, Cambodia and Hallegatte et al., 2016
Basemap: World Topographic map, Esri et al.

Figure 26: Poverty exposure bias of the 2000 flood in the year 2013. A positive bias means poor people are more exposed to floods than average and the other way around for a negative bias.

Box 4B - Urban growth

As part of the land use change in this paragraph, the urban growth in Cambodia will also be examined. At the moment, the population density data is on a too course scale to use it for urban development analysis. Therefore damages to urban development in particular will not be modelled as it is done with for example the agricultural area data from the land cover maps; and so only a qualitative description will be given here. It would be recommended to have urban data on a finer scale in further to be able to locate households and dense populated areas more precise. In this research this will be done on a rougher scale using population density and household data on district level. However, in this part a qualitative description of the urban developments in Cambodia will be described using the NOAA Nighttime Lights Composite. In these satellite images, taken at night, the urban growth can be seen in Cambodia between 1998 and 2013 (see Figure 27).

Figure 27 reveals the urban growth of Cambodia between 1998 and 2013, which are the modelled current and past years in the report. A clear urban growth has taken place in these years, with Phnom Penh as most striking growing city, but also Siem Reap, Battambang, Kampong Cham, Kracheh and Sihanoukville have had a significant growth. Except for the urban areas in the provinces of Preah Sihanouk, Kampot and Kep all other urban growth takes mainly place in the Lower Mekong basin and particularly in the Mekong floodplain. One last remark to these maps: the 2013 situation seems to have a doubled, perhaps a tripled, urban area relative to 1998, but concluding this would be an overestimation. In the years between 1998 and 2013 satellites have improved and the urban development was also due to a better accessibility to electricity. Nevertheless, there is a certain urban growth within these years.



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Based on NOAA - Nighttime Lights Composite, Natural Earth datasets and World Topographic Map, Esri et al.

Metadata

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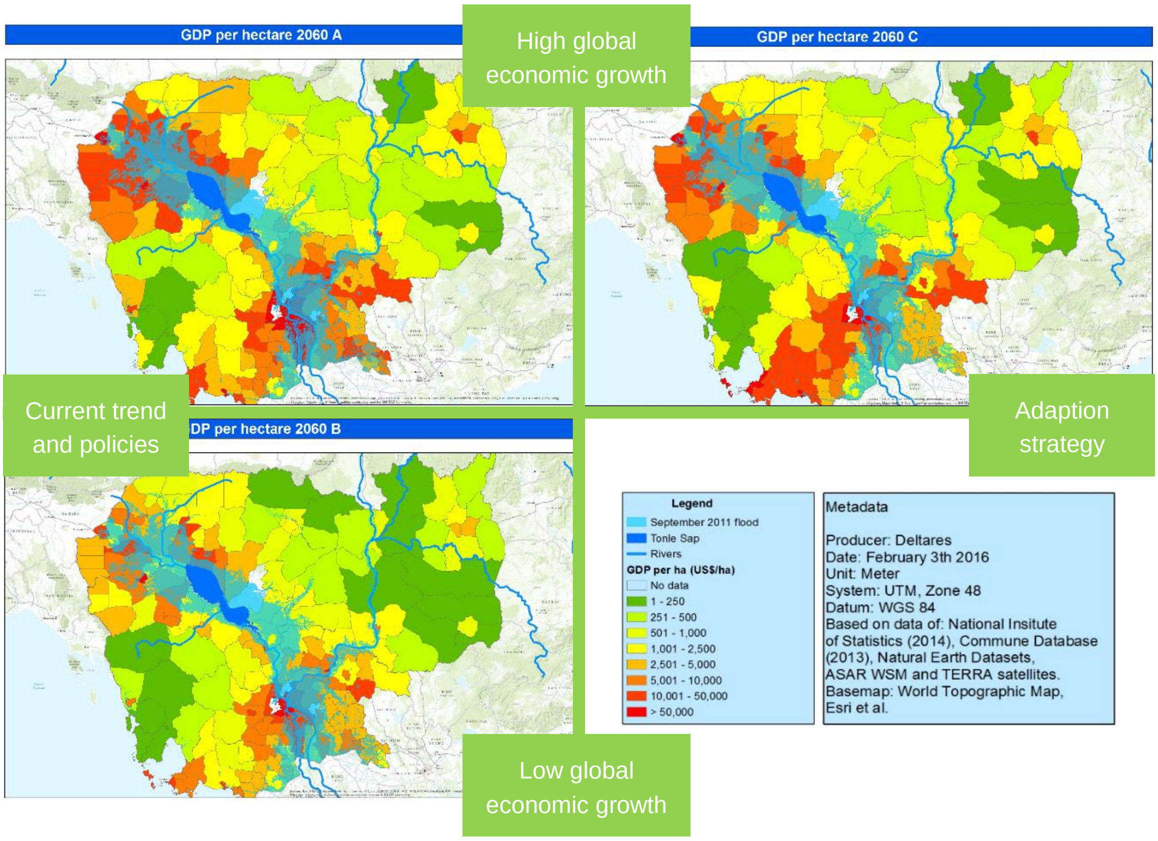
Unit: Meter
System: UTM, Zone 48
Datum: WGS 84
Based on NOAA - Nighttime Lights Composite, Natural Earth datasets and World Topographic Map, Esri et al.

Figure 27: Cambodia by night. Light intensities reveal urban areas and their growth within the time. The lights on the sea are oil/gas platforms and some non-urban areas in the maps are enlightened due to the presence of mines. Source: Nighttime Lights Composite - NOAA.

5 Analysis future situation

5.1 Impacts on the economy

As stated before the impact on the economy is expected to increase with the future socio-economic developments in Cambodia. In the previous chapter, the increase in economic damage from 1998 to 2013 was already displayed. This paragraph will focus on the future – 2060 – economic impacts and will examine the three scenarios and their influence on the economic damage. Figure 28 provides a visualisation of the by flood affected GDP when flooded by a flood similar to the 2011 flood.



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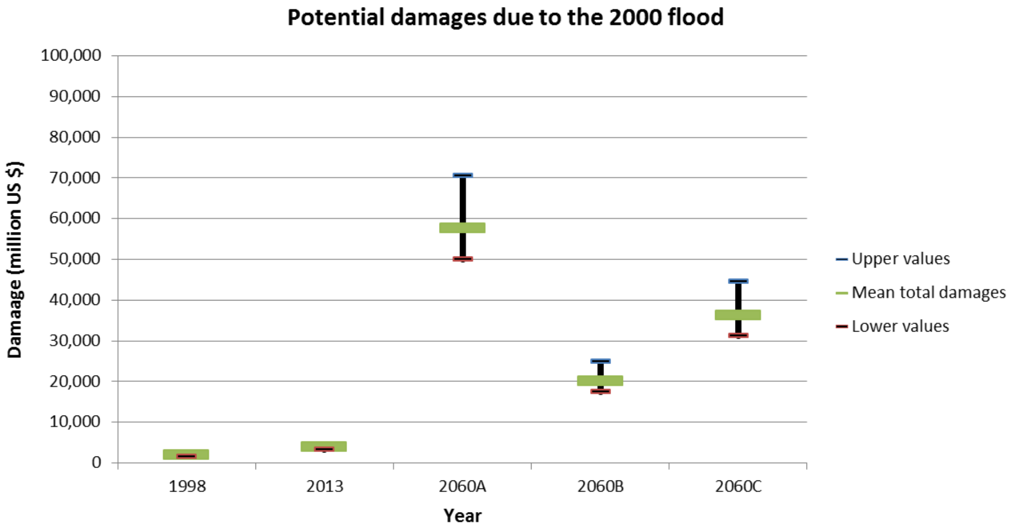
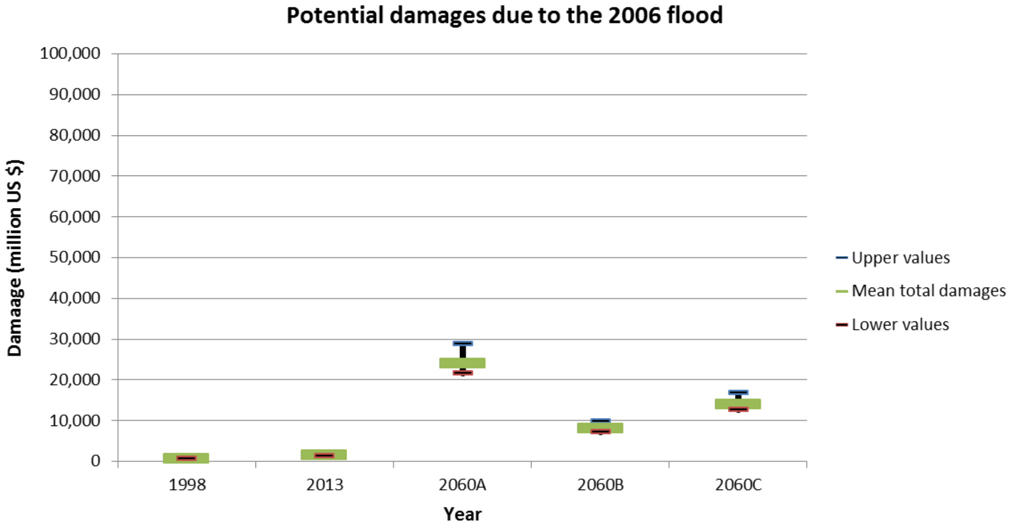
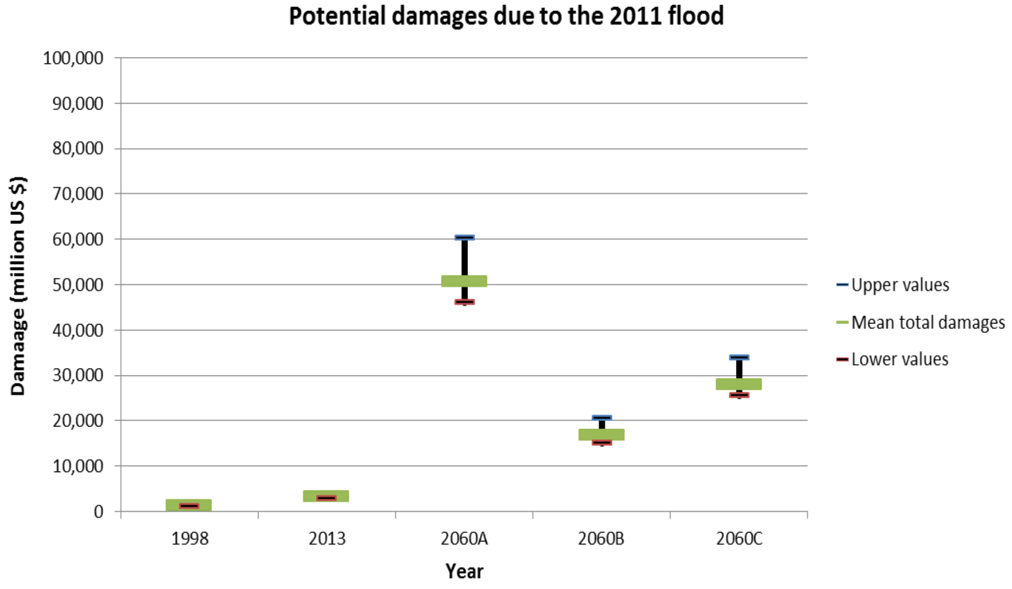
Datum: WGS 84
Based on data of: National Insitute of Statistics (2014), Commune Database (2013), Natural Earth Datasets, ASAR WSM and TERRA satellites.
Basemap: World Topographic Map, Esri et al.

Figure 28: Visualisation of the flooded GDP for the three scenarios as a result of the 2011 flood. Source: The Commune Database (2013), National Institute of Statistics (2014), ASAR WSM and TERRA satellites.

The figure above gives already a clear picture of the flood impacts on the different scenario, but in Figure 29 the potential damages are displayed and the graphs give a clear quantitative result. The results will be further discussed below.


Potential damages due to the 2000 flood
Damaage (million US $)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1998
2013
2060A
2060B
2060C
Year
Upper values
Mean total damages
Lower values


Potential damages due to the 2006 flood
Damaage (million US $)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1998
2013
2060A
2060B
2060C
Year
Upper values
Mean total damages
Lower values


Potential damages due to the 2011 flood
Damaage (million US $)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1998
2013
2060A
2060B
2060C
Year
Upper values
Mean total damages
Lower values

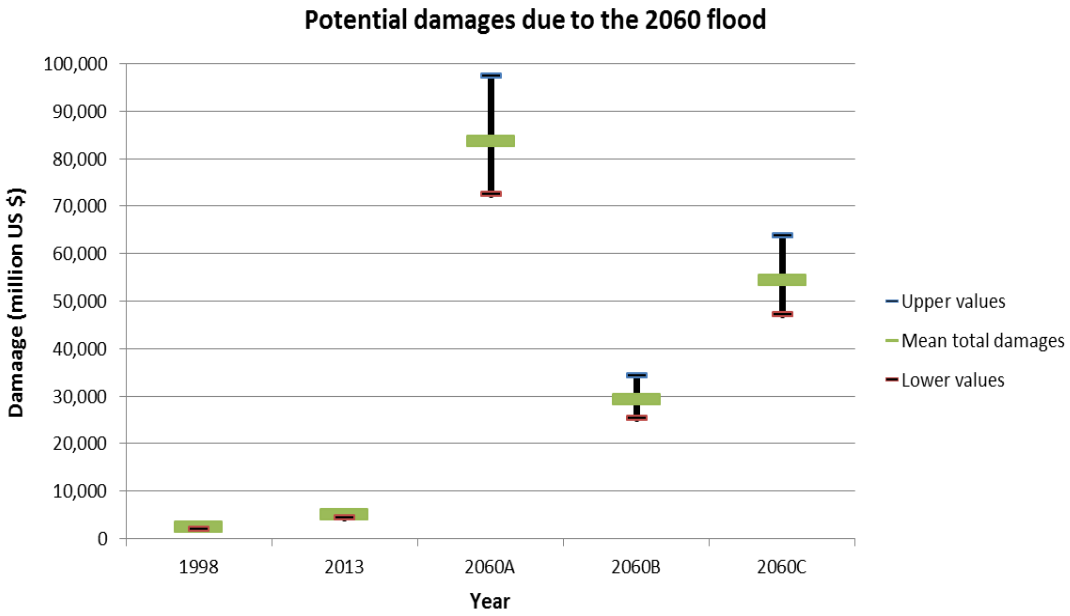


Figure 29: Potential current and future economic impact as a result of the 2000, 2006, 2011 or 2060 flood.

As in the previous chapter, the results will only be discussed in relative terms. The absolute damages give an indication of the expected damages, but are still error prone due to rough scaled data.

In comparison with the 1998 and 2013 flood damages, the 2060 scenarios result in evident higher damages. While this is an expected result as a result of economic growth and a (nearly) doubled population in 2060, it is of much more interest to have a look at the difference between these scenarios.

With scenario A and C taking place in a rapidly growing world economy – and Cambodia taking advantage of that -, the 'value' and thus the flood exposure of Cambodia is also expected to increase. Figure 29 displays the resulting increase in economic flood impact with scenario A and C having a significantly higher economic impact than scenario B, a scenario taking place in a slower growing Cambodian and world economy, 1998 and 2013.

Although the flood impact of scenario B is lower than the flood impacts of scenario A and C, it is of course an undesired scenario for Cambodia, because of its inhibited economic growth.
With a desire for a high economic growth, it is interesting to compare scenario A and C. From Figure 29 the higher damage in scenario A than in scenario C cannot be missed. Especially the floods with a higher severity, e.g. 2060 and 2000, show an absolutely clear difference between the two scenarios. Those differences are a result of the flood adaptation in scenario C, as it was formulated in Task 3 (see chapter 2).
Hence scenario C, a scenario were a great part of the economic growth takes place outside the flood, results in a lower economic impact as a result of floods than scenario A, the 'business as usual' scenario.

5.2 Impacts on the population

In the previous chapter the impacts on the population for 1998 and 2013 were already described. Figure 30 provides a visualisation of an overlay of the population density maps of 1998 and 2013 with the 2011 flood. And Figure 31 displays the impacts on the population, though this time in absolute terms, for the future scenarios compared to each other, and compared to 1998 and 2013.

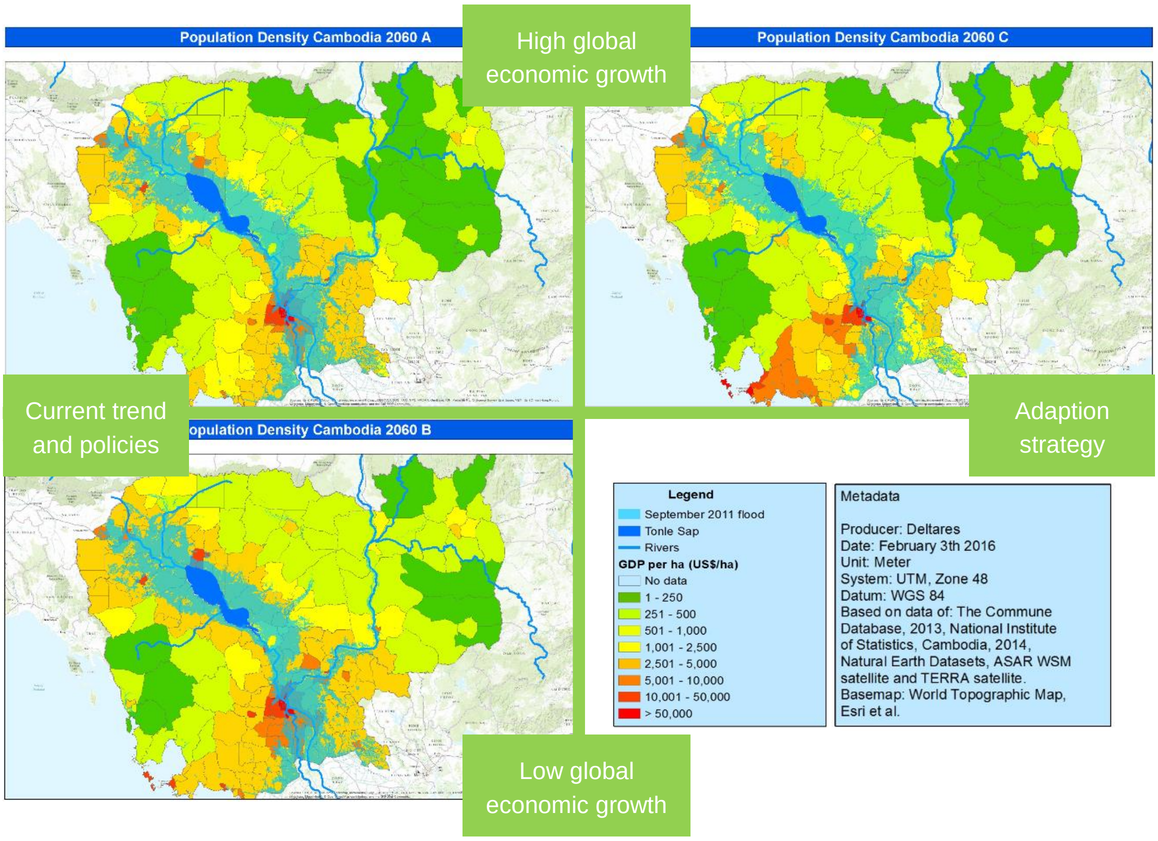
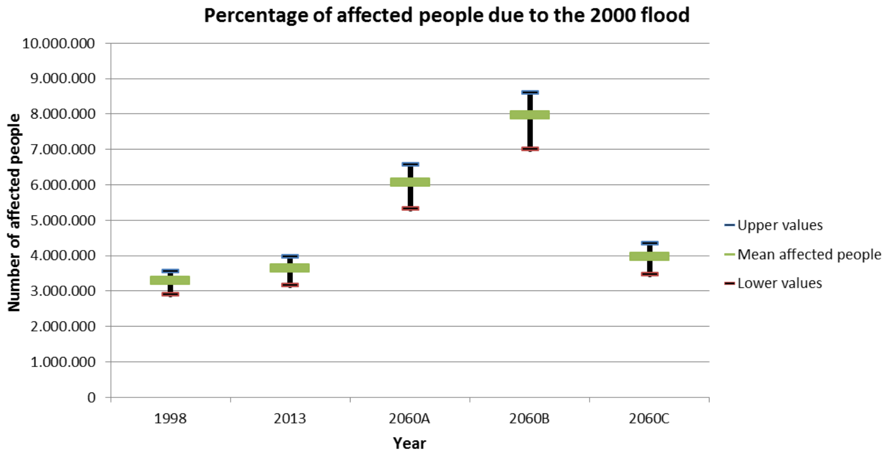
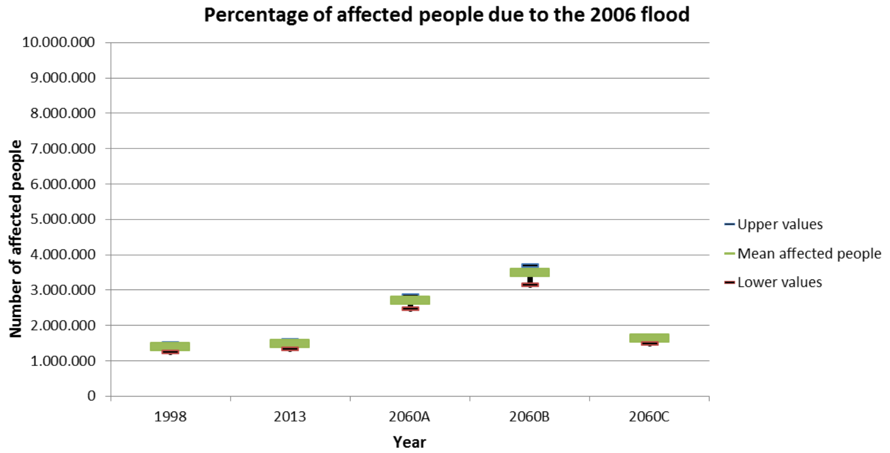
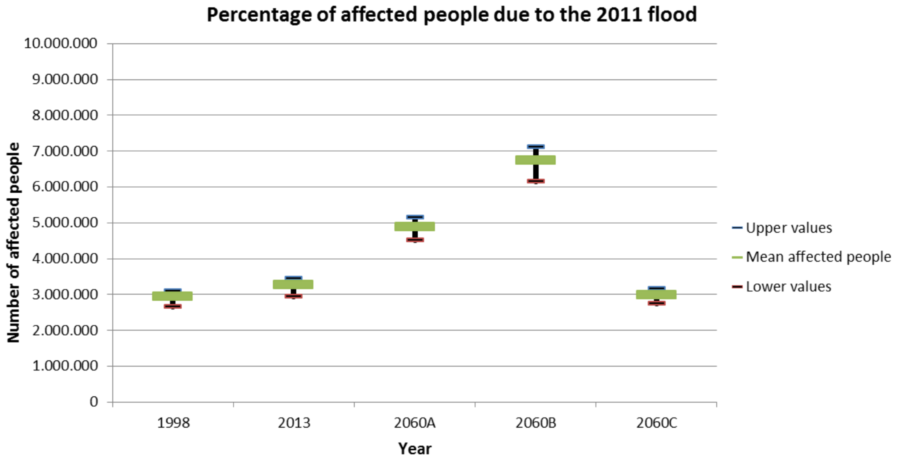


Figure 30: Visualisation of the flood affected people for the three scenarios as a result of the 2011 flood. Source: The Commune Database (2013), National Institute of Statistics (2014), ASAR WSM and TERRA satellites.


Percentage of affected people due to the 2000 flood
Number of affected people
10.000.000
9.000.000
8.000.000
7.000.000
6.000.000
5.000.000
4.000.000
3.000.000
2.000.000
1.000.000
0
1998
2013
2060A
2060B
2060C
Year
Upper values
Mean affected people
Lower values


Percentage of affected people due to the 2006 flood
Number of affected people
10.000.000
9.000.000
8.000.000
7.000.000
6.000.000
5.000.000
4.000.000
3.000.000
2.000.000
1.000.000
0
1998
2013
2060A
2060B
2060C
Year
Upper values
Mean affected people
Lower values


Percentage of affected people due to the 2011 flood
Number of affected people
10.000.000
9.000.000
8.000.000
7.000.000
6.000.000
5.000.000
4.000.000
3.000.000
2.000.000
1.000.000
0
1998
2013
2060A
2060B
2060C
Year
Upper values
Mean affected people
Lower values

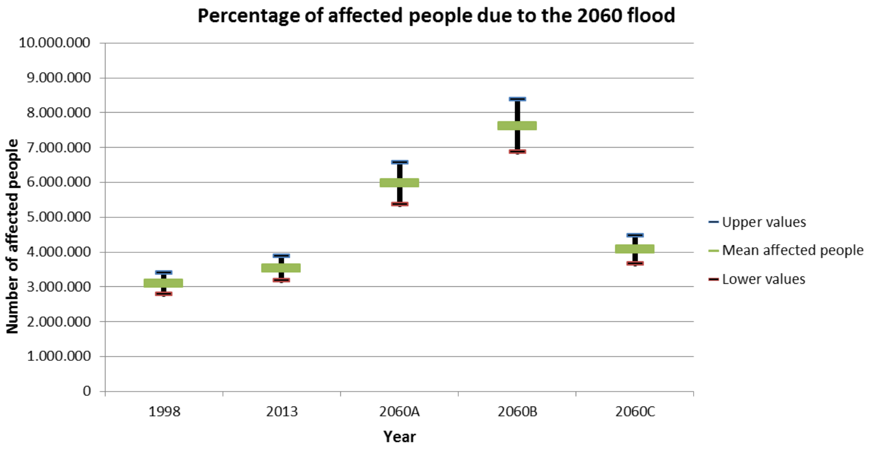


Figure 31: Total number of affected people as a result of the 2000, 2006, 2011 and the potential 2060 flood.

In contrast to the economic impact, the percentage of flood affected people in the 2060 scenarios is in relative terms quite similar to that of 1998 and 2013. However, this is only in relative terms; in absolute terms the number of affected people is, as a result of population growth, higher for the 2060 scenarios than it is for 1998 and 2013.

Scenario A and C both have 20 million inhabitants in 2060, but scenario C does have a clear lower percentage of affected people than scenario A does. This is a result of the flood adaptation in scenario C as described in chapter 2, whereby less Cambodian people live in flood prone areas.

Scenario B has, due to the large increase of people -28 million inhabitants are expected in 2060 -, and a relatively high number of poor people, the highest flood vulnerability at households level of the three scenarios. This scenario has the largest absolute number of people exposed to floods and that is also what the model results show.

Hence, Scenario C has the lowest number of affected people compared with scenario A and B. The absolute number of affected people is even not much higher than the absolute numbers of affected people in 1998 and 2013.

5.3 Results of flood protection

Economic based flood protection

As described in chapter 3 the economic based flood protection focuses on the economically more important cities in the Mekong floodplain. The result of such a protection measure is displayed in Figure 32:

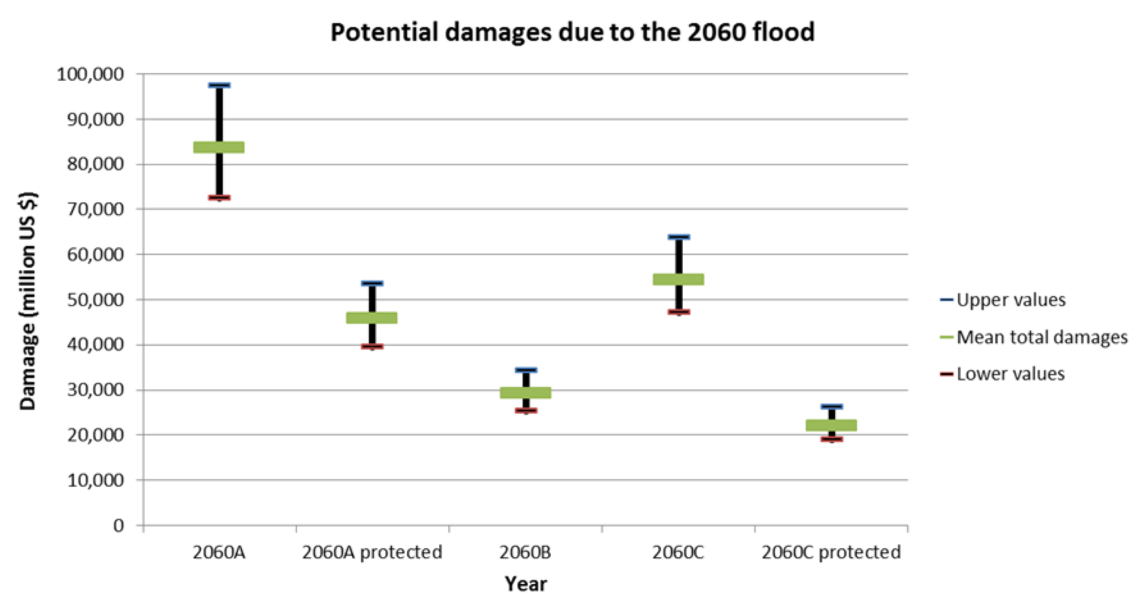


Figure 32: Potential damages due to the 2060 flood for the three 2060 scenarios and based on the (dis-)availability of flood protection.

Remarkable is the high decrease in flood damage for scenario A and C as a result of these protections. The total damage is, of course, expected to decrease as a result of the flood protections, but the total damage is even halved for both scenarios. Scenario C has even a lower total damage than scenario B when flood protection is available. However, expected is that the damage to housing and the GDP is overestimated and as a result of that the decrease in flood damage in the figure above may be too high as well.

Still the damage in scenario A is higher than in scenario B and C, though it is not as extremely high as it is without flood protections.

People based flood protection or economic based flood protection

While the economic based flood protection seems to have certain advantages, it is questionable whether the total population benefits from it or not. Figure 33 displays the number of flood affected poor people in poor class 1 and 2 with the people based flood protection of scenario B included. The number of flood affected poor people has a slight decrease in scenario B where the people based flood protection is included. In scenario A and C the decrease is even larger while the protection is economic based in both scenarios. However, in relative terms, the percentage of flood affected poor people is higher for scenario A and C with economic based flood protections than without those flood protections. The people based flood protection in scenario B on the other hand results in lower percentages of flood affected poor people than without this protection.

It remains thus questionable whether economic or people based flood protections should be in favour.

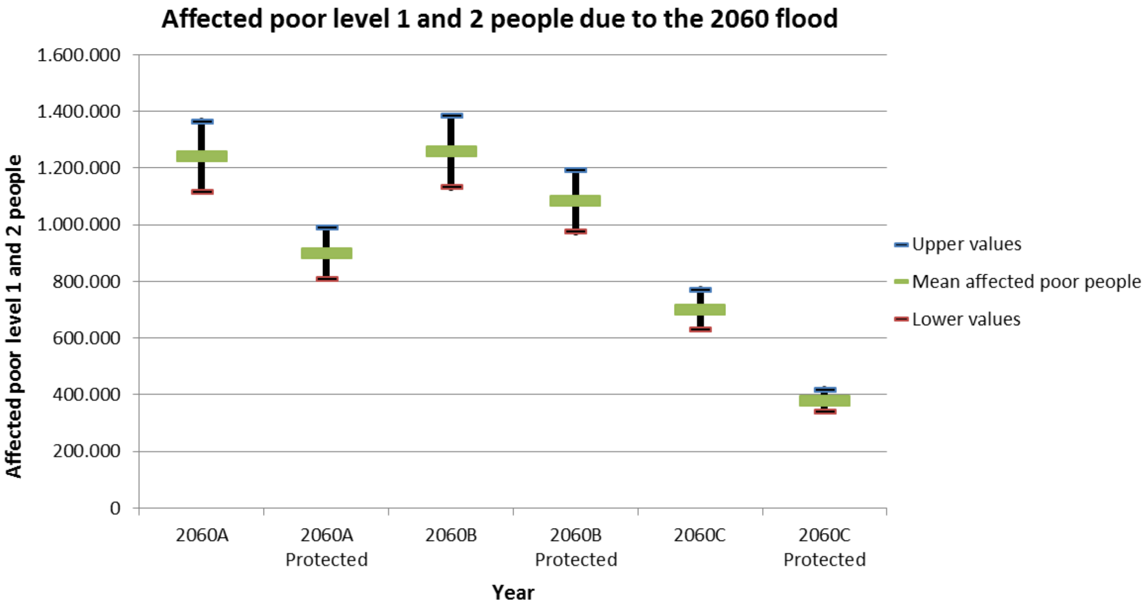


Figure 33: Number of affected poor level 1 and 2 people due to the 2060 flood. Within the scenarios the (dis-)availability of flood protection is modelled and compared.

Conclusion and recommendations

As stated before in this report, the model results are only intended to be used in relative terms and thus to compare different years and scenarios with each other.

The economic damage as a result of floods has increased in the past years and will do so towards the future. The impacts of the 2000 and the 2011 floods in Cambodia have shown an increasing trend in economic damage and the same trend is visible in the model results between 1998 and 2013. Towards 2060 the economic damage will further rise as a result of socio-economic developments within Cambodia. However, the impact is different for the three scenarios and scenario A reveals by far the highest economic damages. Scenario C results in lower economic damages and so will scenario B, although scenario B has a weaker economy than scenario A and C resulting in a lower flood exposure from economic perspective.

When looking at the number of affected population, there is an increasing trend in absolute terms. However, the results display the number of affected people as a percentage of the total number of inhabitants, and thus in relative terms. The comparison of the years and scenarios in relative terms, gives a decreasing trend of flood affective people between 1998 and 2013. In 2060 the percentage of flood affected people is not that much deviating from 1998 and 2013, with scenario A and B having a slightly higher percentage of flood affected people. Scenario C on the other hand results in the lowest percentage of affected people when compared to 1998, 2013, and scenario A and B. This lower percentage is a result of the flood adaptation in scenario C whereby a great part of the population growth takes place between the cities of Sihanoukville and Phnom Penh and thus outside flood prone areas.

Moreover, the World Bank (Hallegatte *et al.*, 2016) concluded that on the average more poor people are flood impacted. The expectation that the poorest people are most affected by floods did also result from the model. Although this was just a start in modelling the flood exposures of the poorest inhabitants, it seems that the poorer people are more exposed to floods than average. However, further research needs to be done in order to have significant evidence in proving this hypothesis.

As an additional assessment some rough scaled flood protections were modelled with Delft-FIAT. The economic based flood protection whereby ten flood prone and economically important cities were protected in scenario A and C, resulted in a halving of the total flood damage for these scenarios. While the total damage in scenario A remained the highest of the three scenarios, the total damage of scenario C became even lower than that of scenario B after the flood protections. However, expected is that the damage to housing and the GDP is overestimated and as a result of that the decrease in flood damage in the figure above may be too high as well. So, the total damage decreases as a result of flood protections, but in all likelihood it will not be as much as modelled in this research.
The people based flood protections, as it was modelled for scenario B, resulted in a lower absolute and relative number of flood affected poor people than without flood protections. Comparing this to the impact of the economic based flood protections in scenario A and C, this type of flood protection (the economic based flood protection) resulted in a higher percentage of flood affected poor people than without those flood protections. However, this is only in relative terms, while in absolute terms, the number of flood affected (poor) people has the highest decline with the economic based flood protections of scenario A and C. It is thus questionable if Cambodia should choose for a people based flood protections rather than an economic based flood protection.

Combining all of these results, scenario C may be seen as the most beneficial scenario for Cambodia. It is a scenario in an advantageous world economy – so is scenario A too -, which is of course desired, but scenario C distinguishes itself from scenario A by its flood adaptation. And together with the model results it is clear that Cambodia is less impacted by future floods in scenario C than it is in scenario A and B. Especially when this scenario is implemented together with flood protections, both the number of affected people and the total economic damage is lower than for scenario A and B.
And although this research is not intended to recommend a certain scenario, the results are clear and may be used in the consideration for the implementation of a certain scenario.

Recommendations for further research
This research has just been a start in the assessment of future flood risks in Cambodia. Further research, perhaps with the use of Delft-FIAT, offers many more possibilities in the estimation of flood impacts. The model has now been run with rough scaled – on district or commune base – data, which could be further improved by refining the scale of the data.
Household and establishment data could e.g. be implemented on a building level with the use of GIS when data and time availability allow this.
Also the damage functions and their corresponding maximum damages were on a national scale, while this could vary between districts, communes or even villages. Estimations of these functions and maximum damages could be done by local counterparts resulting in a finer scale of the input data. The extrapolation of these functions and damages to the 2060 scenarios was now done by estimating it with the GDP growth, but this could result in wrong damages and should thus be further studied.
Also the water depth maps were on a rough scale and could be further improved with the use of more precise flood extents and a Digital Elevation Model on a finer scale.

Important is the fact that in this research there is only modelled with single flood events, while modelling with multiple flood events, various recurrence times and multiple climate scenarios would allow giving flood probabilities together with their corresponding flood impacts for various recurrence times and climate models. However, this is a time-consuming process whereby a Monte Carlo analysis would be desired.

Additional to this research some subjects could be further assessed. With e.g. proper land use models future damages to the agriculture can be assessed and proposed flood protections could also be assessed within the model. Also additional was the start with modelling the flood impact on the poorest population of Cambodia. It is questionable whether the used method with Delft-FIAT is a proper way of examining this subject. At least more years and flood events should be examined before the result may be seen as significant. Still, this report might be a good starting point for further research to the flood exposure of poor people together with the World Bank report by Hallegatte *et al*. (2016). In the poverty analysis it might be worthwhile to display the total number of flood affected poor people for the different scenarios. It then perhaps might give a clear result of the effect of the different scenarios on the number of flood affected poor people.

Last, and stated before in chapter 2, effects of upstream developments in the Lower Mekong Basin are not taken into account, but could have a major effect on future flood impacts in Cambodia. The effects of upstream developments are thus recommended for further research.

Discussion

Assessing the impacts of single flood events on a rough scale, as it is done in this research, is regarding the data and time availability perhaps a logical choice, but it is an error prone approach. In this last chapter some of the results will be discussed based on their probable deviations.

As already stated in the results, the damage to households may be overestimated with the model. This overestimation is a result of the rough household data scale together with a damage function that is on a national level, while many of the flood affected households are elevated by the use of stilts and are thus insensitive for water depths of around two meters. As described in the recommendations, refining the data scale would certainly solve this problem.

Also the Gross Domestic Product is discussable since there is a lack of literature describing the total economic impact of a flood, while the total flood damage in the model results is for a great part a result of losses in the GDP. Therefore this part of the model could not be evaluated as it was done for the infrastructural and housing damages. The high band widths of the results corresponding to the GDP, give an indication of the sensitivity of this parameter.
Part of this was also a result of the absence of a damage functions for the GDP. In this research is was assumed that there is no damage to the GDP at a water depth below the 0.30 meter and there is maximum damage to the GDP at a water depth of 0.30 meter or higher. In real life this is of course not valid and a better damage function is thus desired.

For the affected population the same problem arises as with the GDP. There is no damage function available for affected population and therefore the damage function was the same as it was with the GDP, thus below 0.30 meter no flood affection of the people and at a water depth of 0.30 meter or higher all people in that particular grid cell are flood affected.
However, the question arises when an inhabitant is flood affected. Without an answer to this question, a damage function cannot be made and the assessment can only be done in relative terms as it is done in this research.

The last error prone subject is the infrastructure. The roads were obtained from the Open Street Maps database, which gives a fair representation of the national roads and the railroads, but the mostly unpaved rural roads had worse data coverage. Expected was that only 10% of the total number of rural roads were present in the Open Street Maps database. However, this is an error prone assumption – multiplying the resulting rural road damages with a factor 10 – and it should be better in further research to have a detailed road map. Furthermore the maximum damages to the infrastructure were not extrapolated to future values, because it was unclear what the growth in the maximum damage for the infrastructure would be and whether or not the future flood protections of the roads would increase.

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Appendices

5.4 Appendix 1: Scenario estimations

Population			1998	2000	2010	2011	2013	2020	2030	2040	2050	2060
(In million of people)		scenario A	11,6	12,2	14,4	14,6	14,9	17	18	19	20	20
		scenario B	11,6	12,2	14,4	14,6	14,9	17	20	23	25	28
		scenario C	11,6	12,2	14,4	14,6	14,9	17	18	19	20	20
		scenario D	11,6	12,2	14,4	14,6	14,9	17	20	23	25	28

			1998	2000	2010	2011	2013	2020	2030	2040	2050	2060
GDP growth rate	%	Scenario A	5,1	8,8	5,9	7,1	7,4	8	7	7	6	5
as used in scenarios		Scenario B	5,1	8,8	5,9	7,1	7,4	5	4	4	3	3
Average annual real GDP		Scenario C	5,1	8,8	5,9	7,1	7,4	8	7	7	6	5
growth rates (%)		Scenario D	5,1	8,8	5,9	7,1	7,4	5	4	4	3	3

			1998	2000	2010	2011	2013	2020	2030	2040	2050	2060
GDP (constant prices of	million	Scenario A	3308	4.027	8.693	9.308	10.723	18.378	36.152	71.116	127.359	207.454
$mln 2005)		Scenario B	3308	4.027	8.693	9.308	10.723	15.089	22.335	33.061	44.432	59.712
as used in scenarios		Scenario C	3308	4.027	8.693	9.308	10.723	18.378	36.152	71.116	127.359	207.454
		Scenario D	3308	4.027	8.693	9.308	10.723	15.089	22.335	33.061	44.432	59.712

GDP per capita			1998	2000	2010	2011	2013	2020	2030	2040	2050	2060
Constant prices of 2005		scenario A	285	330	604	638	720	1.114	2.008	3.743	6.465	10.373
		scenario B	285	330	604	638	720	888	1.117	1.469	1.777	2.133
		scenario C	285	330	604	638	720	1.114	2.008	3.743	6.465	10.373
		scenario D	285	330	604	638	720	888	1.117	1.437	1.777	2.133

				1998	2000	2005	2006	2007	2008	2009	2010	2011	2013	2020	2030	2040	2050	2060
Share GDP (at constant prices of 2000) Note: the GDP of 1998, 2000 and 2010 are at current prices.	%	Scenario A	Agriculture	46,3	37,8	32,4	31,7	31,9	34,9	35,7	36,0	36,7	33,6	25	20	15	12	10
			Industry	17,4	23,0	26,4	27,6	26,8	23,8	23,1	23,3	23,5	25,6	30	35	40	42	45
			Services	36,3	39,1	41,2	40,8	41,3	41,3	41,3	40,7	39,8	40,9	45	45	45	46	45
		Scenario B	Agriculture	46,3	37,8	32,4	31,7	31,9	34,9	35,7	36,0	36,7	33,6	35	34	32	31	30
			Industry	17,4	23,0	26,4	27,6	26,8	23,8	23,1	23,3	23,5	25,6	25	26	28	29	30
			Services	36,3	39,1	41,2	40,8	41,3	41,3	41,3	40,7	39,8	40,9	40	40	40	40	40
		Scenario C	Agriculture	46,3	37,8	32,4	31,7	31,9	34,9	35,7	36,0	36,7	33,6	25	20	15	12	10
			Industry	17,4	23,0	26,4	27,6	26,8	23,8	23,1	23,3	23,5	25,6	30	35	40	42	45
			Services	36,3	39,1	41,2	40,8	41,3	41,3	41,3	40,7	39,8	40,9	45	45	45	46	45
		Scenario D	Agriculture	46,3	37,8	32,4	31,7	31,9	34,9	35,7	36,0	36,7	33,6	35	32	30	28	25
			Industry	17,4	23,0	26,4	27,6	26,8	23,8	23,1	23,3	23,5	25,6	25	28	30	32	35
			Services	36,3	39,1	41,2	40,8	41,3	41,3	41,3	40,7	39,8	40,9	40	40	40	40	40

				1998	2000	2005	2006	2007	2008	2009	2010	2011	2013	2020	2030	2040	2050	2060
Employment sector share Note: values of 2000 and 2010 are not available.	%	Scenario A	Agriculture	77,5	73,7				72,2	57,6	54,2	55,8	48,7	45	42	40	35	30
			Industry	4,2	8,4				8,6	15,9	16,2	16,9	19,9	23	25	27	30	35
			Services	18,2	17,9				19,2	26,5	29,6	27,3	31,5	32	33	33	35	35
		Scenario B	Agriculture	77,5	73,7				72,2	57,6	54,2	55,8	48,7	50	50	50	50	50
			Industry	4,2	8,4				8,6	15,9	16,2	16,9	19,9	20	20	20	20	20
			Services	18,2	17,9				19,2	26,5	29,6	27,3	31,5	30	30	30	30	30
		Scenario C	Agriculture	77,5	73,7				72,2	57,6	54,2	55,8	48,7	42	35	28	20	15
			Industry	4,2	8,4				8,6	15,9	16,2	16,9	19,9	25	27	30	30	30
			Services	18,2	17,9				19,2	26,5	29,6	27,3	31,5	33	38	42	50	55
		Scenario D	Agriculture	77,5	73,7				72,2	57,6	54,2	55,8	48,7	45	42	40	38	35
			Industry	4,2	8,4				8,6	15,9	16,2	16,9	19,9	20	22	22	22	25
			Services	18,2	17,9				19,2	26,5	29,6	27,3	31,5	35	36	38	40	40

Figure 34: Estimations of the values for scenario A-D based on the World Bank database.

5.5 Appendix 2: Used datasets

Population

Migration:

Data regarding urbanization is acquired from the General Population Census of Cambodia 2008, National Institute of Statistics and Ministry of Planning. The data provides urban and rural population numbers for 1998 and 2008.

Current and future population densities:

Data regarding the demography of Cambodia on district level has been acquired between 1998 and 2013. The Commune Data Base (2013) delivered population data for the years 2009, 2010, 2011, 2012 and 2013 (although it seems that the data of 2009 don’t seem to be the true values for that year, so they won’t be used for now). Furthermore, the Cambodian National Institute of Statistics (2014) delivered demography data for the years 1998 and 2008.

GDP (Gross Domestic Product)

The GDP at current 2005 prices is available per year from the World Bank Database (World Bank, 2015). The database contains GDP values, distributions of the GDP per sector, employment rates (both in total aspect as per sector) and it contains growth rates for the GDP. Furthermore, the data employment distribution per sector (agriculture, industry or service) for every district was available through the Cambodian Flood Management and Mitigation Programme (FMMP).

Households

The maximum household damage will be calculated using the damages and losses data of the PFERNA Team Assessment (2013) together with The World Bank Dataset of the inflation in Cambodia.

Infrastructure

Railroads are obtained from the Natural Earth 2015 database on a 10 meter precision scale. The roads were obtained, with the use of a Python script, from the Open Street Map datasets (2015). These roads have been split in primary, secondary and tertiary roads using a simple select by attributes function. What should be realized, is that Open Street Map is an open source database and it doesn’t cover every road in Cambodia, because it is still under development. For urban areas the coverage of Open Street Maps is fairly good in Cambodia - probably even more precise than with Google Maps e.g. -, but for rural areas less information is available and therefore roads may be missing. The overall coverage is probably enough for an estimate as will be made here.

For the planning of the future (rail)roads the Flood Management and Mitigation Programme was used from the National Transport Planning (Khy A., 2015). And for the economic loss after a flood, data of the 2011 flood damages and losses by the Asian Development Bank (2012) have been used.

Poverty

In a cooperation of: the Minstry of Planning Cambodia, GIZ Germany, Federal Ministry for Economic Cooperation and Development Germany, Australian Aid, Australian Government: Department of Foreign Affairs and Trade (2014) a big project has taken place to indicate poor households and poor people in Cambodia. From their database the percentages of poor people were obtained on commune level. The database is incomplete for some communes, but it is useable.

Land cover maps
Land cover maps of 2000 and 2010 were obtained from the Climate Change Initiative, Land Cover of the European Space Agency. The land cover has a spatial resolution of 300 meters.

Urban development
In the qualitative description of the urban development of Cambodia, satellite images taken by night were used of the Nighttime Light Composite of the NOAA. NOAA (2016): *"The files are cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. In cases where two satellites were collecting data - two composites were produced. The products are 30 arc second grids, spanning -180 to 180 degrees longitude and -65 to 75 degrees latitude."* Used is the stable lights dataset, which has less deviations due to haze, forest fires, etc.

Water depth maps
The water depth maps were created from the Digital Elevation Model (DEM) of Southeast-Asia with a spatial resolution of 500 m together with the flood extents of 2000, 2006, 2011 and 2060, though 2060 is of course an estimation. The 2000 and 2006 (September 21) extents were obtained with the courtesy of the Mekong River Commission, the 2011 flood extent was obtained from the ASAR WSM and TERRA satellites which is a combination of satellite images between September 21 and September 27, courtesy of the United Nations.
Both the DEM and satellite images aren't very precise, which will result in a non-precise water depth map, where this is wanted when the spatial socio-economic data is precisely located.
However, most of the data is on district level, a quite rough scale, which allows it to use these water depth maps.

5.6 Appendix 3: Estimation of the parameters

Population densities

For every year in the dataset, the population density (both in persons/km^2 and in persons/ha) was calculated by dividing the number of inhabitants per district of that year by the area of the district.

Estimations for the 2060 population densities for the different scenarios have been made. Instead of doing this by extrapolating the current population growth between 1998 and 2013, this was done by correcting for the tremendous urbanization rate in Cambodia. Using the current population growth would also erroneously take into account fertility of a district, which is currently high for some districts, but will not persist until 2060. Thus, not fertility, but urbanization will have a major role in determining the population per district in 2060.The correction for the urbanization in Cambodia was done by using the urbanization trends between 1998 and 2008 per province and by scaling this to the expected level of urbanization in 2060 for the different scenarios. For scenario A and C an urbanization level of 55% is expected, and for scenario B an urbanization level of 35% is expected according to the scenarios made.
The annual urban growth rate between 1998 and 2008 was calculated by:

$$GR = \frac{N_{urban\,2008} - N_{urban\,1998}}{N_{urban\,1998} * 10} * 100\% \qquad (0.1)$$

Where: $N_{urban\,2008}$ is the number of urban population per province in 2008 and $N_{urban\,1998}$ is the number of urban population per province in 1998. There was a conditional made in this formula, because Phnom Penh is expected to have the highest urban growth rate for the 2060 scenarios. A province having a higher urban growth rate will be lowered in its growth rate to the maximum growth rate, which is the same as that of Phnom Penh.
With the annual urban growth rate the number of urban people per province in 2060 was calculated starting with the 2008 values:

$$N_{urban\,2060} = N_{urban\,2008} * \left(\left(\frac{GR}{100}\right) + 1\right)^{52} \qquad (0.2)$$

Where: $N_{urban\,2060}$ and $N_{urban\,2008}$ are the number of urban population per province in 2060 and 2008 respectively and $\frac{GR}{100}$ is the annual urban growth rate as a fraction. With this formula the number of urban population will slightly overestimate the number of urban people in 2060 scenario A and C, but will give an enormous overestimation for 2060 scenario B. Correcting for this was done by given a correction factor to all the provinces based on the ratio between the estimated total urban population and the urban population as it was stated by the scenarios. For scenario A en C it is assumed that the total number of inhabitants is 20,000,000 of which 11,000,000 are urban and 9,000,000 are rural. The total number of inhabitants for scenario B is assumed to be 28,000,000 of which 8,400,000 are urban and 19,600,000 are rural. The correction was made using the following formula:

$$N_{urban\,corrected\,2060} = N_{urban\,2060} * \frac{N_{t,urban\,2060}}{N_{t,urban}} \qquad (0.3)$$

Where: $N_{urban\,corrected\,2060}$ is the corrected number of urban population per province in 2060 for a certain scenario, $N_{urban\,2060}$ is the estimated number of urban population per province in 2060, $N_{t,urban\,2060}$ is the total number of urban population for a certain scenario in 2060 and $N_{t,urban}$ is the total number of urban population according to the first estimation.

Then the other half of the total number of inhabitants is rural and this has to be calculated as well. Known is the number of rural population per province in 2008 and the total number of rural population for the three 2060 scenarios. With these numbers, a rural population on province scale can be calculated using:

$$N_{rural\ 2060} = N_{rural\ 2008} * \frac{N_{t,rural\ 2060}}{N_{t,rural\ 2008}} \tag{0.4}$$

Where: $N_{rural\ 2060}$ is the number of rural population per province in 2060 for a certain scenario, $N_{rural\ 2008}$ is the number of rural population per province in 2008, $N_{t,rural\ 2060}$ is the total number of rural population for a certain scenario in 2060 and $N_{t,rural\ \ 2008}$ is the total number of rural population in 2008.

From of this point the urban and rural population for the three scenarios in 2060 is known on province level, though it must be stated that the population numbers for scenario A and C are until this point still the same. The population can be divided over the associated districts. This has been done by taking the ratio of the 2008 inhabitants per district by its province inhabitants of 2008, and multiplying this with the number of urban/rural inhabitants for the 2060 scenarios on province level:

$$N_{u,r\ 2060\ district} = N_{u,r\ 2060} * \frac{N_{d\ 2008}}{N_{p\ 2008}} \tag{0.5}$$

Where: $N_{u,r\ 2060\ district}$ is the number of urban or rural population per district in 2060 for a certain scenario, $N_{u,r\ 2060}$ is the number of urban or rural population per province in 2060 for a certain scenario – this is the result of formula 1.3 and 1.4-, $N_{d\ 2008}$ is the number of population per district and $N_{p\ 2008}$ is the number of population of the associated province.
Thus, the total number of inhabitants per district for a certain scenario is then the sum of the number of urban and rural population as calculated above.

To estimate the population for scenario C, the districts between Phnom Penh and Sihanoukville have got an extra growth rate of 60% and the districts in the floodplain have got an extra growth rate of -60%. After that, the population density was calculated for the three scenarios by dividing the number of inhabitants by the area of its district.

GDP (Gross Domestic Product)
In this part the GDP per district for the years 1998 and 2013 will be calculated, where after the estimations for the different 2060 scenarios will be made based on an extrapolation of the World Bank data and the GDP distribution per sector and district in 1998 and 2013.
For 1998 and 2013 the total number of employed people per sector and per district was calculated using the number of people per district and the percentage of employed people per sector and district, with the following formula:

$$N_{e\ =\ f_{s,d}} * N_d \tag{0.6}$$

Where N_e is the number of employed people in a sector for a certain district, $f_{s,d}$ is the fraction of employed people for a sector (e.g. agriculture) in a certain district and N_d is the number of inhabitants in a district.
In the used data it was assumed that the used definition for the industrial sector was different than that of the World Bank. Instead of an overall employment rate of 19,9% and 4,2% in the industrial sector for 2013 and 1998 respectively, the total employment rate of the used district sector employment share was 0,7% and 3,9% for 2013 and 1998 respectively. As a result of this the agricultural sector and the service sector were also having deviating values, where the agricultural sector was often a lot higher and the service sector a bit lower than the World Bank data.
Because of the overall use of World Bank data a correction has to be made:

$$N_{wb} = \frac{f_{wb,t}}{f_{s,t}} * N_e \qquad (0.7)$$

Where N_{wb} is the number of employed people in a sector for a certain district after the correction, $f_{wb,t}$ is the total fraction of employed people for a certain sector according to the World Bank data, $f_{s,t}$ is the total fraction of employed people for a certain sector according to district based employment data and N_e is again the number of employed people in a sector for a certain district before the correction is executed.

Then, the GDP at constant 2005 prices of that year was subdivided in the GDP per sector (agriculture, industry and services) using the GDP distribution at constant 2005 prices of the World Bank data. With these results it is possible to calculate the GDP distribution per district, subdivided per sector. This distribution was calculated using the following formula:

$$GDP_d = \frac{GDP_t * f_{GDP,s}}{N_{wb,t}} * N_{wb} \qquad (0.8)$$

Where GDP_d is the GDP per sector for a certain district, GDP_t is the total GDP of that year, $f_{GDP,s}$ is the fraction of GDP distribution per sector, $N_{wb,t}$ is the corrected total number of employed people in a sector and N_{wb} is the corrected number of employed people in a sector for a certain district.

One last note to the GDP distributions: they are all measured in agriculture, industry, services and taxes, while only the first three are used in the calculations. The percentages of the agriculture, industry and services were corrected for the absence of the taxes, so that the total percentage is still 100%. From the 1998 and 2013 values maps were made and later on this will also be done for the different 2060 scenarios.

With the results of the previous part and the assumptions for the 2060 scenarios, the GDP values per district can be calculated. To do this, the GDP growth, total GDP, GDP share per sector and employment sector share were extrapolated, using the World Bank data, to 2060 for all the scenarios. These values are then the expected 2060 values, for a given scenario, on national level. The next step is to calculate these values on district level. The above described method was used to calculate the GDP per district and sector for 2060, with the only difference that the total GDP, the GDP sector share and the employment rate per sector were different with the assumptions made for the 2060 scenarios.

The only missing data for these calculations are the number of inhabitants per district in 2060 and the percentage of employed people per district and sector. An estimation of the number of inhabitants per district was already made for the different scenarios; see also the demography part of this report. With this estimation, also an estimation of the total number of urban and rural inhabitants per district was made. Then, only the percentage of employed people per district and sector has to be estimated. The ratios, as they were in 2013, were maintained; with the only assumption that the industrial and service sector will grow at the expense of the agricultural sector. Therefore it is assumed that the urban people will work in the industrial and service sector and that the rural people will work in the agricultural sector. This is an assumption that will never be fully fulfilled, but it will give a good view of the 2060 situation for the different scenarios.

Per district, the number of employed people in the agricultural sector will then be:

$$N_a = f_t * N_{d,r} \qquad (0.9)$$

Where, N_a is the number of employed people per district in the agricultural sector, f_t is the total, so all sectors together, of employed people per district and $N_{d,r}$ is the number of rural inhabitants for a certain district.

The industrial and service sector have to share the urban population according to the assumptions, so the following two formulas have been used:

$$N_i = \left(f_t * N_{d,u}\right) * \left(\frac{f_i}{f_i + f_s}\right) \tag{0.10}$$

$$N_s = \left(f_t * N_{d,u}\right) * \left(\frac{f_s}{f_i + f_s}\right) \tag{0.11}$$

Where, N_i and N_s are the number of employed people per district in the industrial and service sector respectively, f_t is the total, so all sectors together, of employed people per district, $N_{d,u}$ is the number of urban inhabitants for a certain district, f_i is the fraction of employed people in the industrial sector in 2013 according to the National Institute of Statistics (2014) and f_s is the same as f_i, but then for the service sector.

Now, the number of employed people per sector and district are known, but these are still not corrected for the World Bank data. This correction and subsequently the calculation of the GDP per district is done in the same as for 1998 and 2013, so with the two formulas above to calculate N_{wb} and GDP_d.

Some last remarks

One is that the employment sector share of the National Institute of Statistics (2014) for districts with a SEZ have been adjusted, because they are expected to result in a higher employment sector share for the industrial sector and, the service sector. For scenario A, all current and future SEZ's according to Open Development Cambodia (2015) were given a 10% sector share for the industrial sector - where they usually had around 1% - at the expense of the agricultural sector. The same methodology was used for scenario C, but here the SEZ's in the floodplain are left out of these calculations. In scenario B this methodology wasn't used, because in sector B it is assumed that the share of the SEZ's in the total GDP will be of minor concern.

Secondly, there are districts with high urbanization levels, while they are expected to remain quite rural in the future. In the estimation of the total number of inhabitants, the urbanization rate on province level was taken into account. Now, they've got high urban-rural ratios, because their province got a high urban-rural ratio as result of one major city in that province. To correct for this, the urban-rural ratio of these districts have been adjusted. 30% of the inhabitants will be urban and 70% of the inhabitants in these districts will be rural. With the above given calculations, this will give lower GDP's for these districts.

Last, for scenario C it is assumed that the region between Sihanoukville and Phnom Penh will have the biggest growth of Cambodia. Assumed are high urbanization levels for the districts with the greater cities (Dangkao, Kanding, Krong Kampot, Mean Chey, Saensokh, Stueng Hav and Tuol Krouk). Thus, assumed is that 90% of the inhabitants will be urban and 10% will be rural inhabitants. Some districts around these greater cities (Angk Snuol, Botum Sakor and Chamkar Mon) are assumed to have 75% urban population and 25% rural population. The rural districts between Phnom Penh and Sihanoukville (Chhuk, Chum Kiri, Kampong Seila, Phnum Sruoch, Prey Nob, Thpong and Tuek Chhou) will also certainly urbanize, but not that much. They're expected to have 40% urban population and 60% rural population in 2060 for scenario C.

Households

The maximum damage to households per inhabitant and thus the average household value per inhabitant was calculated for 2013 by dividing the total damage of destroyed households after the 2013 flood by the number of destroyed households, assuming that the households can't have a higher damage than the damage of a destroyed household.

These maximum damages were corrected to constant 2005 values using the inflation rates of The World Bank Database (2015). Subsequently, the maximum damage per inhabitant to households was calculated for 1998 and the 2060 scenarios, still at constant 2005 values. In order to do this, the 2013 maximum damage value was multiplied with a correction factor obtained from the GDP difference between those years:

$$HV_x = HV_{2013} * \frac{GDP_x}{GDP_{2013}} \qquad (0.12)$$

Where: HV_x is the household value per inhabitant in year x, HV_{2013} is the household value per inhabitant in 2013, GDP_x is the GDP of year x and GDP_{2013} is the GDP in 2013.

Infrastructure

From the Open Street Map data and the Natural Earth 2015 data the roads and railroads were obtained. As described above the roads have been split in primary, secondary and tertiary roads using a simple select by attributes function. These data have been used to make a map of the 2015 infrastructural situation.

The Flood Management and Mitigation Programme report (Khy A., 2015) consists of the future infrastructural plans which were used to indicate the 2060 situation for scenario A. In this scenario many new primary and secondary roads will be made, of which most are situated in the floodplain, and the same counts for the new railroads that will be constructed. Also most of the existing roads will be upgraded to qualitative better and/or broader roads.

In contrast to scenario A, scenario B will have nearly as many (rail)roads as in the current, 2015, situation. This has all to do with the low economic growth, causing the government to probably choose for (rail)road upgrading instead of (rail)road renewal.

Scenario C has a population growth mainly between the Phnom Penh area and Sihanoukville, so a growth to the southwest of the country, causing an expected main growth of the labour and thus the infrastructure to the southwest as well. It is expected that mostly in this part of the country, outside the floodplain, great (rail)road renewal and upgrading projects will take place and that in the rest of Cambodia – and mainly in the floodplain – the roads will only be upgraded.

The (rail)road density of Cambodia was estimated in meters per hectare, because Delft-FIAT will use raster grids in its calculations and those are in hectares in this research. This has been done by using the Line Density tool from the ArcGIS spatial analyst toolbox, which calculates per grid cell the density of lines, (rail)roads in this case, for a defined search radius around the grid cell (Silverman B.W., 1986). The search radius was chosen to be as large as the raster size, which is 100 m. The (rail)road density was estimated for the existing (rail)roads and the (rail)roads that are expected in the three scenarios.

After the (rail)road density has been estimated, the maximum damage per meter and infrastructure type will be estimated. Here, a lot of assumptions are made, which certainly have to be taken into account.

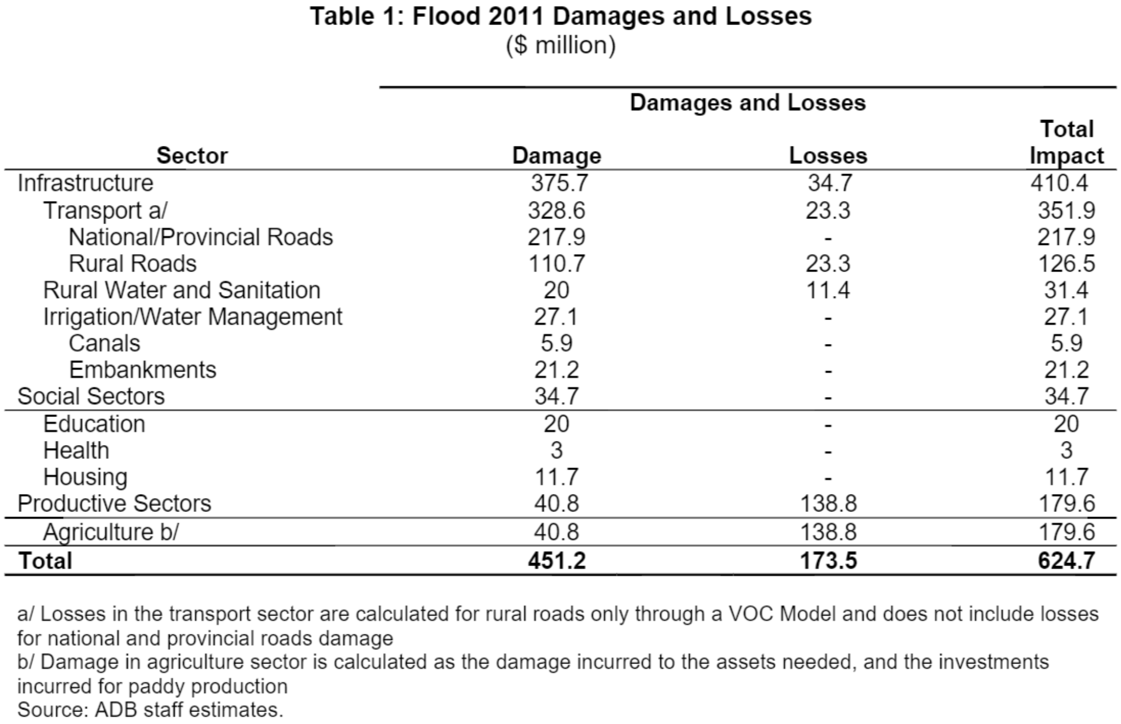

Table 1: Flood 2011 Damages and Losses
($ million)

Sector	Damages and Losses		
	Damage	Losses	Total Impact
Infrastructure	375.7	34.7	410.4
Transport a/	328.6	23.3	351.9
National/Provincial Roads	217.9	-	217.9
Rural Roads	110.7	23.3	126.5
Rural Water and Sanitation	20	11.4	31.4
Irrigation/Water Management	27.1	-	27.1
Canals	5.9	-	5.9
Embankments	21.2	-	21.2
Social Sectors	34.7	-	34.7
Education	20	-	20
Health	3	-	3
Housing	11.7	-	11.7
Productive Sectors	40.8	138.8	179.6
Agriculture b/	40.8	138.8	179.6
Total	**451.2**	**173.5**	**624.7**

a/ Losses in the transport sector are calculated for rural roads only through a VOC Model and does not include losses for national and provincial roads damage
b/ Damage in agriculture sector is calculated as the damage incurred to the assets needed, and the investments incurred for paddy production
Source: ADB staff estimates.

Figure 35: Cambodian damages and losses after the 2011 flood. Table copied from: Asian Development Bank (2012), the Flood Damage Emergency Reconstruction Project.

First of all, the Asian Development Bank has categorized the infrastructure in three categories (see also Figure 35): national/provincial roads, rural roads and a residual (not mentioned as residual, but it will be called the residual from now on). With the above described datasets, four categories of infrastructure (primary roads, secondary roads, tertiary roads and railroads) could be used. In order to match both types of data, two assumptions will be made: the residual term in the Asian Development Bank report will be used as an estimate for the railroad damages and losses, and the primary and secondary roads from the Open Street Map dataset will be combined to national/provincial roads. Furthermore, the rural roads correspond to the tertiary roads.

What furthermore is available, are the total length of infrastructure, per category, that is damaged (see Figure 35). This results in the ratio of damaged infrastructure over the total inundated infrastructure, both per category.
The data of the Asian Development Bank (Figure 35) doesn’t contain affected and damaged length information about the railroads. The affected length could be calculated by using the ‘Identity’ tool in ArcGIS, with the Cambodian railroads as input and a flood Shapefile of 15 October 2011 as output. The result of this should be an attribute table with both the different railroads outside the flooded area and the different railroads inside the flooded area. From the railroads inside the flood area, the length is summed and this gives the total affected length.

Poverty
From the Identification of Poor Households Programme (Ministry of Planning Cambodia *et al.* 2014) poor level 1 and poor level 2 percentages were obtained on commune level. Together with these percentages, the dataset also contains the total population in the communes for the year of data acquisition. However, this year of data acquisition is varying per province and there should be corrected for. Since there is no population data available on a more detailed scale

than on district level, the correction is done with the use of a distribution formula. The total population per commune for a certain year (1998, 2013 or one of the 2060 scenarios) was calculated using the following formula:

$$N_{commune} = \frac{N_{commune\ old}}{\sum N_{communes,\ district}} * N_{district} \qquad (0.13)$$

Where: $N_{commune}$ is the number of inhabitants for a certain commune in a certain year, $N_{commune\ old}$ is the number of inhabitants for a certain commune according to the poor households programme dataset, $\sum N_{communes,\ district}$ is the sum of inhabitants of all communes belonging to a certain district and $N_{district}$ is the number of inhabitants for the same district as calculated in the paragraph 'demography'.

Then the number of people per commune in poor level 1 or poor level 2 is simply calculated using the following formula:

$$N_{commune,poor\ level\ 1/2} = N_{commune} * f_{poor\ level\ 1/2} \qquad (0.14)$$

Where: $N_{commune,poor\ level\ 1/2}$ is the number of inhabitants per commune living in a poor level 1 or poor level 2 class, $N_{commune}$ is the number of inhabitants for a certain commune in a certain year and $f_{poor\ level\ 1/2}$ is the fraction of inhabitants per commune in poor level 1 or 2 according to the Poor Households Programme.

Scenario A and C are a bit more difficult, because those scenarios are expected to have a decreasing poverty, although the inequality will be quite high, especially in scenario A. To correct for this decreasing poverty, the poverty percentages are made dependent on the percentage of people working in the agricultural and industrial sector, because those sectors, especially the agricultural one, are expected to deliver most, if not all, of the poor people.

From the 2013 scenario the ratio 'percentage of people in poor class 1 & 2' to 'agricultural and industrial sector share' was taken and later on used as a factor to calculate the 2060 scenario A and C poor class 1 & 2 values by multiplying this factor with the sector share of the agricultural and industrial sector together. The formulas belonging to those two steps are explained below:

$$r = \frac{f_{poor\ level\ 1\&2}}{f_a + f_i} \qquad (0.15)$$

Where: r is the ratio percentage of people in poor class 1 & 2 to agricultural and industrial sector share, $f_{poor\ level\ 1\&2}$ is the fraction of poor people in level 1 and 2 for a certain district in 2013 and $f_a + f_i$ is the agricultural and industrial employment sector share for the same district.

$$f_{poor\ level\ 1\&2\ 2060A\ or\ C,d} = r * \left(f_{a,2060} + f_{i,2060}\right) \qquad (0.16)$$

Where: $f_{poor\ level\ 1\&2\ 2060\ A\ or\ C}$ is the fraction of poor people in level 1 and 2 for a certain district in 2060 scenario A or C, r is the ratio percentage of people in poor class 1 & 2 to agricultural and industrial sector share and $f_{a,2060} + f_{i,2060}$ is the agricultural and industrial employment sector share for the same district in 2060.

Yet, the fraction of poor people in level 1 and 2 has been calculated on district level instead of commune level, because the employment sector share data is only available on district level. A correction has to made, which resembles to formula 1.12:

$$f_{poor\ level\ 1\&2\ 2060A\ or\ C,c} = \frac{f_{poor\ level\ 1\&2\ 2013}}{\frac{\sum_0^n f_{poor\ level\ 1\&2\ 2013}}{n_{communes,district}}} * f_{(poor\ level\ 1\&2\ 2060AorC,d)} \qquad (0.17)$$

Where: $f_{poor\ level\ 1\&2\ 2060A\ or\ C,c}$ is the fraction of poor people in level 1 and 2 for a certain district in 2060 scenario A or C, $f_{poor\ level\ 1\&2\ 2013}$ is the fraction of poor people in level 1 and 2 for a certain commune in 2013, $\frac{\sum_0^n f_{poor\ level\ 1\&2\ 2013}}{n_{communes,district}}$ is the average of poor people in level 1 and 2 for the district belonging to the commune of $f_{poor\ level\ 1\&2\ 2013}$ and $f_{(poor\ level\ 1\&2\ 2060A\ or\ C,d)}$ is the fraction of poor people in level 1 and 2 for a certain district in 2060 scenario A or C, as calculated in formula 1.15.

Then the number of people per commune in poor level 1 and 2 is simply calculated using the following formula:

$$N_{commune,poor\ level\ 1\&2} = N_{commune} * f_{poor\ level\ 1\&2\ 2060A\ or\ C,c} \tag{0.18}$$

Where: $N_{commune,poor\ level\ 1\&2}$ is the number of people in a certain commune living in poor level 1 and 2, $N_{commune}$ is the number of inhabitants for a certain commune in a certain year and $f_{poor\ level\ 1\&2\ 2060A\ or\ C,c}$ is the fraction of poor people in level 1 and 2 for a certain district in 2060 scenario A or C.

As a last step, the number of people in poor level 1 and the number of people in poor level 2 are calculated assuming that their ratio has stayed the same:

$$N_{commune,poor\ level\ 1/2} = N_{commune,poor\ level\ 1\&2} * \frac{f_{poor\ level\ 1\ or\ 2,2013}}{f_{poor\ level\ 1\&2,2013}} \tag{0.19}$$

Where: $N_{commune,poor\ level\ 1/2}$ is the number of people in a certain commune living in poor level 1 or poor level 2, $N_{commune,poor\ level\ 1\&2}$ is the number of people in a certain commune living in poor level 1 and 2, $f_{poor\ level\ 1\ or\ 2,2013}$ is the fraction of people living in poor level 1 or poor level 2 for a certain commune in 2013 and $f_{poor\ level\ 1\&2,2013}$ is the fraction of people living in poor level 1 and 2 for the same commune in 2013.

N.B. in scenario C these calculations didn’t work out very well for the provinces of Preah Sihanouk and Kampot, since these provinces aren’t quite wealthy in some districts at this moment, while they’re certainly expected to have a decreasing poverty in 2060 scenario C. To correct for this, the poor level 1 and 2 percentages were adjusted to 5.0% the communes of Preah Sihanouk and to 7.5% for the communes of Kampot, though only the communes of Kampot located in the district of Krong-Kampot.

Water depth maps

The calculation of the water depths as result of a certain flooding, was done by estimating the water level and then subtracting the elevation of it. Assumed is that the water level of the flood is slightly decreasing downstream and that the water level is the same at the edges as it is in the middle of the flooding. When these assumptions are satisfied, then, together with some interpolation, the water level height can be estimated by using the elevation of the edges of the flood extent. At this point the water depth is 0 meter, and thus is the water level equal to the elevation, as obtained from the DEM, at those edges.

With the spline with barriers functions in ArcGIS an interpolation is done with as input height data at points along the flood extent edge. The spline with barriers function then returns a polygon with water levels as output.

Subsequently, the elevation is distracted from the water level with the ArcGIS raster calculator only for those places where the land surface is really flooded, since the water level polygon is an interpolation over the whole area and thus gives an overestimation of the flooded area.

5.7 Appendix 4: Explanation of the land cover legend

Table 11: Combination of legend numbers from the land cover map with its land cover type.

Legend number	Land cover type
0	No data
10	Cropland, rainfed
11	Herbaceous cover
12	Tree or shrub cover
20	Cropland, irrigated or post-flooding
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)
50	Tree cover, broadleaved, evergreen, closed to open (>15%)
60	Tree cover, broadleaved, deciduous, closed to open (>15%)
61	Tree cover, broadleaved, deciduous, closed (>40%)
62	Tree cover, broadleaved, deciduous, open (15-40%)
70	Tree cover, needleleaved, evergreen, closed to open (>15%)
71	Tree cover, needleleaved, evergreen, closed (>40%)
72	Tree cover, needleleaved, evergreen, open (15-40%)
80	Tree cover, needleleaved, deciduous, closed to open (>15%)
81	Tree cover, needleleaved, deciduous, closed (>40%)
82	Tree cover, needleleaved, deciduous, open (15-40%)
90	Tree cover, mixed leaf type (broadleaved and needleleaved)
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)
120	Shrubland
121	Shrubland evergreen
122	Shrubland deciduous
130	Grassland
140	Lichens and mosses
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)
152	Sparse shrub (<15%)
153	Sparse herbaceous cover (<15%)
160	Tree cover, flooded, fresh or brakish water
170	Tree cover, flooded, saline water
180	Shrub or herbaceous cover, flooded, fresh/saline/brakish water
190	Urban areas
200	Bare areas
201	Consolidated bare areas
202	Unconsolidated bare areas
210	Water bodies
220	Permanent snow and ice