INLAND WATERWAY TRANSPORT IN THE RHINE RIVER:
SEARCHING FOR ADAPTATION TURNING POINTS

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Master’s Thesis Integrated Water Management submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management, Wageningen University, The Netherlands
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Searching for Adaptation Turning Points

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ABSTRACT

_Inland Waterway Transport (IWT)_ is one of the main economic activities carried out in the Rhine River. Noticeable impacts are expected to occur in the Rhine hydrological regime due to climate change, likely affecting the inland waterway transport sector.

This research aims to identify potential moments in time when socio-economic preferences regarding inland waterway transport (IWT) in the Rhine River will no longer be reached due to the effects of climate change, specifically the effect of _longer and more frequent drought periods_. These potential moments in time are called _adaptation turning points (ATPs)_.

By using the five steps method proposed by the MEDIATION project, we concluded that an ATP will be reached after 2085 solely in the case of the most extreme of the three IPCC scenarios analyzed. This is a point in time when an unfavorable change in the distribution of the freight transport market shares would occur since IWT would no longer be reliable or economically competitive. There is no straightforward answer to the question about the best adaptation measure to face the impacts of low water periods on IWT; however, the behavior of the actors in the IWT market suggests that customers are the ones under more pressure to adapt.

_**Keywords:** Climate change; Inland waterway transport; Low water levels; Rhine; Adaptation turning points_
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SUMMARY

Climate change is the most important global environmental problem of this century (Carter 2007). Green House Gas (GHG) emissions resulted from human activities have enhanced the greenhouse effect by increasing the concentration of gases in the atmosphere, and the actions undertaken to mitigate anthropogenic GHG emissions have been so far unsuccessful (Carter 2007).

The Rhine main stream together with their tributaries and canals, constitute one of the most important commercial inland waterways worldwide (Cioc 2002). Noticeable impacts are expected to occur on the Rhine hydrological regime due to climate change, likely affecting inland waterway transport (IWT) sector.

This research aims to identify potential moments in time when socio-economic preferences regarding IWT in the Rhine River will no longer be reached due to the effects of climate change, specifically the effect of longer and more frequent drought periods. These potential moments in time are called in this research ‘adaptation turning points’ (ATPs). In order to reach this goal, we used the five steps method for the assessment of ATPs developed in the framework of MEDIATION research project.

The stretch between Duisburg and Rotterdam is the region selected for carrying out this research. We consider this stretch as a critical region for navigation purposes because it is an important inland connection between the Ruhr German industrial area and the Port of Rotterdam. Therefore, this may be a sensitive area from the stakeholders’ perspective and likely some ATPs exist.

The relationship between IWT and the Rhine hydrological system is given by the fact that vessels sail through the fairways built along the Rhine River, and vessels’ transport capacity depend on the water depth and width of the shipping channels (Krekt et al. 2010). In fact, the relationship between water depth and loading capacity is direct: the lower the water depth, the lower the vessels’ loading capacity (Davidse 2012).

The main physical changes triggered by climate change on the Rhine River are changes on water discharge, river morphology and water temperature. These three physical changes involve potential implications for the normal development of IWT since they may cause modifications on available water depths, limiting the normal traffic along the river. However, the most severe and likely impact is the one related to changes on water discharge.

Water depth is a relevant indicator when assessing climate change impacts on the IWT sector. Accordingly, we identified a water depth threshold which is suitable for our assessment. We defined this threshold as the minimum water depth required for normal propeller performance. Then, we recognized the interval [1.7-2.1] (meter) as the threshold value.

According to the stakeholders interviewed, given this water depth threshold, the situation socio-economically unacceptable for the IWT sector is described as the moment in time when the minimum water depth required for normal vessels’ propeller performance is not reached during—at least- 7 days in a row, every year. Once this point is reached, IWT companies will face severe logistics problems which will make impossible to guarantee transportation to fulfill the requirements of their customers.

We translated this critical situation into timescale by using climate scenarios and hydrological projections to assess when the turning points may occur. For this research purposes, we used the
hydrological projections obtained by Hurkmans et al. (2010) by using the Variable Infiltration Capacity (VIC) model and the atmospheric datasets resulted from the regional climate model REMO for three SRES scenarios, namely: A1B, A2, and B.

Those three scenarios were analyzed. We identified only one moment in time when the minimum water depth for normal propeller performance will not be reached during -at least- 7 days in a row, every year. This socio-political threshold will be reached after 2085 in case of the most extreme of the three SRES scenarios analyzed (A1B).

Consequently, we concluded that after 2085 an ATP may be reached, triggering an unfavorable change in the distribution of freight transport market shares. This redistribution will be explained by the increased IWT prices, and the loss of reliability of the IWT sector since they will not be able to guarantee transportation to their customers anymore.

Finally, we analyzed some alternative adaptation strategies that the IWT sector may take to cope with the potential impacts of climate change. The design of lighter and wider vessels, increasing storage capacity, and some river management measures like canalization, dredging, and longitudinal dams, are examples of adaptation measure that can be implemented by IWT companies, shippers and policy-makers. The ratio between costs and benefits of a certain measure is hard to determine. However, the behavior of the actors in the IWT market suggests that shippers are the ones under more pressure to adapt.

We concluded this research offering some final recommendations:

- We recommend improving the MEDIATION method for assessing ATP by including some guidelines to choose a suitable threshold.
- As a topic for further research we recommend to study about shippers’ adaptation capacity to climate change as well as the alternative adaptation strategies that this group of stakeholders can implement. Studying about adaptive policies like flexible inventory management strategies may result especially interesting.
I. INTRODUCTION

Climate change is the most important global environmental problem of this century (Carter 2007). Green House Gas (GHG) emissions resulted from human activities have enhanced the greenhouse effect by increasing the concentration of gases in the atmosphere, and the actions undertaken to mitigate anthropogenic GHG emissions have been so far unsuccessful (Carter 2007). As a matter of fact, the political failure of the Kyoto protocol to negotiate global emissions reduction makes the goal of holding global warming to 2°C unlikely to be reached (Smith et al. 2011).

Consequences related to the changing climate conditions are expected at global level, but also at regional level, and hydrological systems such as the Rhine River Basin will not be an exception (Flörke et al. 2011). The Rhine River is one of the most important hydrological systems of Europe with about 1,320 km long and a catchment area covering about 200,000 km² within nine states, namely: Germany, Switzerland, France, The Netherlands, Belgium, Luxembourg, Austria, Lichtenstein and Italy (ICPR 2009). The Rhine River supplies water for multiple human activities in the riparian states, activities that are being threatened by projected climate change impacts (Flörke et al. 2011).

In this context, waterborne transport is one of the principal human activities carried out in the Rhine River. Nowadays, the Rhine main stream together with their tributaries and canals, constitute one of the most important commercial inland waterways worldwide (Cioc 2002). Its geographical location and its well-developed infrastructure allow about 300 million tons of cargo and 2 million containers to be transported each year, connecting important industrial areas, such as Ruhr and Basel, with main European harbors such as Rotterdam and Antwerp (Pauli 2010).

Noticeable impacts are expected to occur on the Rhine hydrological regime due to climate change, likely affecting inland waterway transport sector. It is expected that the higher average runoff during winter increases the peak flow frequency, halting navigation traffic more often (Middelkoop and Kwadijk 2001; Flörke et al. 2011). Alternatively, reduced water depths during summer would lead to the restriction of navigable fairway width (Wurms et al. 2010) limiting ships’ loading capacity more often and for longer periods (Middelkoop et al. 2001; Middelkoop and Kwadijk 2001).

Traffic problems related to drought periods are expected to be more severe for navigation purposes than those related to flooding (Krekt et al. 2010; Wurms et al. 2010). Drought periods will
cause low water depths; hence, restricted loading capacity, lower speeds, higher fuel consumption (Flörke et al. 2011) and increased risk of grounding (Jonkeren et al. 2008). Moreover, limiting loading capacity will lead to higher freight prices, resulting in negative welfare effects on the riparian states (Jonkeren et al. 2008).

The management strategy, the policy objectives and/or social preferences with regard to the inland waterway transport sector in the Rhine River are likely to be challenged by these changing climate conditions. The unfeasibility to invest in further dredging measures due to environmental issues or the unwillingness to pay higher freight prices due to economical reasons are only examples of the diversity of socio-political thresholds that may be reached in the future due to climate change.

This research aims to identify potential moments in time when socio-economic preferences regarding inland waterway transport in the Rhine River will no longer be reached due to the effects of climate change, specifically the effect of longer and more frequent drought periods. These potential moments in time are called in this research ‘adaptation turning points’ (ATPs).

This research has been developed in the framework of MEDIATION research project which aims to develop a common platform for sharing a diverse set of methods and tools for assessing climate change impacts, vulnerability and adaptation as well as an integrated methodology to support adaptation policy development at different levels in Europe.

I.1. Outline of the report

Chapter II presents the basic elements of our research project, namely: the conceptual framework, the research objective, research questions and methods.

Chapter III presents the study area and the socio-ecological sector of concern in order to scope the assessment. In Section III.1 the specific study area within the Rhine River Basin is presented and briefly described. In Section III.2, we present a detailed description of inland waterway transport (IWT) as the socio-ecological sector of concern.

Chapter IV presents a summary of the main potential impacts of climate change on IWT. In the last section of the Chapter, the severity and likeliness of each one of these potential impacts is discussed in order to focus our attention on the climate change impact that results to be the most outstanding.

Chapter V presents a selection of indicators and threshold values for potential impacts of climate change on IWT. Three potential thresholds are evaluated, namely: an economic threshold, a policy related threshold and a technical threshold. The three thresholds are explained in the sections V.1, V.2, and V.3. Then in section V.4, the three thresholds are evaluated in order to recognize a suitable threshold for IWT, so further assessment of Adaptation Turning Points (ATPs) on IWT can be performed.

Chapter VI presents the intermediate steps and the analysis we performed to finally determine adaptation turning points in the IWT sector. Section VI.1 presents the results obtained about the stakeholders’ preferences in terms of how long an IWT company may handle a dry period. Section VI.2 presents the analysis we performed to translate ATPs into time scale. Then, Section VI.3 presents the analysis and discussion of the results presented in this chapter.
Chapter VII presents a summary of the main alternative adaptation strategies that the IWT sector may take to cope with the potential impacts of climate change. Finally, Chapter VIII presents our final discussion, conclusions and recommendations.
II. THE RESEARCH PROJECT

II.1. Conceptual Framework

In this section, the key concepts to be used in this thesis are explained. Section II.1.1 addresses the concept of ‘adaptation to climate change’, in section II.1.2 the concepts of ‘tipping point’ is briefly exposed to later explain in section II.1.3 the ‘adaptation tipping points (ATPs) approach’ developed by Kwadijk et al. (2010). Finally, in section II.1.4 the term ‘turning points’ is presented as a slight variation from the ATPs concept, and the five steps method developed by MEDIATION to assess turning points is described.

II.1.1. Adaptation to climate change

The concept of adaptation has its origins in biology (Smit and Wandel 2006). Widely speaking, adaptation refers to a group of actions undertaken by a system to better cope with a perturbation (Gallopín 2006; Smit and Wandel 2006). These actions may involve a.o. adjustments, behavioral changes, proactive measures or reactive responses (Adger et al. 2004; Gallopín 2006).

Gallopín (2006) offers a definition of adaptation in the context of climate change based on previous ideas exposed by the IPCC. The author states that adaptation to climate change can be defined as “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harms, or exploits beneficial opportunities” (Gallopín 2006). In the same line, Kwadijk et al. (2010) defines adaptation to climate change as the “actions targeted at a specific vulnerable system, in response to actual or expected climate change, with the objective to either limit negative impacts or exploit positive impacts” (Kwadijk et al. 2010).

Then, adaptation analysis in climate change studies aims to determine to what extent the negative effects of climate change can be mitigated by displaying adaptation measures (Smit and Wandel 2006).

II.1.2. Tipping Points

The concept of tipping point has been defined by Lenton et al. (2008) as a “critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system” (Lenton et al. 2008).

Recently, the concept of tipping point has been started to be used in climate change studies (Russill and Nyssa 2009), in a broader way, to describe a variety of changes in the Earth system (Lenton et
These changes may be associated a. o. to abrupt or non-linear transitions, positive feedbacks, thresholds crossing, irreversibility, reversible phase transitions, and bifurcations (Lenton et al. 2008; Russill and Nyssa 2009).

The definition of tipping point to be used in this thesis is given by Kwadijk et al. (2010). The authors claim that the concept of ‘tipping points’ in climate change research is used “to indicate the point where a system change initiated by an external forcing no longer requires the external forcing to sustain the new pattern of change” (Kwadijk et al. 2010).

II.1.3. Adaptation tipping points

In congruence with what was explained in section II.1.2, Kwadijk et al. (2010) has proposed the concept of ‘adaptation tipping points’. The authors define this term as those points where “the magnitude of change due to climate change or sea level rise is such that the current management strategy will no longer be able to meet the objectives” (Kwadijk et al. 2010). Once a tipping point is reached, a new strategy is needed. Then, the adaptation tipping points approach gives information about whether a management strategy may fail and -if so- when, allowing policy makers to plan adaptation measures (Kwadijk et al. 2010).

According to the authors, the adaptation tipping points approach contains elements from a vulnerable bottom-up approach (Kwadijk et al. 2010). The authors claim that the analysis proposed in the framework of the adaptation tipping point approach does not start focusing on a specific scenario (as the classical top-down approach does) but it starts focusing on the policy objectives specified for different socio-ecological sectors (Kwadijk et al. 2010). Figure 1 shows a scheme of the adaptation tipping points approach.

II.1.4. Adaptation turning points (ATPs)

Researchers involved in the MEDITATION project have proposed the concept of ‘adaptation turning points (ATPs) using as starting point the adaptation tipping point approach developed by Kwadijk et al. (2010). An adaptation turning point (ATP) is “a situation where a socio-political threshold is reached, due to climate change induced changes in the biophysical system” (Werners 2012).

The difference between the ATPs approach proposed in MEDITATION project and the adaptation tipping point approach proposed by Kwadijk et al. (2010) lies in the nature of the threshold to be reached. The Kwadijk’s approach only considers those thresholds related to formal policy objectives (Kwadijk et al. 2010). Whereas, the ATPs approach involves a broader definition of
threshold to include not only formal policy objectives but also social preferences, stakes and interests (Werners 2012).

According to the ATPs approach, a socio-political threshold is reached when climate change results in conditions that stakeholders consider unacceptable. Then, it indicates that the current management strategy has failed and a new strategy is needed (Werners 2012).

The ATP(s) approach has been used in previous researches. De Groot (2012) analyzed the existence of ATP(s) in the agriculture sector developed in the Twentekanalen region of the Rhine River basin due to changes in water discharge (de Groot 2012), and Bölscher (2011) searched ATP(s) for the Rhine salmon policy due to high water temperatures and low water discharges (Bölscher 2011).

MEDIATION proposes five practical steps for the assessment of adaptation turning points (see Figure 2).

---

**I. Scope the assessment**
- Identify target region and socio-ecological sectors of concern

**II. Identify key potential impacts of climate change**
- Make a thorough list of possible consequences of climate change for the region and the sectors of concern
- Prioritise climate change trends and impacts based on potential severity and likeliness (use trends + extreme scenarios)

**III. Determine socio-political objectives of concern**
- Select indicators and threshold values for potential impacts on sectors & regions
- Determine which situation is acceptable according to: a) analysis of policy objectives, standards or administrative arrangements, b) public opinion, and/or c) statistics

**IV. Determine adaptation turning points**
- Determine how much change a sector can handle, given the thresholds value independently from time
- Ask: which climate conditions are critical for reaching the policy objectives? What are climate conditions beyond which the current strategy fails?
- Methods: compare with design criteria; consult experts and/or representatives from different sectors; assess historical variation of boundary conditions.
- Translate turning points to timescale. Use climate scenarios to assess when the turning points may occur.

**V. Determine alternative adaptation strategies**
- Assess which strategies actors may use to respond to adaptation turning points.
- Consider a different strategy or additional measures to postpone or resolve a turning point (methods depend on scale, score these alternatives to policy targets )
- Assess how easy it is to switch between strategies in time

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**Figure 2. MEDIATION five steps for Assessment of Adaptation Turning Points**
Source: Based on (Werners 2012)
II.2. **Research Objective**
This research aims to identify potential moments in time when the current policy objectives or social preferences regarding inland waterway transport (IWT) in the Rhine River will no longer be able to meet their objectives from the stakeholders’ perspective, due to longer and more frequent drought periods induced by climate change. These potential points of failure are called ‘adaptation turning points’.

II.3. **Research Questions**
The main research question to be answered by this research is:

*Are the existing IWT policies or social preferences in the target region expected to fail from the stakeholders’ perspective in the light of decreasing discharge conditions due to climate change? When may we expect these turning points to be reached?*

The following sub-questions have been posed to answer the main research questions:

a) What are the critical areas for navigation purposes along the Rhine River? Why?
b) What are the expected climate change impacts in the target region?
c) Which impacts are the most likely to occur? Which are potentially the most severe of them?
d) How these impacts will affect inland waterway transport in the target region?
e) Which are the most relevant indicators to be considered for the climate change impacts identified?
f) What are the relevant policy objectives, standards and/or administrative arrangements that regulate inland navigation in the target region?
g) What indicators’ values are considered as thresholds by the current management strategy?
h) May these policy objectives, standards and/or administrative arrangements fail from a stakeholder perspective due to climate change because it results in a situation socio-economically unacceptable? How can this socio-economically unacceptable situation be described?
i) Considering the threshold values established by the current management strategy and climate change trends, when in time climate conditions may trigger that situation considered as socio-economically unacceptable?
j) Which adaptation strategies have been proposed to cope with the expected climate change impacts in the target area? Which are their advantages and limitations?

II.4. **Research Methods**
The research methodology will follow the five steps presented in section II.1.4. In this section, each one of the five steps is linked to the sub-questions posed in section II.3. Then, the methods to be used to answer these sub-questions are explained by specifying activities and sources of information.

Step I: Scope the assessment

a) What are the critical areas for navigation purposes along the Rhine River? Why?
   Activity: Literature review
   Source: scientific journals and official reports (a.o. CCNR, CHR, ICPR, PIANC)
Step II: Identify key potential impacts of climate change

b) **What are the expected climate change impacts in the target region?**
   Activity: Literature review
   Source: scientific journals and official reports (a.o. CHR, ICPR, PIANC)

c) **Which impacts are the most likely to occur? Which are potentially the most severe of them?**
   Activity: Literature review
   Source: scientific journals and official reports (a.o. CHR, ICPR, PIANC)

d) **How these impacts will affect inland waterway transport in the target region?**
   Activities: Literature review & semi-structured interviews
   Source: scientific journals and official reports (a.o. CCNR, CHR, ICPR, PIANC); interviews with navigation companies representatives and/or experts on inland navigation

Step III: Determine socio-political objectives of concern

e) **Which are the most relevant indicators to be considered for the climate change impacts identified?**
   Activity: Literature review
   Source: scientific journals and official reports (a.o. CCNR, CHR, ICPR, PIANC)

f) **What are the relevant policy objectives, standards and/or administrative arrangements that regulate inland navigation in the target region?**
   Activities: Literature review & semi-structured interviews
   Source: scientific journals and official reports (a.o. CCNR, CHR, ICPR, PIANC); interviews with navigation companies representatives and/or policy makers

g) **What indicators’ values are considered as thresholds by the current management strategy?**
   Activities: Literature review & semi-structured interviews
   Source: scientific journals and official reports (a.o. CCNR, CHR, ICPR, PIANC); interviews with navigation companies representatives and/or policy makers

Step IV: Determine adaptation turning points

h) **May these policy objectives, standards and/or administrative arrangements fail from a stakeholder perspective due to climate change because it results in a situation socio-economically unacceptable? How can this socio-economically unacceptable situation be described?**
   Activity: Semi-structured interviews
   Source: interviews with navigation companies’ representatives, inland navigation experts and/or policy makers

i) **Considering the threshold values established by the current management strategy and climate change trends, when in time climate conditions may trigger that situation considered as socio-economically unacceptable?**
   Activity: Literature review & use of VIC hydrological model + SRES climate change scenarios
   Source: scientific journals and official reports (a.o. CHR, ICPR, PIANC)
Step IV: Determine alternative adaptation strategies

j) Which adaptation strategies have been proposed to cope with the expected climate change impacts in the target area? Which are their advantages and limitations?

Activity: Literature review
Source: scientific journals and official reports (a.o. CHR, ICPR, PIANC)

II.4.1. Semi-structured interviews for data collection

Semi-structured interviews were applied to obtain primary information. The interviewees were classified in two sub-groups: the first one composed by IWT companies’ representatives, and the second one composed by experts and policy makers. Eleven interviews were applied, three with IWT companies’ representatives and eight with experts and policy makers.

We used the snow ball sampling technique to obtain new contacts. At the end of each interview we asked the interviewee to give the contact details of two or three people from among their acquaintances, belonging to any of the two groups previously defined.

The snow ball sampling technique was successful to obtain contact details of experts and policy makers. In total, we contacted sixteen people from which we interviewed eight. According to Gray (2006), a sample size of eight is usually enough when applying interviews to get the different perspectives present in a group (Gray 2006). The size of eight resulted to be appropriate in the case of the sample of experts and policy makers since we were able to reach data saturation.

However, we did not obtain as much contact details of IWT companies’ representatives as we wished. We contacted eight IWT companies obtaining a low rate of positive answers for interviews. From the eight companies contacted, only three were willing to give an interview, three refused by reason of time constraints and the others did not reply.

Table 1 shows the semi-structured interviews applied during the development of the research. The interview guides are shown in Appendix A.
Table 1. Semi-structured interviews applied

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization / Area</th>
<th>Group</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Henk Blaauw</td>
<td>MARIN / Inland Shipping Coordinator</td>
<td>Experts and policy makers</td>
<td>19-04-2012</td>
</tr>
<tr>
<td>2. Michael Paprocki</td>
<td>Bundesanstalt für Wasserbau</td>
<td>Experts and policy makers</td>
<td>----</td>
</tr>
<tr>
<td>5. Jos Davidse</td>
<td>ThyssenkruppVeerhaven B.V. / Shipping Department</td>
<td>IWT company representatives</td>
<td>05-06-2012</td>
</tr>
<tr>
<td>8. Bas Turpijn</td>
<td>Rijkswaterstaat/ Transportation Economist at Netherlands Department for Public Works</td>
<td>Experts and policy makers</td>
<td>21-06-2012</td>
</tr>
<tr>
<td>11. Nico Casant</td>
<td>Tankmatch B.V.</td>
<td>IWT company representatives</td>
<td>02-07-2012</td>
</tr>
</tbody>
</table>

¹The interview was answered by email
²The interviewee decided to remain anonymous
III. SCOPING THE ASSESSMENT

In this thesis we used the method for assessing adaptation turning points proposed by the MEDIATION Project. Accordingly, the general objective of this chapter is to scope the assessment by presenting the study area and the socio-ecological sector of concern. In Section III.1 the specific study area within the Rhine River Basin is presented and briefly described. In Section III.2, we present a detailed description of inland waterway transport (IWT) as the socio-ecological sector of concern.

III.1. The study area: the Rhine River from Duisburg to Rotterdam

The Rhine River is about 1,320 km long and its catchment area covers about 200,000 km² where about 58 million people live (ICPR 2009). Approximately 55% of the Rhine catchment area lies on Germany, 28% is distributed among Switzerland, France and The Netherlands, and the remaining area spreads over Belgium, Luxembourg, Austria, Lichtenstein and Italy (Görgen et al. 2010).

The Rhine River is divided into five geographical sections through its path from the Alps into the North Sea. The Alpine Rhine is the section flowing from the Alps into the Lake Constance. The High Rhine covers the stretch between Lake Constance and Basel. The Upper Rhine flows from Basel to Bonn where it becomes into the Lower Rhine. In the border between Germany and The Netherlands, the Rhine splits into three main branches forming the river delta as it is indicated in Figure 3. The three branches are: The Waal River, the Nederrijn River and the Ijssel River which flows into the Lake IjsseI (ICPR 2009).

The region addressed in this study is the river stretch between Duisburg and Rotterdam (see Figure 3). It means, the Lower Rhine between Duisburg and Lobith (the German-Dutch border) and the Waal River.

The reason behind the selection of the Duisburg-Rotterdam stretch as the study area for this research’s purposes is because this stretch represents an important inland connection between the Ruhr German industrial area and the Port of Rotterdam. Therefore, we had reasons to think this may be a sensitive area from the stakeholders’ point of view; hence some ATPs may exist. The Nederrijn River is not taken into account since it does not represent an important inland waterway.
Actually, about 150,000 vessels pass Lobith every year (Görgen et al. 2010) and only about 15,000 of them use the Nederrijn River fairway (Stuurman 2012).

The waterway profile is unvarying along this stretch. From Duisburg (km 763) to Rotterdam (km 955) the inland waterway is 2.80 meters depth and 150 meters width (CCNR 2012). Hydrological data used further on this study are based on measurements taken at Lobith gauging station, located in the Rhine River km 865, in the border between Germany and The Netherlands (Görgen et al. 2010).

![Figure 3. Rhine River between Duisburg and Rotterdam](source: www.iksr.de)

It is worth to mention that the stretch Duisburg-Rotterdam is not the only critical area for navigation along the Rhine River. The Kaub area, in Germany, is considered to be a navigation bottleneck because of the severe restrictions related to low water levels in the area (Jonkeren et al. 2011). Furthermore, the river section upstream Loreley is also considered a navigation bottleneck in this case due to safety issues related to the pronounced curves that characterize the stretch (Zentgraf and Dettmann 2010). However, we did not consider these stretches. Even though we think ATPs may exist on these river sections, the time available for this research is not enough to address more than one critical study area.

### III.2. IWT as the socio-ecological sector of concern

The socio-ecological sector of concern is restricted to inland waterway freight transport (IWT). Passenger transport and transport from bank to bank (ferry service) are activities excluded from this study. By inland waterway freight transport (IWT), we understand the activity of transportation by inland waterway vessel of any kind of bulky goods (such as agricultural products, chemicals, mineral products, petroleum, etc.).

IWT is an important transport mode in The Netherlands and Germany. IWT accounts for about 20% of the total amount of freight transported in The Netherlands (Krek et al. 2010) and 16% of the total amount of freight transported in Germany (Jonkeren et al. 2011).

Currently, IWT is the most environmentally friendly mode of freight transport (Pauli 2010). Moreover, IWT is the cheapest mode of freight transport in terms of Euros per ton transported (Jonkeren et al. 2008) and a significant portion of the industrial sector relay on this service as part of its logistic chain.
The relationship between IWT and the Rhine hydrological system is given by the fact that vessels sail through the fairways built along the Rhine River, and vessels’ transport capacity depends on the water depth and width of the shipping channels (Krek et al. 2010). Moreover, water depth on the fairways may determine whether vessels can sail or not (CCNR 2011).

In fact, according to the CCNR regulations, river traffic is restricted when water level is too high. This regulation involves two measures depending on how high the water level is. The first measure is the restriction of vessels’ speed, and the second -and most severe- is traffic halting (CCNR 2011; M.K. 2012). The reason behind this regulation is related to safety issues regarding flooding risk and dikes’ strength and stability (Turpijn 2012).

Consequently, climate change may affect IWT by altering the Rhine hydrological regime. On one hand, expected increased water discharges during winter will increase peak flow frequency, halting navigation traffic more often (Middelkoop and Kwadijk 2001; Flörke et al. 2011).

On the other hand, expected dry periods will affect IWT by limiting loading capacity. Low water discharges mean low water depths and low water depths will affect IWT by limiting transport capacity. As a matter of fact, as it is explained by Mr. Jos Davidse from Thyssenkrupp Veerhaven, water depth is directly related to vessels’ loading capacity:

“Normally we are transporting with four or six [barges] … at full capacity the draft of the barges is 4 meters... when we have four barges loading at 4 meters draft we have about 11,000 tons of cargo, with 6 barges we have 16,500 tons of cargo. Normally we are transporting for steel production in Duisburg. When they are producing at 100%, we are transporting about 70,000-80,000 tons per day. You can imagine when water [depth] is going down under 4 meters, each 10 centimeters we load 85 tons less... that means when we have 3 meters [draft] – what is quite common on the Rhine- every barge is only loading instead of 2,800 tons only 1,900 tons” (Davidse 2012)

The relationship between water depth and vessels’ loading capacity has become more sensitive during the last decades due to the sustained trend towards scaling up that has been observed in the IWT sector during the last 50 years. Figure 4 shows the average increase in tonnage in the West European fleet during the last 50 years. This tendency is expected to continue in the future. In fact, the average vessel size is projected to keep increasing from 1% to 1.5% every year (Wurms et al. 2010).

Apart from limiting loading capacity, lower water depths increase risk of grounding. Skippers can easily access to information about available water depths to adjust vessels’ draft. However, during periods of low water depths, grounding cannot be totally prevented because skippers may take too much risk when loading without respecting safety margins (Verheij 2006).

It is worth to mention that during periods of low water discharges there is no threshold beyond which navigation is restricted (CCNR 2011). According to the CCNR: “it is the responsibility of each

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3 At the international level, inland navigation in the Rhine River Basin is administrated by the Central Commission for the Navigation of the Rhine (CCNR). This international institution is responsible for regulating technical requirements concerning vessels and people involved in inland navigation, transport of dangerous substances and traffic conditions (CCNR 2011)

4 Article 10.01 of the Rhine Police Regulation

5 For better understanding about this concept see Figure 5
vessel’s skipper to determine whether it is possible to travel within a given section of the waterway despite the reduced water depth” (CCNR 2011).

![Graph of average increase in tonnage in the West European fleet](image)

**Figure 4. Average increase in tonnage in the West European fleet**

Source: (BVB 2009)

The seriousness of problems caused by changing water discharge is related to the duration of high or low water periods. In words of Wurms et al. (2010) “the concerns of inland shipping are much more pronounced by droughts than by flood events, as droughts caused by general weather situations usually last for several weeks” (Wurms et al. 2010). Similar results have been obtained by researcher of Knowledge for Climate project, who affirm that future periods of low water levels will trigger more serious problems for IWT than high flows, since high water periods will occur only occasionally (Krekt et al. 2010). The potential impacts of climate change on IWT are explained in detail on Chapter IV.
Figure 5 explains some key IWT concepts:

- **Water level** refers to the vertical distance between the water surface and a specific reference level, in The Netherlands this reference level is the Normal Amsterdam Peil (NAP).
- **Water depth** refers to the vertical distance between the river bed and water surface in a determined spot along the river.
- **Draft** (or draught) refers to the vertical distance between the water surface (or waterline) and the bottom of a vessel’s hull.
- Finally, **clearance** refers to the vertical distance between the river bed surface and the bottom of a vessel’s hull.

Figure 5. Key IWT concepts: water depth, water level, draft and clearance

### III.3. Conclusions chapter III

The first step of the MEDIATION method for the assessment of adaptation turning points is to scope the assessment by identifying the target region and socio-ecological sector of concern (Werners 2012).

The target region selected in this case is the stretch between Duisburg and Rotterdam. We consider this stretch as a critical region for navigation purposes because it is an important inland connection between the Ruhr German industrial area and the Port of Rotterdam. Therefore, this may be a sensitive area from the stakeholders’ perspective and likely some ATPs may exist.

The socio-ecological sector of concern is inland waterway freight transport (IWT) what is defined for this research purposes as the activity of transportation by inland waterway vessel of any kind of bulky goods.

The relationship between IWT and the Rhine hydrological system is given by the fact that vessels sail through the fairways built along the Rhine River, and vessels’ transport capacity depend on the water depth and width of the shipping channels (Krekt et al. 2010). In fact, the relationship between water depth and loading capacity is direct: the lower the water depth, the lower the vessels’ loading capacity (Davidse 2012). Moreover, water depth on the fairways may determine whether vessels can sail or not since river traffic is restricted by the CCNR when water level is too high (CCNR 2011).
IV. IDENTIFYING POTENTIAL IMPACTS OF CLIMATE CHANGE ON INLAND WATERWAY TRANSPORT (IWT)

The second step of the MEDIATION method for assessing adaptation turning points is to identify key potential impacts of climate change for the region and sector of concern and prioritize them based on potential severity and likeliness (Werners 2012).

Potential impacts of climate change on the Rhine River Basin have been the matter of study of several research projects such as RheinBlick2050, ACER project and Climate Adaptation among others. Moreover, the impacts of these climatic changes on inland waterway transport (IWT) along the Rhine River have been addressed in research projects like KLIWAS, Knowledge for Climate and the work carried out by the permanent environmental commission of PIANC (EnviCom) about climate change and navigation.

A summary of the main potential impacts of climate change on IWT is presented as follow. This summary is based on information collected from scientific articles and reports elaborated in the framework of the projects mentioned above as well as relevant information obtained during interviews carried out in this research.

The objective of the last section of this Chapter is to prioritize climate change impacts by discussing the severity and likeliness of each one of them. The level of certainty about the link between climate change and the physical changes observed is also considered in the analysis. Then, in the following steps of the assessment, we will focus our attention on the climate change impact that results to be the most outstanding according to the discussion.

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6 Climate Adaptation—modeling water scenarios and sectoral impacts, leaded by the Center for Environmental Systems Research (CESR), in collaboration with Ecologic, Alterra and CMCC.

7 Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt-Entwicklung von Anpassungsoptionen, financed by the German Federal Ministry for Transport, Building and Urban Development (BMVBS).

8 Research project carried out by Deltares, VU University Amsterdam, Delft University of Technology, TNO, ARCADIS, Port of Rotterdam and the Dutch Ministry of Infrastructure and the Environment.
IV.1. Changes on water discharge

Currently, the Rhine River is a mixed snowfed – rainfed system (Middelkoop and Kwadijk 2001). Due to climate change, the Rhine River is expected to become into a predominantly rainfall driven system (Middelkoop and Kwadijk 2001; Krekt et al. 2010; van Dorsser 2012). Increased precipitation is expected during winter, leading to higher discharge volumes and hence, more frequent peak flows during winter time. Moreover, higher temperatures will trigger precipitation to fall as rain instead of snow, resulting in lesser snow storage in the Alps during winter. Lower snow storage, together with increased evaporation during summer, will result in lower discharge volumes during summer and autumn (Krekt et al. 2010).

The project RheinBlick2050 leaded by the International Commission for the Hydrology of the Rhine Basin (CHR) focuses on the identification of future climate change impacts on the Rhine River discharge and its main tributaries (Görgen et al. 2010). By using a data-synthesis and multi-model approach, researchers were able to recognize scenario bandwidths and tendencies of future potential hydrological changes in the Rhine River Basin for the near future (from 2021 to 2050) and far future (2071 to 2100) (Görgen et al. 2010). The results obtained for the Lobith gauging station, in terms of high and low flows, are presented as follow.

Table 2 shows the scenario bandwidths and tendencies obtained for four high flow measures at Lobith gauging station. The variable MQH refers to the “mean maximum discharge; arithmetic mean of all annual maximum discharges (per hydrological year) per time span (here: 30-year, 3000-year); hydrological yearbook primary statistic” (Görgen et al. 2010). The variable HQ10 refers to the “discharge corresponding to a 10-year return period, i.e. discharge which occurs once every 10 years; calculated from a fitted distribution to the annual (hydrological year) maximum discharge values per time span in a return level plot; for HQ10 a 30-year time-span is used” (Görgen et al. 2010). The variable HQ100 is equivalent to HQ10, but with reference to a 100-year return period (a 3000-year time-span from the rainfall generator is used); and finally, the variable HQ1000 is equivalent to HQ100, but with reference to a 1000-year return period (Görgen et al. 2010).

<table>
<thead>
<tr>
<th>Target measure (m$^3$/s)</th>
<th>Gauging station</th>
<th>2021 to 2050</th>
<th>2071 to 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHQ</td>
<td>Lobith</td>
<td>0 to +20%</td>
<td>-5 to +20%</td>
</tr>
<tr>
<td>HQ10</td>
<td>Lobith</td>
<td>-5 to +15%</td>
<td>0 to +35%</td>
</tr>
<tr>
<td>HQ100</td>
<td>Lobith</td>
<td>0 to +20%</td>
<td>0 to +25%</td>
</tr>
<tr>
<td>HQ1000</td>
<td>Lobith</td>
<td>-5 to +20%</td>
<td>-5 to +30%</td>
</tr>
</tbody>
</table>

Source: (Görgen et al. 2010)

Colors indicate the extent of the change:

- small tendency to increase (ensemble average between 5 and 10% increase)
- tendency to increase (ensemble average more than 10% increase)
- no tendency

Table 2 shows for all variables no clear or small tendency to increase in the near future. However, in the far future the variables MHQ, HQ10 and HQ1000 show a clear tendency to increase.

Table 3 shows the scenario bandwidths and tendencies obtained for low flow measures at Lobith gauging station. The variable NM7Q refers to “the lowest arithmetic mean of discharge during 7 consecutive days; calculated per hydrological season; averaged to 30-year long-term annual or
seasonal means” (Görgen et al. 2010). The variable FDQ90 refers to the “discharge undershot on 10% of all days of a 30-year period i.e. the 90th percentile of the flow duration curve representing 10950 days, no leap years taken into account” (Görgen et al. 2010).

Table 3. Scenario bandwidths and tendencies for low flow measures at Lobith gauging station

<table>
<thead>
<tr>
<th>Target measure (m$^3$/s)</th>
<th>Gauging station</th>
<th>2021 to 2050</th>
<th>2071 to 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>NM7Q summer</td>
<td>Lobith</td>
<td>+/- 10%</td>
<td>-30 to -10%</td>
</tr>
<tr>
<td>NM7Q winter</td>
<td>Lobith</td>
<td>0 to +15%</td>
<td>-5 to +15%</td>
</tr>
<tr>
<td>FDCQ90</td>
<td>Lobith</td>
<td>+5 to +15%</td>
<td>-20 to 0%</td>
</tr>
</tbody>
</table>

Source: (Görgen et al. 2010)

Colors indicate direction of change:
- increase
- decrease
- no tendency

Table 3 shows for the variable NM7Q -in summer- no clear tendency in the near future but a clear tendency of decreasing in the far future. In winter, there is an increase trend in the near future but no clear tendency in the far future. For the variable FDCQ90, increase in the near future is identifiable but there is a decrease in the far future.

Consistent results have been obtained by Dorsser (2012) by using hydrological projections for the Rhine River according to the KNMI’06 scenarios. Based on previous work carried out by the Rijkswaterstaat, van Dorsser (2012) explains the implications of climate change on water discharge in the Rhine River at Lobith gauging station according to the KNMI’06 scenarios. Water discharge projections for 2050 and 2100 can be observed in Figure 6.

As it is shown in Figure 6, between December and May, increased water discharges are expected to occur for both near and far future and for the four KNMI’06 scenarios. Besides, lower water discharges are expected to occur between June and November for both time spans but only for the two more extreme KNMI’06 scenarios: G+ and W+. The invariability of projected water discharges observed during summer time for G and W scenarios was explained by Dorsser (2012): “for these scenarios the reduced snow based flow is fully compensated by an increased amount of rain during the summer” (van Dorsser 2012).

As it was explained in Section III.2, the expected changes on water discharge will affect IWT by altering the water depth available for navigation. Higher water discharges will increase peak flow frequency, halting navigation traffic more often and for longer periods (Middelkoop and Kwadijk 2001; Flörke et al. 2011). Alternatively, lower water discharges will lead to restricted vessels’ loading capacity, lower speeds, higher fuel consumption (Flörke et al. 2011) and increased risk of grounding (Jonkeren et al. 2008).

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IV.2. Changes on river morphology

Climate change may lead to changes on river morphology. The expected changes on river discharge explained on the previous section would cause changes on river bed erosion, sedimentation and sediment transport (Moser et al. 2008). However, the actual incidence of climate change on river morphology changes is not clear enough. As Mr. Bas Turpijn from Rijkswaterstaat explains:

“The relation between climate change and morphological processes is not quite evident yet. Many people say erosion and sedimentation is, of course, a natural process but a small part of it will be affected by climate change” (Turpijn 2012)

On the other hand, Hendrik Havinga, expert from the Rijkswaterstaat, affirms that the Dutch part of the Rhine River is currently facing autonomous river bed erosion. Besides, this phenomenon would not be directly related to climate change but it may be attributed to four main anthropogenic causes:

a) The river coming from the Germany is transporting less sediment than it is needed to reach equilibrium, and the river -by means of water velocity- is able to take sediment from the river bed. The lack of sediment can be explained by the canalization and the construction of dams for hydropower and flood protection in different drain branches flowing to the Rhine like Mosel, Ruhr and Lippe.

b) The subsidence$^{10}$ observed in the Ruhrort area because of (iron and coal) mining.

c) The building of dikes and groins that have increased water velocity and therefore sediment transport capacity.

d) The different composition of river bed material in relation to the German part of the Rhine. It has been observed a decreasing grain diameter of the river bed from Germany to The Netherlands. In fact, in Germany it has been observed 2 cm diameter gravel, meanwhile in Nijmegen the grain diameter decrease to 2 mm. Again, the difference of grain diameter increases sediment transport capacity in the Dutch part of the river.

$^{10}$Subsidence is the process of land lowering in relation to a specific reference level like sea level. In The Netherland this phenomenon can be explained due to soil consolidation.
Despite the lack of clarity about the relation between climate change and changes on river morphology, it must be noticed the enhanced negative consequences for navigation which result from the combined effect of bed erosion and low water depths.

In theory, river bed erosion does not represent a problem for IWT by itself. Water surface will lower together with the river bed and water depth would remain the same. However, an additional factor must be taken into account in the case of the river stretch between Duisburg and Rotterdam. There are three critical spots along the stretch Duisburg – Rotterdam, located in Nijmegen, Erlecom and Sint Andries (Buitendijk 2012; Havinga 2012). These spots are characterized by the presence of fixed layers on the river bed. These layers are not being eroded at the same rate as the rest of the river bed, becoming into a sort of available water depth thresholds for navigation purposes (see Figure 7).

The evident impact of river bed erosion on IWT along the Rhine River has become a more urgent issue than climate change for the Rijkswaterstaat. Indeed, the institution is currently focusing its efforts on looking for adaptation measures to face changes on river morphology instead of focusing directly on climate change issues:

“...our attention on morphological issues is very high at this moment. Climate change[impacts] (one of the most extreme scenarios) will occur maybe after 2050 -it’s the long term;-well, bed level degradation is a short term issue-it is before 2050 and for Rijkswaterstaat this is more an issue than climate change”. “Because of that, our attention to climate change is now shifting to [river] morphology”(Turpijn 2012)

**IV.3. Changes on water temperature**

Uniform increase in air temperature is projected in all regions of the Rhine Basin (HYDRON GmbH 2009; Görgen et al. 2010). For the near future, these changes would range from 0.5°C to 2.5°C in winter and up to 2.0°C in summer (Görgen et al. 2010). For the far future changes are expected to be more pronounced, ranging from 2.5°C to 4.5°C in winter and from 2.5°C to 5.0°C in summer (Görgen et al. 2010).

Air temperature is directly related to water temperature. According to PIANC – Envicom, changes on water temperature would - in some way - affect IWT in the Rhine River (Moser et al. 2008). Warmer water temperatures will trigger oxygen deficits, which will have negative effects on
aquatic ecosystems (Moser et al. 2008). Discharging water over spillweirs is a mitigation measure normally used to face oxygen deficit and this measure may lead to reduced water depths for navigation purposes (Moser et al. 2008).

IV.4. Analysis and discussion Chapter IV

The second step of the MEDIATION method for assessment of adaptation turning points is to identify key potential impacts of climate change for the region and sector of concern. Those potential impacts of climate change were prioritized based on potential severity and likeliness (Werners 2012).

In this chapter, changes on water discharge, river morphology and water temperature were described as main physical changes triggered by climate change on the Rhine River. These three physical changes involve potential implications for the normal development of IWT since they may cause modifications on available water depths, limiting the normal traffic along the river.

Changes on water discharge show direct consequences on efficiency, safety and reliability of IWT. High discharges will cause traffic problems and low water discharges will limit loading capacity and will increase grounding risk. Moreover, problems for IWT associated to droughts will be more serious than problems associated to high flow periods.

Despite the urgency and seriousness of morphological changes on the Rhine River, there is no enough knowledge about the actual connection between this phenomenon and climate change. This gap of knowledge makes unfeasible –for example- to generate reliable projections of river bed erosion due to climate change; hence, it becomes impossible to find adaptation turning points on IWT due to changes on river morphology.

Finally, potential implications of increased water temperature on IWT are circumstantial. The extend of the impact of warmer water temperatures on available water depths depends on external factors like the environmental policies applied on a particular stretch of the river or the sensitivity to oxygen deficit of the species to be protected.

Due to the reasons explained above, we dismiss the impacts that changes on river morphology and temperature may have on IWT and we think the most severe and likely impact is the one related to changes on water discharge. Therefore, the objective of the present research was narrowed to identify potential Adaptation Turning Points on IWT in the Rhine River, due to longer and more frequent drought periods induced by expected changes on water discharge. These hydrological changes will have a direct impact on water depth, which has been found to be a key IWT variable.

Following the MEDIATION method for assessing Adaptation Turning Points (ATPs), the next chapter is devoted to recognize a suitable threshold value for further assessment of ATPs on IWT. From Chapter III we concluded that water depth is a key IWT variable, and in the present Chapter we have found that hydrological changes triggered by climate change will have direct consequences on water depth. Consequently, the three thresholds to be evaluated correspond to three water depth values.
V. SEARCHING FOR THRESHOLDS FOR INLAND WATERWAY TRANSPORT

The third step of the MEDIATION method for assessing Adaptation Turning Points (ATPs) is to determine socio-political objectives of concern. In order to determine those socio-political objectives, a selection of indicators and threshold values for potential impacts on sectors and regions has to be done. In congruence with the findings presented on Chapters III and IV, water depth is the indicator selected for searching threshold values for potential impacts on IWT.

Three potential thresholds were evaluated, namely: an economic threshold, a policy related threshold and a technical threshold. The three thresholds are explained in the following sections. The objective of this evaluation is to recognize a suitable threshold for IWT, so further assessment of Adaptation Turning Points (ATPs) on IWT can be performed.

We think a suitable threshold must accomplish two conditions: it must be plausibly fixed in time, and, in case of an economic threshold, it must be supported on realistic assumptions. Therefore, these are the two criteria we apply to identify our threshold on Section V.4.

V.1. Economic threshold

We defined the economic IWT threshold as the low water depth that makes inland waterway transport not economically competitive in comparison with rail or road transport, considering a potential freight price raise.

As it was already explained in Section IV.1, low water depths will affect IWT by limiting transport capacity. During periods of low water depths, vessels can transport less tons per trip and, as a result, the cost per ton transported increases. Therefore, freight prices in the IWT market increase (Jonkeren et al. 2008; Koetse and Rietveld 2009).
The IWT market in the Rhine River can be described as a competitive market, where demand is inelastic\textsuperscript{11} and supply is perfectly elastic\textsuperscript{12}(Jonkeren et al. 2008). Jonkeren et al. (2008) gives three important reasons that support the assumption about the inelastic demand, they are:

a) There is a noticeable difference between prices per ton transported by vessel and ton transported by rail or road\textsuperscript{13}. Therefore, a huge increase on freight prices in the IWT market is needed for rail or road transport to become competitive.

b) Inland vessels can transport far more tons per trip than other transport modes like rail or road. Therefore, substitution is difficult.

c) Shippers\textsuperscript{14} relay on IWT as part of their production chain and transport costs are a small portion of the total production costs. Therefore, paying higher prices for IWT during low water periods results more convenient than halting production processes.

Jonkeren et al. (2008) made an extensive research on economic implications of low water levels for the IWT market in the Rhine River. They provide an analysis of the economic impacts of the dry period occurred on 2003 in the Kaub area. By applying multiple regression methods on a data set of about 728 journeys, the authors proved the inverse relationship between water levels and freight prices. Furthermore, they showed that freight price increases by 103% when water levels go down 81 cm (Pegel Kaub)(Jonkeren et al. 2008). Finally, the authors estimated a welfare loss\textsuperscript{15} of about €189 million due to the dry period occurred on 2003 by using the concept of economic surplus (Jonkeren et al. 2008).

Jonkeren et al. (2011) discussed modal split effect triggered by low water levels on IWT in the Kaub related market. By using a GIS-based network model, the authors modeled freight transport over a multimodal network (inland vessel, rail or road) in the Kaub area. This virtual network was composed by nodes, each one representing a link, a transport mode and a type of transport. Then, different transport costs were assigned to each flow between two nodes (Jonkeren et al. 2011). After applying the model under different KNMI'06 climate scenarios, the authors estimated a lowering of the annual amount of tones transported by inland vessels of about 2.3% by 2050 in the case of G+, and about 5.4% in the case of W+ scenario. Changes close to zero were estimated in the cases of G and W scenarios (Jonkeren et al. 2011).

Despite the research was carried out in the Kaub related market, Jonkeren et al. (2011) concluded that similar effects can be expected in other areas of the Rhine River. Moreover, the effect in other areas may be less severe than the effect estimated in Kaub. In other words, given the most extreme KNMI'06 scenario, the effect of low water levels on competitiveness of IWT in any other location within the Rhine by 2050 should not be more than a reduction of 5.4% of the amount of tons annually transported by inland vessels(Jonkeren et al. 2011).

\textsuperscript{11} The economic term ‘elasticity of the demand’ refers to the change of the quantity demanded of a specific commodity given a variation on price of that commodity. Demand is inelastic when a high variation in price leads to a small change in the quantity demanded.

\textsuperscript{12} The economic term ‘elasticity of the supply’ refers to the change of the quantity supplied of a specific commodity given a variation on price of that commodity. Supply is perfectly elastic when a small variation on price leads to a big variation on the quantity supplied.

\textsuperscript{13} In fact, the prices per ton transported by rail or road can easily treble the price per ton transported by inland navigation vessel (Buitendijk 2012)

\textsuperscript{14} Shippers are those companies that want their goods to be transported by inland vessel.

\textsuperscript{15} In this case, welfare loss is calculated as the extra costs for inland waterway transport as a result of water levels below 140 cm.
V.2. **Policy threshold: the OLR value**

The policy threshold we evaluated is the minimum water depth guaranteed by the OLR value. OLR stands for *Overeengekomen Lage Rivierstand* what can be translated to English as Agreed Low Water Level. The OLR value is a theoretical water level at which the Dutch government –through the Rijkswaterstaat-guarantees a minimum water depth. Currently, the OLR value guarantees a water depth of 2.8 meters (7.52 meters NAP) at 5%, which means that water depth should not be lower than 2.8 meters during more than $20^{16}$ days per year (Havinga 2012; Stuurman 2012).

The OLR value derives from the *Overeengekomen Lage Afvoer* (OLA) value, the Agreed Low Discharge in English, also called the discharge 5% (Q5%). At Lobith, the OLA has been estimated to be about 1020 m$^3$/s (see Figure 8). Then, at this water discharge the government guarantees a minimum water depth of 2.8 meters for at least 345 days per year (Havinga 2012).

The OLR value cannot be assumed to be unchanging. The OLR value is naturally decreasing very year at the same rate as bed erosion what is about 1 to 2 cm per year (Havinga 2012). Moreover, the OLR value does not guarantee a fixed water depth. The water depth guaranteed by the OLR value is revised by government every ten years (Turpijn 2012). In fact, until 2006 the OLR was fixed to guarantee 2.5 meters water depth. Consequently, dredging measures had to be used by the Rijkswaterstaat to guarantee a water depth of 2.8 meters at the present (Havinga 2012).

The guaranteed minimum water depth has been fixed to be 2.8 meters in the entire stretch Duisburg-Rotterdam (CCNR 2012). However, in Germany the *Gleichwertigen Wasserstands* (GIW) value -Equivalent Water Level in English- is used instead of the OLR value. The difference between them is that the OLR is a theoretical value that guarantees a fixed water depth along the river from Lobith to Rotterdam, and the GIW is a theoretical value that guarantees different water depths along the German section of the Rhine. For example, the guaranteed minimum depth at Cologne is 2.5 meters whereas at Duisburg is 2.8 meters.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure8}
\caption{The OLA value in a discharge hydrograph}
\end{figure}

\footnote{Not necessarily in a row}


V.3. **Technical threshold**

The technical threshold assessed in this research is defined as the minimum water depth required for normal propeller performance.

In simple words, the propeller is a sort of fan that, by rotational motion, generates thrust force for moving a vessel (see Figure 9). Traditionally one propeller is employed to move a vessel, sometimes two and less frequently three (MAN Diesel & Turbo 2011).

The physical principles behind a propeller performance are out of the scope of this research. However, two basic facts must be understood for this research's purposes:

a) A minimum draft is needed for the propeller(s) to be able to generate enough thrust force to move a vessel.

b) The specific minimum draft needed depends on the vessels size. The bigger the barge the bigger the propeller; therefore, the deeper the draft required (Casant 2012; Davidse 2012; M.K. 2012). Van Dorsser (2012) identifies an average minimum draft required for normal propeller performance. The author claims that “most of the representative barges will not be able to sail at draft below 1.6 meters as there will be insufficient water to keep the propellers submerged” (van Dorsser 2012).

Then, after interviewing three IWT companies about the minimum draft their vessels required for normal propeller performance and the average proposed by van Dorsser (2012), we obtained the following results:

“For a normal inland vessel the minimum draft of 1.6 is possible, but for our barges we need 1.8 to 1.85 meters;...1.6 for us is too low” (Davidse 2012)

“If they [the propellers] are out of the water you have no force to go forward...”... “[the minimum draft goes from] 1.4 to 1.6 meters or something there in between... the larger the vessel the larger the draft, so smaller vessels with smaller draft are in advantage on this point.....” (M.K. 2012)

“Yes, that’s an average value... In average, if you say 1.6 meters for a double hull barge as a minimum draft, it’s a good value... that’s makes sense to use it” (Casant 2012)

Based on the information we obtained from these interviews, we propose the following interval of threshold values for the variable ‘minimum draft’: [1.4 – 1.8] meters.

---

17See Figure 5. Key IWT concepts: water depth, water level, draft and clearance
In order to convert this interval of minimum draft values into an interval of minimum water depth values, a minimum clearance\textsuperscript{18} value is needed. According to Mr. Turpijn from Rijkswaterstaat, a recommended minimum safety clearance –also called keel clearance– is 30 cm (Turpijn 2012).

Then, we propose the following interval of threshold values for the variable ‘minimum water depth for normal propeller performance’: [1.7-2.1] meters.

Figure 10 shows an illustration of the values we identified for minimum draft, clearance and minimum water depth.

\textbf{Figure 10. Minimum water depth for normal propeller performance}

\section*{V.4. \textit{Analysis and discussion Chapter V}}

The third step of the MEDIATION method for assessing ATPs is to determine socio-political objectives of concern and the first step to determine those socio-political objectives is to select indicators and threshold values for potential impacts on IWT.

In congruence with findings presented on Chapter IV, water depth was the indicator selected for searching threshold values for potential impacts on IWT. Then, three potential threshold values for the indicator ‘water depth’ were assessed, namely: an economic threshold, a policy related threshold and a technical threshold.

The first and second threshold values were ruled out and the technical threshold was selected for assessing ATPs. The reasons behind this choice are explained in the following sections.

\textit{V.4.1. About the economic threshold:}

We defined the economic threshold as ‘the low water depth that makes inland waterway transport not economically competitive in comparison with rail or road transport, considering a potential freight price raise’.

\textsuperscript{18} See Figure 5. Key IWT concepts: water depth, water level, draft and clearance
The literature review presented above shows the definition we proposed to define this potential economic threshold was flawed. Our definition suggests a potential complete modal shift from IWT to rail or road transport; whereas, scientific literature shows this scenario is unrealistic given the characteristics of the IWT market in the Rhine River. Jonkeren et al. (2011) proposes a better approach when analyze a potential modal split effect by estimating IWT market share losses due to low water levels instead of an absolute modal shift effect.

Jonkeren et al. (2011) concludes that the modal-split effect in other areas may be less severe than the effect estimated in the Kaub location. Therefore, we can assume that given the most extreme KNMI’06 climate scenario, the reduction of tons transported by inland vessels in the stretch Duisburg-Rotterdam will not be higher than 5.4%.

Given that the demand on IWT market is inelastic, it results reasonable to think that shippers bear most of the increased transport costs during low water periods\(^\text{19}\). Therefore, any attempt to identify ATPs due to increased IWT prices should include shippers as key stakeholders. However, shippers were not considered as stakeholders during the data collection stage in the present research.

The reason to exclude shippers from the analysis is based on the erroneous assumption that shippers were able to easily shift from one transport mode to another. Then, they would shift to another transport mode when IWT freight prices got higher than rail or road transport.

For the reasons explained above, we dismissed the economic threshold as a suitable threshold for identifying ATPs on IWT. It is worth to mention that we do not dismiss the existence of economic ATPs on IWT; however, a different approach is needed as well as a more accurate definition of the threshold to be found.

\textit{V.4.2. About the policy threshold:}

The policy threshold we evaluated is the OLR value. The OLR value is a theoretical water level at which the Dutch government guarantees a minimum water depth. Currently, the OLR value guarantees a minimum water depth of 2.8 meters (7.52 meters NAP) during, at least, 345 days per year.

At first glance the guaranteed minimum water depth of 2.8 meters seemed to be a suitable threshold for assessing ATPs. However, this value is subject to a policy that may change each ten years. Then, it would be a mistake to assume a constant guaranteed minimum depth by 2050 (or by 2100) and any attempt to find ATPs by using this threshold would be flawed or at least it would result on highly uncertain ATPs. For this reason, we dismissed the policy threshold as a suitable threshold for identifying ATPs on IWT.

\textit{V.4.3. About the technical threshold:}

The technical threshold we evaluated was defined as ‘the minimum water depth required for normal propeller performance’ and we propose [1.7-2.1] meters as the interval of threshold values for this variable.

We found this threshold to be the most suitable of the three thresholds evaluated (economic, policy and technical) for further assessing ATPs. We based our decision on two main reasons:

\(^{19}\) This assumption was corroborated by Mrs. Buitendijk from Koninklijke Schuttevaer during interview.
a) Unlike the economic threshold we analyzed, this technical threshold is based on realistic assumptions. As a matter of fact, a minimum water depth required for normal propeller performance can be calculated as a function of two variables: minimum draft required for normal propeller performance, and a minimum safety clearance. Both values are well known by the experts.

b) Unlike the policy related threshold we analyzed, it results reasonable to assume that this interval of threshold values will remain fixed in the future. This threshold strongly depends on vessels’ design which is not dynamic enough to make us foreseen a dramatic change in the future.

To summarize, three potential thresholds were assessed, namely: an economic threshold, a policy related threshold and a technical threshold. The first and second ones were ruled out and the possible ATPs will be identified by using the technical threshold. The results of the analysis of possible ATPs are presented in Chapter VI.
VI. LOOKING FOR ADAPTATION
TURNING POINTS ON INLAND
WATERWAY TRANSPORT

The fourth step of the MEDIATION method for assessing Adaptation Turning Points (ATPs) is to determine adaptation turning points (Werners 2012). In congruence with the results obtained from the last step (see Chapter 0), we define the ATPs as ‘the point in time when inland waterway transport will not be reliable anymore because the minimum water depth required for normal propeller performance is not reached for longer and/or more frequent periods’.

The first step to find these ATPs is to determine how much change a sector can handle, given the threshold value independently from time (Werners 2012). In this case, the threshold value corresponds to the minimum water depth for propeller performance which we estimated in Chapter V to be the interval ranged from 1.7 to 2.1 meters. By doing a “What if” exercise, we asked the IWT companies’ representatives interviewed to give their preferences in terms of how long the company could handle such a dry period. The results are presented in section VI.1.

The second step to find the ATPs is to translate the turning points to timescale by using climate scenarios and hydrological projections to assess when the turning points may occur. For these purposes, we used the hydrological projections obtained by Hurkmans et al. (2010) by using the Variable Infiltration Capacity (VIC) model and the atmospheric datasets resulted from the regional climate model REMO for three SRES scenarios. The results are presented in Section VI.2.3.

An intermediate step was needed in order to translate the turning points into timescale. Given that we use hydrological projections in terms of future water discharges (m$^3$/s), we translate our water depth range into equivalent water discharges. For doing that, we use the rating curve to make the relationship between water discharge and water level at Lobith, and we estimated a relationship between water level and water depth by using the OLR standard. The results are presented in Sections VI.2.1 and VI.2.2.
VI.1. Stakeholders’ preferences

In Chapter V, we defined the threshold value ‘minimum water depth for propeller performance’ and we estimated this value to be the interval ranged from 1.7 to 2.1 meters.

During interviews with the three IWT companies’ representatives, we performed a ‘What if’ exercise (see Appendix A). The objective of this exercise was to determine how long the IWT sector can cope with a dry period defined as a number of days in a row with water depths below the minimum water depth needed for normal propeller performance.

We obtained the following results:

“Maybe 3 days [in a row] is acceptable... [7 days in a row] it’s really difficult; we are in big problems... We cannot use our own capacity anymore, we are only depending on pop market inland ships, and then we need 80 or 70 ships and so many ships are not available in the market, it’s very expensive, that’s one, but also not available... Under 1.8 [meters draft] we cannot guarantee transportation to our company in Germany...” (Davidse 2012)

“[10 days in a row] the problem is getting bigger for us because you have costumers up there and they want to get products, you have costumers here, but if all the barges that normally go up the river stay here and have to transport something here, there will be a big problem after a week or 10 days. There will be some big problems for the costumer and also for the barges because it is not enough work just to here around to keep all the barges busy.” (M.K. 2012)

“... 3 day it is possible maybe, but 7 days... if you sail in average with 2,000 tons upstream and in certain point you only can sail with 500 tons, you need 4 times the barges than you need in average and there’s no so many barges, so there’s a lot of demand in the market ... most of the time in low water situations the prices on the pop market are also increasing but you have also your contract obligations to fulfill, so a low water situation is for planning and for costumers always stressful” (Casant 2012)

Table 4 shows a summary of the answer obtained from the interviews with IWT companies’ representatives. It is worth to mention that we also asked some policy makers about this topic. However, they declared themselves unable to give an answer since this question concerns only to IWT companies which operate on the River.

<table>
<thead>
<tr>
<th>IWT company representative – IWT company</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jos Davidse – Thyssenkrupp Veerhaven</td>
<td>No more than 7 days in a row</td>
</tr>
<tr>
<td>M.K. – IWT company</td>
<td>No more than 10 days in a row</td>
</tr>
<tr>
<td>Nico Casant – Tankmatch B.V.</td>
<td>No more than 7 days in a row</td>
</tr>
</tbody>
</table>

The answers from the IWT companies’ representatives interviewed give a clear idea about the length of the dry periods they are able to cope with. However, we still need a parameter in terms of frequency of dry periods. The Koninklijke Schuttevaer -through their report entitled
‘Streefbeeld Binnenvaart ten Behoeve van de Deltaprogramma’s’- answer this question when affirm that “transportation loss is expected to occur only when every year more than two weeks a navigable depth\(^{20}\) of 1.8 m or less is available on the Middle and Upper Rhine, or less than 1.6 m is available on the Waal river in The Netherlands” (Buitendijk 2011).

**VI.2. Adaptation Turning Points on IWT**

After identifying the stakeholders’ preferences in terms of how long they may cope with a low water period, the second step to find the ATPs is to translate the turning points to timescale.

For doing that, an intermediate step was needed. Given that we had hydrological projections in terms of future water discharges (m\(^3\)/s), we translated our water depth range into equivalent water discharges. We used the rating curve to make the relationship between water discharge and water level at Lobith location, and we estimated a relationship between water level and water depth by using the OLR standard. The results are presented in Sections VI.2.1 and VI.2.2.

Finally, we used the Special Report on Emission Scenarios (SRES) scenarios developed by the IPCC and the hydrological projections obtained by Hurkmans et al. (2010) by means of the Variable Infiltration Capacity (VIC) model. The results are presented in Section VI.2.3.

**VI.2.1. The rating curve**

In theory, a rating curve explains the relationship between water discharge (m\(^3\)/s) and water depth (or water level) in a determined area within a river (Havinga 2012). The relationship is based on two basic equations:

**Equation 1:**

\[ u = c \sqrt{h \cdot i} \]

- \( u \) = water velocity
- \( c \) = roughness coefficient
- \( h \) = depth
- \( i \) = slope

**Equation 2:**

\[ Q = B \cdot h \cdot u = B \cdot c \cdot h^{3/2} \cdot i^{1/2} \]

(Havinga 2012)

Then, by measuring water velocity in the field, it is possible to build a relationship like the one shown in Figure 11 (Havinga 2012). Figure 11 shows the rating curve explaining the relationship between water discharge (m\(^3\)/s) and water level at Lobith location in the Rhine River for the time-span November 1\(^{st}\) 2010 to November 1\(^{st}\) 2012.

The curve described on Figure 11 is based on data kindly provided by the Rijkswaterstaat. This curve relates water discharge (m\(^3\)/s) to water level (m + NAP); therefore, the relationship between water level and water depth is still needed. The method used to translate water level into water depth is explained in the next section.

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\(^{20}\) In this case, navigable depth must be understood as draft.
VI.2.2. From water level to water depth

According to Mrs. Quartel from Rijkswaterstaat, there is not a direct relationship between water depth and water level due to the constant morphological changes in the cross-section of the Rhine River (Quartel 2012).

An appropriate way to estimate a relationship between these two variables is by means of the OLR standard (Quartel 2012). As it was explained in section V.2, the Rijkswaterstaat is in charge of the maintenance of the fairway to guarantee a minimum water depth of 2.8 meters at a discharge of 1020 m$^3$/s. This discharge occurs at a water level of 7.39 m +NAP at Lobith location. Then, by extrapolating this relationship:

- 2.8 m water depth $\rightarrow$ 7.39 m + NAP
- 1.7 m water depth $\rightarrow$ 6.29 m + NAP
- 2.1 m water depth $\rightarrow$ 6.69 m + NAP

According to the rating curve presented on Section VI.2.1, this interval of water level values correspond to the interval of discharge values [611 – 754] m$^3$/s (Quartel 2012). It is worth to mention that these discharge values are low and they have never been measured in the field, so this section of the rating curve is model-based (Quartel 2012).
VI.2.3. Hydrological projections

Hurkmans et al. (2010) carried out a study to project stream flow changes on the Rhine River basin due to climate change (Hurkmans et al. 2010). To do so, the authors made use of the Variable Infiltration Capacity (VIC) model\(^{21}\) which made run with the atmospheric datasets resulted from the regional climate model REMO (Hurkmans et al. 2010). These atmospheric datasets were available for three SRES scenarios\(^{22}\): A2, A1B and B1 (Hurkmans et al. 2010).

The SRES scenarios involve a set of four scenario families, namely: A1, A2, B1 and B2. Each one of these scenario families represents a qualitative and quantitative description of a possible future development, also called a storylines (Nakicenovic et al. 2000). The storylines consider demographic, social, economic, technological, and political factors to describe alternative futures for the four scenario families (Nakicenovic et al. 2000). Table 5 shows a brief description of the three scenarios used in this research.

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>VARIABLE</th>
<th>A1B</th>
<th>A2</th>
<th>B1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Population growth</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>GDP growth</td>
<td>very high</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>Energy use</td>
<td>very high</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Land- use changes</td>
<td>low</td>
<td>medium/high</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>Resource availability*</td>
<td>medium</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Pace and direction of technological</td>
<td>rapid</td>
<td>slow</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>Change favoring</td>
<td>balanced</td>
<td>regional</td>
<td>efficiency &amp; dematerialization</td>
</tr>
</tbody>
</table>

*Resource availability of conventional and unconventional oil and gas.
Source: (Nakicenovic et al. 2000)

The output of the exercise carried out by Hurkmans et al. (2010) is a group of datasets of daily water discharge (m\(^3\)/s) at different locations within the Rhine River basin for the years 2002 to 2100, and for the three SRES scenarios. We used the results obtained for Lobith location to identify periods of 7 days (or longer) of water discharge lower than 754 m\(^3\)/s and lower than 611 m\(^3\)/s, for the years 2013 to 2100. The results we obtained for scenarios A1B and A2 are shown in Figures 12 and 13. The results obtained for scenario B1 are not presented since it corresponds to the least severe of the three scenarios analyzed. It is worth to mention that model analysis is out of scope of this research; hence data generated by the VIC model is taken as given information.

\(^{21}\) The VIC model is a physically based hydrological model developed by Liang et al. (1994)

\(^{22}\) The Special Report on Emissions Scenarios (SRES) developed by the Intergovernmental Panel on Climate Change (IPCC)
Figure 12. Periods of seven consecutive days (or more) of low water discharge per year - Scenario A1B

Figure 12 shows the projected number of days of low water discharge per year according to the results obtained for the scenario A1B. The first graph shows the number of days per year of water discharge $<611\text{m}^3/\text{s}$. The second graph shows the number of days per year of water discharge $<754\text{m}^3/\text{s}$. In either cases, only periods of 7 days or longer were considered. The different colors in the same column represent different periods of 7 or more days in a row of low water discharge ($Q< 611\text{ m}^3/\text{s}$ or $Q< 754\text{ m}^3/\text{s}$) during the same year. For example, in the second graph ($Q<754\text{ m}^3/\text{s}$), only one period of 9 days in a row is projected on 2053, and four periods of 11, 7, 12 and 21 days in a row are projected on 2099 coming to a total of 51 days of low water discharge during that year.
Figure 13. Periods of seven consecutive days (or more) of low water discharge per year - Scenario A2

Figure 13 shows the projected number of days of low water discharge per year according to the results obtained for the scenario A2. The first graph shows the number of days per year of water discharge <611 m³/s. The second graph shows the number of days per year of water discharge <754 m³/s. In either cases, only periods of 7 days or longer were considered. The different colors in the same column represent different periods of 7 or more days in a row of low water discharge (Q< 611 m³/s or Q< 754 m³/s) during the same year. For example, in the second graph (Q<754 m³/s), only one period of 7 days in a row is projected on 2028, and four periods of 21, 15, 12 and 7 days in a row are projected on 2096 coming to a total of 55 days of low water discharge during that year.
VI.3. Analysis and discussion Chapter VI

The objective of this Chapter was to determine adaptation turning points in the IWT sector which is the fourth step of the MEDIATION method for assessing Adaptation Turning Points (ATPs) (Werners 2012). We define the ATPs searched in this research as ‘the point in time when inland waterway transport will not be reliable anymore because the minimum water depth required for normal propeller performance is not reached for longer and/or more frequent periods’.

The first step we followed to find these ATPs was to determine how much change the IWT sector could handle, given the threshold value ‘minimum water depth for propeller performance’ independently from time (Werners 2012). By doing a “What if” exercise, we asked the IWT companies’ representatives interviewed to give their preferences in terms of how long the company could handle such a dry period. We obtained two relevant answers: ‘no more than 7 days in a row’, and ‘no more than 10 days in a row’. Then, we took the value ‘7 days in a row’ for further analysis.

The reasons the IWT companies’ representatives put forward to explain their preferences were mainly related to logistics issues and the impossibility of guaranteeing transportation to fulfill the requirements of their customers.

Then, we translated the turning points to timescale by using climate scenarios and hydrological projections to assess when the turning points may occur. For this research purposes, we used the hydrological projections obtained by Hurkmans et al. (2010) by using the Variable Infiltration Capacity (VIC) model and the atmospheric datasets resulted from the regional climate model REMO for three SRES scenarios, namely: A1B, A2, and B.

These three scenarios were analyzed. The scenarios A1B and A2 turned out to be the most severe; therefore, they are the most relevant for further analysis. In the next sections, we analyze the results obtained for both scenarios, and finally we discuss the sources of uncertainty that limit these results.

VI.3.1. About the scenario A1B

According to the IPCC SRES scenarios nomenclature, A1 stands for a storyline and a scenario family. In words of Nakicenovic et al. (2000), A1 describes “a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income” (Nakicenovic et al. 2000).

The A1B scenario belongs to one of the four groups of scenarios that make up the A1 storyline and scenario family. According to Nakicenovic et al. (2000), this group of scenarios “assumes a balanced mix of technologies and supply sources, with technology improvements and resource assumptions such that no single source of energy is overly dominant” (Nakicenovic et al. 2000).

The A1B scenario stands out as the most severe of the three scenarios analyzed in this research. The hydrological dataset provided by Hurkmans et al. (2010) for the A1B scenario suggests a noticeable increase of dry periods in terms of length and frequency in the future. An intricate period for the IWT sector is projected to occur on 2032 since 41 days of low water discharge (Q<754m$^3$/s) were estimated, divided into two periods of 27 and 14 days in a row. From those 41
days of low water discharge, 18 are expected to be extremely dry (Q<611 m$^3$/s) affecting even the smallest (and therefore the least draft demanding) vessels. A similar dry period is projected to occur on 2037. Such severe dry periods will trigger a crisis on the IWT sector; however, they are isolated events that will unlikely represent an ATP.

Since 2053, a sustained increase in frequency and length of low water periods is projected. The frequency of dry periods increases until reaching a point about 2085 when a dry period is expected to occur almost every year. In fact, at least 14 days of low water discharge (Q<754m$^3$/s) are expected every year between 2085 and 2088, and six dry years are projected during the last decade of the century. The most severe years will be 2091 and 2099 since 48 and 51 days of low water discharge (Q<754m$^3$/s) are expected. Moreover, from those 48 and 51 days, 29 and 19 are expected to be extremely dry (Q<611 m$^3$/s), giving no space for any kind of vessel to sail.

The situation projected for the years after 2085 is close to the scenario described by the Koninklijke Schuttevaer (Buitendijk 2011). This organization claims that transportation loss is expected to occur only when the available draft is 1.6 m (what is equivalent to a water depth of 1.9 m) or less during two weeks every year on the Waal River in The Netherlands.

The assessment we have carried out in this research considered a water depth interval ranging from 1.7m to 2.1m and a dry period will occur almost every year when considering the upper value. The situation described by the Koninklijke Schuttevaer is slightly more extreme than the situation evaluated in this research since they consider a minimum water depth of 1.9m instead of 2.1m.

However, the minimum water depth proposed by the Koninklijke Schuttevaer does not consider the biggest vessels that navigate in the stretch Duisburg – Rotterdam such as the barges belonging to Thyssenkruup. Moreover, given the trend that has been observed in the IWT sector towards building bigger barges, we think a minimum water depth of 2.1m is a suitable value for the analysis.

Then, considering a minimum water depth of 2.1 m as a valid value, we can affirm that for the A1B scenario an ATP on the IWT sector is expected to occur after 2085. This ATP will represent a point in time when a unfavorable change in the distribution of freight transport market shares occur. This share loss is explained by the increasing IWT prices and the loss of reliability of the IWT sector because the IWT companies will not be able to guarantee transportation to fulfill the requirements of their customers.

VI.3.2. About the scenario A2

According to Nakicenovic et al. (2000), the storyline and scenario family A2 describes “a very heterogeneous world where the underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines” (Nakicenovic et al. 2000).

The hydrological dataset provided by Hurkmans et al. (2010) for the A2 scenario suggests two unfavorable periods for the IWT sector in the near future: the first one during the years 2028 and 2029 and the second one during 2053 and 2054. However, the dry periods projected for these years will likely affect only the bigger barges since no day of extremely low water discharge (Q<611 m$^3$/s) is expected to occur. Some logistic problems for IWT during these years seem plausible; nevertheless, these will not trigger an ATP on the IWT sector.
Frequency and length of dry periods increase starting from 2077. However, they will not reach a frequency as high as one dry period every year. Three critical years are projected to occur during the last two decades of the century. The first one on 2082 with 34 days of low water discharge (Q<754 m$^3$/s), from them 12 are projected to be extremely dry (Q<611 m$^3$/s). The second one will occur on 2093 with 33 days in a row of low water discharge (Q<754 m$^3$/s), from which 23 days are projected to be extremely dry (Q<611 m$^3$/s). Finally, a third critical period is expected in 2096 with 55 days of low water discharge (Q<754 m$^3$/s) from which 11 are projected to be extremely dry (Q<611 m$^3$/s).

Certainly the three periods described above will trigger a series of crisis in the IWT sector during the last decades of the century; however, we do not have the basis to affirm that an ATP will results from them.

VI.3.3. **About the sources of uncertainty**

Our results are based on predictions about the future; hence, they are unavoidably linked to some sources of uncertainty. We recognize three sources of uncertainty in our results: the use of a model based section of the rating curve, the potential inaccuracy of the VIC model, and the validity of the SRES scenarios assumptions.

First, given that the hydrological projections available for our research were in terms of future water discharges (m$^3$/s), we translated our water depth range into an equivalent interval of water discharges. To do so, we used the rating curve to make the relationship between water discharge and water level at Lobith location. The water level values we related to water discharge were extremely low and they have never been measured in the field (Quartel 2012). Therefore, there is an inherent uncertainty associated to the use of a model based section of the rating curve.

Second, our results are based on the hydrological projections obtained by Hurkmans et al. (2010) by using the Variable Infiltration Capacity (VIC) model. The VIC model has been questioned by Te Linde et al. (2008). The authors compared the performance of the hydrological models VIC and HBV$^{23}$ in climate change scenario studies by assessing their accuracy in predicting water discharge using historical data of the Rhine basin (Te Linde et al. 2008). The authors concluded that “the HVB model performed much better than the VIC model” (Te Linde et al. 2008); moreover, the authors confirm that “even for a well documented river basin such as the Rhine, more complex modeling does not automatically lead to better results” (Te Linde et al. 2008).

Finally, the hydrological projections we used are framed within the SRES scenarios published by the Intergovernmental Panel on Climate Change (IPCC) on 2000. The assumptions behind the SRES scenarios have been target of criticism from some sectors of the scientific community. For instance, Castled and Henderson (2003) argues that the SRES scenarios lack of accurate economic projections about GDP growth (Castles and Henderson 2003). The authors claim that “the IPCC should try to ensure a more balanced, informed and professional treatment of the economic and statistical aspects of its work” (Castles and Henderson 2003).

Along the same line, Höök et al. (2010) states that the SRES scenarios overestimate the future availability of non-renewable energy sources (Höök et al. 2010). Regarding this issue, the authors

$^{23}$ The Hydrologiska Byråns Vattenbalansavdelning (HBV) model was developed for the Rhine Basin by the Dutch Institute for Inland Water Management and Waste Water Treatment (RIZA) and the German Federal Institute of Hydrology (BfG).
claim that “SRES is underpinned by a paradigm of perpetual growth and technological optimism as well as old and outdated estimated regarding the availability of fossil energy” (Höök et al. 2010).

Moreover, in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change carried out on 2007, the authors dismiss some of the SRES scenarios when claim that “for the next two decades, a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected” (Bernstein et al. 2007).
VII. EXPLORING ALTERNATIVE ADAPTATION STRATEGIES

The fifth and final step of the MEDIATION method for assessing Adaptation Turning Points (ATPs) is to determine alternative adaptation strategies that the IWT sector may take to cope with the potential impacts of climate change (Werners 2012).

A summary of the main adaptation strategies to face the impacts of climate change on IWT is presented as follow. This summary is based on information collected from scientific articles and IWT reports as well as relevant information obtained during the interviews carried out in this research.

The objective of this Chapter is to identify and assess which strategies actors may use to respond to the adaptation turning points we have found on Chapter VI. The assessment is done in terms of the advantages and disadvantages of the different strategies; however, determining the best adaptation strategy is not the purpose of the present Chapter.

VII.1. Lighter and wider vessels

New vessels’ design is maybe the first thought that comes up when asking stakeholders about potential adaptation strategy during the interviews. They claimed that the aim is to design wider, shallower and lighter barges which demand less draft for sailing. In other words, barges capable to transport more cargo than the average during low water depth periods.

This new vessel design involves new shapes as well as new building materials. New materials must be lighter and, at the same time, as resistant as steel. The option offered by Blaauw (2009) is to utilize components of composite materials where possible (Blaauw 2009).

24 “Composite material, also called composite, a solid material that results when two or more different substances, each with its own characteristics, are combined to create a new substance whose properties are superior to those of the original components in a specific application. The term composite more specifically refers to a structural material (such as plastic) within which a fibrous material (such as silicon carbide) is embedded” Britannica. (2012). “Composite Material.” Retrieved August 21st, 2012, from http://www.britannica.com/EBchecked/topic/130093/composite-material.
This strategy offers the evident advantage of transporting more cargo despite low water depths. According to Blaauw (2009), a new design may increase vessels' capacity by 20% with an increment of 10% in costs. Nevertheless, there are also some disadvantages. In fact, barges that offer better performance during low water conditions result less optimal for higher water levels (Blaauw 2009). This is explained by Mr. Casant from Tankmatch B.V.:

“… you can design a barge which is specially built to sail very good on a very limited draft... But that will also affect if the barge is sailing with more average depth [since] it will cost –for example- more fuel ... [So,] you can built a barge specially for one thing but you lose something on the other part, if the 99% of the year it’s not low water -or not so low water- it doesn’t make sense to build such a barge” (Casant 2012)

As it is explained by Mrs. Buitendijk from the Koninklijke Schuttevaer, the trade-off between efficiency during low and high water level periods reduces the incentives to invest in a new vessel design:

“[he has to load less during low water levels] but that is 3 months in a year, the other 9 months he is going to load full capacity ... so, there’s no problem. He [the ship owner] is never going to build another ship when he can- [during] 9 month a year- use his all capacity” (Buitendijk 2012)

Moreover, the current characteristics of the IWT market in the Rhine give no incentives for ship owners to invest in new ships to transport more cargo during low water periods:

“When there are low water levels on the Rhine River, the ship of 3,000 tons can only load 2,000 tons, then for [transporting] the same amount of cargo you need more ships, that means the price goes up. They get extra paid because the water levels are low. So, low water levels means big business for ship owners” (Buitendijk 2012)

An alternative solution to minimize vessels’ draft is adding extra buoyancy during low water periods (Krekt et al. 2010). It means, adding floating devices like airbags or float tubes aside of a common barge to ‘lift’ it and decrease draft. According to Krekt et al. (2010), this measure has already been put into practice in the 17th century in Amsterdam where they added this devices to vessels to avoid sandbanks (Krekt et al. 2010). However, the feasibility of implementing this measure in modern barges depends on technical issues like the room available in the shipping lanes (Krekt et al. 2010).

**VII.2. Increasing storage capacity and other logistics measures**

Implementing adaptation strategies to overcome the potential impacts of climate change on IWT is not a task exclusively for ship owners. Shippers also can adopt strategies to mitigate the impacts of low water periods on their logistics chains.

For example, increasing storage capacity is one of the measures that shippers can implement to avoid, or at least mitigate, the negative effects of low water periods (Krekt et al. 2010; Stuurman 2012). Increasing storage capacity will allow having safety stock when low water situations occur,
avoiding production halt because of shortage of inputs. Mr. Nico Casant from Tankmatch B.V. explains this situation from the point of view of IWT companies:

“It is not that from one day to another there is a low water situation because it takes at least a month or something like that. On a certain point we inform costumers: be careful, we see water level going down and it [will keep] going down more, [so] take precautions. If possible let’s stock. For example, you plan now to have products delivered within 2 or 3 weeks, if I may advise you, bring the products now. Because, we foreseen some problems within 2 week and then maybe we cannot sail to your destination anymore.

Then it is up to the costumer if they can have the product available or if they can buy it (because most of the time you have to buy it somewhere). But we have to inform the customers: take care maybe there is going to be a problem.” (Casant 2012)

On 2010, researchers of the project Knowledge for Climate carried out a workshop with stakeholders and expert to identify appropriate logistic management measures (Krekt et al. 2010). The result was a list of measures which have been classified in five groups: structural, responsive, transparency, cooperative, and financial measures (Krekt et al. 2010).

Structural measures are those intended to change the primary logistic choices of a shipper company to avoid or reduce the chance of disturbance, or mitigate the impact of a disturbance (Krekt et al. 2010). An example of structural measure is to opt for modal shift from IWT to rail or road (Krekt et al. 2010).

Responsive measures are those which do not need to be planned in advance. Simply accepting the consequences of low water levels and the consequent reduced transport capacity is a responsive measure (Krekt et al. 2010).

Transparency measures are those intended to increase transparency of the supply chain by releasing information. Cooperative measures are those intended to create cooperation among stakeholders (among shippers and/or IWT companies) during low water periods to -for example- carry out the transport (Krekt et al. 2010).

Finally, financial (or contractual) measures are those intended to create arrangements between stakeholders (among shippers and/or IWT companies) to – for example- transfer the risks of low water levels (Krekt et al. 2010).

**VII.3. River management**

River management strategies involve all those physical measures aimed to modify water depth of free flowing waterways. River management strategies include: dredging, groynes management, and weirs construction, among others. In this case, policy-makers are the responsible of implementing such measures. In the following sections, three river management strategies for increasing water depth are discussed, namely: dredging, canalization, and longitudinal dams.
VII.3.1. **Dredging measures**

Dredging is perhaps the most popular river management measure to modify water depth. According to Krekt et al. (2010), dredging is the cheapest\(^\text{25}\) measure to improve navigability (Krekt et al. 2010). However, its execution causes alteration on river traffic and increases the risk of accident (Krekt et al. 2010). Moreover, dredging does not guarantee increased navigation depth (Krekt et al. 2010).

A variation of a simple dredging measure is offered by Wurms et al. (2010). The authors assess the feasibility of implementing a width reduced fairway, a so-called ‘fairway within fairway’, as adaptation strategy in the Rhine stretch between Mainz and St. Goar (Wurms et al. 2010). This measure involves dredging material from the river bed to create a deeper and narrower fairway with the objective of gaining flow depth during low water discharge periods (Wurms et al. 2010).

The authors conclude that “from a technical point of view, a width reduced, deepened ‘fairway within fairway’ seems to be a suitable measure for the purpose of gaining flow depth” (Wurms et al. 2010). However, the authors recognize that further research about morphological issues is needed in order to implement measures to maintain the equilibrium of the river bed as well as the ‘fairway within fairway’ structure (Wurms et al. 2010).

VII.3.2. **Canalization**

The researchers involved in the project Knowledge for Climate have investigated about canalization as an adaptation measure to guarantee the navigability in the section the Rhine River between Rotterdam and the Ruhr area (Krekt et al. 2010). The canalization would be done by building some weirs in combination with lock-complexes which would be closed during low water periods to guarantee a minimum water depth in the fairway (Krekt et al. 2010; van der Toorn 2010).

Van der Toorn (2010) developed a rough estimation of costs and benefits of applying this measure in the Rhine River assuming that four weir-lock-complexes have to be built (van der Toorn 2010). The total cost of such an infrastructure was estimated to be about €3,820 million, and benefits—in terms of reduction of transport costs—were estimated to be between €3,500 and €5,600 million for KNMI’06 scenarios G+ and W+ (van der Toorn 2010).

VII.3.3. **Longitudinal dams**

Longitudinal dams are intended to increase the navigation depth by reducing the main-channel width (Giri 2011). This measure represents an alternative to groynes management and it offers the following advantages:

a) Longitudinal dams do not increase hydraulic roughness; therefore, they do not lead to higher flood levels as groynes do (Giri 2011)

b) According to Huthoff (2011), Longitudinal dams allows “additional flow area to be created behind the dams to lower flood levels” (Huthoff 2011), and

c) Longitudinal dams allows an “easy readjustment of inlets/outlets to correct for unwanted morphodynamic effects; hence, they minimize dredging efforts” (Huthoff 2011)

However, longitudinal dams are more expensive than groynes. According to Krekt et al. (2010) the cost of modifying or constructing groynes in the Wall River varies from €0.5 to €1.5 million per

\(^{25}\) It may cost from €2 to €40 per m\(^3\) depending on volume and ground conditions (Krekt et al. 2010)
kilometer, and the cost of constructing longitudinal dams varies from €1 to €3.5 million per kilometer (Krekt et al. 2010). Figure 14 shows an illustration of longitudinal dams.

Figure 14. Longitudinal dams
Source: (Giri 2011)

VII.4. Analysis and Discussion Chapter VII
In this Chapter we presented a review of some adaptation measures that can be implemented to face the impacts of low water periods on IWT. We are aware that additional adaptation measures exist apart from the ones we mentioned in this Chapter. This review is based on information obtained from literature review and the interviews we carried out in this research; therefore, the measures we discussed are those which are more important according to the opinion of the interviewed stakeholders or most commonly mentioned in literature.

Implementing an adaptation measure to face climate change is a task that can be undertaken by IWT companies, shippers and policy-makers. However, the level of urgency for adapting seems to differ between stakeholders. The current characteristics of the IWT market suggest that IWT companies (or ship owners) have no incentives to invest in adaptation measures; therefore, the adaptive capacity must be displayed by shippers which have to make their supply chain more flexible by investing in logistic improvements.

In Section VII.3 we presented some river management measures that may improve navigability during low water periods. The Rijkswaterstaat is the institution responsible for implementing these measures in The Netherlands. These measures were roughly related to economic costs. However, the feasibility of implementing river management measures does not depend only on a cost-benefit analysis. It also depends on environmental issues since most of these measures have the potential to affect the river ecosystems.

Moreover, despite its low cost, the effectiveness of dredging depends on the river morphology and the processes of erosion and sedimentation occurring in the river bed. Given the current autonomous erosion that it is taking place in the Dutch part of the Rhine and the fixed layers
located along the Waal River (see Section IV.2), the effectiveness of dredging measures seems to be highly uncertain.

Finally, there is no straightforward answer to the question about the best adaptation measure to implement to face the impacts of low water periods on IWT. The uncertainty attached to climate change studies makes difficult to estimate the actual severity of the consequences associated to low water levels in the Rhine River. As a result, the ratio between costs and benefits of a certain measure is also hard to determine. However, we think the behavior of the actors in the IWT market gives some clear signals about who are the ones under more pressure to adapt: the shippers.
VIII. GENERAL DISCUSSION & FINAL CONCLUSIONS

VIII.1. General discussion of the results

The purpose of this research was to identify potential moments in time when the current policy objectives or social preferences regarding inland waterway transport (IWT) in the Rhine River will no longer be able to meet their objectives from the stakeholders’ perspective, due to longer and more frequent drought periods induced by climate change.

To reach our purpose we used the concept of Adaptation Turning Points proposed by Werners (2012) as a variation of the ideas expressed by Kwadijk et al. (2010). An ATP is “a situation where a socio-political threshold is reached, due to climate change induced changes in the biophysical system” (Werners 2012). When this threshold is reached, the socio-ecological system studied will move towards an alternative equilibrium state.

We defined our socio-ecological system as inland waterway freight transport (IWT) in the stretch between Duisburg and Rotterdam of the Rhine River. After understanding how the IWT sector is interrelated to the Rhine hydrological system as well as the IWT stakeholders’ preferences, we defined the critical situation to be identified in the future as the moment in time when the minimum water depth required for normal vessels’ propeller performance is not reached during –at least– 7 days in a row, every year.

By using hydrological projections from Hurkmans et al. (2010), we searched for these critical situations in the future, until 2100. We were able to recognize several moments in time when the minimum water depth for normal propeller performance will not be reached during periods longer than 7 days in a row. Since these moments were isolated events, we interpreted them as future crises in the IWT sector because, during these dry periods, IWT companies will face severe troubles to fulfill the necessities of their customers (shippers).

Despite the severity of those crises, we did not have information to support the idea of a turning point to be reached. To better understand this idea, we have to keep in mind that changes come from a former crisis but not all crisis trigger change (Gallopín 2006; Young 2010). Then, our results suggest that the IWT sector may face several stresses due to hydrological changes caused by...
climate change, without reaching an ATP. Furthermore, the resilience of the IWT sector can be
explained by its adaptive capacity (e.g. limiting cargo according to available water depth) and its
strong position in the freight market mainly because of its lower prices and its huge transport
capacity.

We identified only one moment in time when the minimum water depth for normal propeller
performance is not reached during at least 7 days in a row, every year. This socio-political
threshold will be reached after 2085 in case of the most extreme of the three SRES scenarios
analyzed (A1B). The sources of uncertainty of our results were discussed on Section VI.3.3.
Consequently, after 2085 an unfavorable change in the distribution of freight transport market
shares is expected.

The IWT sector could experiment a market share loss because it would lose efficiency and
reliability. IWT prices could rise because of the limited vessels’ loading factor. The IWT service
would become unstable, and during some extremely dry periods no vessel—not even the smallest
ones—would be able to sail.

It is worth to mention that our results are only applicable for the river stretch between Duisburg
and Rotterdam. There are other more critical areas in the Rhine River in terms of available water
depth. According to Jonkeren et al. (2011), the Kaub area, in Germany, is the most sensitive area of
the river because at this location the water level has the most severe effect on the load factor of
vessels (Jonkeren et al. 2011). Therefore, we can speculate that an ATP as the one we described in
this study would be likely reached in the Kaub area sooner. In fact, Jonkeren et al. (2011) estimated
the share loss of the IWT sector due to low water levels in Kaub location. The author concluded
that the lowering of the annual amount of tones transported by inland vessels will be about 2.3%
by 2050 in the case of G+, and about 5.4% in the case of W+ scenario (Jonkeren et al. 2011).

The calculation of the magnitude of the share loss expected in the stretch Duisburg-Rotterdam is
out of the scope of this research. Besides, no conclusion can be drawn from Jonkeren et al. (2011)
since these calculations are based on a dataset exclusively relevant to the Kaub related market.

Finally, we are aware that the description of our socio-political thresholds as the moment in time
when the minimum water depth required for normal vessels’ propeller performance is not reached
during at least 7 days in a row, every year, leaves one unresolved question: every year during
how many years? We do not have the answer for that and even if we had one, projections made
for the period after 2100 would be highly uncertain.

VIII.1.1. MEDIATION method for assessment of ATPs

We follow the five steps method proposed in MEDIATION project to assess ATPs. The method is
clear and it resulted to be applicable to our socio-ecological sector of concern and appropriate to
reach our research objective. However, from our experience using the method, we may offer some
insights that would be helpful in further applications:

a) To avoid confusion (as it happened to us at the beginning of the research), a clear
distinction must be made between the following concepts: relevant indicator, threshold,
threshold value, and the critical situation that represent an ATP. As a way of illustration, in
our case:

• The relevant indicator: water depth (meters)
- **The threshold**: the minimum water depth required for normal vessels’ propeller performance
- **The threshold value**: [1.7-2.1] meters
- **The critical situation**: the moment in time when the minimum water depth required for normal vessels’ propeller performance is not reached during—at least- 7 days in a row, every year.

b) The ATPs approach, developed in the framework of MEDIATION research project, involves a broader definition of threshold to include not only formal policy objectives but also social preferences, stakes and interests (see Section II.1.4).

Yet, not all kinds of thresholds are suitable for carrying out a proper ATPs assessment. In Chapter V, we evaluated three different thresholds and the evaluation is not explicit in the MEDIATION method. However, during the development of our research we realized that a suitable threshold value for an appropriate ATPs assessment should fulfill some requirements: it must be plausibly fixed in time, and -in case of an economic threshold- it must be supported on realistic assumptions.

**VIII.1.2. Limitations of the research**

We recognize some limitations of our research. We carried out only three interviews with IWT companies’ representatives. This limited amount is explained by the low rate of positive answers we obtained from the companies we contacted during the two month available for applying interviews.

Besides, during the development of our research we realized that including the shippers’ perspective in our analysis would have enriched our results. Again, given the short time available, it resulted unfeasible to arrange interviews with this kind of companies.

**VIII.2. Final conclusions**

We identified three critical areas for navigation purposes along the Rhine River: the stretch Duisburg-Rotterdam, the Kaub area and the river section upstream Loreley. The stretch Duisburg-Rotterdam is an important inland connection between the Ruhr German industrial area and the Port of Rotterdam. The Kaub area, in Germany, is considered to be a navigation bottleneck because of the severe restrictions related to low water levels in the area (Jonkeren et al. 2011). Finally, the river section upstream Loreley is also considered a navigation bottleneck in this case due to safety issues related to the pronounced curves that characterize the stretch (Zentgraf and Dettmann 2010). The region addressed in this study was the river stretch between Duisburg and Rotterdam.

The expected climate change impacts in the target region are changes on water discharge, river morphology and water temperature. These three physical changes involve potential implications for the normal development of IWT since they may cause modifications on available water depths for navigation purposes.

The most severe and likely impact is the one related to changes on water discharge. Therefore, the objective of our research was narrowed to identify potential Adaptation Turning Points on IWT in the Rhine River, due to longer and more frequent drought periods induced by expected changes on water discharge.
Hydrological changes will have a direct impact on water depth. Low water depths will affect the IWT sector by limiting transport capacity and increasing risk of grounding. Despite the seriousness of the consequences of low water depths on IWT, there is no threshold beyond which navigation is restricted (CCNR 2011). According to the CCNR: “it is the responsibility of each vessel’s skipper to determine whether it is possible to travel within a given section of the waterway despite the reduced water [depth]” (CCNR 2011).

Water depth (meters) is a relevant indicator when assessing climate change impacts on the IWT sector. Accordingly, water depth thresholds were evaluated from three perspectives: economic, policy and a technical threshold.

We defined the economic IWT threshold as the low water depth that makes inland waterway transport economically inconvenient (in comparison with rail or road transport), due to increased freight prices. The policy threshold we evaluated was the minimum water depth guaranteed by the OLR value, and the technical threshold was defined as the minimum water depth required for normal propeller performance. The first threshold was ruled out because it was not supported on reasonable assumptions, and the second threshold was ruled out because it will likely vary in the future. The technical threshold was found more suitable to assess the ATPs and the interval [1.7-2.1] (meter) was defined as the threshold value.

After consulting stakeholders, we defined the situation socio-economically unacceptable as the moment in time when the minimum water depth required for normal vessels’ propeller performance is not reached during –at least- 7 days in a row, every year. Once this point is reached, IWT companies will face severe logistics problems which will make impossible to guarantee transportation to fulfill the requirements of their customers.

We identified only one moment in time when the minimum water depth for normal propeller performance will not be reached during -at least- 7 days in a row, every year. This socio-political threshold will be reached after 2085 in case of the most extreme of the three SRES scenarios analyzed (A1B).

This ATP will represent a point in time when an unfavorable change in the distribution of freight transport market shares occurs. This share loss is explained by the increasing IWT prices and the loss of reliability of the IWT sector because they will not be able to guarantee transportation to their customers anymore.

We analyzed some alternative adaptation strategies that the IWT sector may take to cope with the potential impacts of climate change. The design of lighter and wider vessels, increasing storage capacity, and some river management measures like canalization, dredging or longitudinal dams, are examples of adaptation measure that can be implemented by IWT companies, shippers and policy-makers.

There is no straightforward answer to the question about the best adaptation measure to face the impacts of low water periods on IWT. The uncertainty attached to climate change studies makes difficult to estimate the actual severity of the consequences associated to low water levels in the Rhine River. As a result, the ratio between costs and benefits of a certain measure is also hard to determine. However, the behavior of the actors in the IWT market suggests that shippers are the ones under more pressure to adapt.
VIII.3. Recommendations

To conclude, we would like to offer some final recommendations:

- As an improvement for the five steps method of MEDIATION project to assess ATPs, we recommend to explicitly include some guidelines to choose a proper threshold. We offered some guidelines based on our experience (see Section VIII.1.1); however, additional useful guidelines may exist.

- Further research about the impacts of climate change on the IWT sector in any stretch of the Rhine River must consider shippers as a key stakeholder group.

- We concluded that, in the IWT market, the shippers have the highest urgency to adapt to the impacts of climate change. So, as a topic for further research we recommend to study about shippers’ adaptation capacity to climate change as well as the alternative adaptation strategies that this group of stakeholders can implement. Studying about adaptive policies like flexible inventory management strategies may result especially interesting.
REFERENCES


APPENDIX A: INTERVIEW GUIDES

1. **Interviewee**: Henk Blaauw  
   MARIN / Inland Shipping Coordinator  
   **Date**: April 19th, 2012  
   **Place**: MARIN offices, Wageningen  
   **Group**: Experts and policy makers

1. **To scope the assessment**  
   a) Which one do you think is a good target region for my research?  
   b) What do you think are the most important impacts of climate change on navigation?

2. **About stakeholders**  
   a) What do you think are the main stakeholders I should take into account for my research?

3. **Sources of information**  
   a) Could you recommend some relevant literature for my research?

2. **Interviewee**: Michael Paprocki  
   Bundesanstalt für Wasserbau  
   **Date**:  
   **Place**:  
   **Group**: Experts and policy makers

1. **About potential climate change consequences**:  
   a) Do you agree with the statement: "the most critical consequence of climate change on inland waterway transport during summer time is the reduced navigation depth due to low water levels"?  
   b) Apart from low water levels, do you know other possible consequences of climate change on inland waterway transport in the stretch between Duisburg and Rotterdam?

2. **About thresholds**:  
   a) Could you identify a threshold for the variable ‘water discharge’? For example: a minimum discharge (m3/s) suitable for navigation purposes.  
   b) Based on which criteria did you identify this threshold value?  
   c) Do you think this threshold may be reached before 2050? Before 2100? Which data set/ model would you use to identify this point on time?

3. **About adaptation measures**:  
   a) Do you know which adaptation strategies/measures are been implemented / planned nowadays in response to expected low water levels?  
   b) Which institutions are involved in the implementation of these strategies/measures?

4. **Finally**,  
   a) Could you recommend some relevant literature (reports, scientific publications) about this topic?  
   b) Do you know other (2 or 3) expert people who may be willing to give me an interview? Could you give me their contacts details?

3. **Interviewee**: Peter Stuurman  
   Rijkswaterstaat / Nautical Traffic manager  
   **Date**: May 25th, 2012  
   **Place**: Rijkswaterstaat offices, Arnhem  
   **Group**: Experts and policy makers

5. **About potential climate change consequences**:  
   b) Do you agree with the statement: "the most critical consequence of climate change on inland waterway transport during summer time is the reduced navigation depth due to low water levels"?  
   c) Apart from low water levels, do you know other possible consequences of climate change on inland waterway transport in the stretch between Duisburg and Rotterdam?
6. About thresholds:
   It is objective of my research to identify a discharge threshold value below which inland navigation become intricate because, for example, loading capacity turns out to be too low or because the risk of grounding become too high. Then,
   a) Could you indentify a threshold for the variable ‘water discharge’? (I mean a minimum discharge (m³/s) suitable for navigation purposes)
   b) Based on which criteria did you identify this threshold value?
   c) Do you think this threshold may be reached in the future? Which data set/ model would you use to identify this point on time?

7. About adaptation measures:
   a) Do you know which adaptation strategies/measures are been implemented / planned nowadays in response to expected low water levels?
   b) Which institutions are involved in the implementation of these strategies/measures?

8. Finally,
   a) Could you recommend some relevant literature (reports, scientific publications) about this topic?
   b) Do you know other (2 or 3) expert people who may be willing to give me an interview? Could you give me their contacts details?

4. Interviewee: Milou Wolters
   Rijkswaterstaat Center for Transport and Navigation / Department of Vessel Traffic Management
   Date: May 31st, 2012
   Place: Rijkswaterstaat offices, Utrecht
   Group: Experts and policy makers

1. About potential climate change consequences:
   a) Do you agree with the statement: “the most critical consequence of climate change on inland waterway transport during summer time is the reduced navigation depth due to low water levels”?
   b) Apart from low water levels, do you know other possible consequences of climate change on inland waterway transport in the stretch between Duisburg and Rotterdam?

2. About thresholds:
   It is objective of my research to identify a discharge threshold value below which inland navigation become intricate because, for example, loading capacity turns out to be too low or because the risk of grounding become too high. Then,
   a) Could you indentify a threshold for the variable ‘water discharge’? (I mean a minimum discharge (m³/s) suitable for navigation purposes)
   b) Based on which criteria did you identify this threshold value?
   c) Could you briefly explain the OLR value? How is it determined? Do you think this value may be affected by climate change in the future?

3. About adaptation measures:
   a) Do you know which adaptation strategies/measures are been implemented / planned nowadays in response to expected low water levels?
   b) Which institutions are involved in the implementation of these strategies/measures?

4. Finally,
   a) Could you recommend some relevant literature (reports, scientific publications) about this topic?
   b) Do you know other (2 or 3) expert people who may be willing to give me an interview? Could you give me their contacts details?
1. About potential climate change consequences:
   a) According to your perception, to what extent the expected low water levels would affect inland navigation in the stretch between Duisburg and Rotterdam?

2. About thresholds:
   I would like to propose some fictitious scenarios to discuss, taking into account two different thresholds values.
   a) First: the guaranteed minimum depth
      Currently, in the stretch between Rotterdam and Duisburg the guaranteed minimum depth is 2.80 meters. Theoretically, this value may be lower no more than 20 days per year.
      Which one of these fictitious situations becomes unacceptable for the company?:
      ✓ The guaranteed minimum depth of 2.8 meters is not reached during 7 days in a row
      ✓ The guaranteed minimum depth of 2.8 meters is not reached during 10 days in a row
      ✓ The guaranteed minimum depth of 2.8 meters is not reached during 2 weeks in a row
      ✓ The guaranteed minimum depth of 2.8 meters is not reached during 30 days per year
      ✓ Other……………………………………………………………………………………………………………………
   b) Second: minimum water depth for propeller performance
      There is a minimum water level needed for shipping. In fact, a standard vessel needs at least about 1.6 meters of water depth to keep the well functioning of propellers.
      Which one of these fictitious situations becomes unacceptable for the company?:
      ✓ Water depth is below 1.6 meters during 3 days in a row
      ✓ Water depth is below 1.6 meters during 7 days in a row
      ✓ Water depth is below 1.6 meters during 10 days in a row
      ✓ Water depth is below 1.6 meters during two weeks in a row
      ✓ Other……………………………………………………………………………………………………………………

3. About adaptation measures:
   a) Is Thyssenkrupp Company planning/implementing any adaptation strategy/measure in response to expected low water levels?

4. Finally,
   a) Do you know other (2 or 3) people working on navigation companies who may be willing to give me an interview? Could you give me their contacts details?

5. Interviewee: Jos Davidse
   Thyssenkrupp Veerhaven B.V. / Shipping Department
   Date: June 5th, 2012
   Place: Thyssenkrupp offices, Brielle
   Group: IWT company representatives

6. Interviewee: Nick Lurkin
   Central Bureau for Inland Navigation - en Binnenvaart (CBRB) / Health, Safety and Environmental Affairs
   Date: June 7th, 2012
   Place: CBRB offices, Rotterdam
   Group: Experts and policy makers

1. About potential climate change consequences:
   a) Do you agree with the statement: "the most critical consequence of climate change on inland waterway transport during summer time is the reduced navigation depth due to low water levels"? 
   b) Apart from low water levels, do you know other possible consequences of climate change on inland waterway transport in the stretch between Duisburg and Rotterdam?
2. About thresholds:
   It is objective of my research to identify a discharge threshold value below which inland navigation
   become intricate because, for example, loading capacity turns out to be too low or because the risk
   of grounding become too high. Then,
   a) Could you indentify a threshold for the variable ‘water discharge’? (I mean a minimum
      discharge (m³/s) suitable for navigation purposes)
   b) Based on which criteria did you identify this threshold value?
   c) Could you briefly explain the OLR value? How is it determined? Do you think this value may be
      affected by climate change in the future?

3. About adaptation measures:
   a) Do you know which adaptation strategies/measures are been implemented / planned
      nowadays in response to expected low water levels?
   b) Which institutions are involved in the implementation of these strategies/measures?

4. Finally,
   a) Could you recommend some relevant literature (reports, scientific publications) about this
      topic?
   b) Do you know other (2 or 3) expert people who may be willing to give me an interview? Could
      you give me their contacts details?

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<th>Interviewee: M. K.</th>
<th>Date: June 20th, 2012</th>
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<tbody>
<tr>
<td>7</td>
<td>IWT Company</td>
<td>Place: IWT company offices</td>
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<td></td>
<td></td>
<td>Group: IWT company representatives</td>
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1. About potential climate change consequences:
   a) According to your perception, to what extend the expected low water levels would affect
      inland navigation in the stretch between Duisburg and Rotterdam?

2. About thresholds:
   a) I would like to propose a fictitious scenario to discuss, taking into account the thresholds value
      described as the minimum water depth for propeller performance:
      There is a minimum water level needed for shipping. In fact, a standard vessel needs at least about
      1.6 meters of water depth to keep the well functioning of propellers.
      Which one of these fictitious situations becomes unacceptable for the company?:
      - Water depth is below 1.6 meters during 3 days in a row
      - Water depth is below 1.6 meters during 7 days in a row
      - Water depth is below 1.6 meters during 10 days in a row
      - Water depth is below 1.6 meters during two weeks in a row
      - Other........................................................................................................

   b) I know some companies in Germany charge low water surcharges when water depth goes
down 140-150 cm Pegel Kaub. Are there any similar criteria for low water surcharges in The
Netherlands? If so, at what water depth is it applied?

3. About adaptation measures:
   a) Is IWT Company planning/implementing any adaptation strategy/measure in response to
      expected low water levels?

4. Finally,
   a) Do you know other (2 or 3) people working on navigation companies who may be willing to give
      me an interview? Could you give me their contacts details?
1. About potential climate change consequences:
   a) Apart from low water levels related problems, do you know other possible consequences of climate change on inland waterway transport in the stretch between Duisburg and Rotterdam?

2. About thresholds:
   It is objective of my research to identify a discharge threshold value below which inland navigation become intricate because, for example, loading capacity turns out to be too low or because the risk of grounding become too high. Then,
   a) I would like to propose a fictitious scenario to discuss, taking into account the thresholds value described as the minimum water depth for propeller performance:
      According to literature, there is a minimum water depth needed for shipping. In fact, a standard vessel needs at least about 1.6 meters of water depth to keep the well functioning of propellers. Which one of these fictitious situations do you think it becomes unacceptable for the inland waterway transport sector?:
         ✓ Water depth is below 1.6 meters during 3 days in a row
         ✓ Water depth is below 1.6 meters during 7 days in a row
         ✓ Water depth is below 1.6 meters during 10 days in a row
         ✓ Water depth is below 1.6 meters during two weeks in a row
         ✓ Other........................................................................................................
   b) Some companies in Germany charge low water surcharges when water depth goes down 140-150 cm Pegel Kaub. Are there any similar criteria for low water surcharges in The Netherlands? If so, at what water depth is it applied?
   c) Could you briefly explain the OLR value? How is it determined? Do you think this value may be affected by climate change in the future?

3. About adaptation measures:
   a) Do you know which adaptation strategies/measures are been implemented / planned nowadays in response to expected low water levels?
   b) Which institutions are involved in the implementation of these strategies/measures?

4. Finally,
   a) Do you know other (2 or 3) expert people who may be willing to give me an interview? Could you give me their contacts details?
b) According to literature, there is a minimum water depth needed for shipping. In fact, a standard vessel needs at least about 1.6 meters of water depth to keep the well functioning of propellers. Which one of these fictitious situations do you think it becomes unacceptable for the inland waterway transport sector?:

- Water depth is below 1.6 meters during 3 days in a row
- Water depth is below 1.6 meters during 7 days in a row
- Water depth is below 1.6 meters during 10 days in a row
- Water depth is below 1.6 meters during two weeks in a row
- Other

c) Some companies in Germany charge low water surcharges when water depth goes down 140-150 cm Pegel Kaub. Are there any similar criteria for low water surcharges in The Netherlands? If so, at what water depth is it applied?

3. **About adaptation measures:**

   a) Do you know which adaptation strategies/measures are been implemented / planned nowadays in response to expected low water levels?

5. **Finally,**

   a) Do you know other (2 or 3) people working on navigation companies who may be willing to give me an interview? Could you give me their contacts details?

<table>
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<tr>
<th>Interviewee: Hendrik Havinga Rijkswaterstaat</th>
<th>Date: June 27th, 2012</th>
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<tbody>
<tr>
<td>Date: June 27th, 2012</td>
<td>Place: Rijkswaterstaat Oost Nederland. Arnhem</td>
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<tr>
<td>Group: Experts and policy makers</td>
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1. **About the subsidence effect**
   a) What is the difference between subsidence and the process of erosion and sedimentation of a river bed?
   b) Isn’t the erosion and sedimentation process a natural process? Why we should think it could be worst due to climate change?

2. **About the critical point in the river**
   a) According to some interviewees, there are three specific critical spots along the stretch Duisburg-Rotterdam, due to the existence of fixed layers in the river bed. Do you know where they are located?

3. **About discharge and water levels**
   a) What is the difference between water depth and water level?
   b) How can I convert water depth into water discharge in the stretch Duisburg-Rotterdam? Can I use a discharge rating curve?

4. **About the OLR value**
   a) How is the OLR value calculated?
   b) How discharge variability due to climate change will affect this number?

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<tr>
<th>Interviewee: Nico Casant Tankmatch B.V.</th>
<th>Date: July 2nd, 2012</th>
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<tbody>
<tr>
<td>Date: July 2nd, 2012</td>
<td>Place: Tankmatch B.V. offices Werkendam</td>
</tr>
<tr>
<td>Group: IWT company representatives</td>
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</tr>
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1. **About potential climate change consequences:**
   a) To what extend the expected low water depths would affect inland navigation in the stretch between Duisburg and Rotterdam?

2. **About thresholds:**
   a) I would like to propose a fictitious scenario to discuss, taking into account the threshold value described as the minimum draft for propeller performance:
According to literature, there is a minimum draft needed for shipping. In fact, a standard vessel needs at least about 1.6 meters draft to keep the well functioning of propellers. Which one of these fictitious situations becomes unacceptable for the company?:

✓ Available draft is below 1.6 meters during 3 days in a row
✓ Available draft is below 1.6 meters during 7 days in a row
✓ Available draft is below 1.6 meters during 10 days in a row
✓ Available draft is below 1.6 meters during two weeks in a row
✓ Other

b) I know some companies in Germany charge low water surcharges when water depth goes down 140-150 cm Pegel Kaub. Are there any similar criteria for low water surcharges in The Netherlands? If so, at what water depth is it applied?

3. **About adaptation measures:**

a) Is Tankmatch Campany planning/implementing any adaptation strategy/measure in response to expected low water levels?