



# Impact of climate change on the competitive position of inland waterway transport

## Knowledge for Climate

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## Inhoudsopgave

1.	Introduction.....	5
1.1	Background.....	5
1.2	Content of report .....	5
2.	Approach.....	7
3.	Scenarios .....	9
3.1	Base year and future time horizon.....	9
3.2	Economic and climate scenario.....	9
3.3	Comparison reference and climate change situation.....	10
4.	Impact of closing frequency of the Maeslantkering .....	11
4.1	Introduction .....	11
4.2	Water levels .....	11
4.3	Methodology cost calculations.....	12
4.4	Direct impact and consequences for the competitive position of inland waterway transport..	13
5.	Impact of low water levels on the main rivers on inland waterway transport .....	14
5.1	Introduction .....	14
5.2	Water levels .....	14
5.3	Methodology.....	19
5.3.1	BIVAS model and results .....	20
5.3.2	TRANS-TOOLS model and results .....	28
5.3.3	Competitive position of Rotterdam – port choice .....	33
5.4	Direct impact of low water levels on main rivers on inland waterway transport.....	34
6.	Summary, conclusions and recommendations .....	36
	References.....	38
Annex A –	Description of the KNMI climate change scenarios (in Dutch) .....	40
Annex B –	Overview absolute water levels W+ and reference situation 2050, worst case 10 day period .....	42





## **1. Introduction**

### **1.1 Background**

As a consequence of climate change more and more severe periods with high water are expected during winter time and more and more severe periods with low water are expected during summer time. More periods with higher and lower water levels than currently occur might lead to increased transport costs (when more vessels are needed to ship the same volume of goods) and reduced reliability of inland waterway transport (when the inland waterway transport is not feasible anymore).

The goal of this Knowledge for Climate study, Water and Transport, is to analyze the impact of climate change on inland waterways, identify the problems and their magnitude and to elaborate the most effective solutions for these problems.

This report is one of the sub-reports of the Water and Transport study and it describes the analysis that has been made by TNO to determine the impact of climate change on the competitive position of inland waterway transport. Given the climate change scenarios for a future situation up to the year 2050, the report answers the question: is there any problem concerning the competitive position of inland waterway transport, and if there is, how big is this problem?

### **1.2 Content of report**

In chapter 2 the approach of the analysis is described globally. Chapter 3 gives an overview of the scenarios that are used to make a comparison between a reference situation and a climate change situation. For the impact on the competitive position of inland waterway transport two types of analysis are distinguished in this report. One analysis concerns the impact of high sea water levels and the corresponding closing frequency of the Maeslantkering on the inland waterway transport, which is described in chapter 4. The other analysis focuses on the impact of lower water levels on the main rivers on the inland waterway transport and is described in chapter 5. Finally, in chapter 6 a summary of the approach, the main conclusions and recommendations for further research are included.

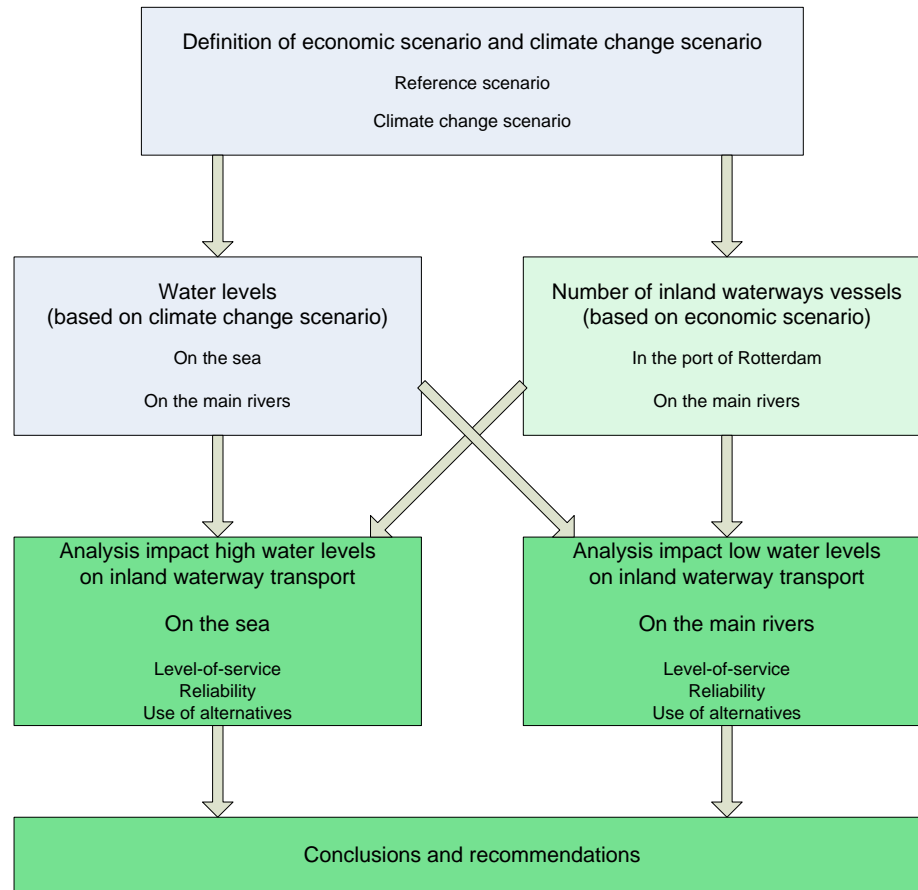




## 2. Approach

This chapter gives a global overview of the approach that has been applied in this study to determine the impact of climate change on the competitive position of inland waterway transport. An illustration of the approach is given in figure 2.1.

**Figure 2.1: Global overview of the approach**



As the figure shows the approach starts with the definition of the scenarios for the selected time horizon 2050. Two scenarios are mentioned: an economic scenario and a climate change scenario to determine the water levels in 2050.

The climate change scenario is used to determine the future water levels on the sea and on the main rivers. The economic scenario is used to determine the future volume of freight flows and the number of vessels needed to transport these volumes.

Then both the water levels and the number of ships per ship type are used to determine the direct impact on inland waterway transport: level-of-service, reliability and the use of alternatives. The level-of-service, or the performance, of the inland waterway transport is affected by the change in transport costs and times, while delays and obstructions caused by lower water levels will affect the reliability of the inland waterway transport. Furthermore, if the impact is high, alternatives can be found in other transport modes or another port choice, for instance the choice to go to the port of Hamburg in stead of the port of Rotterdam.

Finally, the results are analyzed and the main conclusions and recommendations are presented.



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The grey parts in the overview are input for the analysis in this report. The definition of the scenarios has been carried out with all partners in the consortium. The analysis of the water levels has been carried out by Deltares.

The light green part – determination of number of inland waterways vessels – has been done partly by Rijkswaterstaat (RWS) and partly by TNO.

The green parts in the overview have been carried out by TNO. Most effort has been put in the analysis of the impact of low water levels on the main rivers on the inland waterway transport.





### 3. Scenarios

An important starting point for work in this report concerns the scenarios that are used. Together with all partners in the consortium it has been decided what scenarios to use for this study. The main characteristics of the scenarios are described in this chapter.

#### 3.1 Base year and future time horizon

##### **Base year data: 2004**

Both for the water levels and for the number of inland waterways vessels base year data are needed. Because transport data about the number of vessels is available for the year 2004 based on the Basisbestand Goederenvervoer 2004 study (NEA/TNO, 2007) and because data about water levels in the year 2004 are available, it has been decided to take the year 2004 as the reference year for the base year data. Besides, it is mentioned that the water levels in the year 2004 are slightly below average. This means that concerning the water levels 2004 is not representing an average year, but a year with water levels slightly below the average.

##### **Time horizon: 2050**

Since it is expected that most of the impact of climate change will take place on a very long term, it makes not much sense to analyze the impact of climate change for the next 10 or 20 years. Therefore, it has been decided to take the year 2050 as the time horizon when serious impact of climate change is expected.

#### 3.2 Economic and climate scenario

##### **Economic scenario: Global Economy (WLO)**

As mentioned in the previous chapter, an economic scenario is necessary to determine the volume of the freight flows (for all transport modes) and the number of vessels needed (for inland waterway transport) to transport these volumes. From the four WLO scenarios (CPB/MNP/RPB, 2006), the Global Economy scenario, which is the scenario that has – by far – the highest growth and the highest volume of freight flows, has been chosen for this study. The reason this scenario has been chosen is that in this study it is intended to determine an upper bound for the impact of climate change.

One remark has to be made concerning the Global Economy scenario. The WLO scenarios have been elaborated up to the year 2040, not up to the year 2050. In the Netherlands no scenarios are available for the period between 2040 and 2050. Therefore it has been decided to use the Global Economy 2040 scenario for the time horizon 2050. An implicit assumption is that in the period 2040 – 2050 the freight volumes will not change. This assumption is probably not correct, but since there is no information about the period 2040 – 2050 and the Global Economy scenario is already a – very – high growth scenario it was agreed to make these assumptions. By following this approach the Global Economy scenario becomes a bit less high growth scenario up to 2050.

##### **Climate change scenario: W+ scenario**

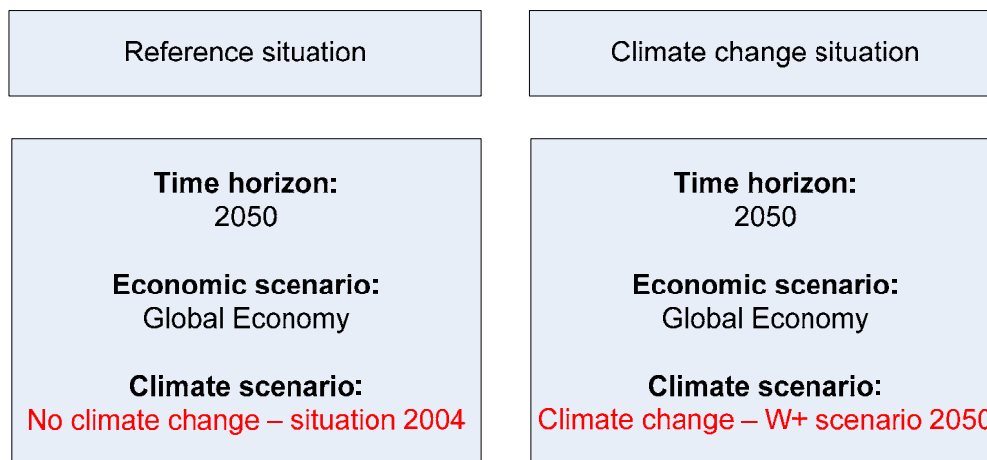
The climate change scenario is an important input for this study to determine the change in water levels on the sea and on the main rivers. In 2006 the KNMI has developed four new climate scenarios for the Netherlands that have been based on worldwide scenarios (KNMI, 2006). A brief description is included in annex A (in Dutch). For this study the two scenarios W and W+ are used, where the W+ scenario has the highest impact on water levels. From the first results it became clear very soon that the impact of the W scenario on the water levels is rather limited. Therefore, the W+ scenario has been used as the worst case climate change scenario.

### 3.3 Comparison reference and climate change situation

#### Impact climate change: comparison reference situation and climate change situation

In order to analyze the impact of the climate change, a comparison will be made between a reference situation without climate change and a situation including climate change. A schematic overview of these two situations is given in figure 3.1.

Figure 3.1: Schematic overview reference situation and climate change situation



This figure shows that for both the reference situation and the climate change situation the time horizon 2050 is used in combination with the Global Economy scenario. This means that in both situations, the number of inland waterways vessels is exactly the same. In both situations the climate scenario is different. In the reference situation it is assumed that no climate change will take place, more practical this means that the water levels in 2050 are the same as the water levels that have been observed in 2004. In the climate change situation it is assumed that the W+ scenario will be reality. This means that in 2050 the water levels will be in line with the W+ scenario (more and more severe periods with high water in winter and mainly more and more severe periods with low water in summer time).

By comparing the situations that only differ in climate scenario (water levels), a pure analysis of the impact of climate change can be made.

#### Characteristics climate change situation: worst case

The climate change situation that is used in this study can be characterized as a worst case climate situation. Reasons for this are that the base year data about the water levels in 2004 concerns already a year with water levels below the average, that the Global Economy scenario leads to a – very – high growth of the number of inland waterways vessels and that from the four KNMI scenarios the W+ scenario is the scenario with the highest impact on the water levels.



## 4. Impact of closing frequency of the Maeslantkering

### 4.1 Introduction

Climate change does not only have impact on the water levels on the main rivers (with high water in winter time and low water in summer time), but it is also expected to have impact on the sea water level (increase of the sea water level).

In the Rotterdam area a number of storm surge barriers have been constructed to prevent regions that lie below the sea water level from flooding. The two storm surge barriers that prevent the regions from high sea water levels and that are relevant for this study are the Maeslantkering on the Nieuwe Waterweg and the Hartelkering on the Hartelkanaal (see figure 4.1).

Figure 4.1: Locations of storm surge barriers Maeslantkering and Hartelkering



In case of a storm with high sea water levels the storm surge barriers are closed to stop the seawater entering the rivers and canals. Consequently, the rivers and canals are also obstructed for inland waterways and sea vessels.

Currently, it is expected that these storm surge barriers have to close once every 10 years. The relevant questions for this study are: what will be the increase of the sea water level in the W+ scenario, how will this influence the closing frequency of the Maeslantkering and what will be the impact of this on the competitive position of inland waterway transport?

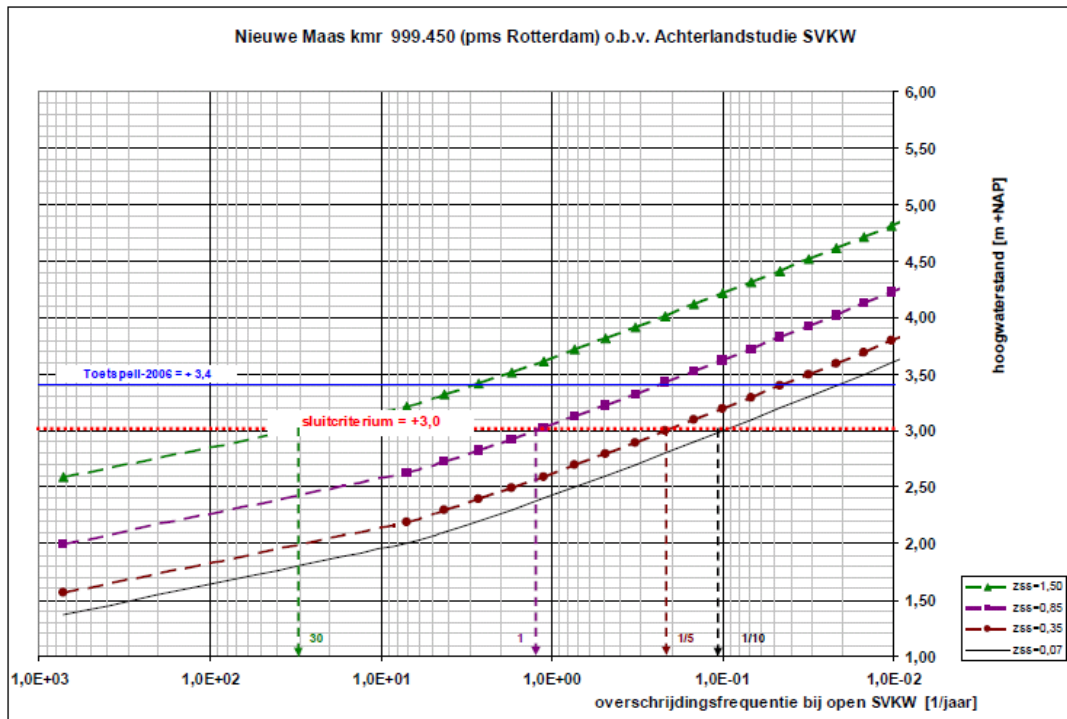
### 4.2 Water levels

In the W+ scenario it is expected that at the time horizon 2050 the sea water level will increase with 0.35 meter. In figure 4.2 an overview is given of the relation between the sea water level and the closing frequency of the Maeslantkering (Bruggers, 2006). In this figure the water level above NAP is shown against the closing frequency. The curves represent different water level increases. At the moment the closing regime of the Maeslantkering closes it when the water level reaches above 3.0 meter + NAP. The black line represents the current situation; the red dotted line represents an increase of the water level of 0.35 meter, the purple curve an increase of 0.85 meter and the green curve an increase of 1.50 meter. This figure shows that in the current situation – base on the current closing regime – the Maeslantkering is expected to close once every 10 years. When the sea water level increases with 0.35 meter – as is expected in the W+ scenario in 2050 – it is expected that the Maeslantkering closes once every 5 years.



The year 2100 is outside the scope of this study. However, it is interesting to see that in the worst case climate scenarios where an increase of the sea water level up to 1.30 meter is expected, the closing frequency of the Maeslantkering will rapidly increase to about 30 times per year (increase of water level 1.50 meter).

Figure 4.2: Relation between sea water level and closing frequency Maeslantkering



### 4.3 Methodology cost calculations

In this paragraph the methodology is described that is applied to calculate the costs related to the closure of the Maeslantkering.

When the Maeslantkering closes, also the Hartelkering closes. This means that both, vessels passing the Maeslantkering and vessels passing the Hartelkering, are hindered when the storm surge barriers are closed. When the storm surge barriers close, the obstruction lasts 24 hours.

In order to calculate the costs of the closure, it is necessary to know the number of vessels passing the storm surge barriers. For the current situation, figures from the MER Maasvlakte 2 (Projectorganisatie Maasvlakte 2, 2006) have been used because in this source the split has been made between the number of vessels on the Nieuwe Waterweg and on the Hartelkanaal. Then the growth figures from the Global Economy scenario have been used to raise the number of vessels on the rivers and canals to the time horizon 2050 in the same way as in the study Batenverkenning, Klimaatbestendigheid Nederland Waterland (TNO, 2009).

After this step the total number of vessels passing the Maeslantkering is known both for sea vessels and for inland waterways vessels. When the storm surge barriers close, different reactions can be expected. Some vessels will just wait and continue their journey afterwards without changing anything, some vessels will also wait, but after the storm surge barriers open again, they will catch up the time losses by sailing at higher speeds in order to meet the agreed arrival times in the scheduled services. In the report 'Evaluatie sluitingsregime Maeslantkering, consequentie document' (Witteveen+Bos, 2009) assumptions have been made about the shares of the vessels that will wait without catching up and the vessels that will wait and catch up time losses. These figures have been used in this study. Also the waiting costs and catching up costs have been taken over from this report.



Based on this input, the total costs of the closures of the Maeslantkering and Hartelkering in the years 2010 and 2050 have been determined. The most import assumptions and the final results are presented in table 4.1.

Table 4.1: Costs of closures of the storm surge barriers in the Rotterdam area

	2010		2050	
	Closing frequency 1:10		Closing frequency 1:5	
	Maeslantkering	Hartelkering	Maeslantkering	Hartelkering
Number of days per year	0.10	0.10	0.2	0.2
Duration obstruction sea in hours	24	24	24	24
Duration obstruction inland waterways in hours	24	24	24	24
Number of hindered sea vessels per year	16.4	0	44.3	0
Number of hindered inland waterways vessels per year	10.3	32.6	28.9	91.5
Number of sea vessels waiting per year	2.0	0	5.3	0
Number of inland waterways vessels waiting per year	6.2	19.6	17.4	54.9
Number of sea vessels catching up time losses per year	14.4	0	39.0	0
Number of inland waterways vessels catching up time losses per year	4.1	13.0	11.6	36.6
Waiting costs per day sea	€15,000	€0	€15,000	€0
Waiting costs per day inland waterways	€2,875	€2,875	€2,875	€2,875
Costs catching up time losses sea	€26,190	€0	€26,190	€0
Costs catching up time losses inland waterways	€9,225	€9,225	€9,225	€9,225
Sub total	<b>€463,641</b>	<b>€176,510</b>	<b>€1,257,035</b>	<b>€495,258</b>
<b>Total costs</b>	<b>€640,151</b>		<b>€1,752,293</b>	
Total costs inland waterways	€32,367		€51,986	
Total costs sea	€407,784		€1,100,308	

The table shows that on average the annual costs of the closures of the Maeslantkering and the Hartelkering are more than 232 thousand Euro for inland waterway transport and more than 407 thousand Euro for sea transport in the year 2010 (with a closing frequency of once every 10 years). In the year 2050 – with a closing frequency of once every 5 years – the costs for inland waterway transport are more than 651 thousand Euro and for sea transport more than 1.1 million Euro. The main factors explaining the difference in costs between 2010 and 2050 are the doubled closing frequency of the storm surge barriers and the increased number of vessels passing the storm surge barriers.

#### 4.4 Direct impact and consequences for the competitive position of inland waterway transport

The direct impacts from the increased sea water in 2050 in the Rotterdam area are:

- Doubled closing frequency of the storm surge barriers to once every 5 years;
- At each closure, the inland waterway transport (and sea transport) is obstructed for 24 hours;
- The costs of the closures increase for inland waterway transport from more than 232 thousand Euro in 2010 to more than 651 thousand Euro per year in 2050.

The question is whether these impacts will influence the competitive position of inland waterway transport. Since the storm surge barriers close not very often in 2050 (24 hours every 5 years), the number of hindered ships is still rather limited and the costs do not increase extremely, it is expected that the competitive position of inland waterway transport is not affected by this increase in closing frequency.

Also for maritime transport an occasional obstruction of 24 hours is acceptable. If obstructions take longer than 24 hours, sea vessels will go more to other seaports.

The expected closing frequency of the storm surge barriers once every 5 years in 2050 is an estimate. Although this figure is uncertain even with a closing frequency just a bit higher or a bit lower, the conclusion holds that no impact is expected on the competitive position of inland waterway transport.

Again a remark is made concerning the year 2100. In case of a closing frequency of 30 times per year it is expected that this will have influence on the competitive position of inland waterway transport.



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## 5. Impact of low water levels on the main rivers on inland waterway transport

### 5.1 Introduction

In general, climate change has an impact on the water level on the main rivers and canals, both concerning high water in winter time and low water in summer time. This chapter is about the impact of changed water levels on the main rivers and canals within, to, from and through the Netherlands. However, because the expected impact of high water levels is much less than the expected impact of low water levels and because a part of the methodology to determine the direct impact is only capable to determine the impact of low water levels (the BIVAS model), this chapter only deals with the impact of low water levels.

This chapter starts with a description of the impact of climate change on the water levels according to the W+ scenario which is main input for the analysis of the impact of climate change on the competitive position of inland waterway transport. In the next paragraph the methodology is described that has been applied to determine the impact on the competitive position of inland waterway transport. In the last paragraph an overview is given of the direct impact and the main conclusions.

### 5.2 Water levels

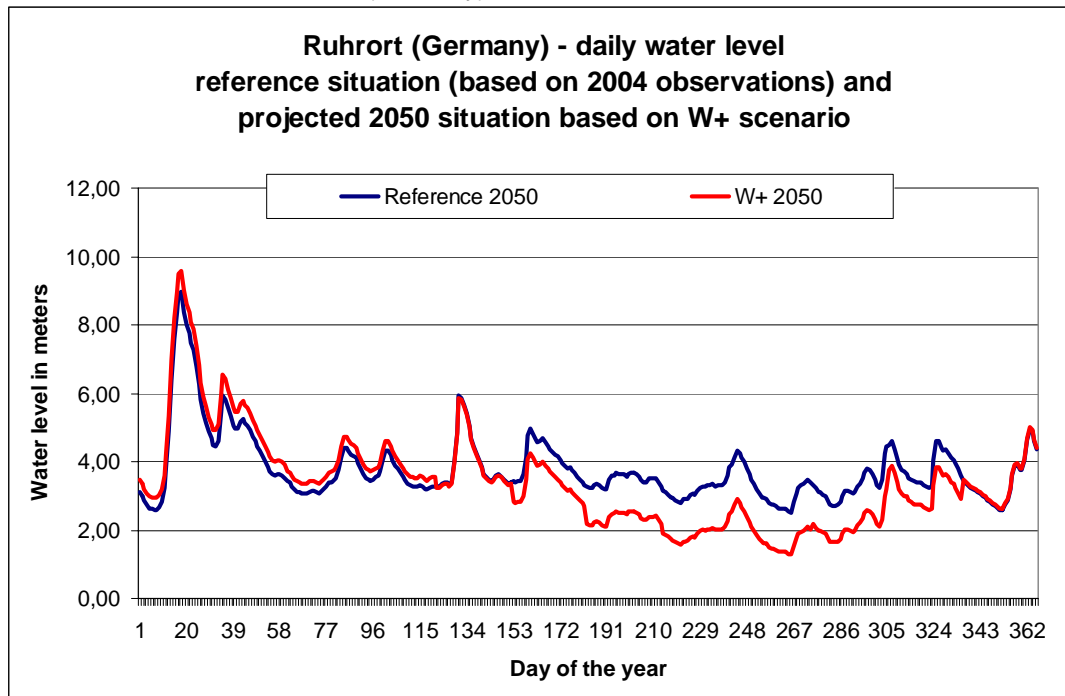
Based on the KNMI W+ climate scenario, Deltares has translated the scenarios into daily water levels on the main rivers and canals in, to and from the Netherlands. This has been done for the reference situation 2050 (based on 2004 observations of water levels, without the impact of climate change) and for the W+ situation 2050 (based on 2004 observations of water levels, including the impact of climate change up to 2050). For more information about this exercise, reference is made to the report 'Effecten van klimaatverandering op de waterhuishouding' (Deltares, 2010).

In figure 5.1 an example is given of the water levels on a specific location. The figure shows the daily water levels in the reference situation 2050 and the W+ situation 2050 at the Rhine near Ruhrort in Germany. From this figure it becomes clear that in the first half of the year, in the W+ situation slightly higher water levels are expected. In the second half of the year, the difference between the two situations goes in the other direction. In this case, in the W+ situation water levels are expected to be substantially lower than in the reference situation with a number of peak periods with water levels below 2.0 meter.

Although the water levels are different between the two situations, the pattern over the year is the same. The reason for this is that Deltares applied the expected impact of climate change on the water levels up to 2050 on the observed water levels for the year 2004. It is noticed that because the water levels in 2004 are slightly below average and because the pattern in the W+ scenario is the same as the pattern over the year in 2004, the water levels in the W+ scenario 2050 are strongly linked to the observed water levels in 2004. Because it was not possible for Deltares to change this in their methodology to determine the water levels, these results are used for this study. However, it should be kept in mind that especially the pattern over the year could be different in the W+ scenario 2050.



Figure 5.1: Overview daily water levels in the reference situation and the W+ scenario, location Ruhrort (Germany)



To get an idea of the locations where the water levels change due to climate change, in figure 5.2 an overview is included with the difference of the water levels in the 10 day period with the lowest water level in the W+ situation (10 day period around day 267 in figure 5.1). The figure shows the difference in water levels based on the input from Deltares as it has been implemented in the BIVAS model.

In this figure only the rivers and canals are included if there is any difference in water level between the W+ situation and the reference situation in 2050. Some parts of the waterways that are shown in the figure are missing, for instance the Rhine is green in the neighborhood of Rotterdam, yellow/orange near the border with Germany and missing in between. For these parts of the Rhine that have no color (missing in the map) there is no difference in water level between the W+ situation and the reference situation.

Only the main rivers are visible in this figure with different colors:

- The rivers in the area near Rotterdam are green meaning that the water level in the W+ scenario increases between 0 and 0.5 meter compared to the reference situation. The increase in water level is caused by the increase in the sea water level;
- Some parts of the waterways along the Rhine and the Waal in the middle of the Netherlands and on the Meuse near Venlo are light green. This means that the water levels decrease with between 0 and 0.5 meter;
- Some parts of the Rhine and the Waal and especially the IJssel are yellow meaning that the water levels decrease between 0.5 and 1.0 meter;
- Near the border with Germany parts of the Rhine and Waal are yellow meaning that the water levels decrease between 1.0 and 1.5 meter;
- The Rhine in Germany is purple meaning that the water levels decrease between 1.5 and 2.0 meter.
- The Meuse is green because the Meuse is a canalized river, where the water levels are regulated. Note that this does not mean that the river basin isn't affected by the climate change. Reference is made to the report 'Effecten van klimaatverandering op de waterhuishouding' (Deltares, 2010)



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A first conclusion from this figure is that, due to the climate change according to the W+ scenario, the most severe problems will arise along the IJssel, the Rhine and the Waal near Arnhem/Nijmegen and especially the Rhine in Germany.

It is noticed that in this figure only the main rivers are visible with changes in water levels. This does not mean that at smaller rivers and canals there is no change in water levels. The reason that smaller rivers and canals are not visible in this figure is that Deltares did not translate the climate change scenarios into changed water levels on these waterways. Deltares produced only results for the main rivers and canals. It was not possible for Deltares to produce the results for smaller waterways and in a first stage of the project it was expected that the impact of the climate change on smaller waterways would be minimal. In a later stage a discussion was started whether the impact of climate change on smaller waterways should be included, because there are some arguments that there are substantial impacts on the water levels of smaller waterways as well. However, the largest share of the inland waterway transport will make use of the larger waterways.

In this study and in the methodology applied for the results in this report, only the impact of climate change on the main rivers and canals is taken into account.

In annex B an overview is given of the absolute water levels in the W+ situation and the reference situation that have been used to determine the differences in water levels.

Figure 5.3 shows an overview of the inland waterways network with several well-known “low water related bottlenecks” along the Rhine in Germany (Ruhrort and Kaub), along the Rhine and the Waal near Arnhem and Nijmegen and on the IJssel and the Meuse.

By combining figures 5.2 and 5.3 it is obvious that in the W+ scenario the most severe problems due to low water levels will arise near the locations highlighted in figure 5.3.





Figure 5.2: Overview difference in water levels between the W+ situation 2050 and the reference situation 2050, in the worst case 10 day period

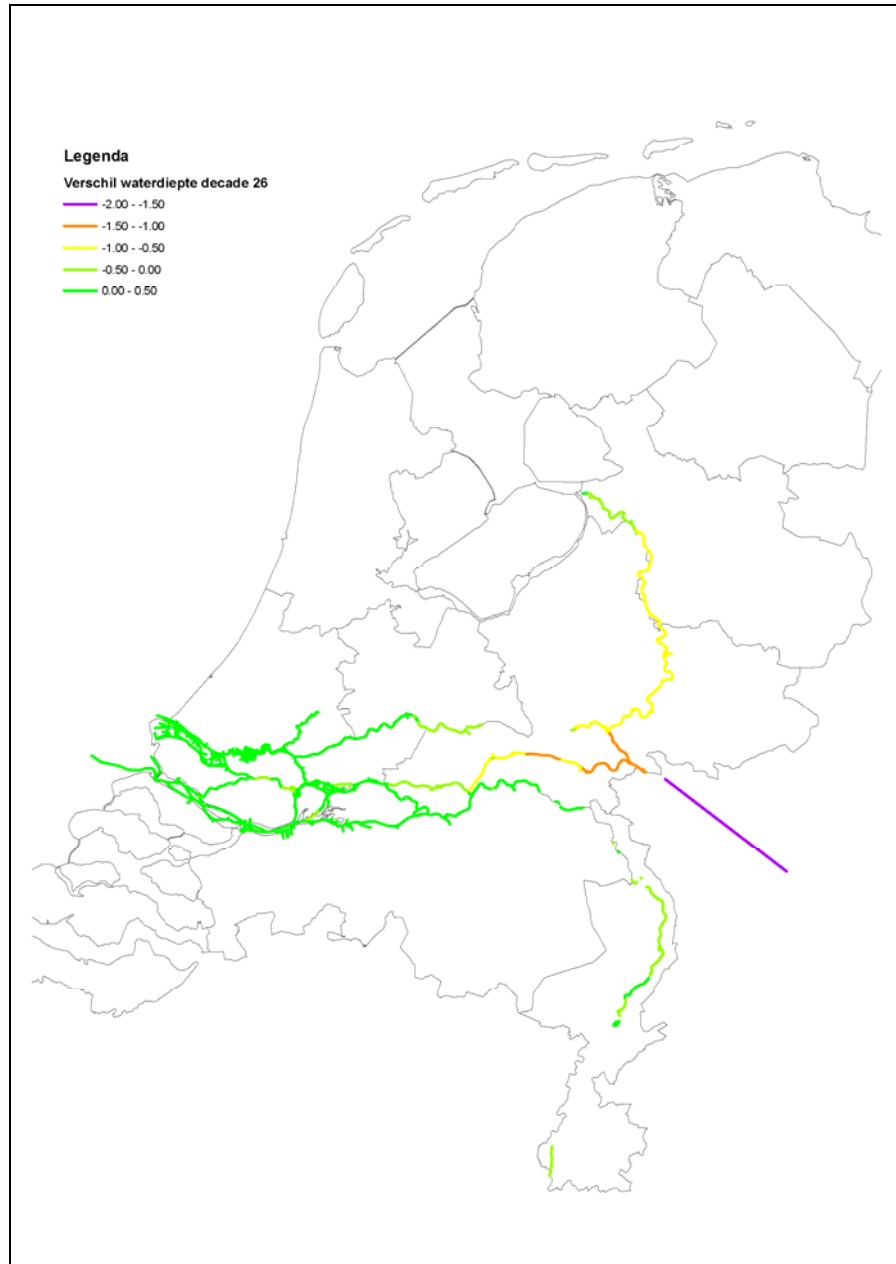
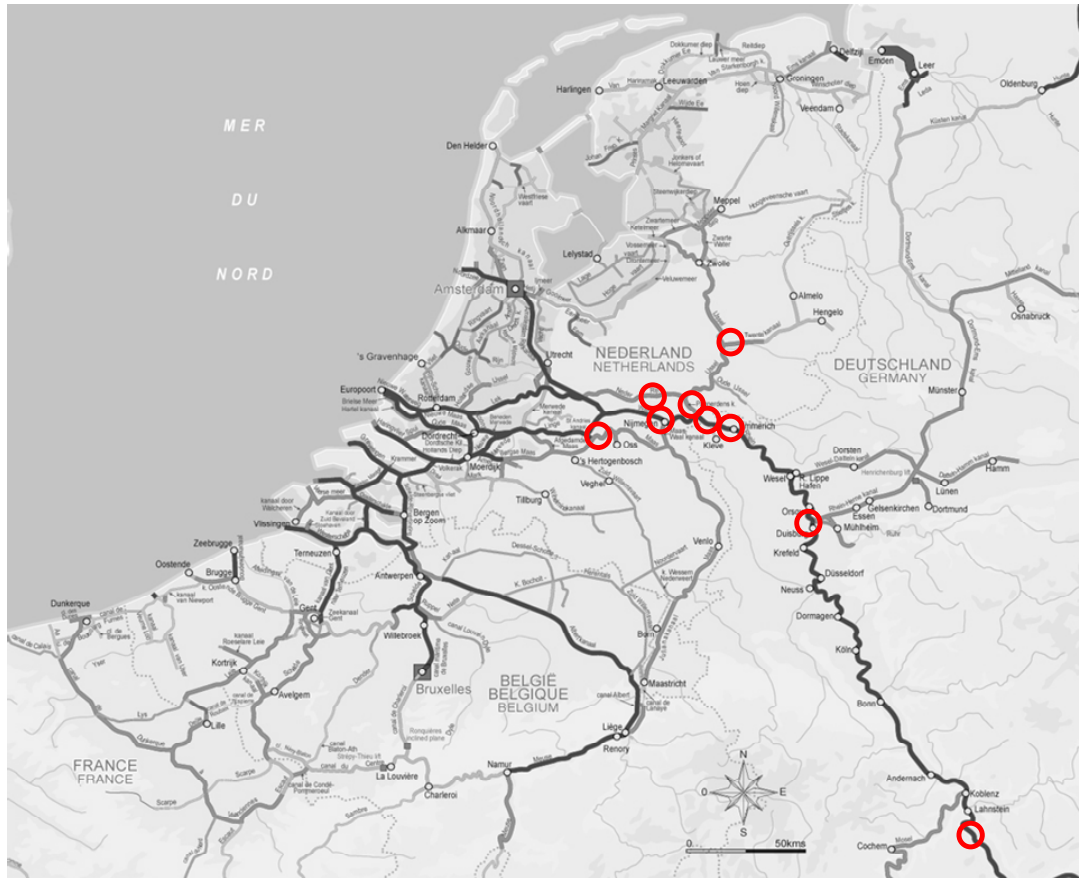




Figure 5.3: Overview low water related bottlenecks





### 5.3 Methodology

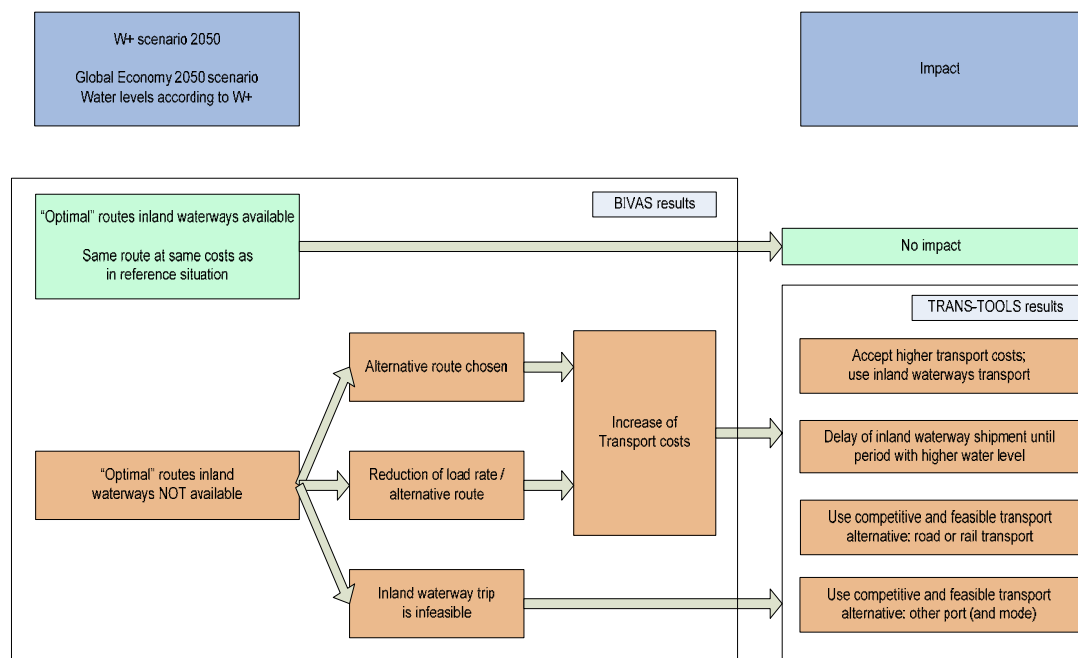
This paragraph describes the methodology that has been applied to determine – given the expected water levels according to the W+ scenario 2050 described in the previous paragraph – the impact of climate change on the competitive position of inland waterway transport.

In figure 5.4 a schematic overview is given of the methodology that has been applied to determine the direct impact of climate change on the competitive position of inland waterway transport.

In the methodology three main blocks can be distinguished:

- The water levels on the rivers. This input that has been determined by Deltares and that has been described in the previous paragraph is taken as given. In the overview it is included in the blue block in the upper-left corner;
- Impact of low water levels on route choice, reduction of load rates, obstruction of waterways and change in level-of-service (due to change in transport costs and times) with the BIVAS model. This part is included in the large square on the lower-left corner indicated with BIVAS results;
- Impact of the changes in level-of-service (costs and times) and obstruction of waterways (reliability) on the behavior of shippers and transport operators. As a consequence of increased level-of-service and decreased reliability of inland waterway transport, these actors can react in different ways. The options considered here are: acceptance of reduced level-of-service and reduced reliability (they will still use inland waterway transport), delay of inland waterway transport in case of obstruction on the waterways (they still use inland waterway transport, but at a later time), building up stocks in the neighborhood of the client or the sea port (that can be used in case inland waterway transport is not feasible) or a shift to another competitive and feasible transport alternative (road or rail transport, possibly in combination with other another route choice including another port choice). The way actors will react and the impact on the competitive position of inland waterway transport is modeled with the TRANS-TOOLS model. This part is included in the square on the lower-right corner indicated with TRANS-TOOLS results.

Figure 5.4: Overview methodology to determine direct impact of climate change on inland waterway transport





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In the next part of this paragraph a description is included of the BIVAS model and the TRANS-TOOLS model and how these models have been applied in this study.

### 5.3.1 BIVAS model and results

#### *BIVAS model in general*

The BIVAS model (Binnenvaartanalyse Systeem) has been developed by RWS to make assignments of inland waterways vessels on the inland waterways network. The model is mainly used to analyse the traffic on the inland waterways network, to analyse the impact of obstructions in the network and to make analyses of long term future scenarios of inland waterway transport.

Recently a number of modifications and extensions have been made to the BIVAS model which are relevant for this project as well:

- Economies of scale at replacement of old vessels. It is a trend that when old vessels are replaced, they are replaced by larger vessels since this is more efficient. In scenario calculations up to the year 2050 this should be taken into account. Because larger vessels can transport more goods in one journey, fewer vessels are needed to transport the same amount of goods. On the other hand, the size of these vessels is larger and they have a higher draught which is also very relevant for this study.
- Assignment of inland waterway vessels per season and per 10 day period. Originally, the BIVAS model made assignments for the whole year. In that case, it is not possible to take into account differences in water levels along the year. Now that assignments can be made per 10 day period, also the water levels can be varied per 10 day period which is very relevant for this study;

RWS coordinated the update of the BIVAS model. A first version of the BIVAS model including these modifications and extensions was available and has been used for this study.

For more information about BIVAS reference is made to the following website: <http://bivas.chartasoftware.com>. Besides a general description of an application of the BIVAS model is described in the RWS report *Klimaat en Binnenvaart, Gevolgen klimaatverandering voor de binnenvaart* (RWS, 2010).

#### *Application of BIVAS model for this study*

The application of the BIVAS model for this study has been done in a number of steps:

- First of all, RWS has made a forecast of the volume of goods and number of ships according to the Global Economy scenario 2050, taking into account the economies of scale concerning the size of the vessels (mentioned under the modifications of the BIVAS model);
- The Deltares results of the water levels according to the W+ scenario 2050 have been aggregated from daily results to average water levels per 10 day period by RWS. The reason for this is that BIVAS cannot make assignments per day, but it can make assignments with different water levels per 10 day period (mentioned under the modifications of the BIVAS model);
- Then RWS has applied the BIVAS model to assign the number of ships per 10 day period onto the inland waterways network with the corresponding average water level for the 10 day period. This is repeated for all 36 10 day periods. The result of BIVAS consists both of the annual results and of the results of each 10 day period;
- These results have been transferred to TNO for in-depth analysis.



### *BIVAS results*

TNO received the detailed results of the BIVAS model runs from RWS. Before these results were used as input for the TRANS-TOOLS model, the results have been analysed in detail in order to:

- Better understand the working of the BIVAS model and the corresponding results;
- To check the plausibility of the BIVAS model results since this was the first time the update of the BIVAS model including a number of extensions was applied.

In order to better understand the BIVAS model results, the way the BIVAS model works is globally explained:

- BIVAS assigns each vessel from the input origin/destination matrix to the inland waterways network taking into account the dimensions of the vessels including draught of the vessels;
- This is done by selecting the route in the network with the lowest travel cost;
- In case in the W+ scenario the vessel can be assigned to the same route and with the same transport costs as in the reference situation, there is no impact of the climate scenario. This is illustrated in the green blocks in figure 5.4;
- In case in the W+ scenario another route becomes the route with the lowest travel cost, this route will be chosen to transport the goods. An alternative route will lead to an increase in level-of-service compared to the reference situation. This is illustrated in figure 5.4 in the lower-left square with “alternative route chosen”. It is mentioned that – especially on the international routes – there are very limited alternatives available in the network. Therefore, it is not expected that this situation will occur very often;
- In case in the W+ scenario no routes are feasible anymore (neither the original route in the reference situation neither any alternative route) because the water level is too low for the navigation of the vessel, the load rate of the vessel will be decreased. The load rate is decreased until the draught of the vessel lowered enough to make navigation feasible again given the water levels on the rivers (possibly on an alternative route). This is illustrated in figure 5.4 in the lower-left square with “reduction of load rate / alternative route”. A consequence of this approach is that more vessels are needed to transport the same amount of goods which leads to an increase in the level-of-service. A condition applied in this approach is that the load rate may be lowered that much that maximum 2 vessels are needed to transport the same amount of goods (in order to prevent that for example 20 vessels are needed to transport the same amount of goods);
- In case in the W+ scenario the load rate is lowered until 2 vessels are needed to transport the same amount of goods and still no route is feasible because of the low water levels, it is determined that the inland waterway trip is not feasible at that moment (the planned inland waterway transport does not take place). This is illustrated in figure 5.4 in the lower-left square with “inland waterway trip is infeasible”. The infeasible trips lead to a decrease of the reliability of inland waterway transport (in the BIVAS model the impact of this on the level-of-service is not determined).

Based on the first results received from RWS and the first analyses made by TNO a number of modifications have been made by TNO:

- In the reference situation 2050 – without low water levels resulting from climate change – there is already a substantial amount of infeasible trips in the BIVAS results. Further analysis showed that these trips are infeasible for unclear reasons (it could be because of low water, but most of these trips are infeasible because of technical reasons such as data problems in the origin/destination matrix or in the inland waterways network). TNO decided to leave the trips that are already infeasible in the reference situation out of the analysis of this study. It is recommended to solve the technical problems and reduce the number of infeasible trips in the reference situation for future applications;
- The inland waterways network does not provide many alternative routes in the network, especially not for international routes. An analysis of alternative routes chosen in the BIVAS model showed that sometimes very illogical alternative routes are chosen. TNO applied a check on the logic of alternative routes and modified illogical routes in the BIVAS results. For a future application it is recommended to modify the BIVAS model in such a way that illogical routes are not chosen anymore.



Furthermore, a number of observations have been made of possible improvements that could not be modified in this study, but that might be considered for other applications in the future:

- The approach to search for alternative routes or to reduce the load rate is a discrete choice. Either an alternative route is chosen, if this is not possible, then the load rate will be reduced. However, it is possible that the reduction of the load rate leads to lower transport costs than the choice for an alternative route. In BIVAS a comparison of the transport costs should be made in order to determine what is the best choice;
- In case it is decided in the BIVAS model to reduce the load rate, more than one vessel is needed to transport the same amount of goods. In this approach, the extra vessel needed will be a vessel of the same type as the original vessel. However, it would be more logical to have an option to choose a vessel of a different type (a smaller one).

The proposed modifications and observations have been discussed with RWS. This helps RWS to make a plan for further improvements of the BIVAS model in the future.

Now a number of results based on the BIVAS model runs are shown. In the results a distinction is made for the annual results and for the results of the worst case 10 day period in the year (10 day period around day 267 in figure 5.1). The reason this distinction is made is that if only average results for the whole year are shown, this might lead to the impression that the impact of the climate change scenario is rather limited because in the first half of the year there are no problems and in the second half of the year there are several peaks with problems, but also several peaks without any problems (see figure 5.1). The climate change scenario leads to very temporarily problems over the year, therefore it is good to have not only an overview of the impact for the whole year, but for a specific moment in the year with the highest impact as well.

In the figures presented below the total volume of inland waterway transport within, from, to and through the Netherlands is distinguished in a number of classes:

- Infeasible Reference situation – The volume that is already infeasible in the reference situation. As explained before, this is mostly due to some technical problems in the BIVAS model. For the analyses of the impact of the climate change, it can be neglected. Therefore the infeasible volume of the reference situation are not shown in these figures;
- Infeasible W+ situation – The volume that becomes infeasible in the W+ situation (due to the impact of climate change) compared to the reference situation;
- Factor 1.0 – Volume of inland waterway transport that is feasible and has no change or a very limited change in transport costs. Actually, for this volume, there is no substantial impact of the climate change scenario;
- Factor 1.25 – Volume of inland waterway transport for which the transport costs increase between 0 and 25% in the W+ scenario compared to the reference scenario;
- Factor 1.5 – Volume of inland waterway transport for which the transport costs increase between 25 and 50%;
- Factor 2.0 – Volume of inland waterway transport for which the transport costs increase between 50 and 100%;

In figure 5.5 an overview is given of the shares of the total volume of inland waterway transport by impact class for both the annual results and for the worst case 10 day period in the year.

The share of infeasibles in the reference situation is around 13% in the annual results and 14% in the 10 day period results. Again these results are not that important and can be neglected. Therefore they are not shown in figure 5.5.

Much more important is the share of infeasibles in the W+ scenario (impact of the climate change scenario). In the annual results the share is 6%, in the 10 day period the share is 30%. This means that these shares of the inland waterway transport volume can not be transported due to low water problems at that moment.

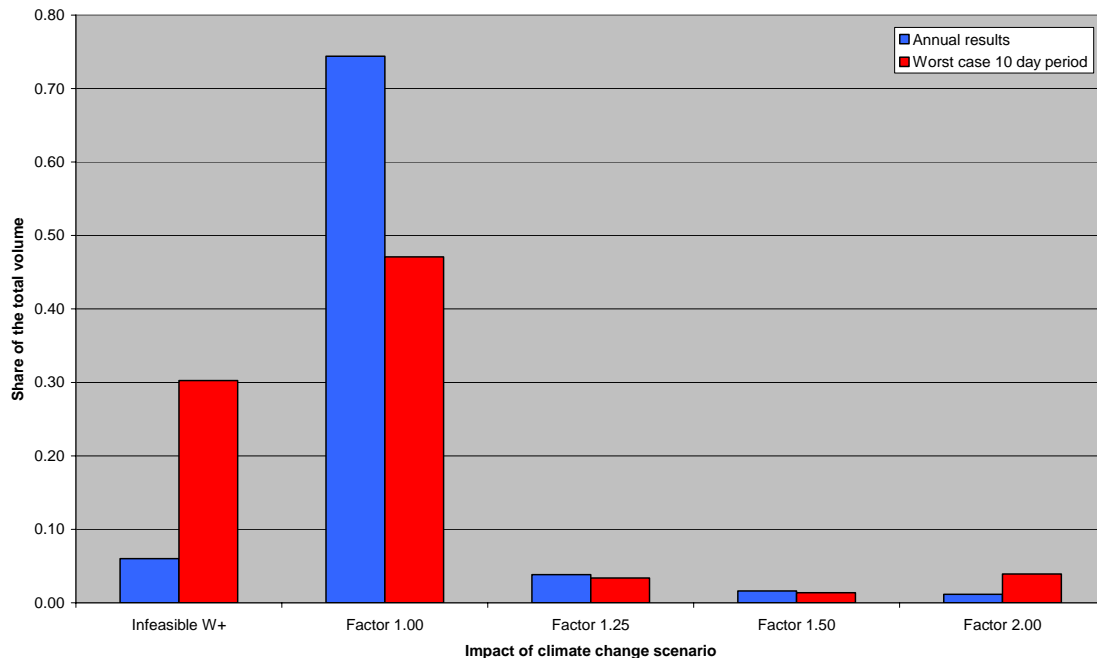
The share of the volume on which climate change does not have an impact is 74% in the annual results and 47% in the 10 day period.

The volume of inland waterway transport that faces increases in transport costs in the W+ scenario is 7% in the annual results and 9% in the 10 day period (shares of the factors 1.25, 1.50 and 2.00 together).



This figure stresses the conclusion that the W+ climate change scenario has severe impact during specific periods in the year, while the annual impact is still substantial, but less high.

Figure 5.5<sup>1</sup>: Overview shares total volume by impact class, both annual results and results worst case 10 day period



The next figures have been made with a split per ship class, a split per commodity and a split per origin/destination on country level.

In the figures 5.6 and 5.7 the results are presented for the split by ship class, the first figure includes the annual results, the second figure includes the results of the worst case 10 day period.

The annual results show that for the barges the share of infeasible volume is already quit high in the reference situation (technical problems in BIVAS). The share of the volume that is infeasible in the W+ scenario is highest for barges and convoys. The share of the volume with substantial cost changes is highest for the motor vessels. It seems as if the impact of the climate change leads mostly to infeasible trips for barges en convoys (and limited increases in transport costs for these ship classes) and leads to an increase in transport costs for motor vessels (and limited number of infeasible trips for this ship class).

The results of the worst case 10 day period show a comparable result. Especially for the convoys the share of the volume of infeasible trips is very high (more than 50% of the total volume).

<sup>1</sup> The share of the infeasible trips in the reference situation (around 13 and 14%) is not shown here. Those trips are infeasible due to technical problems in the BIVAS model, and therefore infeasible in the reference situation as well as in the W+ situation.



Figure 5.6: Impact of low water level on main rivers on inland waterway transport, annual results by ship class

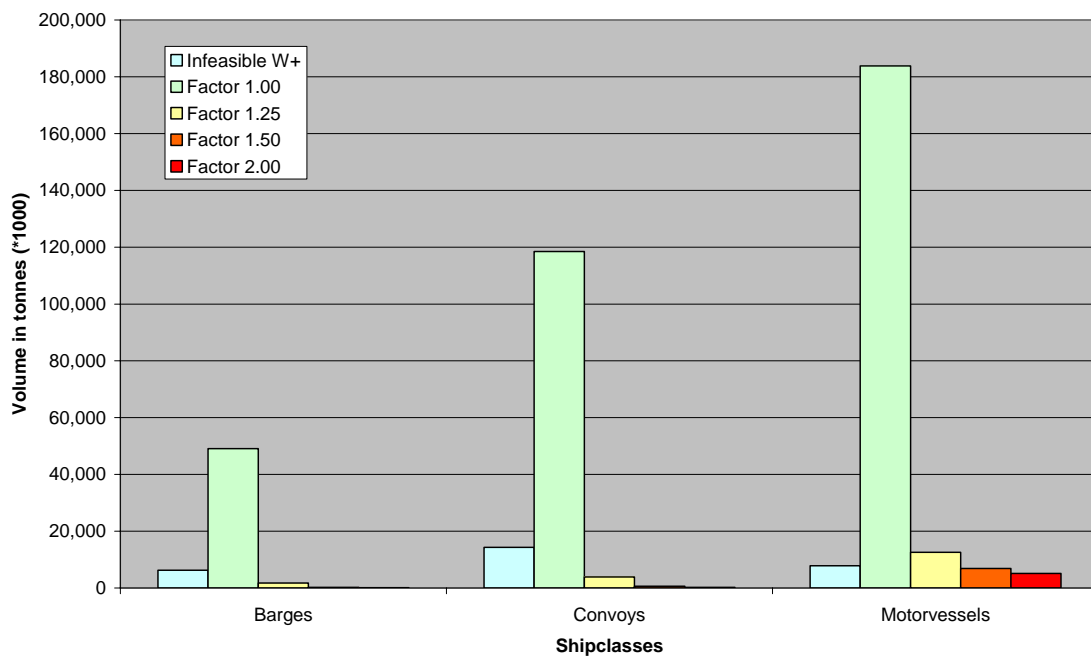
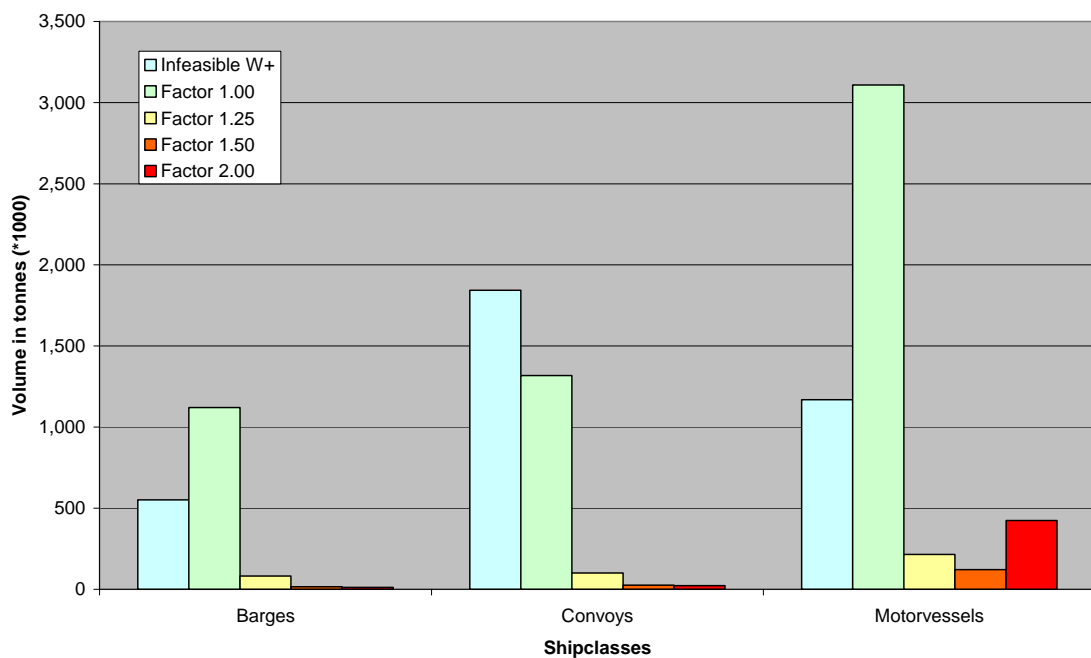


Figure 5.7: Impact of low water level on main rivers on inland waterway transport, results worst case period by ship class







In the figures 5.8 and 5.9 the results are presented for the split by commodity group. The first figure includes the annual results. The second figure includes the results of the worst case 10 day period.

The annual results by commodity show that the volume of inland waterway transport that becomes infeasible in the W+ scenario is relatively high for the commodities ores (20%), solid mineral fuels (10%), metal products (9%) and fertilizers (7%). The commodities for which the W+ scenario has the relative highest impact on the transport costs are metal products (15%), fertilisers (12%), minerals and building materials (11%) and food (11%). The commodity machinery and other products (high valued goods, to a large extent shipped in containers) has relative low shares for the impact classes. However, because of the very large volume of the total commodity, the volume of infeasible transport is still rather high and almost the largest volume compared to the other commodities.

The results of the worst case 10 day period show very high shares of infeasible transport for the dry bulk commodities solid mineral fuels (47%) and ores (46%). For solid mineral fuels the share of transport that is feasible and faces substantial increases in transport costs is also high with 13%. For ores, this share is very limited with 2%. It seems that the transport of ores is either infeasible or faces no impact of the climate change. The commodity machinery and other products has a share of about 30% infeasible transport in the W+ scenario leading to a substantial volume of infeasible transport, the highest volume compared to the other commodity groups.

Figure 5.8: Impact of low water level on main rivers on inland waterway transport, annual results by commodity

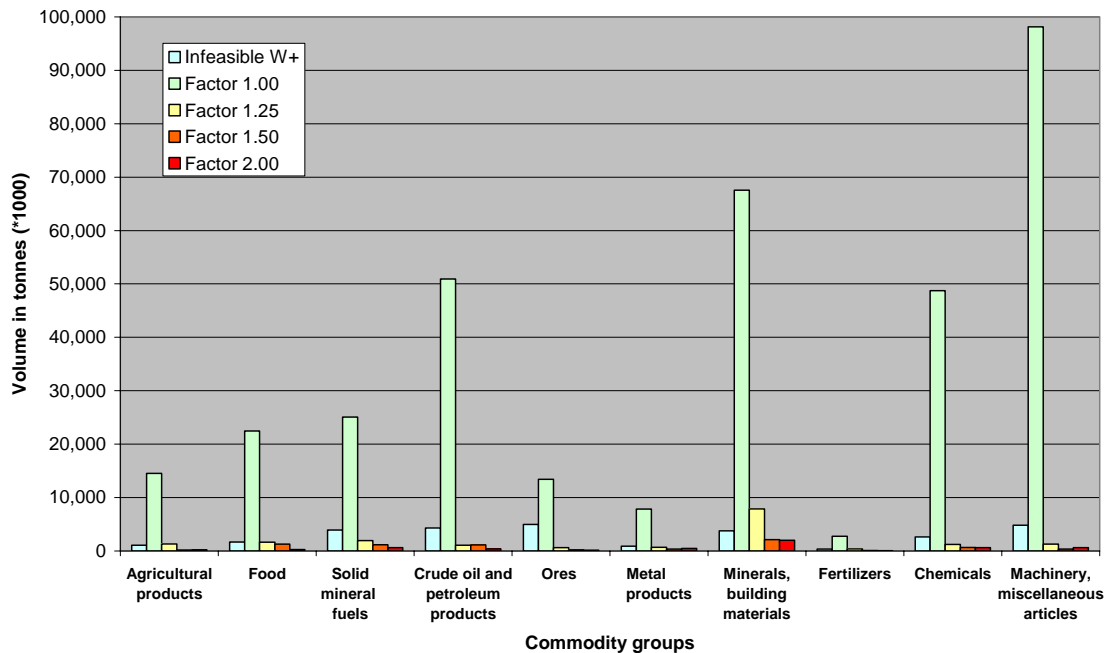
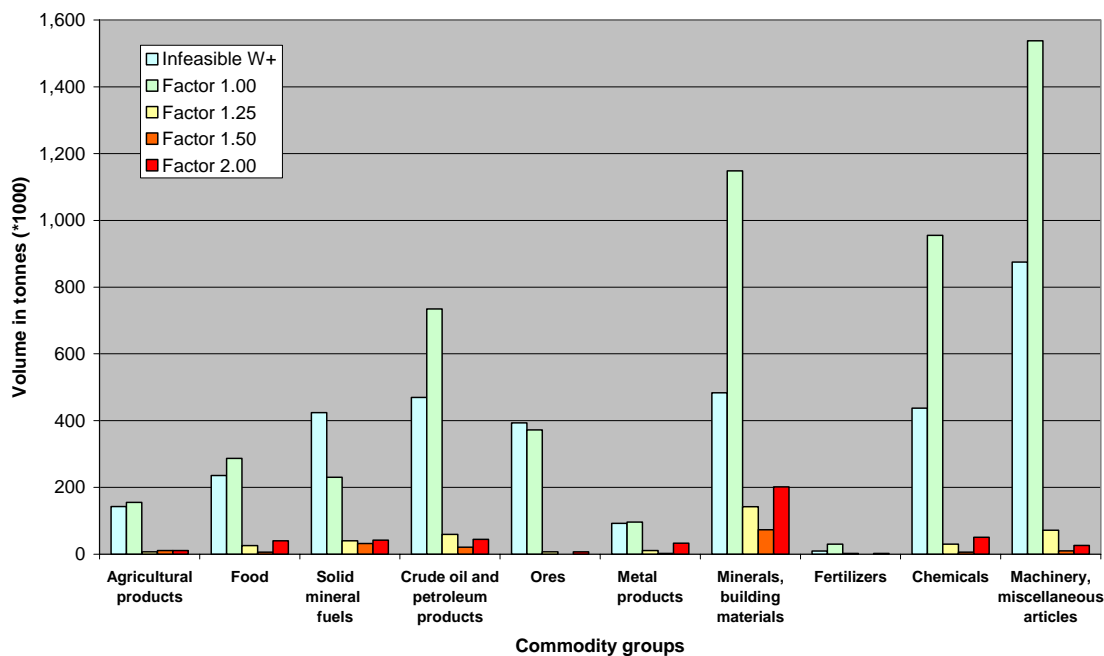




Figure 5.9: Impact of low water levels on main rivers on inland waterway transport, results worst case period by commodity



In the figures 5.10 and 5.11 the results are presented for the split by origin/destination relations on country level: the first figure includes the annual results, the second figure includes the results of the worst case 10 day period.

The figures contain the flows from other countries (Belgium – B, Germany – D and France – F) to the Netherlands – NL and the other way around. Besides, also the inland waterways flows within the Netherlands are included (indicated with NL – NL in the figures).

The annual results show that the share of infeasible transport resulting from the W+ scenario is by far the highest for the relation NL – D (15%). Also in the other direction D – NL this share is high (9%). Since the volumes on the relation NL – D and D – NL are also high, the volume of infeasible transport is the highest on this relation. The volume of infeasible transport is quite limited on the other relations.

For the share and volume of inland waterway transport that is feasible, but faces substantial transport cost increases the same pattern is visible in the results. On the relations NL – D and D – NL both the shares and the volumes are by far the highest compared to the other relations.

For the domestic inland waterway transport (NL – NL) it is noticed that the volume of infeasible transport in the reference situation is very high (technical problems in BIVAS). After the relations to and from Germany, the domestic transport is the relation with the highest volume of infeasible transport and the highest volume of transport facing substantial transport cost increases.

The results for the worst case 10 day period show the same pattern as for the annual results.



Figure 5.10: Impact of low water levels on main rivers on inland waterway transport, annual results by origin/destination relation

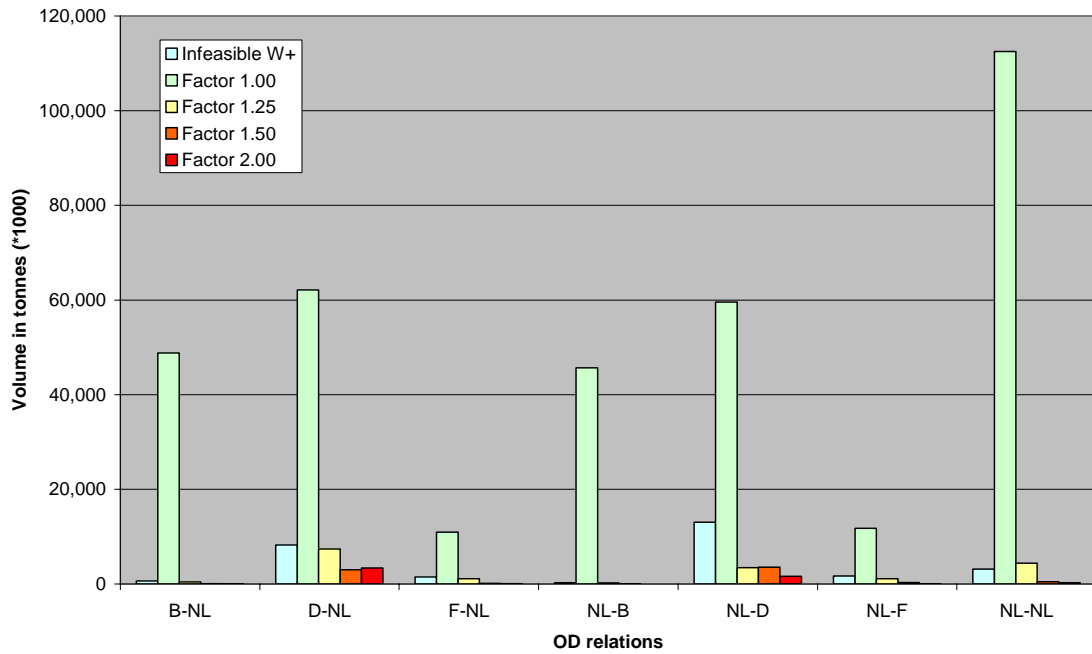
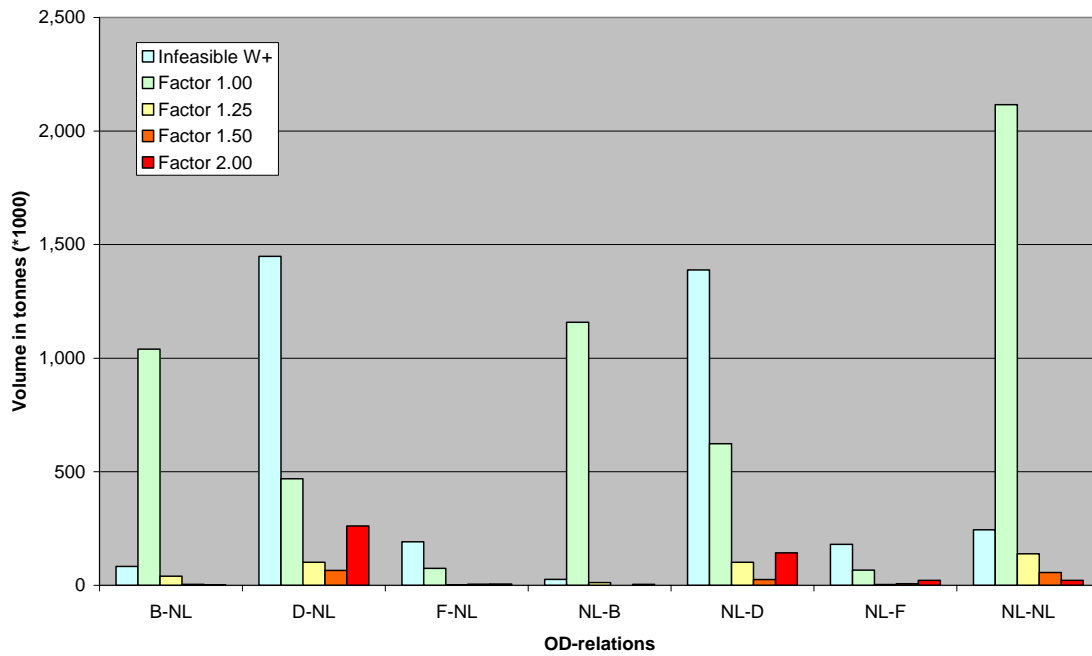


Figure 5.11: Impact of low water levels on main rivers on inland waterway transport, results worst case period by origin destination relation





### 5.3.2 TRANS-TOOLS model and results

In the previous paragraph the BIVAS model and results have been described. The results of the BIVAS model in terms of infeasible transport volume and increased transport costs are used as input for the TRANS-TOOLS model in order to determine how the actors in the transport market are expected to react on the impact of the W+ climate change scenario (see also figure 5.4 for a schematic overview):

- Acceptance of reduced level-of-service and reduced reliability (they will still use inland waterway transport);
- Delay of inland waterway transport in case of obstruction on the waterways (they still use inland waterway transport, but at a later time);
- Building up stocks in the neighborhood of the client or the sea port (that can be used in case inland waterway transport is not feasible);
- Shift to another competitive and feasible transport alternative (road or rail transport, possibly in combination with other route choice including port choice).

#### *TRANS-TOOLS model in general*

TRANS-TOOLS is a European transport network model covering current and future regional transport describing transport volume (tonnes) and performance (transport units and distances). This regional transport covers more than 300 regions in Europe for 4 transport modes, namely road, rail, inland waterways and sea, and the 99 commodity groups according to the 2-digit NSTR classification. The model has been developed in a project for the European Commission (version 1 under coordination of TNO), and is therefore also owned by the European Commission. Since the model is IPR free<sup>2</sup>, it is freely available for use by anyone interested. The TRANS-TOOLS model is an aggregate transport model meaning that the freight transport is modeled at the aggregated level of regions contrary to disaggregate models that model the freight transport at company level.

The TRANS-TOOLS model has been applied for many European and national projects to analyze policy measures and to analyze the impact of long term economic and transport scenarios. Currently TRANS-TOOLS is applied to provide input for the new White Paper of the European Commission. In the Netherlands the model has been applied – amongst others – to produce new long term scenario calculations for the throughput in the seaports of the Hamburg – Le Havre range as input for the new strategic plan of the Port of Rotterdam and to produce new long term scenario calculations of rail transport within, to, from and through the Netherlands for the confrontation between the rail transport demand and rail infrastructure supply by ProRail (Dutch railway manager).

For more information about TRANS-TOOLS reference is made to TRANS-TOOLS Deliverable 3 (TNO, 2005) and to the European Commission's TRANS-TOOLS website: <http://energy.jrc.ec.europa.eu/transtools/>.

#### *Application of TRANS-TOOLS model for this study*

The application of the TRANS-TOOLS model for this study has been done in a number of steps:

- That part of the inland waterway transport that is already infeasible in the reference situation (technical problems in BIVAS) is filtered out of the input data since these transport flows lead to an incorrect comparison between the reference situation and the W+ situation;
- First of all, scenario calculations have been made with the TRANS-TOOLS model for all freight flows based on the Global Economy 2040 scenario. These results cover the future transport volumes between regions for inland waterway transport as well as road and rail transport. These results are necessary for the modal-split calculations in the TRANS-TOOLS model;
- The output of the BIVAS model (level-of-service and infeasible inland waterways trips) is transferred into input of the TRANS-TOOLS model per 10 day period over the year. Besides, the level-of-service of the other transport modes road and rail is determined;
- Based on this input the modal-split module in the TRANS-TOOLS model has been run. This modal-split module has been calibrated per commodity group and determines changes in the

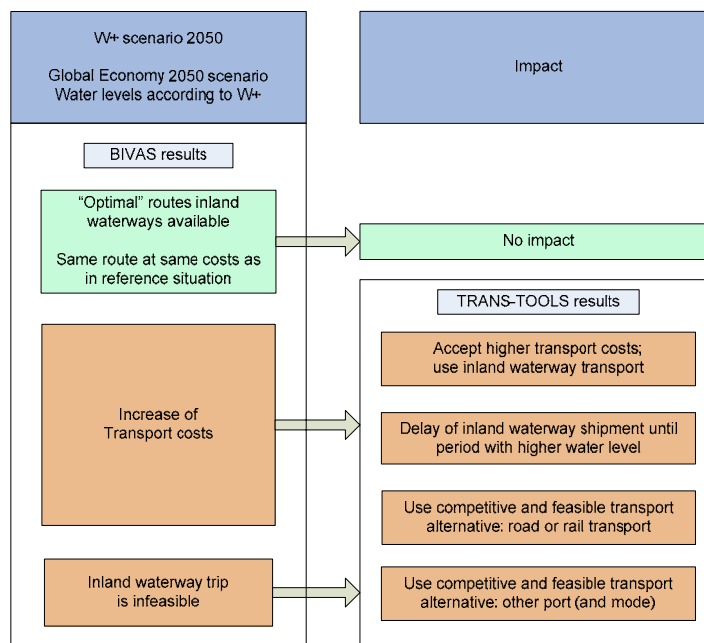
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<sup>2</sup> Intellectual property right free



- modal-split based on the generalized transport costs and the shares in volumes of the transport modes road, rail and inland waterways;
- In the modal-split model a distinction has been made between that part of the inland waterway transport that is still feasible in the W+ scenario, but faces higher transport costs and that part of the inland waterway transport that becomes infeasible (unreliable):
    - Inland waterway transport that is still feasible, but faces higher transport costs. For this part of the inland waterway transport, the generalized transport costs increases leading to a decrease of the competitive position of inland waterway transport compared to road and rail transport. As a consequence the modal-split module shifts part of the inland waterway transport – based on the estimated coefficients – to road and rail transport. The extent of this shift depends on the commodity group, the increase in generalized costs of inland waterway transport, the generalized costs of inland waterway transport compared to the generalized costs of road and rail transport and the transport volumes of the separate transport modes. As a result, part of the inland waterway transport with increased generalized transport costs will shift to the other transport modes, but another part with increased generalized transport costs will still use the inland waterway transport mode.
    - Inland waterway transport that becomes infeasible (unreliable). For this part of the freight transport it is not feasible to use the inland waterway transport mode anymore at the moment the transport was planned because water levels are too low to make use of inland waterway transport. In the model, it is assumed that the actors in the transport market will wait until the inland waterway transport becomes feasible again. The generalized cost of the delayed inland waterway transport is calculated by including additional costs for the delay time consisting of the value-of-time of the goods and the value-of-reliability of the goods. Then – with these generalized transport costs for inland waterway transport – the modal-split module in TRANS-TOOLS is run in the same way as described above for the feasible transport. As a result, part of the inland waterway transport with increased generalized transport costs will shift to the other transport modes, but another part with increased generalized transport costs will still use the inland waterway transport mode, but with delay at a moment in time that inland waterway transport is feasible again.
- This is shown in figure 5.12 below.
- These calculations have been made for a number of representative 10 day periods. As a last step, the results of these 10 day periods are combined to produce the results for the whole year.

Figure 5.12 Overview methodology modal-split module (part of figure 5.4)





### TRANS-TOOLS results

The figures 5.13 and 5.14 show the TRANS-TOOLS results, the first figure shows the annual results, the second figures shows the results of the worst case 10 day period.

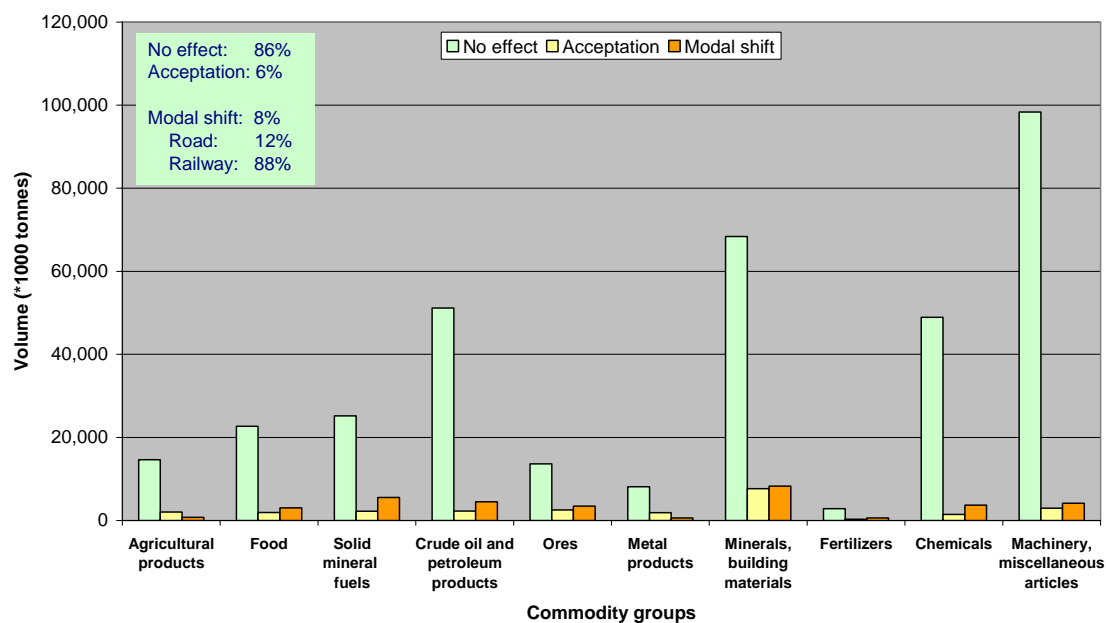
For the whole year, from the total inland waterway transport within, to, from and through the Netherlands 86% of the total volumes is not affected by the impact of the W+ climate change scenario. This volume consists of the transport volumes between origins and destinations that do not face any impact all year (no impact all year) and of the transport volumes between origins and destinations that do face problems at specific periods, but not all year (no impact largest part of the year).

From the 14% of the transport volume that is confronted with the impact of climate change, 6% is expected to accept the impact (use inland waterway transport at higher costs) and for 8% of the volume the increase of the transport costs is high enough to consider using an alternative transport mode (road or rail). For that part of the transport where an alternative mode is considered, rail transport is by far most attractive (88%) followed by road transport (12%).

Compared to other studies, the 8% modal-shift in this study does not seem to differ so much from for example the 5.4% modal-shift found in the report Adaptation to climate change in inland waterway transport (Jonkeren, 2009). However, in this study the modal-shift concerns all inland waterway transport within, to, from and through the Netherlands, while in the Jonkeren study the modal-shift concerns the inland waterway transport on the Rhine in Germany. Therefore, the 8% modal-shift in this study is a relative high modal-shift. Looking to the absolute volumes, around 40 million tonnes of inland waterway transport has an incentive to consider using other transport alternatives.

The figures show the effect by impact class (acceptation and modal-split) for each of the commodities. In absolute volume, the commodities building minerals and material and machinery and other products show the highest impact for both the total impact (acceptation and modal-split) and for the modal-split effect.

Figure 5.13: Modal-split effect TRANS-TOOLS, annual results per commodity group<sup>3</sup>



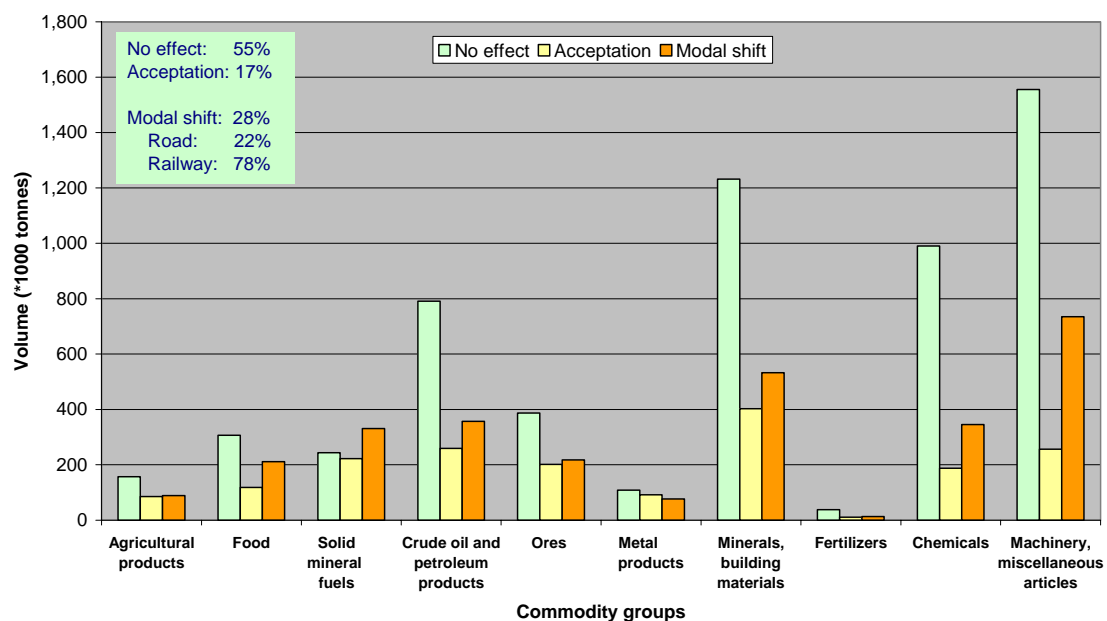
<sup>3</sup> For all OD relations



For the worst case 10 day period, 55% of the total transport volume within, to, from and through the Netherlands is not confronted with the impact of the W+ climate change scenario at all. From the 45% that is affected, 17% is expected to accept the impact (use inland waterway transport at higher costs) and 28% of the total volume the increase of the transport costs is high enough to consider using an alternative transport mode (road or rail). For that part of the transport where an alternative mode is considered, rail transport is by far most attractive (78%) followed by road transport (22%).

Compared to the annual results, a clear difference in the results of the worst case 10 day period is that the impact of the commodity machinery and other products is relatively high. From this, it can be concluded that bulk products are already confronted with the impact of climate change with limited low water levels while high valued intermediate and end products are confronted with the impact of climate change with substantial low water levels. This conclusion is logical related to the characteristics of the commodities and the different ship classes used for these commodities. Bulk products are transported unpackaged in large quantities, which have heavy weights. The high valued intermediate and end products are transported in containers or a piece. Fewer quantities are transported at once, and so the weights are lower. The ship types carrying bulk products have a larger draught than the ship types carrying high valued intermediate and end products.

Figure 5.14: Modal-split effect TRANS-TOOLS, results worst case 10 day period per commodity group<sup>4</sup>



When interpreting and / or using these results, it is relevant to consider the following issues:

#### *Incidental problems or structural problems*

In this study, the W+ climate change scenario is taken as the climate scenario for the future year 2050. In this scenario – which is a worst case climate change scenario – it is assumed that in each year around 2050 several periods occur with low water levels causing problems for inland waterway transport. This means that the low water levels in this scenario are treated as structural problems. In the TRANS-TOOLS model, the low water levels occurring during several periods in a year are also treated as structural problems.

<sup>4</sup> For all OD relations



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It is stressed that the low water levels due to climate change are considered to be a structural problem in the W+ scenario 2050 because it is noticed that many people look at the climate change problems as incidental problems, both for the current situation and for the future situation. The perception of climate change problems being incidental problems was noticed amongst others at the Knowledge for Climate workshop of this project organized in April 2010 with several stakeholders. Also in the interviews with stakeholders reported by the VU (VU, 2009), the problems are seen as incidental problems causing not so much troubles. Since reactions by stakeholder can be very different depending on whether the problems are incidental or structural, it makes a substantial difference for instance in relation to the modal-split effects.

At the moment the climate change problems are incidental problems. In the W+ climate change scenario, these problems will stay incidental the next years, but the frequency will increase. Closer to the year 2050, the problems occur that often that they are not incidental anymore, but they become structural. In the period from present to 2050, actors in the transport market will first try to find flexible solutions for incidental problems and later on they will try to find structural solutions for structural problems.

Once again, in this study the climate change problems are being treated as structural problems leading to structural reactions made by actors in the transport market.

#### *Feasibility of shift to road and rail transport*

The previous remark concerning incidental or structural problems is especially relevant in relation to the feasibility of the shift to road and rail transport. In case of incidental problems, it is the question whether it is possible to organize a strong shift to road and rail transport. In case of structural problems as they are considered in this study, the problems are no surprise and the shift to road and rail can be organized on a structural basis.

From the about 40 million tonnes for which the generalized transport costs increase that much that other transport modes are considered, for 35 million tonnes the rail transport would be most attractive, for 5 million tonnes the road transport would be most attractive.

In the TRANS-TOOLS model, possible capacity problems of transport modes are not taken into account. Both for rail and road the relevant question is whether there is enough capacity to handle such a shift in transport volume. Up to 2050 in a high economic growth scenario, capacity has to be expanded anyway (by additional infrastructure and / or more efficient organization of transport). For the volume of transport shifting to road, it is expected that this will not cause too much capacity problems on the road network (although this is not in line with policy goals and measures, but this is a different story). For the volume of transport shifting to rail, it is expected that this volume might cause capacity problems on the rail network (reduction of 6% of inland waterway transport corresponds to an increase of about 22% of total rail transport in relation to the Netherlands). However, if a shift takes place to rail transport, it does not necessarily mean that the transport takes place between the same port and the hinterland region. In case the rail capacity in Rotterdam and other ports in the Netherlands is not enough, the goods can be shipped to Hamburg and Bremen (if there is capacity) which have a much higher share of rail transport in their hinterland flows.

In general, it is very difficult to predict the available capacity of transport modes on a very long term up to 2050. In many long term scenario studies, it is assumed that if demand is higher than supply, somehow it will be organized that demand and supply meet each other (especially if there is enough time).

The capacity of the transport modes road and rail might be a problem when a substantial volume of inland waterway transport shifts to these transport modes. Although it is very difficult to give a concrete idea about the extent of the capacity problems, given the structural problems in 2050, the very long term until 2050 and the possible shift to the ports of Hamburg and Bremen there might be limited capacity problems.





### 5.3.3 Competitive position of Rotterdam – port choice

A first reaction if the inland waterway transport to and from Rotterdam is obstructed could be to try to transport the goods with inland waterway transport to and from another seaport. However, the low water problems on the inland waterways network will obstruct inland waterway transport to and from other surrounding seaports such as Antwerp, Vlissingen, Terneuzen, Moerdijk and Amsterdam as well. Another possibility could be to shift the goods to Hamburg and Bremen and transport the goods with inland waterway transport to the hinterland regions in Germany. However, the share of inland waterway transport in these German seaports is not that high and the inland waterways accessibility via these ports is not that good.

If a shift takes place to the transport alternatives road and rail transport, it is possible that – depending on transport costs and available capacity (see also feasibility of shift to road and rail transport) – a shift takes place to other seaports, especially to the German seaports Hamburg and Bremen that have good railway services and good rail connections to the German hinterland. If this happens, up to around 4% of the total inland waterway transport could shift to these German ports.

#### *Other possible reactions to deal with climate change problems*

In the applied methodology a number of possible reactions are taken into account:

- Alternative route inland waterway transport (BIVAS);
- Reduction of load rate inland waterway transport (BIVAS);
- Acceptance of increased generalized transport costs of inland waterway transport (TRANS-TOOLS);
- Delay of inland waterway transport in case of obstruction on the waterways, they still use inland waterway transport, but at a later time (TRANS-TOOLS);
- Shift to another competitive and feasible transport alternative, road or rail transport (TRANS-TOOLS).

However, other reactions are also possible such as use of other (smaller) vessels with less draught, building up stocks near the client or the seaport in times there are no water level problems or temporarily sourcing from other regions. These reactions have not been taken into account, only those bullet wise listed above have been included in the applied method. For the other reactions, it was – at this moment – not possible to include these in the methodology. A more structured overview of possible reactions is included in the TNO report 'Robuuste logistiek, adaptatiestrategie voor logistieke operaties' (TNO, 2008).

#### *Uncertainty*

In this study, a long term scenario analysis is made based on an economic scenario and a climate change scenario for the year 2050. Then the BIVAS model and the TRANS-TOOLS models have been applied. In these models several assumptions have been applied in order to finally determine the impact of the W+ climate change scenario on the competitive position of inland waterway transport.

Because of the application of several scenarios in combination with models including assumptions, the long term up to 2050 and the temporary problems during a year, there is quite some uncertainty about the outcomes of this exercise. Therefore, it is important that the results are analyzed in the light of the applied scenarios and models and that the results are not interpreted as absolute figures, but that they give an indication of the expected impact.



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## 5.4 Direct impact of low water levels on main rivers on inland waterway transport

The direct impact of low water levels on the main rivers can be summarized as follows:

### *Water levels*

- There is a large difference between the impact of the W+ climate change scenario from an annual perspective and from a specific period perspective. In the annual results, the impact of climate change is dampened because the low water levels lead only to problems during and a (limited) number of periods during and after summer time, besides these periods, the climate change has no or limited impact;
- There can be quite large differences between the periods where climate change leads to problems depending on the exact water levels, the duration of the problems and the frequency that problematic periods return;

### *Annual results*

- For the whole year, from the total inland waterway transport within, to, from and through the Netherlands 86% of the total volumes is not affected by the impact of the W+ climate change scenario;
- From the 14% of the inland waterway transport that is confronted with the impact of the climate change, 7% becomes infeasible (unreliable because the goods cannot be delivered at the planned moment) and 7% is still feasible, but against increased generalized transport costs;
- The increase in unreliability and level-of-service leads to a modal-shift of 8% of the total annual volume. From this volume 88% has an incentive to shift to rail transport and 12% to shift to road transport;

### *Results 10 day worst case period*

- For the worst case 10 day period, the volume not affected by the impact of the W+ climate change scenario is 55%.
- From the 45% of the volume that is confronted with the impact of climate change, 35% becomes infeasible (unreliable because the goods cannot be delivered at the planned moment) and 10% is still feasible, but against increased generalised transport costs;
- The increase in unreliability and level-of-service leads to a modal-shift of 28% of the total volume in this 10 day period. From this volume 78% has an incentive to shift to rail transport and 22% to shift to road transport;
- From an annual perspective you could say that 7% of the total volume becomes infeasible transport by inland waterway transport. From a more detailed perspective you could say that during summer time within three months three periods occur causing serious low water problems leading to 30% of the total volume becoming infeasible each period for duration between 15 to 25 days each period. This happens on a structural basis and therefore, structural solutions are needed.

### *Results by ship class, commodity and origin/destination relation*

- Barges and convoys face the highest impact in terms of infeasible transport, while motor vessels face the highest increase in transport costs;
- The dry bulk commodities have the highest share and volume of inland waterway transport facing problems of the climate change scenario. The machinery and other products do not



have the highest share, but this commodity has a large volume of goods that is confronted with mainly infeasible transport and increased transport costs;

- The transport flows on the relations to and from Germany have by far the highest share and volume of goods facing problems due to low water levels. After these flows to and from Germany, also the domestic flows in the Netherlands are confronted with a substantial impact of the climate change scenario.

*Competitive position of inland waterway transport and Rotterdam*

Because of a structural increase of the unreliability of inland waterway transport and a structural increase of the generalized transport costs of inland waterway transport on a substantial part of the origin/destination relations (mainly between the Netherlands and Germany), the competitive position of inland waterways decreases. As a consequence a modal-shift is expected towards mainly rail and road transport as described above.

A threat for the competitive position of Rotterdam is a possible shift of goods from inland waterway transport via Rotterdam towards rail transport via the ports of Hamburg and Bremen. Around 4% of the total inland waterway transport in Rotterdam could shift towards these German ports in the Global Economy scenario 2050.

*Difference in generalized transport costs*

From the total annual inland waterway transport, 14% of the volume is affected by the W+ climate change scenario which leads to an increase of the generalized transport costs of inland waterway transport within, to, from and through the Netherlands with more than 20% (more than 350 million Euro).



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## 6. Summary, conclusions and recommendations

In this report, the main question being answered is: is there any problem concerning the competitive position of inland waterway transport, and if there is, how big is this problem due to changes in water levels in the W+ climate change scenario?

In the following, a summary of the approach is given followed by the main conclusions and recommendations for further research.

### *Summary of the approach*

Important starting points for the analysis of this study are:

- Time horizon 2050;
- Global Economy scenario – high growth economic scenario;
- W+ scenario – worst case climate change scenario;
- Translation of W+ scenario into sea water levels and water levels on the main rivers.

The situation considered in this study is a worst case situation with high volumes of inland waterway transport (based on the Global Economy scenario) and a severe impact of climate change (based on the W+ scenario) where the problems resulting from climate change are structural problems (problems occur every year a number of times around 2050).

In order to analyze the impact of climate change, a reference situation without climate change and a W+ situation including climate change have been determined. The impact of the W+ climate change scenario on route choice, changes in loading rate (both resulting in increased level-of-service) and infeasibility of inland waterway transport (resulting in a decrease of the reliability) due to low water levels has been determined with the BIVAS model. The impact of the W+ climate change scenario on the acceptance of the impact (use of inland waterway transport against higher costs), on the possible mode shift toward road and rail transport and on the possible shift of goods towards other seaports is determined with the TRANS-TOOLS model.

Additionally, a brief analysis has been made of the impact of climate change on the closing frequency of the storm surge barriers in the Rotterdam area and the effect of this on inland waterway transport.

### *Conclusions*

Based on the scenarios, assumptions, models and interpretations of the results, the following main conclusions can be drawn:

#### *Annual results*

- For the whole year, from the total inland waterway transport within, to, from and through the Netherlands 86% of the total volumes is not affected by the impact of the W+ climate change scenario;
- From the 14% of the inland waterway transport that is confronted with the impact of the climate change, 7% becomes infeasible (unreliable because the goods cannot be delivered at the planned moment) and 7% is still feasible, but against increased generalized transport costs;
- The increase in unreliability and level-of-service leads to a modal-shift of 8% of the total annual volume. From this volume 88% has an incentive to shift to rail transport and 12% to shift to road transport;



### *Results 10 day worst case period*

- For the worst case 10 day period, the volume not affected by the impact of the W+ climate change scenario is 55%.
- From the 45% of the volume that is confronted with the impact of climate change, 35% becomes infeasible (unreliable because the goods cannot be delivered at the planned moment) and 10% is still feasible, but against increased generalized transport costs;
- The increase in unreliability and level-of-service leads to a modal-shift of 28% of the total volume in this 10 day period. From this volume 78% has an incentive to shift to rail transport and 22% to shift to road transport;

Coming back to the question whether there is a problem concerning the competitive position of inland waterway transport and the extent of this problem, it can be concluded that on specific markets such as between the Netherlands and Germany the competitive position of inland waterway transport is threatened, especially during and after summer time.

Concerning the increase of the closing frequency of the storm surge barriers in the Rotterdam area, it is concluded that the increase of the closing frequency of once every 10 years now to once every 5 years in 2050 will not have a substantial impact on the competitive position of inland waterway transport neither on the competitive position of the port of Rotterdam.

### *Recommendations*

Based on the analyses, a number of recommendations for further research have been identified.

- Sensitivity analysis with a different base year  
In the analysis of the water levels it turned out that the selection of the base year 2004 has a strong impact on the results. The data of the number of vessels are based on the year 2004 and raised until 2050. Also the water levels of 2004 (year with lower than average water levels) have been raised to the year 2050 showing exactly the same pattern in peaks in 2050 as in the year 2004. It is recommended to apply a sensitivity analysis with another base year in order to analyze the impact of another base year on the final results.
- Sensitivity analysis with impact of climate change on water levels of small rivers and canals  
In the analyses, only the impact of climate change on water levels of the main rivers has been taken into account. During the project a discussion was started that the impact of climate change on smaller rivers and canals might be relevant as well. It is recommended to apply a sensitivity analysis including climate change impact on small rivers and canals in order to analyze the impact this on the final results.
- Distinction between incidental and structural problems  
In this study, the problems resulting from the W+ climate change scenario are considered as structural problems since periods with low water levels are expected to occur several times each year around 2050. Since the reactions of actors in the transport market and the solutions might be very different dependent on whether the problems are incidental or structural, it is important to make a distinction between incidental problems on the middle to long term and structural problems on a long term up to 2050.
- Improvements of the BIVAS model  
While using and checking the BIVAS model results, a number of problems have been encountered such as: high share of infeasible transport in the reference situation, selection of illogical routes and lacking trade-off between selection of alternatives (route or load rate). It is recommended to improve these items in BIVAS and to use this improved BIVAS version in further applications.
- Combination of TRANS-TOOLS results with other possible reactions  
In the applied methodology a number of reactions of actors in the transport market have been taken into account. However, other reactions such as the use of other (smaller) vessels with less draught, building up stocks near the client or the seaport or temporarily sourcing from other regions should be taken into account and combined with the TRANS-TOOLS results.



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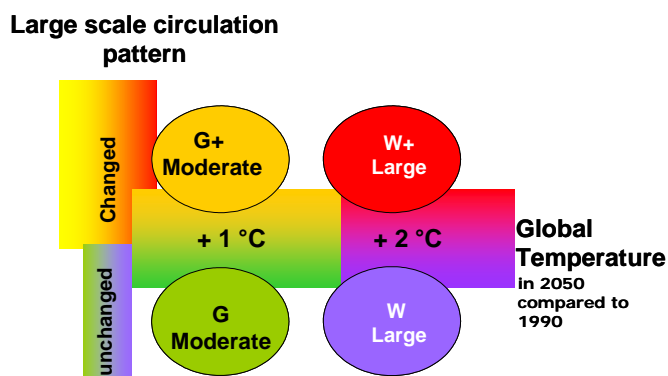


## Annex A – Description of the KNMI climate change scenarios (in Dutch)

In 2006, presenteerde het KNMI vier nieuwe klimaatscenario's voor Nederland. Deze scenario's zijn gebaseerd op scenarios uit 5 verschillende algemene circulatiemodellen (GCMs). Vanwege de schaalgrootte van de modellen hebben de afgeleide scenario's voor Nederland ook betrekking op het stroomgebied van de Rijn in Duitsland. Voor subcontinentale schaalniveau's zoals het stroomgebied is een GCM niet geschikt, daar is het nodig deze te regionaliseren tot regionale circulatiemodellen (RCM). De RCM simulaties voor de KNMI scenario's zijn gemaakt in context van het Europese PRUDENCE project. In PRUDENCE zijn 10 RCM's and 3 GCM's toegepast over een periode van 2 maal 30-jaar: a historische analyse van 1960-1990 en een prognose voor 2070-2100. Een projectie voor het jaar 2050 is gedaan op basis van een lineaire interpolatie tussen 2070 en 2100.

De simulaties laten variabele wisselingen zien in de kracht van westenwind in Nederland. De verwachting is dat een sterke verandering in circulatie zal leiden tot mildere en nattere winters door meer westenwind, vergeleken met scenario's zonder verandering in circulatie. Daarom is ervoor gekozen de scenario's te baseren op temperatuur, maar ook op veranderingen in luchtstromen, om uiteindelijk 4 onderscheidende klimaatscenario's te maken (figuur 1)

Figure A.1: The four KNMI 2006 scenarios







De 4 klimaatscenario's zijn samengevat in table 1 en tonen de bandbreedte waarbinnen verschillende klimaatomstandigheden zich kunnen ontwikkelen.

Table A.1: Changes in the main climate parameters according to the KNMI 2006 scenarios for 2050

	G	G+	W	W+
summertime				
mean temperature (K)	0.9	1.4	1.7	2.8
10% warmest days (K)	1	1.8	2	3.6
10% coldest days (K)	0.9	1.1	1.8	2.2
mean precipitation (%)	2.8	-9.5	5.5	-19
wet day frequency (%)	-1.6	-9.6	-3.3	-19.3
mean precipitation on wet day (%)	4.6	0.1	9.1	0.3
median of wet day precipitation (%)	-2.5	-6.2	-5.1	-12.4
precipitation on 0.01 wettest days (%)	12.4	6.2	24.8	12.3
wintertime				
mean temperature (K)	0.9	1.1	1.8	2.3
10% warmest days (K)	0.8	1	1.7	1.9
10% coldest days (K)	1	1.4	2	2.8
mean precipitation (%)	3.6	7	7.3	14.2
wet day frequency (%)	0.1	0.9	0.2	1.9
mean precipitation on wet day (%)	3.6	6	7.1	12.1
median of wet day precipitation (%)	3.4	7.3	6.8	14.7
precipitation on 0.01 wettest days (%)	4.3	5.6	8.6	11.2



## Annex B – Overview absolute water levels W+ and reference situation 2050, worst case 10 day period

In this annex two figures are included showing the absolute water levels in the W+ and the reference situation 2050 on the inland waterways network. These results concern the water levels in the worst case 10 day period of the year.

Figure B.1: Absolute water levels in the W+ situation, worst case 10 day period of the year

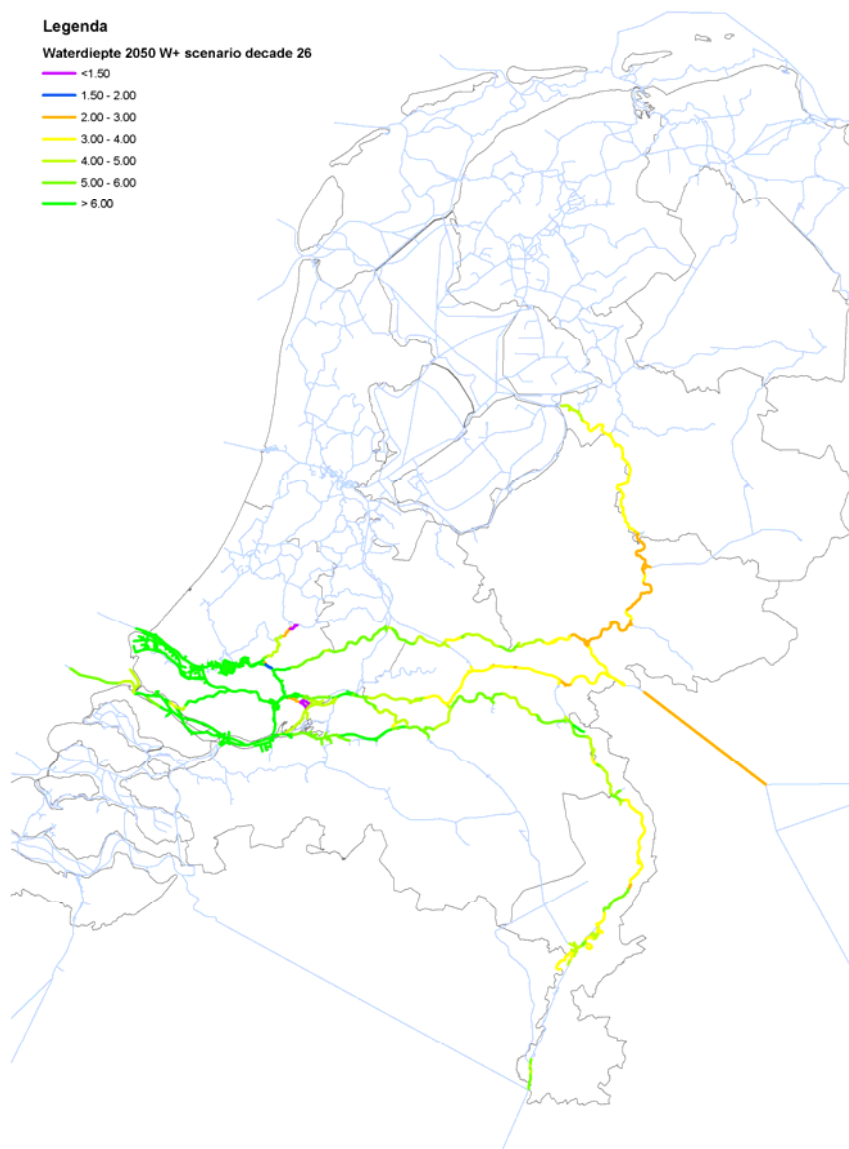




Figure B.2: Absolute water levels in the reference situation, worst case 10 day period of the year

