The inland navigation analysis system BIVAS

Analysis, validation and recommendations for improvement

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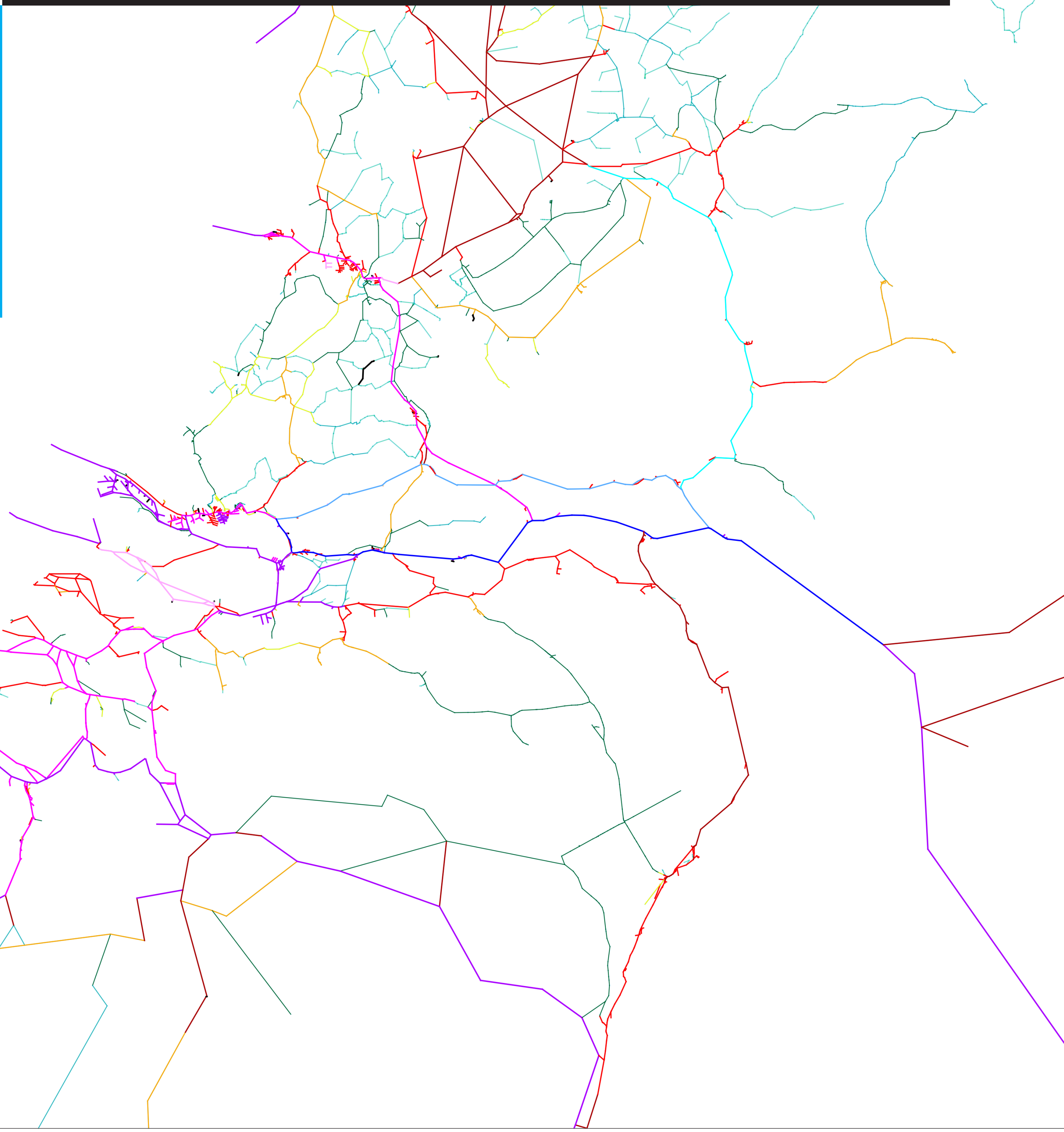

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Challenge the future

THE INLAND NAVIGATION ANALYSIS SYSTEM BIVAS

ANALYSIS, VALIDATION AND RECOMMENDATIONS FOR IMPROVEMENT

by

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SUMMARY

This thesis focuses on the inland navigation analysis system BIVAS. This is a software tool which, given a waterway network and a set of inland navigation trips, can compute the optimal routes over the network for the entered inland navigation trips. BIVAS supports the answering of policy questions about the intensity of traffic on the inland waterways and the effects of interventions, blockages, possible economic developments, fleet changes and/or climate change.

The incentive to carry out this research on BIVAS is twofold. At first it was found from a BIVAS computation simulating the actual situation in 2011, done by Miete (2014), that the allocation of the trips on part of the waterways in BIVAS, is not yet equivalent to the allocation that took place in reality.

Secondly BIVAS is within the Delta Programme used as one of the effect modules of the Fresh Water Delta-model (Kroon & Ruijgh, 2012). For the Delta Programme BIVAS is used to compute the expected economic loss for inland navigation as a result of changing water conditions. Klijn et al. (2012) computed with BIVAS an economic loss of 40 million Euro for a combination of the inland navigation trips that took place in 2008 and the water conditions in 1976, which was an extremely dry year. RIZA (2005) and Jonkeren (2009) estimated an economic loss of around 100 million Euro for the year 2003, which was a dry year as well. The difference between the economic loss computed with BIVAS and the estimated economic loss for 2003 is remarkable. BIVAS does not seem to work well when computations with changing water conditions are done.

In order to get better results for the Delta Programme it is at first necessary to ensure that for an existing year the allocation of the trips by BIVAS is equivalent to the allocation that took place in reality. Therefore the objective of this study is to analyse and validate the functioning of BIVAS for an existing year and, based on this, give recommendations for the improvement of BIVAS.

Because of data availability an instrumental case study on the year 2011 is done, and in order to keep overview, a small part of the European inland navigation network is chosen as research area; the Rotterdam-Lobith corridor. Within this area all characteristics found in the complete network are present, the majority of the inland waterway transport in the Netherlands takes place, the availability and placement of reference points is sufficient, and at the reference points the number of passages computed by BIVAS differ strongly from the number of passages recorded in reality.

In addition to BIVAS, the LSM-Light (SOBEK model of the Netherlands used to generate day-by-day changing water conditions for BIVAS), the Nieuwe Koppeling LSM-BIVAS (Matlab model used to convert data from the LSM-Light to input data for BIVAS), and the Conversion IVS90-BIVAS (Tool used to convert trips recorded in reality to trips and reference data that can be used in BIVAS), are used for this study.

This study consists of three parts. At first a literature study existing of an overview of inland navigation within the Netherlands (Characteristics, systems, classifications, water availability and expectations for the future), and of descriptions of the computational methods of BIVAS, the LSM-Light, the Nieuwe Koppeling LSM-BIVAS, and the Conversion LSM-BIVAS, has been carried out.

The next step was to perform a data analysis existing of the analysis and, whenever possible, validation of the input of BIVAS. In addition, the reference data and the trips are used to analyse the reaction of inland navigation to changing water conditions in reality.

The last part of the study consisted of computations. At first computations were done with the data and settings Rijkswaterstaat currently uses for their computations, and, following from the findings on these computations and the data analysis, other scenarios that could improve the results of BIVAS were created and analysed.

The main conclusion of this study is that BIVAS as it is at this moment, is far from an optimal model, and can not be used sufficiently reliable. Clearly, within the Rotterdam-Lobith corridor, the differences in the costs to travel via the various possible routes, are very small. This makes it difficult to get the allocation through the Rotterdam-Lobith corridor correct.

From the data analysis it was found that not all of the input is accurate. The desired vessel speeds seem to be the biggest problem, since from the analysis of the computations it is found that BIVAS is fairly sensitive for the speed of the vessel over the ground during the allocation of the trips.

Using a water scenario with daily varying water conditions was expected to improve the results of BIVAS. Therefore computations were done with the daily varying water conditions over 2011. However, using the present water scenario for 2011 deteriorates the results. This is mainly because the sensitivity of BIVAS for the flow velocities is not the same as the sensitivity of the skippers for the flow velocities in reality.

The present water scenario does not include the opening and commissioning of the weirs and locks as a result of low and/or high discharge periods. For the Correct control weirs scenarios the opening of the weirs in the Neder-Rijn and Lek during high discharge periods were included. Including this turns out to be no improvement for BIVAS. Why this is no improvement is unknown, but it could be because the commissioning of the Prinses Marijkesluis during high discharge periods is not included, whereby the delay to sail via the Amsterdam-Rijnkanaal in these periods is not included. It could also be that the resistance to travel via the Neder-Rijn and Lek because of their difficult navigability, is not correctly included in BIVAS.

BIVAS allocates much more trips than in reality via the route Lek - Amsterdam-Rijnkanaal. This is most probably for a large part caused by incorrect origin nodes in the Port of Rotterdam. The correct origin nodes can not be found retroactively, therefore a scenario with an ad hoc solution was created. The intersection between the Lek and the Amsterdam-Rijnkanaal is adjusted in a way that there is and extra resistance to allocate a trip via this route. The ad hoc solution improves the results with approximately 25%, but the ad hoc solution is not completely satisfying, because it also brings negative side effects, and does not address the core problem.

Based on the literature review, data analysis and computations recommendations are defined to improve the functioning of BIVAS. For the input there are two main recommendations. At first for almost all kinds of the network data of BIVAS a very little amount of incorrect values are found. It is recommended to check all the network data and improve these values. Secondly the inaccurate desired vessel speeds seem to be a large problem, since BIVAS is for the allocation of the trips very sensitive to these. By collecting data on vessel speeds via radar or AIS the desired vessel speeds could be improved.

Since incorrect origin/destination nodes within the Rotterdam-Lobith corridor seem to have a large effect on the allocation of the trips by BIVAS, and the IVS90 does not always include the exact origin or destination of the trips, it is important to stimulate the skippers in the future to always include the exact waterway number and hectometring.

When the exact origin or destination of the trips is unknown, the trips are linked to the node in the UN-LOCODE area that has the most vessels of the same vessel type leaving or arriving. It might be better to not only use the vessel type to link the vessels to a node, but also the type of goods they carry. In this way it is expected that more trips are linked to the correct nodes.

The analysis of the reference data shows that the opening and commissioning of the locks within the Amsterdam-Rijnkanaal affect the choice of route of skippers. The Prinses Marijksluis at the Amsterdam-Rijnkanaal is in BIVAS not included as a lock. Changing this arc to a lock in the database will solve this. However, the Prinses Marijkesluis is only during high water levels in use. The Prins Bernhardsluis is not in use during low discharge periods, this is also not included in the present BIVAS version. The locks in the database have the option to include a minimum and maximum operating water level. For the Prinses Marijkesluis and the Prins Bernhardsluis these will have to be included in order to be controlled correctly.

To further improve BIVAS more research should be done. Since BIVAS should reflect the reality as well as possible, it is recommended to start with research on the choices of skippers in reality. How do they deal with the tide, when do they choose to sail with less load or to postpone their trip, how sensitive are they to the degree of difficulty of a certain route, and how sensitive are they to the uncertainty of the waiting time at locks and bridges?

The allocation of the trips by BIVAS through the Rotterdam-Lobith corridor is clearly sensitive to the flow velocities, and changes in the flow velocities have a much larger effect on the allocation of the loaded vessels than on the allocation of the empty vessels. How these differences can be reduced should be investigated in the future.

PREFACE

This thesis represents the result of the graduation project that I conducted to obtain the degree of Master of Science in Civil Engineering at the Delft University of Technology. I have conducted the research at Deltares in Delft, in collaboration with Rijkswaterstaat.

Before I started my thesis project I carried out an internship at the River Dynamics and Inland Shipping department of Deltares. This internship focussed on the morphology of a part of the river Meuse; the Grensmaas. After the completion of the internship I indicated to Deltares that for my graduation project I was looking for a topic including a combination of water and transport & planning. They then offered me the topic of this thesis; BIVAS. I would like to thank them for giving me the opportunity to do my graduation work on this topic.

I would like to thank all members of my committee for their help and feedback on my work. Henk Verheij for the assistance in keeping overview of the whole graduation process and the help with the structuring of my research and report. Jurjen de Jong for helping me with thinking through what further steps had to be taken and the technical assistance, Onno Miete for all his knowledge of BIVAS, Winnie Daamen for her accurate and critical view on my report and Tiedo Vellinga for his optimism and accurate questions during my committee meetings.

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1
INTRODUCTION

This research consists of the analysis, validation and recommendations for improvement of BIVAS, a software tool designed to carry out network analysis for inland navigation (Charta Software, 2016).

This chapter contains the introduction on the research done. In Section 1.1 an introduction to BIVAS is given. The problem that gave rise to the research is formulated in Section 1.2 and in Section 1.3 the objective and research questions of the research are stated. The research scope and limitations are given in Section 1.4, Section 1.5 describes the contribution of the research to science and practice and in Section 1.6 the research methodology is described. The last section; Section 1.7, presents the outline of the report.

1.1. INTRODUCTION TO BIVAS

At the beginning of the 21st century the Dienst Verkeer en Scheepvaart (Centre for Transport and Navigation) of Rijkswaterstaat (executive agency of the Ministry of Infrastructure and Environment of the Netherlands) had the need for a tool to carry out network analysis of the Dutch inland shipping network. The tool had to support the answering of policy questions about the intensity of the traffic on the inland waterways and the effects of interventions, blockages, possible economic developments, fleet changes and/or climate change. In 2006 Charta Software started with the development of the tool, which was named BIVAS.

BIVAS is, in Dutch, the abbreviation for "Inland navigation analysis system" (BInnenVaart Analyse Systeem). This section includes an introduction to BIVAS. In Subsection 1.1.1 the functioning of the program is described and in Subsection 1.1.2 the importance of BIVAS for current issues is addressed.

1.1.1. FUNCTIONALITY

BIVAS can, given a waterway network and a set of inland navigation trips, compute the optimal routes over the network for the set of inland navigation trips. The starting point of a BIVAS computation is a scenario, which may represent the network and shipping movements of an existing period or a possible future situation.

A scenario exists at least of the following:

- A network via which the trips can be allocated.
- A traffic scenario consisting of the trips and that have to be allocated.
- Parameters for the various vessel types used for the trips.
- Parameters valid for all trips of the traffic scenario.

} Required for the allocation of the trips over the network.

Network

The network of a BIVAS scenario consists of nodes and connections between them; arcs. The arcs can be waterways, locks, weirs or bridges. For all arcs the dimensions, water conditions (flow velocity, flow direction and water depth) and some characteristics have to be included. Part of the characteristics apply to all arc types, but there are also characteristics which are specific for a certain type of arcs.

In BIVAS the present European waterway network is included. When a scenario is created it is possible to use and/or adjust this network.

Traffic scenario

In the traffic scenario of a BIVAS scenario should be included per trip; the departure date, origin, destination, draught, weight, characteristics of the freight and dimensions and characteristics of the vessel. Traffic scenarios of a number of recent years are provided with every version of BIVAS. These traffic scenarios reflect the actual trips that took place in these years. For a BIVAS scenario one of the provided traffic scenarios can be used or a new traffic scenario can be constructed.

Parameters for the various vessel types

Per vessel type the following parameters should be included in the BIVAS scenario in order to allocate the trips over the network:

- The expected velocity on a certain arc.
- The expected energy use per hour on a certain arc.

} Depending on the waterway class of the arc and whether the vessel is loaded or empty.

- The labour, maintenance and other costs per hour and/or kilometre.

Parameters valid for all trips

In order to do a computation with BIVAS several parameters valid for all trips of the scenario should be defined. The main parameters are the optimization objective (travel time or costs) and the start and end date of the scenario.

A scenario may also include:

- A water scenario for (part of) the network including water conditions changing over time.
- A fleet mutation scenario with which it can be determined per trip in the traffic scenario whether the vessel type, load factor and/or the number of trips should be adjusted.
- Growth rates, per for example; origin, destination or the type of goods being transported, that can be applied to the trips of the traffic scenario.
- A reference trip set with data on how the trips of the traffic scenario took place over the network in reality.

By applying a water scenario the water conditions on (part of) the arcs can be changed per day, month, year or any other period between a day and a year. Per period and arc on which the water scenario will be applied a flow velocity, water level and water depth have to be included. A water scenario can be a reflection of the real water conditions within the year of the traffic scenario used, but can also consist of expected water conditions in the future so that, for example, the impact of climate change on inland navigation can be predicted.

A fleet mutation scenario and/or growth rates can be used to adjust the used traffic scenario in such a way that it represents a possible future traffic scenario. A reference trip set can be used to compare the allocation of the trips by BIVAS to the allocation that took place in reality.

1.1.2. IMPORTANCE OF BIVAS FOR CURRENT ISSUES

Currently, BIVAS is important software because of two main research issues. At first, many hydraulic structures that were build just after WOII are at the end of their service life and should be replaced. BIVAS can assist in the determination of the capacity, dimensions and/or placement of the new hydraulic structures.

Secondly BIVAS is part of the Deltamodel Freshwater of the Delta Programme. Through climate change the supply of water will change. Within the Deltamodel Freshwater BIVAS is used to compute, for the various Delta Scenarios, the economic loss due to changing water conditions for inland navigation (Kroon & Ruijgh, 2012). For an explanation of the Delta Programme and Deltamodel Freshwater see Appendix A.

1.2. PROBLEM FORMULATION

BIVAS works reasonably at this moment, but when a computation is done for a year in the past, where the traffic scenario and the network reflect the reality of this year, the allocation of the trips on part of the waterways is not yet correct. Results of a computation for the year 2011 done by Miete (2014) show that at part of the available reference points the amount of vessels passing in BIVAS differ strongly from the amount of vessels passing in reality.

The causes for the different allocation of the trips by BIVAS in comparison to the allocation in reality are not known. However, some possible reasons are:

- Currently there is no water scenario included, so over a whole year the same water conditions are used. In reality water conditions do change over time.
- Routes that are difficult to navigate, for example because of sharp bends, are in real life expected to bechosen less often by skippers. This is not included in BIVAS.
- The allocation of the trips by BIVAS follows from computations with a large amount of input data. To what extent this input data is correct is unknown.

Within the framework of the Delta Programme BIVAS computations are done including a traffic scenario of a year with average water conditions; 2008. The economic loss for this traffic scenario in combination with a water scenario of an extremely dry year; 1976, gave an economic loss of about 40 million euros (Klijn et al., 2012).

The real situation in 2003, which was a dry year, can be compared to this scenario. For this year RIZA (2005) and Jonkeren (2009) carried out studies to identify the economic loss for inland navigation. They computed an economic loss of around 100 million euros for the year 2003.

The drought in 2003 was less extreme than in 1976 (Beersma et al., 2004), and in 2008 more freight was transported than in 2003 (Eurostat, 2016). Therefore the economic loss computed with BIVAS for the traffic scenario of 2008 in combination with a water scenario of 1976 should be larger than the economic loss for 2003 computed by RIZA (2005) and Jonkeren (2009), but this is not the case. The computed economic loss by RIZA (2005) and Jonkeren (2009) is 60 million euros more, which is remarkable. BIVAS does not seem to work well when computations are done with changing water conditions.

Several reasons for the possible poor performance of BIVAS, when a scenario is used with water conditions differing from the water conditions in the year of the used traffic scenario, are known:

- For potential future scenarios traffic scenarios representing a certain year are used. The types and load factors of the vessels used for the trips in these traffic scenarios are therefore adapted to the water conditions corresponding to these trips. It is the question whether these traffic scenarios can be used for potential future scenarios, because the water conditions over a year may differ strongly from year to year.
- When trips are not possible via their normal route, in BIVAS at first an alternative route is searched. Only when there is no alternative route, a reduced load is considered. The question is whether an alternative route is always a better option than reducing the load.
- BIVAS uses a fixed departure time per trip. When there is no alternative route or reduced loading possible the trip is marked as impossible. In real life it is possible that the trip does take place, but later in time.
- In BIVAS, when the loading of a vessel is reduced due to smaller water depths, the vessel will have to take more trips to get all freight at its destination, but only once a return trip is calculated. This is because a round trip is modelled as two separate trips. For instance if a vessel has to sail three times, only once a return trip is calculated, because the empty vessel can sail when there are smaller water depths.

1.3. OBJECTIVE AND RESEARCH QUESTIONS

As described in the previous section, the performance of BIVAS is not yet optimal. In order to get better results for the Delta Programme it is at first necessary to ensure that for an existing year the allocation of the trips by BIVAS is equivalent to the allocation that took place in reality. Therefore the objective of this research is:

Analysing and validating the functioning of BIVAS for an existing year and, based on this, give recommendations for the improvement of BIVAS.

The research objective leads to the following main research question:

MAIN RESEARCH QUESTION

To what extent does BIVAS currently function correctly for an existing year and how can the functioning of BIVAS be improved?

SUB-QUESTIONS

In order to be able to answer the main research question a number of sub-questions are developed.

The first three sub-questions deal with the analysis and validation of the present functioning of BIVAS:

A. Which input,that is of relevance for this study, is stored in the database included with BIVAS and to which extent is this input correct?

B. What is in reality the reaction of inland navigation to changing water conditions on the Dutch waterway network?

C. What differences are there with the reference trip set when a computation is done with the data and settings Rijkswaterstaat currently uses to do computations with for an existing year, and how can these differences be explained?

A computation with BIVAS requires a large amount of input data. Sub-question A addresses this input data. To examine how BIVAS allocates the trips in comparison to the choice of route of the skippers in reality it is important to know how skippers react to changing water conditions. Sub-question B addresses this. Finally should for the analysis and validation of the present functioning of BIVAS be looked into the differences between the allocation by BIVAS and the choice of route of the skippers in reality (*sub-question C*).

Currently there are no daily varying water conditions included in a BIVAS computation. In reality water conditions do change over time, therefore it is expected that using a water scenario including daily varying water conditions will improve the functioning of BIVAS. The second group of sub-questions relate to the use of a water scenario including daily varying water conditions:

D. To what extent does, for a situation that occurred in reality, a water scenario including daily varying water conditions reflect the actual water conditions on the waterways?

E. What differences are there with the reference data and the computation without a water scenario when a computation for an existing year is done with a water scenario, and how can these difference be explained?

A water scenario with daily varying water conditions is a simplification of reality. In reality the water conditions are completely dynamical and change over a day as well. In addition, in BIVAS values per waterway segment are used, while in reality the values vary over the width and the length of a waterway segment. Sub-question D addresses the differences between the real water conditions and the water scenario. To investigate how BIVAS reacts to the water scenario and to find out to what extent the water scenario improves the results of BIVAS sub-question E is included.

The sixth sub-question addresses other possible improvements:
F. What changes can be made to the input and boundary conditions of BIVAS that could reduce the differences with the reference data and to what extent are these changes an improvement?
Based on the findings of the input analysis, the computations with the data and settings Rijkswaterstaat currently uses and the computations with the water scenario new scenarios can be developed and tested. Sub-question F addresses this.

The last sub-question is not directly related to the main research question, but since one of the incentives to carry out this research is the use of BIVAS for the Delta Programme and the present way BIVAS is used for the Delta Programme seems to be incorrect. it has been chosen to dedicate one research question to the Delta Programme:
G. How can with the existing possibilities of BIVAS computations be done for the Delta Programme?

In an ideal world BIVAS would function completely correct when the results are one hundred percent in accordance to reality. However, this is practically impossible. Rijkswaterstaat accepts a deviation of a couple of percentage points per reference point or route. Roughly speaking this means that results with a deviation of less than ten percent are acceptable.

1.4. RESEARCH SCOPE AND LIMITATIONS

In order to maintain overview only it has been chosen to analyse a small part of the Dutch waterway network more thoroughly. Which area this is and why this area has been chosen is described in Subsection 1.4.1. In Subsection 1.4.2 the impossibilities of the research are described.

1.4.1. RESEARCH AREA

BIVAS is a program at network level. Analysis on this level is only possible up to a certain extent, because otherwise the overview is lost. Therefore a research area has been chosen which will be analysed more thoroughly. Part of the objective of the study is to give recommendations for the improvement of BIVAS. These recommendations will have the largest effect on the improvement of BIVAS when the research area is a reflection of the whole network, a large number of vessels pass through the research area and the difference between the number of vessels passing in reality and in BIVAS at the points for which reference data is available is large.

The following has to be present within/apply for the research area:

- Rivers (Natural waterways)
- Canals (Man made waterways)
- Various waterway classes.
- Locks
- Weirs
- Influence of the tide.
- Various route options between origin and destination.
- All vessel types have to sail through the area in reality.
- Sufficient amount of points for which reference data is available.
- Useful placement of points for which reference data is available.

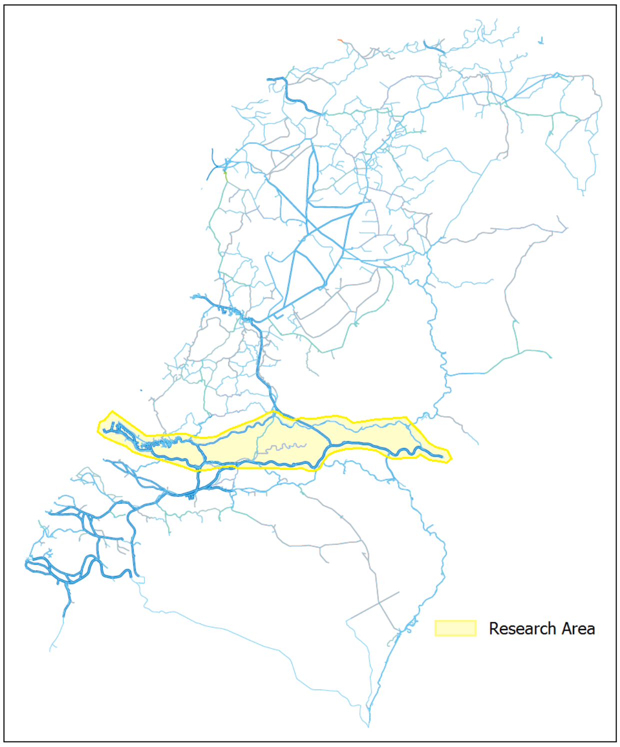


Figure 1.1: Location of the research area of the study within the Dutch inland waterway network.

The chosen research area is the area including the Rhine branches between the Port of Rotterdam and the border with Germany at Lobith. In this area there are enough reference points available. These points are placed in a way that the route of a trip through the area can be reconstructed reasonably well. Results of computations done by Miete (2014) show that, at the reference points within this area, the amount of vessels passing in BIVAS differs strongly from the amount of vessels passing in reality. In addition; the majority of the inland waterway transport in the Netherlands takes place within this area (Jonkeren, 2009). In Figure 1.1 the chosen research area is highlighted.

In the remaining part of the report the research area will be referred to as the "Rotterdam-Lobith corridor".

1.4.2. LIMITATIONS OF THE RESEARCH

Within the research, there are limitations for three reasons. First, If you want to make certain specific changes to BIVAS, the computational method of BIVAS should be changed, which is for example the case for spreading trips over several days. Adjusting of the computational method of BIVAS is not possible within this research because it can only be modified by Charta Software and, because of time restraints, this is not possible within this research. That the computational method can not be adjusted means for this study that no adjustments on the computational method of BIVAS that could possibly improve the results of BIVAS can be tested.

The second limitation is due to privacy regulations on the reference data used for the construction of the trips that are included in the available traffic scenarios. It is not allowed to attach an ID of the vessel to a trip. Extra return trips that are not included because of lowering of the load can therefore not be simulated correctly. A vessel often does not go back to its origin, but to another place and also often with a new load. The new destination and load of the vessel is unknown due to the privacy regulations. Within this research it is, due to the privacy regulations, not possible to investigate the movements of specific vessels, whereby gathering information on the choices of skippers is limited.

The third limitation is the availability of data. At the start of this research only for the years 2011 and 2013 accurate traffic scenarios with their corresponding reference data were available and only for 2011 it was possible to create a proper water scenario. Therefore the research could only be fully based on the year 2011 and partially on the year 2013. As a result, it is not possible to compare similar periods of the year to each other. When the research is based on only one year it may be that special events happening only in that year are not discovered.

1.5. CONTRIBUTION TO SCIENCE AND PRACTICE

The scientifical contribution of this research is to get better understanding of the relation between inland navigation and water conditions. The current knowledge about this is limited. It is for example not known when, why and how skippers choose for an alternative route, reducing the load, or a combination of these. Analysis of the vessel movements and the draughts of the vessels in relation to the water conditions within the Rotterdam-Lobith corridor will help in understanding the decision-making of the skippers. By the better understanding of the decision-making the reaction of inland navigation on changing water conditions in the future can be predicted better, which will help to improve the functioning of BIVAS.

The contribution to practice of this research is that, when the performance of BIVAS is improved, BIVAS will give more plausible results, making it more useful for the computation of possible future scenarios. Next to this it will be more cleare for which issues BIVAS can and can not be used.

1.6. RESEARCH METHODOLOGY

In order to answer the research questions and reach the objective of this research a research methodology has been setup. The used research methodology exists of a literature review (Subsection 1.6.1), a data analysis (Subsection 1.6.2) and model computations (Subsection 1.6.3).

1.6.1. LITERATURE REVIEW

The research started with a literature review. The literature review can be divided in two parts. The first part of the literature review is about inland navigation in the Netherlands. The aim is to find out how the Dutch inland waterway transport is constructed and which aspects of the Dutch inland waterway transport are of importance for the use of BIVAS. Questions answered are; What is the history of inland navigation in the Netherlands?, what is the importance of inland navigation for freight transport?, which systems and classifications are used?, how develops the fleet?, how do the water conditions develop over time?, and, how is the research area constructed?

The second part of the literature review addresses BIVAS and the software related to BIVAS used for this study, with the aim to get insight in the computational methods of these. The adressed version of BIVAS is BIVAS 3.2.2, which was released in November 2014 and is used for the computations in this study. Next to BIVAS the LSM Light 1.2 model (SOBEK model of the Netherlands used to generate daily varying water conditions for BIVAS), the Nieuwe Koppeling LSM-BIVAS (Matlab model used to convert data from the LSM-Light to input data for BIVAS) and the Conversion IVS90-BIVAS (Tool used to convert trips recorded in reality to trips and reference data that can be used in BIVAS) are adressed.

1.6.2. DATA ANALYSIS

The next step is a data analysis. The data analysis can also be divided in two parts. At first the input of BIVAS which is of relevance for this study is analysed and, whenever possible, validated (*sub-questions A and D*). The aim of the input analysis is to check to what extent the input is correct.

Secondly the measured discharges at Lobith, the reference data and the trips of 2011 are used to analyse the relation between inland navigation and changing water conditions in reality, with the aim to find out how skippers react to changing water conditions in reality (*sub-question B*).

1.6.3. MODEL COMPUTATIONS

Finally, BIVAS scenarios are created, computed, analysed and compared to the reference data and each other. To analyse the present functioning the differences between the allocation of BIVAS and the choice of route by skippers in reality (*sub-question C*), at first computations are done with the data and settings Rijkswaterstaat currently uses to do computations with for an existing year.

Hereafter, with the aim to get a better understanding for which parameters the allocation by BIVAS is the most sensitive and/or to try to create a better reflection of the reality various other scenarios are developed, computed and analysed. The first scenario created for this study is the Without current scenario. In this scenario the flow velocity is on all waterways zero, which is not the case in reality. It is created to test the sensitivity, of the allocation of the trips by BIVAS, for the flow velocities.

The second scenario created for this study is the Water scenario LSM scenario. This scenario includes a water scenario with the daily water conditions (depth and flow velocities) of 2011. In reality water conditions change over time, therefore it is expected that including a water scenario with daily water conditions will improve the results of BIVAS. By analysing and validating the results of the Water scenario LSM scenario the handling of daily varying water conditions by BIVAS can be indicated (*sub-question E*).

Following on from the preceding scenarios, scenarios that might be an improvement for the results of BIVAS are created, computed, analysed and validated (*sub-question F*). The first of these scenarios is the Correct control weirs scenario. This scenario includes the opening of the weirs at the Neder-Rijn and Lek during high water levels, which happens in reality, but is not included in the preceding scenarios.

The second scenario that is created to possibly improve the results of BIVAS is the Adjusted intersection at Wijk bij Duurstede scenario. From the analysis of the computations with the preceding scenarios it appeared that in BIVAS the amount of vessels sailing via the Lek, Amsterdam-Rijnkanaal and Waal towards Germany is excessively large in comparison to reality. In order to get better results for this route a scenario with an ad hoc solution, whereby an additional delay is added for sailing via this route, has been created.

To answer the last sub-question (*sub-question G*) the Delta Programme scenario is created, computed, analysed and as far as possible validated. Presently the use of BIVAS for the Delta Programme seems to be incorrect. There is, with the current possibilities of BIVAS, a scenario created that represents the reaction of inland navigation on lower water levels due to climate change. This has been done by combining the trips of a median period with the water conditions of a dry period.

1.7. REPORT STRUCTURE

The report structure follows the Research methodology as given in Section 1.6. Figure 1.2 shows the structure of the report.

In Chapter 2 the aspects of inland navigation in the Netherlands (importance for freight transport, classifications of vessels and waterways and water conditions) and the characteristics of the Rotterdam-Lobith corridor are described. In Chapter 3 a description of the functioning and computational method of BIVAS and the software related to BIVAS is given. Chapter 4 consists of an analysis of the input for the BIVAS computations and in Chapter 5 the setup of the computations done is described. Chapter 6 includes the analysis of the results of the computations with the Rijkswaterstaat scenarios and in Chapter 7 all results of the computations with the scenarios created for this research are analysed. In Chapter 8 the conclusions of the research are summarized , and in the final chapter; Chapter 9, recommendations on the improvement of the input for BIVAS, software and systems related to BIVAS and the computational method of BIVAS are given. Chapter 9 addresses also the recommendations for further research.

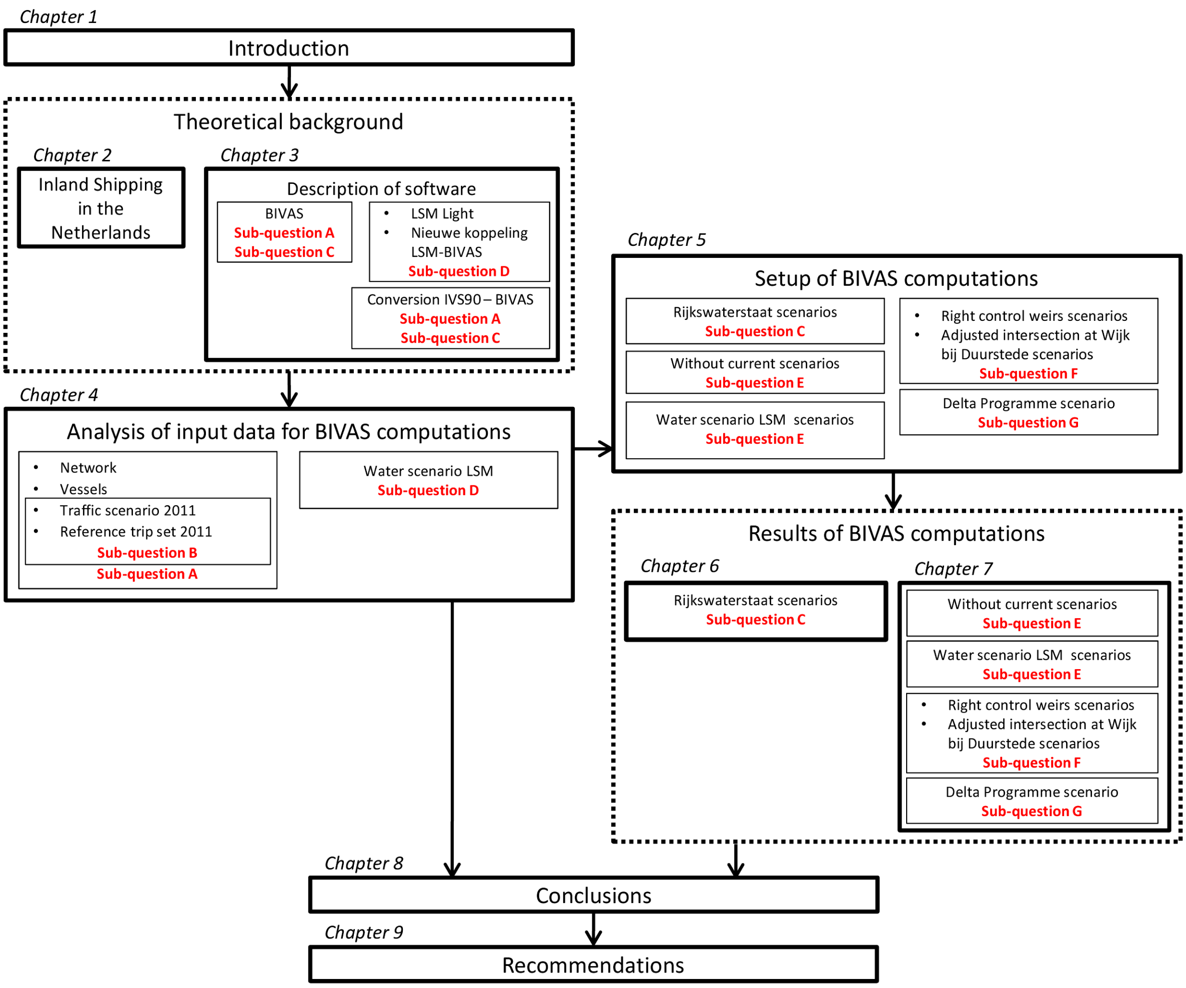


Figure 1.2: Overview report structure

2
INLAND NAVIGATION IN THE NETHERLANDS

This chapter includes the theoretical background for the research. In Section 2.1 is, to give a background to the complexity of the Dutch inland waterway network and therefore the development of BIVAS, the history of inland shipping in the Netherlands described. In Section 2.2 the importance of inland navigation for freight transport in the Netherlands in indicated, showing the importance of an inland navigation model like BIVAS for the Dutch economy.

Section 2.3 includes the waterway and vessel classifications used by Rijkswaterstaat. The classifications in BIVAS are based on these classifications. The reference data and traffic scenarios included with BIVAS come from the IVS90, the system that is used in the Netherlands to keep track of inland navigation. Section 2.4 gives an overview of the IVS90.

To show that the inland navigation fleet changes over time, whereby the average difference between the water depth and the draught of the vessels changes, and thereby the importance of research after the effects of changing water conditions becomes more important, are in Section 2.5 the historical fleet development and the expectations for the fleet development in the future described.

In Section 2.6 is, to show that the water conditions develop over time, through which again the importance of research after the effects of changing water conditions becomes more important, an overview of the availability of water for inland navigation historically and in the future is given. In order to get a good impression of the water conditions in 2011, the year used for this study, the water conditions in this year are analysed in this section as well. For this study various discharge periods are used. Which periods those are and why those periods are chosen is also described in this section.

The Rotterdam-Lobith corridor is chosen as research area for this research. In Section 2.7 the characteristics of this area are described. The last section of this chapter, Section 2.8 summarizes the conclusions of everything discussed in this chapter.

2.1. HISTORY OF INLAND NAVIGATION IN THE NETHERLANDS

Brolsma (2011) describes the development of the inland navigation vessels and waterway infrastructure in the Netherlands. This section is based on this report.

Until the nineteenth century inland vessels were sailboats or horse/man pulled barges. Steam ships were introduced in the beginning of the nineteenth century and motorised vessels were introduced in the beginning of the twentieth century.

Around the beginning of the common era the Romans build the first waterways in the Netherlands. They built the Corbulo canal (linking the Maas and Rhine) and the Drusus canal (Linking the Rhine and the Gelder-sche IJssel). Until the seventeenth century most waterways were natural, but during the 'Golden Age', a time of great economic growth, there was a rising demand for mobility. Therefore in the seventeenth century a system of canals for pulled barges was created. In the period after this there was very little development, but in the nineteenth century after the defeat of Napoleon the decision was made to merge the Netherlands and Belgium into one kingdom. King William I tried to unite the Netherlands and Belgium by building canals like the Zuid-Willemsvaart and the Nieuwe Waterweg. In 1850 the government made the decision to normalise the river Waal, with as primary goal to prevent flooding, but with as important secondary goal to create a more easily navigable route between the Port of Rotterdam and the industrialising German hinterland. After World War II motorised vessels rapidly replaced steam ships, causing a major expansion in scale. This led to the creation of large modern waterways, like the Amsterdam-Rijnkanaal and the Schelde-Rijnkanaal. To regulate the discharge distribution and thereby the water depth on the Rhine-branches three weir and lock complexes were built in the Neder-Rijn (Amerongen and Driel) and Lek (Hagestein) during the sixties.

2.2. IMPORTANCE OF INLAND NAVIGATION FOR FREIGHT TRANSPORT IN THE NETHERLANDS

In the Netherlands reight transport takes place via road, rail or inland waterway. The relative share of each of these transport modes is defined as the modal split. For freight transport the modal split is based on tonne-kilometre; the transport of one tonne of goods over a distance of one kilometre.

Table 2.1 includes for the years 2009 and 2014 the modal split for inland freight transport in the Netherlands, for its neighbours Germany and Belgium and for the European Union in total. It can be seen that for the Netherlands the relative share of the transport via inland watewrways is large, and is considerably larger than in the other countries, making inland navigation a very important transport mode for freight transport in the Netherlands. In addition, it can be seen that the relative share for freight transport via inland waterways has grown for the Netherlands, Belgium and thereby the whole European Union between 2009 and 2014, which shows that within the European Union the importance of inland navigation has, relatively to the other transport modes, grown.

Table 2.1: Modal split of inland freight transport in 2009 and 2014, in percentage of total tonne-kilometres (Eurostat, 2016).

	2009	Inland			**2014**	Inland		
		Waterways	Rail	Road		Waterways	Rail	Road
	Total tkm	**% of total tkm**[1]			**Total tkm**	**% of total tkm**[1]		
European Union	2,154,393	6.1	16.9	77.1	2,236,343	6.7	18.4	74.9
Germany	536,780	10.4	17.9	71.8	598,425	9.9	18.8	71.3
Netherlands	90,215	39.5	6.2	54.3	105,796	46.6	5.8	47.6
Belgium	57,887	12.2	11.0	76.7	65,513	16.0	11.1	72.9

[1] Figures may not add up to 100% due to rounding

2.3. WATERWAY AND VESSEL CLASSIFICATION

In this section the classification systems used to classify the inland waterways and vessels are described and based on these classifications an overview of the European and Dutch inland waterway networks is given.

2.3.1. CLASSIFICATION SYSTEMS

In 1954 the European Conference of Ministers of Transport (ECMT) accepted a European classification for inland waterways. Over the years the classification has been updated. The current classification is the CEMT1992 classification (ECMT, 1992). The criteria for the CEMT1992 classification are length, width, draught and load capacity of the biggest vessel or barge allowed on the waterway, or for which the waterway is considered suitable. The classification of the waterway classes runs from 0 up to and including VII and from class V there can be an a, b or c designation. This designation has to do with lengthwise coupled barges and convoys. The full CEMT1992 classification can be found in Table B.1 in Appendix B.

Dofferhoff et al. (2002) and ten Hove (2008) show that the figures of the CEMT1992 classification do not meet the scale expansion that occurred over the past years and that the figures are no longer representative for the current West European inland navigation fleet. Therefore in the Netherlands a new classification for waterways is defined based on the CEMT1992 classification; the Rijkswaterstaat (RWS) 2010 classification. This classification is shown in Table B.2 in Appendix B.

In the Netherlands the vessel classification is linked to the waterway classification. The vessel types are classified based on the waterway classification and have the same designation. In Table B.2 in Appendix B the vessel classification can also be found.

2.3.2. OVERVIEW EUROPEAN AND DUTCH INLAND WATERWAY NETWORK

Figure C.1 in Appendix C is a map of all main European waterways including their name, CEMT class, whether they are free-flowing rivers, canalized rivers or canals. The map also includes the locations of locks, ship lifts and dams.

Of the Dutch network a more detailed map is enclosed. Figure C.2 in Appendix C is a map of the Dutch inland waterway network including the names and CEMT classes of all Dutch inland waterways and all hydraulic structures present in the network.

In addition to the CEMT1992 and RWS2010 classifications the main waterways in the Netherlands can be divided in three types (V&W & VROM, 2004):

- Trunk waterways (550 km) - Suitable for four-barge pushed convoys (CEMT Class VIb) and four layers of containers.

- Main waterways (900 km)
  - Arterial Main waterways - Suitable for four-barge pushed convoys (CEMT Class VIb) and four layers of containers.
  - Other Main waterways - Suitable for Europa I pushed convoys (CEMT Class IV) and three layers of containers.
- Other waterways (5200 km)

A waterway is a trunk waterway when more than 25,000 TEUs and/or five million tonne of international freight per year are/is transported over it. Main waterways meet the same criteria, but for domestic transport.

The trunk and main waterways of the Netherlands are shown in Figure 2.1.

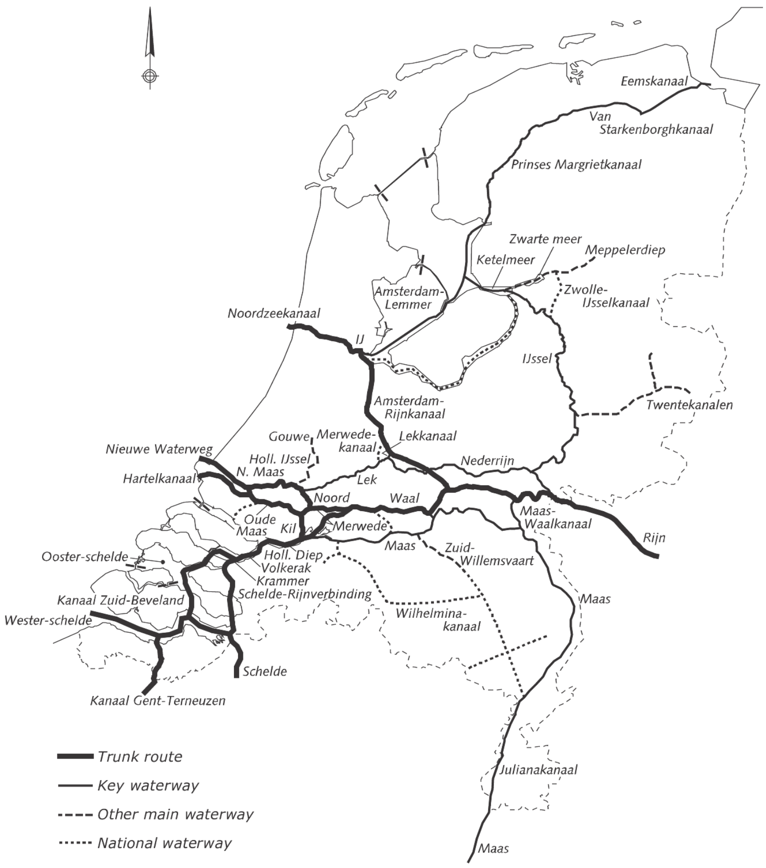


Figure 2.1: Trunk and main waterways according to V&W & VROM (2004). Reprinted from Brolsma & Roelse (2011).

2.4. IVS90 - INFORMATION AND TRACKING SYSTEM FOR SHIPPING

IVS90 is, in Dutch, the abbreviation for "Information and tracking system for shipping" (Informatie- en Volgsysteem voor de Scheepvaart). It comprises a daily updated database with data on shipping in the Netherlands.

The IVS90 is maintained by Rijkswaterstaat. Due to privacy considerations only the data within the IVS90 that can not directly be linked to a specific vessel is optionally provided for studies.

This section includes a summary of the goal of the IVS90 and the data recorded in the IVS90. The source for this summary is the article "Reglement IVS90" (DGG, 1999).

2.4.1. GOAL

The goal of the IVS90 is the systematic capture, storing of and making available of data on the shipping traffic at the Dutch inland waterways for the benefit of:

- Promoting safe and efficient navigation.
- Quick and effective action in case of accidents.
- Minimizing the reporting of vessel data at locks and traffic posts.
- Gathering data about the shipping traffic.
- Statistics and policy analysis.

2.4.2. RECORDED DATA

The IVS90 contains data on commercial vessels, including the non-cargo vessels, service and working vessels, and large recreational craft, that are using the (main) waterways.

The IVS90 incorporates the following data per vessel:

- Reference data
  - Name
  - Loading capacity
  - Official ship number (Inland vessels) or Lloyd's number (Seagoing vessels)
  - Vessel type
  - Gross registered tonnage
  - Callsign
  - Name of the owner
  - Propulsion code
  - Nationality
  - Dimensions; Length, width and maximum draught
- Travel information
  - Dimensions; Actual draught and height
  - Dangerous goods level
  - Control on signalling
  - Number of crew
- Block data (per waterway section)
  - Reporting time of sailing in and reporting time of sailing out
  - Sailing direction
  - Global position within waterway section
- Route data
  - Route according to the IVS encodings
- Wait port data (per wait port)
  - Duration of stay
- Freight data
  - Name
  - Vessel type
  - Container number
  - Number and size of the containers
  - Weight of the freight
  - Kind of freight and the VN-number corresponding to this
  - ADNR classification
  - IMO classification (Hazardous Substances) or NSTR number (other substances)
  - Potentially present loading permits
  - Place of origin and place of destination
- Lock data (per lock)
  - Turn number
  - Estimated time of arrival
  - Reporting time
  - Time of confirmation of the turn
  - Passage time
- Chamber data (per (partial) chamber)
  - Locking briefing number
  - Time of sailing in
  - Locking direction
  - Time of sailing out
  - Chamber code

2.5. Fleet development

In 2010 TNO has, commisioned by RWS-DVS, conducted a study on the historical development and the expectations for the future of the Dutch inland fleet. The results of this study are described in the report "Vlootontwikkeling binnenvaart" (Groen & van Meijeren, 2010). The report did not include infrastructural developments. Therefore RWS-DVS decided to revise the report, which led to the report "Herziening Vlootontwikkeling Binnenvaart" (Turpijn et al., 2010). This section is based on the data and approach used in the revised report. It has been found that the tables and graphs of this report are not all fully consistent with the approach described in the report, therefore in a number of cases new tables and graphs are created. If this is the case, it is indicated in the table or graph.

The inconsistencies in the report are described in Subsection 2.5.1. Subsection 2.5.2 consists of an analysis of the historical fleet development and in Subsection 2.5.3 the prognosis for the future is discussed.

2.5.1. Inconsistencies in tables and graphs of the report "Herziening Vlootontwikkeling Binnenvaart"

There are the following inconsistencies in the assumptions, tables and graphs of Turpijn et al. (2010):

1. The Oostersluis and Prinses Margrietsluis were upgraded from CEMT class IV to V during the study period. In the report it is assumed that the upgrade was completed just before 2000, while in fact the upgrade was completed at the end of 2001 (Rijkswaterstaat et al., 2017).
2. The figures on the load capacity between 1970 and 2000 were visually read from a graph of the report "Een nieuwe standaardvloot voor de verkeersmodellen" (RWS-AVV, 2000), while this report also contains tables with the exact figures.
3. It is stated that the average load capacity for all representative counting points together per CEMT class is defined as the sum of the tonnes for all representative counting points of the CEMT class in a certain year, divided by the sum of the number of vessel passages for all representative counting points of the CEMT class in this year. However, the average load capacity for the representative counting points of a CEMT class together is, for the figure used in the report, calculated by the sum of the average load capacity per representative counting point divided by the number of representative counting points. Thus, in the report it is indicated that a weighted average is used, but this has not happened.
4. The average growth of the average load capacity per waterway class in tonne per year is for the period 1970-2008 calculated by dividing the difference between the average load capacity in 1970 and 2008 by

eight instead of 38 and for the period 1970-2000 by dividing the difference between the average load capacity in 1970 and 2000 by eight instead of 30.

5. For the expectations of the development of the load capacities per CEMT class in the future are in the report two variants described. The first one is a variant based on the period 1970-2008 and the second one is based on the period 1970-2000. For the figure including the results of this variants are, however, instead of the results of the variant based on the period 1970-2000, the results of a variant based on the period 2000-2008 used.

For this report new tables and figures were made. In these new tables and figures the Oostersluis and Prinses Margrietsluis are class V from 2002 onwards (1), the exact figures from the tables in the report "Een nieuwe standaardvloot voor de verkeersmodellen" (RWS-AVV, 2000) are used (2), for the average load capacity per CEMT class the weighted average is used (3), the average growth of the average load capacity in tonne per year is calculated in the right way for the periods 1970-2008 and 1970-2000 (4) and the variant for the expectations of the development of the load capacity based on the period 1970-2000 is used instead of a variant based on the period 2000-2008 (5).

2.5.2. FLEET DEVELOPMENT HISTORICALLY

The historical fleet development is approached in two ways:

- The development of the number of passages per vessel type and CEMT class (IV,V and VI) for the period 2000-2008.
- The development of the average load capacity per CEMT class (IV,V and VI) in the period 1970-2008.

For both approaches data from a number of representative counting points (see Figure D.1 in Appendix D which counting points) is used. There is not for all years data from all counting points available; The average load capacity in the period 1970-1998 is available only every even year and the data for 2003 is lacking completely.

DEVELOPMENT OF NUMBER OF VESSEL PASSAGES HISTORICALLY

Table 2.2 shows for all representative counting points together per vessel category and per year, the share of the total number of passages in the year. The numbers referring to these percentages are given in Table D.1 of Appendix D. Table 2.2 shows that the share of the Motor vessels shrinks over the years and the shares of the Pushed convoys and Coupled units grow. The growth for the Coupled units is the largest, almost 60%. For the CEMT classes separately the trends are similar. The numbers for the CEMT classes separately can be found in Table D.2 in Appendix D.

Table 2.2: Percentage of total number of passages per vessel category at the representative counting points for CEMT classes IV, V and VI together, 2000-2008.

	Percentage of total number of passages								
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Motor vessels	92.2%	92.3%	91.9%	N/A	91.2%	91.7%	91.2%	90.7%	90.4%
Pushed convoys	5.5%	5.2%	5.3%	N/A	5.8%	5.9%	5.9%	5.9%	6.0%
Coupled units	2.3%	2.6%	2.8%	N/A	3.0%	2.4%	2.9%	3.4%	3.6%

Within the different vessel categories there are also changes visible. The tables and figures with the numbers and shares per RWS class can be found in Section D.2 in Appendix D. For two of the three vessel categories changes are clearly visible. For the Pushed convoys there are no big changes. For the Motor vessels upscaling has taken place; there is a clear shrinkage of the share of the smaller vessels and a clear growth of the share of the larger vessels (see Figure 2.2). For the Coupled units a clear growth of the share of the RWS class C3l and a clear shrinkage of the share of RWS class C3b can be seen (see Figure 2.3), skippers prefer a length coupling more often over a width coupling.

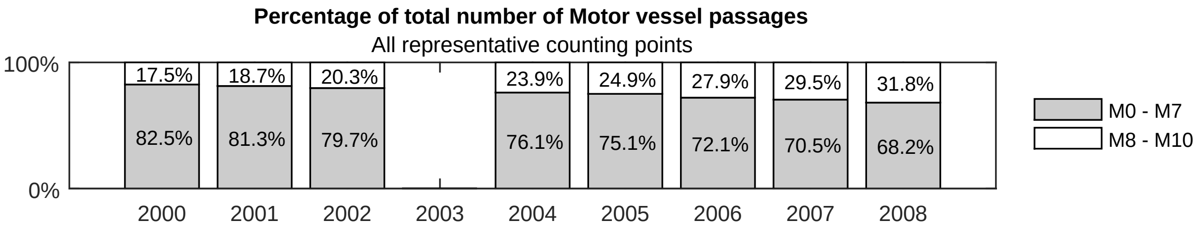


Figure 2.2: Percentage of total number of Motor vessel passages at all representative counting points, 2000-2008. M0 up to and including M7 relative to M8 up to and including M10.

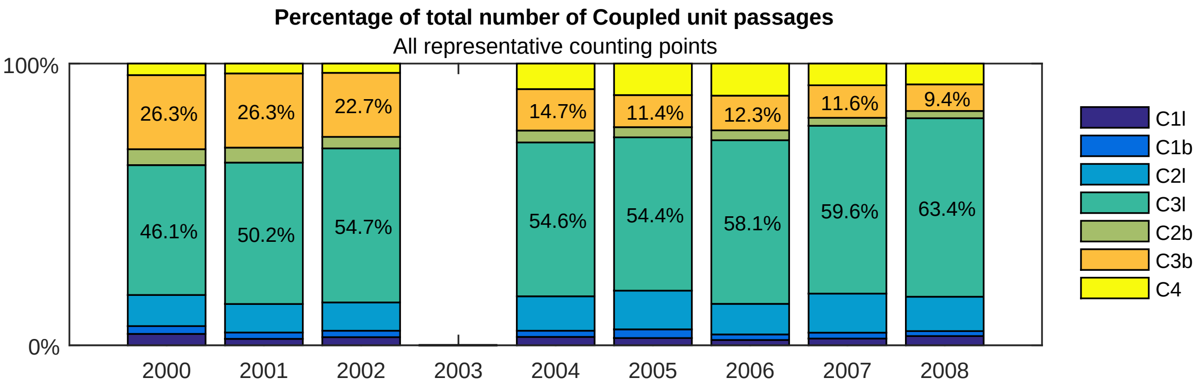


Figure 2.3: Percentage of total number of Convoy passages at all representative counting points, per RWS coupled unit class

DEVELOPMENT OF AVERAGE LOAD CAPACITY HISTORICALLY

The historical development of the average load capacity per CEMT class is shown in the first part (1970 -2008) of Figure 2.4. The trend for the representative counting points per CEMT class is comparable to the trend per CEMT class as a whole. The breakdowns by counting point can be found in Section D.3 in Appendix D.

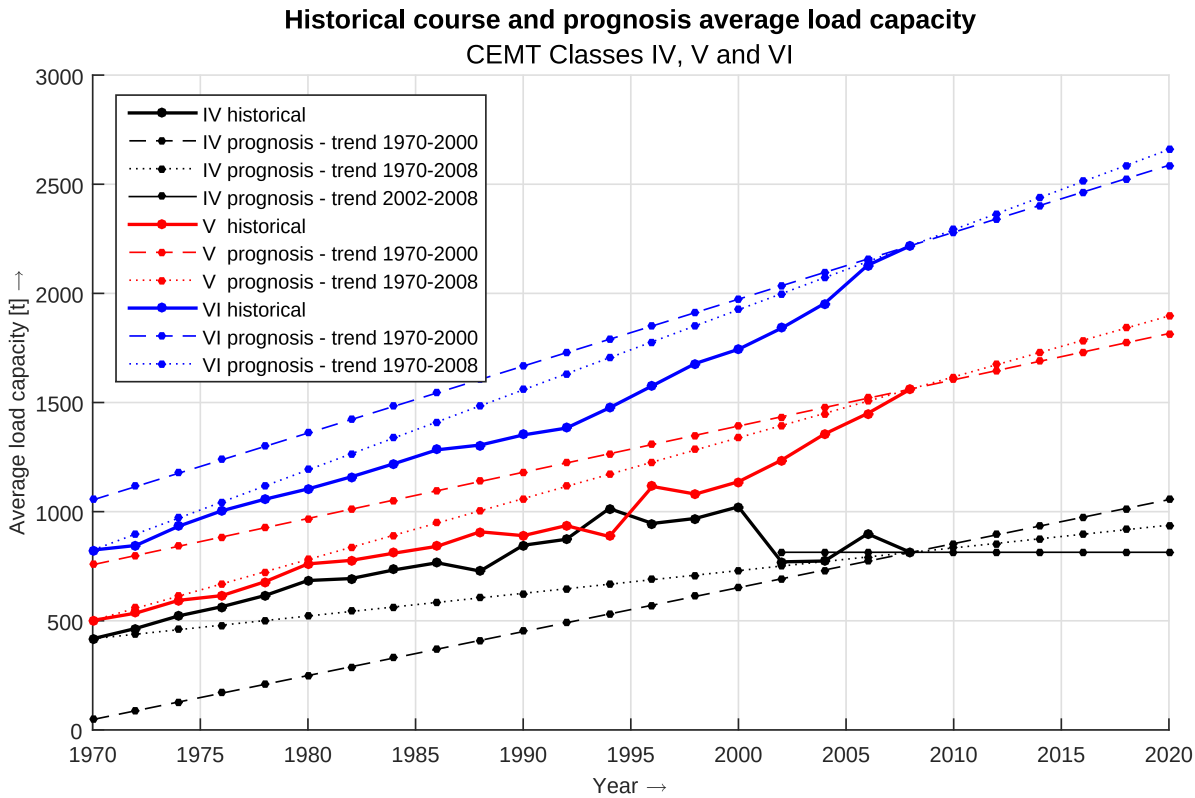


Figure 2.4: Historical course and prognosis average load capacity on CEMT classes IV, V and VI, 1970-2020.

From Figure 2.4 the following can be seen:

- Up to 2000 upscaling takes place on all three CEMT classes by on average between 2.5% to 3.0% per year.
- After 2000 the upscaling on CEMT class IV stagnates and between 2000 and 2002 there is even down-scaling. This downscaling has to do with the upgrading of the Prinses Margrietkanaal from class IV to V. This upgrade started in 1995 and was finished at the end of 2001. So, before 2002 the counting points Prinses Margrietsluis and Oostersluis were class IV and from 2002 they were class V. Before the Prinses Margrietkanaal was officially a class V the canal was already used by larger vessels, causing a growth in the average load capacity for CEMT class IV.
- From 2000 the upscaling on CEMT classes V and VI was even larger than in the period 1970-2000, on average an annual growth of 3.9% took place for CEMT class V and for class VI on average an annual growth of 3.4% took place.

The findings are in line with the observation that smaller vessels are usually replaced by larger vessels. These larger vessels can only sail on the higher CEMT classes, whereby stabilization of the average load capacity of the vessels using the lower CEMT classes is expected.

2.5.3. PROGNOSIS FLEET DEVELOPMENT

For the expected fleet development in the period 2008-2020 a global analysis is done. This analysis includes the following:

- Trend analysis average load capacity 1970-2008 and extending this trend to the period 2008-2020.
- Major developments affecting upscaling.
- Expectations and conclusions from other sources.
- Conclusions on the expected fleet development in the future.

TRENDANALYSIS AVERAGE LOAD CAPACITY PER WATERWAY CLASS 1970-2020

Based on the data between 1970 and 2008 the trend of the growth of the average load capacity can be established and extended to 2020. This is done for the average load capacity per CEMT class. Two variants are specified in Turpijn et al. (2010).

For the first variant a linear trend line for the whole period 1970-2008 is specified, where the year on year developments in this period are taken into account. Thereafter this trend is extended from 2008 to 2020. The second variant is based on the period 1970-2000. For this period the average yearly growth rate is defined, which is then applied from 2008 to 2020. These different methods have been chosen because the period 2000-2008 is considered being a boom with many new vessels.

Since on CEMT class IV in the period 2000-2008 stagnation instead of larger growth takes place there is for this study and for class IV only a third variant created. This variant predicts for the future no growth, but a stabilization of the average load capacity on CEMT class IV that is equal to the average of the average load capacity on CEMT class IV in the years 2002 up to and including 2008.

Both variants are, per waterway class, shown in Figure 2.4. Table 2.3 includes for the two variants per CEMT class the average predicted growth per year. The variant based on the period 1970-2008 gives a smaller growth for class IV and larger growths for classes V and VI than the variant based on the period 1970-2000. This is as expected since for class IV stagnation on the upscaling has taken place since 2000.

Table 2.3: Predicted average growth in tonnes per year of the average load capacity on CEMT classes IV, V and VI, for the three variants used to predict the fleet development from 2008 on.

	Average predicted growth *[tonne/year]*		
	Variant 1970-2000	**Variant 1970-2008**	**Variant 2002-2008**
IV	20	10	0
V	21	28	-
VI	31	37	-

MAJOR DEVELOPMENTS AFFECTING UPSCALING

According to TNO the drivers for upscaling in the **past** years were:

- ***Positive expectations cargo flows*** — Expectations of strong growth in maritime cargo flows and linked to this a strong growth in inland cargo flows that can be by inland vessels.
- ***Demolition and old for new regulations 90s and early 2000s*** — Through an advantageous demolition regulation for inland vessels many old vessels are replaced by new ones.
- ***Replacement of single hull tankers by double hull tankers*** — For the environmental safety there has been an impulse to replace single-hull tankers to double hull tankers (past and future years).
- ***Exploitation of new small vessels can be difficult*** — New small vessels are relatively expensive and can hardly be used 24/7 on the Dutch market, making the operation of a new small vessel difficult.

The question is whether and to what extent these developments will continue in the coming years.

The following developments will, according to TNO, probably affect upscaling in the **future**:

- ***Economic crisis*** — As a result of the economic crisis the cargo flows are significantly reduced. Because of this reduction there is overcapacity. Before the crisis many ships have been ordered and those ships are now built, therefore the crisis will have a restricted effect on the degree of upscaling. On the long term it is the question whether the upscaling will go on.
- ***Goal modal split and capacity inland shipping*** — For the second Maasvlakte agreements are made on a mandatory modal split. On the long term is, because of these agreements, a higher demand for inland shipping expected.
- ***Need for small vessels*** — Through the upscaling over the past years smaller vessels are replaced by larger vessels, but for the smaller waterways in the Netherlands small vessels will still be needed. The question is whether the exploitation of these ships remains feasible in the future.

EXPECTATIONS AND CONCLUSIONS FROM OTHER SOURCES

In Turpijn et al. (2010) the following other sources are covered:

- Assumptions of RWS-DVS
- Study TNO
- Study NEA

Assumptions of RWS-DVS

RWS-DVS uses for their studies assumptions on the expected upscaling defined in the report "Deelrapportage Vaarwegen voor de Nationale Markt en Capaciteits Analyse (NMCA)" (RWS-DVS, 2011). These asumptions are given in Table 2.4.

Table 2.4: Expected growth load capacity in tons/year. From; RWS-DVS (2011)

	Increase in the load capacity of the inland fleet *[tonne/year]*		
CEMT class	**Present-2020**	**2021-2040**	**After 2040**
II	0	0	0
III	10	5	0
IV	15	8	0
Va	20	10	0
Vb	25	13	0
VIb	30	15	0
VIc	40	20	0

Study TNO

For the study "Directe transporteffecten Kanaal Gent-Terneuzen" (van Meijeren et al., 2009) a number of sources on the degree of upscaling in the past and for the future were consulted by TNO to estimate the degree of upscaling.

Based on those sources they defined the following expectations on the development of the average load capacity in the future:

- 2% per year till 2010
- 1% per year between 2010 and 2020
- 0.5% per year from 2020 onwards

Study NEA

In the report "MIT-verkenning sluis Grave" (NEA, 2005) the expectations for the fleet development in the future are also covered.

In this report it is concluded that when the trend from the past is extended to 2020 the following growth of the average load capacity will take place:

- Dry bulk: 1.5-2% per year
- Liquid bulk: 0.5-1% per year

Comparing the expectations from these studies to the expectations in the report "Herziening Vlootontwikkeling Binnenvaart" (Turpijn et al., 2010), the assumptions RWS-DVS has made are comparable, whereas the predicted growth in the other two studies is smaller. A possible explanation for this could be that in the TNO study only a limited amount of counting points of waterway classes IV, V and VI are included, while in the other studies the whole Dutch inland waterway network is considered. The potential for upscaling on the smaller waterways is limited compared to the potential for upscaling on the larger waterways. By also taking into account the smaller water ways the growth of the average load capacity will be smaller.

CONCLUSIONS ON THE EXPECTED FLEET DEVELOPMENT FOR THE FUTURE

Based on the global trend analysis, several other studies and developments that will affect the upscaling it is difficult to make firm predictions on the expected fleet development for the future.

Not taking into account the developments that will affect the upscaling in the future an average growth of the load capacity of around 2% per year is expected on waterway classes V and VI. On the lower classes that no further upscaling will take place, since the new larger vessels can only sail on the higher CEMT classes.

The combined effect of the developments that will affect the upscaling is uncertain. It is expected that due to the economic crisis and limitations on the water depth smoothing of the upscaling will take place.

2.6. WATER CONDITIONS ON THE DUTCH INLAND WATERWAYS

The water level on the Dutch waterways depends on rainfall and evaporation in the Netherlands and the supply of water from the river Rhine and the river Meuse. The supply of water from the river Rhine is most important for the water level on the Dutch waterways. From the discharge at Lobith (river Rhine at the border with Germany) it can be seen whether there are high, average, or low water levels on the Dutch waterways.

In Subsection 2.6.1 the average discharge over a year at Lobith historically and the expected average discharge over a year in the future is described, in order to show the expected effects of climate change on the water conditions at the Dutch inland navigation network, and Subsection 2.6.2 describes, in order to create a clear image of the water conditions in the years for which traffic scenarios are included with BIVAS, the discharge at Lobith in 2011 and 2013. In this subsection also the median discharges at Lobith of the years 2002 up to and including 2013 are analysed in order to find the discharge belonging to the median period used within this research.

For this study are, in order to find out what the differences are in load factor, draught and allocation of the trips during different water conditions, various discharge periods used. Subsection 2.6.3 adresses those periods.

2.6.1. DISCHARGE AT LOBITH HISTORICALLY AND IN THE FUTURE

The yearly average discharge at Lobith, with data taken into account from the year 1901 onwards, is 2200 m^3/s (Dillingh, 2013). In the summer the discharge is on average samller than in the winter, see the Ref. 1961-1995 line in Figure 2.5.

Based on reference data of the discharge at Lobith between 1961 and 1995 and the KNMI'06 climate change scenarios (van den Hurk et al., 2006) prognoses on the discharge at Lobith in 2050 and 2100 are made by te Linde (2011) and Turpijn & Weekhout (2011). Figure 2.5 shows those prognoses.

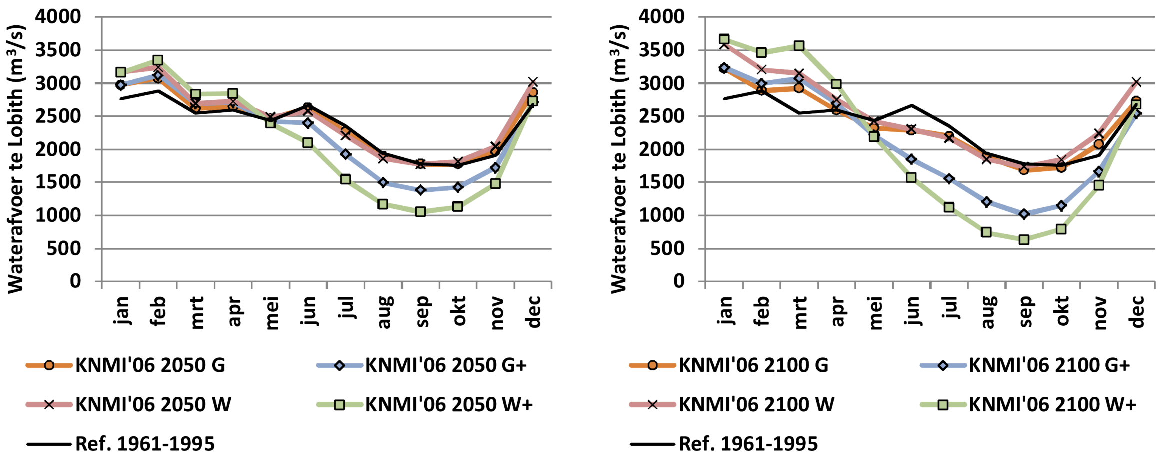


Figure 2.5: Prognosis discharge at Lobith KNMI'06 climate change scenarios 2050 (te Linde, 2011) and 2100 (Turpijn & Weekhout, 2011). Reprinted from Dorsser (2012).

From Figure 2.5 it can be seen that the high discharge during winter is expected to grow for all scenarios, and that the low discharge during the summer is expected to shrink for the G+ and W+ scenarios.

The growth of the higher discharge during winter will affect inland shipping by reduced available headroom at bridges and the decommissioning of shipping for safety reasons (for example because of risk of flooding of quays). The shrinkage of the low discharge during summer will cause that more often it will not be possible to sail fully loaded or not at all.

2.6.2. CHARACTERISTICS DISCHARGE AT LOBITH IN THE RECENT PAST

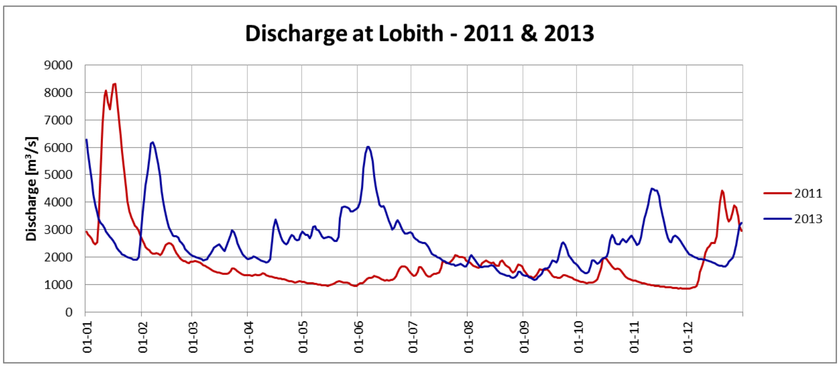


Figure 2.6: Discharge at Lobith in 2011 and 2013 [m^3/s]

The traffic scenario's available in BIVAS 3.2.2 are of 2011 and 2013. Therefore it is decided to look into the characteristics of those years.

Figure 2.6 shows the daily discharge at Lobith of the years 2011 and 2013. For 2011 it can be seen that there is a high peak in the discharge in January and a small peak in the discharge in December. The remaining part of the year the discharge is between 800 and 2000 m^3/s. 2013 has less extreme discharge changes, and on average a higher discharge, than 2011.

Figure 2.7 shows for the years 2002 up to and including 2013 the yearly median discharge, the 10-year moving average of the yearly median discharge and the average of the 10-year moving averages of the yearly median discharge. The data for this figure is retrieved from Waterbase (Helpdesk Water, 2015).

The Figure shows that the yearly median discharge in 2011 is low compared to the other years, indicating that 2011 was a dry year. In 2013 the yearly median discharge is high compared to the other years, indicating that it was a wet year.

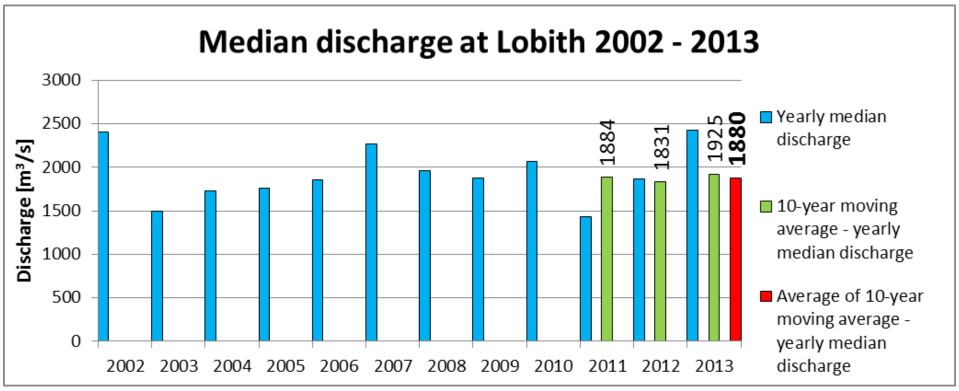


Figure 2.7: Yearly median discharge at Lobith 2002-2013

2.6.3. DISCHARGE PERIODS USED IN THIS STUDY

For this study are, in order to find out what the differences are in load factor, draught and allocation of the trips during different water conditions, various discharge periods used.

The following discharge periods of 2011 are used:

- Period of two weeks with on average the lowest discharge of the year at Lobith (in the remaining part of the report referred to as "Low").
- Period of two weeks with on average the highest discharge of the year at Lobith (in the remaining part of the report referred to as "High").
- Period of two weeks with on average the 10-year moving median discharge at Lobith averaged over 2011, 2012 and 2013 (in the remaining part of the report referred to as "Median").
- The Whole year

The number of shipping movements per day varies over the week, on saturday and sunday less trips take place than on the other days of the week. By using a time frame of two weeks for the Low, High and Median periods this is equivalently included in all the computations. The time frame of two weeks is chosen instead of a time frame of one week or three or more weeks for several reasons. When one week is used the amount of results is too little and the sensitivity for a particular day is too high. When three or more weeks are used the range of the discharge is too wide.

Low

A low discharge at Lobith decreases the water depths and flow velocities on the Dutch waterways, which will probably effect the maximum draught and choice of route of the skippers. In order to analyse the effect of smaller water depths and lower flow velocities as good as possible the period with on average the lowest discharge of the year is chosen.

High

A high discharge at Lobith increases the water depths and flow velocities on the Dutch waterways, which will probably effect the maximum height and choice of route of the skippers. The two-week period with on average the highest discharge of the year is chosen, because the effect of larger water depths and higher flow velocities is expected to be the largest during this period, and thereby clearly visible.

Median

The effects of smaller/larger water depths and lower/higher flow velocities can only be seen when a comparison is made with an average situation. For the average situation the two-week period with on average a discharge equal to the 10-year moving median discharge at Lobith is chosen. A median discharge is chosen instead of an average discharge because the discharge during the high discharge periods usually has a bigger difference with the average discharge than the discharge during the low discharge periods, and the high discharge periods have a shorter duration than the low discharge periods. Therefore the median discharge period reflects the average situation better than the mean discharge period.

The median discharge varies widely over the years. Therefore it is chosen to use the 10-year moving median. The 10-year moving median still varies reasonably and therefore to get the same median in the years 2011 and 2013, the average of the 10-year moving median for 2011, 2012 and 2013 is taken.

Whole year

In order to analyse the effects of the low discharge periods and high discharge periods on the total the whole year is analysed as well.

Table 2.5 contains the time spans and average discharges of the selected periods of 2011 and Figure 2.8 visualizes these periods.

Table 2.5: Discharge periods computations 2011 - Time frames and average discharges

2011	Time span [dd-mm – dd-mm]	Average discharge [m^3/s]
Whole year	01-01 – 31-12	1821
Median	20-02 – 05-03	1884
Low	21-11 – 04-12	864
High	09-01 – 22-01	7126

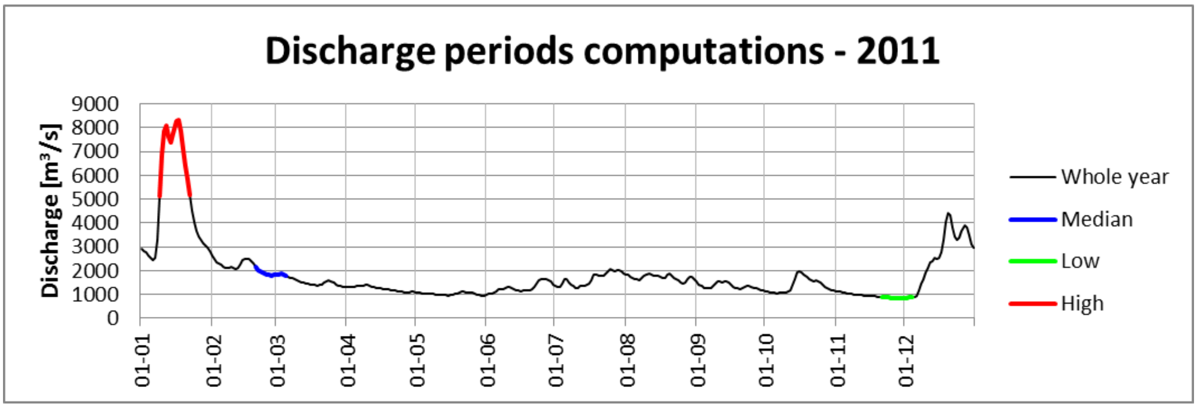


Figure 2.8: Discharge at Lobith 2011 - periods computations

2.7. CHARACTERISTICS ROTTERDAM-LOBITH CORRIDOR

This section describes the characteristics of the Rotterdam-Lobith corridor in reality. In Figure 2.9 the names and CEMT classes of the main waterways belonging to the Rotterdam-Lobith corridor are given. Alongside this, the IVS countingpoints within the Rotterdam-Lobith corridor for which reference data is available in BIVAS, are highlighted.

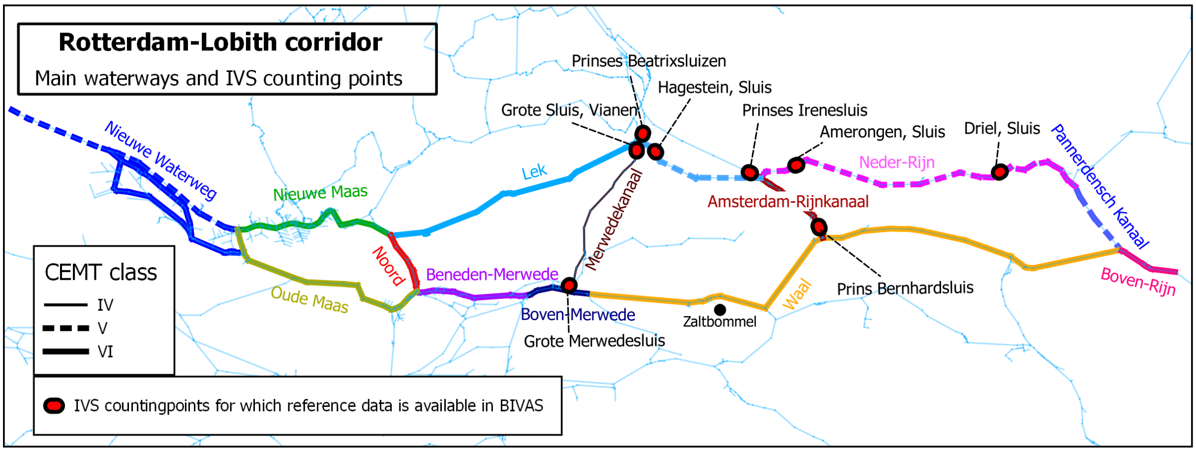


Figure 2.9: Rotterdam-Lobith corridor: Main waterways and IVS counting points

The Rotterdam-Lobith corridor is influenced by the tide and the discharges of the rivers Rhine and Meuse. The tidal influence reaches to Zaltbommel on the lower part of the corridor and on the upper part of the corridor to the lock and weir complex Hagestein (Voorsluijs, 2013; van Loon et al.,2011).

The Neder-Rijn is a canalised river with two lock and weir complexes; Driel and Amerongen. The Lek is a partly canalised river with one lock and weir complex; Hagestein. In the part of the Merwedekanaal belonging to the Rotterdam-Lobith corridor there is no influence of the tide and river discharges, because the canal is closed off from the Lek and Boven-Merwede with locks. The part of the Amsterdam-Rijnkanaal belonging to the Rotterdam-Lobith corridor has a lock at the connection with the Waal and a lock at the connection with the Neder-Rijn and Lek, but only the lock at the connection with the Waal; the Prins Bernhardsluis, is almost always in use.

The lock at the connection with the Neder-Rijn and Lek; the Prinses Marijkesluis, is only put into use during extreme high water (5.5 m +NAP (Blom & Mahmoud, 2004)). In the period 2003-2015 the Prinses Marijkesluis has only thrice been in use for a couple of days. This was in the years 2003, 2011 and 2012. The Prins Bernhardsluis is normally in use, but during low water, when the water level at the Waal side of the lock drops below 3 m +NAP, the lock is opened. The Prins Bernhardsluis is on average 60 to 80 days per year open (HydroLogic BV, 2013). Only a slight flow caused by suction from the Lek is possible in the Amsterdam-Rijnkanaal, because the canal is normally closed on one of the sides.

2.8. CONCLUSIONS

Inland navigation has a long history in the Netherlands. Nowadays it is, after road transport, the second most important transport mode for freight transport in the Netherlands. The gap between these two transport modes is decreasing, making inland navigation and thereby software like BIVAS more and more important for the Dutch economy.

In the Netherlands there is a database with data on shipping in the Netherlands, the IVS90. This database is used to create the traffic scenarios and reference trip sets of existing years that are included with BIVAS. Due to privacy considerations only the data within the IVS90 that can not be linked to a specific vessel can be used within BIVAS, therefore it is not possible in BIVAS to link the trips of a particular vessel to each other. This means that when in BIVAS a trip is divided in more trips because of reducing of the load, this can not be extrapolated to the possible return trip, since it is not known which trip is the next trip of the vessel.

In the recent past a large upscaling of the inland fleet has taken place, whereby the average draught of the vessels has increased. On the lower waterway classes the upscaling has stagnated, but on the higher waterway classes it is expected that upscaling will continue in the upcoming years. Upscaling leads to, on average, smaller under keel clearances, which causes a larger interaction between the maximum load of vessels and the water depth. Therefore it is important to include the relation between draught, speed and fuel usage of the vessels, and the water depths on the waterways correctly in BIVAS.

In the future it is possible that, due to climate change, the average discharge at Lobith over a year will shrink in the summer and grow in the winter. The larger discharge in winter will affect inland navigation by reduced available headroom at bridges and decommissioning of shipping for safety reasons. The smaller discharge in summer will cause that due to smaller water depths skippers will have to lower the load of their vessel or will not be able to sail at all. This causes, just like upscaling of the fleet, that the relation between inland navigation and the water conditions, and getting this relation included correctly in BIVAS, is becoming more important.

The research area for this study is a complex area with several route options between points. The tide and hydraulic structures will affect the travel times through the area, depending on the water conditions, in various ways. This makes the area a good area to use for investigation of the relation between inland navigation and water conditions.

3
DESCRIPTION OF BIVAS AND RELATED SOFTWARE

In this chapter is, to obtain a good overview of how trips are allocated by BIVAS, in Section 3.1 the functioning and computational method of BVIAS described. In the other sections of this chapter the software related to BIVAS that is of interest for this study is described. Section 3.2 is about the LSM Light 1.2 model, Section 3.3 about the Nieuwe koppeling LSM-BIVAS and Section 3.4 about the conversion IVS90-BIVAS. In Section 3.5 the conclusions of this chapter are given.

Figure 3.1 shows an overview of the input and output of the software described in this chapter and how the software is connected to each other.

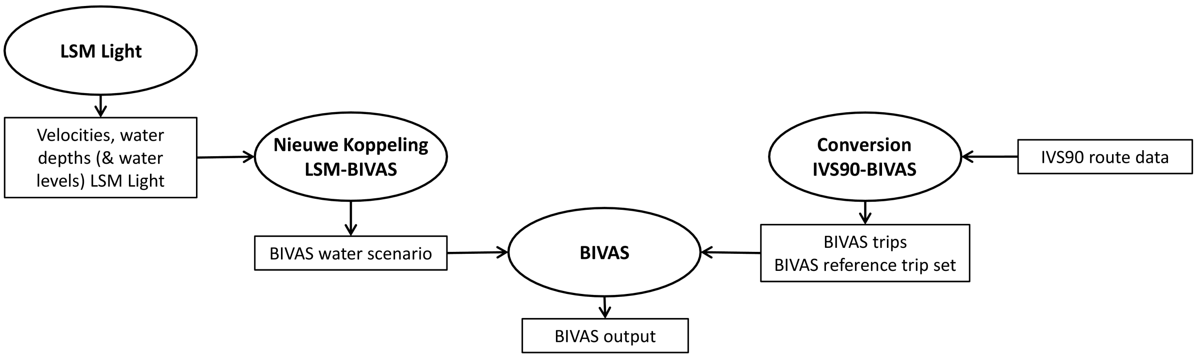


Figure 3.1: Overview of software of interest for the study.

3.1. BIVAS

Over the years four major versions of BIVAS were released, which are all updated several times. The last update of the fourth version, BIVAS 4.1.1, is released recently (April 2016). For this study, an earlier version of BIVAS has been used; BIVAS 3.2.2, which was released in November 2014.

BIVAS is written in Delphi, a software development kit using the programming language Object Pascal, an object-oriented programming language. BIVAS can be downloaded from the website of BIVAS; `bivas.chartasoftware.com/`. To be able to use BIVAS an SQL (database) server is needed. Since BIVAS 3.2 the prefered server is MariaDB (MariaDB Foundation, 2017).

In Subsection 3.1.1 the input and settings of a BIVAS scenario are described. Subsection 3.1.2 describes how BIVAS allocates trips over the network and in Subsection 3.1.3 the output of a BIVAS scenario is described.

The source for this section is the documentation on the website of BIVAS; `bivas.chartasoftware.com/` (Charta Software, 2016).

3.1.1. SCENARIO INPUT AND SETTINGS

A BIVAS scenario consists of the following elements:

- Name — The name of the scenario.
- Description — A description of the scenario.
- Universal Unique Identifier — Unique identification of the scenario.
- Original scenario name — Name of the scenario used as base for the scenario.
- Network — Tables with network properties like nodes, waterways, bridges, weirs, locks etc.
- Characteristics — Tables wit trip properties like ship types, ship speeds, origins and destinations etc.
- Parameters — Settings for the scenario like start and end date, which traffic scenario should be used, the optimization objective (travel time or costs) etc.
- Dimensions for routing — Table where, per height, draught, length, width and load type of a vessel, is indicated whether for the allocation of the trips the values of the traffic scenario or the general values of the vessel types stored in the database should be used.
- Dimensions for emissions — Table where, per height, draught, length, width and load type of a vessel, is indicated whether for the computations of the emissions the values of the traffic scenario or the general values of the vessel types stored in the database should be used.

In Section E.1 in Appendix E tables with all fields and their descriptions of the scenario elements can be found.

3.1.2. SCENARIO COMPUTATION

During the computation of a scenario the trips of the scenario are allocated over the network of the scenario. Figure 3.2 shows the flowchart for a scenario computation. The various components of the flowchart are described in this subsection.

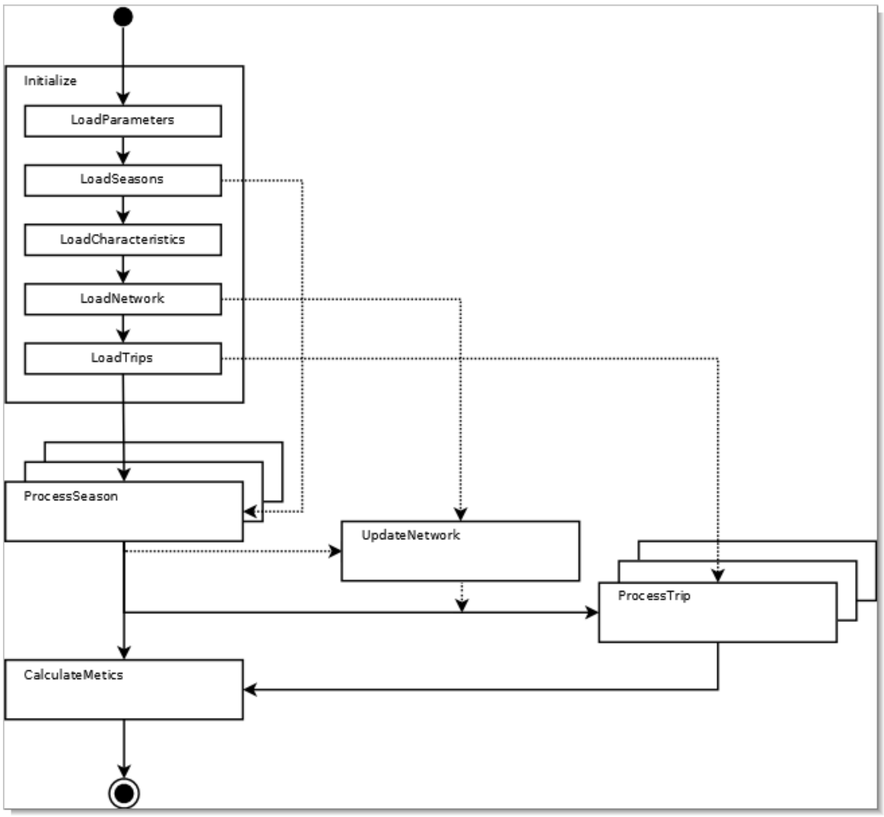


Figure 3.2: Flowchart scenario calculation. Adjusted screen shot from Charta Software (2016).

INITIALIZE

During the initialization at first the parameters of the scenario and the corresponding season definition are loaded. Thereafter the characteristics and the network are loaded. At last the trips of the traffic scenario of the scenario are loaded. While loading the trips a number of steps are completed.

Load trips
Given the selected date range of the scenario, the trips of the traffic scenario within the date range are loaded. Thereafter the trips are adjusted to the applied growth rates and/or fleet mutation. Finally the draught of the vessel of every trip is verified and optionally redetermined.

Redetermination of the draught happens when:
- The draught is smaller than the minimum draught given in the scenario parameters.
- The draught is larger than the maximum draught given in the scenario parameters.
- The vessel type has been modified during the fleet mutation.
- The load has been modified during the fleet mutation.

The new draught is determined by taking the average draught of the RWS class of the vessel and adjusting this draught when the trip is lighter or heavier loaded than average. The calculation of the draught with another loading happens with the factor tonne per centimetre immersion, which is given per vessel type.

PROCESS SEASON AND UPDATE NETWORK
After the initialization the seasons are processed. For every season the arcs for which new water properties are available in the water scenario of the scenario are updated with the values of the water scenario.

PROCESS TRIP
When the network is updated the allocation of the trips over the network can start. Figure 3.3 shows the flowchart for the allocation of the trips.

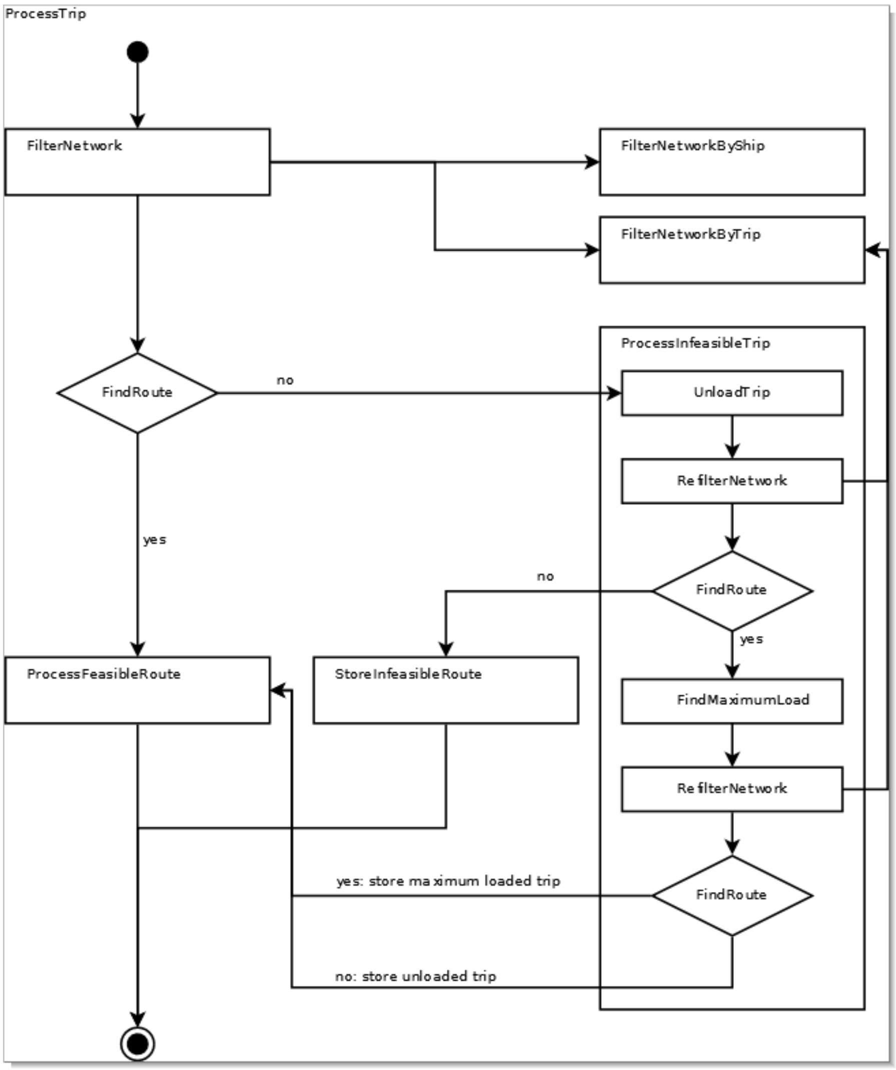


Figure 3.3: Flowchart allocation of the trips. Screenshot from Charta Software (2016).

Filtering network
During the filtering of the network are, per trip, the arcs that can be used selected. After the filtering only the arcs remain that, given the restrictions in Table 3.1, can be part of the route of the trip.

Table 3.1: Restrictions for which the network is filtered per trip

Restriction	Description
Width	The width of the vessel must be less than or equal to the width restriction of the arc.
Length	The length of the vessel must be less than or equal to the length restriction of the arc
Height	The height of the vessel must be less than or equal to the height restrictiom of the arc.
Draught	The draught of the vessel must be less than or equal to the given draught restriction of the arc.
Weirs	A Weir is opened when the water level is equal to or higher than the minimum water level for the weir to be open. A weir should be open in order to be available for a trip.
Dangerous goods level	The dangerous goods level of the trip should be lower than the maximum dangerous good level of the arc.

Determining costs

Arcs available for a trip after filtering get, depending on the selected optimization objective, the transport costs or travel time assigned as costs.

Travel time — In the parameters the optimization objective is given; transport costs or travel time. Since the transport costs also depend on the travel time, the process always starts with the determination of the travel time.

The travel time on an arc depends on:

- The speed of the vessel over the ground given the RWS class, dimensions and load type of the vessel (empty or loaded), and the CEMT class, water depth and flow velocity of the arc.
- The maximum velocity restriction of the waterway for an empty or loaded vessel.
- The length of the arc.
- The defined delay for the arc.
- A possible penalty for exceeding the length and/or width restrictions of the arc.

Equation 3.1 is the equation used in BIVAS to determine, per trip, the travel time via a certain arc. In the equation the minimum of two speeds is used; the maximum vessel speed allowed on the arc, which is stored in the BIVAS database, or the speed of the vessel over the ground, which is computed with Equation 3.2.

For the speed of the vessel is in Equation 3.2 the minimum of three speeds used; the desired speed of the vessel for the arc stored in the BIVAS database, 90% of the theoretical maximum speed (computed by BIVAS with Equation 3.3), or the speed in shallow water (computed by BIVAS with Equations 3.4 and 3.5).

When in the scenario exceeding of the length and/or width restrictions of the arcs is allowed it is possible to set time penalties for the exceeding. These time penalties are only used during the computation of the allocation of the trips. It is also possible to specify time delays for specific arcs. These time delays can be used during the computation of the allocation of the trips only, or can be taken into account in the final results as well. The possibility to specify time delays for an arc is included in BIVAS in order to, for example, take into account delay due to a crowded waterway or due to difficult navigability.

$$T = (\min(V_{gr}, V_r) + t_{pL} * LV + t_{pW} * WV) * L + t_d \tag{3.1}$$

Where:

T	= Travel time via the arc.	[s]
V_{gr}	= Speed over the ground (speed of the vessel relative to the ground).	[m/s]
V_r	= Maximum speed allowed on arc, depending on whether the ship is loaded or empty.	[m/s]
t_{pL}	= Penalty for exceeding the length restriction of the arc.	[s/m]
LV	= Violation of the length restriction of the arc.	[m]
t_{pW}	= Penalty for exceeding the width restriction of the arc.	[s/dm]
WV	= Violation of the width restriction of the arc.	[dm]
L	= Length of arc.	[m]
t_d	= Defined delay for the arc	[s]

$$V_{gr} = \min(V_{s,D}, V_{s,90\%TMS}, V_{s,SW}) + CD * V_c \tag{3.2}$$

Where:

$V_{s,D}$	= Desired speed of the vessel stored in BIVAS Database.*	[m/s]
$V_{s,90\%TMS}$	= 90% of the theoretical maximum speed of the vessel.*	[m/s]
$V_{s,SW}$	= Speed in shallow water.*	[m/s]
CD	= Current direction.	[-]
V_c	= Flow velocity.	[m/s]

* Depending on vessel type, waterway class and whether the vessel is loaded or empty.

$$V_{s,90\%TMS} = 0.9(8gh)^{1/2}\cos\left(\frac{\pi + \arccos\left(1 - \min\left(0.5, \frac{A_{s,ST,D}}{A_{c,CEMT}}\right)\right)}{3}\right)^{1\,1/2} \tag{3.3}$$

(Balanin & Bykov, 1965)

$$V_{s,SW} = 1.18 V_{s,D} C_{SW}^{-0.75 - \frac{A_{s,ST,D}}{A_{c,CEMT}}} \tag{3.4}$$

$$C_{SW} = \frac{1}{1 - e^{4(1-\frac{h}{D})}} \tag{3.5}$$

Where:

g	= Acceleration of gravity.	$[m/s^2]$
h	= Water depth.	[m]
$A_{s,ST,D}$	= $B_{s,ST} \times D$ = Vessel's underwater amidships cross section.	$[m^2]$
$B_{s,ST}$	= Average ship's beam at midships section of the vessel type (stored in database).	[m]
D	= Draught of the vessel.	[m]
$A_{c,CEMT}$	= Wet cross sectional area of the waterway, per CEMT class (stored in database).	$[m^2]$
C_{SW}	= Shallow water factor.	[-]

For arcs that are bridges or locks the travel time is defined differently. At a bridge the travel time is determined by the passage time (normal travel time), when the vessel does not experience problems from the height restriction (in closed position). If the ship experiences problems from the height restriction the service time of the bridge is taken into account. The travel time for a lock is given by the sum of the expected overlay, waiting and lockage time.

Costs — When the optimization objective is travel time, the costs for an arc are equal to the travel time, but when the optimization objective is transport costs further computation is needed.

The composition of the transport costs is as follows:

- Transport costs per arc, existing of:
  - Fuel usage per hour, per vessel type and CEMT class.
  - Repair and maintenance costs per kilometre, by vessel and appearance type.
  - Labor costs per hour, by vessel and appearance type.
  - Material costs per hour, by vessel and appearance type.
- Costs of loading and unloading, subdivided by vessel and appearance type.
- Costs of waiting for loading.
- Costs of waiting for bridges and locks.

Find route

It is assumed that in reality the skippers choose the route with the lowest costs or, when there are time constraints, the fastest route. Therefore after determining the travel time and costs per arc the shortest path method is used to find the fastest or cheapest route according to the travel time or costs. This method is an implementation of Dijkstra's shortest path algorithm (Dijkstra, 1959).

Process infeasable trip

When no route can be found for a trip at first the maximum unloading defined in the parameters takes place. This is done to see whether at all there is a possible route when the draught is at its minimum. After the maximum unloading has been applied the network is re-filtered.

When with maximum unloading a route can be found the maximum load is determined with which the ship can use all the arcs on this route. The network is, based on this load, filtered another time, to determine whether the found route is still the route with the lowest costs. Thereafter the calculated maximum load of the trip is saved. Also the number of trips is adjusted, so there will be more trips with less load. The trips for which, after maximum unloading, still no route can be found, are stored as infeasible trips.

Calculate metrics

The last step in the scenario computation is to determine the statistics (Metrics) about the routes found. There are standard metrics that are always computed and optional metrics for which it should be specified whether they should be computed. The computed metrics are the output of a scenario computation.

3.1.3. SCENARIO OUTPUT

Standardly only some key figures are output of a scenario computation. Next to these key figures other output can be generated as well.

KEY FIGURES

- Number of trips — Number of trips for which a route has been searched.
- Number of routes — Number of trips for which a route has been found.
- Total travel time — Total travel time for all the trips for which a route has been found.
- Total costs — Total travel costs for all the trips for which a route has been found.
- Total distance — Distance travelled by all vessels combined.
- Total waiting time — Total of waiting and overlay time of all trips at locks.
- Total weight — Total transported weight.
- Number of ton kilometer — Total tonne kilometre.
- Emmissions — Total emissions in kton, subdivided in various types of emissions.
- Average load factor — Average load factor of the loaded trips for which a route has been found.
- Average load capacity — Average load capacity of the trips for which a route has been found.
- Total TEU — Number of TEU transported.

For the key figures it holds that everything is calculated including the extra trips due lowering the load. For example the number of trips for which a route has been searched is not the number of trips loaded from the traffic scenario, but this number plus the extra trips defined during the computation because of lowering of the load in order to find a route.

OPTIONAL OUTPUT

- Trips — Characteristics of the trips for which a route has been searched, including the optionally during the computation applied fleet mutation, growth factors, calibration and lowering of the load.
- Routes — Characteristics of the routes of the trips for which a route has been found. The arcs used for a trip, and per used arc the travel time, energy use and costs.
- Route Statistics — Statistics per route. Number of arcs in route, total travel time, costs, distance travelled and energy use.
- Infeasible trips — List with the ID's of the trips for which no route could be found.
- Arc usage statistics — Statistics per direction of an arc like number of trips allocated via the arc, average costs for using the arc, width of the widest vessel and draught of the vessel with the largest draught allocated via the arc .
- Arc usage statistics details — Arc usage statistics subdivided per vessel type, load type (loaded or empty) and NSTR (type of goods) type .
- Origin trip end point statistics — Per origin, vessel type, load type and NSTR type the number of trips with this origin node and the average travel time of a trip with this origin node (infeasible trips not included).
- Destination trip end point statistics — Per destination, vessel type, load type and NSTR type the number of trips with this destination node and the average travel time of a trip with this destination node. (infeasible trips not included)
- Counting point statistics — Per counting point, vessel type and load type, the number of trips and the number of TEU allocated along the counting point.
- Waiting time statistics — Statistics per lock on the average waiting and overlay time.
- Emission statistics — Statistics on the emissions per direction of an arc, vessel type, load capacity class and load type (empty or loaded).
- Reference comparison — Statistics per counting point on the comparison between the BIVAS scenario and the reference trip set, subdivided per vessel and load type.

The optional output can be visualized and used to create aggregated results. In Section E.2 in Appendix E tables with all fields of the raw optional output and the possible aggregated results can be found.

3.2. LSM LIGHT

To generate water scenarios, for an existing year or possible future scenarios, the LSM Light can be used. The LSM Light is a SOBEK model of the Netherlands. SOBEK is an integrated software package for flood forecasting, control of irrigation systems, optimization of drainage systems, design of sewer overflow, salt intrusion, river morphology and surface water quality. The complex flows and water related processes in almost any water system can be modelled with the SOBEK modules. The various modules represent phenomena and physical processes in an accurate way, in 1D network systems and 2D horizontal grids (Deltares, 2015).

The LSM is the nationwide SOBEK model of the Netherlands. It takes the whole Dutch water system into account. The LSM Light can compute water levels, water depths and flow velocities on the Dutch waterways. In the LSM Light the water levels and depths are coupled to nodes, and the flow velocities are coupled to waterway segments. The water depths and flow velocities at 00:00 of every day can, via the Nieuwe koppeling LSM-BIVAS (Subsection 3.3), be converted to a water scenario.

The version of SOBEK used for this study is 2.13002B and the version of the LSM Light used is 1.2.

3.3. NIEUWE KOPPELING LSM-BIVAS

The Matlab model Nieuwe koppeling LSM-BIVAS (New coupling LSM-BIVAS) is used for the conversion of the output of the LSM Light to a water scenario for BIVAS. Matlab is a programme that can be used for numerical computation, visualization and programming. With MATLAB data can be analysed, algorithms can be developed and models and applications can be created (The MathWorks, Inc., 2016).

The Nieuwe koppeling LSM-BIVAS creates only for part of the Dutch waterway network a water scenario. Figure 3.4 shows for which BIVAS arcs a water scenario is created.

In the Nieuwe koppeling LSM-BIVAS are, based on the nearest neighbour principle, LSM Light nodes and waterway segments coupled to BIVAS arcs. When the nearest neighbour principle is used, not all couplings are correct, since sometimes a node or waterway segment of a nearby waterway can be closer to the BIVAS arc, than the waterway that represents this arc. Therefore for part of the arcs the corresponding nodes and/or waterway segments are selected manually.

The flow velocities at the coupled waterway segments of the LSM Light are, without adjustment, used in the water scenario. For the water depths a possible correction takes place. The water depth defined in the LSM Light is the largest water depth across the width of the channel. In BIVAS the used water depth should be the minimal water depth available across the width of the fairway of the channel. This minimal water depth is obtained by subtracting a correction depth from the largest water depth across the width of the channel. The correction depths used in the Nieuwe Koppeling LSM-BIVAS are computed with the same method as the method used in van der Mark (2011).

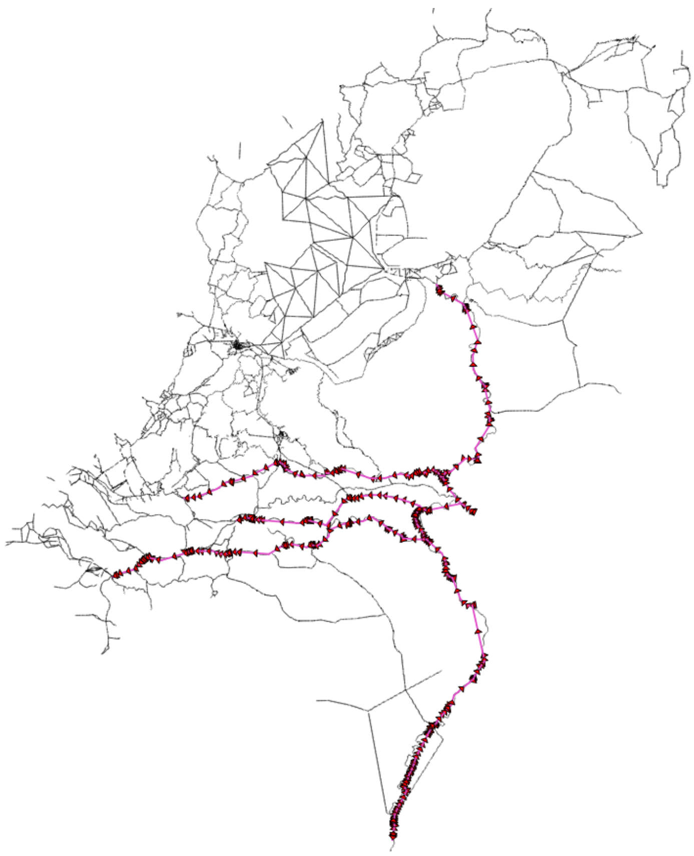


Figure 3.4: BIVAS arcs for which a water scenario is created by the Nieuwe Koppeling LSM-BIVAS.

A full description of the Nieuwe koppeling LSM-BIVAS can be found in de Jong (2014).

3.4. CONVERSION IVS90-BIVAS

The source of the trips and the reference trip sets included in the BIVAS database is the IVS90. The reference trip set is created by extracting per trip the counting points passed and the date and time at which the passages took place.

The IVS90 counting points that are included in BIVAS are at bridges and locks and can therefore by name be coupled to the correct BIVAS arcs. The conversion of the trips recorded in the IVS90 to BIVAS trips is more complicated. The characteristics of the trips (vessel type, draught, etc.) can be adopted one-to-one, but this is not possible for the origins and destinations.

RWS-DVS (2013) describes how the origins and destinations recorded in the IVS90 are linked to BIVAS origin and destination nodes. In the IVS90 the origins and destinations are specified by ISRS codes. The ISRS codes include the waterway number and hectometring. Since the Dutch part of the BIVAS network is based on the ViN and the NWB-V (see Section 4.1), most of the origins and destinations from the IVS90 can be coupled to BIVAS nodes. For part of the origins and destinations no coupling can be made with the ISRS code. In these cases the coupling is based on the UNLOCODE and RWS vessel class. The UNLOCODE is a locationcode existing of a Landcode and Placecode. For Rotterdam this code is for example NLRTM. Based on the with the ISRS codes succesfully coupled origins and destinations the most common node for a given UNLOCODE and RWS vessel class is coupled as origin or destination. When the combination of the vessel class and UNLOCODE does not exist in the succesfully coupled origins and destinations the coupling is based on the UNLOCODE only.

3.5. CONCLUSIONS

BIVAS allocates the trips over the network by finding the fastest or cheapest route per trip, using Dijkstra's shortest path algoritm (Dijkstra, 1959). In order to divine the shortest path for a trip the travel time (and travel costs) per arc are computed.

The travel time on an arc depends on:

- The speed of the vessel over the ground given the RWS class, dimensions and load type of the vessel (empty or loaded), and the CEMT class, water depth and flow velocity of the arc.
- The maximum velocity restriction of the waterway for an empty or loaded vessel.
- The length of the arc.
- The defined delay for the arc.
- A possible penalty for exceeding the length and/or width restrictions of the arc.

The composition of the transport costs is as follows:

- Transport costs per arc, existing of:
  - Fuel usage per hour, per vessel type and CEMT class.
  - Repair and maintenance costs per kilometre, by vessel and appearance type.
  - Labor costs per hour, by vessel and appearance type.
  - Material costs per hour, by vessel and appearance type.
- Costs of loading and unloading, subdivided by vessel and appearance type.
- Costs of waiting for loading.
- Costs of waiting for bridges and locks.

From the lists above it can be seen that when the water conditions change this only influences the determination of the speed of the vessel over the ground. It is notable that in BIVAS the fuel usage of the vessel per hour does not depend on the water conditions and the speed of the vessel, while in reality it does (the total fuel usage in BIVAS does depend on the water conditions and speed of the vessel, via the travel time). This may influence the correctness of the allocation of the trips by BIVAS.

The Nieuwe koppeling LSM-BIVAS creates only for part of the Dutch inland waterway network a water scenario. Next to this only the water depths and flow velocities of the LSM Light are converted to the water scenario. The water levels are not converted. For a correct control of the weirs in the network the water levels should be converted as well.

The correctness of the conversion of the IVS90 to BIVAS is questionable for the origins and destinations that can not be coupled based on the waterway number and hectometring, because it can not be verified whether the coupling based on the UNLOCODE and RWS vessel couples the trip to the BIVAS origin and/or destination node that is the closest to the origin and/or destination of the trip in reality.

4
ANALYSIS OF INPUT AND REFERENCE DATA FOR BIVAS COMPUTATIONS

In this chapter the input stored in the BIVAS database for the BIVAS scenario of 2011 is analysed and when possible validated. Among this input are the traffic scenario and the reference trip set of 2011. These are constructed from data of the IVS90 (Section 2.4) and can therefore be used to analyse the reaction of inland navigation to changing water conditions in reality, which is done in this chapter as well. Next to the input stored in the BIVAS database a water scenario of 2011, constructed with the LSM Light (Section 3.2) and the Nieuwe koppeling LSM-BIVAS (Section 3.3), is used as input for the BIVAS computations. To what extent this water scenario reflects the actual water conditions of 2011 is also addressed in this chapter.

Section 4.1 addresses the network, Section 4.2 the vessel characteristics, Section 4.3 the traffic scenario, Section 4.4 the reference trip set and Section 4.5 the water scenario. Section 4.6 summarizes the conclusions of this chapter.

4.1. NETWORK

The BIVAS network includes all Dutch inland waterways and the European waterways that are reachable from the Dutch inland waterway network. The network consists of nodes and connections between them; arcs. Arcs can be waterway sections, bridges, locks or weirs.

In this section is at first the origin of the available network data described. Thereafter the network data important for this study is visualised and analysed.

4.1.1. ORIGIN OF THE NETWORK DATA

The Dutch part of the network is based on the NWB-V; Nationaal Wegen Bestand - Vaarwegen (National Roads File - Waterways) and the ViN; Vaarwegkenmerken in Nederland (Waterway characteristics in the Netherlands).

The NWB-V is a digital geographical file of all waterways navigable by professional and recreational vessels in the Netherlands (RWS-CIV, 2013a). It exists of waterway junctions and waterway sections. A waterway junction is a start or end point of one or more waterway sections, a waterway section is a part of a waterway between two waterway junctions. Basically, the waterway junctions are the BIVAS nodes and the waterway sections the BIVAS arcs. However, part of the waterway sections are splitted for the BIVAS network, in order to distinguish all bridges, locks, weirs and transshipment locations alongside the waterway sections within the network. Per transshipment location one node is added to the network and for bridges, locks and weirs nodes are added at both ends of the structures. The information placement and characteristics of the added nodes and arcs comes from the ViN. Figure 4.1 shows an example of the BIVAS network.

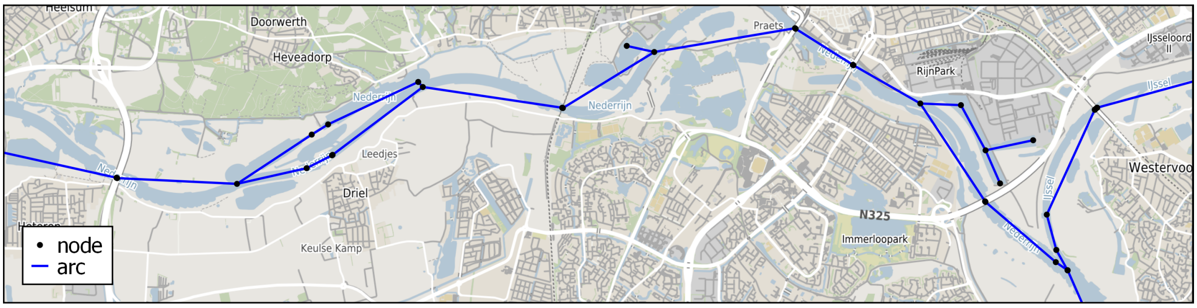


Figure 4.1: Example of the BIVAS network.

The ViN is a database existing of all characteristics of the waterways needed for the inland navigation policy or relevant for research (RWS-CIV, 2016a; RWS-CIV, 2016b). The ViN includes, for example, the locations and operating times of locks and bridges and the maximum allowed dimensions of a vessel per waterway section.

Not all the characteristics of the arcs within the Dutch part of the BIVAS network come from the ViN, and the characteristics that do come from the ViN are not always included for all waterway sections. However, the network data that does have the NWB-V or the ViN as origin is considered to be very accurate, since those systems are continuously monitored and adjusted.

When no water scenario is included in a computation BIVAS uses, when available, the default water conditions stored in the SQL-database. In the database is, for the Dutch part of the network, for every arc a depth and a flow velocity stored. The stored values of the flow velocities come from a SOBEK computation and are the average flow velocities of a day with median water conditions. It is unknown whether the SOBEK computation was of an actual or artificial year. The depths stored in the BIVAS database are not from the SOBEK-computation and it is unknown where they do come from.

The network outside of the Netherlands is derived from TRANS-TOOLS (TOOLS for TRansport Forecasting ANd Scenario testing), an European transport network model developed in collaborative projects funded by the European Commission Joint Research Centre's Institute for Prospective Technological Studies (IPTS, JRC-Sevilla) and DG TREN (Ibánez-Rivas, 2010). In the network that comes from TRANS-TOOLS bridges and locks are not included (except two locks in Belgium, the Royersluis and the Boudwijnsluis). Also, no default water depths are available for the network that comes from TRANS-TOOLS, so for the water depth on the arcs that come from TRANS-TOOLS the average depth of the waterway class of the arc, stored in the database, is used.

The NWB-V, the ViN and TRANS-TOOLS are thoroughly maintained and are therefore very reliable. In Figure F.1 in Appendix F is for all characteristics that are stored in the BIVAS database indicated whether their main origin is the ViN, the SOBEK computation, or that the origin is unknown.

4.1.2. NETWORK DATA OF IMPORTANCE FOR THIS RESEARCH

Focused on the Rotterdam-Lobith corridor, an overview of the network characteristics of importance to this study is given in this subsection. The characteristics discussed are:

- Waterway classification.
- Length, width and default depth of the waterways.
- Default flow velocities.
- Maximum allowed draught, width, length and speed on the waterways.

WATERWAY CLASSIFICATION

The arcs are classified based on BIVAS CEMT classes. The BIVAS CEMT classes exist of the CEMT classes 0 up to and including VIc and four extra classes; Unknown, IJssel, Lek and Waal. The three extra classes; IJssel, Lek and Waal, are added at the request of RWS-DVS, because of the great differences in the characteristics that can occur between waterways of the same class. By creating this extra classes the values of the BIVAS data linked to the waterway classification should, on average, be better approached than when the values of the official CEMT classes of the arcs are used. Figure 4.2 shows the BIVAS CEMT classes of the waterways within the Rotterdam-Lobith corridor. In Section F.2 in Appendix F figures showing the BIVAS CEMT classes of the whole network can be found.

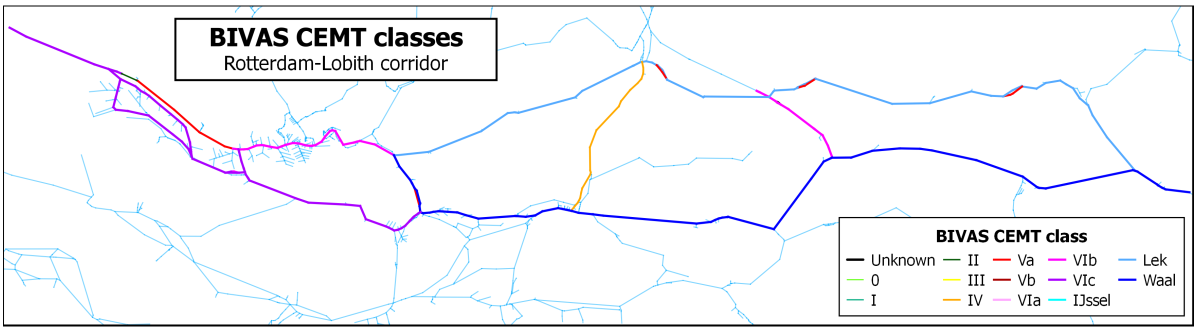


Figure 4.2: BIVAS CEMT classes of the arcs within the Rotterdam-Lobith corridor.

The Pannerdensch Kanaal, the Neder-Rijn and the Lek are of the BIVAS CEMT type Lek. In reality the Pannerdensch Kanaal, the Neder-Rijn, and the Lek between the Amsterdam-Rijnkanaal and the Merwedekanaal are CEMT type Va and the Lek between the Merwedekanaal and the Noord is CEMT type VIa. So, in reality the Lek between the Merwedekanaal and the Noord is available for larger vessels. The Boven-Rijn, Waal, Boven-Merwede, Beneden-Merwede and the Noord are of the BIVAS CEMT type Waal, in reality they are all CEMT type VIc.

The other waterways within the Rotterdam-Lobith corridor are all of the same BIVAS CEMT class as the CEMT class they are in reality, except for the western part of the Nieuwe Waterweg, which is of the BIVAS

CEMT class II whereas in reality it is most probably class Va (in the ViN there is no CEMT class designated to this part of the Nieuwe Waterweg). The CEMT class II is probably chosen as class because the port that is connected to this part of the Nieuwe waterweg; the Berghaven te Hoek van Holland is of this class. However, it seems more plausible that the class is of the same class as the other part of the Nieuwe Waterweg.

The classification of the waterways influences the allocation of the trips via the following parameters:

- Wet cross sectional area.
- Desired speed per vessel type.
- Fuel usage per vessel type.
- Maximum under keel clearance.

The first three of these parameters are in reality dependent on the width and the depth of the waterways, which can both differ significantly between waterways of the same CEMT class, also for the new defined waterway classes. It might be better to not link those parameters to the waterway classification or to create a more extensive classification.

LENGTH, WIDTH AND DEFAULT DEPTH

The lengths of the arcs come from the NWB-V and the ViN and are therefore reliable when compared to reality. The width and default depth of the arcs do not come from one of those sources. It seems that the width and default depth of the arcs are generally the width and depth stored in the BIVAS database per waterway class (those values can be found in Table F.1 in Appendix F). The origin of those widths is unknown. As described above the width of waterways of the same waterway class can differ significantly in reality.

Currently the widths of the arcs are not used during the computation of the allocation of the trips. The widths influence in reality the wet cross sectional area and thereby the vessel speed and fuel usage. Those are in BIVAS defined per waterway class and are therefore not dependent of the actual width of the arcs.

For all arcs within the Rotterdam-Lobith corridor default depths are stored in the BIVAS database. Figure 4.3 visualizes the default depths on arcs in the Rotterdam-Lobith corridor. The default water depths are, when no water scenario is included, used for the definition of the speed of a vessel on a certain arc.

The vessel speed used for the allocation is the minimum of three speeds:

- The desired speed stored in the BIVAS database per; the vessel type, load type of the vessel and the BIVAS CEMT type of the arc.
- 90% of the theoretical maximum speed of the vessel on the arc.
- The speed in shallow water of the vessel on the arc.

In both the computation of 90% of the theoretical maximum speed and the computation of the speed in shallow water the water depth is used (Equations 3.3, 3.4 and 3.5).

When no water scenario is included the default depths are in first instance not used to define whether a vessel can be allocated via a certain arc, since when no water scenario is included this is done by the default maximum draught stored in the BIVAS database, see the following subsubsection on the maximum allowed draught, width, length and speed.

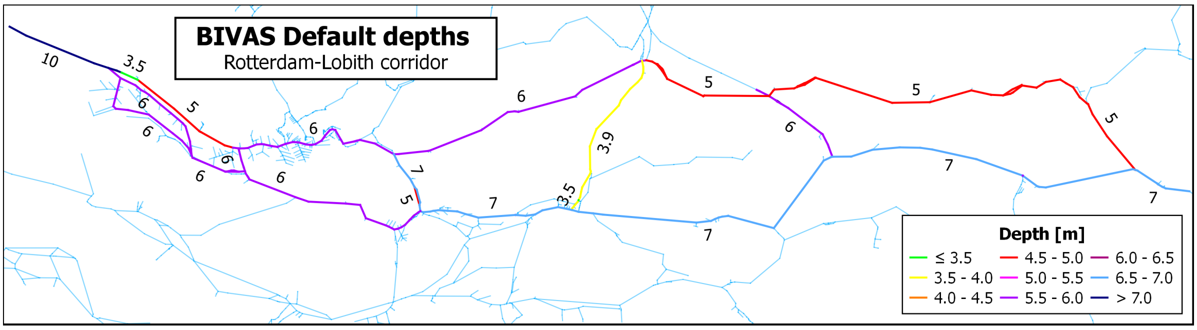


Figure 4.3: Default depths on the arcs within the Rotterdam-Lobith corridor.

Figure 4.3 shows some notable things. The default water depth at the waterways with the BIVAS CEMT type Waal is 7 meter, whereas the default water depths at the waterways west of those waterways is generally smaller; 6 or 5 meter. In reality the water depth increases from East to West. The real average water depth on the Oude Maas is for example ≈9 meter and the real average water depth on the Nieuwe Waterweg ≈15 meter (Rijkswaterstaat, 2016). These depths are much larger than the default water depths stored in the BIVAS database.

For the BIVAS CEMT types Waal and Lek the default water depth is often to large in comparison to reality. So is for example the average water depth on the Nieuwe Merwede in reality about 5 meter instead of the 7 meter stored as default depth in the BIVAS database.

In conclusion it can be said that the default water depths for the Rotterdam-Lobith corridor are on average too small for the classic BIVAS CEMT types and on average too large for the extra defined BIVAS CEMT types. This has an influence on the theoretical maximum speed and the speed in shallow water, whereby in BIVAS a different speed than in reality can be normative.

DEFAULT FLOW VELOCITIES

Figure 4.4 shows, for the Rotterdam-Lobith corridor, the default flow velocities stored in the BIVAS database. It is difficult to say whether these values are right, but they appear to be plausible, since for all arcs with a velocity the flow is positive. What can not be right is that on parts of the Oude and Nieuwe Maas and the Hartel- and Calandkanaal there is no current. The average current of a day should always be positive seawards.

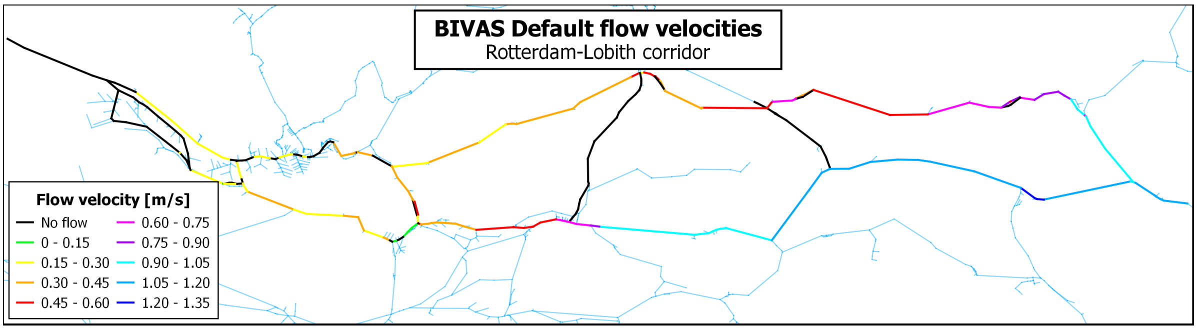


Figure 4.4: Default flow velocities on the arcs within the Rotterdam-Lobith corridor.

MAXIMUM ALLOWED DRAUGHT, WIDTH, LENGTH AND SPEED

In BIVAS is, for part of the arcs, a maximum allowed draught, width, length, and speed of the vessels using the arcs (empty and loaded), defined. The maximum allowed draught, width and length that come from the ViN are realiable. However, not all of the values come from the ViN. The maximum allowed speed is never from the ViN and has an unknown origin.

Maximum allowed draught

Figure 4.5 shows the maximum allowed draughts on the waterways within the Rotterdam-Lobith corridor. From the figure it can be seen that on the vast majority of the waterways there are no restrictions on the draught, which is because in the ViN there are no restrictions on the draught included for these waterways.

Not all of the maximum allowed draughts come from the ViN. The maximum allowed draughts between the Noord and the North sea do not come from the ViN. The source of these maximum allowed draughts is unknown and the values seem to be somewhat random.

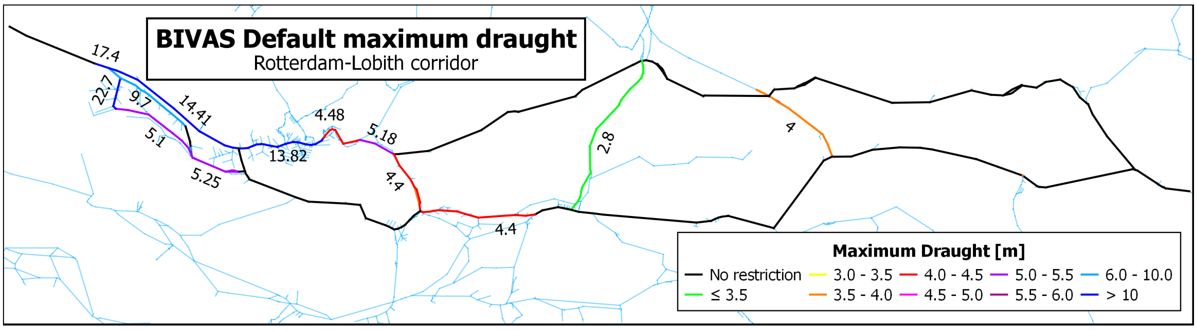


Figure 4.5: Maximum allowed draughts on the arcs within the Rotterdam-Lobith corridor.

Since in BIVAS, when no water scenario is used, the maximum allowed draught for an arc determines whether a vessel can be allocated via the arc or not, the maximum allowed draught stored in the BIVAS database plays an important role in the allocation of the trips.

For inland navigation it holds that the draught is generally less than 4.5 meter, which means that no restriction on the draught will be, under median circumstances, no problem on the Lek, Waal and the Merwedes, since on these waterways the depth on a median day is sufficient for a draught of 4.5 meters. For the Pannerdensch kanaal and Neder-Rijn it is the question whether the depth on a median day will be sufficient for a draught of 4.5 meter. In addition, in the future the maximum draught for inland navigation might increase. Therefore, it might be better to also include maximum draughts for the waterways that do not have a restriction and check the already defined maximum draughts, or to use the default depth for the definition of the maximum draught. When it is chosen to use the default depths it must be taken into account that they are incorrect and should be adjusted first.

Maximum allowed width and length

Figure 4.6 and Figure 4.7 show the maximum allowed width and length of vessels using the waterways of the Rotterdam-Lobith corridor. For both the maximum allowed width and length it holds that they mainly come from the ViN.

The values for the western part of the Nieuwe Waterweg seem to be incorrect again. In the ViN there are no restrictions on the width and length included for this part of the Nieuwe Waterweg. The restrictions in BIVAS are the ones of the port connected to this part of the Nieuwe waterweg; the Berghaven te Hoek van Holland. However, it seems more plausible that the restrictions will be the same as the restrictions for the other part of the Nieuwe Waterweg.

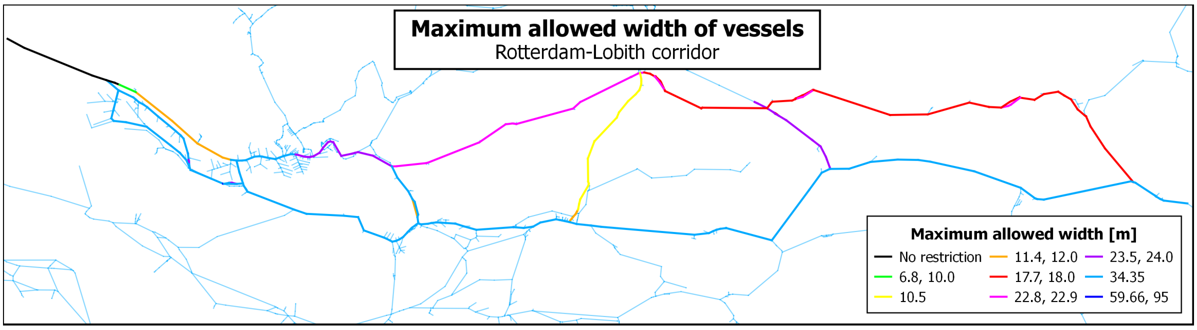


Figure 4.6: Maximum allowed widths of vessels on the arcs of the Rotterdam-Lobith corridor.

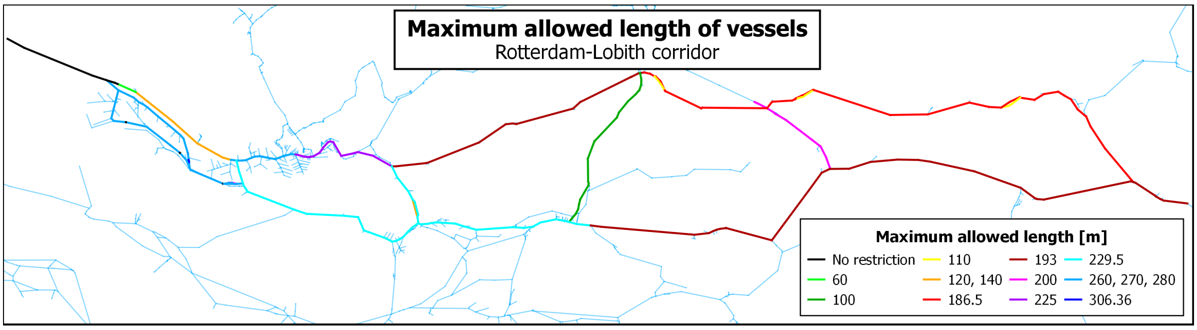


Figure 4.7: Maximum allowed lengths of vessels on the arcs of the Rotterdam-Lobith corridor.

Maximum allowed speed

Within the Rotterdam-Lobith corridor there are only for the Merwedekanaal (12km/h) and the Amsterdam-Rijnkanaal (18km/h) maximum speeds defined. These maximum speeds are correct (Vaartips.nl, 2011; Stichting Waterrecreatie Nederland, 2016). Whether there are specific maximum speeds on the other waterways within the Rotterdam-Lobith corridor is unknown, but it is known is that the maximum speed on all Dutch inland waterways is 20 km/h.

4.2. VESSELS

In this section the characteristics of the vessel types stored in the BIVAS database of importance for this study are addressed. Subsection 4.2.1 addresses the classification of the vessels, Subsection 4.2.2 adresses the desired speeds per vessel type, load type and waterway class and Subsection 4.2.3 addresses the fuel usage per hour per vessel type, load type and waterway class.

4.2.1. CLASSIFICATION

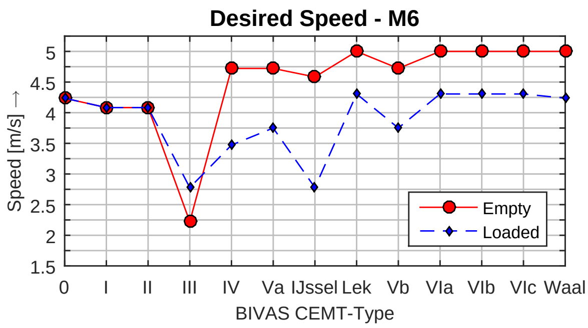
The vessel types used in BIVAS are based on the RWS2010 classification. The vessels are classified according to the range in beam, length and draught of the reference vessels of the RWS2010 classification. Based on the RWS2010 classes (except classes BIIa-1 and BIIL-1), vessel types are determined.

For every trip is, next to the vessel type, the exact width, length, and draught of the vessel included. This data comes from the IVS90. The length and width of the vessel are reliable, since those are for all vessels accurately documented in the IVS90. The draught is less reliable, because it has to be provided to the IVS90 by the skippers for every separate trip.

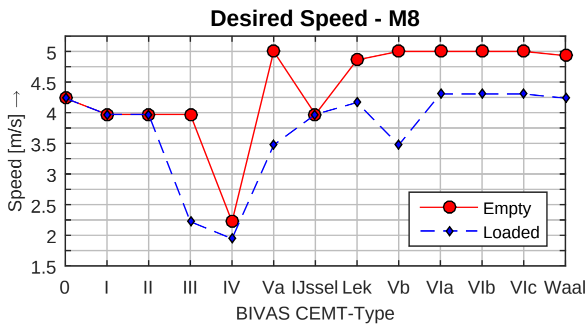
4.2.2. DESIRED SPEEDS

For every vessel type, load type of the vessel (empty or loaded) and BIVAS CEMT class a desired vessel speed is stored in the BIVAS database. When the stored desired speed is the minimum of the three vessel speeds defined during the allocation, the stored desired speed is used.

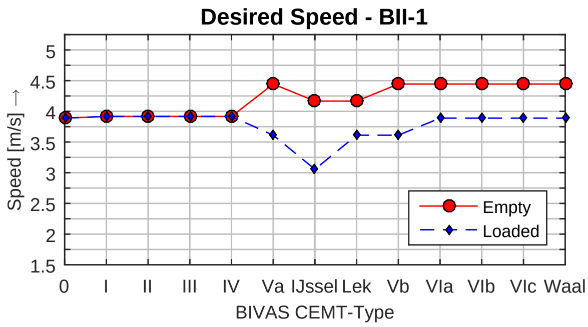
Figures 4.8a up to and including 4.8d show for the two most used Motor vessel types, and the most used Pushed convoy and Coupled unit types the desired speeds stored in the BIVAS database. The figures for all other vessel types can be found in Section G.1 in Appendix G.



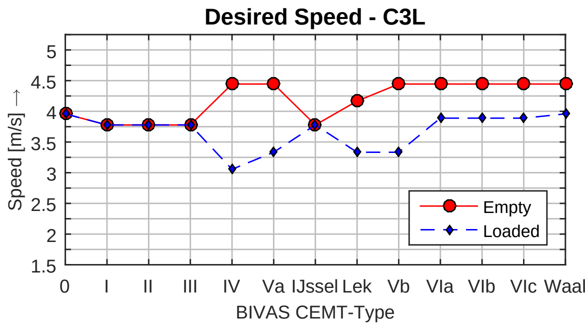
(a) M6



(b) M8



(c) BII-1



(d) C3L

Figure 4.8: Vessel types M6, M8, BII-1 and C3L; desired speeds stored in BIVAS database, for the various CEMT types and the load type (empty or loaded).

It is unclear what the exact source of the stored desired speeds is. What can be seen from Figures 4.8a up to and including 4.8d is that the values are certainly not all accurate. Looking for example at Figure 4.8b it can be seen that at some of the BIVAS CEMT types the empty and loaded desired speeds are the same, and at others the difference can be up to 2 m/s. Figure 4.8a shows that on BIVAS CEMT type III the desired speed of a loaded vessel is higher than the desired speed of an empty vessel, and Figure 4.8c shows that the desired speed of an empty vessel increases between BIVAS CEMT types IV and Va while the desired speed of a loaded vessel decreases. All of those examples are not logical and therefore the values of the desired speeds are certainly not all accurate.

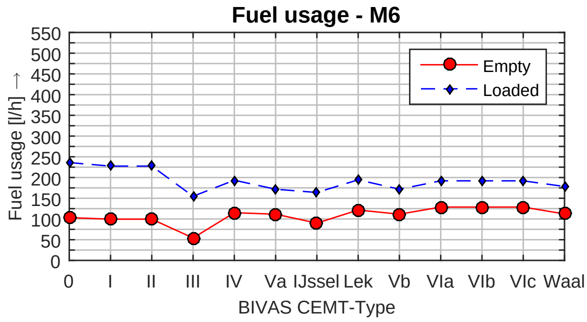
Since in BIVAS the shallow water speed and theoretical maximum speed are computed as well, it is in first instance incomprehensible that there is also a speed stored in the database. However, this is done because when there is more than sufficient depth and width, the theoretical maximum speed is usually higher than the speed that can be reached by a vessel given its power. In addition, the vessel speeds in reality also depend on the traffic on and the characteristics of the waterways.

4.2.3. FUEL USAGE

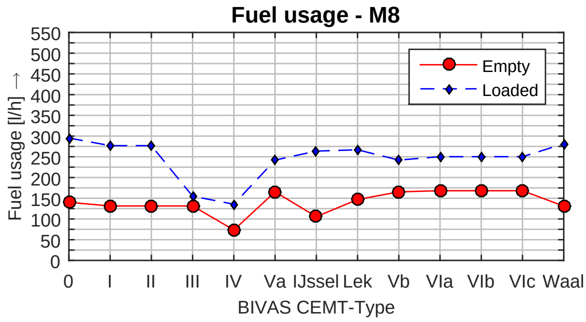
The fuel usage in liters per hour is for every vessel type, load type (empty or loaded) and BIVAS CEMT class stored in the BIVAS database. Figures 4.9a up to and including 4.9d show the fuel usage per hour for the two most used Motor vessel types, and the most used Pushed convoy and Coupled unit types. The figures for all other vessel types can be found in Section G.2 in Appendix G.2.

The source of the fuel usage per hour not known either, and again not all values seem to be accurate. It is for example illogical that between BIVAS CEMT types VIc and Waal the fuel usage of a loaded M8 vessel increases while the fuel usage of an empty M8 vessel decreases.

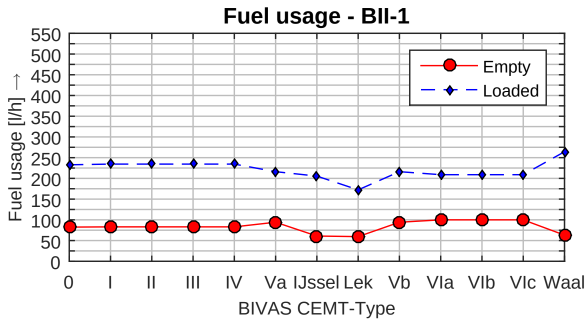
In reality the fuel usage depends on the length, width and draught of the vessel, the wet cross sectional area of the waterway, and the speed of the vessel. In BIVAS none of these parameters is taken into account for the fuel usage per hour used for the computation of the allocation of the trips, because the stored fuel usage is used.



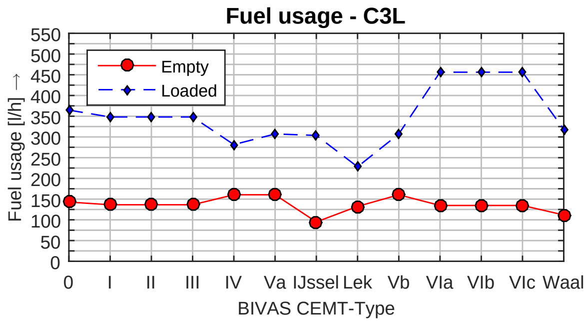
(a) M6



(b) M8



(c) BII-1



(d) C3L

Figure 4.9: Vessel types M6, M8, BII-1 and C3L; fuel usage per hour stored in BIVAS database, for the various BIVAS CEMT types and the load type (empty or loaded).

In BIVAS there is a possibility to compute emissions. For this computation all parameters on which the fuel usage depends in reality are used to define the fuel usage. Probably because of longer computation time this is not done for the allocation of the trips. However, for a traject like the Rotterdam-Lobith corridor where the differences in the costs for different routes is small it might be better to include the computation of the fuel usage as well for the allocation of the trips.

4.3. TRAFFIC SCENARIO 2011

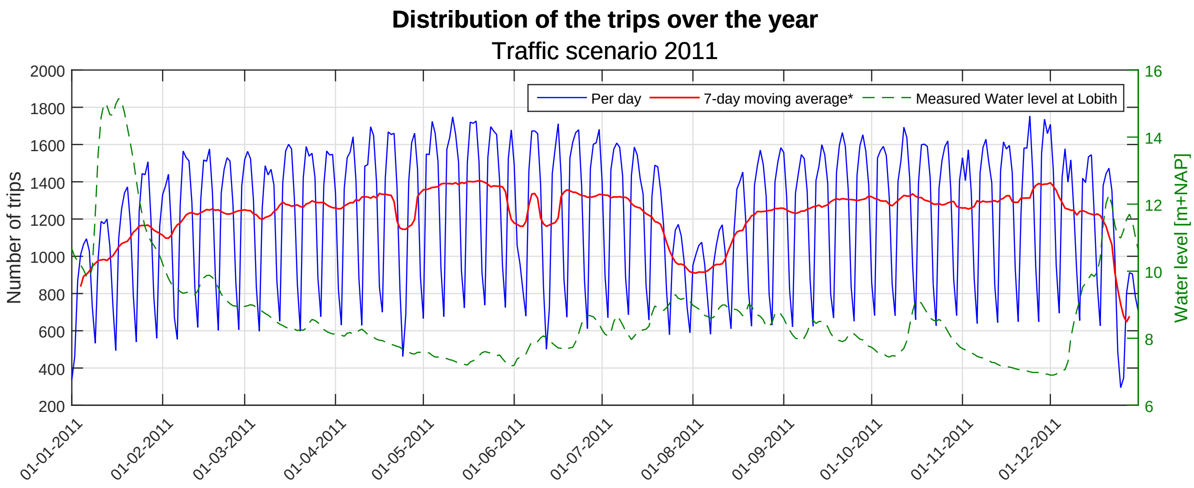
In this section the traffic scenario of 2011, which is constructed from data of the IVS90, is analysed. The traffic scenario is both input data and data that can be used to analyse the relation between inland navigation and water conditions. In this section is initially looked into the relation between inland navigation and water conditions. In addition is, whenever possible, also looked into the reliability of the data. In Subsection 4.3.1 the distribution of the trips over the year is examined, in Subsection 4.3.2 the average draught of the loaded vessels and in Subsection 4.3.3 the number of trips per vessel type.

4.3.1. DISTRIBUTION OF TRIPS OVER THE YEAR

The total number of trips in the traffic scenario for 2011 is 445,527. This gives an average number of trips per month of 37,127, per week of 8,544 and per day of 1,221. The distribution of the trips over the year is shown in Figure 4.10. From the figure it can be seen that there is a dip in the number of trips during the weekends, this is because only part of the vessels are operated seven days a week. The figure shows also the 7-day moving average of the trips per day, whereby the difference in the number of trips per day over a week is filtered out, and the distribution of the trips over the whole year becomes better visible.

The holiday seasons can clearly be seen in the distribution of the trips over the year, the average number of trips per day is lower in the beginning of January and the end of December because of the winter holidays, and between the second half of July and the first half of August because of the summer holidays. Small dips can be seen because of Easter (end of April), Ascension (beginning of June) and Pentecost (middle of June).

From the graph it seems that the winter holidays last until the end of January. This is not the case. Because of extreme high water levels in January 2011 inland navigation was disrupted on part of the network (IenM, 2011), which is the cause for the smaller number of trips during this period. During the extremely low discharge periods of 2011 (middle of May and beginning of December) the number of trips is a bit larger than



* Average of three days before, day itself and three days after

Figure 4.10: Traffic scenario 2011; distribution of the trips over the year

during the remainder of the year. Because of draught restrictions more trips had to take place to get all freight to their destinations.

The distribution of the trips over the year is accurate up to a certain extent. The departure dates and times of the trips are expected to be correct, since the expectation is that the skippers enter these correctly in the IVS90. However, when in reality a trip took longer than one day this can not be seen in the distribution, because only the departure dates and times are included in the BIVAS database. Using the reference data, the distribution of the durations can be approached. 336,702 (≈75%) of the trips in the traffic scenario passed one or more IVS90 counting points. Table 4.1 includes for these trips the distribution of the number of trips per number of days at least one IVS90 counting point has been passed. The table shows that the majority of the trips passed IVS90 counting points between one and three days. Generally spoken the water conditions will not be varying too much over three days, whereby it is fine to place trips that took longer than one day, on one day in BIVAS.

Table 4.1: Reference trip set 2011; the number of trips per number of days the trips have passed at least one IVS90 counting point.

No. of days	No. of trips	% of total no. of trips
1	271900	74.15
2	82472	22.49
3	10188	2.778
4	1772	0.483
5	324	0.088
6	35	0.010
7	11	0.003

4.3.2. AVERAGE DRAUGHT OF THE LOADED VESSELS OVER THE YEAR

Figure 4.11 shows the average draught of the loaded vessels over the year. From the figure it can be seen that the average draught of the loaded vessels follows the water level over the year, and that low water levels have a stronger influence on the average draught of the loaded vessels than high water levels. In addition, vessels that are operated seven days a week have on average a larger draught than the other vessels, since larger vessels are more often operated seven days a week.

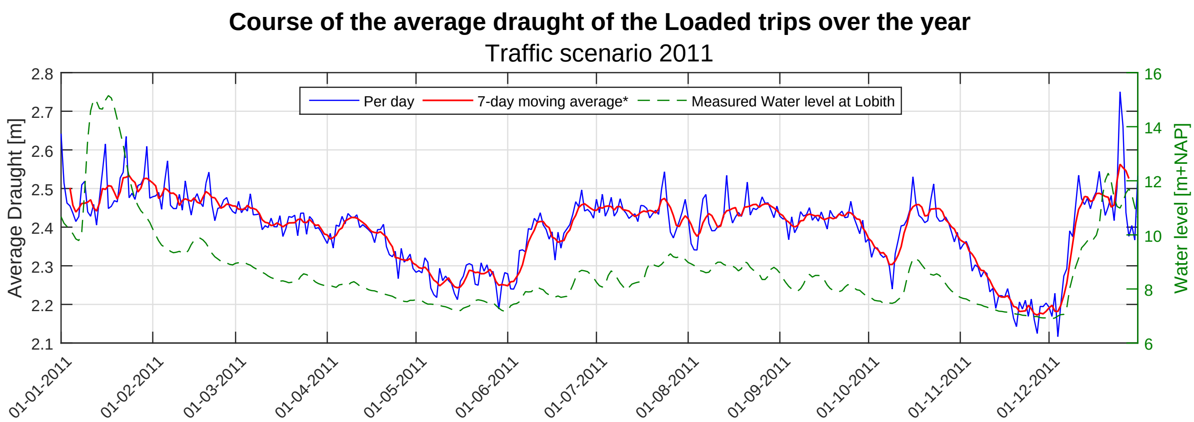


Figure 4.11: Traffic scenario 2011; course of the average draught of the loaded trips over the year

The average draught of the loaded vessels over the year is expected to be not entirely accurate. The draught does come from the IVS90, but is less reliable, since for every separate trip it has to be provided by the skipper.

4.3.3. TRIPS PER VESSEL TYPE

In Table 4.2 are, for the traffic scenario of 2011, the total number of trips and the number of loaded trips per vessel category are given. The largest amount of the trips, around 90%, takes place by Motor vessel. 7% of the trips takes place by Pushed convoy and 3% of the trips takes place by Coupled unit. Pushed convoys are, relatively to Motor vessels and Coupled units, more often sailing empty.

Table 4.2: Traffic scenario 2011; number of trips per vessel category

Vessel category	No. of trips	No. of loaded trips
Motor vessels	398,813	229,524
Pushed convoys	32,490	15,432
Coupled units	14,224	10,134

Figure 4.12 shows, per vessel type, the total number of trips and the number of loaded trips in 2011. The largest amount of trips, around 23% of the total trips. takes place by M8 vessel. The second most used vessel is the M6, around 15% of the total trips takes place by this vessel. The other vessels which are used often are the M2 (≈11%), M3 (≈9%) and M4 (≈9%).

When a Pushed convoy is used for a trip, most often a BII-1 Pushed convoy is used (≈3% of all trips). The other most used pushed convoys are the BI and BII-4 (both ≈1% of total trips). The BO-1, BO-2, BII-2B and BII-6B Pushed convoys are relatively to the other Pushed convoys, more often sailing empty. This is probably because of the fact that pushed convoys are combined vessels, which means coupling and decoupling of parts can take place, whereby a pushed convoy can change categories.

The most used coupled unit is the C3l coupled unit (≈2% of all trips). For coupled units the ratio between loaded and empty trips varies relatively much between the various coupled units. This is again probably because of the fact that coupled units are combined vessels, whereby a coupled unit can change category when parts are coupled or decoupled.

The numbers on the trips per vessel category and type are reliable since the vessel category and type are accurately documented in the IVS90. This analysis of the distribution shows that the correctness of the characteristics of the M8, M6, M4, M3 and M2 vessel types are most important in BIVAS.

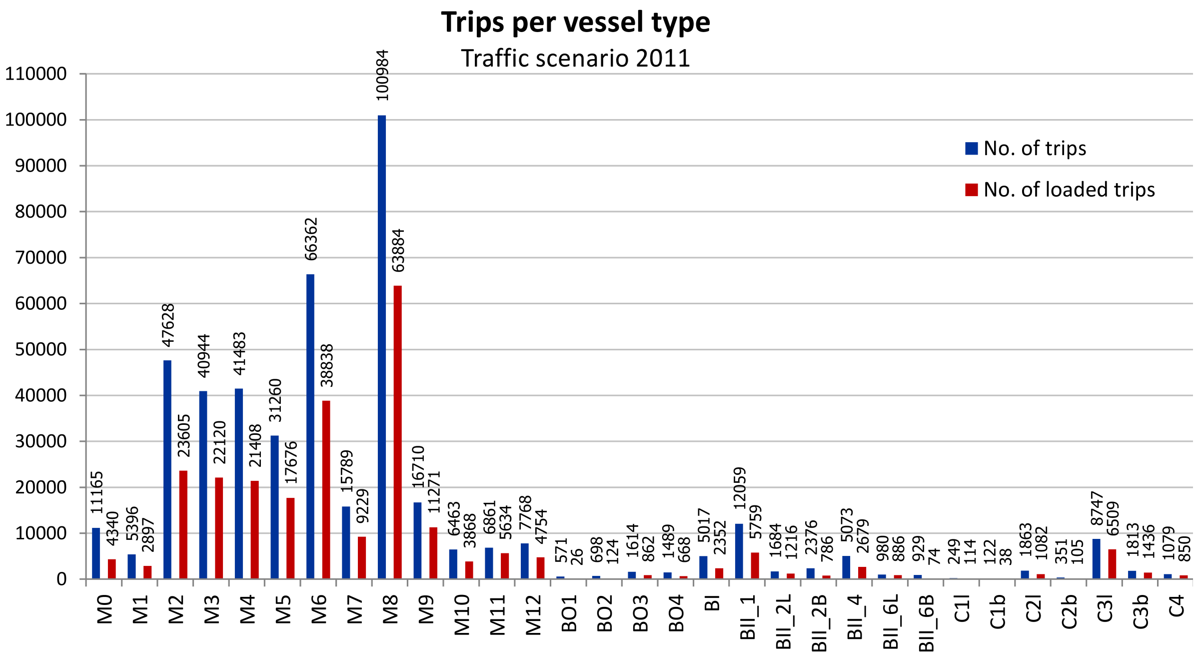


Figure 4.12: Traffic scenario 2011; trips per vessel type

4.4. REFERENCE TRIP SET 2011

The reference trip set includes data on how the trips took place over the network in reality. For all trips the reference trip set includes which, and when, counting points of the IVS90 were passed in reality. Within the Rotterdam-Lobith corridor there are several IVS90 counting points. The IVS90 counting points within the Rotterdam-Lobith corridor are given in Subsection 4.4.1.

In Subsections 4.4.2 and 4.4.3 the reference trip set of 2011 is analysed. This is done for two reasons. At first to define the accuracy of the reference trip set (Subsection 4.4.2) and secondly to analyse the reaction of inland navigation to changing water conditions in reality (Subsection 4.4.3). The analysis is done on counting point level (per counting point), and on route level (per string of counting points on a route).

4.4.1. Reference points Rotterdam-Lobith corridor

Within the Rotterdam-Lobith corridor there are six points for which reference data from the IVS90 is available in BIVAS:

- Hagestein, Sluis - *Lek, east of the Merwedekanaal*
- Amerongen, Sluis - *Neder-Rijn, west*
- Driel, Sluis - *Neder-Rijn, east*
- Prins Berhardsluis - *Amsterdam-Rijnkanaal, at the connection with the Waal*
- Grote Merwedesluis - *Merwedekanaal, at the connection with the Boven-Merwede*
- Grote Sluis, Vianen - *Merwedekanaal, at the connection with the Lek*

Next to these four IVS countingpoints there are two more IVS counting points that can be helpful for the analysis of the shipping movements on the Rotterdam-Lobith corridor:

- Prinses Beatrixsluizen - *Lekkanaal, connection of the Lek and the Amsterdam-Rijnkanaal north of the Merwedekanaal*
- Prinses Ireneseluis - *Amsterdam-Rijnkanaal, north of Neder-Rijn and Lek*

Figure 4.13 show the locations of all the IVS90 counting points that are used as reference points in this research.

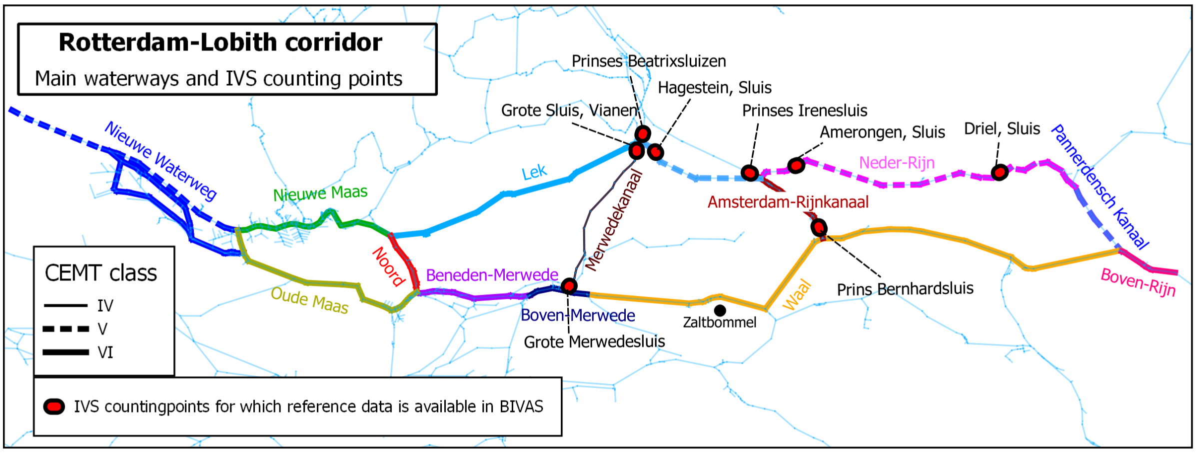


Figure 4.13: Rotterdam-Lobith corridor; main waterways and IVS countingpoints.

4.4.2. Accuracy reference trip set 2011

The reference trip set included in BIVAS comes from the IVS90. It appears that some of the trips that are present in the reference trip set are not present in the traffic scenario. This is because for a small part of the trips it is not possible to link the origin and/or destination recorded in the IVS90 to a BIVAS node. Therefore these trips are not included in the traffic scenario. However, they are not excluded from the reference trip set, which affects the comparison between the reference trip set and the BIVAS results. For 2011 there are 1,677 passages in the reference trip set that are of trips that are not in the traffic scenario. These 1,677 passages are ≈0.2% of the total number of passages in the reference trip set.

Accuracy on counting point level

The four reference points within the Rotterdam-Lobith corridor with the highest number of passages according to the IVS90 in 2011 are included in the analysis on counting point level. Table 4.3 contains for these points the number of passages and the number of extra passages due to passing more than once per trip.

Something to notice from the table is that the number of passages at Driel, Sluis is a lot smaller than the number of passages at Amerongen, Sluis, while there are no intersections with other waterways between these locks, and also no large ports. The larger number of passages at Amerongen is due to silt deposits at the Gat van Ingen (Broekema, 2011), which lays just after Amerongen, Sluis. The silt is collected from the river Vecht, and is via the Amsterdam-Rijnkanaal and the Neder-Rijn transported to the Gat van Ingen. Another route than this route is practically impossible for the trips from and to the Gat van Ingen. This means that, when there are changes in the allocation of the trips between different BIVAS scenarios, the percentual effects will be larger at Driel, Sluis than at Amerongen, Sluis.

Table 4.3: Reference trip set 2011; number of passages at main counting points within the Rotterdam-Lobith corridor.

	No. of passages	Extra passages due to passing more than once per trip	
		[No.]	**[%]**
Hagestein, Sluis	7598	20	0.26%
Driel, Sluis	8560	45	0.53%
Amerongen, Sluis	11651	22	0.19%
Prins Bernhardsluis	36183	659	1.82%

The extra passages due to passing more than once in Table 4.3 are errors in the reference trip set. These extra passages can be in the reference trip set through coupled units or pushed convoys that decouple before a lock and pass in parts ,or through round trips that are recorded as one trip in the IVS90.

ACCURACY ON ROUTE LEVEL

There is a large number of routes possible via a combination of the counting points within the Rotterdam-Lobith corridor and the counting points useful for the analysis of the routes through the Rotterdam-Lobith corridor. From a quick first analysis of the routes via the counting points in reality it was found that the counting points on the Merwedekanaal are almost never part of a route in which also one or more of the other counting points within the Rotterdam-Lobith corridor is/are present. Therefore the routes via the counting points on the Merwedekanaal are not included in the analysis on route level.

The total number of trips in 2011 with a route along one or more of the counting points within the Rotterdam-Lobith corridor and the counting points useful for the analysis of the routes in reality, according to the reference trip set, is 94,379. Of this routes 1,867 routes are impossible, because they involve several passages at the same counting point or an impossible sequence of passages along the counting points. The reasons for the existence of these routes in the reference trip set can be the same as the reasons given for the extra passages on lock level, and, in addition, it is also possible that the passage times at the counting points are not registered correctly ,or that the passage of a counting point is not registered.

4.4.3. REACTION OF INLAND NAVIGATION TO CHANGING WATER CONDITIONS IN REALITY

In order to find how the choice of route of inland navigation is influenced by changing water conditions in reality, the number of trips that passed the counting points/took a specific route along the counting points are analysed. This is done by comparing the trips of the various discharge periods defined in Subsection 2.6.3 to each other.

COMPARISON OF THE TRIPS OF THE VARIOUS DISCHARGE PERIODS ON COUNTING POINT LEVEL

Figure 4.14 shows per discharge period, counting point, direction, and load type; the relative share of the number of passages according to the IVS90 with respect to the total number of trips in the discharge period. From the figure it can be seen that the median discharge period and the whole year discharge period have fairly the same distribution and that the low discharge period and the high discharge period differ clearly from these two. The whole year discharge period does differ a bit from the median discharge period. The influence of periods like the low discharge period on the whole year seems to be strong, which supports that 2011 was a dry year.

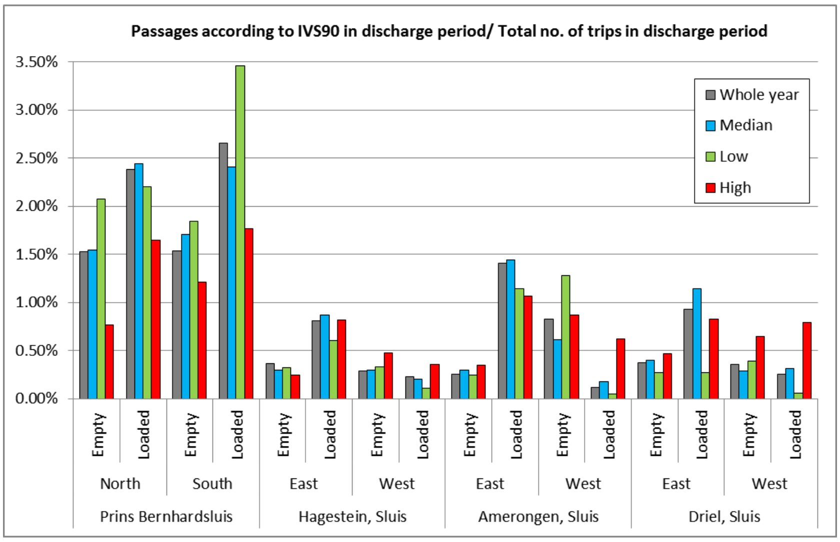


Figure 4.14: Passages per load type, direction and counting point according to IVS90, as percentage of the total number of trips in the discharge periods (2011).

During low discharge periods it is expected that, because of larger water depths on the Neder-Rijn and Lek (through the weirs on these rivers) than on the Waal, a larger part of the vessels will sail via the Neder-Rijn and Lek. Judging from the chosen low discharge period, this appears not to be true. For the empty vessels there is in the westward direction indeed a slight growth visible compared to the median period, but for the loaded vessels a clear shrinkage can be seen. Since the share of loaded vessels is larger the total part of the vessels using the Neder-Rijn and Lek is smaller during the low discharge period. But why? An explanation could be that the maximum draught is not determined by the water depth somewhere at the Waal, but by the water depth somewhere upstream of both the Neder-Rijn and the Waal. The maximum draught vessels can sail with will then depend on the water depth somewhere upstream, making the water depth at the Waal always sufficient. The vessels can sail with a larger keel clearance on the Neder-Rijn and Lek than on the Waal, but probably because of the locks they have to pass on the Neder-Rijn and Lek, the skippers still prefer the route via the Waal.

For especially the low discharge period the figures on the empty vessels in northern direction and the loaded vessels in southern direction passing the Prins Bernhardsluis differ from the figures of the median and whole year discharge periods. The share of the empty vessels in northern direction is much larger, which could be partly caused by the larger share of empty vessels choosing the Lek instead of the Waal, but this can not explain the total difference. The share of loaded vessels in southern direction is much larger, because of the larger share of loaded vessels choosing the Waal instead of the Neder-Rijn, but again this can not explain the total difference.

During the high discharge period the ratio between the empty and loaded vessels and the directions is, for the Prins Bernhardsluis. about the same as for the whole year and median discharge period, but a smaller share of the total trips pass the lock. A possible explanation for this is that sailing on the Amsterdam-Rijnkanaal between the Waal and the Neder-Rijn was less favourable in this period, because the Prinses Marijkesluis was in use during part of the high discharge period. This lock causes delay and it has chambers with a width of only 18 meters, while one of the chambers of the Prins Bernhardsluis has a width of 24 meters (RWS-CIV, 2016a).

The weirs in the Neder-Rijn and Lek were open during the high discharge period, causing higher flow velocities and, since the vessels can sail via the open weirs, less delay. A larger part of the vessels sailing westwards use the Lek and the Neder-Rijn during the high discharge period, which is mainly caused by loaded vessels. Therefore it seems that the main reasons for sailing westwards via the Lek and Neder-Rijn are larger water depths and higher flow velocities. If the sailing via the open weirs would have been the main reason it is expected that also for the empty vessels the part of the vessels using this route would be larger.

The part of the vessels sailing eastwards via the Lek and Neder-Rijn during the high discharge period is not much different from the median and whole year periods. Presumably higher flow velocities (route becomes less favourable) and larger water depths (route becomes more favourable) cancel each other out.

COMPARISON VARIOUS DISCHARGE PERIODS ON ROUTE LEVEL

There are over 40 routes possible via the counting points within the Rotterdam-Lobith corridor. It is impossible to adress all of these routes and still keep a clear view. To keep the analysis clear four routes are investigated more thoroughly during this research. These routes are selected based on the number of vessels taking these routes in reality or the number of trips BIVAS allocates via these routes for the Whole year Rijkswaterstaat scenario (>2888; at least 3% of the total number of trips that passed one or more of the counting points in reality in 2011), and on the deviation (>0.05) from 1.0 of the ratio between the number of trips allocated via these routes by BIVAS and the number of trips that took these routes in reality. The routes in Table 4.4 are the four routes meeting these criteria. In the remaining part of the report these routes will be referred to as "the remarkable routes".

Table 4.4: Routes meeting criteria for in depth analysis on route level.

	No. of trips sailing route		
	IVS90	**BIVAS**	**BIVAS/IVS90**
Prinses Irenesluis - Prins Bernhardsluis	14456	15854	1.10
Prins Bernhardsluis - Prinses Irenesluis	14073	15308	1.09
Hagestein, Sluis - Amerongen, Sluis - Driel, Sluis	2839	3537	1.25
Hagestein, Sluis - Prins Bernhardsluis	796	6147	7.72

Figure 4.15 shows, for the remarkable routes, per discharge period the relative share of the number of vessels sailing via the route according to the IVS90 with respect to the total number of trips in the discharge period. The figure shows for the whole year and the median discharge period approximately comparable values, and the ratio between empty and loaded vessels for the various routes does not show extreme differences between those discharge periods either. The low discharge period shows a clear difference with the median and whole year discharge periods for three of the four routes. For the route *Prinses Irenesluis - Prins Bernhardsluis* the low discharge period shows values comparable to the median and whole year discharge periods. For the route *Prins Bernhardsluis - Prinses Irenesluis* the ratio between the empty and loaded vessels is reversed.

During the low discharge period the Prins Bernharsluis was not in use, since the lock is opened when the water level at the Waal-side of the lock drops below 3m+NAP. The water level on the Amsterdam-Rijnkanaal between the Prins Bernhardsluis, the Prinses Irenseluis and the Lek up to Hagestein, drops in this case to the same level as the level at the Waal. The opening of the Prins Bernhardsluis is on one hand positive (lockage not needed, no delay) and on the other hand negative (smaller water depths). The reversed ratio for the route *Prins Bernhardsluis - Prinses Irenesluis* could be caused by the smaller water depths, less loaded vessels are able to sail via this route. However, this seems not to be the cause, since the same effect can not be seen for the reversed route. The reversed ratio could be just a coincidence.

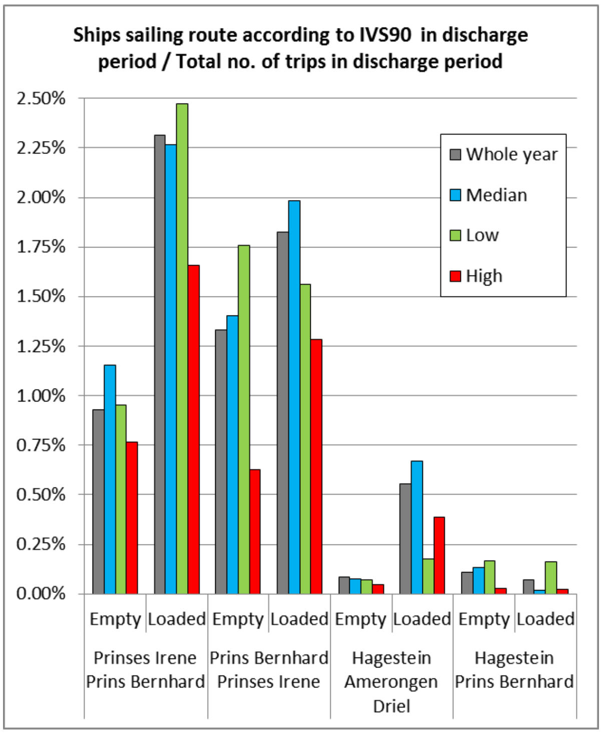


Figure 4.15: Vessels sailing route in IVS90/Total number of trips in discharge period (2011).

The share of the loaded vessels taking the route *Hagestein, Sluis - Amerongen, Sluis - Driel,Sluis* during the low discharge period is fairly smaller than during the median and whole year discharge periods. For the route *Hagestein, Sluis - Prins Bernhardsluis* the share of the loaded vessels is fairly larger. For the empty vessels no clear difference with the median and whole year discharge periods can be seen. Therefore it seems that the free passage through the Prins Bernhardsluis is not the reason for the difference, but that smaller water depths on the Neder-Rijn and the Pannerdensch kanaal than on the Waal are.

The figures for the high discharge period differ significantly from the figures for the median and whole year discharge periods. The ratios between the empty and loaded vessels per route are comparable to these ratios for the Median and whole year discharge periods, but the share of the number of vessels taking the routes is fairly smaller for all four routes. The commissioning of the Prinses Marijkesluis, which is located at the crossing of the Amsterdam-Rijnkanaal, Neder-Rijn and Lek, is probably the main cause for the smaller shares of the three routes for which part of the route runs via the Amsterdam-Rijnkanaal. For the route *Hagestein, Sluis - Amerongen, Sluis - Driel, Sluis* the cause is presumably the larger flow velocity through opening of the weirs. When the weirs are opened the flow velocity increases and the relative advantage of the route compared to a route (partly) via the Waal shrinks.

4.5. WATER SCENARIO 2011

In this section the water scenario of 2011, constructed with the Nieuwe koppeling LSM-BIVAS is analysed. In Subsection 4.5.1 the water levels of the water scenario are compared to measurements of the water levels in reality and in Subsection 4.5.2 are the average water depths and flow velocities of the water scenario analysed for the median discharge period.

4.5.1. COMPARISON WATER LEVELS OF WATER SCENARIO AND MEASURED WATER LEVELS

For all measurement points for which water level data of 2011 is available in Waterbase (Helpdesk Water, 2015), and that lay on a waterway included in the water scenario, the water levels in reality over the year 2011 are compared to the water levels over the year 2011 of the water scenario. Figures 4.16, 4.17 and 4.18 show the comparisons for the measurement points Lobith, Zaltbommel and Hagestein Beneden, all the other comparisons can be found in Section H.1 in Appendix H.

From the figures it can be seen that at Lobith the water level of the water scenario is almost the same as the water level measured in reality. So, at Lobith the water levels of the water scenario are reliable.

At Zaltbommel the measured water level is for the periods with higher water levels significantly higher, and thereby the water level of the water scenario during high discharge periods is unreliable at the point where the tide has no influence anymore. However, the significantly higher measured water level during a high discharge period will not cause problems for BIVAS, since the water depth will also be large enough when the water level of the water scenario is a meter lower than the water level was in reality. During the periods with lower water levels the water level of the water scenario is, at Zaltbommel, about the same as the measured water level and thereby reliable.

At the measuring point Hagestein Beneden the influence of the tide can be clearly seen for the measured water level, which in the figure is always the water level at 00:00. For the water levels of the water scenario the influence of the tide is less visible, but it seems that the water level of the water scenario is about the average of the measured water level.

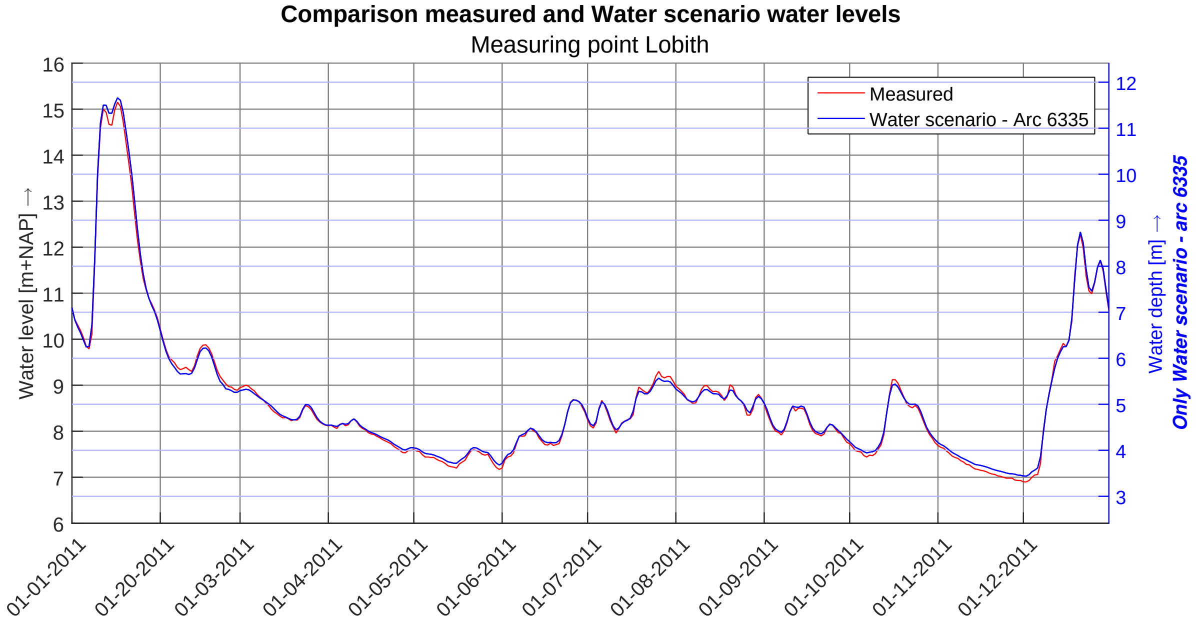


Figure 4.16: Comparison of measured and water scenario water levels; Lobith 2011.

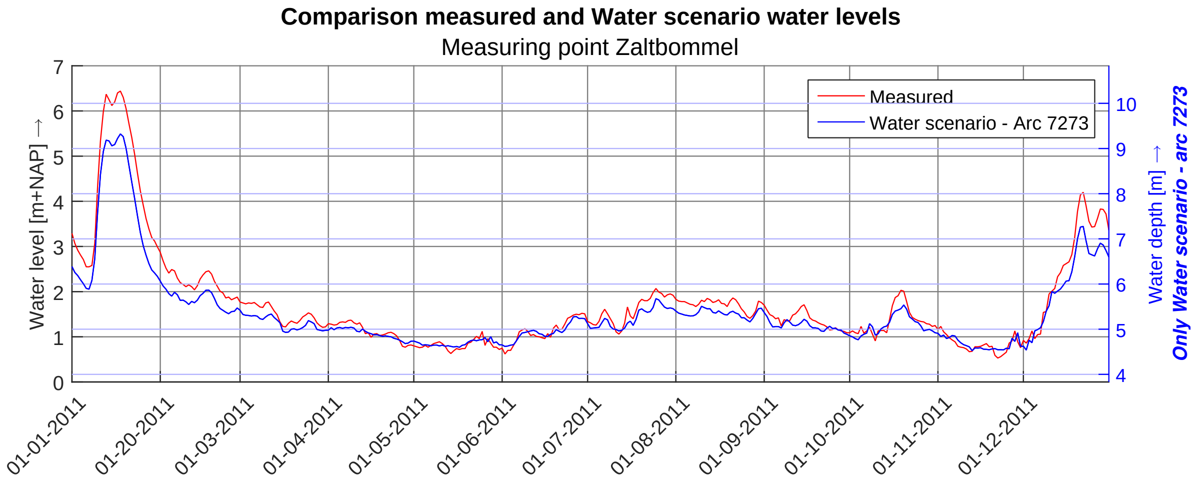


Figure 4.17: Comparison of measured and water scenario water levels; Zaltbommel 2011.

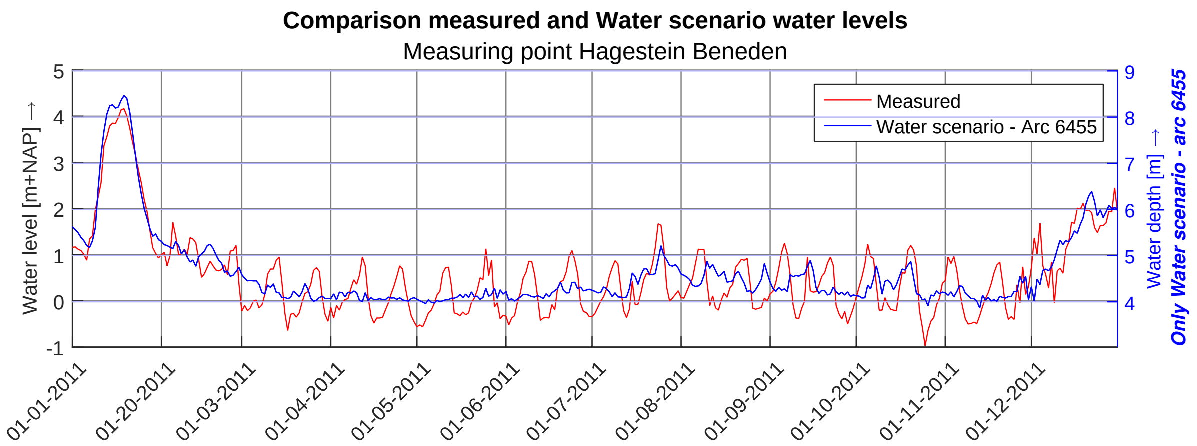


Figure 4.18: Comparison of measured and Water scenario water levels; Hagestein Beneden 2011.

4.5.2. ANALYSIS WATER DEPTH AND FLOW VELOCITIES WATER SCENARIO

Figure 4.19 shows, for the median discharge period, the average depths of the water scenario. The depth on the Waal is between 4 and 6 meters, clearly smaller than the 7 meters stored as default depth. On the Neder-Rijn, just after the intersection with the IJssel, the depth is between 3 and 4 meters, much smaller than the stored depth of 5 meters. On the remainder of the Neder-Rijn and on the Lek the depth is between 4 and 6 meters, which is more in line with the stored depth of 5 meters. On the Pannerdensch kanaal the depth is comparable to the stored water depth as well.

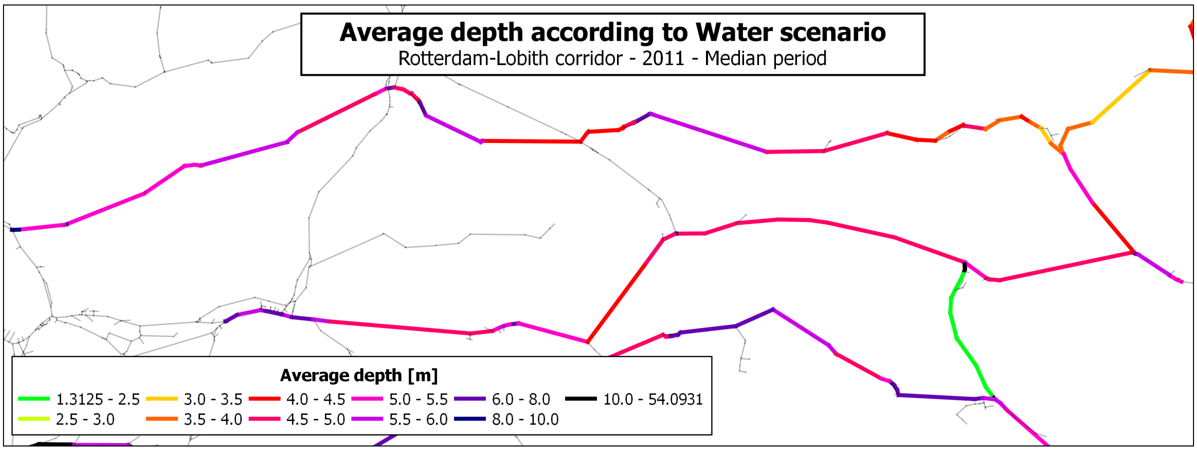


Figure 4.19: Water scenario 2011; average water depths of median discharge period on the Rotterdam-Lobith corridor (all arcs included in the water scenario; Figure H.22 in Appendix H).

Figure 4.20 shows the correction depths used in the Nieuwe Koppeling LSM-BIVAS. When these correction depths are compared to the depths in Figure 4.19 it can be seen that often when the correction depth is the water depth is smaller as well. This can for example be seen for the Neder-Rijn just after the intersection with the IJssel. Therefore part of the correction depths on the Rotterdam-Lobith corridor are expected to be too large.

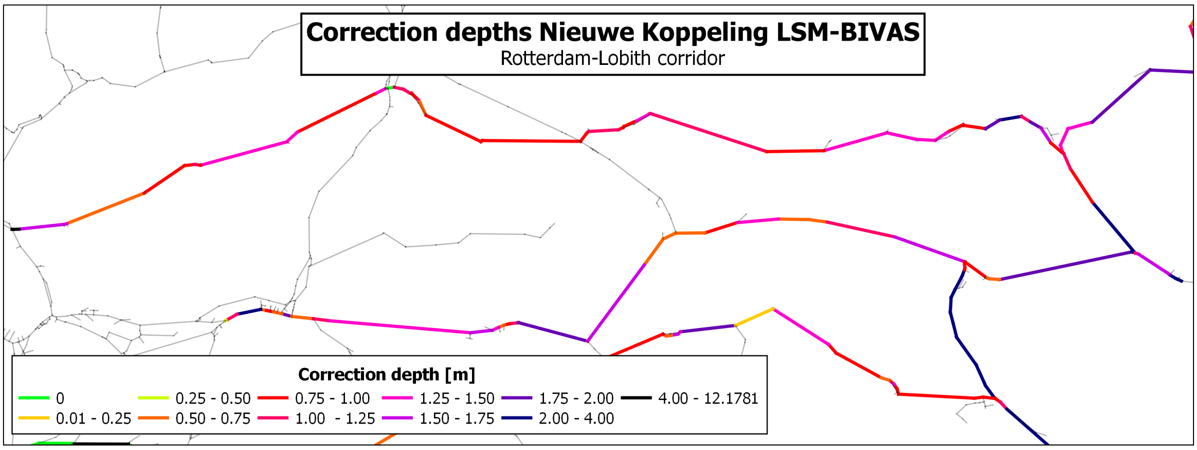


Figure 4.20: Correction depths defined in Nieuwe Koppeling LSM-BIVAS; Rotterdam Lobith corridor (all arcs included in the water scenario; Figure H.24 in Appendix H).

In Figure 4.21 the average flow velocities of the water scenario in the median discharge period are shown. The velocities in the Rotterdam-Lobith corridor are credible, since the velocities are higher upstream and never negative. In comparison to the default stored velocities the average velocities of the water scenario during the median discharge period are smaller, and the difference between the default velocities and the velocities from the water scenario is relatively larger on the Neder-Rijn and Lek than on the Waal. On one of the arcs the velocity of the water scenario is definitely wrong; on the arc of the lock at Driel the average flow velocity is 2 m/s, which is wrong since the flow velocity at a lock should be zero.

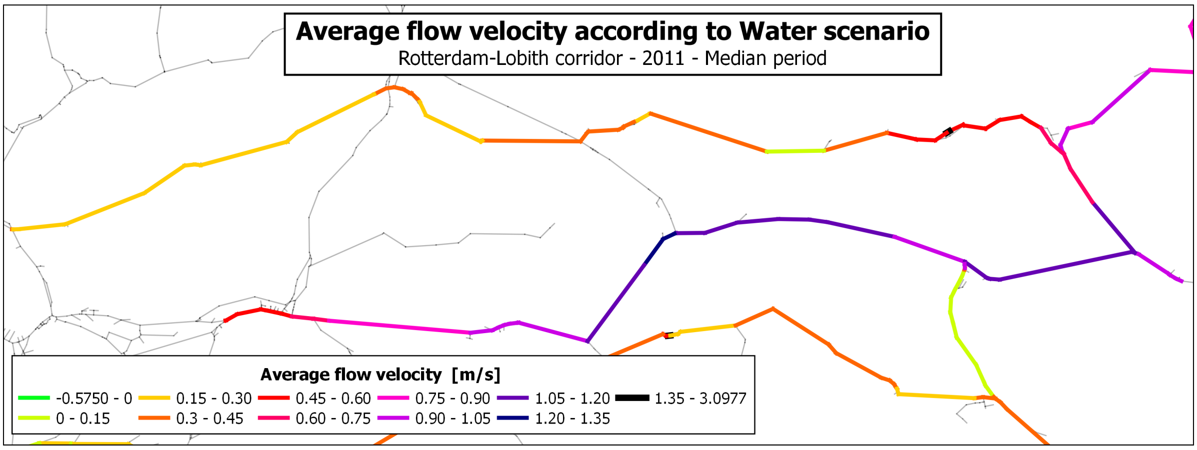


Figure 4.21: Water scenario 2011; average flow velocities of median discharge period on the Rotterdam-Lobith corridor (all arcs included in the water scenario; Figure H.23 in Appendix H).

4.6. CONCLUSIONS

This chapter addressed the analysis of the input data and the analysis of the relation between inland navigation and water conditions. Subsection 4.6.1 includes the conclusions on the input data and Subsection 4.6.2 includes the conclusions on the relation between inland navigation and water conditions.

4.6.1. INPUT DATA ANALYSIS

The location of the nodes and arcs, and the length of the arcs in BIVAS are reliable. For all other network data it holds that it is or not reliable, or just partly reliable.

The widths of the waterways are in BIVAS specified per arc, but for most arcs the average width specified per BIVAS CEMT type is used. The wet cross sectional areas are not specified per arc at all, but only per BIVAS CEMT type. For both the width and the cross sectional area it holds that in reality they vary between waterways of the same class (and change when the water conditions change). The widths are currently not used in the computation, so they do not affect the allocation of the trips by BIVAS. The wet cross sectional areas are used in the computation of the vessel speed and the wrong values might affect the allocation of the trips by BIVAS.

The majority of the default flow velocities in BIVAS seem to be plausible, but on part of the waterways within the Port of Rotterdam there is no flow, which is incorrect, since the average current of a day should always be positive seawards.

The majority of the maximum allowed widths and lengths of the vessels stored in the BIVAS database are correct. For the maximum allowed draughts it might be better to also include maximum draughts for the waterways that do not have a restriction and check the already defined maximum draughts, or to use the default depth for the definition of the maximum draught. When it is chosen to use the default depths it must be taken into account that they are incorrect and should be adjusted first.

The desired speed and the fuel usage per hour of a vessel are linked to the BIVAS CEMT class of the arc. In reality they depend on the depth and wet cross sectional area of the waterways, which can both differ significantly between waterways of the same BIVAS CEMT class. Next to this the origin of the desired vessel speed and fuel usage per hour are unknown and are part of the values certainly incorrect.

The distribution of the trips over the year differs in BIVAS from reality, because in BIVAS it is assumed that a trip takes place on only one day, while in reality a trip can take longer than a day. In principle this seems to be no problem, since the water conditions do generally not differ much over a couple of days.

The water level of the water scenario does not show much influence of the tide, while in reality the influence can clearly be seen. However, since the water conditions of the water scenario are defined per day, BIVAS computes with timesteps of a day and skippers take the tide into account in reality it is hard to define how the tide should be included in the water scenario.

The flow velocities of the water scenario seem to be plausible, but they differ strongly from the default flow velocities stored in the BIVAS database. It is the question whether the default flow velocities or the average velocities of the median period of the water scenario are most correct for an average day for inland navigation.

On arcs of the same waterway the correction depths of the Nieuwe koppeling can differ strongly. Whether this is correct is unknown, but it would be good to check them whenever possible.

Concluding it can be said that a large part of the input data is incorrect, unreliable or can not be checked. It is important to take this into account during the analysis of the results of the BIVAS computations.

4.6.2. RELATION BETWEEN INLAND NAVIGATION AND WATER CONDITIONS

The average draught of the loaded vessels follows the water level over the year. Low water levels have a stronger influence on the average draught than high water levels.

During the low discharge period it would be expected that because of more reliable water depths at the Neder-Rijn and Lek more vessels would sail via these rivers. However, this is not the case, most probably because the maximum draught a vessel can sail with during low discharge periods is defined by the water depth somewhere upstream, making the water depth at the Waal always sufficient. The Amsterdam-Rijnkanaal is used more during the low discharge period, most likely caused by the opening of the Prins Bernhardsluis during low discharge periods.

During the high discharge period the weirs in the Neder-Rijn and Lek were open. This is caused larger flow velocities and water depths on these rivers, which makes these rivers in westward direction more appealing. The Amsterdam-Rijnkanaal is less appealing during the high discharge period, most probably caused by the commissioning of the Prinses Marijkesluis, which is normally open, but in use during extreme high discharge periods.

5
SETUP OF BIVAS COMPUTATIONS

This chapter describes the setup of the BIVAS computations done. The computations are done for the various discharge periods described in Subsection 2.6.3. In Section 5.1 an overview of the computations done is given, is described how they are related to the research questions and is described which and how the results are analysed and validated. Sections 5.2 up to and including 5.7 contain the setup of the various scenario types.

5.1. OVERVIEW COMPUTATIONS

Table 5.1 gives an overview of the computations done. It includes, per scenario type, for which discharge periods computations are done, which scenario is used as base scenario, and to which sub-question it is related.

Table 5.1: Overview computations.

			Computed discharge periods			
Scenario type	**Based on**	**Sub-question**	**Whole year**	**Median**	**Low**	**High**
Rijkswaterstaat	2011: Basis	C	✓	✓	✓	✓
Without current	Rijkswaterstaat	E	✓	✓	✓	✓
Water scenario LSM	Rijkswaterstaat	E	✓	✓	✓	✓
Correct control weirs	Water scenario LSM	F	✓	✗	✗	✓
Adjusted intersection at Wijk bij Duurstede	Rijkswaterstaat / Water scenario LSM	F	✓	✓	✓	✓
Delta programme	Water scenario LSM	G	✗	✓	✗	✗

For the analysis of the present functioning of BIVAS (*sub-question C*), computations have been done with the Rijkswaterstaat scenarios; scenarios with the data and settings Rijkswaterstaat currently uses to do computations with BIVAS for an existing year. It has been chosen to do computations for the same periods as the periods used to analyse the reaction of inland navigation to changing water conditions, so it can be properly analysed how BIVAS deals with the differences in input due to changing water conditions, and what the differences are between the allocation by BIVAS and the allocation in reality.

Three result groups of the Rijkswaterstaat scenarios are analysed. At first a global analysis is done on the way the traffic scenario of 2011 is globally handled by BIVAS; which trips are not allocated or allocated with a reduced load, why does this happen, and how can this be prevented? The second group of results analysed are the statistics, which is mainly done to indicate how BIVAS broadly handles the differences in the traffic scenario between the various discharge periods. The last group of results is the allocation of the trips through the Rotterdam-Lobith corridor. For the allocation a reference comparison is carried out; per counting point and per route via the various counting points. This reference comparison should indicate which differences there are in the allocation by BIVAS and the choice of route of the skippers in reality.

From the analysis of the results of the Rijkswaterstaat scenarios it is expected that the flow velocities have a strong influence on the allocation of the trips. When a water scenario is used not only the flow velocities, but also the water depths become dynamic. To see purely the sensitivity of BIVAS for the flow velocities the Without current scenarios, scenarios without flow, are created.

Two groups of results are analysed; the statistics and the allocation of the trips through the Rotterdam-Lobith corridor. To get a view on the sensitivity of BIVAS for the flow velocities these results are compared to the results of the Rijkswaterstaat scenarios.

Currently a BIVAS scenario for an existing year does not include the varying water conditions over the year. Since in reality the water conditions do change over time computations with the Water scenario LSM scenarios including the daily varying water conditions in 2011, are done and analysed (*Sub-question E*).

The statistics and the allocation through the Rotterdam-Lobith corridor are analysed. These results are, to find out how BIVAS reacts to the daily varying water conditions, compared to the results of the Rijkswaterstaat scenarios, and to find out whether using a water scenario is an improvement or not, compared to the reference data.

After the computations including the water scenario it is investigated which changes can be made to the boundary conditions and/or input of BIVAS that could improve the performance of BIVAS (*sub-question F*). Based on this investigation two new scenario types are constructed; the Correct control weirs scenarios and the Adjusted intersection at Wijk bij Duurstede scenarios.

The Correct control weirs scenarios are constructed because the weir control is not included correctly in the present BIVAS scenarios. Opening of the weirs influences the travel time, since lockage is not needed when the weirs are open. By including a correct control of the weirs a better reflection of reality is created.

The statistics and the allocation through the Rotterdam-Lobith corridor of the Correct control weirs scenarios are compared to the results of the Water scenario LSM scenarios to find out how BIVAS reacts to the correct control of the weirs, and are compared to the reference data to investigate whether the Correct control weirs scenario type is an improvement for BIVAS

The Adjusted intersection at Wijk bij Duurstede scenario type includes an ad hoc solution for a route that is used often in BIVAS, but almost never in reality. The travel time via this route in BIVAS has been made longer in order to investigate whether the differences between the BIVAS results and reality become smaller.

The statistics and allocation through the Rotterdam-Lobith corridor are compared to the Rijkswaterstaat scenarios (reaction of BIVAS on the adjusted intersection) and the reference data (is the adjusted intersection an improvement or not?).

Finally a scenario is created for the Delta Programme (*sub-question G*). By combining water conditions of a low discharge period and ae traffic scenario of a median discharge period the additional costs for inland navigation due to smaller water depths and flow velocities can be determined.

From the Delta Programme scenario only the statistics are analysed and compared to the results of the Rijkswaterstaat scenario, with the aim to find out how BIVAS reacts to the combination of a traffic scenario of a median discharge period and a water scenario of a low discharge period.

5.2. RIJKSWATERSTAAT SCENARIOS

The Rijkswaterstaat scenario type is the scenario type including the data and settings Rijkswaterstaat uses to do computations for an existing year. The Rijkswaterstaat scenarios for all discharge periods are computed. This is done to be able to do a good analysis of the present performance of BIVAS on the allocation of the trips for the various discharge periods. The Rijkswaterstaat scenario is, with a few modifications, the base scenario included in BIVAS 3.2.2; Basis: 2011. Table 5.2 includes for the parameters that of interest for this study the settings for Basis:2011 and the settings for the Rijkswaterstaat scenarios.

From the Table it can be seen that the height restriction is disabled in both cases. This is because the height of the vessels is not derived from the IVS90, but is the same for every vessel of a certain RWS class. The difference with reality is too large and there is no source from which the height can be derived, therefore the height restriction is disabled.

Changed parameters

Dangerous goods restriction enabled On all waterways of the BIVAS network it is allowed to sail with freight with the highest dangerous good level. Therefore enabling the dangerous goods restriction makes no sence.

Enable restriction relaxation When the restriction relaxation is not enabled 15 to 20% of the trips can not be allocated. This is partly caused by wrong width and length restrictions of arcs, and partly caused by waivers given to vessels in reality. With the restriction relaxation enabled the reflection of the reality becomes better.

Travel time standard deviation To be able to analyse the allocation of the trips through the Rotterdam-Lobith corridor it has been chosen to use no travel time standard deviation.

Table 5.2: Settings parameters Basis:2011 and Rijkswaterstaat scenarios.

		Basis:2011	**Rijkswaterstaat**
Season definition		The whole year[1]	Id.
Minimum draught	*[m]*	0.5	Id.
Maximum draught	*[m]*	4.5	Id.
Length restriction enabled		✓	Id.
Width restriction enabled		✓	Id.
Dangerous goods restriction enabled		✓	✗
Depth restriction enabled		✓	Id.
Height restriction enabled		✗	Id.
Water scenario		✗	Id.
Optimization objective		Costs	Id.
Maximum unload factor for infeasible trips[2]		0.67	Id.
Idle engine use factor[3]		0.15	Id.
Traffic scenario		2011_v20140502	Id.
Travel time standard deviation	*[sec/min]*	5	0
Enable restriction relaxation		✗	✓
Length penalty[4] *(x m violation x km arc length)*	*[min]*	100,000	Id.
Width penalty[4] *(x dm violation x km arc length)*	*[min]*	100,000	Id.
Reference trip set		IVS90	Id.

[1] In order to include varying water conditions a year can be divided in seasons. The season definition indicates this division. For scenarios that do not include a water scenario there is only one season; the whole year.
[2] Indicates how much of the load may be unloaded when the trip is not possible with its given weight. For example a factor of 0.67 means that the maximum unloading is 67% of the original weight.
[3] Factor is the factor applied on the energy use while waiting for bridges and locks.
[4] Only used during the allocation of the trips. Not included in the final travel time and costs.

5.3. WITHOUT CURRENT SCENARIOS

To test the sensitivity of BIVAS for the current computations are done without current. The computations without current are done for all four discharge periods. To be able to do a computation without current a water scenario with a velocity being zero at all the waterways is used (Table 5.3). The Current_zero_all water scenario is created by exporting the water conditions of the waterways with default velocities being not zero from the SQL database as .csv-file, changing the velocities of those waterways to zero and fomatting the .csv file to the format of a water scenario.

Table 5.3: Changed settings parameters between Rijkswaterstaat scenarios and Without current scenarios.

	Rijkswaterstaat	**Without current**
Water scenario	✗	Current_zero_all

5.4. WATER SCENARIO LSM SCENARIOS

Water conditions change over time. The maximum load factor of the vessels depends on the water conditions on the waterways. Therefore applying a water scenario belonging to the traffic scenario 2011 is expected to improve the performance of the Rijkswaterstaat scenarios. The water scenario for 2011 is converted from output of the LSM. A brief description on how this is done is given in Section 3.3. The computations with the Water scenario LSM scenario type are done for all the 2011 discharge periods.

Because the water depths of the water scenarios converted from the LSM are per day, the season definition had to be changed as well. A new season definition had to be loaded into de database. In the database a season definition in days is available, but this season definition is for a leap year. If this season definition is used for a normal year the coupling of the water data and the trips is not correct after the 28th of February. All the water data at the first of March is coupled to the trips on the 29th of February, which do not exist, because there was no 29th of February. The water data at the 2th of March is coupled to the trips on the 1st of March and so on. To get a correct coupling of the water scenarios and the trips in a normal year a season definition is made where the 29th of February is left out.

The parameters changed between the Rijkswaterstaat scenarios and the Water scenario LSM scenarios are given in Table 5.4.

Table 5.4: Changed settings parameters between Rijkswaterstaat scenarios and Water scenario LSM scenarios.

	Rijkswaterstaat	Water scenario LSM
Season definition	The whole year	Days_without_29-02
Water scenario	✗	Water_scenario_LSM_2011

5.5. CORRECT CONTROL WEIRS SCENARIOS

The following weirs which are part of the Rotterdam-Lobith corridor are present in BIVAS:

- Driel, Stuw - *Neder-Rijn, east*
- Amerongen, Stuw - *Neder-Rijn, west*
- Hagestein, Stuw - *Lek, east of Merwedekanaal*

In BIVAS the weirs are controlled on the water level of the weir itself. Table 5.5 gives the default minimum water level at which the weirs will be opened, and the stored water levels at the weirs when no water scenario is included. From the table it can be seen that when no water scenario is included, the weirs will be closed during the whole year. Beside this, the values of the minimum water levels at which the weirs are opened are incorrect. This is concluded from a comparison between the measured water levels (token from Waterbase (Helpdesk Water, 2015)) just above and just below the weirs. This comparison is visualized in Figure 5.1.

Table 5.5: Default minimum water levels at which weirs in the Neder-Rijn and Lek are openend and the water levels at those weirs stored in BIVAS.

	Minimum water level at weir to be opened [m]	Stored water level [m]
Driel	10	0
Amerongen	11.4	0
Hagestein	11.4	0.88

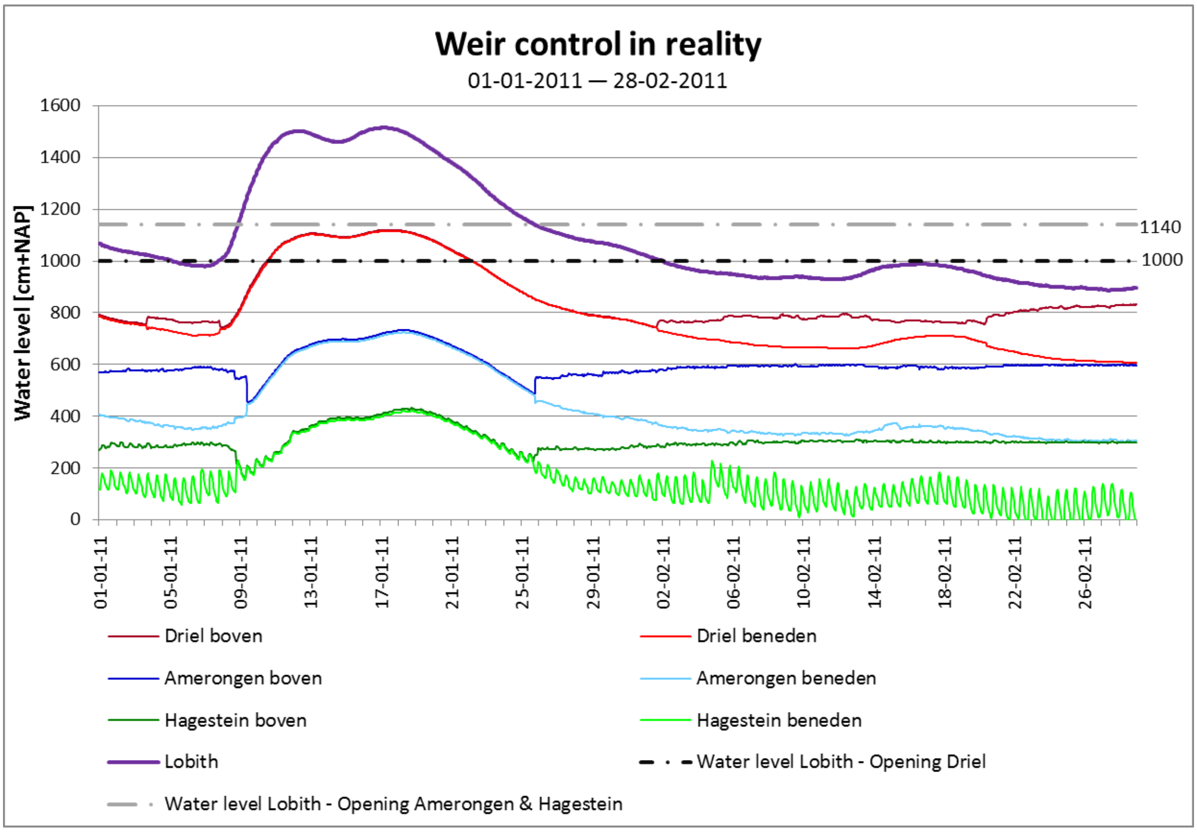


Figure 5.1: Weir control in reality, 01-01-2011 - 28-02-2011.

The minimum water levels stored in BIVAS at which the weirs are opened seem to be the water levels at Lobith at which the weirs are opened. This appears to be so, because in several news articles of Rijkswaterstaat on the opening of the weirs it is stated that the weir at Driel is opened when a water level of 10m +NAP is reached at Lobith and and the weirs at Amerongen and Hagestein are opened when a water level of 11.4m +NAP is reached at Lobith. Figure 5.1 supports this.

In reality the weirs are open during flood periods. For vessels it is then possible to sail through the opened weir instead of using the lock, which reduces the travel time via the Lek and Neder-Rijn. In BIVAS the weirs are not opened when no water scenario is included because of the default water level values at the weirs, which are lower than the minimum water levels at the weirs to be opened. It is expected that the performance of BIVAS during flood periods will improve when the weirs are opened during these periods.

As described above the weirs are in reality controlled by the water level at Lobith. When the water level at Lobith reaches 10m +NAP the weir at Driel is opened and when the water level at Lobith reaches 11.4m +NAP the weirs at Amerongen and Hagestein are opened. When the water level at Lobith drops below 11.4m +NAP the weirs at Amerongen and Hagestein are closed and when the water level drops below 10m +NAP the weir at Driel is closed.

The water scenario from the Nieuwe Koppeling LSM-BIVAS does not include water data for the weirs. This means that when the water scenarios from the LSM are used the water levels and flow velocities at the arcs thath are weirs, are not changed. So, the weirs in BIVAS will not be open when they were open in reality. In order to ensure that this does happen the Nieuwe-Koppeling LSM-BIVAS is adjusted. The arcs of the weirs are added to the conversion and the water level is added for all the arcs which are part of the conversion.

For the weirs it has been chosen not to link the water level at the weir, but the water level at Lobith. This is done because the water level at the weirs when they are opened or closed is not always the same water level. Next to this, the water levels at the weirs drop after opening of the weirs, and the water levels at the weirs are in reality during the year sometimes higher than the water levels at which the weirs are opened. Figure 5.1 illustrates this.

From the figure it can be seen that the water level at the weirs drops after the opening of the weirs. It can also be seen that the weir at Driel is opened around 7,5m +NAP, and that the water level at Driel upstream of the weir (Driel boven) was over 8m +NAP while the weir was closed and the water level at Lobith was below 10m +NAP. By controlling the weirs on the water level at Lobith it is the expectation that the weirs will be controlled in BIVAS most like they were controlled in reality.

The computations are done for the high discharge period and for the whole year. The other periods are not calculated, because in those periods there were no days at which the water level at Lobith was above 10m +NAP.

5.6. ADJUSTED INTERSECTION AT WIJK BIJ DUURSTEDE SCENARIOS

From the analysis of the computations with the preceding scenario types it appears that the amount of vessels sailing via the Lek, Amsterdam-Rijnkanaal and Waal to Germany is excessively high in BIVAS compared to reality. In reality there are only a few vessels turning from the Lek on to the Amsterdam-Rijnkanaal South at the intersection of the Lek, Neder-Rijn and Amsterdam-Rijnkanaal at Wijk bij Duurstede.

In order to get a better ratio between the number of vessels in BIVAS taking this route and the number of vessels in reality taking this route the intersection at Wijk bij Duurstede is adjusted in such a way that only the turn from the Lek to the Amsterdam-Rijnkanaal South has an artificial delay during the computation. Figure 5.2 is a schematization of how this is done. Since the network in BIVAS only exists of nodes and arcs between those nodes the construction of the figure had to be made. In this way only the vessels turning between the Lek and the Amsterdam-Rijnkanaal get an artificial delay during the computation. The extra arcs of the adjusted intesections have exactly the same properties as the original arcs. The distance from the original intersection of the extra arcs is at least 5km, this is done, because when the artificial delay is high and the distance of the extra arcs is not far enough from the original intersection,

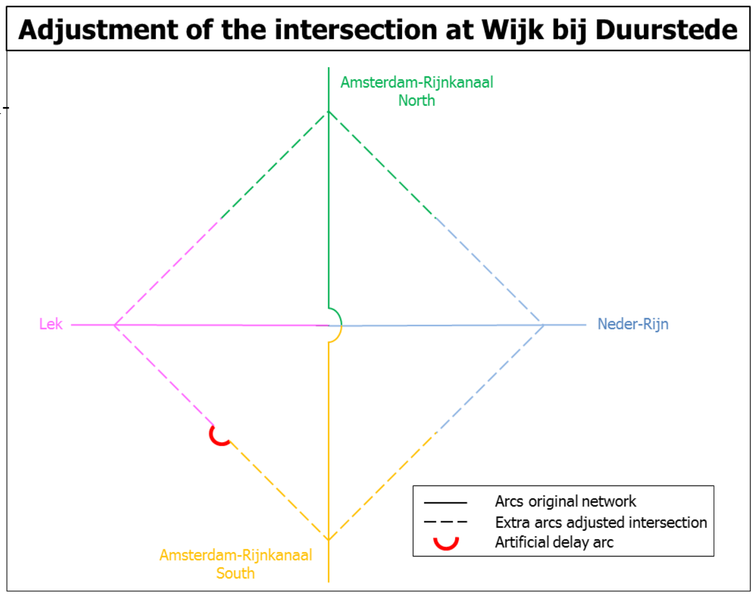


Figure 5.2: Adjusted intersection at Wijk bij Duurstede.

the route via the pink, blue and yellow lines will be faster/cheaper then the route via the artificial delay arc, which is not wanted since then the delay arc is not functional anymore. In BIVAS it is possible to add an artificial delay to an arc, that is only used during the allocation of the trips. So, the time and costs of the artificial delay are not included in the final result of the computation.

The computations are done for all periods, since the adjustment has an effect for all the periods. The optimal artificial delay per period is iteratively found by performing computations with various artificial delays.

It was not possible to create new arcs, BIVAS does not work properly anymore when new arcs are added to the SQL-database. Therefore arcs were used via which no vessels were allocated for the Rijkswaterstaat scenarios.

5.7. DELTA PROGRAMME SCENARIO

The present way BIVAS is used for the Delta Programme is incorrect. For the Delta Programme traffic scenarios representing a certain year are used. The types and load factors of the vessels used for the trips in these traffic scenarios are therefore adapted to the water conditions corresponding to these trips. The water scenarios used for the Delta Programme are also of a certain year, so it can be that the water conditions support the traffic scenario during part of the year and during another part of the year are the complete opposite.

One of the goals of the Delta Programme is to compute the expected economic loss for inland navigation due to climate change. It is expected that a computation with a water scenario of a low discharge period and the traffic scenario of a median discharge period can be used to find the expected economic loss due to climate change.

The trips of the median discharge period are the ones that took place in reality during median water conditions and therefore the trips for which there is no economic loss. By taking these trips and a water scenario of a low discharge period the economic loss due to lower water levels can be computed.

For the Delta Programme scenario the Water scenario LSM scenario is used as base, with the water conditions of the low discharge period shifted to the median discharge period.

5.8. CONCLUSIONS

The Rijkswaterstaat scenario type is the scenario type that is currently used by Rijkswaterstaat to do computations for an existing year. This scenario type is not the same as the base scenarios stored in BIVAS. The recommendation is to adjust the base scenarios to the Rijkswaterstaat scenario type in new versions of BIVAS.

The stored season definition in days is for a leap year. In new versions of BIVAS it is adviced to add a season definition for normal years as well.

In BIVAS the weirs at the Neder-Rijn and Lek are controlled on the water level at the weirs, while in reality they are controlled on the water level at Lobith. By taking the water level at Lobith as the water levels at the weirs the weirs can be controlled in the right way, but this is a "dirty" solution. It is adviced to note this in the BIVAS documentation or to change this to a more "clean" solution.

For the construction of the adjusted intersection at Wijk bij Duurstede it was not possible to create new arcs. Therefore it has been chosen to replace arcs that were not used in the Rijkswaterstaat scenarios. For new versions of BIVAS it should be made possible to create new arcs.

6
RESULTS RIJKSWATERSTAAT SCENARIOS

In this chapter the differences between the reference data and the results of the Rijkswaterstaat scenarios are examined. Section 6.1 gives a global analysis of how BIVAS handled the traffic scenario. The trips for which no route has been searched, the infeasible trips and the trips for which the load has been reduced are examined and the intensities on the various waterway sections are analysed. Section 6.2 consists of analysis of the overall scenario statistics for the different discharge periods and Section 6.3 consists of a thorough analysis of the results for the Rotterdam-Lobith corridor. In this section the results of the computations with BIVAS are compared to the available reference data. The last section of this chapter, Section 6.4 summarises the conclusions of the chapter.

6.1. GLOBAL ANALYSIS

A global analysis is done on the way the traffic scenario of 2011 is globally handled by BIVAS; which trips are not allocated or allocated with a reduced load, why does this happen, and how can this be prevented? Table 6.1 contains global data about the way the traffic scenario was handled by the Rijkswaterstaat Whole year scenario. Subsections 6.1.1, 6.1.2 and 6.1.3 address the errors in this data. In Subsection 6.1.4 the distribution of the trips by BIVAS in comparison to the reference data is addressed.

Table 6.1: Rijkswaterstaat Whole year scenario; statistics of importance for global analysis

Rijkswaterstaat		**Whole Year**
Trips in traffic scenario	[a]	445,527
Trips for which a route has been searched	[b]	440,876
Trips for which no route has been searched	[a - b]	4,651
Trips for which a route has been found	[c]	439,287
Infeasible trips	[b - c]	1,589
Trips including extra trips through reduced of load	[d]	444,520
Extra trips through trips for which the load has been reduced	[c - d]	5,233
Trips for which the load has been reduced		18,233

6.1.1. TRIPS FOR WHICH NO ROUTE HAS BEEN SEARCHED

From Table 6.1 it can be seen that for 4,651 trips no route has been searched. There are two causes for this. The first cause holds for only a small part of the trips; nineteen trips. For these trips the origin or destination node does not exist in the BIVAS network. This is the case for the nodes 8764 and 8773. It appears that these nodes do exist in the SQL-database included with BIVAS 2.7, where they are located near Ghent, Belgium. From BIVAS 3.0, the TRANS-TOOLS network is used for the arcs and nodes outside of the Netherlands. Nodes 8764 and 8773 were hereby replaced by nodes from the TRANS-TOOLS network, but are still included in the conversion of the IVS data to the traffic scenario. Since the TRANS-TOOLS network is more extensive than the old foreign network it is not easily defined which new nodes reflect the old nodes 8764 and 8773.

The second cause holds for all the other trips; 4,632 trips. These trips are trips for which the destination node is the same as the origin node. BIVAS can not handle these trips, because in BIVAS these trips are seen as trips for which no movement takes place. Table I.1 in Appendix I contains per node and zone the number of trips for which this is the case. The four nodes for which the number of trips that have the same destination as origin is the highest are discussed below.

21255 - 410 trips

Node 21255 lies in the Port of Antwerp. The trips for which this node is the origin and destination node are trips with all kinds of vessel types that are mainly empty. The port area of this port is only included in outline in the BIVAS network, whereby multiple branches of the port are assigned to the same node. So, when a vessel is unloaded at branch A of the port and it moves to branch B of the port in order to be loaded again, it has not moved in the BIVAS network when branches A and B are represented by the same node.

8308 - 420 trips
Node 8308 is located in the canal through Zuid-Beveland in the province Zeeland. The trips for which this node is the origin and destination node, are trips with mainly empty M0 vessels. There are two possible reasons for these trips. At first there is a shipyard located within the area near the node which caries out afloat repairs and repairs while vessels are sailing. The vessels used for those repairs sail to a vessel and then back to the shipyard. This is probably listed as one trip, since a vessel is not seen as a destination. Besides the shipyard there is also a bunker station located in the area near the node. A bunker station has bunker vessels which sail from the bunker station to a vessel that need to be bunkered, and back to the bunker station. Here again this is probably listed as one trip .

3291 - 519 trips
Node 3291 is located in the industrial port of Meppel. The trips for which this node is the origin and destination node are trips with mainly loaded pushed convoys. These trips pass various IVS90 countingpoints according to the IVS90 data. It seems that round trips are recorded as one trip in the IVS90. Why this is case for this specific node is unknown.

8308 - 588 trips
Node 8308 lies again in a port; the Port of Amsterdam. It is located in the area of a bunker station. Since the trips for which this node is the origin and destination node are trips with mainly empty M0 vessels it is expected that the trips are trips with bunker vessels that sail between vessels and the bunker station, which is probably listed as one trip.

Since there are several causes for the trips with the same destination as origin node, there are also several solutions to make sure these trips will not be like this in the traffic scenario anymore. For trips between branches within a port the network should be extensived and the roundtrips that are recorded as one trip in the IVS90 should be splitted into two trips. The solution for the trips because of afloat repairs or bunkering is more difficult to define since these trips can have a moving destination. It might be a solution to take them out of the traffic scenario completely.

6.1.2. INFEASIBLE TRIPS

Infeasible trips are trips for which a route is sought in BIVAS, but not found. There are 1,589 infeasible trips. These trips can be divided in two groups.

The first group consists of trips that are not possible because their origin and destination node are not connected to each other. This is the case for fifteen trips that have the nodes 21676, 21667 or 21666 as origin or destination. These nodes lie on the Peene in Germany. Figure 6.1 shows that nodes 21676 and 21677 are not connected by an arc. By adding an arc between these nodes this group of infeasible trips will not be infeasible anymore.

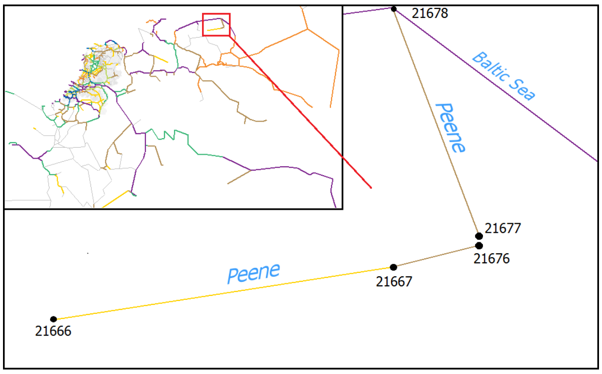


Figure 6.1: Arcs representing the Peene, that are not connected to the rest of the network.

The other group is a group of 1,574 trips. These are infeasible because they are not possible due to draught restrictions, even when the load is reduced by the maximum unload percentage (67%). On a random basis, a number of these trips have been examined. From this examination it seems that incorrect draught restrictions on subsidiary waterways, or violations of the draught restrictions in reality are the reason these trips are infeasible. Adjusting the maximum draught on these waterways to the correct values would solve the infeasibility of these trips.

6.1.3. TRIPS WITH REDUCED LOAD

For part of the trips BIVAS could not find a route without reducing the load.

Trips not possible in BIVAS in first instance, but possible when the load is reduced by maximum 67%, are the trips for which the load has been reduced. When the load is reduced for a trip, the number of trips of this trip is increased by the number of times that the vessel has to sail extra in order to bring all freight to the destination. The number of additional trips is not necessarily an integer. For example when ten percent of the freight can not be

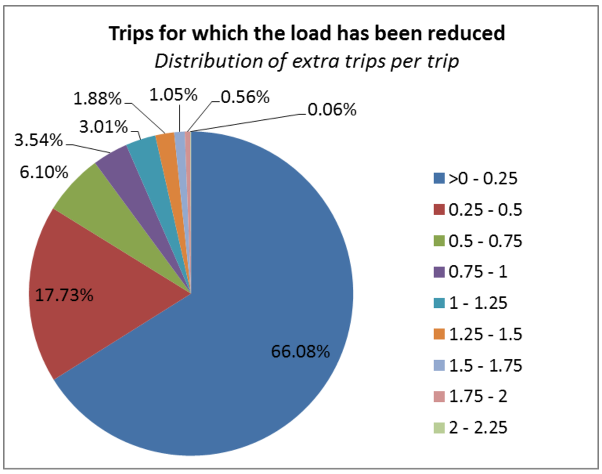


Figure 6.2: Rijkswaterstaat Whole year scenario; distribution of the amount of extra trips per trip for which the load has been reduced.

brought on the first trip the number of additional trips is 10/90≈0.111. Table 6.1 shows that the number of trips for which the load has been reduced is 18,233. These trips together add 5,233 extra trips to the total number of trips for the Rijkswaterstaat Whole year scenario. Figure 6.2 shows the distribution of additional trips per trip for which the load has been reduced. About two-thirds of the trips for which the load has been reduced have a small increase (< 0.25) of the number of trips.

In reality the vessels were able to sail with the original draught included in the traffic scenario. Incorrect draught restrictions in BIVAS or violations of the draught restrictions in reality are the cause of the trips with reduced load. Checking and adjusting the maximum allowed draught on the BIVAS arcs will solve the problem.

6.1.4. Distribution of the trips over the BIVAS network

For the Rijkswaterstaat Whole year scenario the distribution of the trips over the Dutch part of the BIVAS network is shown in Figure 6.3. The boxed sections in the figure are the intensities measured in reality at the IVS90 counting points. It can be seen that the computed intensities are generally of the same order of magnitude as the measured intensities. The main North-South and West-East connections are clearly visible in the figure.

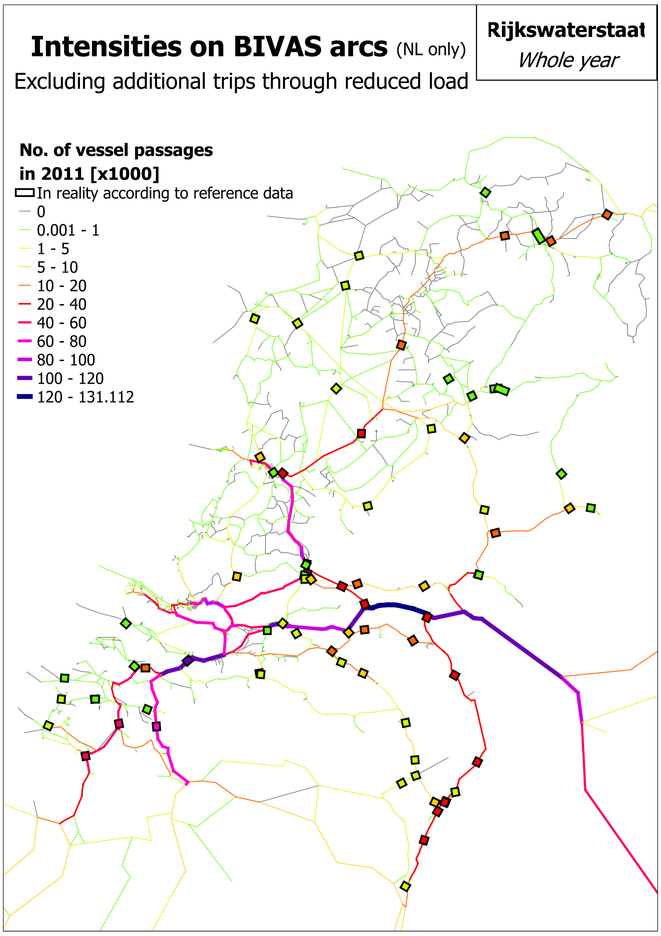


Figure 6.3: Rijkswaterstaat Whole year scenario; intensities on the Dutch BIVAS network, and measured intensities in reality (Fullsize; Figure I.1 in Appendix I).

Figure 6.4 shows, for the Rijkswaterstaat Whole year scenario, the distribution of the trips over the Rotterdam-Lobith corridor and the intensities measured in reality at the IVS90 counting points. There is a substantial difference between the measured intensities and the instensities computed by BIVAS. The ratio between the measured intensities and the intensities computed by BIVAS are approximately; 3 (Merwedekanaal), 0.6 (Lek between Merwedekanaal and Amsterdam-Rijnkanaal), 0.9 (Amsterdam-Rijnkanaal) and 1.1 (Neder-Rijn). BIVAS allocates not enough trips via the Merwedekanaal and the Neder-Rijn and too many trips via the Lek and the Amsterdam-rijnkanaal. The figure shows that the Waal is the main waterway and the Lek and the Neder-Rijn are the secondary waterways for traffic from and to Germany. The ratio of the number of trips using the Lek and Neder-Rijn and the Waal lies between the 8:1 (Between Mewedekanaal and Amsterdam-Rijnkanaal) and 16:1 (Between Amsterdam-Rijnkanaal and Maas-Waalkanaal) according to the Rijkswaterstaat Whole year scenario.

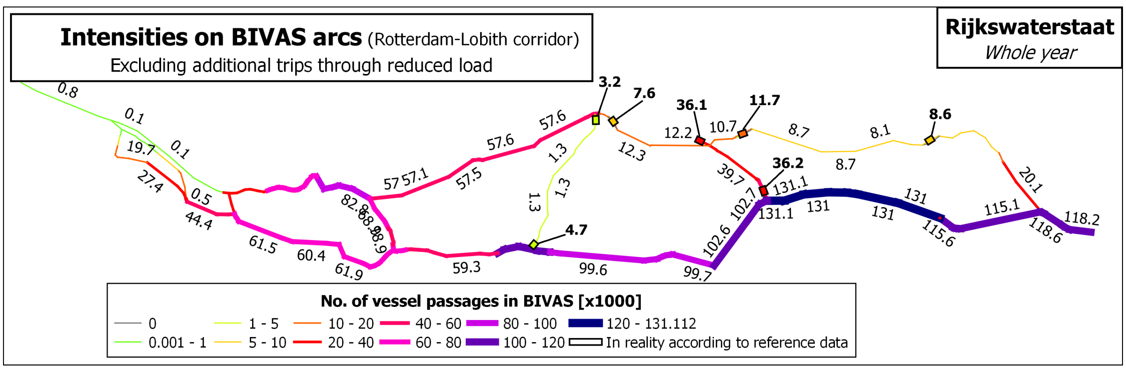


Figure 6.4: Rijkswaterstaat Whole yearscenario; intensities on the Rotterdam-Lobith corridor, and measured intensities in reality.

6.2. STATISTICS ANALYSIS

The statistics are mainly analysed to indicate how BIVAS broadly handles the differences in the traffic scenario between the various discharge periods. Table 6.2 contains overall statistics of the Rijkswaterstaat scenarios. The table shows clear differences between the Low, Median and High scenarios. These differences are primarily caused by the differences in the composition of the trips for the different discharge periods.

Table 6.2: Rijkswaterstaat scenarios; overall statistics.

		Whole year	**Median**	**Low**	**High**
Trips for which route is searched	[No.]	440876	17119	18793	14247
Infeasible trips	[No.]	1589	55	71	70
	[%[1]]	0.36%	0.32%	0.38%	0.49%
Additional trips due to reduced load	[No.]	5233	212	180	168
	[%[1]]	1.19%	1.24%	0.96%	1.18%
Costs per tonne kilometer	[(€/(tkm))x10^3]	22.27	20.07	30.42	19.98
Average load factor loaded trips	[-]	0.65	0.68	0.57	0.68

[1]Of total number of trips in the scenario for which a route has been searched by BIVAS.

The total number of trips during the low discharge period is significantly higher and the load factor significantly lower than during the median discharge period. This is because the maximum draught that could be sailed with, was smaller in this period, resulting in more trips and a lower load factor.

BIVAS computes a slightly higher percentage of infeasible trips for the Low scenario than for the Median scenario. This is probably a coincidence, since for the Rijkswaterstaat scenarios the default maximum draughts are used. Because of the, on average, smaller draughts of the trips during the low discharge period, the default maximum draughts should basically be less often a problem for the trips of the Low scenario than for the trips of the Median scenario. That the default maximum draughts are less often a problem for the trips of the Low scenario can be seen from the percentage of additional trips due to reduced load, which is significantly lower for the Low scenario than for the Median scenario. The smaller load factor of the trips in the low discharge period results in 1.5 times larger costs per tonne kilometre for the Low scenario than for the Median scenario.

Far fewer trips were carried out during the high discharge period than during the median discharge period because of disruptions on the network (see Subsection 4.3.1). The load factor is for the High scenario the same as for the Median scenario. During high discharge periods there are vessels that can sail with more load, because they can sail with a larger draught, but also vessels that can sail with less load, because there is less headroom available under fixed bridges. These two effects cancel each other out, resulting in about the same average load factor, costs per tonne kilometre and percentage of additional trips due to reduced load for the High scenario as for the Median scenario. The percentage of infeasible trips is significantly higher for the High scenario than for the Median scenario which is probably caused by the trips with larger draughts in the high discharge period.

The effect of the low discharge periods in 2011 can clearly be seen in the Whole year scenario. For the whole year the average load factor is ≈4.5% lower, and the costs per tonne kilometer are ≈10% higher than during the median and high discharge periods. This supports the fact that 2011 was a dry year.

6.3. REFERENCE COMPARISON ROTTERDAM-LOBITH CORRIDOR

The comparison with the reference data takes place in two steps. At first on counting point level (Subsection 6.3.1), whereby the number of passages at the locks within the Rotterdam-Lobith corridor in BIVAS are compared to those according to the IVS90. Secondly the comparison is done on route level (Subsection 6.3.2). For this comparison the number of vessels taking a certain route in BIVAS are compared to the number of vessels that took this route in reality according to the IVS90.

6.3.1. REFERENCE COMPARISON NO. OF PASSAGES PER IVS COUNTING POINT

For all scenarios are, per direction of the counting points and per load type (empty or loaded), the number of passages in BIVAS compared to the number of passages in reality. All the results of this comparison can be found in Table I.3 of Appendix I.

For all scenarios there are great differences between the number of passages at the various IVS counting points in BIVAS and in reality. To determine for which scenario the trips are allocated the most accurate, is for each scenario the average deviation from the reference computed. This average deviation is computed with Equation 6.1. Table 6.3 includes the average deviations of the various scenarios.

$$D = \frac{\sum_{i=1}^{n} |B_i - R_i|}{\sum_{i=1}^{n} R_i} \tag{6.1}$$

Where:

D = Average deviation from the reference for a certain scenario
B_i = Number of passages in BIVAS, divided by counting point and direction (i).
R_i = Number of passages in reality, divided by counting point and direction (i).

Of the three different discharge periods the median discharge period scenario has the smallest average deviation and the low discharge period the highest, which is as expected. The water conditions in BIVAS are for all periods the same, which is not the case in reality, and in reality clear differences in choice of route by the skippers can be seen for the different discharge periods, see Section 4.4. The average deviation is the smallest for the Whole year scenario. This is caused by contradictions in the deviations for the low and high discharge periods, that cancel each other out.

Since the default water conditions of BIVAS are intended to reflect a median day, the smallest average deviation for the Median scenario is as expected. That the deviation for the Low scenario is the largest is also expected, since in reality the allocation during the low discharge period differs as well the most from the allocation during the median discharge period.

Because the default water conditions of BIVAS represent a median day and these are the water conditions used for the Rijkswaterstaat scenarios, BIVAS should be able to allocate the trips of the median scenario as in reality. Therefore it has been chosen to analyse the median scenario thoroughly. Figure 6.5 contains the ratios between the number of passages in BIVAS and the number of passages according to the IVS90 for part of the counting points. Table 6.4 contains these as well, but also the actual numbers.

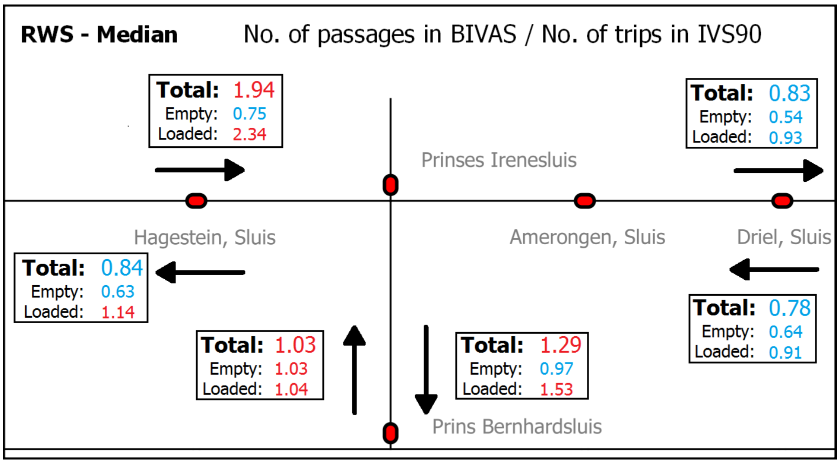


Figure 6.5: Rijkswaterstaat Median scenario; number of passages in BIVAS/number of passages in IVS90, per IVS90 counting point and direction.

Table 6.3: Average deviation from IVS90 for Rijkswaterstaat scenarios; counting point level.

	D
Whole year	0.12
Median	0.13
Low	0.19
High	0.26

Table 6.4: Rijkswaterstaat Median scenario; comparison number of passages BIVAS and IVS90, per IVS90 counting point and direction.

Rijkswaterstaat - Median		No. of passages in BIVAS / No. of passages in IVS90						
		IVS90	**BIVAS**	***Ratio***		**IVS90**	**BIVAS**	**Ratio**
Hagestein, Sluis	**East**	202	392	1.94	**Empty**	51	38	0.75
					Loaded	151	354	2.34
	West	87	73	0.84	**Empty**	51	32	0.63
					Loaded	36	41	1.14
Driel, Sluis	**East**	267	221	0.83	**Empty**	69	37	0.54
					Loaded	198	184	0.93
	West	104	81	0.78	**Empty**	50	32	0.64
					Loaded	54	49	0.91
Prins Bernhardsluis	**North**	690	714	1.03	**Empty**	268	276	1.03
					Loaded	422	438	1.04
	South	712	922	1.29	**Empty**	296	287	0.97
					Loaded	416	635	1.53

A very small portion of the difference between BIVAS and the IVS90 is caused by the trips that are present in the reference trip set, but not in the traffic scenario, extra passages due to passing more than once per trip

(Subsection 4.4.2), the trips for which no route has been searched (Subsection 6.1.1) and the infeasible trips (Subsection 6.1.2).

From Figure 6.5 it can be seen that BIVAS allocates, in both directions and for both the empty and loaded vessels, too few trips via the Neder-Rijn (Driel, Sluis) and that the difference for the loaded vessels is smaller than for the empty vessels. A possible explanation for the smaller number of passages in BIVAS is that the delay caused by the locks has a larger influence on the allocation in BIVAS than it has in reality on the choice of route. The difference between the empty and loaded vessels can only be related to the differences in the draughts and the vessel speeds between the empty and the loaded vessels because these parameters are the only two that are different between the loaded and the empty vessels. the effect of these parameters is further investigated in the analysis of the Without current and the Water scenario LSM scenarios.

For the empty vessels on the Lek the same as for the Neder-Rijn holds, but is the other way round for the loaded vessels. The number of extra passages via Hagestein, Sluis and the Prins Bernhadsluis in Table 6.4 show thath the extra loaded vessels that sail eastward on the Lek seem to prosecute their route via the Amsterdam-Rijnkanaal and vice versa. Whether this is indeed the case is further examined on routelevel.

6.3.2. COMPARISON WITH REFERENCE DATA ON ROUTE LEVEL

The comparison on route level is done for the four remarkable routes defined in Subsection 4.4.3. For all the scenarios are, per route, the number of routes in BIVAS compared to the number of routes according to the IVS90. Table I.4 in Appendix I includes the results for all the scenarios. Here only the results of the Median scenario are analysed.

Table 6.5 shows the number of passages in BIVAS, the number of passages in reality and the ratio between them for the Median scenario. Figure 6.6 is a visualization of the ratios in Table 6.5.

Table 6.5: Rijkswaterstaat Median scenario; comparison number of routes in BIVAS to number of routes according to the IVS90, for the remarkable routes, in total and per load type.

Rijkswaterstaat - Median	No. of routes BIVAS/No. of routes IVS90						
	IVS90	**BIVAS**	**Ratio**		**IVS90**	**BIVAS**	**Ratio**
Prinses Irenesluis - Prins Bernhardsluis	592	632	1.07	**Empty**	200	202	1.01
				Loaded	392	430	1.10
Prins Bernhardsluis - Prinses Irenesluis	586	649	1.11	**Empty**	243	267	1.10
				Loaded	343	382	1.11
Hagestein, Sluis - Amerongen, Sluis - Driel, Sluis	129	130	1.01	**Empty**	13	6	0.46
				Loaded	116	124	1.07
Hagestein, Sluis - Prins Bernhardsluis	26	216	8.31	**Empty**	23	20	0.87
				Loaded	3	196	65.33

The first thing that can be seen from Table 6.5 and Figure 6.6 is that the number of vessels taking one of the routes via the Prins Bernhardsluis and the Prinses Irenesluis is, for both directions, too large in BIVAS. The vessels that are, but should not have been, allocated via one of these routes ,should have taken a route including the Neder-Rijn or Lek and the Prinses Irenesluis. It seems that the Waal in combination with the Amsterdam-Rijnkanaal has not enough resistance in BIVAS in comparison to the Neder-Rijn or the Lek.

The ratios for the empty vessels via the routes *Hagestein, Sluis - Amerongen, Sluis - Driel, Sluis* and *Hagestein, Sluis - Prins Bernhardsluis* are too small, while the ratios for the loaded vessels are too large, which supports the findings for the comparison on lock level and will be further investigated in the analysis of the Without current and the Water scenario LSM scenarios.

The ratio for the number of loaded vessels via the route *Hagestein, Sluis - Prins Bernhardsluis* is extremely large. Which suggests that the Lek in combination with the Amsterdam-Rijnkanaal has a smaller resistance than the Waal east of the Amsterdam-Rijnkanaal. However, this contradicts with the findings on the two routes via the Prins Bernhardsluis and the Prinses Irenesluis. It could be that only the Neder-Rijn has a too large resistance in comparison to the Amsterdam-Rijnkanaal and the Lek, but there is as another possible cause as well.

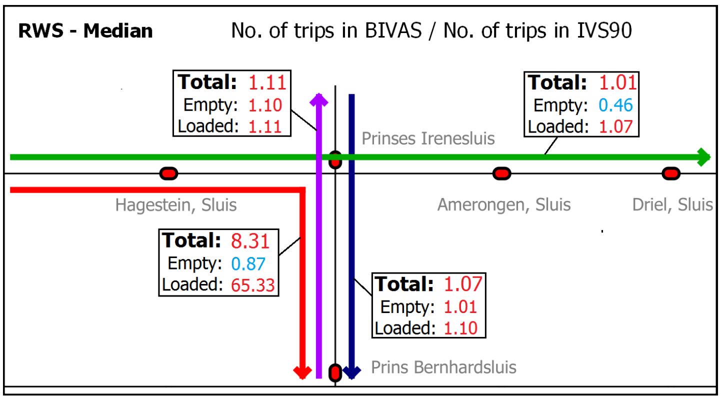


Figure 6.6: Rijkswaterstaat Median scenario; ratios between the number of routes in BIVAS and the IVS90. Per remarkable route, in total and per load type.

The other possible cause is that the origin nodes of the extra routes via *Hagestein, Sluis - Prins Bernhardsluis* are incorrect. As origin is in the IVS90 for part of the trips only the UNLOCODE included. This code is a locationcode existing of a Landcode and Placecode. For Rotterdam this code is for example NLRTM. RWS-DVS (2013) describes how the trips with only this UNLOCODE are linked to BIVAS origin and destination nodes. Per vessel type and UNLOCODE the nodes are defined that have the most trips leaving or arriving based on the trips for which more location data is availabe. Trips with only a UNLOCODE are then linked to a node based on their vessel type. Whether this node is indeed the node that is the most close to the origin of destination of the trip in reality is the question.

It is well possible that part of the trips taking the route *Hagestein, Sluis - Prins Bernhardsluis* do not have the correct origin node. For 120 of the trips nodes that are designated to trips that only included the UNLOCODE are the origin nodes. Given the difference between the number of trips that are allocated in BIVAS via the route and that went via the route in reality (see Table 6.5), this can not be the only cause.

6.4. CONCLUSIONS

From the global analysis of the Rijkswaterstaat scenarios it was found that for ≈1% of the trips in the traffic scenario no route is searched at all. There are two causes for this:

- Origin or destination nodes that do not exist in the present BIVAS network.
- Same origin node as destination node.

There are also trips that BIVAS could not allocate; the infeasible trips. This is caused by:

- A gap in the network at the Peene in Germany.
- Incorrect draught restrictions on part of the subsidiary waterways.
- Violations of the draught restrictions on the subsidiary waterways in reality.

Next to the infeasible trips there are trips that were not possible in BIVAS with the load the vessels carried in reality. For these trips additional trips due to reduced load are computed by BIVAS. The causes for these additional trips due to reduced load are also the second and third cause for the infeasible trips.

Comparison of the intensities on the waterways computed by BIVAS with the intensities measured in reality shows that globally the computed intensities are of the same order of magnitude as the measured intensities. Looking more closely into the Rotterdam-Lobith corridor shows that not enough trips are allocated via the Merwedekanaal and the Neder-Rijn and too many trips are allocated via the Lek and the Amsterdam-Rijnkanaal.

Since the water conditions of the Rijkswaterstaat scenario represent a median day the median period should be the period for which the average deviation in the allocation from the reference is the smallest. From the three two-week periods the median period turns out to have the smallest deviation. However, the smallest average deviation overall, is the deviation for the Whole year scenario. This is caused by contradictions in the deviations for the low and high discharge periods that cancel each other out.

There is a large difference in the average deviation for the three two-week discharge periods. Since the water conditions for the Rijkswaterstaat scenario are always the conditions on a median day, it is expected that these large differences are caused by the incorrect water conditions for the other periods. Including the correct water conditions is expected to improve the results for the other periods. Therefore the Water scenario LSM scenarios are developed and analysed.

The reference comparison on counting point level for the median period shows that the deviations for all counting points and every direction, except for the Prins Bernhardsluis in Northern direction, is more than ten % and thereby not acceptable. For the reference comparison on route-level it turns out that only the route *Hagestein, sluis - Prins Bernhardsluis* has a completely unacceptable deviation of 731%. This is most probably at least partly caused by trips with incorrect origin nodes within the port of Rotterdam.

From the reference comparisons on lock-level and route-level there are following findings:

- Between the empty and the loaded trips there are clear differences in the allocation.
- The resistance of a route via the Neder-Rijn is relative to the resistance of a route including a combination of the Waal east of the Amsterdam-Rijnkanaal and the Amsterdam-Rijnkanaal too large in BIVAS.
- The resistance of a route via the Lek in combination with the Amsterdam-Rijnkanaal is too small relative to the resistance of a route via the Waal.

Between the empty and the loaded trips the only difference is the desired vessel speed stored in the BIVAS database. Or these are wrong, or BIVAS does not handle these differences correctly.

BIVAS allocates significantly more vessels via the Lek and Neder-Rijn Eastward than Westward, which gives rise to the presumption that in BIVAS the influence of the flow on the allocation of the trips is large. To investigate this the Without current scenario is developed and analysed.

7
Results BIVAS computations: Scenario types developed for this study

This chapter consists of the analysis of the results of the computations done with all the scenario types that are created for this study. In Chapter 5 the relations of these scenarios to the research questions and the setup of these computations is described.

Section 7.1 includes the investigation of the influence of the flow on the allocation of the trips, based on the Without current scenarios. Section 7.2 deals with the effects of using a water scenario corresponding to the daily varying water conditions in 2011, on the allocation of the trips by BIVAS in comparison to reality. In Section 7.3 the effects of the correct control of the weirs in the Neder-Rijn and Lek on the allocation of the trips are examined and Section 7.4 deals with the reaction of the allocation of the trips when the artificial delay between the Lek and the Amsterdam-Rijnkanaal at the intersection at Wijk bij Duurstede is included. The last scenario type; the Delta Programme scenario type, which is dealed with in Section 7.5, is a special case, for this scenario type the effect on the costs when the trips of the median discharge period are combined with the water scenario for the low discharge period is investigated. In Section 7.6 the conclusions for all the different scenario types are summarized.

Only the thoroughly analysed results of the computations are included in this report, all the other results are stored at RWS-DVS.

7.1. Without current scenarios

From the analysis of the results of the Rijkswaterstaat scenarios it is expected that the water conditions, and especially the flow velocities on the waterways, have a strong influence on the allocation of the trips. To investigate the influence of the flow velocities on the allocation of the trips by BIVAS, computations with the Without current scenario type were done.

For the Without current scenario type all scenarios are computed and in this chapter only the relevant results these computations are shown. The Without current scenarios are only computed to test the sensitivity of the allocation of the trips for the current, not to identify to what extent it is a possible improvement for the performance of BIVAS. Therefore only the reaction of BIVAS is analysed and not whether the reaction has a positive or a negative effect on the number of correctly allocated trips by BIVAS.

In Subsection 7.1.1 the statistics of the Without current scenarios are compared to the statistics of the Rijkswaterstaat scenarios. Subsection 7.1.2 consists of the comparison on counting point level and Subsection 7.1.3 on the comparison on route level. In Subsection 7.1.4 the findings of the comparisons are summarized.

7.1.1. Without current scenarios versus Rijkswaterstaat scenarios - Statistics

Table 7.1 includes the costs per tonne kilometre for the Without current scenarios and the percentage change of these costs in comparison to the Rijkswaterstaat scenarios.

For all scenarios the costs per tonne kilometre shrink when the flow is removed. Which shows for the Rijkswaterstaat scenarios that counter currents have a larger effect on the costs than supporting currents, since a counter current increases the costs relatively more than a supporting current decreases them. The way this works can be explained with the formula used to define the speed of the vessel over the ground (Equation 7.1). Assume a vessel going upstream on an arc. The minimum of the vessel speeds for this vessel

Table 7.1: Without current scenarios; costs per tonne kilometre for the various discharge periods and percentage change from the Rijkswaterstaat scenarios.

Without current	Costs per tonne kilometre **[(€/(tkm))x10^3]**	% change from RWS
Whole year	22.02	-1.13%
Median	19.85	-1.09%
Low	30.06	-1.17%
High	19.71	-1.33%

on this arc is 3m/s and the flow velocity on the arc 1m/s, resulting in a speed over the ground of 2m/s. Would the same vessel sail downstream on the arc the speed over the ground is 4m/s. Removing the current on the arc means that the vessel will sail $\frac{3-1}{2} * 100$ =50% faster upstream and $\frac{(3-4}{4} * 100$ =-25% slower downstream. The speed over the ground determines (partly) the travel time via the arc, which itself partly determines the costs for sailing via the arc.

$$V_{gr} = \min(V_{s,D}, V_{s,90\%TMS}, V_{s,SW}) + CD * V_c \tag{7.1}$$

Where:

$V_{s,D}$	= Desired speed of the vessel stored in BIVAS Database	[m/s]
$V_{s,90\%TMS}$	= 90% of the theoretical maximum speed of the vessel	[m/s]
$V_{s,SW}$	= Speed in shallow water	[m/s]
CD	= Current direction	[-]
V_c	= Velocity of the water	[m/s]

There is no clear difference in the percentual decrease of the costs per tonne kilometre for the whole year, median and low discharge periods. For the high period the percentual decrease is a bit larger, why this is the case is unknown, but it probably has something to do with differences in the composition of the trips for the various periods.

7.1.2. WITHOUT CURRENT SCENARIOS VERSUS RIJKSWATERSTAAT SCENARIOS - COUNTING POINT LEVEL

For the median period the reaction on the omission of the current on counting point level in comparison to the Rijkswaterstaat scenario is visualized in Figure 7.1. Table 7.2 contains the corresponding numbers. Only the results for the Median scenario are shown here, because the type of reaction on the omission of the current is, on counting point level, the same for all the periods.

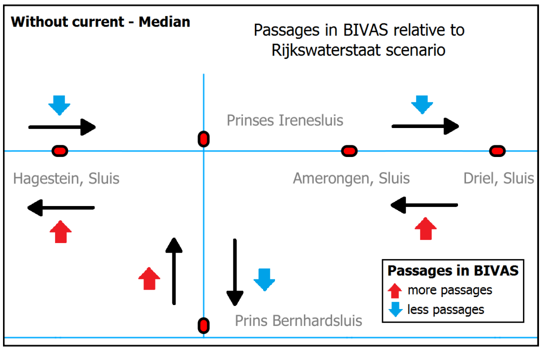


Figure 7.1: Without current Median scenario; passages in BIVAS relative to Rijkswaterstaat scenario.

Table 7.2: Without current Median scenario; change in no. of passages and percentage change relative to Rijkswaterstaat scenario.

Without current Median	Changes relative to RWS scenarios **No. of passages and percentage**					
Hagestein, Sluis	**East**	-261	-67%	**Empty**	-6	-16%
				Loaded	-255	-72%
	West	+42	+58%	**Empty**	+7	+22%
				Loaded	35	+85%
Driel, Sluis	**East**	-81	-32%	**Empty**	-2	-9%
				Loaded	-79	-34%
	West	+35	+34%	**Empty**	+1	+1%
				Loaded	+34	+189%
Prins Bernhardsluis	**North**	+35	+5%	**Empty**	+8	+3%
				Loaded	+27	+6%
	South	-186	-20%	**Empty**	-14	-5%
				Loaded	-172	-27%

From Figure 7.1 and Table 7.2 it can be seen that the allocation of the trips through the Rotterdam-Lobith corridor is clearly sensitive to the flow velocities. The default flow velocities stored in the BIVAS database and used for the Rijkswaterstaat scenarios are, on the waterways shown in the figure:

- Lek: ≈0.39m/s
- Neder-Rijn: ≈0.65m/s
- Waal west of Amsterdam-Rijnkanaal: ≈0.83m/s
- Waal east of Amsterdam-Rijnkanaal: ≈1.14m/s
- Amsterdam-Rijnkanaal: 0m/s

Removing the current has the largest effect on the Waal. The reaction on the ommission of the current is therefore as expected. In upstream direction the reduction of the counter current is larger for the Waal than for the Lek and the Neder-Rijn, making the route via the Waal relatively more favourable than the route via the Lek and the Neder-Rijn. In downstream direction it is the other way round. The reduction of the supporting current is larger for the Waal, making the route via the Neder-Rijn and Lek relatively more favourable than the route via the Waal.

The reaction on the allocation of the trips by BIVAS is larger for the loaded trips than for the empty trips. This is caused by the relatively larger difference, for the loaded vessels, between the speed over the ground for the Without current scenario and the Rijkswaterstaat scenario. This can again be explained using the formula for the speed over the ground (Equation 7.1). The only parameter that changes in this formula between the computation of the Rijkswaterstaat scenario and the Without current scenario is the flow velocity. The vessel speed is different for empty and loaded vessels. For all vessel types the speed of a loaded vessel is lower than the speed of an empty vessel, which makes the relative effect of the removal of the current on the speed over the ground larger for the loaded vessels.

7.1.3. WITHOUT CURRENT SCENARIOS VERSUS RIJKSWATERSTAAT SCENARIOS - ROUTE LEVEL

Figure 7.2 shows, for the Median scenario and remarkable routes, the change in the number of trips and the corresponding percentage, from the Rijkswaterstaat scenario to the Without current scenario.

From this figure it can be seen that for the shown routes the reaction on the removal of the current is the strongest for the route *Hagestein, Sluis - Prins Bernhardsluis*. The trips that are no longer allocated via this route are now allocated via the Waal. This shift has a large effect on the intensity on the Lek between the lock at Hagestein and the intersection with the Amsterdam-Rijnkanaal, since the decrease of 196 trips is ≈42% of the intensity of ≈460 vessels in the Rijkswaterstaat scenario on this part of the Lek. The effect on the intensity on the section of the Waal parallel to this section of the Lek is smaller, but not neglible, since it is about 5% of the intensity of ≈4000 vessels in the Rijkswaterstaat scenario on this part of the Waal. On the part of the Amsterdam-Rijnkanaal between the Lek and the Waal the shift is ≈12% of the intensity in the Rijkswaterstaat scenario. The percentual reaction for the route *Hagestein, Sluis - Prins Bernhardsluis* is probably larger then the reaction for the route *Hagestein, sluis - Amerongen,Sluis - Driel, Sluis* because part of the route is already via the Waal.

The reaction for both routes via the Prinses Irenesluis and Prins Bernhardsluis is small in relation to the reaction for the other routes. This is because these routes can both be part of routes via the Waal in westward direction (downstream) and eastward direction (upstream) (see Figure 7.3). Since the reactions for the trips upstream and downstream are opposite to each other they partly cancel each other out.

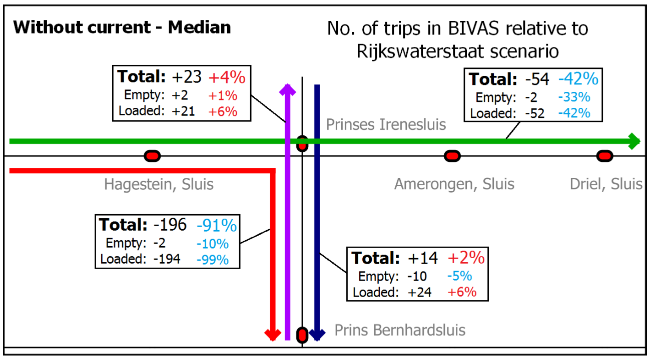


Figure 7.2: Without current Median scenario; Amount of trips relative to the Rijkswaterstaat scenario for the remarkable routes.

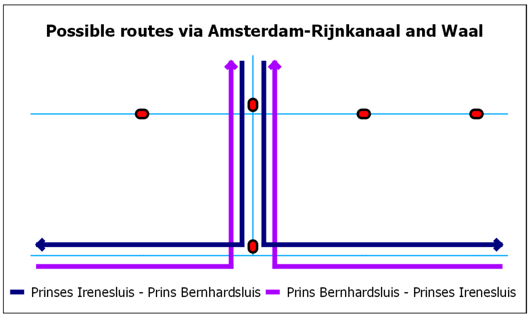


Figure 7.3: Possible routes via Amsterdam-Rijnkanaal and Waal.

7.1.4. WITHOUT CURRENT SCENARIOS - CONCLUSIONS

From the analysis of the results of the Without current scenarios it is found that the allocation of the trips through the Rotterdam-Lobith corridor is clearly sensitive to the flow velocities, that counter currents have a larger effect on the costs to sail via an arc than supporting currents, and that changing flow velocities have a larger effect on the allocation for the loaded vessels than for the empty vessels.

7.2. WATER SCENARIO LSM SCENARIOS

The Rijkswaterstaat scenarios are computed with the default water conditions. Those do not vary over the year. In reality, the water conditions do change. Skippers respond to these variations with lowering of the load (Section 4.3) and/or choosing another route (Section 4.4). By adding daily varying water conditions it is expected that the allocation of the trips over the network by BIVAS will be a better reflection of the allocation of the trips in reality.

In Subsection 7.2.1 the overall statistics are analysed. The analysis of the allocation of the trips is done in two ways. At first the reaction of BIVAS to the usage of the water scenario is compared to the results of the Rijkswaterstaat scenarios (Subsection 7.2.2). Secondly it is analysed whether the Water scenario LSM scenarios reflect the allocation in reality better than the Rijkswaterstaat scenarios (Subsection 7.2.3).

For the Water scenario LSM scenarios results for all counting points used in this study are included in Section I.2 in Appendix I.

7.2.1. WATER SCENARIO LSM SCENARIOS - STATISTICS

Table 7.3 contains scenario statistics for the Water scenario LSM scenarios in comparison to the Rijkswaterstaat scenarios. A large percentual growth of the infeasible trips can be seen for all three periods. For the infeasible trips it holds for all periods that the trips which where infeasible in the Rijkswaterstaat scenarios are also infeasible in the Water scenario LSM scenarios. This is expected, since the causes for these infeasible trips are not related to the daily varying water conditions introduced by the LSM water scenario, see Subsection 6.1.2.

Table 7.3: Water scenario LSM scenarios; relevant scenario statistics for the Water scenario LSM in comparison to the statistics of the Rijkswaterstaat scenarios.

Water scenario LSM		Numbers and % change from Rijkswaterstaat scenarios							
		Whole year		**Median**		**Low**		**High**	
Infeasible trips	[No.]	2813	+77%	91	+65%	127	+79%	130	+86%
Additional trips due to reduced load	[No.]	11129	+113%	432	+104%	487	+171%	208	+24%
Costs per tonne kilometer	$[\frac{€}{tkm} \mathrm{x}10^3]$	22.32	+0.2%	20.18	+0.6%	30.22	-0.7%	20.20	+1.1%

The new infeasible trips are for ≈90% trips with as origin or destination node the nodes 6921 or 6930. These nodes are located in the Nijmegen Port area, which is located alongside the Maas-Waalkanaal. A large correction depth of 3.0889m is used for the Maas-Waalkanaal in the conversion of the output of the LSM to the water scenario. The Maas-Waalkanaal is a canal and the method used to define the correction depths is only feasible for river profiles, so for the Maas-Waalkanaal the correction depth should not be determined with the used method. For a canal there should be no correction depth.

The wrong correction depth causes next to the extra infeasible trips extra lowering of the load for part of the trips (Over the whole year ≈37% extra additional trips due to reduced load), and another allocation of part of the trips compared to a water scenario where the correction depth for the Maas-Waalkanaal is zero. Figure 7.4 visualizes this. It can be seen that with a correction depth of 0m the intensity on the Maas-Waalkanaal doubles and that the intensities on the Rotterdam-Lobith corridor change as well.

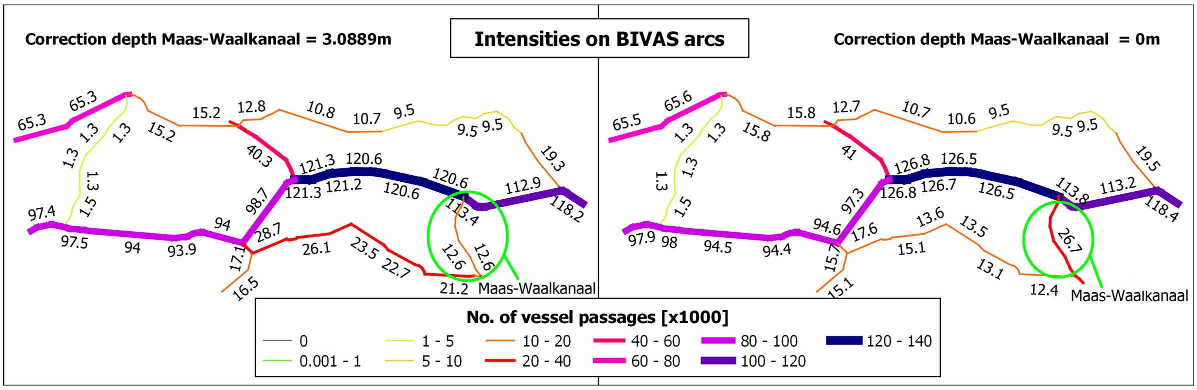


Figure 7.4: Water Scenario LSM Whole year scenario; intensities on BIVAS arcs for correction depth Maas-Waalkanaal =3.0889m and =0m.

The growth of the amount of additional trips is for the Median and Low scenarios not only caused by the wrong correction depth on the Maas-Waalkanaal. When a water scenario is used it is determined by the depth of the arc and the minimum required under keel clearance whether a vessel can sail via an arc or not. When no water scenario is included this is determined by the maximum allowed draught defined for the arc.

In reality all vessels sailed with the draught from the traffic scenario. This means that at some arcs the water depth is incorrect or that in reality the vessels sailed with a smaller keel clearance than the minimum required under keel clearance from BIVAS. The minimum required under keel clearance is in BIVAS determined with Formula 7.2.

In Subsection 4.5.1 the water levels of the water scenario are compared to the water levels measured in reality. From this comparison it was found that the water levels of the water scenario at measuring points that have no influence of the tide are accurate for the median and low discharge period, but that the water levels at measuring points that do have influence of the tide are not accurate. Incorrect depths in the water scenario can therefore be caused by incorrect correction depths in the coupling of the LSM and BIVAS and by incorrect water levels of the LSM.

$$D_{max} = h - \max(UKC_{min,abs}, h - \frac{h}{1 + UKC_{min,rel}}) \tag{7.2}$$

where:

D_{max}	= Maximum permissible draught.	[m]
h	= Water depth.	[m]
$UKC_{min,abs}$	= Absolute minimum under keel clearance (depending on CEMT type).	[m]
$UKC_{min,rel}$	= Relative minimum under keel clearance (depending on CEMT type).	[-]

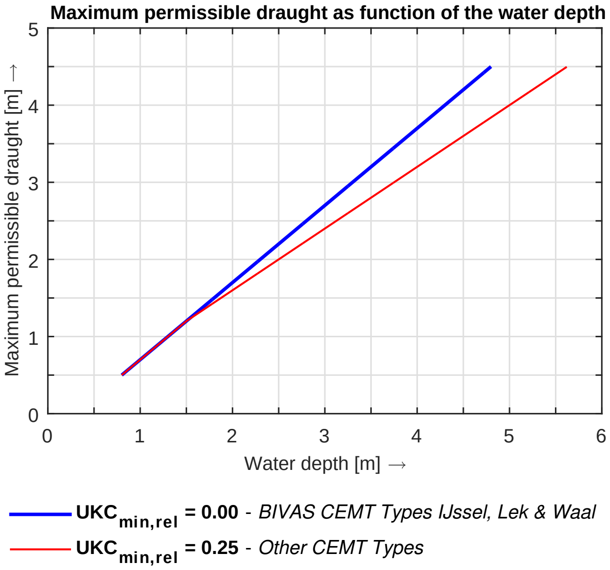


Figure 7.5: Maximum permissible draught as function of the water depth for BIVAS CEMT types and for other CEMT types.

The value for the absolute minimum under keel clearance is the same for all the BIVAS CEMT types; 0.3m. For the relative under keel clearance, there are two different values stored in the BIVAS database. The value for the BIVAS CEMT types IJssel, Lek and Waal is 0.00, and for the other CEMT types the value is 0.25, which means that there should be at least 25% of the draught of the vessel between the keel of the vessel and the bottom of the waterway. Figure 7.5 shows the maximum permissible draught as a function of the water depth for both the BIVAS CEMT types IJssel, Lek and Waal, and the other CEMT types. Up to a depth of 1.5m the absolute minimum under keel clearance is the largest for both. For larger depths this still applies to the BIVAS CEMT types, but for the other CEMT types the function of the relative minimum under keel clearance is then the largest. The larger the water depth, the larger the difference in the maximum permissible draught between the BIVAS CEMT types and the other CEMT types.

Table 7.3 shows the costs per tonne kilometre as well. These costs rise for all scenarios except the Low scenario. This is because counter currents have a larger effect on the average costs per tonne kilometre than supporting currents (see Subsection 7.1.1), and for the Median, High and Whole year scenario the average flow velocities are higher than the flow velocities stored in the BIVAS database. For the Low scenario the flow velocities are on average lower than the stored flow velocities and therefore the costs per tonne kilometre of the Water scenario LSM scenario are smaller than for the Rijkswaterstaat scenario.

7.2.2. WATER SCENARIO LSM SCENARIOS VERSUS RIJKSWATERSTAAT SCENARIOS

In this subsection the results of the Water scenario LSM scenarios and the results of the Rijkswaterstaat scenarios are compared. The three different two-week discharge periods are analysed separately from each other. This is done because the reaction of BIVAS depends on the water conditions. The comparison is made on counting point-level and on route-level. Only the comparison on counting point-level is analysed here, since the results on route-level support the findings on counting point-level.

MEDIAN DISCHARGE PERIOD

Figure 7.6 shows the reaction of the allocation of the trips by BIVAS for the Median Water scenario LSM scenario in comparison to the Rijkswaterstaat scenario. Table 7.4 contains the numbers corresponding to this figure. From the figure and the table it can be seen that with the introduction of the water scenario a distinct change in the allocation of the trips through the Rotterdam-Lobith corridor occurs for the Median scenario. Change of the allocation of a trip happens when the costs to travel via a different route are smaller than the costs of the route determined for the Rijkswaterstaat scenario.

The following three parameters can change and thereby influence the costs for an arc when a water scenario is introduced:

- Flow velocity on the arc.
- Maximum allowed draught of the vessels using the arc. } Depending on water depth.
- Velocity of the vessels using the arc.

In the Median scenario all three parameters cause, to a greater or lesser extent, the change in the allocation of the trips. The change in flow velocity has the largest influence on the change of the allocation of the trips. The flow velocities from the water scenario differ significantly from the default flow velocities, see Figure 7.7. The difference is significantly larger for the Neder-Rijn and the Lek than for the Waal. The smaller flow velocities on the Neder-Rijn and Lek cause less traffic upstream and more traffic downstream over these rivers. For the empty vessels the reaction in upstream direction is not there or not as expected. That the reaction is not there is caused by the fact that empty vessels are less sensitive to the flow velocities (see Subsection 7.1.2).The shrinkage of two passages at Hagestein is caused by the incorrect correction depth at the Maas-Waalkanaal.

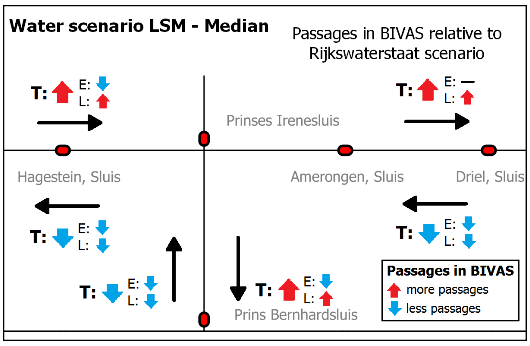


Figure 7.6: Water Scenario LSM Median scenario; growth/shrinkage of number of passages relative to Rijkswaterstaat scenario.

Table 7.4: Water Scenario LSM Median scenario; passages in BIVAS relative to Rijkswaterstaat scenario.

Water scenario LSM - Median	Changes relative to RWS scenario No. of passages and percentage					
Hagestein, Sluis	**East**	+159	+41%	**Empty**	-2	-5%
				Loaded	+161	+46%
	West	-10	-14%	**Empty**	-1	-3%
				Loaded	-9	-22%
Driel, Sluis	**East**	+48	+22%	**Empty**	-	-
				Loaded	+48	+26%
	West	-6	-7%	**Empty**	-1	-3%
				Loaded	-5	-10%
Prins Bernhardsluis	**North**	-72	-10%	**Empty**	-2	-1%
				Loaded	-70	-16%
	South	+62	+7%	**Empty**	-5	-2%
				Loaded	+67	+11%

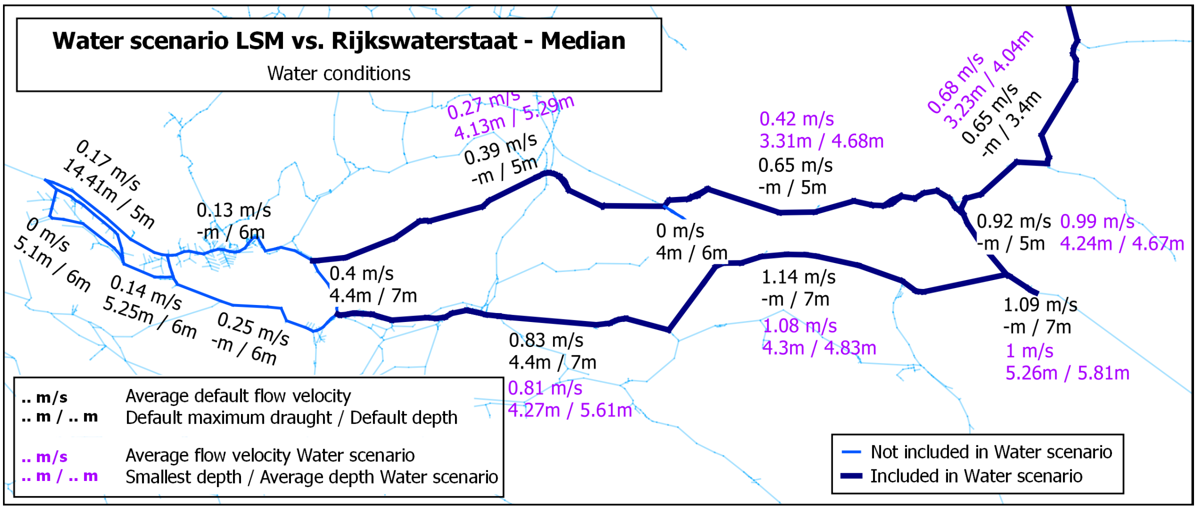


Figure 7.7: Water scenario LSM Median scenario; water conditions on the Rotterdam-Lobith corridor for the Base scenario and the Water scenario LSM scenario.

In Figure 7.7 the smallest and the average water depths of the water scenario are shown. The water depth minus the minimum under keel clearance gives the maximum allowed draught. For the arcs of the Rotterdam-Lobith corridor that are included in the water scenario the minimum under keel clearance is always 0.3m (see Subsection 7.2.1).

The trips of the traffic scenario have a maximum draught of 4.5m. The maximum draughts for the water scenario are not always sufficient for this draught. Mainly on the Neder-Rijn this is the case. It could be that part of the trips that used the Neder-Rijn in the Rijkswaterstaat scenario are, as a result of this, allocated via the Waal in the Water scenario scenario. This can not clearly be seen from Table 7.4, but an indication for this can be the smaller change at Driel than at Hagestein in upstream direction.

The water depths of the water scenario influence also the vessel speeds. The speed of the vessel on an arc is the minimum of three velocities; The desired speed stored in the BIVAS database, 90% of the theoretical maximum speed and the shallow water speed. For the Rijkswaterstaat scenarios the desired speed is generally the minimum, but when the ratio between the draught and the water depth shrinks the theoretical maximum speed or the shallow water speed can become the minimum.

Figure 7.8 shows for a loaded trips with the most used vessel; the M8, draughts between 0.5 and 4.5m, and water depths of 3, 4 and 5m, which vessel speed is the minimum on the BIVAS CEMT types Lek and Waal. The figure shows that for a depth between 3 and 4 meters the minimum speed is not the desired speed anymore for smaller draughts at the BIVAS CEMT type Lek than at the BIVAS CEMT type Waal. This means that the vessel speed at the BIVAS CEMT type Lek decreases quicker with smaller water depths than the vessel speed at the BIVAS CEMT type Waal.

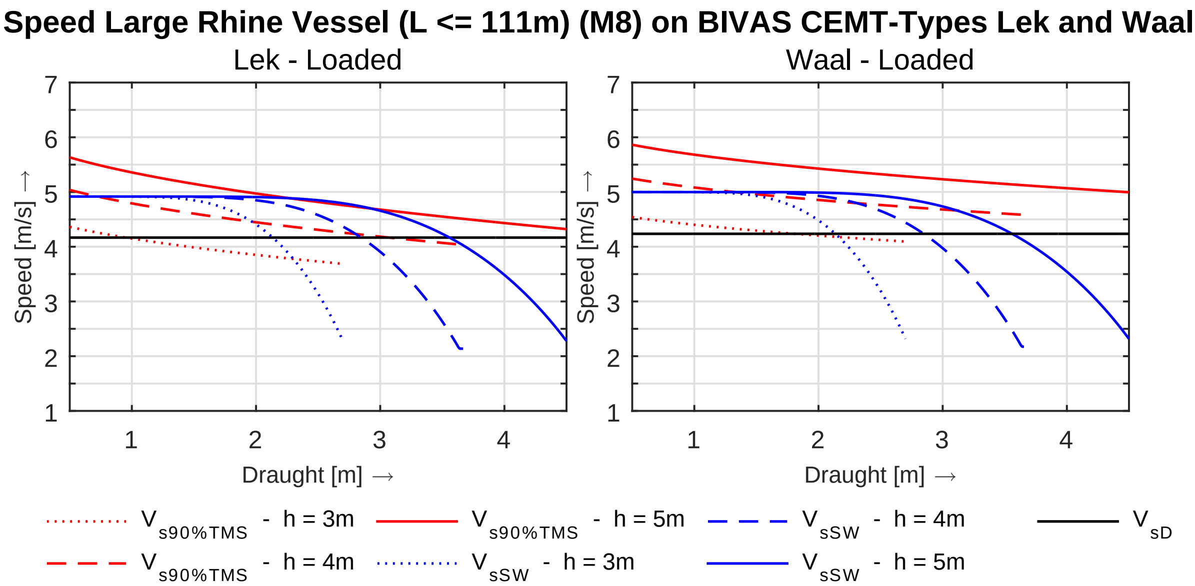


Figure 7.8: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Large Rhine Vessel (M8) on BIVAS CEMT-Types Lek and Waal, depending on water depth of the waterway and draught of the vessel (other vessels and waterway classes; see Appendix J).

In the median scenario there are water depths between 3 and 4 m at the Neder-Rijn. It could be that part of the trips that used the Neder-Rijn in the Rijkswaterstaat scenario are, as a result of this, allocated via the Waal in the Water scenario scenario. This can not clearly be seen from Table 7.4, but an indication for this can again be the smaller change at Driel than at Hagestein in upstream direction.

LOW DISCHARGE PERIOD

The reaction of BIVAS on lock level for the Low scenario is shown in Figure 7.9. the corresponding numbers are shown in Table 7.5. Figure 7.10 shows the water conditions on the BIVAS arcs for the Low scenario and the Rijkswaterstaat scenarios.

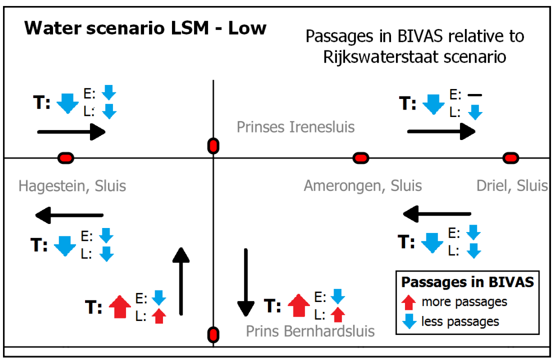


Figure 7.9: Water Scenario LSM Low scenario; growth/shrinkage of number of passages relative to Rijkswaterstaat scenario.

Table 7.5: Water Scenario LSM Low scenario; passages in BIVAS relative to Rijkswaterstaat scenario.

Water scenario LSM - Low	Changes relative to RWS scenario **No. of passages and percentage**					
Hagestein, Sluis	**East**	-40	-8%	**Empty**	-3	-6%
				Loaded	-37	-8%
	West	-16	-21%	**Empty**	-2	-5%
				Loaded	-14	-38%
Driel, Sluis	**East**	-66	-25%	**Empty**	-	-
				Loaded	-66	-28%
	West	-15	-27%	**Empty**	-1	-3%
				Loaded	-14	-56%
Prins Bernhardsluis	**North**	+49	+6%	**Empty**	-3	-1%
				Loaded	+52	+13%
	South	+14	+1%	**Empty**	-2	-1%
				Loaded	+16	+2%

For the Low scenario the flow velocity is not the main cause for the change in the allocation of the trips, since the change of the flow velocity would cause a growth upstream via the Lek and Neder-Rijn and a shrinkage downstream. The shrinkage is in both directions, this is most likely caused by the vessel speeds. The vessel speed at the BIVAS CEMT type Lek decreases quicker with smaller water depths than the vessel speed at the BIVAS CEMT type Waal. This makes sailing via the Waal more favourable, since on the Waal it is possible to sail with a higher speed. The maximum allowed draught is probably not the cause of the shrinkage in both directions on the Neder-Rijn and Lek, since the average depth on the Waal east of the Amsterdam-Rijnkanaal is smaller than the average depth on the Neder-Rijn, which would increase the amount of traffic on the Neder-Rijn instead of the decrease that can be seen.

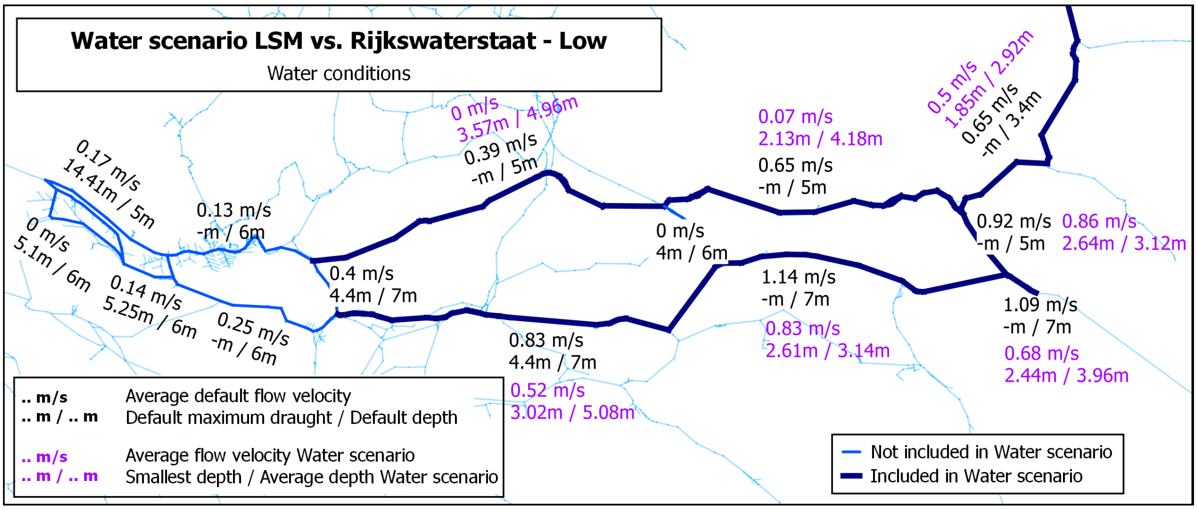


Figure 7.10: Water scenario LSM Low scenario; water conditions on the Rotterdam-Lobith corridor for the Rijkswaterstaat scenario and the Water scenario LSM scenario.

HIGH DISCHARGE PERIOD

Figure 7.11 shows the reaction of BIVAS to the water scenario for the high period. Table 7.6 contains the values corresponding to this figure. Figure 7.12 shows the water conditions on the BIVAS arcs for the High scenario and the Rijkswaterstaat scenarios.

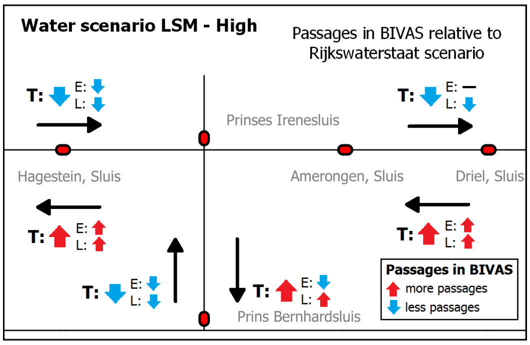


Figure 7.11: Water Scenario LSM High scenario; growth/shrinkage of number of passages relative to Rijkswaterstaat scenario.

Table 7.6: Water Scenario LSM High scenario; passages in BIVAS relative to Rijkswaterstaat scenario.

Water scenario LSM - High	**Changes relative to RWS scenario No. of passages and percentage**					
Hagestein, Sluis	**East**	-249 -70%	**Empty**	-6	-20%
			Loaded	-243	-75%
	West	17 +26%	**Empty**	+2	+7%
			Loaded	+15	+39%
Driel, Sluis	**East**	-19 -10%	**Empty**	-	-
			Loaded	-19	-12%
	West	18 +37%	**Empty**	+1	+6%
			Loaded	+17	+55%
Prins Bernhardsluis	**North**	-16 -4%	**Empty**	-4	-2%
			Loaded	-12	-5%
	South	+177 +25%	**Empty**	-7	-3%
			Loaded	+184	+37%

For the high discharge period only te flow velocities cause the change in the allocation. The growth of the flow velocity at the Neder-Rijn and the Lek is larger than at the Waal. This causes less traffic upstream and more traffic downstream via the Neder-Rijn and the Lek. The maximum allowed draught and the vessel velocity are no cause for the change in the allocation, because the depths of the water scenario in the high discharge period are large enough for the maximum draught of the trips, and large enough to make the desired speed the minimum vessel speed.

7.2.3. WATER SCENARIO LSM SCENARIOS VERSUS REFERENCE DATA

For the analysis of the Rijkswaterstaat scenario the average deviation from the reference; D, is used to indicate the difference in the allocation on counting point level between the reference data and BIVAS. To determine whether using the water scenario from the LSM constitutes an improvement, the D is also determined for the Water scenario LSM scenarios. The values of D are for both the Rijkswaterstaat and the Water scenario LSM scenarios shown in Table 7.7.

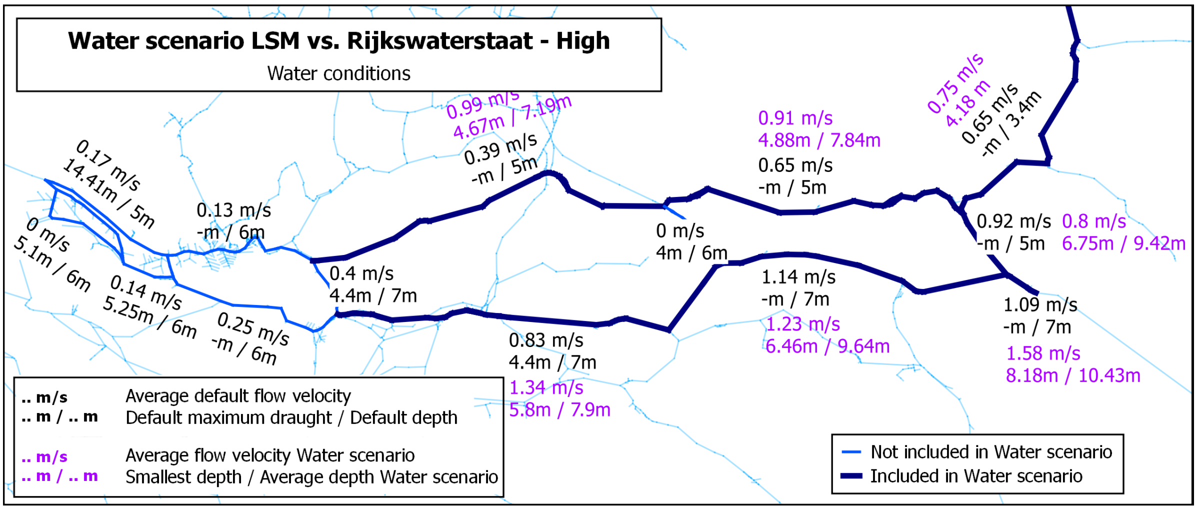


Figure 7.12: High scenario - Water conditions on the Rotterdam-Lobith corridor for the Rijkswaterstaat scenario and the Water scenario LSM scenario

Table 7.7 shows that the water scenario worsens the results for the Whole year, Median and High scenarios, whereby High deteriorates the most. For the Low scenario the use of the water scenario does give an improvement of the results.

Whether the use of the water scenario is an improvent or not is also determined on counting point-level, per direction and load type. These results are included in Table I.6 of Appendix I. They are not discussed here because no clear conclusions can be drawn from them.

Using the water scenario does on average worsens the results, but it could be that reaction for the different discharge periods in comparison to each other is right. To determine this is for the low and high discharge periods the relative change between these periods in reality and the median period in reality compared to the change between the Rijkswaterstaat scenarios and the Water scenario LSM scenarios of these periods. These numbers are included in Table 7.8.

Table 7.7: Average deviation from IVS90 for RWS and WS scenarios - counting point-level

	D	
	RWS	**WS**
Whole year	0.12	0.21
Median	0.13	0.18
Low	0.19	0.14
High	0.26	0.39

Table 7.8: Water scenario LSM Low and High scenarios; relative change between period and median period in reality versus Relative change between Water scenario LSM scenario and Rijkswaterstaat scenario.

			Low		*High*	
			IVS90 relative to IVS90 Median	**WS relative to RWS**	**IVS90 relative to IVS90 Median**	**WS relative to RWS**
Hagestein, Sluis	**East**	**Empty**	+9%	-6%	-15%	-20%
		Loaded	-30%	-8%	-6%	-75%
	West	**Empty**	+13%	-5%	+63%	+7%
		Loaded	-47%	-38%	+74%	+39%
Driel, Sluis	**East**	**Empty**	-31%	-	+18%	-
		Loaded	-76%	-28%	-28%	-12%
	West	**Empty**	+37%	-3%	+126%	+6%
		Loaded	-80%	-56%	+154%	+55%
Prins Bernhardsluis	**North**	**Empty**	+34%	-1%	-50%	-2%
		Loaded	-10%	+13%	-33%	-5%
	South	**Empty**	+8%	-1%	-29%	-3%
		Loaded	+44%	+2%	-27%	+37%

From this table the following is found:

- When there are smaller depths and velocities BIVAS does react in the right way on the Neder-Rijn and Lek for the loaded vessels, but less strong than in reality. For the empty vessels the reaction of BIVAS is completely the opposite of the reaction of the skippers in reality.
- When there are smaller depths and velocities BIVAS does react completely different on the Amsterdam-Rijnkanaal than the skippers did in reality.
- When there are larger depths and velocities BIVAS reacts in the right way on the Neder-Rijn and Lek, but in Westward direction (downstream) the reaction is not strong enough.

- When there are larger depths and velocities BIVAS does react completely different on the Amsterdam-Rijnkanaal than the skippers did in reality.

These findings can be explained in the following way:

- The sensitivity for smaller flow velocities is for empty vessels in BIVAS much larger than in reality.
- The sensitivity for the flow velocity is for loaded vessels in BIVAS too small in comparison to reality.
- In BIVAS is opening of the weirs in the Lek and the Neder-Rijn (less delay via these rivers) during high discharge periods not taken into account.
- In BIVAS is the opening of the Prins Bernhardsluis during low discharge periods (less delay when using the Amsterdam-Rijnkanaal) not taken into account.
- In BIVAS is the use of the Prinses Marijkesluis during high discharge periods (more delay when using the Amsterdam-Rijnkanaal) not taken into account.

7.2.4. WATER SCENARIO LSM SCENARIOS - CONCLUSIONS

From the analysis of the overall statistics of the Water scenario LSM scenarios it is found that the correction depth for the Maas-Waalkanaal used in the conversion of the water data from the LSM to the water scenario for BIVAS is not right and should be adjusted.

There are extra additional trips for the Median and Low scenario, which means that the water depths at some of the arcs are not correct or that the vessels sailed with a smaller keel clearance in reality than the minimum required under keel clearance in BIVAS.

The following three parameters can change and thereby influence the costs for an arc when a water scenario is introduced:

- Flow velocity on the arc.
- Maximum allowed draught of the vessels using the arc.
- Velocity of the vessels using the arc.

} depending on water depth.

For the Median scenario the change in the flow velocity has the largest influence on the allocation of the trips, but also the maximum allowed draught and the vessel speed have to a lesser extent an influence on the allocation of the trips. For the Low scenario the vessel speed has the largest influence on the allocation of the trips, followed by the flow velocity. The maximum allowed draught does not really have an influence on the allocation for the Low scenario. For the High scenario only the flow velocity influences the change of the allocation of the trips.

Using the water scenario worsens the results for the Whole year, Median and High scenarios. For the low discharge period it improves the results.

To determine whether the reaction for the different discharge periods in comparison to each other is correct is for the low and high discharge periods the relative change between these periods in reality and the median period in reality compared to the change between then Rijkswaterstaat scenarios and the Water scenario LSM scenarios of these periods.

From this comparison the following was found:

- The sensitivity for smaller flow velocities is for empty vessels in BIVAS much larger than in reality.
- The sensitivity for the flow velocity is for loaded vessels in BIVAS too small in comparison to reality.
- In BIVAS is opening of the weirs in the Lek and the Neder-Rijn (less delay via these rivers) during high discharge periods not taken into account.
- In BIVAS is the opening of the Prins Bernhardsluis during low discharge periods (less delay when using the Amsterdam-Rijnkanaal) not taken into account.
- In BIVAS is the use of the Prinses Marijkesluis during high discharge periods (more delay when using the Amsterdam-Rijnkanaal) not taken into account.

How the differences between the reality and BIVAS in the sensitivities for the flow velocity can be reduced for both the empty and the loaded vessel is unknown. In this study this is not further adressed, but it should be investigated in the future. The opening of the weirs in the Lek and the Neder-Rijn can be included. In the Correct control weirs scenarios this is included. The opening and commissioning of the Prins Bernhardsluis and the Prinses Marijkesluis can not be included in the current version of BIVAS, BIVAS should be adjusted for this.

7.3. CORRECT CONTROL WEIRS SCENARIOS

The opening of the weirs at Hagestein, Amerongen and Driel during high water levels is not included in the Water scenario LSM scenarios. In reality when the weirs are open the vessels can sail via the opened weir instead of via the lock, which reduces the travel time and thereby the costs via the Neder-Rijn and the Lek. To include this opening of the weirs in the scenarios the correct control weirs scenarios are created. Since only during high water levels the weirs are opened only the whole year and high scenario are computed and analysed.

In Subsection 7.3.1 the overall statistics of the Correct control weirs scenarios are analysed, in Subsection 7.3.2 the results of the Correct control weirs High scenario are compared to the results of the Water scenario LSM High scenario and in Subsection 7.3.3 it is investigated whether the correct control of the weirs improves the allocation of the trips. Subsection 7.3.4 summarizes the conclusions for the Correct control weirs scenarios.

7.3.1. CORRECT CONTROL WEIRS - STATISTICS

Table 7.9 shows for the Correct control weirs High and Whole year scenarios the costs per tonne kilometre and the percentual change from the Water scenario LSM scenarios. There is a small shrinkage for the High scenario, but the effect on the Whole year scenario of the correct control of the weirs is negligible. That the costs per tonne kilometre shrink for the High scenario is as expected, since the costs to sail via a lock are higher than the costs to sail via an opened weir.

Table 7.9: Correct control weirs scenario; costs per tonne kilometre and percentage change from the Water scenario LSM scenarios

Correct control weirs	Costs per tonne kilometre **[(€/(tkm))x10^3]**	% change from WS LSM
Whole year	22.33	-0.00%
High	20.16	-0.19%

7.3.2. CORRECT CONTROL WEIRS VERSUS WATER SCENARIO LSM SCENARIOS

Figure 7.13 is a visualisation of the change in number of passages for the Correct control weirs High scenario at the counting points Hagestein, Driel and Prins Bernhard, in comparison to the Water scenario LSM scenario. Table 7.10 contains the corresponding numbers.

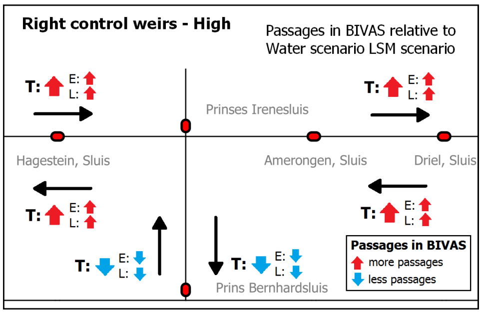


Figure 7.13: Correct control weirs High scenario; growth/shrinkage of number of passages relative to Water scenario LSM scenario.

Table 7.10: Correct control weirs High scenario; passages in BIVAS relative to Water scenario LSM scenario.

Correct control weirs High	Changes relative to WS-LSM scenarios **No. of passages and percentage**					
Driel, Sluis	**East**	+577	+356%	**Empty**	87	+395%
				Loaded	490	+350%
	West	+155	+231%	**Empty**	78	+411%
				Loaded	77	+160%
Hagestein, Sluis	**East**	+486	+458%	**Empty**	53	+221%
				Loaded	433	+528%
	West	+66	+80%	**Empty**	43	+143%
				Loaded	23	+43%
Prins Bernhardsluis	**North**	-100	-24%	**Empty**	-46	-28%
				Loaded	-54	-22%
	South	-433	-49%	**Empty**	-47	-24%
				Loaded	-386	-56%

From the figure and the table it can be seen that the effect on the allocation of the trips of the opening of the weirs is large. Both eastward and westward a large amount of extra trips are allocated via the Neder-Rijn and the Lek. For the Amsterdam-Rijnkanaal an effect can also be seen. Part of the trips that were allocated via the Waal and the Amsterdam-Rijnkanaal to northward are now allocated via the Neder-Rijn or Lek and the Amsterdam-Rijnkanaal.

Westward (downstream) the reaction is smaller than eastward (upstream). This is probably linked to the fact that the flow velocities have a larger effect on the costs in upstream direction than in downstream direction.

7.3.3. Correct control weirs scenarios versus reference data

For the Correct control weirs scenarios is again the average deviation from the reference; D, used to indicate the difference in the allocation on counting point-level between the reference data and BIVAS. In Table 7.11 the values of D for the Correct control weirs and Water scenario LSM High and Whole year scenarios are included. For the High scenario controlling the weirs as in reality worsens the results. For the Whole year scenario there is almost no effect.

Table 7.11: Average deviation from IVS90 for WS and RCW scenarios; counting pointlevel

	D	
	WS	**RCW**
Whole year	0.21	0.21
High	0.39	0.41

Controlling the weirs in the correct way worsens the results, but it could be that the reaction of BIVAS is comparable to the reaction of the skippers in reality. To determine this the relative change on counting point level between the median and high discharge period in reality is compared to the relative change between the Rijkswaterstaat High scenario and the Correct control weirs High scenario. Table 7.12 includes the these numbers, and the numbers for the High Water scenario LSM scenario relative to the Rijkswaterstaat scenario.

Table 7.12: High discharge period; relative change between period and median period in reality versus relative change between Water scenario LSM scenario and Rijkswaterstaat scenario, and relative change between Correct control weirs scenario and Rijkswaterstaat scenario.

High			**IVS90 relative to IVS90 Median**	**WS relative to RWS**	**RCW relative to RWS**
Hagestein, Sluis	**East**	**Empty**	-15%	-20%	+263%
		Loaded	-6%	-75%	+94%
	West	**Empty**	+63%	+7%	+246%
		Loaded	+74%	+39%	+229%
Driel, Sluis	**East**	**Empty**	+18%	-	+250%
		Loaded	-28%	-12%	+224%
	West	**Empty**	+126%	+6%	+306%
		Loaded	+154%	+55%	+145%
Prins Bernhardsluis	**North**	**Empty**	-50%	-2%	-30%
		Loaded	-33%	-5%	-25%
	South	**Empty**	-29%	-3%	-27%
		Loaded	-27%	+37%	-40%

From Table 7.12 the following is found:

- The opening of the weirs causes that in both directions on the Neder-Rijn and Lek the amount of traffic grows significantly. Westward this is in reality the case as well, but eastward not.
- The opening of the weirs causes that the reaction on the Amsterdam-Rijnkanaal is comparable to the reaction in reality.

From these findings the following can be concluded:

- Opening of the weirs in BIVAS causes too much lowering of the costs for travelling via the Neder-Rijn and Lek in BIVAS.
- Opening of the weirs gives better results for the Amsterdam-Rijnkanaal in BIVAS, however, the reason for this is not the same reason as in reality. In reality this is caused by the Prinses Marijkesluis, which was in use during the high discharge period, in BIVAS it is caused by the too high attractiveness of the Neder-Rijn and the Lek.

7.3.4. Correct control weirs scenarios - Conclusions

The effect on the allocation of the trips on the opening of the weirs is large. In both eastward and westward directiona large amount of extra trips are allocated via the Neder-Rijn and the Lek. For the Amsterdam-Rijnkanaal an effect can also be seen. Part of the trips that were allocated via the Waal and the Amsterdam-Rijnkanaal northward are now allocated via the Neder-Rijn or Lek and the Amsterdam-Rijnkanaal.

Westward (downstream) the reaction is smaller than eastward (upstream). This is probably linked to the fact that the flow velocities have a larger effect on the costs in upstream direction than in downstream direction.

The opening of the weirs worsens the results. From a comparison between the reaction of the skippers in reality and the reaction in comparison to the Rijkswaterstaat scenario the following is concluded:

- Opening of the weirs in BIVAS causes too much lowering of the costs for travelling via the Neder-Rijn and Lek in BIVAS.
- Opening of the weirs gives better results for the Amsterdam-Rijnkanaal in BIVAS, however, the reason

for this is not the same reason as in reality. In reality this is caused by the Prinses Marijkesluis, which was in use during the high discharge period, in BIVAS it is caused by the too high attractiveness of the Neder-Rijn and the Lek.

To translate these conclusions into improvements for BIVAS more research should be done on the reaction to larger water depths of skippers in reality. It might be that looking at the costs, sailing via the Neder-Rijn and Lek is in reality cheaper when the weirs are open, but that skippers just stick to their normal route via the Waal, but it can also be the case that the Neder-Rijn and Lek are, when the locks are not in use, modelled to cheap in comparison to reality.

7.4. ADJUSTED INTERSECTION AT WIJK BIJ DUURSTEDE SCENARIOS

From the analysis of the Rijkswaterstaat scenarios it is found that especially via the route Hagestein, Sluis at the Lek and the Prins Bernhardsluis at the Amsterdam-Rijnkanaal BIVAS allocates for all the different discharge periods much more trips than in reality.

In order to improve the ratio between BIVAS and the IVS90 for this route senarios with an ad hoc solution are created; the Adjusted intersection at Wijk bij Duurstede scenarios. In these scenarios an artificial delay for the turn from the Lek to the Amsterdam-Rijnkanaal is added.

There are scenarios created without and with a water scenario for all four discharge periods. The most optimal artificial delay for every scenario is found iteratively by running computations with various artificial delays. Table 7.13 gives the most optimal artificial delay per scenario. The most optimal delay is different for all scenarios, this is because for all scenarios the composition of the trips in the traffic scenario is slightly different (See Section 4.3) and the allocation of the trips over the network in reality is different (See Section 4.4). From Table 7.13 it can be seen that for the scenarios including a water scenario the optimal artificial delay is significantly larger than for the scenarios without a water scenario.

Table 7.13: Optimal artificial delay for the Adjusted intersection scenarios.

	Optimal artificial delay [min]	
	AI ex. WS	**AI incl. WS**
Whole year	9.65	27.25
Median	11.7	25.15
Low	8.75	14.9
High	15.35	25

An ad hoc solution as this is added to get better results for a specific scenario. The objective here is to get the most correct results for the Whole year scenario 2011. Since the Rijkswaterstaat scenario gives more correct results than the Water scenario LSM scenario it is chosen to analyse the results for the Whole year Adjusted intersection scenario without using a water scenario here.

In Subsection 7.4.1 the results of the adjusted intersection scenario are compared to the results of the Rijkswaterstaat scenario, in Subsection 7.4.2 it is investigated to what extent the Adjusted intersection is an improvement for the comparison with reality, and in Subsection 7.4.3 the conclusions from the analysis of the Adjusted intersection scenarios are summarized.

7.4.1. ADJUSTED INTERSECTION SCENARIOS VERSUS RIJKSWATERSTAAT SCENARIOS

Figure 7.14 shows the change in the number of passages at the counting points between the Adjusted intersection without water scenario Whole year scenario and the Rijkswaterstaat whole year scenario. Table 7.14 contains the corresponding numbers. From the figure and the table it can be found that adding an artificial delay between the Lek and the Amsterdam-Rijnkanaal does not only influence the counting points Hagestein and Prins Bernhardsluis.

The major changes that occured are:

- ≈60% of the trips that because of the artificial delay do not use the route via Hagestein and Prins Bernhard anymore ar now fully allocated via the Waal.
- ≈35% of of the trips that because of the artificial delay do not use the route via Hagestein and Prins Bernhard anymore ar now allocated via the Lek and the Prinses Beatrixsluizen on to the Amsterdam-Rijnkanaal and afterwards the Waal.
- ≈5% of of the trips that because of the artificial delay do not use

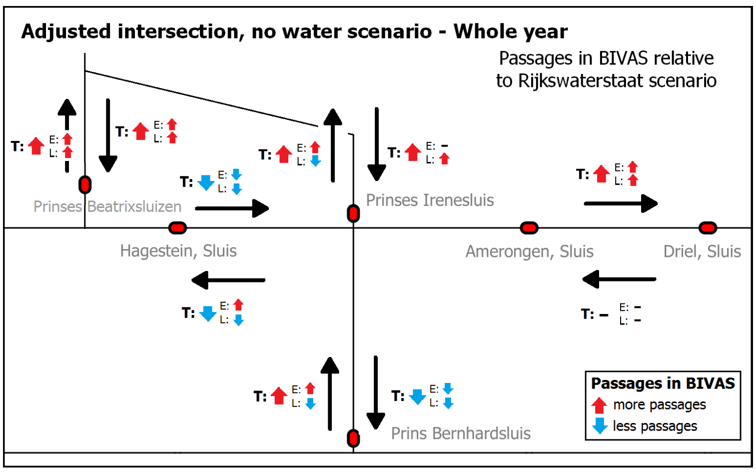


Figure 7.14: Adjusted intersection Whole year scenario, without water scenario; growth/shrinkage number of passages relative to Rijkswaterstaat scenario.

the route via Hagestein and Prins Bernhard anymore ar now allocated via the Lek and the Neder-Rijn.

Table 7.14: Adjusted intersection Whole year scenario, without water scenario; passages in BIVAS relative to Rijkswaterstaat scenario.

Adjusted intersection, no water scenario - Whole year		Changes relative to RWS scenario **No. of passages and percentage**				
Prinses Beatrixsluizen	**North**	+1858	+8%	**Empty**	+1	+0%
				Loaded	+1857	+12%
	South	+8	+0%	**Empty**	+6	+0%
				Loaded	+2	+0%
Prinses Irenesluis	**North**	+1	+0%	**Empty**	+4	+0%
				Loaded	-3	-0%
	South	+1852	+10%	**Empty**	-	-
				Loaded	+1852	+13%
Hagestein, Sluis	**East**	-4979	-45%	**Empty**	-84	-6%
				Loaded	-4895	-50%
	West	-9	-0%	**Empty**	+5	+1%
				Loaded	-14	-1%
Driel, Sluis	**East**	+392	+6%	**Empty**	+10	+1%
				Loaded	+382	+7%
	West	-	-	**Empty**	-	-
				Loaded	-	-
Prins Bernhardsluis	**North**	+3	+0%	**Empty**	+4	+0%
				Loaded	-1	-0%
	South	-3509	-15%	**Empty**	-100	-1%
				Loaded	-3409	-20%

7.4.2. ADJUSTED INTERSECTION SCENARIOS VERSUS REFERENCE DATA

The artificial delay for the turn between the Lek and the Amsterdam-Rijnkanaal provides an optimization of the results for the counting points Hagestein, Sluis (eastward) and Prins Bernhardsluis (southward), but has an effect on the other counting points as well. The final effect on the overall results is therefore questionable.

An indicator for this is the average deviation from the reference; D. For all the adjusted intersection scenarios the D is determined. Table 7.15 contains the D values of the Adjusted intersection scenarios in and those of the Rijkswaterstaat and Water scenario LSM scenarios.

Table 7.15: Average deviation from the IVS90 for the AI scenarios in comparison to the RWS and WS scenarios

	D			
	RWS	**AI ex. WS**	**WS**	**AI incl. WS**
Whole year	0.12	0.09	0.21	0.18
Median	0.13	0.1	0.18	0.14
Low	0.19	0.14	0.14	0.11
High	0.26	0.21	0.39	0.4

From the table it can be seen that for the Adjusted intersection scenarios without a water scenario the overall results improve for all the scenarios. For the adjusted intersection scenarios including a water scenario the results improve for the Whole year, Median and Low scenarios, but they deteriorate for the High scenario.

The detoriation for the High scenario when a water scenario is included, is caused by the fact that although the route via Hagestein and the Prins Bernhardsluis is without the adjusted intersection much more often computed by BIVAS as the cheapest route, the total amount of vessels passing Hagestein in eastward direction is too low in BIVAS in comparison to reality. This means that the results for Hagestein worsen when the route *Hagestein, Sluis - Prins Bernhardsluis* is optimized. For the Prins Bernhardsluis southward the results do improve when the intersection is adjusted, but not enough in comparison to the detoration at Hagestein, because part of the trips that were first allocated via Hagestein and Prins Bernhard do still pass Prins Bernhard. This is because they are now allocated via the Prinses Margrietsluizen, the Prinses Irenesluis and the Prins Bernhardsluis.

The Whole year adjusted intersection scenario without a water scenario gives the lowest D value. For this scenario it is counting point-level analysed to what extent adjusting the intersection at Wijk bij Duurstede is an improvement.

In Table 7.16 are for the Rijkswaterstaat and the Adjusted intersection Whole year scenario the ratios between the number of passages in BIVAS and the number of passages according to the IVS90 at the counting points within the Rotterdam-Lobith corridor included. Also the absolute change between the two scenarios in the deviation of 1 is included in the table. A positive absolute change means that the deviation of 1 has become larger, which means that the deviation of the number of passages recorded in the IVS90 has become larger as well.

Table 7.16: Adjusted intersection Whole year scenario, without water scenario; changes in comparison to reference data relative to the Rijkswaterstaat scenario.

Adjusted intersection no water scenario - Whole year		Changes relative to RWS scenario *No. of passages in BIVAS / No. of passages in IVS90*						
		RWS	**AI**	**Absolute change**		**RWS**	**AI**	**Absolute change**
Prinses Beatrixsluizen	**North**	0.98	1.05	+0.03	**Empty**	0.96	0.96	-0.00
					Loaded	0.98	1.10	+0.09
	South	1.01	1.01	+0.00	**Empty**	1.03	1.03	+0.00
					Loaded	0.99	0.99	-0.00
Prinses Irenesluis	**North**	1.00	1.00	+0.00	**Empty**	1.03	1.03	+0.00
					Loaded	0.98	0.98	+0.00
	South	1.03	1.13	+0.10	**Empty**	0.91	0.91	-
					Loaded	1.08	1.22	+0.14
Hagestein, Sluis	**East**	2.12	1.17	-0.95	**Empty**	0.84	0.79	+0.05
					Loaded	2.70	1.34	-1.35
	West	0.84	0.84	+0.00	**Empty**	0.57	0.57	-0.00
					Loaded	1.19	1.17	-0.01
Driel, Sluis	**East**	1.08	1.14	+0.07	**Empty**	0.56	0.56	-0.01
					Loaded	1.28	1.38	+0.09
	West	0.66	0.66	-	**Empty**	0.43	0.43	-
					Loaded	0.99	0.99	-
Prins Bernhardsluis	**North**	0.98	0.98	-0.00	**Empty**	1.04	1.04	+0.00
					Loaded	0.94	0.94	+0.00
	South	1.28	1.09	-0.19	**Empty**	0.98	0.97	+0.01
					Loaded	1.45	1.16	-0.29

From the table it is found that:

- The reallocation of the trips that at first went via Hagestein and Prins Bernhard is not positive for the comparison with the reality for the trips that are reallocated via the Prinses Beatrixsluizen, Prinses Irenesluis and the Prins Bernhardsluis, and not positive for the trips that are reallocated via Hagestein, Sluis and Driel, Sluis. Only the trips that are with the adjusted intersection completely allocated via the Waal improve the comparison with the reality.
- For empty vessels the adjusted intersection is no improvement, since for empty vessels the total number of passages at Hagestein and Prins Bernhard was too low for the Rijkswaterstaat scenarios. Adding the adjusted intersection lowers these numbers even more.

7.4.3. ADJUSTED INTERSECTION SCENARIOS - CONCLUSIONS

For the different scenarios for which the most optimal artificial delay has been determined the most optimal delay differs. This is because of differences in the composition of the trips, the allocation in reality and the water conditions.

Adding the artificial delay does not only influence the counting points Hagestein, Sluis and Prins Bernhardsluis. The allocation of the trips that without the artificial delay were allocated via Hagestein and Prins Bernhard, but with the artificial delay not anymore happens with the artificial delay in the following way:

- ≈60% fully via the Waal.
- ≈35% via the Lek and the Prinses Beatrixsluizen on to the Amsterdam-Rijnkanaal and then the Waal.
- ≈5% of via the Lek and the Neder-Rijn.

The artificial delay is overall an improvement. Only when the total number of passages at Hagestein in westward direction is already too low the trips that are reallocated via the Prinses Margrietsluizen, the Prinses Irenesluis and the Prins Bernhardsluis are the cause of an overall deterioration instead of an improvement. Also for the scenarios were the artificial delay in an overall improvement there are negative effects of adding the artificial delay.

Adding the artificial delay has the following negative side effects:

- The reallocation of the trips that at first went via Hagestein and Prins Bernhard is not positive for the comparison with the reality, for the trips that are reallocated via the Prinses Beatrixsluizen, Prinses

Irenesluis and the Prins Bernhardsluis, and not positive for the trips that are reallocated via Hagestein, Sluis and Driel, Sluis.

- For empty vessels the adjusted intersection is no improvement, since for empty vessels the total number of passages at Hagestein and Prins Bernhard were too low for the Rijkswaterstaat scenarios. Adding the adjusted intersection lowers these numbers even more.

The negative side effects can not be taken away, since it is not possible in BIVAS to adjust the network only for specific trips, and when you would for example want to take away the reallocation via the Prinses Beatrixsluisen, the Prinses Irenesluis and the Prins Bernhardsluis, on this route an artificial delay should be added as well. Adding and artifical delay on this route will also effect the trips that take this route already without the adjusted intersection.

7.5. DELTA PROGRAMME SCENARIO

The Delta Programme scenario is the median Rijkswaterstaat scenario with a water scenario including the water conditions of the low discharge period.

In Table 7.17 the statistics of the BIVAS computations with the Median Rijkswaterstaat scenario and the Delta Programme scenario are given.

Table 7.17: Comparison statistics Delta Programme scenario and Median Rijkswaterstaat scenario

Median		**Rijkswaterstaat**	**Deltaprogramme**	**% change**
Infeasible trips	[no.]	55	107	+95%
Additional trips due to reduced load	*[no.]*	212	1162	+448%
Total costs	[€ x 10^6]	116	161	+39%
Total distance	[km x 10^3]	3931	5448	+39%
Tonne kilometre	[tkm x 10^6]	4058	6360	+57%
Costs per tonne kilometre	[(€/tkm)x10^3]	20.07	19.78	-1.42%
Average load factor loaded trips	[-]	0.68	0.63	-8.44%

As expected the number of infeasible trips and trips due to reduced load is significantly higher for the Delta Programme scenario. The trips of the median discharge period sailed with draughts corresponding to the water depths in the median discharge period, when the water depths of the low discharge period are used more vessels will have to reduce their load in order to sail. This is confirmed by the shrinkage in the average load factor of the loaded trips.

Since there are more trips that have to take place through reducing the load, the total distance sailed, and thereby the total costs have grown. However, the costs per tonne kilometre shrinked. This is because the average transport costs per kilometre shrink when the flow velocities shrink because of the relatively larger effect on the costs of counter currents (see Subsection 7.1.1.

What is noteworthy of the statistics for the Delta Programme scenario is that the tonne kilometres have grown significantly in comparison to the Rijkswaterstaat scenario, which means that there are a large amount of trips allocated via a detour in the Delta Programme scenario. In reality at least part of these trips would probably have reduced their load, or waited with sailing till after the low discharge period, but in BIVAS at first always a route that does not require reducing of the load is searched.

The large amount of detours have a significant effect on the total costs. The with the Delta Programme scenario computed total costs are 45 million euros more than the total cost computed with the Rijkswaterstaat scenario. It is not expected that in reality the economic loss due to low discharges will be 45 million euros in two weeks. Especially when this amount is compared to the economic loss of around 100 million euros computed by RIZA (2005) and Jonkeren (2009) for the whole year 2003, which was a dry year.

7.6. CONCLUSIONS

This section lists per scenario type included in this chapter the main conclusions.

WITHOUT CURRENT SCENARIOS

- The allocation of the trips through the Rotterdam-Lobith corridor is clearly sensitive to the flow velocities.
- Counter currents have a larger effect on the costs to sail via an arc than supporting currents.
- Changing flow velocities have a larger effect on the allocation for the loaded vessels than for the empty vessels.

WATER SCENARIO LSM SCENARIOS

- In the conversion from the LSM to the water scenario the correction depth for the Maas-Waalkanaal is incorrect and should be corrected.
- The water scenario contains for part of the arcs incorrect water depths and/or part of the vessels sailed in reality with a smaller keel clearance than the minimum required under keel clearance defined by BIVAS.
- The water scenario worsens the results for the whole year, median and high discharge periods, only for the low discharge period using the water scenario improves the results.
- The sensitivity for smaller flow velocities is for empty vessels in BIVAS much larger than in reality.
- The sensitivity for the flow velocity is for loaded vessels in BIVAS too small in comparison to reality.
- The non-inclusion of the opening of the Prins Bernhardsluis during low water, the commissioning of the Prinses Marijkesluis during high water and the opening of the weirs at Driel, Amerongen and Hagestein during high water in BIVAS influences the correctness of the results of BIVAS.

How the differences between the reality and BIVAS in the sensitivities for the flow velocity can be reduced for both the empty and the loaded vessel is unknown. In this study this is not further adressed, but it should be investigated in the future. The opening of the weirs in the Lek and the Neder-Rijn can be included. In the Correct control weirs scenarios this is included. The opening and commissioning of the Prins Bernhardsluis and the Prinses Marijkesluis can not be included in the current version of BIVAS, BIVAS should be adjusted for this.

CORRECT CONTROL WEIRS SCENARIOS

Opening of the weirs in BIVAS causes too much lowering of the costs for travelling via the Neder-Rijn and Lek in BIVAS. To translate this conclusion into improvements for BIVAS more research should be done on the reaction to larger water depths of skippers in reality. It might be that looking at the costs, sailing via the Neder-Rijn and Lek is in reality cheaper when the weirs are open, but that skippers just stick to their normal route via the Waal, but it can also be the case that the Neder-Rijn and Lek are, when the locks are not in use, modelled too cheap in comparison to reality.

ADJUSTED INTERSECTION SCENARIOS

Adjusting the intersection at Wijk bij Duurstede has a positive effect on the results of BIVAS.

Adding the artificial delay has the following negative side effects:

- The trips that are reallocated via the Prinses Beatrixsluizen, Prinses Irenesluis and the Prins Bernhardsluis and via Hagestein, Sluis and Driel, Sluis have a negative effect on the results of BIVAS.
- For empty vessels the adjusted intersection detoriates the results.

The negative side effects can not be taken away, since for example extra artificial delays on the network have to be added for this, which will not only affect the trips related to the negative side effects.

DELTA PROGRAMME SCENARIO

BIVAS allocates for the Delta Programme scenario a large amount of trips via a (long) detour. In reality at least part of these trips would probably have reduced their load, or waited with sailing till after the low discharge period, but in BIVAS at first always a route which does not require reducing the load is searched.

8
CONCLUSIONS

This study focuses on the inland navigation analysis system BIVAS, a software tool which, given a waterway network and a set of inland navigation trips, computes the optimal routes over the network for the entered inland navigation trips. BIVAS does not yet give accurate results in all cases. Therefore the objective of this research was:

Analysing and validating the functioning of BIVAS for an existing year and, based on this, give recommendations for the improvement of BIVAS.

To achieve this objective at first a literature review on the inland navigation and the computational methods of BIVAS and the software related to BIVAS has been carried out. Followed by a data analysis whereby the input data for BIVAS has been analysed and whenever possible validated. In addition there is looked into the relation between inland navigation and water conditions. Finally various computations were done and analysed.

In this chapter the conclusions of this study are presented; in Section 8.1 the main conclusions, in Section 8.2 the conclusions on the software, input and reference data and in Section 8.3 the conclusions on the computations.

8.1. MAIN CONCLUSIONS

BIVAS as it is at this moment is far from an optimal model and can not be used sufficiently reliable. Clearly, within the Rotterdam-Lobith corridor, the differences in the costs to travel via the various possible routes are very small. This makes it difficult to get the allocation through the Rotterdam-Lobith corridor correct.

BIVAS uses a large amount of input. Of a part of this input the origin and/or correctness is unknown. That this is the case for the vessel speeds seems to be the biggest problem, since BIVAS is fairly sensitive for the speed of the vessel over the ground during the allocation of the trips.

Using a water scenario with daily varying water conditions is expected to improve the results of BIVAS. However, using the present water scenario deteriorates the results. This is mainly because the sensitivity of BIVAS for the flow velocities is not the same as the sensitivity of the skippers for the flow velocities in reality.

The present water scenario does not include the opening and commissioning of the weirs and locks as a result of low and/or high discharge periods. For the Correct control weirs scenarios the opening of the weirs in the Neder-Rijn and Lek during high discharge periods is included. However, including this is no improvement for BIVAS. Why this is no improvement is unknown, but it could be because the commissioning of the Prinses Marijkesluis during high discharge periods is not included, whereby the delay to sail via the Amsterdam-Rijnkanaal in these periods is not included, but it can also be that the resistance to travel via the Neder-Rijn and Lek because of their difficult navigability is not correctly included in BIVAS.

BIVAS allocates much more trips than in reality via the route Lek - Amsterdam-Rijnkanaal. This is most probably for a large part caused by incorrect origin nodes in the Port of Rotterdam. The correct origin nodes can not be found retroactively, therefore an ad hoc solution is created. The intersection between the Lek and the Amsterdam-Rijnkanaal is adjusted in a way that there is and extra resistance to allocate a trip via this route. The ad hoc solution improves the results with approximately 25%, but is not everything, because it also brings negative side effects and does not address the core problem.

8.2. CONCLUSIONS ON SOFTWARE, INPUT AND REFERENCE DATA

When in BIVAS the water conditions change this only influences the determination of the speed of the vessel over the ground. It is notable that in BIVAS the fuel usage of the vessel per hour does not depend on the water conditions and the speed of the vessel, while in reality it does. This may influence the correctness of the allocation of the trips by BIVAS.

The present version of the Nieuwe koppeling LSM-BIVAS converts only the water depths and flow velocities of the LSM Light to the water scenario. The water levels are not converted, but it is needed to include these in the conversion in order to control the weirs correctly.

Whether the way the origins and destinations of the trips in the IVS90 that can not be coupled based on the waterway number and hectometring to BIVAS nodes is correct, is questionable, because it can not be verified whether the coupling based on the UNLOCODE and RWS vessel class is correct.

Not all of the BIVAS input is correct and for part of the BIVAS input the origin and/or correctness is unknown. The most important conclusions on the input are given here.

The foundation of the BIVAS network is correct, but the widths of the waterways and the wet cross sectional areas are linked to the BIVAS CEMT class of the arc, which means that they are often wrong, since in reality they vary between waterways of the same CEMT class. The widths are currently not used in the BIVAS computations, but the wet cross sectional areas are used in the determination of the vessel speed, whereby the incorrect values have an influence on the allocation by BIVAS.

The desired speed per vessel type, and the fuel usage per hour and vessel type, are linked to the BIVAS CEMT class of the arc as well. In reality they depend on the depth and wet cross sectional area of the waterways, which can both differ significantly between waterways of the same BIVAS CEMT class. Next to this the origin of the desired vessel speed and fuel usage per hour are unknown, and are part of the values certainly incorrect.

The water level of the water scenario does not show much influence of the tide, while in reality the influence can clearly be seen. However, since the water conditions of the water scenario are defined per day, BIVAS computes with timesteps of a day and skippers take the tide into account in reality it is hard to define how the tide should be included in the water scenario.

On arcs of the same waterway the correction depths of the Nieuwe koppeling can differ strongly. Whether this is right is unknown, but it is expected that part of the correction depths is incorrect.

During the low discharge period it would be expected that because of more reliable water depths at the Neder-Rijn and Lek more vessels would sail via these rivers. However, this is not the case. Most probably because the maximum draught a vessel can sail with during low discharge periods, is defined by the water depth somewhere upstream, making the water depth at the Waal always sufficient.

The Amsterdam-Rijnkanaal is used more during the low discharge period, which is most likely caused by the opening of the Prins Bernhardsluis during low discharge periods. During high discharge periods the weirs in the Neder-Rijn and Lek are open. This causes larger flow velocities and water depths on these rivers, which makes these rivers in westward direction more appealing for the skippers. The Amsterdam-Rijnkanaal is less appealing during the high discharge period. This is probably caused by the Prinses Marijkesluis, which is normally open, but in use during extreme high discharge periods.

8.3. CONCLUSIONS COMPUTATIONS

This section contains the most important conclusions per computed scenario type.

8.3.1. RIJKSWATERSTAAT SCENARIOS

The deviation of the allocation of the trips by BIVAS in comparison to the allocation in reality is for all Rijkswaterstaat scenarios too large. Not enough trips are allocated via the Merwedekanaal and the Neder-Rijn and too many trips are allocated via the Lek and the Amsterdam-Rijnkanaal.

There is a large difference in the average deviation for the three two-week discharge periods. Since the water conditions for the Rijkswaterstaat scenario are always the conditions on a median day it is expected that these large differences are caused by the incorrect water conditions for the other periods. Including the correct water conditions is expected to improve the results for the other periods.

The reference comparison on counting point level for the median period shows that the deviations for all counting points and every direction, except for the Prins Bernhardsluis in northern direction, is more then ten % and thereby not acceptable. For the reference comparison on routelevel it turns out that only the route *Hagestein, sluis - Prins Bernhardsluis* has a completely unacceptable deviation of 731%. This is most probably at least partly caused by trips with incorrect origin nodes within the port of Rotterdam.

From the reference comparisons on lock-level and route-level there are following findings:

- Between the empty and the loaded trips there are clear differences in the allocation.
- The resistance of a route via the Neder-Rijn is relative to the resistance of a route including a combination of the Waal East of the Amsterdam-Rijnkanaal and the Amsterdam-Rijnkanaal too large in BIVAS.
- The resistance of a route via the Lek in combination with the Amsterdam-Rijnkanaal is in BIVAS too small relative to the resistance of a route via the Waal.

Between the empty and the loaded trips the only difference is the desired vessel speed stored in the BIVAS database. Or these are wrong, or BIVAS does not handle these differences correctly. BIVAS allocates significantly more vessels via the Lek and Neder-Rijn in eastward direction than in westward direction, which gives rise to the presumption that in BIVAS the influence of the flow on the allocation of the trips is large.

8.3.2. WITHOUT CURRENT SCENARIOS

From the Without current scenarios it has been found that the allocation of the trips through the Rotterdam-Lobith corridor is clearly sensitive to the flow velocities. Counter currents have a larger effect on the costs to sail via an arc than supporting currents, and changing flow velocities have a larger effect on the allocation for the loaded vessels than for the empty vessels.

8.3.3. WATER SCENARIO LSM SCENARIOS

The water scenario worsens the results for the whole year, median and high discharge periods, only for the low discharge period using the water scenario improves the results.

From the Water scenario LSM scenarios it is concluded that the sensitivity for smaller flow velocities is, for empty vessels, in BIVAS much larger than in reality, and that the sensitivity for the flow velocity is, for loaded vessels, in BIVAS too small in comparison to reality. That the sensitivity for the flow velocities in BIVAS is different than in reality can be caused by incorrect vessel speeds over the ground in BIVAS and incorrect fuel usages per hour, but it can also be that skippers do not choose their route completely on costs, they might simply have a preference for a particular route.

The opening of the Prins Bernhardsluis during low water, the commissioning of the Prinses Marijkesluis during high water and the opening of the weirs at Driel, Amerongen and Hagestein during high water is not included in BIVAS. This influences the correctness of the results of BIVAS.

The opening of the weirs in the Lek and the Neder-Rijn can be, and is, in the Correct control weirs scenarios, included. The opening and commissioning of the Prins Bernhardsluis and the Prinses Marijkesluis can not be included in the current version of BIVAS, BIVAS has to be adjusted for this.

8.3.4. CORRECT CONTROL WEIRS SCENARIOS

Opening of the weirs in BIVAS causes too much lowering of the costs for travelling via the Neder-Rijn and Lek in BIVAS. In reality it might be that, looking at the costs, sailing via the Neder-Rijn and Lek is cheaper when the weirs are open, but that skippers just stick to their normal route via the Waal. It can also be the case that the Neder-Rijn and Lek are, when the locks are not in use, modelled too cheap in comparison to reality.

In the Correct control weirs scenario the commisioning of the Prinses Marijke sluis during high discharge periods is not included, whereby there is no extra delay to sail via the Amsterdam-Rijnkanaal, this can also cause that more vessels are allocated partly via the Neder-Rijn or Lek.

8.3.5. ADJUSTED INTERSECTION SCENARIOS

Adjusting the intersection at Wijk bij Duurstede has a positive effect on the results of BIVIS, but has the following negative side effects:

- The trips that are reallocated via the Prinses Beatrixsluizen, Prinses Irenesluis and the Prins Bernhardsluis and via Hagestein, Sluis and Driel, Sluis have a negative effect on the results of BIVAS.
- For empty vessels the adjusted intersection detoriates the results..

The negative side effects can not be taken away, since for example extra artificial delays on the network have to be added for this, which will not only affect the trips related to the negative side effects.

8.3.6. DELTA PROGRAMME SCENARIO

BIVAS allocates for the Delta Programme scenario a large amount of trips via a (long) detour. In reality at least part of skippers would probably have reduced the load, or waited with sailing till after the low discharge period, but in BIVAS at first always a route which does not require reducing of the load is searched.

9
RECOMMENDATIONS

Part of the objective of this study is to give recommendations for the improvement of BIVAS. Based on the conclusions in Chapter 8 recommendations on the input, software and systems related to BIVAS, and BIVAS itself are given in Section 9.1. In addition, in Section 9.2 recommendations for further research are given.

9.1. RECOMMENDATIONS FOR IMPROVEMENT OF BIVAS

The main conclusions state that BIVAS at this moment is far from an optimal model and can not be used sufficiently reliable. Within the Rotterdam-Lobith corridor, the differences in the costs to travel via the various possible routes are very small. This makes it difficult to get the allocation through the Rotterdam-Lobith corridor correct. However, improvement of the results should be possible when the recommendations given in this section are implemented.

9.1.1. RECOMMENDATIONS ON INPUT

Not all of the BIVAS input is correct, and for part of the BIVAS input the origin and/or correctness is unknown. This input should, whenever possible, be checked and improved. This section includes the main recommendations for the improvement of the input.

The widths of the arcs are not correctly included in BIVAS. These widths are not included in the present sources of the network, so another source should be used. A possible source could be the LSM-Light, which includes accurate widths of the waterways.

For almost all kinds of the network data of BIVAS a very little amount of incorrect values has been found. It is recommended to check all the network data and improve these values.

The sources of the desired vessel speeds and fuel usage per hour are unknown, and part of the values are certainly incorrect. BIVAS is for the allocation of the trips very sensitive to these, and therefore it is important to use as correct values as possible. By collecting data on vessel speeds via radar or AIS, and data on fuel usage from skippers the desired vessel speeds and fuel usage per hour could be improved.

On arcs of the same waterway the correction depths of the Nieuwe koppeling can differ strongly. Whether this is right is unknown, but it is expected that part of the correction depths is incorrect. The correction depths that are expected to be incorrect should be checked. This can be done by checking to which LSM-Light segment the arcs with the correction depths that are expected to be wrong, are coupled to and checking what the river profiles of the LSM-Light segments look like.

9.1.2. RECOMMENDATIONS ON SOFTWARE AND SYSTEMS RELATED TO BIVAS

In the Nieuwe Koppeling LSM-BIVAS the water level is not included. When the opening and commissioning of the weirs and locks in the Neder-Rijn and Lek is included in a BIVAS computation, the water level should be included in the Nieuwe Koppeling LSM-BIVAS as well. This can be done by taking the water level of the LSM on the same point as the water depth is taken.

The IVS90 does not always include the exact origin or destination of the trips, by obliging the skippers to always include the exact waterway number and hectometring, this could be improved in the future.

When the exact origin or destination of the trips is unknown the trips are linked to the node in the UN-LOCODE area that has the most vessels of the same vessel type leaving or arriving. It might be better to not only use the vessel type to link the vessels to a node, but also the type of goods they carry. In this way it is expected that more trips are linked to the correct nodes.

In the IVS90 there are, for part of the trips, multiple passages at one counting point recorded. These extra passages should be removed from the reference trip set. Roundtrips recorded as one trip in the IVS90 can not be allocated by BIVAS. These trips should be removed from both the traffic scenario and the reference trip set.

9.1.3. RECOMMENDATIONS ON COMPUTATIONAL METHOD OF BIVAS

BIVAS is for the allocation of the trips very sensitive to speeds. In the present version of BIVAS the desired speed per vessel type, and the fuel usage per hour and vessel type, are linked to the BIVAS CEMT class of the arc. In reality the optimal speed depends on the depth and wet cross sectional area of the waterway, which can both differ significantly between waterways of the same BIVAS CEMT class. However, the optimal speed does not have to be the desired speed, because the vessel speeds will also depend on the traffic on the waterway, and the characteristics of the waterway (a lot of bends or straight for example). Improving the desired speeds using radar or AIS as described above, might be better than computing the desired speed based on the depth and cross sectional area.

Also the fuel usage per hour stored in the BIVAS database is not accurate. Since in reality the fuel usage depends on the dimensions of the vessel, the wet cross sectional area of the waterway and the speed of the vessel it would be better not to use the stored fuel usage, but the fuel usage that can be calculated with all parameters stated above. In BIVAS this is already done when emission computations are included, so this can be easily done.

The Prinses Marijksluis at the Amsterdam-Rijnkanaal is in BIVAS not included as a lock. Changing this arc to a lock in the database will solve this. However, the Prinses Marijkesluis is only during high water levels in use. The Prins Bernhardsluis is not in use during low discharge periods, this is also not included in the present BIVAS version. The locks in the database have the option to include a minimum and maximum operating water level. For the Prinses Marijkesluis and the Prins Bernhardsluis these will have to be included in order to be controlled correctly.

In BIVAS it is not possible to move a trip to another day when the costs to sail on the specified day for the trip become too high, or it is not possible to sail at all. Certainly for the computations for the Delta Programme it might be good to include the possibility to move the trip to another day.

9.2. RECOMMENDATIONS ON FURTHER RESEARCH

BIVAS should reflect the reality. It is not (completely) known how skippers make their choices. In order to get a better reflection of reality the choices of skippers should be investigated. How do they deal with the tide, when do they choose to sail with less load or to postpone their trip, how sensitive are they to the degree of difficultness of a certain route, and how sensitive are they to the uncertainty of the waiting time at locks and bridges?

In this research only the Rotterdam-Lobith corridor is investigated. It is expected that in other parts of the network were there are multiple routes possible, the same phenomena play a role. For these parts of the network it would be good to investigate under which water conditions locks and weirs are in use or opened.

From the analysis of the model computations it was found that the allocation of the trips through the Rotterdam-Lobith corridor is clearly sensitive to the flow velocities, and that varying flow velocities have a much larger effect on the allocation of the loaded vessels than on the allocation of the empty vessels. How these differences can be reduced is not addressed in this study and should be investigated in the future.

In this research is, with the current possibilities of BIVAS, a scenario created that could be used for the Delta Programme. BIVAS allocates for this scenario a large amount of trips via a (long) detour. In reality at least part of the skippers of these trips would probably have reduced their load, or waited with sailing till after the low discharge period, but in BIVAS at first always a route which does not require reducing of the load is searched. For the Delta Programme it is important to investigate how BIVAS could be adjusted in such a way that the choice between sailing later in time, reducing the load, and taking a detour, is as it would be in reality.

References

Balanin, V.V., & Bykov, L.S. (1965). Selection of leading dimensions of navigation canalsections and modern methods of bank protection. In *XXIst International Navigation Congress* (p. 151-169). Stockholm, Sweden.

Beersma, J., Buishand, T., & Buiteveld, H. (2004). *Droog, droger, droogst* (Rep. No. 199-II). De Bilt, the Netherlands: Koninklijk Nederlands Meteorologisch Instituut (KNMI). (ISBN: 9036922607)

Blom, J., & Mahmoud, M.N. (2004). *Toetsrapport Prinses Marijkesluizen* (Rep. No. 8059D-T-2003.0008). Rijkswaterstaat Bouwdienst.

Broekema, P. (2011). *'Aan één bom hebben we meer dan genoeg'.* Retrieved 2017-03-10, from http://nos.nl/artikel/321148-aan-een-bom-hebben-we-meer-dan-genoeg.html

Brolsma, J.U. (2011). *A brief history of inland navigation and waterways* (Rep. No. dvs0811re142). Rijkswaterstaat Centre for Transport and Navigation (RWS-DVS).

Brolsma, J.U., & Roelse, K. (2011). *Waterway Guidelines 2011.* Rijkswaterstaat, Centre for Transport and Navigation (RWS-DVS). (ISBN: 9789036900690)

Charta Software. (2016). *BIVAS, BInnenvaart Analyse Systeem.* Retrieved 2016-09-02, from https://bivas.chartasoftware.com/

Deltacommissie 2008. (2008). *Samen werken met water* (1st ed.). Hollandia Printing. (ISBN: 9789090234847)

Deltares. (2015). *Sobek suite.* Retrieved 2016-09-05, from https://www.deltares.nl/en/software/sobek/

Dijkstra, E.W. (1959). A Note on Two Problems in Connexion with Graphs. *Numerische Mathematik*(1), 269-271.

Dillingh, D. (2013). *Kenmerkende waarden Kustwateren en Grote rivieren* (Rep. No. 1207509-000-ZKS-0010 v4). Delft, the Netherlands: Deltares.

Directoraat-Generaal Goederenvervoer (DGG). (1999). Reglement IVS90. *Staatscourant*(142), 10.

Dofferhoff, N.J.P., Roelse, K., & Westdijk, C.V.J. (2002). *Classificatie en kenmerken van de Europese vloot en de Actieve vloot in Nederland.* Rotterdam, the Netherlands: Rijkswaterstaat Adviesdienst Verkeer en Vervoer (RWS-AVV).

Dorsser, J.C.M. van. (2012). *Scheepvaartscenario's voor het Deltaprogramma.* Rijkswaterstaat Dienst Verkeer en Scheepvaart (RWS-DVS).

European Conference of Ministers of Transport (ECMT). (1992). Resolution No. 92/2 on new classifiction of inland waterways. In *Activities of the conference: Resolutions of the council of ministers of transports and reports approved in 1992* (p. 87-97). Athens, Greece. ([CEMT/CM(92)6/FINAL])

Eurostat. (2016). *Freight transport statistics - modal split - statistics explained.* Retrieved 2016-07-26, from http://ec.europa.eu/eurostat/statistics-explained/index.php/Freight_transport_statistics_-_modal_split

Groen, T., & van Meijeren, J. (2010). *Vlootontwikkeling binnenvaart* (Rep. No. TNO-034-DTM-2010-02071). Delft, the Netherlands: Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (TNO).

Helpdesk Water. Rijkswaterstaat, Water, Verkeer en Leefomgeving (RWS-WVL). (2015). *Waterbase* [Web application]. Retrieved 2015-05-03, from live.waterbase.nl

Hove, D. ten. (2008). *Herziening inventarisatie manoeuvreermiddelen* (Rep. No. 22788.600/3). Wageningen, the Netherlands: Maritiem Research Instituut Nederland (MARIN).

Hurk, B. van den., Klein Tank, A., Lenderink, G., Ulden, A. van., Oldenborgh, G.J. van., Katsman, C., ... Drijfhout, S. (2006). *KNMI Climate Change Scenarios 2006 for the Netherlands* (Rep. No. WR 2006-01). De Bilt, the Netherlands: Koninklijk Nederlands Meteorologisch Instituut (KNMI).

HydroLogic BV. (2013). *Waterverdelings- en verziltingsvraagstukken in het hoofdwatersysteem in West- en Midden-Nederland* (Rep. No. P475). Amersfoort, the Netherlands.

Ibánez-Rivas, N. (2010). *Peer review of the TRANS-TOOLS reference transport model* (Rep. No. JRC60083). Seville, Spain: European Commission Joint Research Centre's Institute for Prospective Technological Studies (IPTS, JRC-Sevilla).

Jong, J. de. (2014). *Voorstel koppeling LSM - BIVAS op basis van maatgevende ondiepte* (Memo No. 1209462-004-BGS-0002). Delft, the Netherlands: Deltares.

Jonkeren, O. (2009). *Adaption to Climate Change in inland waterway transport* (PhD thesis). Vrije Universiteit Amsterdam, Amsterdam, the Netherlands. (ISBN: 9789036101424)

Klijn, F., Velzen, E. van., Maat, J. ter., & Hunnink, J. (2012). *Zoetwatervoorziening in Nederland* (Rep. No. 1205970-000-VEB-0013). Deltares, Delft, the Netherlands.

Kroon, T., & Ruijgh, E. (2012). *Functionale specificaties, kwaliteitseisen en opbouw Deltamodel.* Rijkswaterstaat Waterdienst. (Report Projectteam Deltamodel, v1.1)

Linde, A.H. te. (2011). *Rhine at risk? Impact of climate change on low-probability floods in the Rhine basin and the effectiveness of flood management measures* (Phd thesis). Vrije Universiteit Amsterdam, Amsterdam, the Netherlands. (ISBN: ISBN 9789085707424)

Loon, T. van., Ras, W.J., & Franssen, M. (2011). *Ruimte voor de Lek (Snip 3). Ruimtelijk kwaliteitsplan* (Rep. No. 075175576:D). Rotterdam, the Netherlands: Arcadis.

MariaDB Foundation. (2017). *MariaDB.* Retrieved 2017-02-22, from `https://mariadb.org/`

Mark, R. van der. (2011). *Diepte Sobek* (Memo). Delft, the Netherlands: Deltares.

Meijeren, J. van., Jordans, M., Rooijen, T. van., & Vanherle, K. (2009). *Directe transporteffecen Kanaal Gent-Terneuzen. Resultaten nulaternatief en projectalternatieven* (Rep. No. 2008-D-R0928/A). Delft, the Netherlands: Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (TNO).

Miete, O. (2014). *BIVAS v3.2.0 - periode 2011* [Microsoft Excel spreadsheet]. Rijkswaterstaat Water, Verkeer en Leefomgeving (RWS-WVL).

Ministerie van Infrastructuur en Milieu (IenM). (2011). *Rijkswaterstaat start hoogwaterberichtgeving voor de Rijn.* Retrieved 2016-11-15, from `https://www.rijksoverheid.nl/actueel/nieuws/2011/01/11/rijkswaterstaat-start-hoogwaterberichtgeving-voor-de-rijn`

Ministerie van Verkeer en Waterstaat (V&W), Ministerie van Landbouw, Natuur en Voedselkwaliteit (LNV) & Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (VROM). (2011, September). *Deltaprogramma 2011.*

Ministerie van Verkeer en Waterstaat (V&W), Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (VROM). (2004). *Nota Mobiliteit - Naar een betrouwbare en voorspelbare bereikbaarheid.*

Nederlands Centrum voor Onderzoek, Advisering en Onderwijs op het gebied van Verkeer en Vervoer (NEA). (2005). *MIT-verkenning sluis Grave.*

Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling (RIZA). (2005). *Aard, ernst en omvang van watertekorten in Nederland* (Rep. No. 2005.016). (ISBN: 9036957230)

Rijkswaterstaat. (2016). *Vaarwegenoverzicht.* Retrieved 2016-10-07, from `http://www.rijkswaterstaat.nl/water/vaarwegenoverzicht/index.aspx`

Rijkswaterstaat, Adviesdienst Verkeer en Vervoer (RWS-AVV). (2000). *Een nieuwe standaardvloot voor de verkeersmodellen.* Rotterdam.

Rijkswaterstaat, Centrale Informatievoorziening (RWS-CIV). (2013a). *Handleiding Nationaal Wegenbestand.* Delft, the Netherlands. (Version 3.0)

Rijkswaterstaat, Centrale Informatievoorziening (RWS-CIV). (2013b). *Vaarwegenkaart Nederland* [Map]. Reijers Kaartproducties Veghel.

Rijkswaterstaat, Centrale Informatievoorziening (RWS-CIV). (2016a). *Vaarwegen in Nederland.* Delft, the Netherlands. (Edition October 2016)

Rijkswaterstaat, Centrale Informatievoorziening (RWS-CIV). (2016b). *Vin-applicatie* [Web application]. Retrieved 2016-10-05, from `https://www.vaarweginformatie.nl/fdd/main/infra/vin`

Rijkswaterstaat, Dienst Verkeer en Scheepvaart (RWS-DVS). (2011). Deelrapportage Vaarwegen voor de Nationale Markt en Capaciteits Analyse (NMCA). In *Nationale Markt- en Capaciteitsanalyse.* The Hague, the Netherlands: Ministerie van Infrastructuur en Mileu (IenM). (blg-118236)

Rijkswaterstaat, Dienst Verkeer en Scheepvaart (RWS-DVS). (2013). *Basisbestanden Goederenvervoer 2011 - Basisbestanden Binnenvaart 2011.*

Rijkswaterstaat, Provincie Groningen & Provincie Fryslân. (2017). *Hoofdvaarweg lemmer-delfzijl - historie.* Retrieved 2017-03-08, from `http://lemmer-delfzijl.nl/achtergrond/historie/`

Stichting Waterrecreatie Nederland. (2016). *Knooppunten vaarwegen Amsterdam-Rijnkanaal.* Amsterdam, the Netherlands. (Version 1c)

The MathWorks, Inc. (2016). *Matlab features.* Retrieved 2016-09-05, from `http://nl.mathworks.com/products/matlab/features.html`

Turpijn, B., Roelse, K., Groen, T., & van Meijeren, J. (2010). *Herziening Vlootontwikkeling Binnenvaart.* Rijkswaterstaat Dienst Verkeer en Scheepvaart (RWS-DVS). (Concept report, v0.1. Adjustment TNO-report TNO-034-DTM-2010-02071)

Turpijn, B., & Weekhout, R. (2011). *Klimaat en Binnenvaart. Een strategische verkenning naar de effecten van klimaatverandering op het gebruik van het Hoofdvaarwegennet.* Rijkswaterstaat Dienst Verkeer en Scheepvaart (RWS-DVS).

United Nationd Economic Comission for Europe (UNECE). (2012). *Map of the European Inland Waterway Network* [Map]. Euromapping.

Vaartips.nl. (2011). *Limburg - Hollandse Plassen - Friesland routes.* Retrieved 2016-11-13, from `http://www.vaartips.nl/pdf/vaarroute-lhf.pdf`

Voorsluijs, E. (2013). *Voorkeursstrategie Waal en Merwedes.* Stuurgroep Delta-Rijn, Stuurgroep Rijnmond Drechtseden. Provincie Gelderland.

A
The Delta Programme

In September 2007 the Dutch Cabinet composed the second Delta Committee (Commissie Veerman). The Dutch Cabinet asked the committee to come up with recommendations on how to protect the Netherlands against the consequences of climate change. The issue is how the Netherlands can be made climate proof on the long term, be safe for flooding, and still remain an attractive place to live, work, recreate and invest.

In September 2008 the second Delta Committee presented their advice to the Dutch Cabinet (Deltacommissie 2008, 2008). The Committee asked attention for the sustainability of the current flood protection strategy and freshwater supply within the framework of climate change. They observed a possible increased risk of flooding and a possible widening of the gap between demand and availability of fresh water.

The Dutch cabinet started, partly in response to the advice of the Delta Committee, the Delta Programme. The goal of the Delta Programme is to develop a strategy for sustainable and robust flood protection and freshwater supply on the long term (V&W, LNV & VROM, 2010).

The Delta Programme includes 9 sub-programmes.

Three of these sub-programmes are of importance to the whole of the Netherlands:

- Safety
- Fresh Water
- New construction and restructuring

Six of the sub-programmes focus on a particular area of the Netherlands:

- Rhine Estuary-Drechtsteden
- South-Western Delta Modelinstrumentarium
- Ijsselmeer Region
- Rivers
- Coast
- Wadden Region

A.1. Delta Programme Fresh Water

The sub-programme Fresh Water focusses on how the freshwater supply in the Netherlands can be arranged on the long term, and when decisions and measures need to be taken on this. Freshwater supply comprises, in this case, safe and healthy water (drinking water, bathing water etc.), sufficient availability of water for agriculture, industry and inland navigation, and water as factor in an attractive environment (settlement climate, recreation).

A.2. Set of Delta Instruments

The decisions and strategies of the Delta Programme must have a solid basis in terms of content. Therefore the chosen approach makes sure all sub-programmes use the same up-to-date knowledge, and perform their analysis with the same methods, principles and models.

In order to achieve this a Set of Delta Instruments is developed (Kroon & Ruijgh, 2012). The Set of Delta Instruments comprises:

- Delta Scenarios — Indicate possible future scenarios based on; climate scenarios and scenarios for social-economic developments.
- Deltamodel — **Safety:** Shows the relationship between water level, wave loads and dike strength, and the climate data from the Delta Scenarios, the design of the water system and the measures to be examined.
  Fresh Water: Shows, based on the Delta Scenarios and possible measures, the consequences for demand and supply of fresh water.
- Effectmodules — Make qualitative or quantitative assessments of the consequences for important utilization functions like inland navigation, agriculture and nature.
- Evaluation Framework — Indicates which information is considered significant in the comparison between strategies.
- Delta Portal — Public presentation tool that displays the data from the Set of Delta Instruments in a readable and understandable way for the users.

In order for the Set of Delta Instruments to function properly, it is flanked by two networks:

- Calculation Network — Association of representatives of the subprogrammes with a central project organization. The goal of the Calculation Network is a consistent and uniform execution of the effect provisions done with the Set of Delta Instruments.
- Centre of Expertise for Costs and Benefits — Helps the sub-programmes to get to reliable and uniform estimations of the costs for the proposed measures.

A.3. BIVAS AS PART OF THE DELTAMODEL FRESH WATER

BIVAS is one of the effectmodules of the Fresh Water Deltamodel. For the Delta Programme BIVAS is used to calculate the economic loss for inland navigation due to limitations of the navigable depth.

The Fresh Wwater Deltamodel exists of the Nationaal Hydrologisch Instrumentarium (NHI) and the Landelijk SOBEK Model(LSM). The NHI is used to calculate the ground and surface water flows and the water distribution. The LSM can calculate the discharges and water levels in the rivers and larger canals. The output of the LSM is, for the various Delta Scenarios, together with the expected shipping traffic for these various Delta Scenarios, used as input for BIVAS.

B

CLASSIFICATIONS OF VESSELS AND WATERWAYS

B.1. CEMT 1992 CLASSIFICATION

Notes for Table B.1:

[1] The class of a waterway is determined by the horizontal dimensions of the vessels or pushed units, especially by their width.

[2] The draught of a inland waterway must be specified with reference to local conditions.

[3] Characteristic tonnage for each class according to dimensions and draughts indicated.

[4] Takes into account a security clearance of 30 cm between the highest point of the vessel or its load and the height under the bridge.

[5] Vessels used in the Oder region and on waterways between the Oder and Elbe.

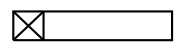
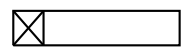
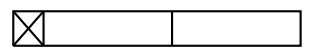
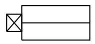
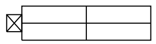
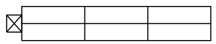
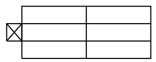
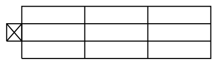
[6] Adapted for container transport:
- 5.25 metres for vessels carrying two layers of containers;
- 7.00 metres for vessels carrying three layers of containers;
- 9.10 metres for vessels carrying four layers of containers;
50 % of the containers may be empty, otherwise ballast must be used.

[7] The first figure relates to existing situations and the second to future developments or, in some cases, also existing situations.

[8] Takes account of the dimensions of motor vessels proposed for ro-ro transport and shipments of containers; the dimensions given are approximate.

[9] Relates to pushed units on the Danube which often consist of more than nine barges.

Table B.1: CEMT 1992 classification of European inland waterways (ECMT, 1992).

Type of inland waterway		Class of navigable waterway [1]	Motor vessels and barges — Type of vessel: General charateristics: Designation	Maximum length L [m]	Maximum beam B [m]	Draught[2] d [m]	Tonnage[3] T [t]	Pushed convoys — Type of convoy: General charateristics: Designation	Maximum length L [m]	Maximum beam B [m]	Draught[2] d [m]	Tonnage[3] T [t]	Minimum height under bridges[4] H [m]
OF REGIONAL IMPORTANCE	To West of Elbe	I	Barge	38.5	5.05	1.8-2.2	250-400						4.0
		II	Campine-Barge	50-55	6.6	2.5	400-650						4.0-5.0
		III	Gustav Koenigs	67-80	8.2	2.5	650-1,000						4.0-5.0
	To East of Elbe	I	Grosse Finow	41	4.7	1.4	180						3.0
		II	BM-500	57	7.5-9.0	1.6	500-630						3.0
		III	[5]	67-70	8.2-9.0	1.6-2.0	470-700		118-132	8.2-9.0	1.6-2.0	1,000-1,200	4.0
OF INTERNATIONAL IMPORTANCE		IV	Johann Welker	80-85	9.5	2.5	1,000-1,500		85	9.5	2.5-2.8	1,250-1,450	5.25 or 7.0[6]
		Va	Large Rhine Vessels	95-110	11.4	2.5-2.8	1,500-3,000		95-110[7]	11.4	2.5-4.5	1,600-3,000	5.25 or 7.0 or 9.1[6]
		Vb							172-185[7]	11.4	2.5-4.5	3,200-6,000	
		VIa							95-110[7]	22.8	2.5-4.5	3,200-6,000	7.0 or 9.1[6]
		VIb	[8]	140	15	3.9			185-195[7]	22.8	2.5-4.5	6,400-12,000	7.0 or 9.1[6]
		VIc							270-280[7]	22.8	2.5-4.5	9,600-18,000	9.1[6]
									193-200[7]	33.0-34.2[7]	2.5-4.5	9,600-18,000	
		VII[9]							195-285[7]	33.0-34.2[7]	2.5-4.5	14,500-27,000	9.1[6]

B.2. RWS 2010 CLASSIFICATION

Table B.2: RWS 2010 classification (Brolsma & Roelse, 2011).

Motor vessels

CEMT class	RWS class	Designation	Beam (m)	Length (m)	Draught (laden) (m)	Cargo capacity (t)	Beam and length (m)
0	M0	Other				1-250	B <= 5.00/ L <= 38.00
I	M1	Péniche	5.05	38.5	2.5	251-400	B = 5.01-5.1 L >= 38.01
II	M2	Kempenaar	6.6	50-55	2.6	401-650	B = 5.11-6.7 L >= 38.01
III	M3	Hagenaar	7.2	55-70	2.6	651-800	B = 6.71-7.3 L >= 38.01
	M4	Dortmund Eems (L <= 74m)	8.2	67-73	2.7	801-1050	B = 7.31-8.3 L = 38.01-74
	M5	Ext Dortmund Eems (L > 74m)	8.2	80-85	2.7	1051-1250	B = 7.31-8.3 L >= 74.01
IVa	M6	Rhine-Herne Vessel (L <= 86m)	9.5	80-85	2.9	1251-1750	B = 8.31-9.6 L = 38.01-86
	M7	Ext. Rhine-Herne (L > 86m)	9.5	105	3	1751-2050	B = 8.31-9.6 L >= 86.01
IVb							
Va	M8	Large Rhine Vessel (L <= 111m)	11.4	110	3.5	2051-3300	B = 9.61-11.5 L = 38.01-111
	M9	Ext. Large Rhine Vessel (L > 111m)	11.4	135	3.5	3301-4000	B = 9.61-11.5 L >= 111.01
Vb							
VIa	M10	Ref. Vessel 13.5 * 110m	13.5	110	4	4001-4300	B = 11.51-14.3 L = 38.01-111
	M11	Ref. Vessel 14.2 * 135m	14.2	135	4	4301-5600	B = 11.51-14.3 L >= 111.01
	M12	Rhinemax Vessel	17	135	4	>= 5601	B >= 14.31 L >= 38.01
VIb							
VIc							
VIIa							

Pushed convoys (Barges)

CEMT class	RWS class	Combination	Beam (m)	Length (m)	Draught (laden) (m)	Cargo capacity (t)	Beam and length (m)
0							
I	BO1		5.2	55	1.9	0-400	B <= 5.2 L = all
II	BO2		6.6	60-70	2.6	401-600	B = 5.21-6.7 L = all
III	BO3		7.5	80	2.6	601-800	B = 6.71-7.6 L = all
	BO4		8.2	85	2.7	801-1250	B = 7.61-8.4 L = all
IVa	BI	Europa I pushed convoy	9.5	85-105	3	1251-1800	B = 8.41-9.6 L = all
IVb							
Va	BII-1	Europa II pushed convoy	11.4	95-110	3.5	1801-2450	B = 9.61-15.1 L <= 111
	BIIa-1	Europa IIa pushed convoy	11.4	92-110	4	2451-3200	B = 9.61-15.1 L <= 111
	BIIL-1	Europa II long	11.4	125-135	4	3201-3950	B = 9.61-15.1 L = 111.01-146
Vb	BII-2l	2-barge pushed convoy long	11.4	170-190	3.5-4	3951-7050	B = 9.61-15.1 L >= 146.01
VIa	BII-2b	2-barge pushed convoy wide	22.8	95-145	3.5-4	3951-7050	B = 15.11-24 L <= 146
VIb	BII-4	4-barge pushed convoy (incl. 3-barge long)	22.8	185-195	3.5-4	7051-12000 (7051-9000)	B = 15.11-24 L = 146.01-200
VIc	BII-6l	6-barge pushed convoy long (incl. 5-barge long)	22.8	270	3.5-4	12001-18000 (12001-15000)	B = 15.11-24 L >= 200.01
VIIa	BII-6b	6-barge pushed convoy wide (incl. 5-barge wide)	34.2	195	3.5-4	12001-18000 (12001-15000)	B >= 24.01 L = all

Coupled units (Convoys) and **Headroom* incl. 30cm spare headroom**

CEMT class	RWS class	Combination	Beam (m)	Length (m)	Draught (laden) (m)	Cargo capacity (t)	Beam and length (m)	Headroom* incl. 30cm spare headroom (m)
0								
I	C1l	2 péniches long	5.05	77-80	2.5	<= 900	B <= 5.1 L = all	5.25*
	C1b	2 péniches wide	10.1	38.5	2.5	<= 900	B = 9.61-12.6 L <= 80	5.25*
II								6.1
III								6.4
								6.6
								6.4
IVa								7*
								7*
IVb	C2l	Class IV + Europa I long	9.5	170-185	3	901-3350	B = 5.11-9.6 L = all	7*
Va								9.1*
								9.1*
								9.1*
Vb	C3l	Class Va + Europa II long	11.4	170-190	3.5-4	3351-7250	B = 9.61-12.6 L >= 80.01	9.1*
VIa	C2b	Class IV + Europa I wide	19.0	85-105	3	901-3350	B = 12.61-19.1 L <= 136	7* only for class IV coupled unit
	C3b	Class Va + Europa II wide	22.8	95-110	3.5-4	3351-7250	B >= 19.11 L <= 136	9.1*
VIb	C4	Class Va + 3 Europa II	22.8	185	3.5-4	>= 7251	B >= 12.61 L >= 136.01	9.1*
VIc								9.1*
VIIa								9.1*

* In classes I, IV and higher the headroom has been adjusted for 2, 3 and 4 layers of containers respectively (headroom on canals relative to reference high water level =1% exceedance/year).

** The characteristics of the reference vessels have a margin of error of ± 1m in the length, and ± 10cm in the beam.

NB:
1: A reference vessel is a vessel whose dimensions determine the dimensions of the waterway and the engineering structures on or in it.
2: New waterways and enlarged waterways are based on the largest reference vessel within a CEMT class.
3: Classes M3, M4, M6, M8, M10 and M11 may be used only for the renovation of existing waterways, locks and bridges.
4: The smallest dimensions of a reference vessel represent the lower threshold for categorising a waterway in a particular standardised class.

C
MAPS

C.1. EUROPEAN INLAND WATERWAY NETWORK

Figure C.1: Map of the European inland waterway network. Reprint of UNECE (2012)

C.2. DUTCH INLAND WATER WAY NETWORK

Figure C.2: Map of the Dutch inland waterway network. Reprint of RWS-CIV (2013b)

D
FLEET DEVELOPMENT

D.1. REPRESENTATIVE COUNTING POINTS FLEET DEVELOPMENT

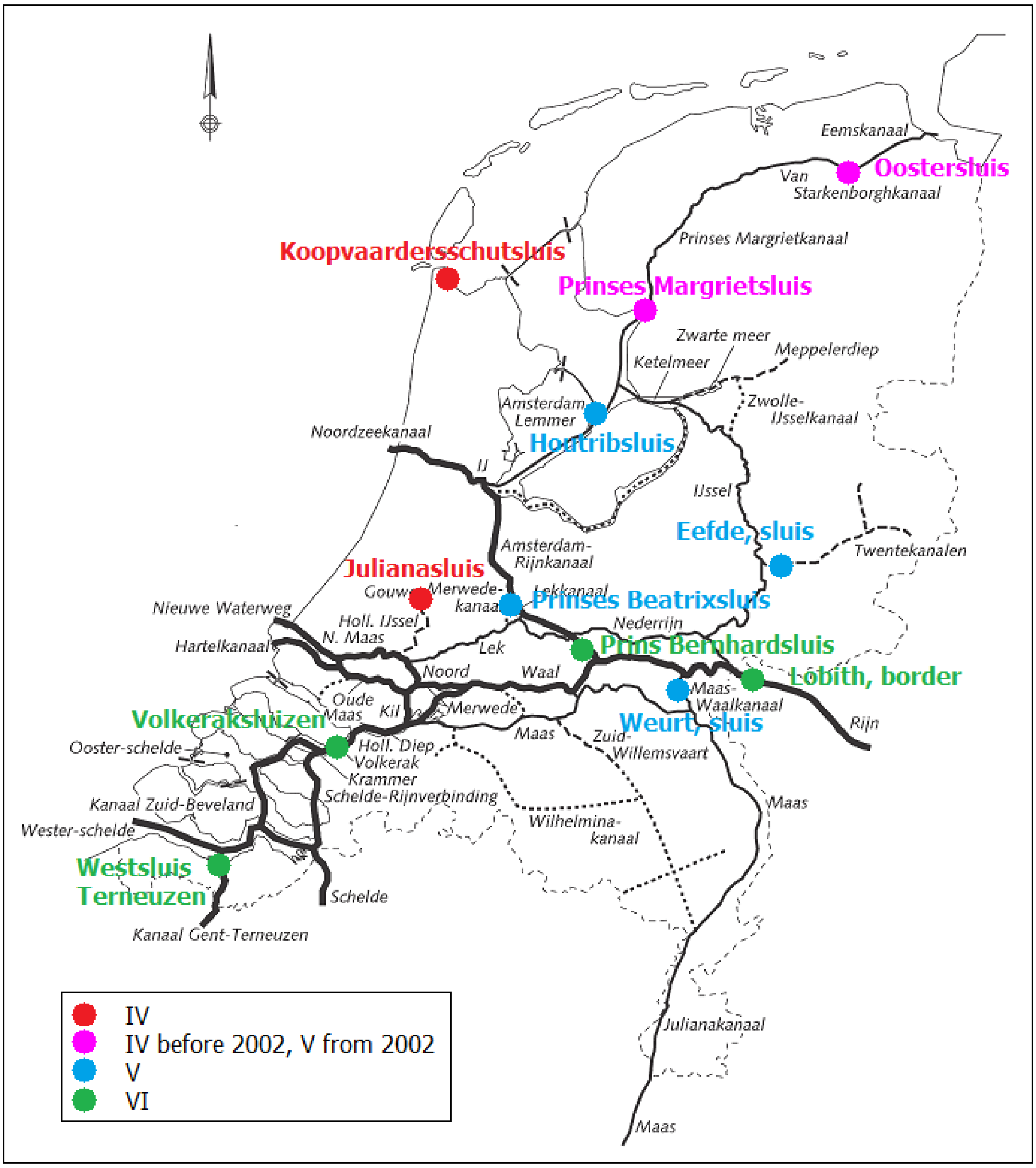


Figure D.1: Representative counting points used for analysis of historical fleet development

D.2. NUMBER OF PASSAGES HISTORICALLY

Table D.1: Number of passages per vessel category; all representative counting points.

	Number of passages								
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Motor vessels	459,078	457,467	442,248	N/A	456,534	374,969	427,645	444,663	419,918
Pushed convoys	27,204	25,636	25,580	N/A	28,951	24,000	27,891	28,816	27,937
Coupled units	11,634	12,782	13,392	N/A	14,902	9,851	13,406	16,674	16,899
Total	497,916	495,885	481,220	N/A	500,387	408,820	468,942	490,153	464,754

Table D.2: Number of passages per vessel category and CEMT class; all representative counting points.

		Number of passages								
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
IV	*Motor vessels*	43,033	41,424	7,794	N/A	5,951	5,169	8,439	7,854	10,782
	Pushed convoys	1,005	889	141	N/A	155	108	241	201	307
	Coupled units	18	26	0	N/A	0	1	0	2	4
	Total	44,056	42,339	7,935	N/A	6,106	5,278	8,680	8,057	11,093
V	*Motor vessels*	122,814	121,037	150,128	N/A	149,918	143,680	156,421	152,628	148,803
	Pushed convoys	6,098	5,242	6,582	N/A	7,282	7,035	8,573	8,626	8,597
	Coupled units	462	557	885	N/A	1,220	989	1,113	1,732	2,044
	Total	129,374	126,836	157,595	N/A	158,420	151,704	166,107	162,986	159,444
VI	*Motor vessels*	293,231	295,006	284,326	N/A	300,665	226,120	262,785	284,181	260,333
	Pushed convoys	20,101	19,505	18,857	N/A	21,514	16,857	19,077	19,989	19,033
	Coupled units	11,154	12,199	12,507	N/A	13,682	8,861	12,293	14,940	14,851
	Total	324,486	326,710	315,690	N/A	335,861	251,838	294,155	319,110	294,217

Table D.3: Number of passages per RWS class and vessel category; all representative counting points.

CEMT classes IV, V and VI		Number of passages								
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Motor vessels	*M0*	5,174	4,931	3,931	N/A	3,319	2,929	3,433	3,434	4,750
	M1	18,593	15,200	13,448	N/A	12,526	9,136	9,341	8,845	7,826
	M2	65,892	59,488	55,056	N/A	51,188	44,306	44,572	45,270	40,350
	M3	55,868	53,574	50,910	N/A	47,629	39,875	42,747	44,332	40,968
	M4	60,731	59,597	58,970	N/A	55,685	43,621	46,102	47,671	44,212
	M5	53,684	55,363	51,289	N/A	50,968	41,326	47,382	50,181	44,332
	M6	87,092	89,597	86,725	N/A	93,711	75,028	84,956	84,035	76,438
	M7	31,724	34,214	32,017	N/A	32,551	25,281	29,704	29,835	27,332
	M8	74,889	79,036	81,263	N/A	94,720	79,488	98,639	108,136	107,794
	M9	875	1,849	2,931	N/A	5,128	6,221	8,755	9,360	11,144
	M10	4,556	4,618	5,708	N/A	9,109	7,758	12,014	13,564	14,772
	Total	459,078	457,467	442,248	N/A	456,534	374,969	427,645	444,663	419,918
Pushed convoys	*BO1*	102	90	97	N/A	84	120	155	138	160
	BO2	243	280	271	N/A	353	294	421	377	508
	BO3	313	207	217	N/A	293	290	417	464	371
	BO4	860	649	762	N/A	1,083	1,044	948	1,060	912
	BI	3,302	2,764	2,859	N/A	2,945	2,816	3,158	3,436	3,769
	BII-1	7,360	6,533	6,926	N/A	7,913	6,648	7,569	7,796	7,978
	BIIL-1	2,419	2,768	2,538	N/A	2,509	2,414	2,571	2,702	2,863
	BII-2l	2,784	2,819	2,681	N/A	3,293	2,676	3,013	3,107	2,859
	BII-2b	3,357	3,283	2,966	N/A	2,968	2,917	2,597	2,611	2,374
	BII-4	6,353	6,083	5,786	N/A	6,694	4,485	5,720	5,169	4,220
	BII-6l	66	76	235	N/A	570	208	659	911	937
	BII-6b	45	84	242	N/A	246	88	663	1,045	986
	Total	27,204	25,636	25,580	N/A	28,951	24,000	27,891	28,816	27,937
Coupled units	*C1l*	469	291	385	N/A	442	252	250	396	551
	C1b	322	286	306	N/A	327	304	264	348	298
	C2l	1,285	1,295	1,344	N/A	1,821	1,354	1,457	2,313	2,063
	C3l	5,365	6,417	7,324	N/A	8,140	5,361	7,786	9,934	10,707
	C2b	656	680	548	N/A	630	356	471	472	437
	C3b	3,061	3,366	3,044	N/A	2,192	1,122	1,651	1,927	1,595
	C4	476	447	441	N/A	1,350	1,102	1,527	1,284	1,248
	Total	11,634	12,782	13,392	N/A	14,902	9,851	13,406	16,674	16,899

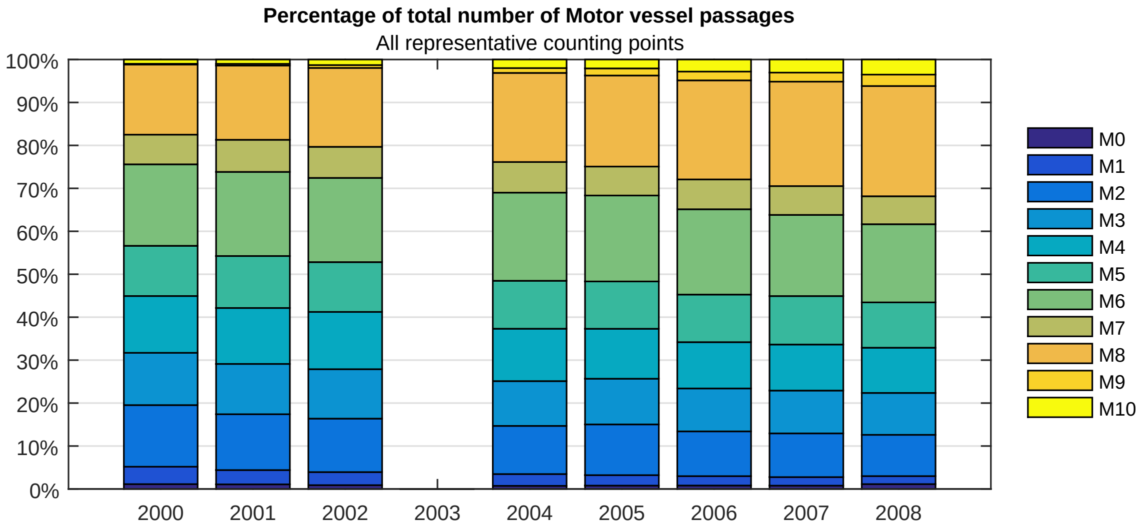


Figure D.2: Percentage of total number of Motor vessel passages at all representative counting points, per RWS class.

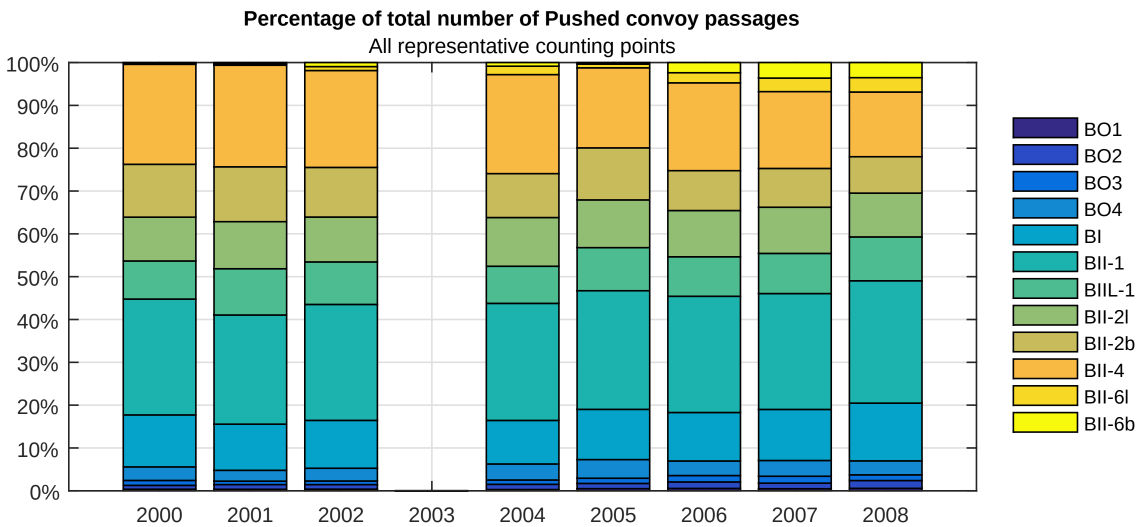


Figure D.3: Percentage of total number of Pushed convoy passages at all representative counting points, per RWS class.

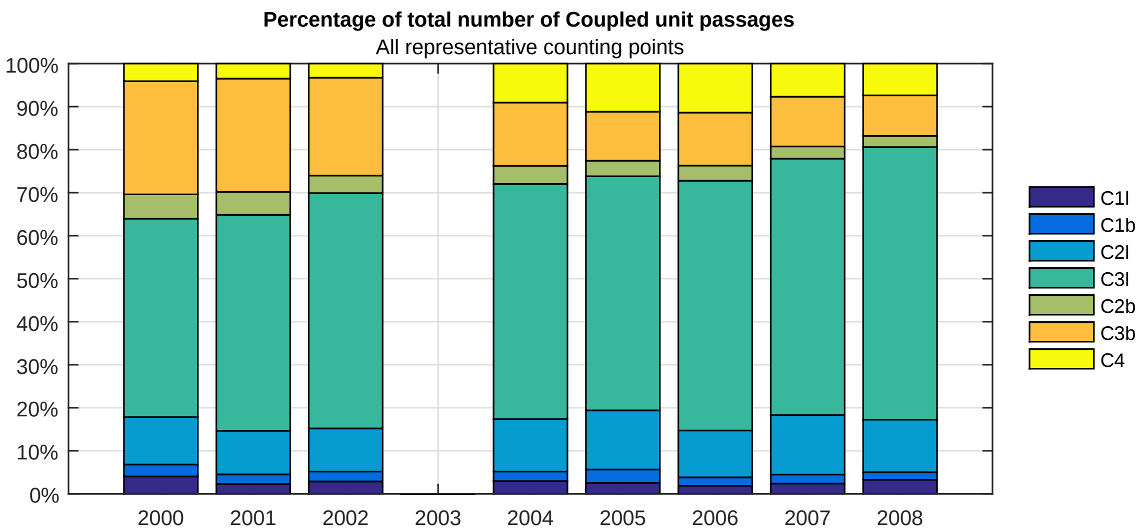


Figure D.4: Percentage of total number of Coupled unit passages at all representative counting points, per RWS class.

Table D.4: Number of passages per RWS class and vessel category; representative counting points of CEMT class IV.

CEMT class IV		Number of passages								
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Motor vessels	*M0*	866	1,054	175	N/A	153	112	161	109	1,611
	M1	967	712	346	N/A	324	209	266	184	68
	M2	7,796	6,875	2,203	N/A	1,591	1,373	1,605	1,375	1,553
	M3	6,862	6,877	2,329	N/A	2,007	1,799	2,368	2,481	2,965
	M4	7,899	7,661	1,801	N/A	1,096	1,105	1,974	2,040	2,911
	M5	4,963	4,700	401	N/A	297	206	286	506	450
	M6	9,071	8,571	513	N/A	466	347	1,724	1,051	864
	M7	1,527	2,044	7	N/A	2	6	7	12	16
	M8	3,080	2,928	19	N/A	15	12	48	96	344
	M9	0	0	0	N/A	0	0	0	0	0
	M10	2	2	0	N/A	0	0	0	0	0
	Total	43,033	41,424	7,794	N/A	5,951	5,169	8,439	7,854	10,782
Pushed convoys	*BO1*	55	61	5	N/A	2	9	10	7	12
	BO2	64	62	11	N/A	5	9	10	14	19
	BO3	57	42	11	N/A	13	9	22	18	42
	BO4	99	60	13	N/A	31	1	14	25	50
	BI	432	287	72	N/A	85	62	123	85	109
	BII-1	200	292	23	N/A	9	12	34	25	40
	BIIL-1	3	2	0	N/A	0	0	1	0	1
	BII-2l	94	83	6	N/A	10	6	27	27	34
	BII-2b	1	0	0	N/A	0	0	0	0	0
	BII-4	0	0	0	N/A	0	0	0	0	0
	BII-6l	0	0	0	N/A	0	0	0	0	0
	BII-6b	0	0	0	N/A	0	0	0	0	0
	Total	1,005	889	141	N/A	155	108	241	201	307
Coupled units	*C1l*	7	15	0	N/A	0	0	0	0	1
	C1b	3	7	0	N/A	0	1	0	0	0
	C2l	5	4	0	N/A	0	0	0	1	3
	C3l	1	0	0	N/A	0	0	0	0	0
	C2b	2	0	0	N/A	0	0	0	1	0
	C3b	0	0	0	N/A	0	0	0	0	0
	C4	0	0	2	N/A	3	4	5	6	7
	Total	18	26	2	N/A	3	5	5	8	11

Table D.5: Number of passages per RWS class and vessel category; representative counting points of CEMT class V.

CEMT class V		Number of passages								
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Motor vessels	*M0*	1,703	1,645	1,825	N/A	1,312	1,414	1,865	1,902	1,559
	M1	4,246	3,643	3,383	N/A	2,837	2,283	2,368	2,412	2,267
	M2	24,891	22,083	24,614	N/A	21,379	21,009	22,335	20,598	19,141
	M3	18,500	17,746	21,320	N/A	19,021	18,271	20,098	18,716	18,319
	M4	19,473	19,158	25,215	N/A	23,324	20,653	20,790	19,716	18,954
	M5	13,115	13,524	16,623	N/A	16,595	17,183	17,989	18,263	16,564
	M6	22,580	23,286	31,288	N/A	34,388	31,527	33,319	30,361	28,513
	M7	5,780	6,282	8,264	N/A	7,844	7,479	7,953	8,458	8,074
	M8	11,767	12,853	16,507	N/A	21,465	20,868	25,497	28,167	30,874
	M9	182	251	320	N/A	490	1,285	1,336	1,168	1,295
	M10	577	566	769	N/A	1,263	1,708	2,871	2,867	3,243
	Total	122,814	121,037	150,128	N/A	149,918	143,680	156,421	152,628	148,803
Pushed convoys	*BO1*	29	21	78	N/A	70	99	126	116	134
	BO2	68	82	155	N/A	207	134	197	189	310
	BO3	154	105	162	N/A	168	187	354	281	237
	BO4	631	325	530	N/A	816	731	758	704	522
	BI	1,157	918	1,125	N/A	1,323	1,371	1,837	1,783	1,963
	BII-1	2,702	2,307	2,925	N/A	2,805	2,611	3,092	3,185	3,048
	BIIL-1	500	564	662	N/A	692	742	798	926	1,015
	BII-2l	676	733	731	N/A	941	873	1,110	1,100	1,054
	BII-2b	178	180	205	N/A	235	251	264	289	269
	BII-4	3	5	7	N/A	25	35	35	48	44
	BII-6l	0	0	0	N/A	0	1	1	4	0
	BII-6b	0	2	2	N/A	0	0	1	1	1
	Total	6,098	5,242	6,582	N/A	7,282	7,035	8,573	8,626	8,597
Coupled units	*C1l*	50	50	50	N/A	91	36	27	63	83
	C1b	45	54	53	N/A	105	49	50	47	42
	C2l	100	156	172	N/A	265	288	264	474	439
	C3l	193	202	514	N/A	583	493	659	1,028	1,351
	C2b	65	88	72	N/A	90	60	47	60	91
	C3b	9	6	24	N/A	51	37	41	37	25
	C4	0	1	0	N/A	35	26	25	23	13
	Total	462	557	885	N/A	1,220	989	1,113	1,732	2,044

Table D.6: Number of passages per RWS class and vessel category; representative counting points of CEMT class VI.

CEMT class VI		Number of passages								
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Motor vessels	*M0*	2,605	2,232	1,931	N/A	1,854	1,403	1,407	1,423	1,580
	M1	13,380	10,845	9,719	N/A	9,365	6,644	6,707	6,249	5,491
	M2	33,205	30,530	28,239	N/A	28,218	21,924	20,632	23,297	19,656
	M3	30,506	28,951	27,261	N/A	26,601	19,805	20,281	23,135	19,684
	M4	33,359	32,778	31,954	N/A	31,265	21,863	23,338	25,915	22,347
	M5	35,606	37,139	34,265	N/A	34,076	23,937	29,107	31,412	27,318
	M6	55,441	57,740	54,924	N/A	58,857	43,154	49,913	52,623	47,061
	M7	24,417	25,888	23,746	N/A	24,705	17,796	21,744	21,365	19,242
	M8	60,042	63,255	64,737	N/A	73,240	58,608	73,094	79,873	76,576
	M9	693	1,598	2,611	N/A	4,638	4,936	7,419	8,192	9,849
	M10	3,977	4,050	4,939	N/A	7,846	6,050	9,143	10,697	11,529
	Total	293,231	295,006	284,326	N/A	300,665	226,120	262,785	284,181	260,333
Pushed convoys	*BO1*	18	8	14	N/A	12	12	19	15	14
	BO2	111	136	105	N/A	141	151	214	174	179
	BO3	102	60	44	N/A	112	94	41	165	92
	BO4	130	264	219	N/A	236	312	176	331	340
	BI	1,713	1,559	1,662	N/A	1,537	1,383	1,198	1,568	1,697
	BII-1	4,458	3,934	3,978	N/A	5,099	4,025	4,443	4,586	4,890
	BIIL-1	1,916	2,202	1,876	N/A	1,817	1,672	1,772	1,776	1,847
	BII-2l	2,014	2,003	1,944	N/A	2,342	1,797	1,876	1,980	1,771
	BII-2b	3,178	3,103	2,761	N/A	2,733	2,666	2,333	2,322	2,105
	BII-4	6,350	6,078	5,779	N/A	6,669	4,450	5,685	5,121	4,176
	BII-6l	66	76	235	N/A	570	205	658	905	937
	BII-6b	45	82	240	N/A	246	90	662	1,046	985
	Total	20,101	19,505	18,857	N/A	21,514	16,857	19,077	19,989	19,033
Coupled units	*C1l*	412	226	335	N/A	351	216	223	333	467
	C1b	274	225	253	N/A	222	254	214	301	256
	C2l	1,180	1,135	1,172	N/A	1,556	1,066	1,193	1,838	1,621
	C3l	5,171	6,215	6,810	N/A	7,557	4,868	7,127	8,906	9,356
	C2b	589	592	476	N/A	540	296	424	411	346
	C3b	3,052	3,360	3,020	N/A	2,141	1,085	1,610	1,890	1,570
	C4	476	446	441	N/A	1,315	1,076	1,502	1,261	1,235
	Total	11,154	12,199	12,507	N/A	13,682	8,861	12,293	14,940	14,851

D.3. AVERAGE LOAD CAPACITY HISTORICALLY

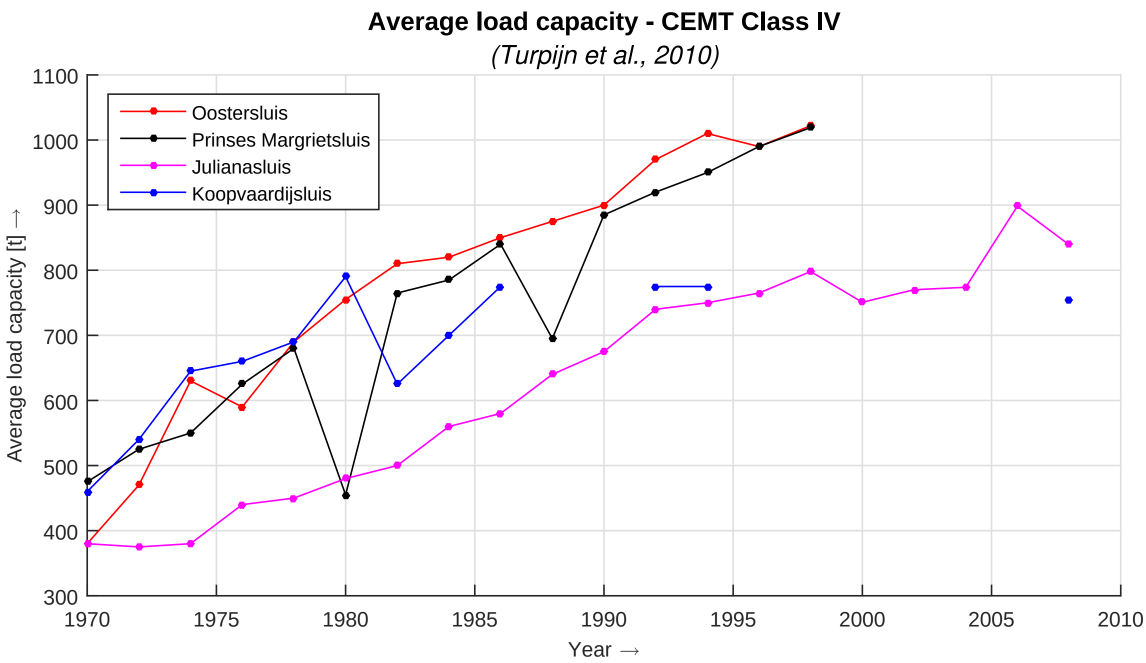


Figure D.5: Average load capacity CEMT class IV (Turpijn et al., 2010).

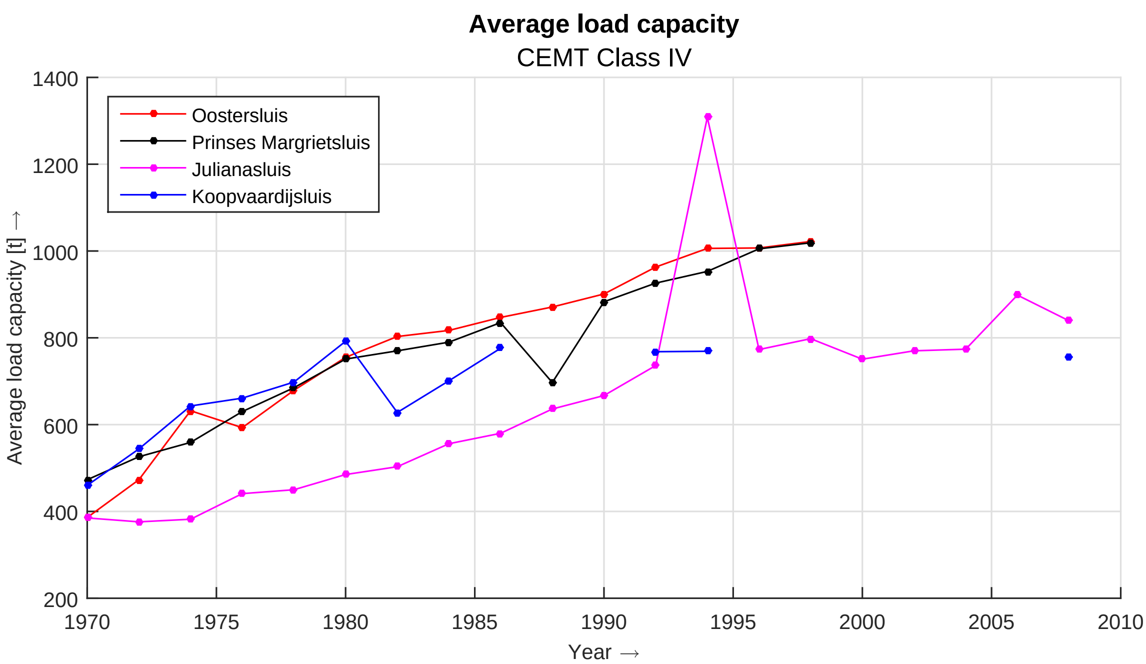


Figure D.6: Average load capacity CEMT class IV (Inconsistencies improved).

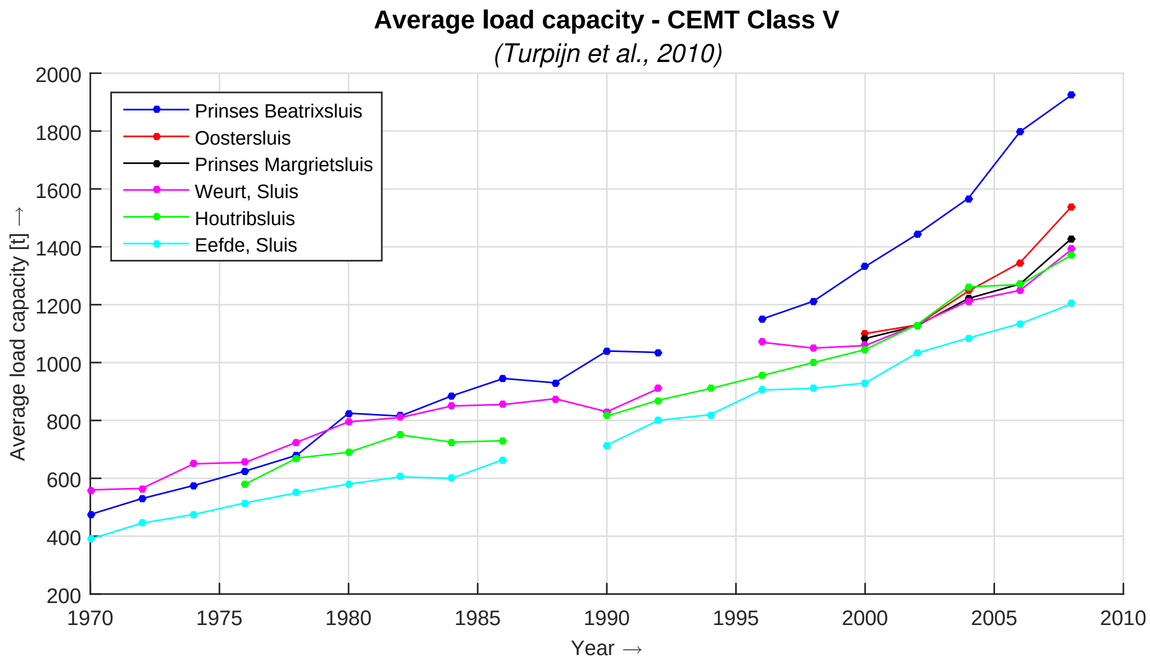


Figure D.7: Average load capacity CEMT class V (Turpijn et al., 2010).

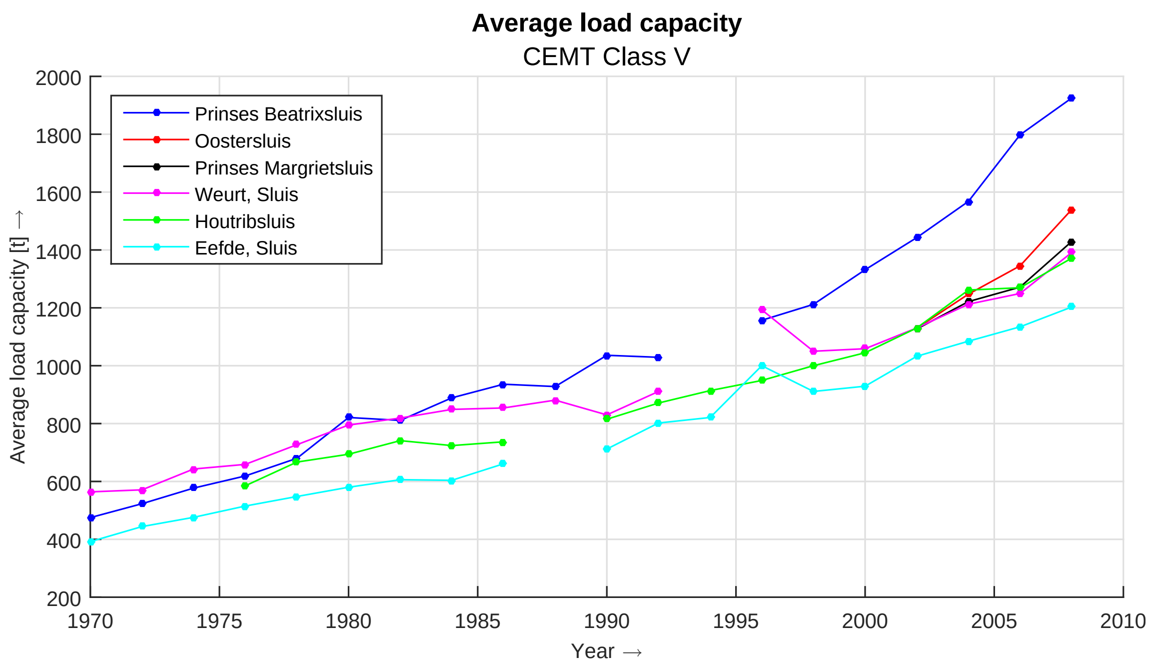


Figure D.8: Average load capacity CEMT class V (Inconsistencies improved).

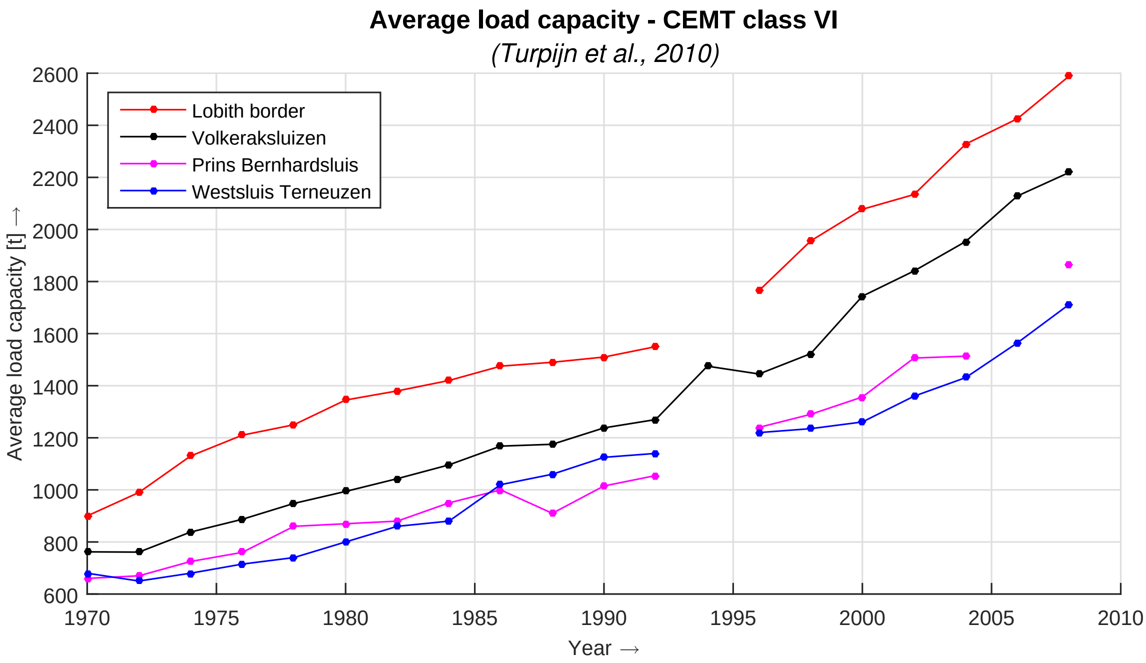


Figure D.9: Average load capacity CEMT class VI (Turpijn et al., 2010).

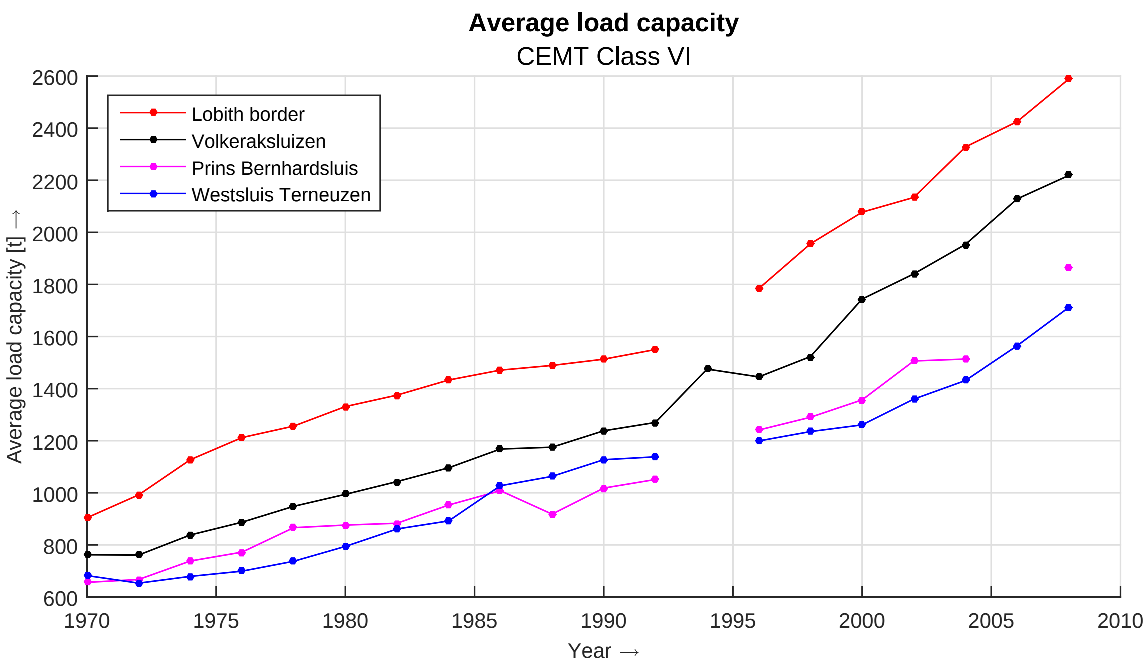


Figure D.10: Average load capacity CEMT class VI (Inconsistencies improved).

Table D.7: Summary of development average load capacity per CEMT class; period 1970-2008 (Turpijn et al., 2010).

	Average load capacity		Average growth	Average growth
	1970	**2008**	**[%/y]**	**[t/y]**
IV	420	797	1.7	47
V	475	1477	3.0	125
VI	760	2088	2.7	166

Table D.8: Summary of development average load capacity per CEMT class; period 1970-2008 (Inconsistencies improved).

	Average load capacity		Average growth	Average growth
	1970	**2008**	**[%/y]**	**[t/y]**
IV	418	813	1.8	10
V	502	1562	3.0	28
VI	824	2219	2.6	37

Table D.9: Summary of development average load capacity per CEMT class; period 1970-2000 (Turpijn et al., 2010).

	Average load capacity		Average growth	Average growth
	1970	**2000**	**[%/y]**	**[t/y]**
IV	420	751	2.0	41
V	475	1091	2.8	77
VI	760	1597	2.5	105

Table D.10: Summary of development average load capacity per CEMT class; period 1970-2000 (Inconsistencies improved).

	Average load capacity		Average growth	Average growth
	1970	**2000**	**[%/y]**	**[t/y]**
IV	418	1022	3.0	20
V	502	1137	2.8	21
VI	824	1744	2.5	31

Table D.11: Summary of development average load capacity per CEMT class; period 2000-2008 (Turpijn et al., 2010).

	Average load capacity		Average growth	Average growth
	2000	**2008**	**[%/y]**	**[t/y]**
IV	751	797	0.8	6
V	1091	1477	3.9	48
VI	1597	2088	3.4	61

Table D.12: Summary of development average load capacity per CEMT class; period 2000-2008 (Inconsistencies improved).

	Average load capacity		Average growth	Average growth
	2000	**2008**	**[%/y]**	**[t/y]**
IV	1022	813	-2.8	-26
V	1137	1562	4.0	53
VI	1744	2219	3.1	59

D.4. AVERAGE LOAD CAPACITY PROGNOSIS

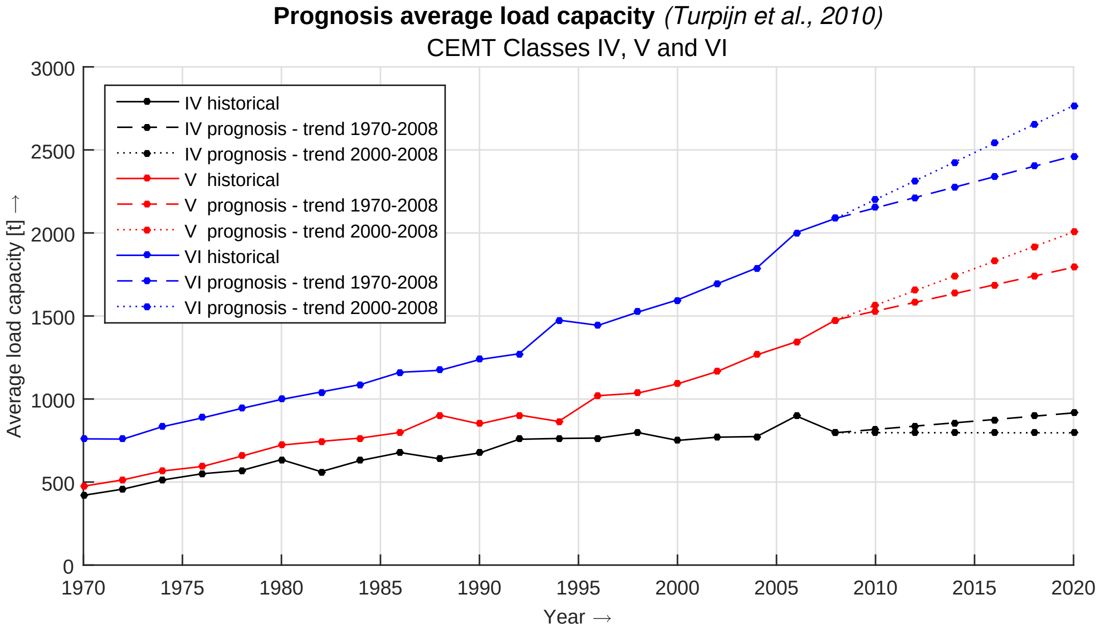


Figure D.11: Prognosis average load capacity; CEMT classes IV, V and VI (Turpijn et al., 2010).

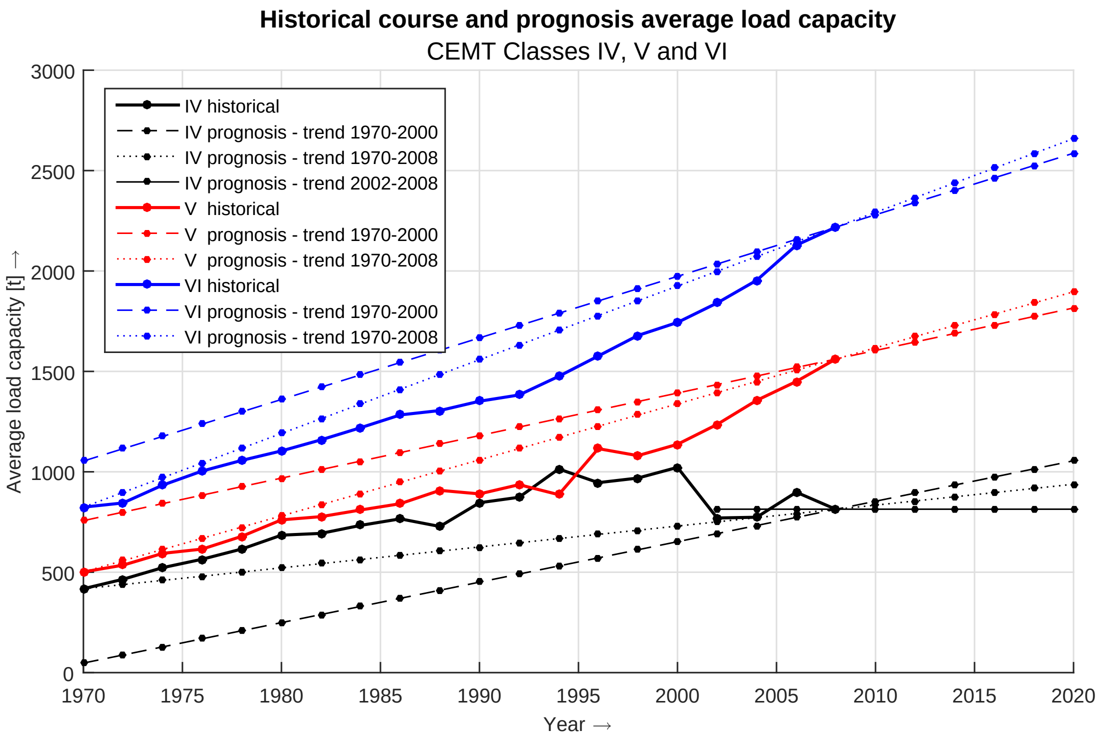


Figure D.12: Prognosis average load capacity; CEMT classes IV, V and VI (Inconsistencies improved).

E

INPUT AND OUTPUT BIVAS SCENARIOS

E.1. INPUT

Table E.1: Input for the characteristics of a BIVAS scenario.

Input for the characteristics of a BIVAS scenario			
Tab	**Description**	**Fields**	**Field description**
Ship types	Properties of the various vessel types included in the scenario	Ship type	ID and RWS class of the vessel
		Category	Vessel category
		CEMT type	CEMT class of the vessel type
		Length	The 10, 50 and 90% percentile of the length of the vessel type in meters
		Width	The 10, 50 and 90% percentile of the width of the vessel type in meters
		Average depth	Average draught of the vessel type in meters
		Average height	Average height above the water of the vessel type in meters
		Empty depth	Draught of an empty vessel of the vessel type in meters
		Average load weight	Average loading of the vessel type in tonnes
		Maximum load weight	Maximum loading of the vessel type in tonnes
		Waterplane coefficient	Factor for the change in draught during loading and unloading of the vessel type
		Residual resistance coefficient	Coefficient for the computation of the residual resistance of the vessel type
Ship speeds	The speed of a vessel per vessel type, empty or loaded vessel and CEMT class of the waterway it is using	Ship type	ID and RWS class of the vessel
		CEMT type	CEMT class of the arcs for which the given vessel velocity holds
		Load type	Load type (empty or loaded) of a vessel for which the given vessel velocity holds
		Speed	Velocity of the vessel in km/h
		Average estimated speed	Estimated speed of the vessel when no other speed is known
Dangerous goods level	Possible dangerous goods levels for a trip	Dangerous goods level	No dangerous goods, flammable, harmful to health, explosive
Load types	Possible load types for a trip	Load type	Empty or loaded
Origins	Nodes that can be the origin of a trip	Trip end point	References to nodes in the network
Destinations	Nodes that can be the destination of a trip	Trip end point	References to nodes in the network
CEMT types	Possible CEMT types	CEMT type	All known CEMT types, and BIVAS types Ijssel, Lek, Waal and unknown
NSTR types	Possible goods categories of a trip	NSTR type	For example fertilizers, chemicals, agricultural products, etc.
Appearance types	Possible appearance types of the goods of a trip	Appearance type	Liquid bulk, dry bulk, container, else

Table E.2: Input for network of a BIVAS scenario.

Input for network of a BIVAS scenario			
Tab	**Description**	**Fields**	**Field description**
Nodes	Modules of the network that determine the coordinates of the start and end points of the waterways, hydraulic structures and trips	*ID*	Identification number of the node
		X	X coordinate node (Rijksdriehoekstelsel)
		Y	Y coordinate node (Rijksdriehoekstelsel)
Arcs	Connectors between nodes, representing the hydraulic structures and waterways	*ID*	Identification number of the arc
		From node ID	Start node of the arc
		To node ID	End node of the arc
		Name	Name of the arc
		Country code	Code representing the country the arc is located in
		Length	Length of the arc in meters
		Width	Width of the arc in meters
		Arc Type ID	ID of the type of arc (general waterway, fixed bridge, drawbridge, etc.)
		CEMT type ID	ID of the CEMT type of the arc
		Maximum length	Maximum allowed length of a vessel using the arc
		Maximum width	Maximum allowed width of a vessel using the arc
		Maximum dangerous goods level	Maximum dangerous goods level of the load of a vessel using the arc
		Maximum speed loaded	Maximum allowed speed on the arc in km/h for loaded vessels
		Maximum speed empty	Maximum allowed speed on the arc in km/h for empty vessels
		Delay	Travel time added to calculated travel time (in min)
		Current direction	Direction of the flow; 1 for From node ID to To node ID and -1 the other way round
		Calibration delay	Travel time added to the calculated travel time (in min), only for the allocation of the trips, removed from the final output
		Direction	Compass direction of the arc from the From node ID to the To node ID
Bridges	Bridges in the network	*Arc*	Arc ID and name of the bridge
		Service time	Service time in minutes
Locks	Locks in the network	*Arc*	Arc ID and name of the lock
		Lockage time	Service time in minutes
		Wait time	Time needed to get through the lock
		Overlay time	Waiting time before a vessel can start its lockage
		Cross section area upper gate	Cross section of the water at upper gate in m^2
		Cross section area lower gate	Cross section of the water at lower gate in m^2
		Switch distance upper gate	Distance in meters between the waiting area and the gate at the side of the upper gate
		Switch distance lower gate	Distance in meters between the waiting area and the gate at the side of the lower gate
		Number of locks	Number of chambers of the lock
		Lock length	Length lock chamber in meters
		Lock width	Width lock chamber in meters
		Operating time	The number of hours per week that the lock is being operated
		Recreational share	The share of recreational vessels using the lock in proportion of 1
		Minimum operating water level	Lower limit in meters of the water level whereby the lock can still be operated
		Maximum operating water level	Upper limit in meters of the water level whereby the lock can still be operated
Dams	Weirs in the network	*Arc*	Arc ID and name of the weir
		Minimum water level	Water level relative to NAP at which the weir is opened
Arc water properties	Default water properties of the arcs in the network (used for an arc when there is no water data from a water scenario available for the arc)	*Arc*	Arc ID and name of the arc
		Water level	Water level in meters, relative to NAP, on the arc
		Depth	Depth in meters on the arc
		Current speed	Current velocity on the arc in m/s
		Maximum depth	Maximum allowed draught of a vessel using the arc
		Maximum height closed	Maximum height in meters above the water, at an arc that is an hydraulic structure, of a vessel using the arc when the hydraulic structure is closed
		Maximum height open	Maximum height in meters above the water, at an arc that is an hydraulic structure, of a vessel using the arc when the hydraulic structure is open

Table E.3: Input for the parameters of a BIVAS scenario.

Input for the parameters of a BIVAS scenario	
Field	**Description**
Scenario year	Year for which the scenario is created and computed.
Start	Month and day the period covered by the scenario starts.
End	Month and day the period covered by the scenario end.
Season definition	Season definition used used to define when the water conditions of the arcs change. Examples are the whole year (same properties the whole year) and days (conditions change every day).
Minimum depth	Minimum draught for the trips of the used traffic scenario.
Maximum depth	Maximum draught for the trips of the used traffic scenario.
Length restriction enabled	Whether or not to take into account the length restriction of the arcs.
Width restriction enabled	Whether or not to take into account the width restriction of the arcs.
Dangerous goods level restriction enabled	Whether or not to take into account the dangerous goods level restriction of the arcs.
Depth restriction enabled	Whether or not to take into account the draught restriction of the arcs.
Height restriction enabled	Whether or not to take into account the height restriction of the arcs.
Water scenario	The water scenario including the water conditions for the scenario.
Growth rates	The growth factors scenario for the trips of the scenario.
Fleet mutation scenario	The fleet mutation scenario for the trips of the scenario.
Calibration	Trips calibration for the scenario.
Motor replacement profile	Motor replacement scenario for the trips used in the scenario.
Optimization objective	Objective for which the allocation of the trips will be optimized (travel time or costs).
Maximum unload factor for infeasible trips	Factor indicating the maximum unloading of trips for which at first no route could be found.
Fuel price	Fuel price in euros per liter.
Idle engine energy use factor	Factor used for the energy use when waiting for a bridge or lock.
Interest rate	Interest rate in %.
Time waiting on load	Average time a vessel has to wait for a new load in hours.
Traffic scenario	Traffic scenario used in the scenario.
Travel time standard deviation	Standard deviation in seconds per minute for the computed travel time on an arc.
Zone definition	Zone definition used to group origins and destinations.
Enable restriction relaxation	When enabled vessels that do not meet the restrictions of an arc can be allocated via the arc, but with a penalty. This penalty is removed after the allocation.
Length penalty	Penalty for the restriction relaxation on the length of a vessel (min/(m violation)*km arc length).
Width penalty	Penalty for the restriction relaxation on the width of a vessel (min/(dm violation)*km arc length).
Reference trip set	Reference trip set for the used traffic scenario. Includes per trip which and when counting points are passed in reality.

E.2. OUTPUT

Table E.4: Standard output of BIVAS; overall statistics.

Field	Description
	Output: Statistics
Number of trips	Number of trips for which a route has been searched in the scenario, including the additional trips due to reduced load
Number of routes	Number of trips for which a route has been found in the scenario, including the additional trips due to reduced load
Total travel time	Travel time in hours (sailing time, lockage time and waiting time at locks), of all trips for which a route has been found, including the additional trips due to reduced load
Total costs	Total variable costs in million euro for all trips a route has been found for, including the additional trips due to reduced load
Total distance	Total distance traveled in megameter by all trips for which a route has been found, including the additional trips due to reduced load
Total waiting time	Total time waiting at locks, including additional trips due to reduced load
Total weight	Total transported weight in kilotonne
Number of ton kilometer	Total number of tonne kilometere (x 1,000,000)
Emissions	Per substance the total emission in kilotonne
Average load factor	The average load factor of the loaded trips
Average load capactity	Average load capacity in tonne of the trips for which a route has been found, including the additional trips due to reduced load
Total TEU	Total number of TEU transported

Table E.5: Optional output of BIVAS; trips.

Field	Description
	Output: Trips
ID	ID of the the trip
Date	Date the trip starts
Origin trip end point node	Origin node
Origin zone name	Origin zone (depending on chosen zone definition)
Destination trip end point node	Destination node
Destination zone name	Destination zone (depending on chosen zone definition)
Ship type	RWS class of the vessel
Dangerous goods level ID	Dangerous goods level of the load
Load type	Load type (loaded or empty)
Total weight	Total transported load
Nstr type code	NSTR type of the load
Appearance type	Appearance type of the load (liquid bulk, dry bulk, container, else)
Depth	Draught of the vessel
Load capacity	Load capacity of the vessel
Load capacity class	Load capacity class of the vessel
TEU	Number of TEU transported
Number of trips	Number of times the trip is carried out
Season ID	Season in which the trip was carried out (depending on chosen season definition)

Table E.6: Optional output of BIVAS; routes.

Field	Description
	Output: Routes
Trip ID	ID of the trip
Origin trip endpoint node	Origin node
Origin zone name	Origin zone (depending on chosen zone definition)
Destination trip endpoint node	Destination node
Destination zone name	Destination zone (depending on chosen zone definition)
Ship type	RWS class of the vessel
Nstr code	NSTR type of the load
Number of segments	Number of arcs used
Number of trips	Number of times the trip is carried out
Travel time	Total travel time per trip in minutes (waiting at locks included, waiting on load excluded)
Costs	Total variable costs per trip in euro
Distance	Total distance travelled per trip in kilometre
Energy use	Total energy use per trip in kilowatt-hour

Table E.7: Optional output of BIVAS; infeasible trips.

Field	Output: Infeasible trips Description
Origin node ID	Origin node
Origin zone name	Origin zone (depending on chosen zone definition)
Destination node ID	Destination node
Destination zone name	Destination zone (depending on chosen zone definition)
Ship Type	RWS class of the vessel
Number of infeasible trips	Number of trips with this origin, destination and vessel type for which no route could be found

Table E.8: Optional output of BIVAS; route statistics.

Field	Output: Route statistics Description
Trip ID	ID of the trip
Number of segments	Number of arcs used
Travel time	Total travel time per trip in minutes (waiting at locks included, waiting on load excluded)
Variable costs	Total variable costs per trip in euro
Fixed costs	Total fixed costs per trip in euro
Distance	Total distance travelled per trip in kilometre
Energy use	Total energy use per trip in kilowatt-hour

Table E.9: Optional output of BIVAS; arc usage, arc usage without direction, arc usage details and arc usage details without direction.

Field	Output: Arc usage (**details**) (<u>with direction</u>) Description
Arc ID	ID of the arc
Arc name	Name of the arc
<u>*Direction*</u>	Direction of usage of the arc
Country	Country in which the arc is located
Arc type description	Arc type (general waterway, weir, certain type of bridge etc.)
Ship type	Breakdown by RWS class
Load type	Breakdown by load type (loaded or empty)
Nstr code	Breakdown by NSTR type
Number of trips	Number of trips that used the arc
Total TEU	Number of TEU transported via the arc
Average travel time	Average travel time via the arc
Average distance	Average distance in kilometre travelled via the arc (average=length of the arc)
Average costs	Average costs in euro for travelling via the arc
Average weight of load	Average load in ton transported per trip via the arc
Average load capacity	Average load capacity in tonne of the vessels using the arc
Depth of normative ship on an arc	Draught in meters of the vessel with the largest draught using the arc
Width of normative ship on an arc	Width in meters of the vessel with the largest width using the arc
Energy use per kilometer	Average energy use in kilowatt-hour per trip using the arc

Table E.10: Optional output of BIVAS; origin trip endpoint and destination trip endpoint.

Field	Output: Origin/Destination trip endpoint Description
Trip endpoint node ID	ID of origin/destination node
Trip endpoint name	Name of origin/destination node
Zone	Zone in which node is located (depending on chosen zone defenition)
Ship type label	Breakdown by RWS class
Load type description	Breakdown by load type (loaded or empty)
Nstr code	Breakdown by NSTR type
Number of trips	Number of trips with this origin/destination node
Average travel time	Average travel time from/to this node

Table E.11: Optional output of BIVAS; counting point.

Field	Output: Counting point Description
Counting point	Counting point ID
Counting point name	Counting point name
Direction	Breakdown by direction
Ship type label	Breakdown by RWS class
Load type description	Breakdown by load type (loaded or empty)
Number of trips	Number of trips passing the counting point (including extra trips due to reduced load)
Total TEU	Total number of TEU passing the counting point

Table E.12: Optional output of BIVAS; waiting time.

Output: Waiting time	
Field	**Description**
Arc ID	Arc ID of the lock
Name	Name of the lock
Share of loaded ships at the uppergate of a lock	Share of loaded vessels at upper gate
Share of loaded vessels at lowergate of a lock	Share of loaded vessels at lower gate
Lock intensity	Total load capacity of all vessels passing the lock (including extra trips due to reduced load)
Average load capacity	Average load capacity of the vessels passing the lock (including extra trips due to reduced load)
Arrival process	Breakdown by arrival process (averagely even, relatively even and relatively uneven)
I/C ratio	Ratio between lock intensity and lock capacity
Time needed for lockage process	Service time in minutes
Calculated wait time	Waiting time calculated based on the computed lock intensity in minutes
Used wait time	Waiting time given as input and used in the computation in minutes
Wait time difference	Difference between the calculated and used waiting times in minutes
Calculated overlay time	Overlay time calculated based on the computed Lock intensity in minutes
Used overlay time	Overlay time given as input and used in the computation in minutes
Overlay time difference	Difference between the calculated and used overlay times in minutes

Table E.13: Optional output of BIVAS; emission.

Output: Emission	
Field	**Description**
Ship type	Breakdown by RWS class
Load capacity class	Breakdown by load capacity class
Cemt type	BIVAS CEMT class of the arc
Direction	Breakdown by direction (upstream, downstream, no flow)
Load type	breakdown by load type
Arc ID	ID of the arc
Arc name	Name of the arc
Substance	Substance type
Number of trips	Number of trips (including extra trips due to reduced load)
Distance	Total distance in kilometer of all trips (including extra trips due to reduced load)
Energy use	Total energy use in kilowatt-hour of all trips (including extra trips due to reduced load)
Emission	Total emission in kilogram of all trips (including extra trips due to reduced load)

Table E.14: Optional output of BIVAS; reference comparison and aggregated reference comparison.

Output: (**Disaggregated**) reference comparison	
Field	**Description**
Counting point name	Name of the counting point
Direction	Breakdown by sailing direction
Ship type	Breakdown by RWS class
Load type	Breakdown by load type (empty or loaded)
Number of routes reference	Number of vessels passing accoring to the IVS90
Number of trips BIVAS	Number of trips passing in BIVAS (including extra trips due to reduced load)
Number of routes BIVAS	Number of trips passing in BIVAS (excluding extra trips due to reduced load)
Number of BIVAS trips per route	Number of trips BIVAS / Number of routes BIVAS
BIVAS trips per reference trip	Number of trips BIVAS / Number of routes reference
BIVAS routes per reference trip	Number of routes BIVAS / Number of routes reference
BIVAS and reference match count	Number of trips passing in BIVAS (excluding extra trips due to reduced load) that pass as well according to the IVS90
BIVAS and reference match percentage	BIVAS and reference match count / Number of routes reference
Number of routes in reference, not in BIVAS	Number of trips passing according to the IVS90 that do no pass in BIVAS
Percentage routes in reference, not in BIVAS	Number of routes in reference, but not in BIVAS / Number of routes reference
Infeasible trips	Number of infeasible trips in BIVAS that pass according to the IVS90
Infeasible trips factor	Infeasible trips / Number of routes reference
Number of routes in BIVAS, not in reference	Number of trips passing in BIVAS (excluding extra trips due to reduced load) that do not pass according to the IVS90
Percentage routes in BIVAS, not in reference	Number of routes in BIVAS, but not in reference / Number of routes reference
Weight reference	Total load in tonne of the trips passing according to the IVS90
Weight BIVAS	Total load in tonne of the trips passing in BIVAS
Weight match factor	Weight BIVAS / Weight reference
Number of TEU in reference	Number of TEU transported by the trips passing according to the IVS90
Number of TEU in BIVAS	Number of TEU transported by the trips passing in BIVAS
TEU match factor	Number of TEU in BIVAS / Number of TEU in reference

F
BIVAS NETWORK

F.1. ORIGIN NETWORK DATA

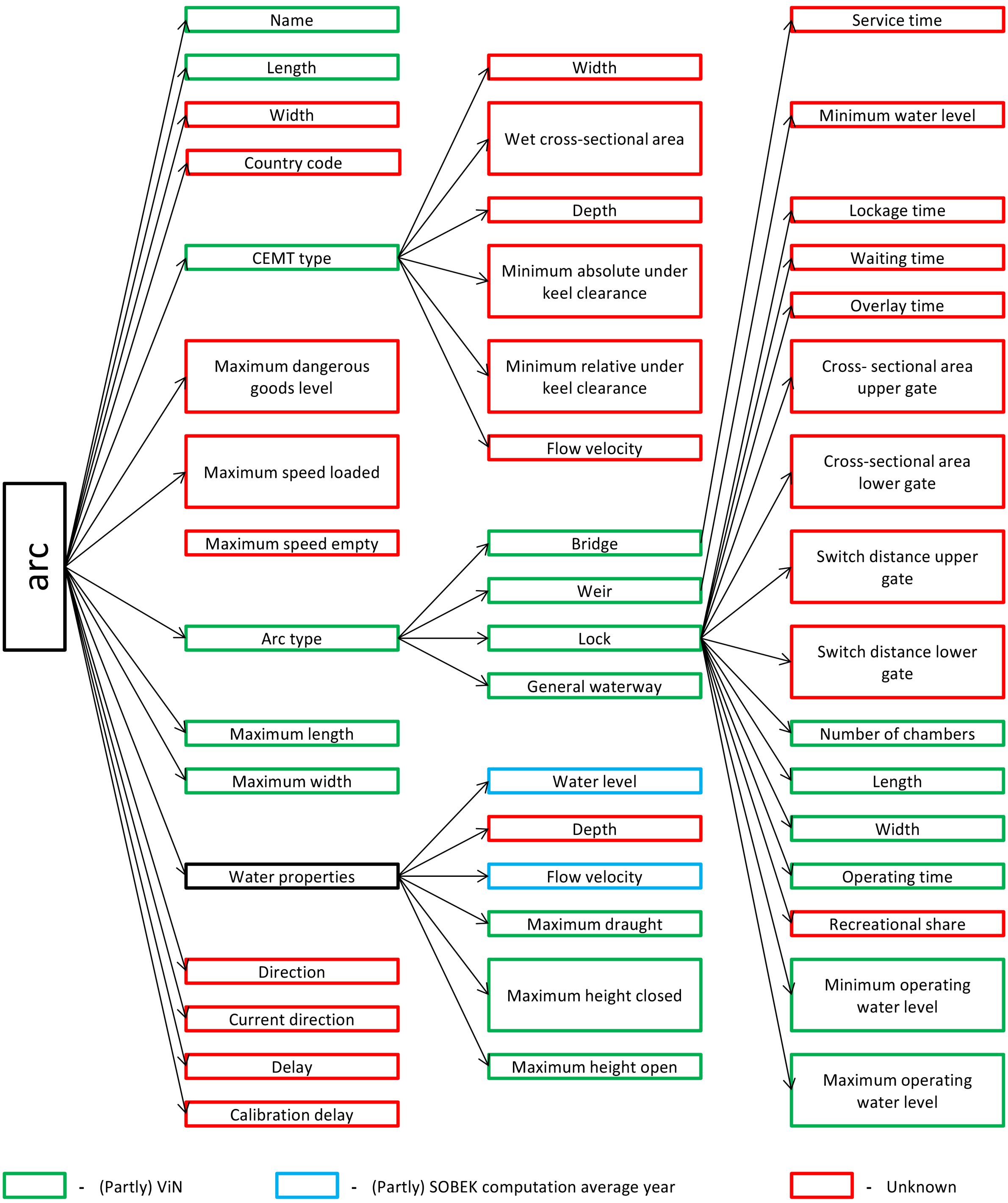


Figure F.1: Origin of network data stored in BIVAS database.

F.2. CLASSIFICATION OF THE BIVAS ARCS

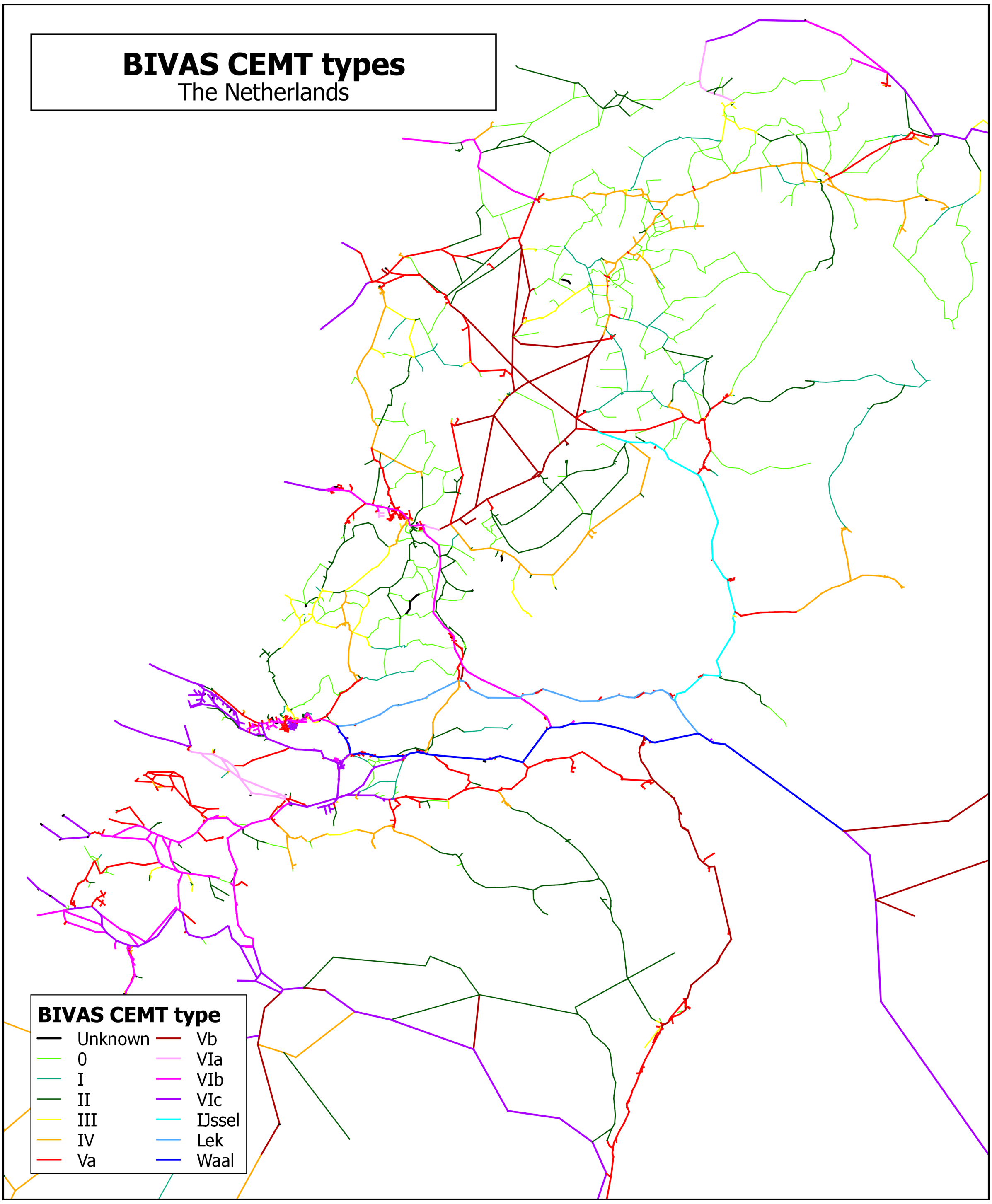


Figure F.2: BIVAS CEMT classes of the arcs within the Dutch part of the network.

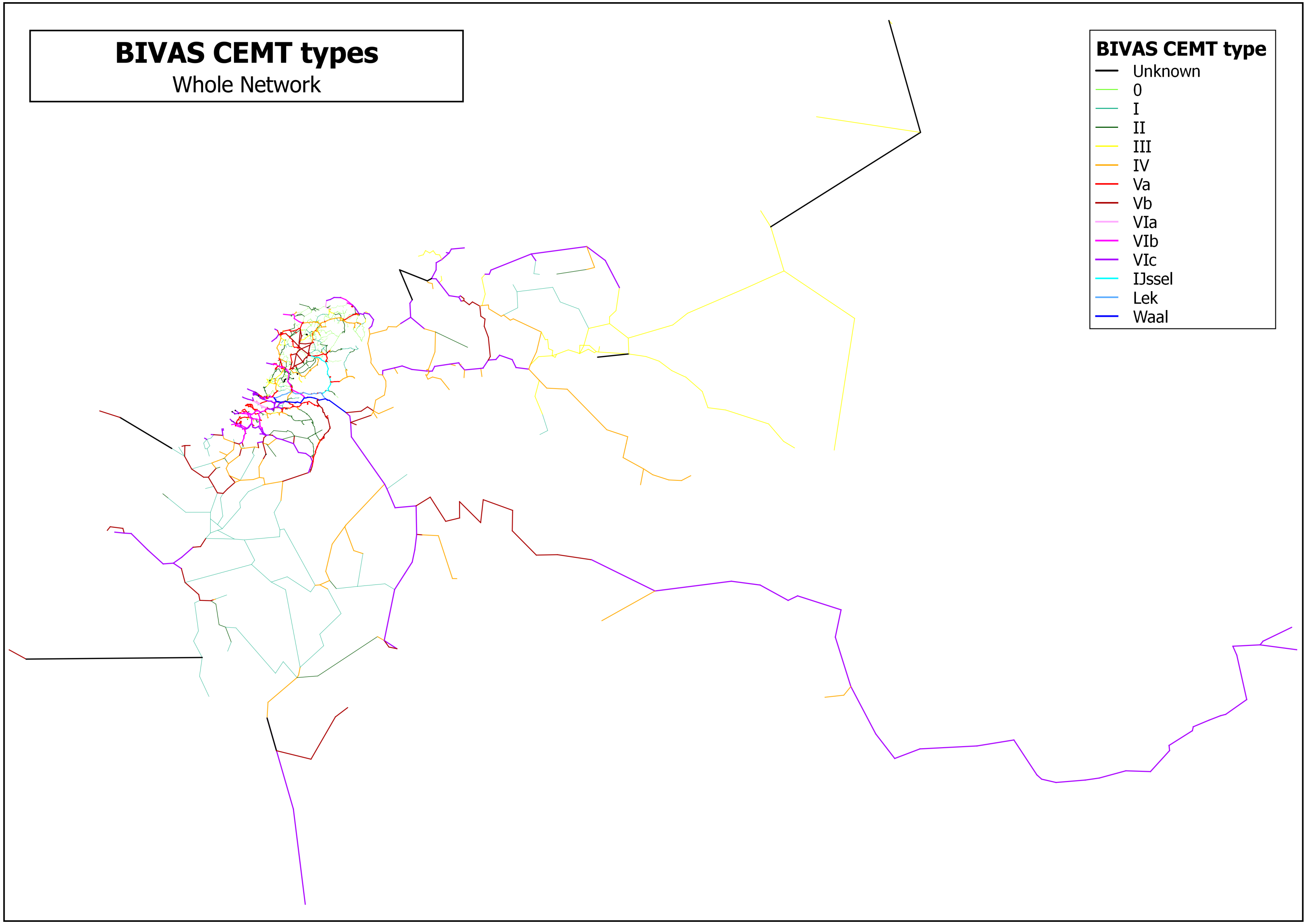


Figure F.3: BIVAS CEMT classes of all arcs within the network.

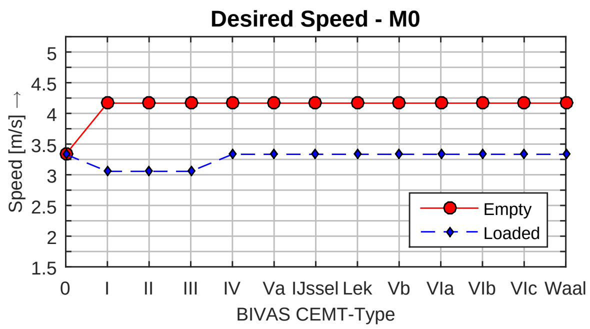
Table F.1: BIVAS CEMT classification, characteristics

BIVAS CEMT type	Width **[m]**	Wet cross-section **[m^2]**	Depth **[m]**	Minimum absolute under keel clearance **[m]**	Minimum relative under keel clearance **[-]**	Flow velocity **[km/h]**
0	40	84	2.1	0.3	0.25	0
I	46	67	3.1	0.3	0.25	0
II	50	83	3.5	0.3	0.25	0
III	50	83	3.5	0.3	0.25	0
IV	70	150	3.9	0.3	0.25	0
IJssel	120	408	3.4	0.3	0	1
Lek	150	750	5	0.3	0	0.8
Va	79	196	5	0.3	0.25	0
Vb	79	196	5	0.3	0.25	0
VIa	100	500	6	0.3	0.25	0
VIb	100	500	6	0.3	0.25	0
VIc	100	500	6	0.3	0.25	0
Waal	250	1,750	7	0.3	0	1.3
Unknown	300	3,000	10	0.3	0.25	0

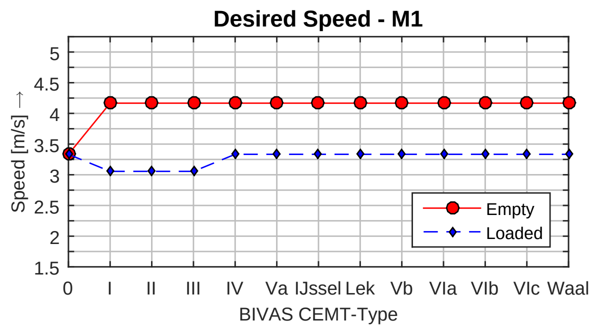
G
BIVAS VESSEL DATA

G.1. Desired speeds

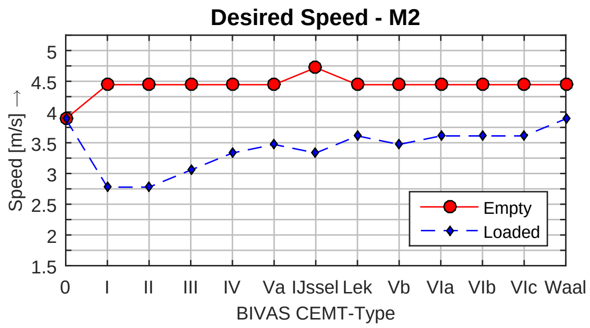
G.1.1. Motor vessels



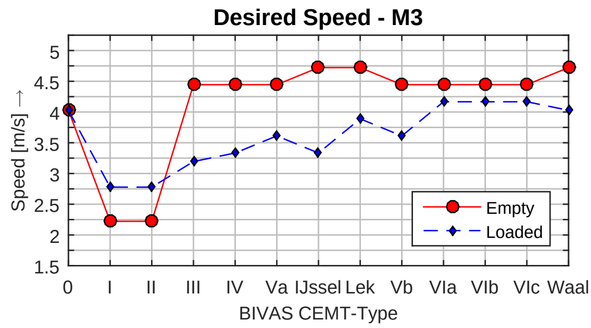
(a) M0



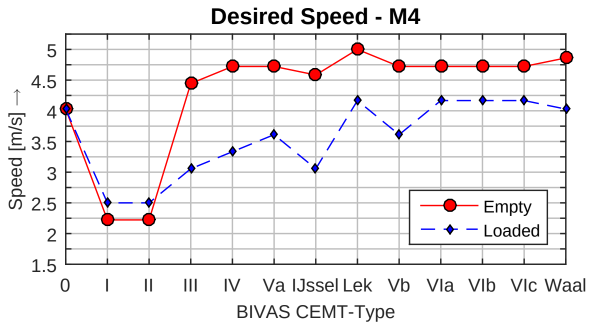
(b) M1



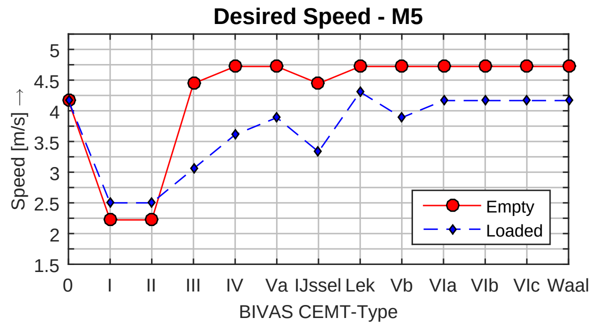
(c) M2



(d) M3

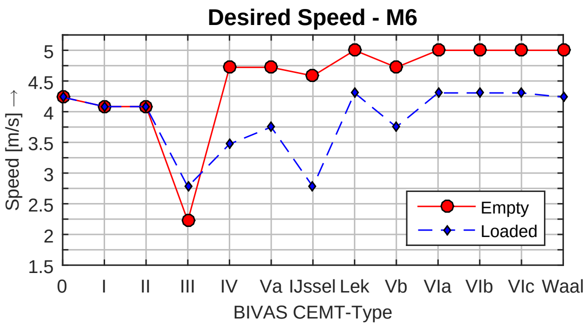


(e) M4

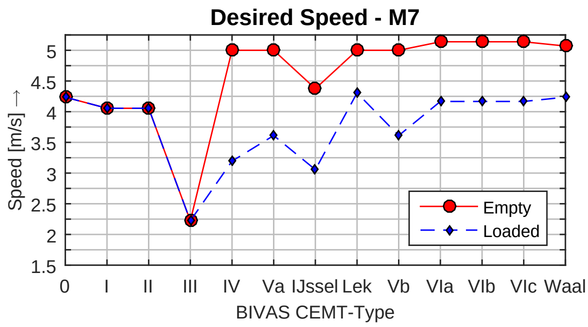


(f) M5

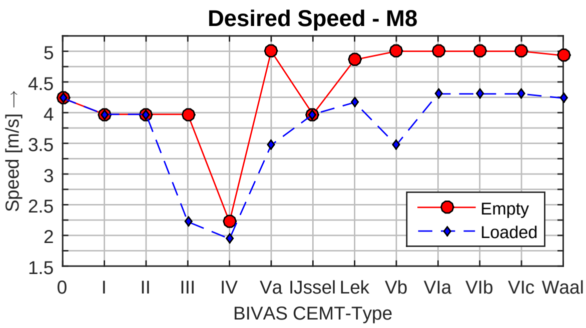
Figure G.1: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the desired speeds stored in the BIVAS database - *Motor vessels (1)*



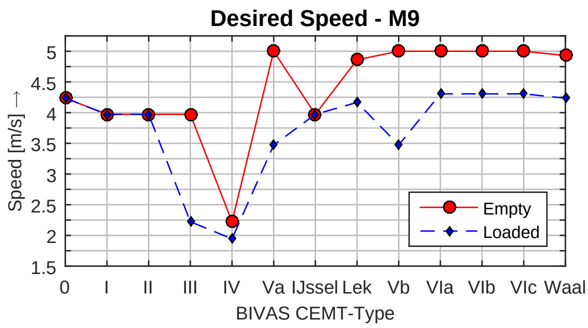
(a) M6



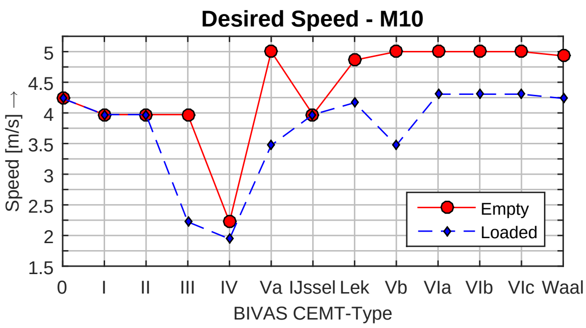
(b) M7



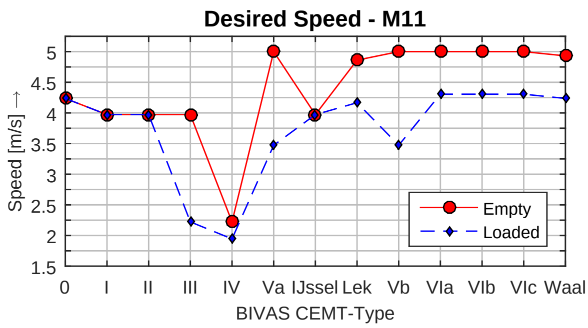
(c) M8



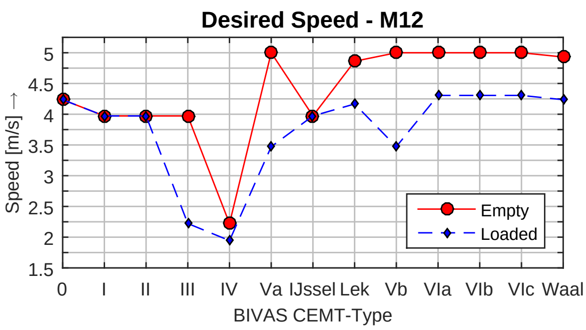
(d) M9



(e) M10



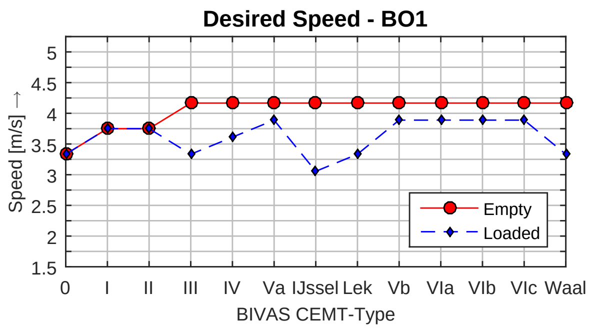
(f) M11



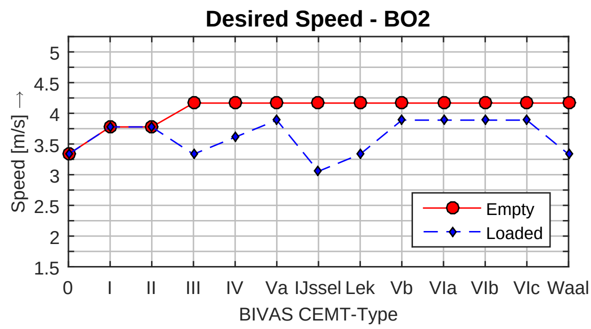
(g) M12

Figure G.2: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the desired speeds stored in the BIVAS database - *Motor vessels (2)*

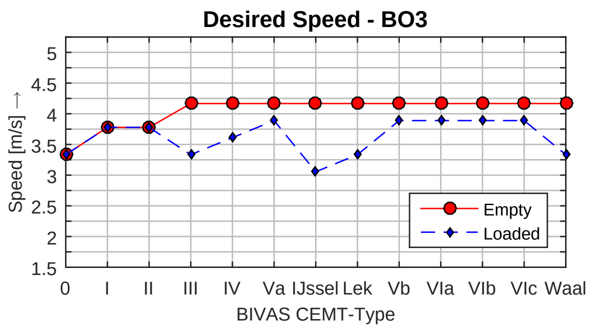
G.1.2. PUSHED CONVOYS



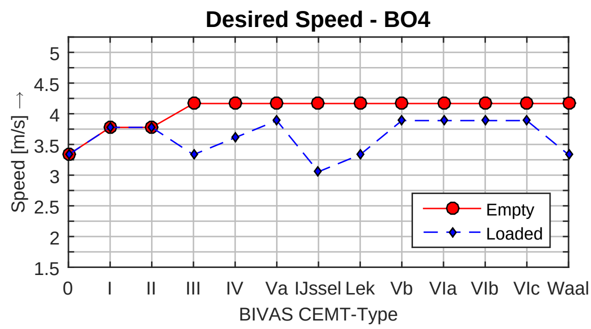
(a) BO1



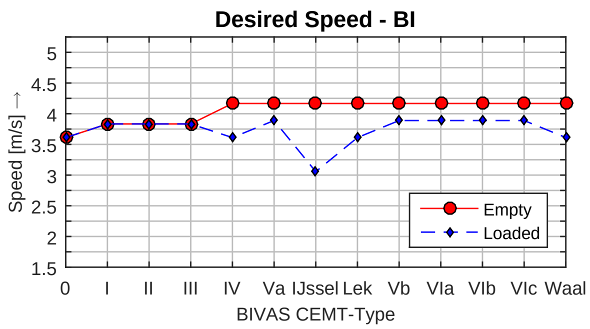
(b) BO2



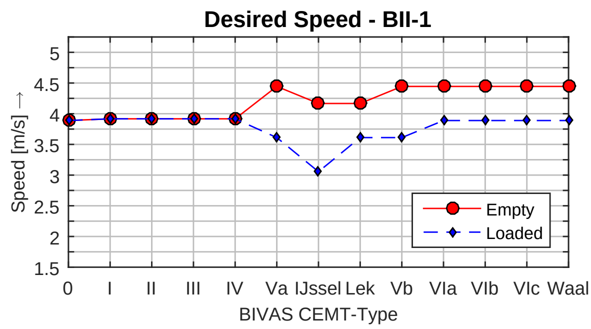
(c) BO3



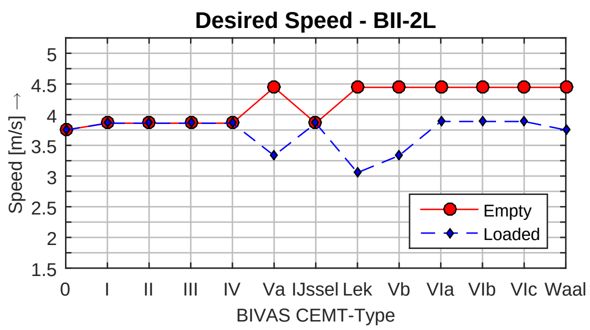
(d) BO4



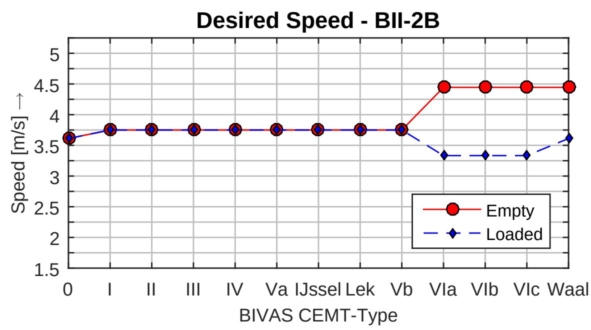
(e) BI



(f) BII-1

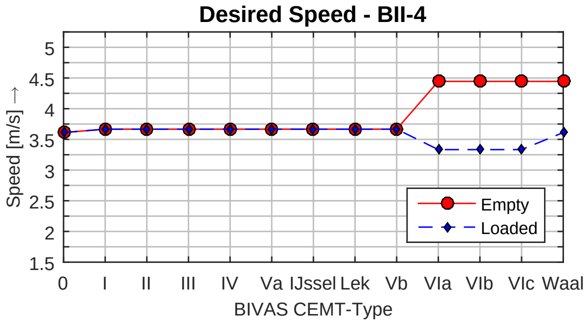


(g) BII-2L

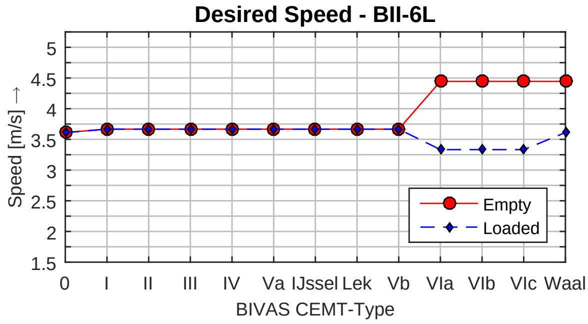


(h) BII-2B

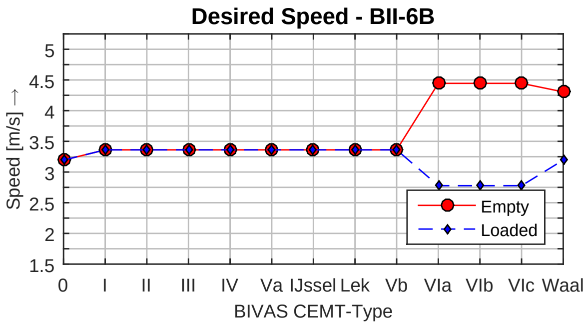
Figure G.3: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the desired speeds stored in the BIVAS database - *Pushed convoys (1)*



(a) BII-4



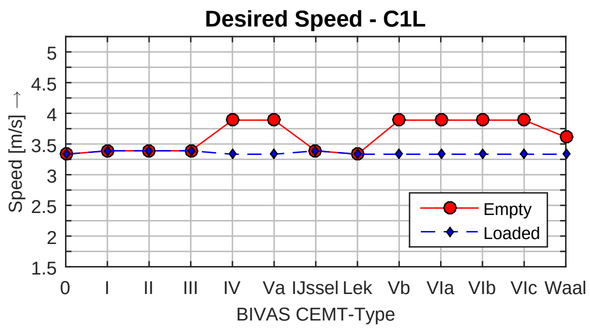
(b) BII-6L



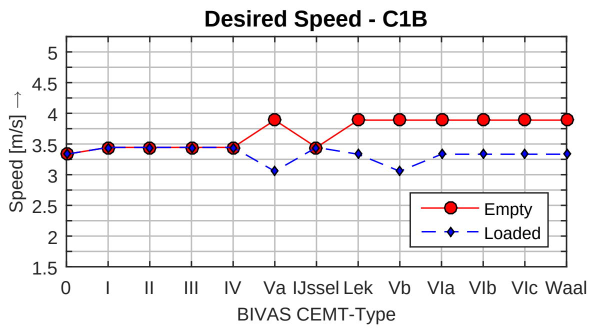
(c) BII-6B

Figure G.4: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the desired speeds stored in the BIVAS database - *Pushed convoys (2)*

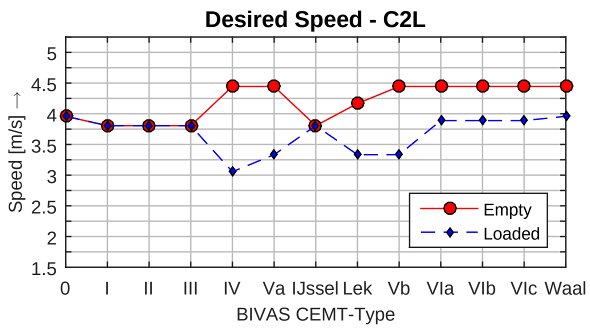
G.1.3. COUPLED UNITS



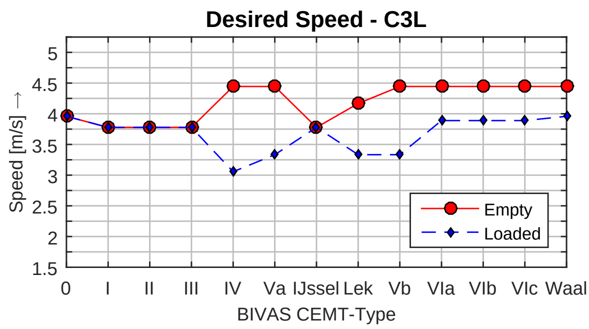
(a) C1L



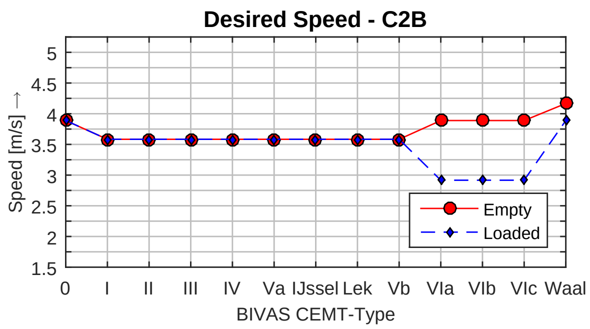
(b) C1B



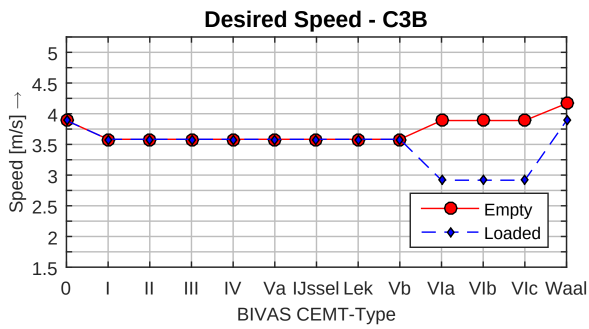
(c) C2L



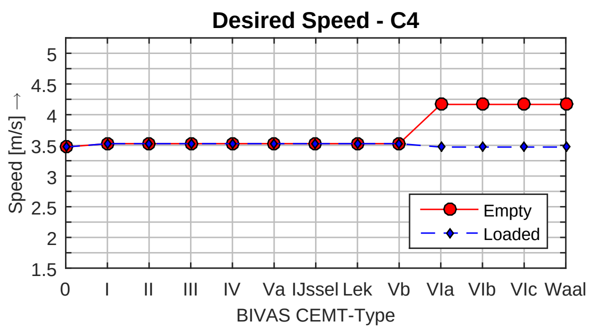
(d) C3L



(e) C2B



(f) C3B

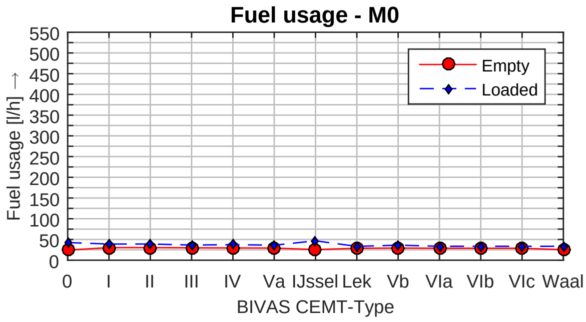


(g) C4

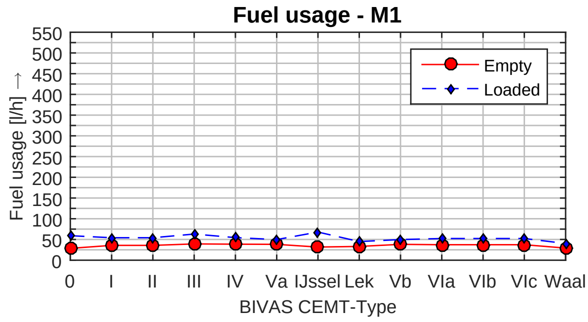
Figure G.5: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the desired speeds stored in the BIVAS database - *Coupled units*

G.2. Fuel usage

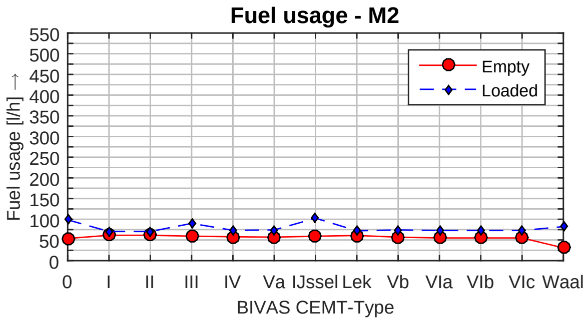
G.2.1. Motor vessels



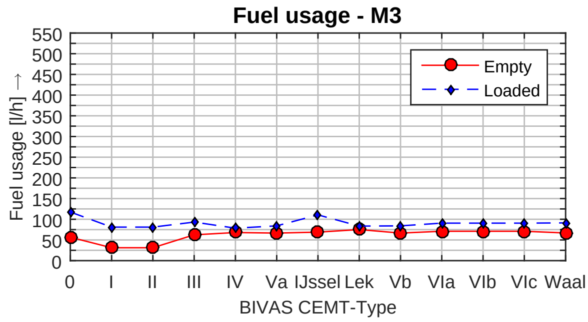
(a) M0



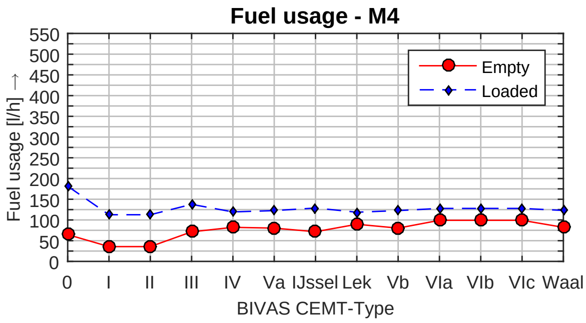
(b) M1



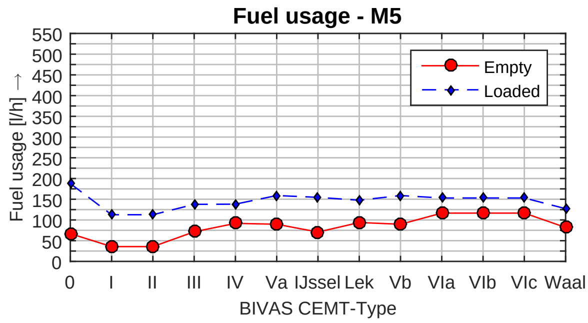
(c) M2



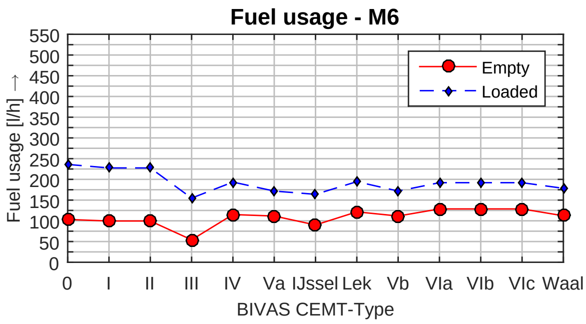
(d) M3



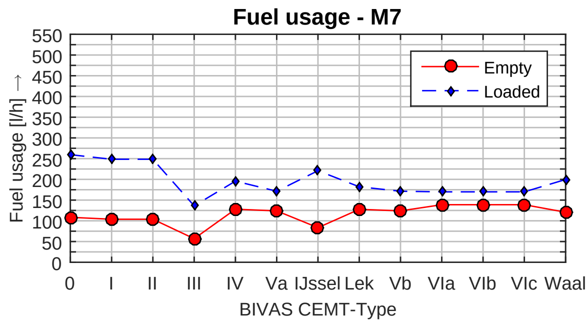
(e) M4



(f) M5

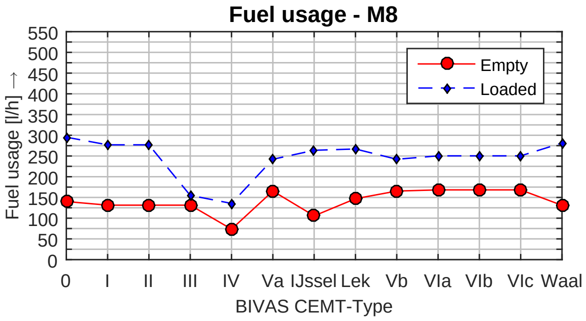


(g) M6

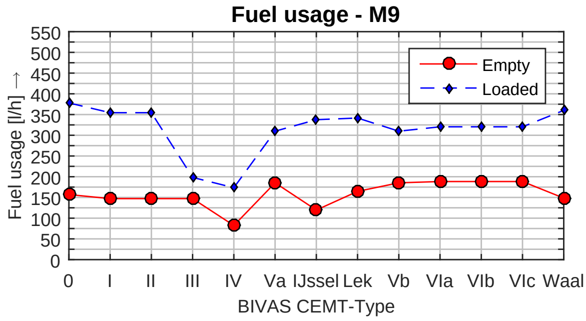


(h) M7

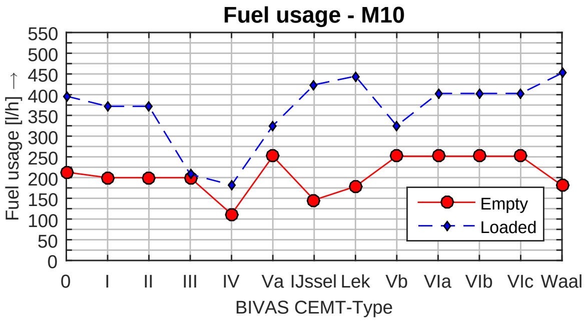
Figure G.6: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the fuel usage per hour stored in the BIVAS database - *Motor vessels (1)*



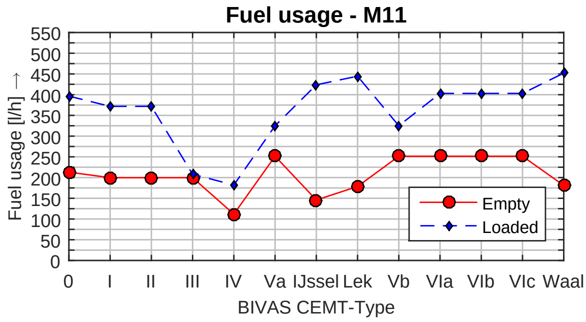
(a) M8



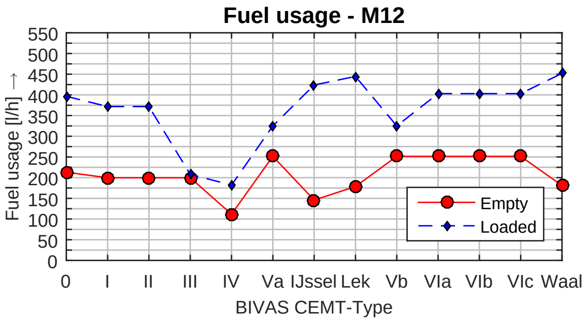
(b) M9



(c) M10



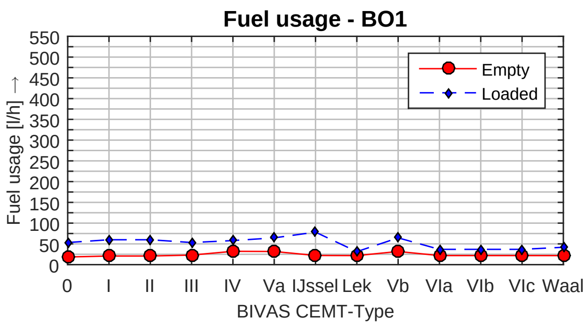
(d) M11



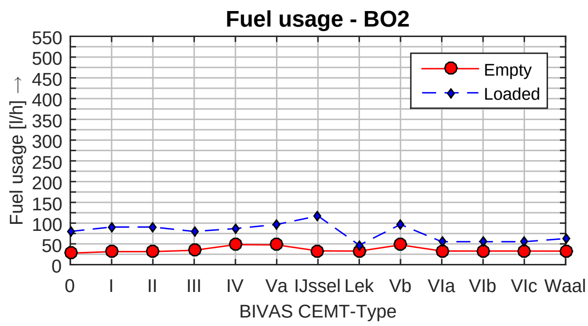
(e) M12

Figure G.7: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the fuel usage per hour stored in the BIVAS database - *Motor vessels (2)*

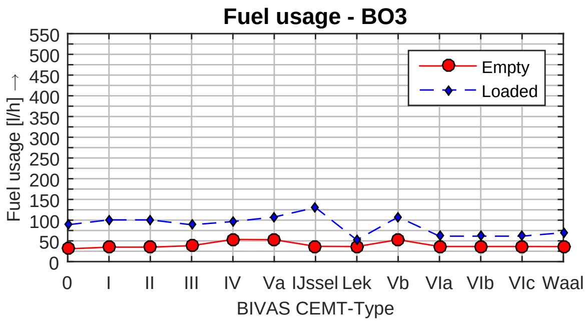
G.2.2. PUSHED CONVOYS



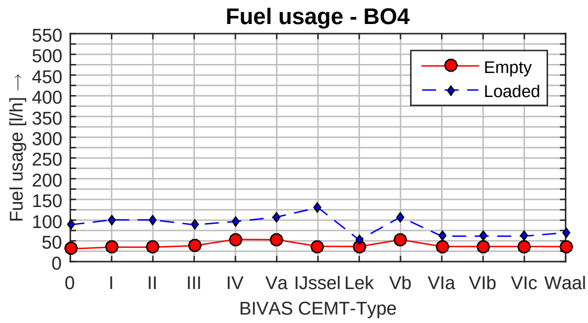
(a) BO1



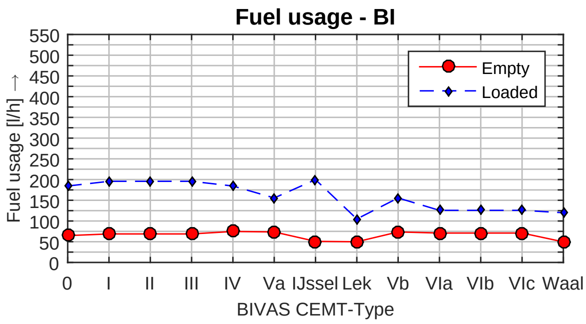
(b) BO2



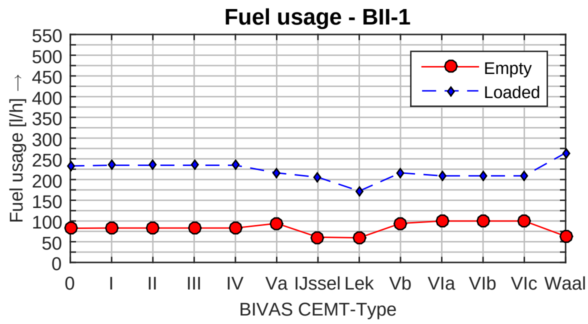
(c) BO3



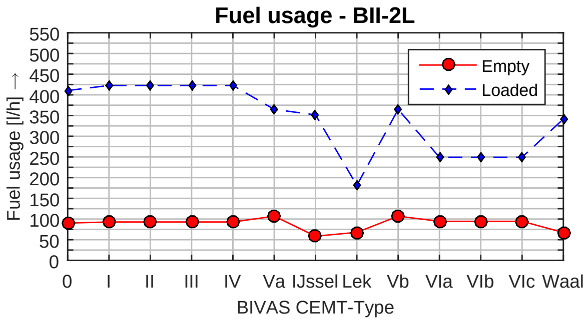
(d) BO4



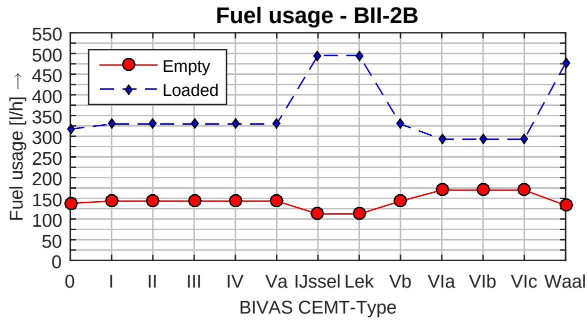
(e) BI



(f) BII-1

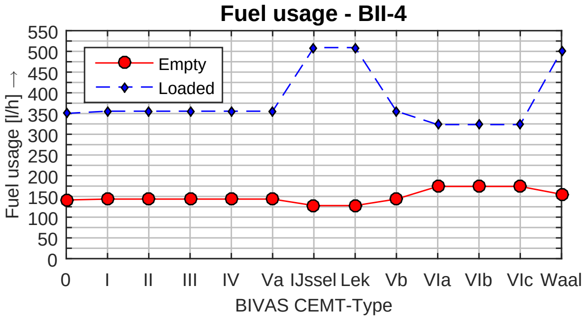


(g) BII-2L

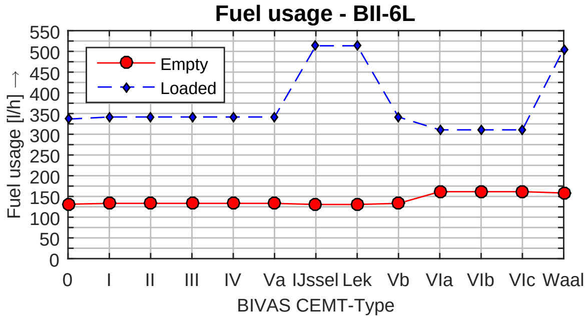


(h) BII-2B

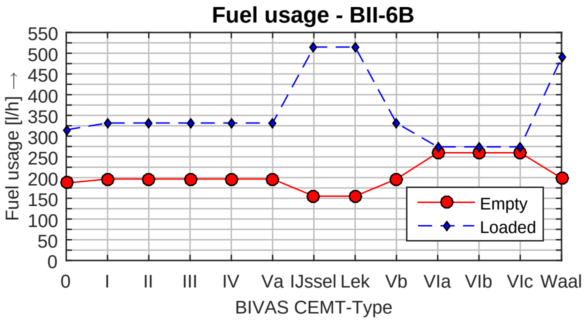
Figure G.8: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the fuel usage per hour stored in the BIVAS database - *Pushed convoys (1)*



(a) BII-4



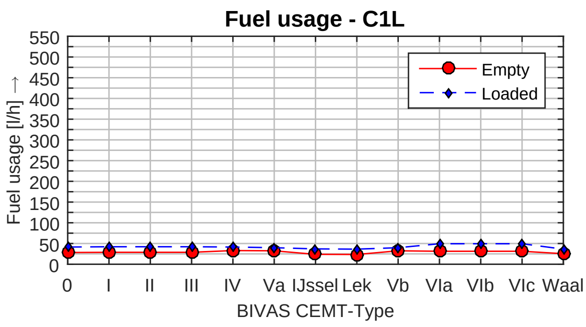
(b) BII-6L



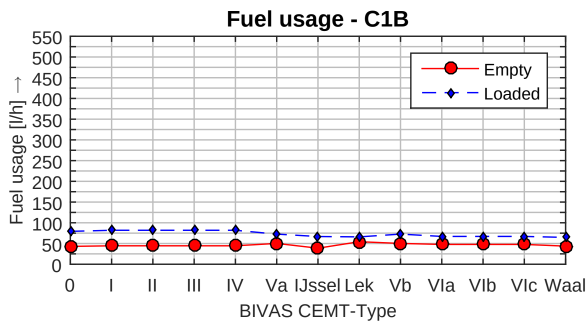
(c) BII-6B

Figure G.9: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the fuel usage per hour stored in the BIVAS database - *Pushed convoys (2)*

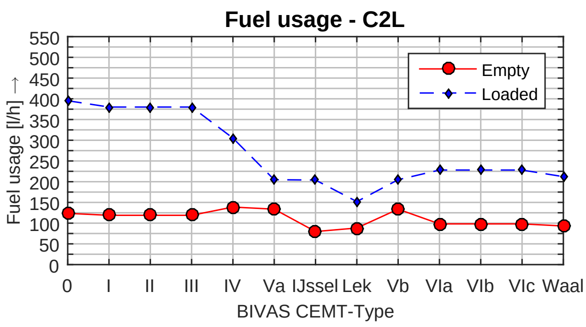
G.2.3. COUPLED UNITS



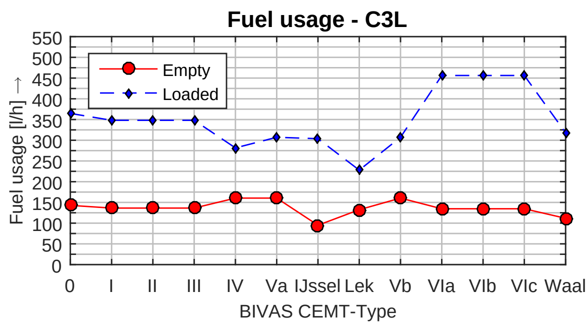
(a) C1L



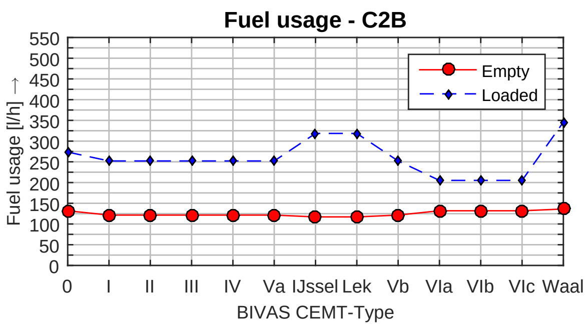
(b) C1B



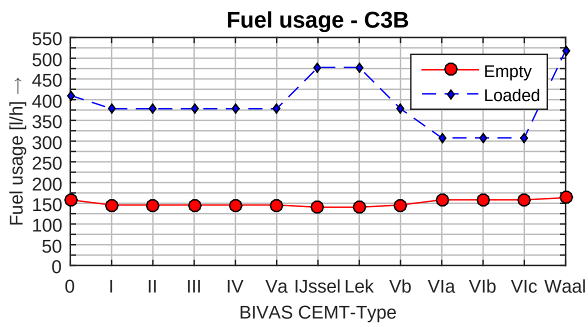
(c) C2L



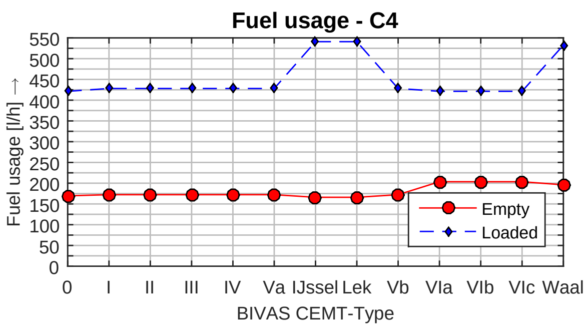
(d) C3L



(e) C2B



(f) C3B



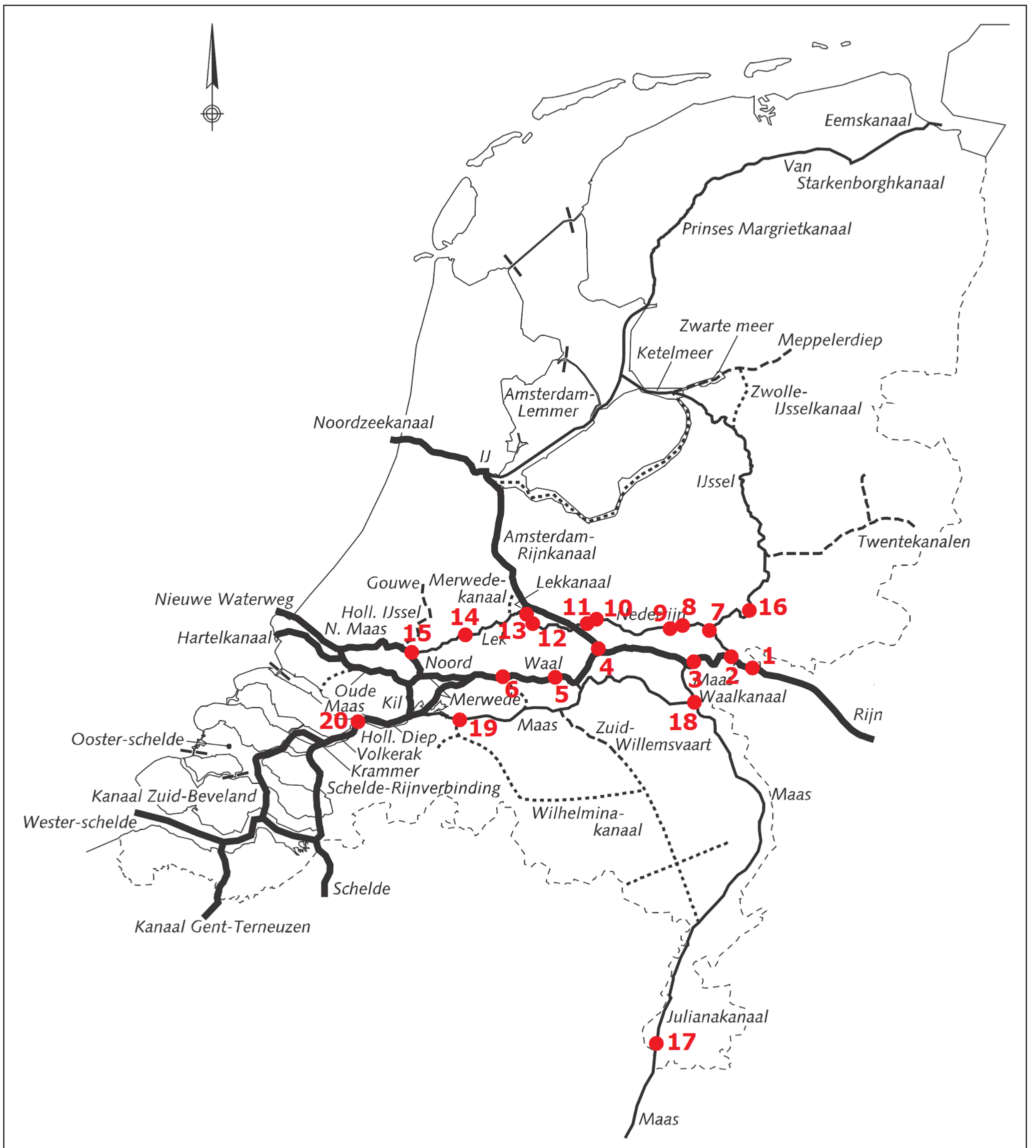
(g) C4

Figure G.10: Per vessel type, for the various BIVAS CEMT types and the load type (empty or loaded), the fuel usage per hour stored in the BIVAS database - *Coupled units*

H
Water scenario of 2011 from Nieuwe Koppeling LSM-BIVAS

H.1. Water levels water scenario 2011 in comparison to measured water levels

H.1.1. Overview Measurement points



1	Lobith	6	Vuren	11	Amerongen Beneden	16	Doesburg Brug
2	Pannerdense Kop	7	IJsselkop	12	Hagestein Boven	17	Sint Pieter Noord
3	Nijmegen Haven	8	Driel Boven	13	Hagestein Beneden	18	Mook
4	Tiel Waal	9	Driel Beneden	14	Schoonhoven	19	Keizersveer
5	Zaltbommel	10	Amerongen Boven	15	Krimpen aan de Lek	20	Rak Noord

Figure H.1: Measurement points for which the water level over 2011 is compared to the water levels in the water scenario of 2011.

H.1.2. COMPARISON PER MEASUREMENT POINT

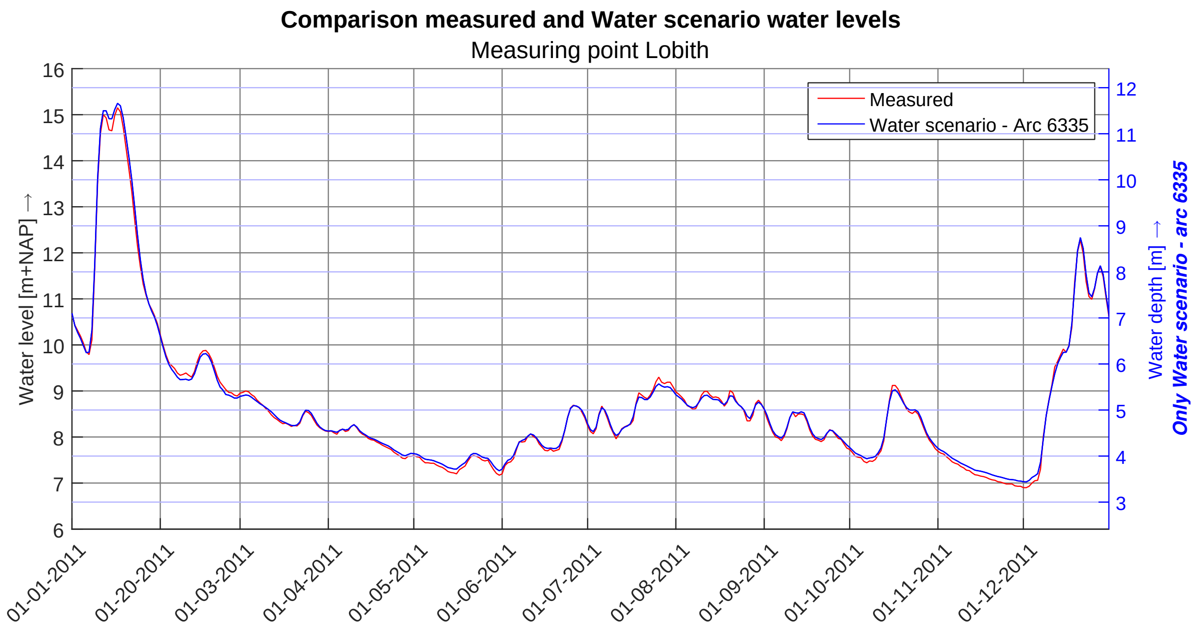


Figure H.2: Comparison of measured and water scenario water levels; Lobith 2011.

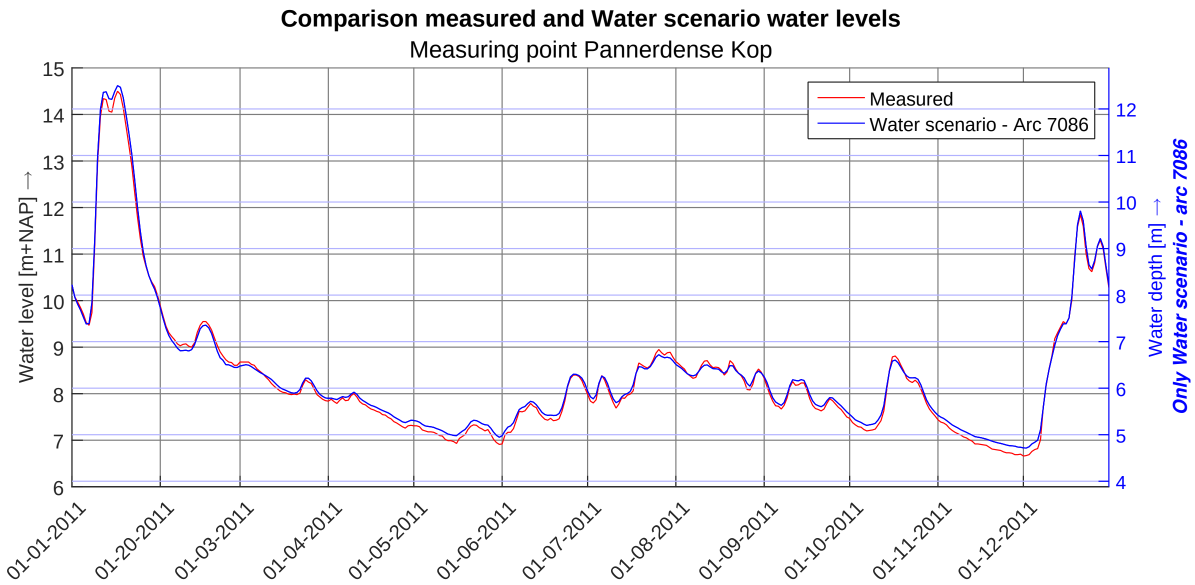


Figure H.3: Comparison of measured and water scenario water levels; Pannerdense Kop 2011.

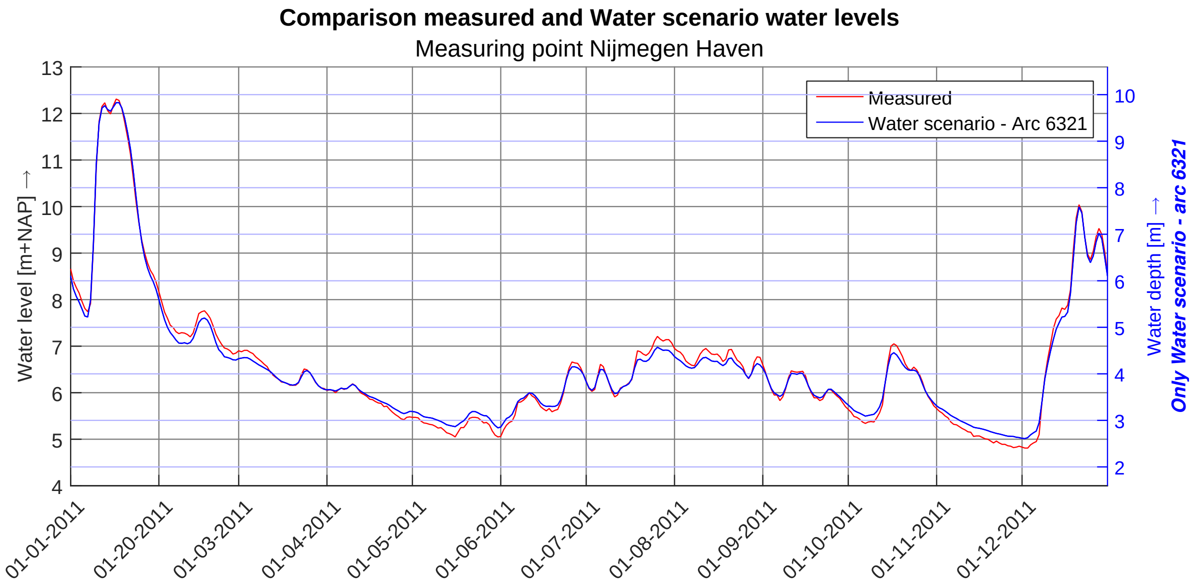


Figure H.4: Comparison of measured and water scenario water levels; Nijmegen Haven 2011.

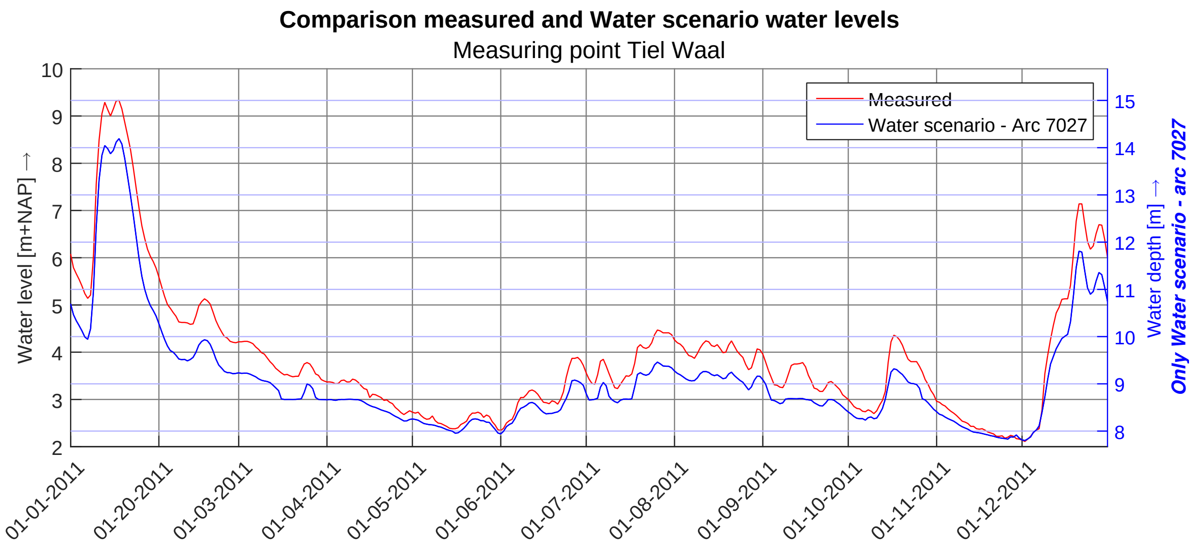


Figure H.5: Comparison of measured and water scenario water levels; Tiel Waal 2011.

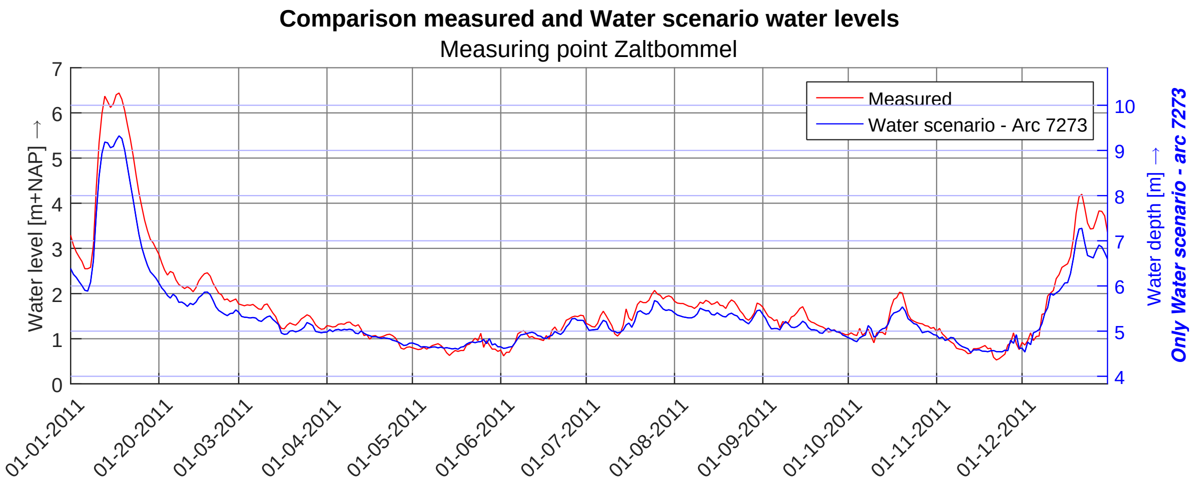


Figure H.6: Comparison of measured and water scenario water levels; Zaltbommel 2011.

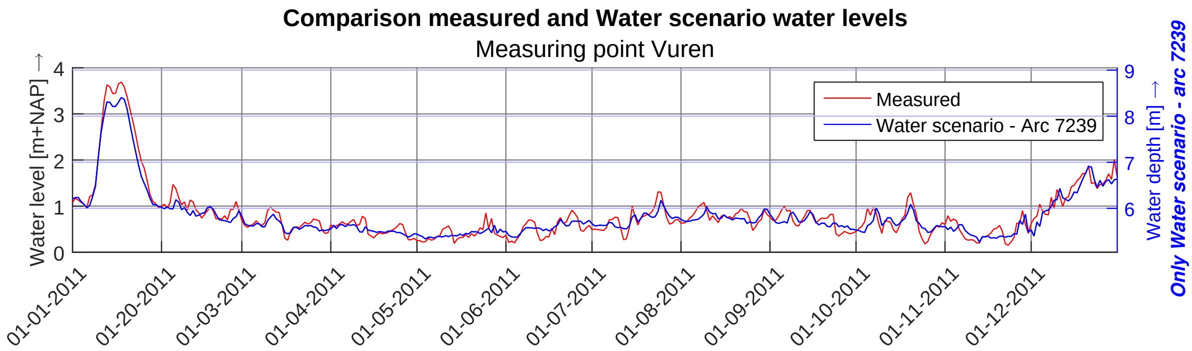


Figure H.7: Comparison of measured and water scenario water levels; Vuren 2011.

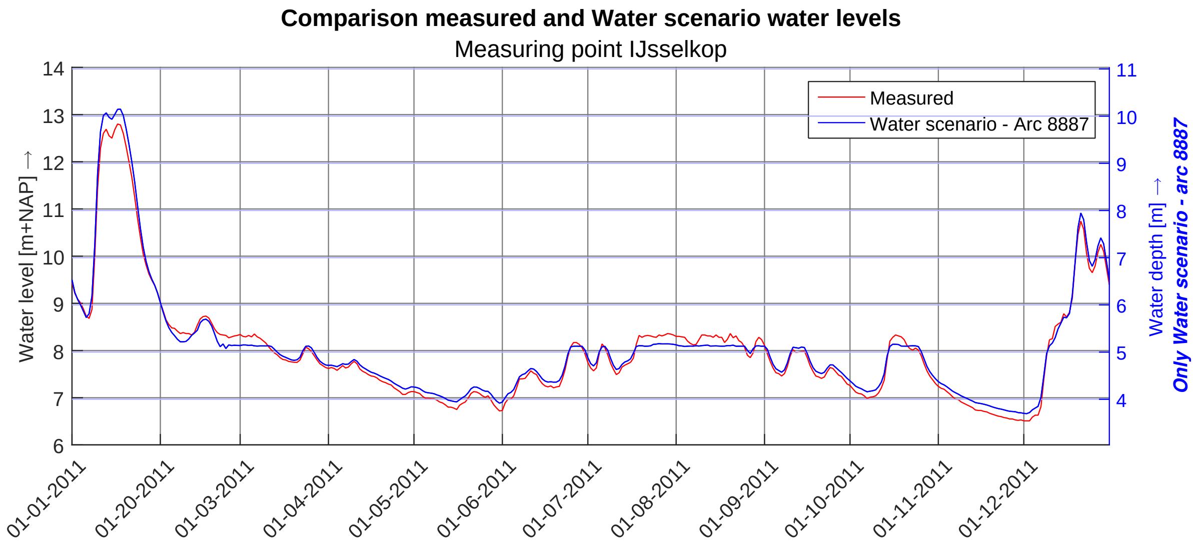


Figure H.8: Comparison of measured and water scenario water levels; IJsselkop 2011.

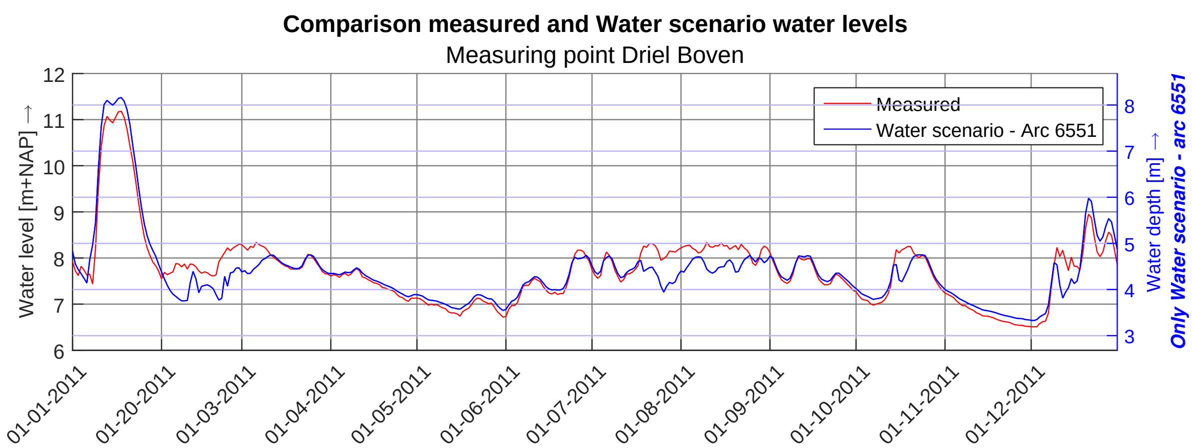


Figure H.9: Comparison of measured and water scenario water levels; Driel Boven 2011.

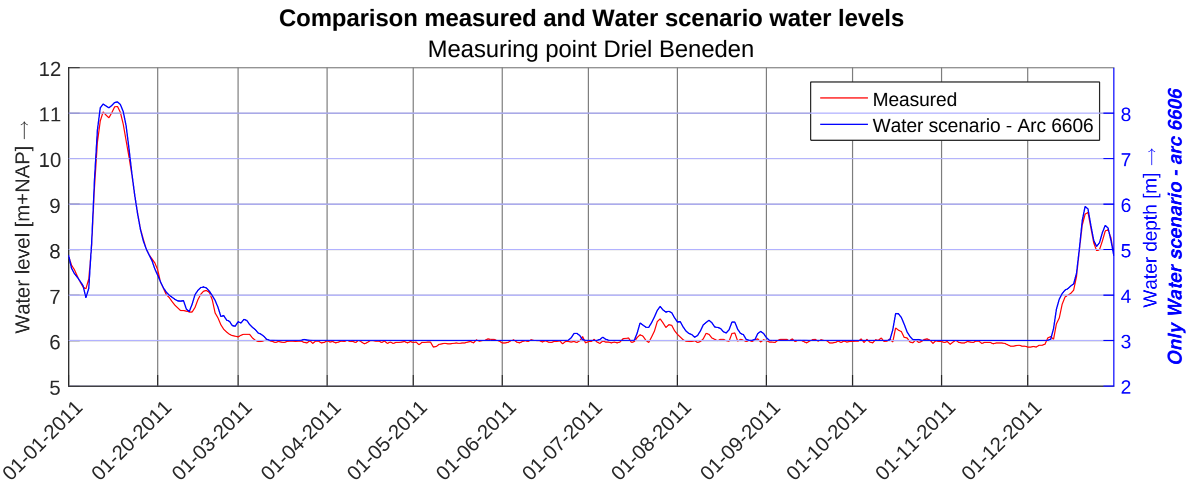


Figure H.10: Comparison of measured and water scenario water levels; Driel Beneden 2011.

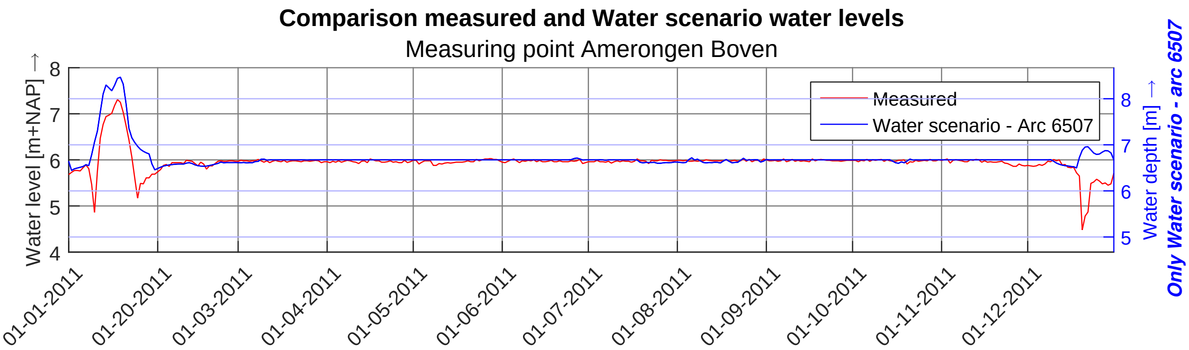


Figure H.11: Comparison of measured and water scenario water levels; Amerongen Boven 2011.

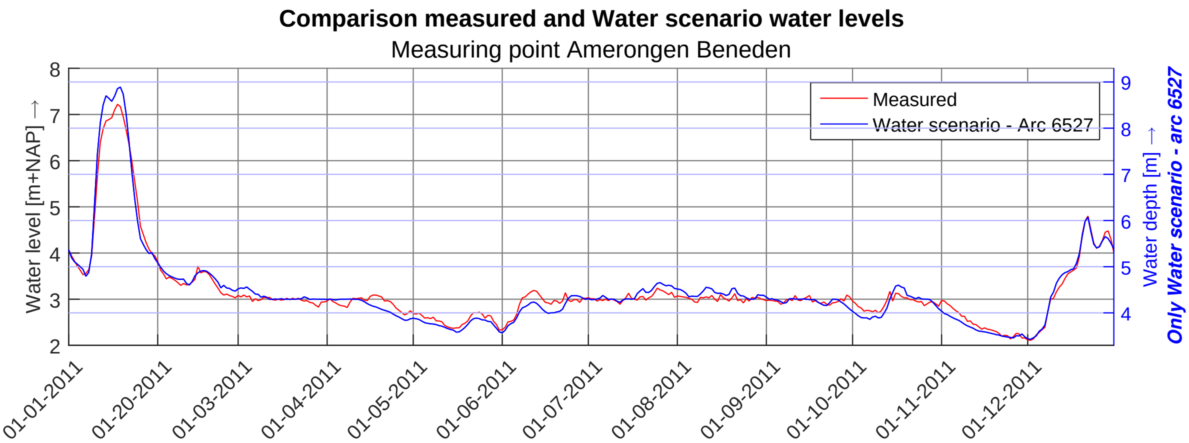


Figure H.12: Comparison of measured and water scenario water levels; Amerongen Beneden 2011.

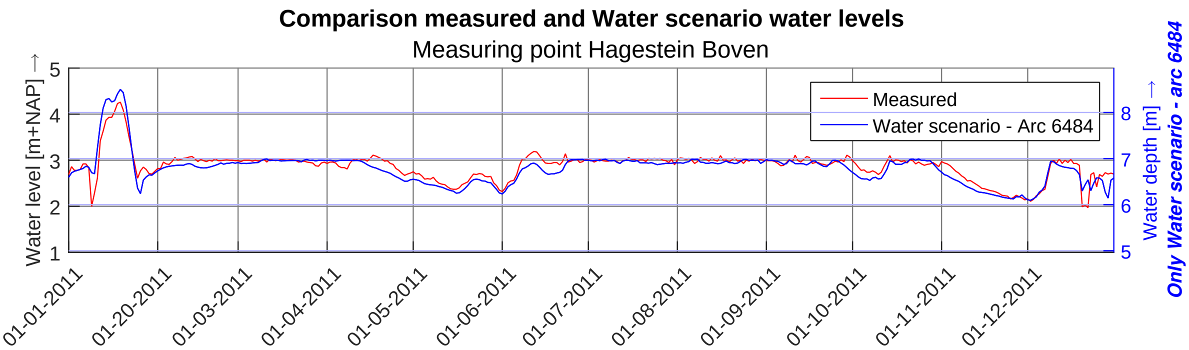


Figure H.13: Comparison of measured and water scenario water levels; Hagestein Boven 2011.

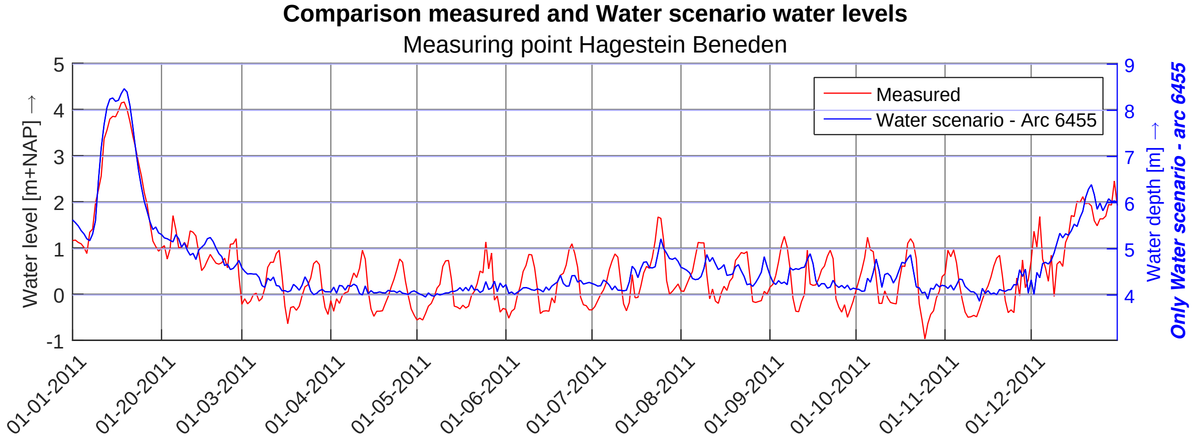


Figure H.14: Comparison of measured and water scenario water levels; Hagestein Beneden 2011.

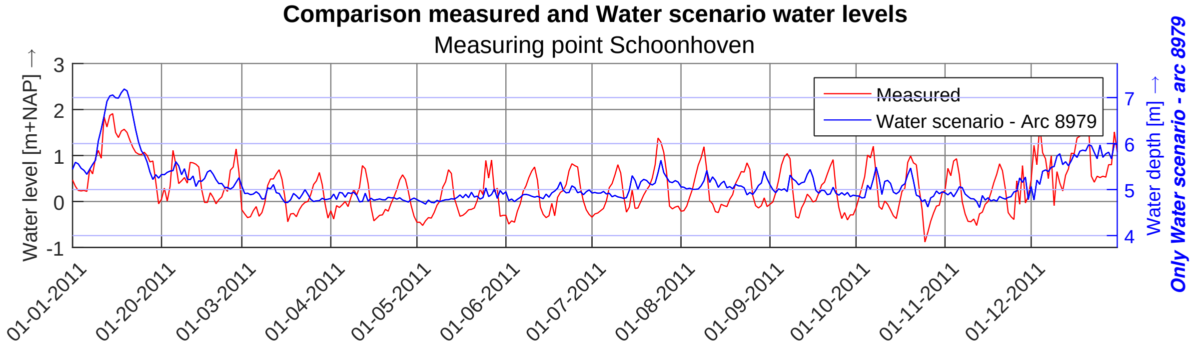


Figure H.15: Comparison of measured and water scenario water levels; Schoonhoven 2011.

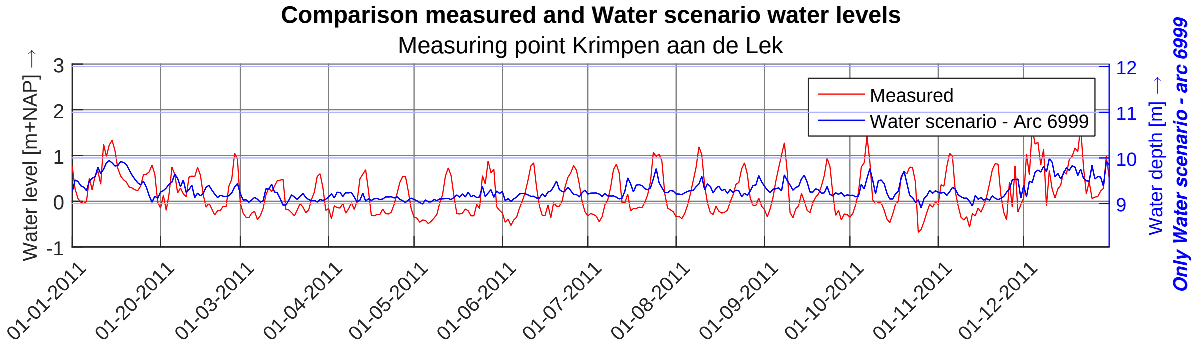


Figure H.16: Comparison of measured and water scenario water levels; Krimpen aan de Lek 2011.

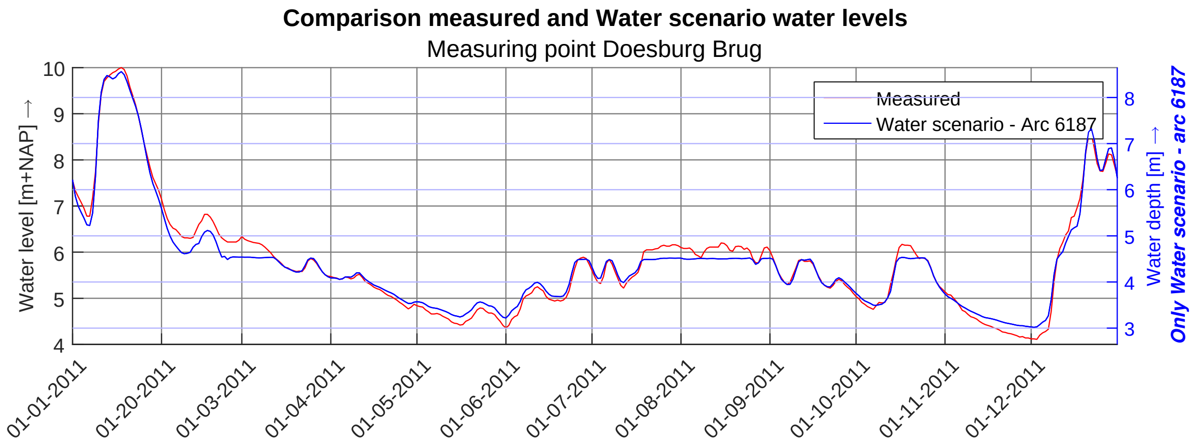


Figure H.17: Comparison of measured and water scenario water levels; Doesburg Brug 2011.

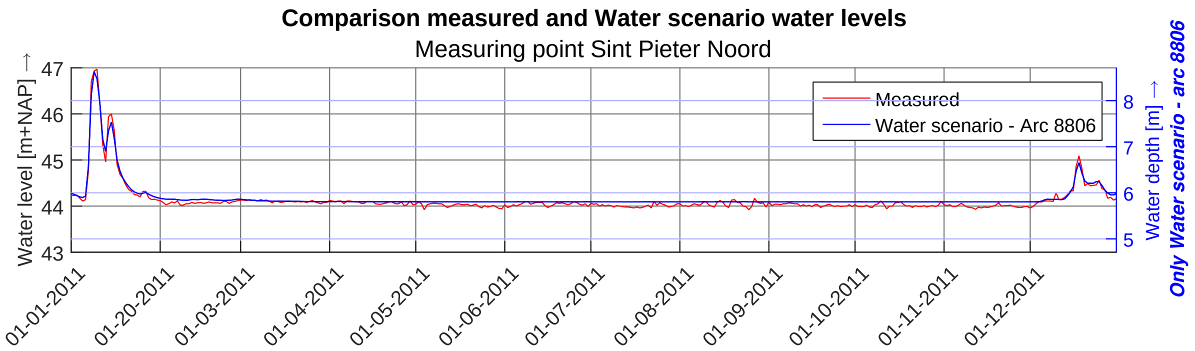


Figure H.18: Comparison of measured and water scenario water levels; Sint Pieter Noord 2011.

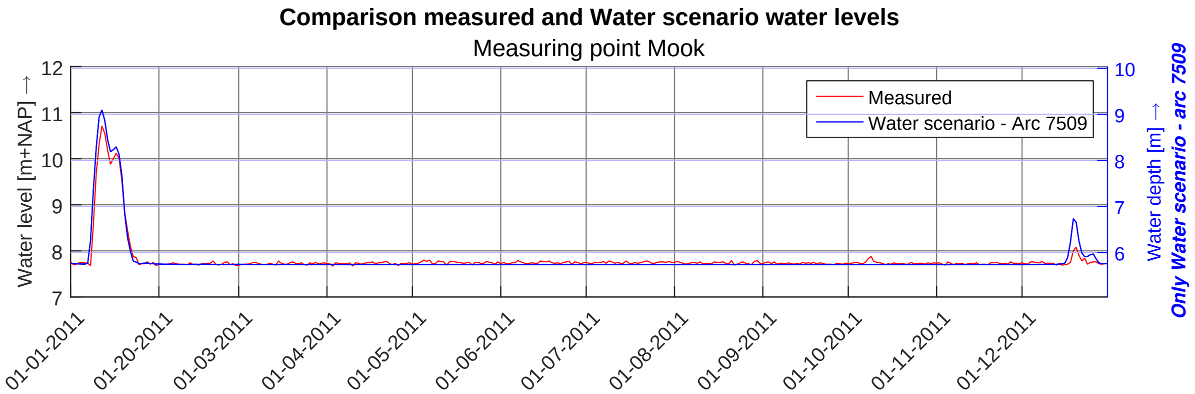


Figure H.19: Comparison of measured and water scenario water levels; Mook 2011.

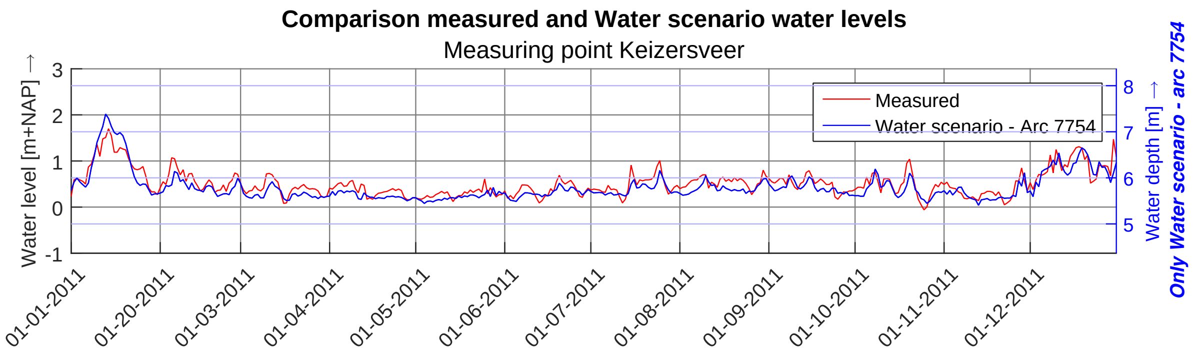


Figure H.20: Comparison of measured and water scenario water levels; Keizersveer 2011.

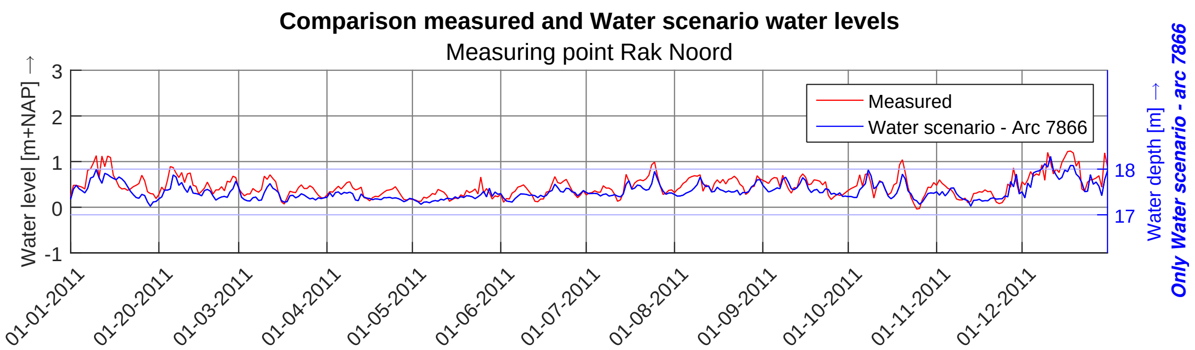


Figure H.21: Comparison of measured and water scenario water levels; Rak Noord 2011.

H.2. WATER CONDITIONS MEDIAN DISCHARGE PERIOD OF WATER SCENARIO 2011

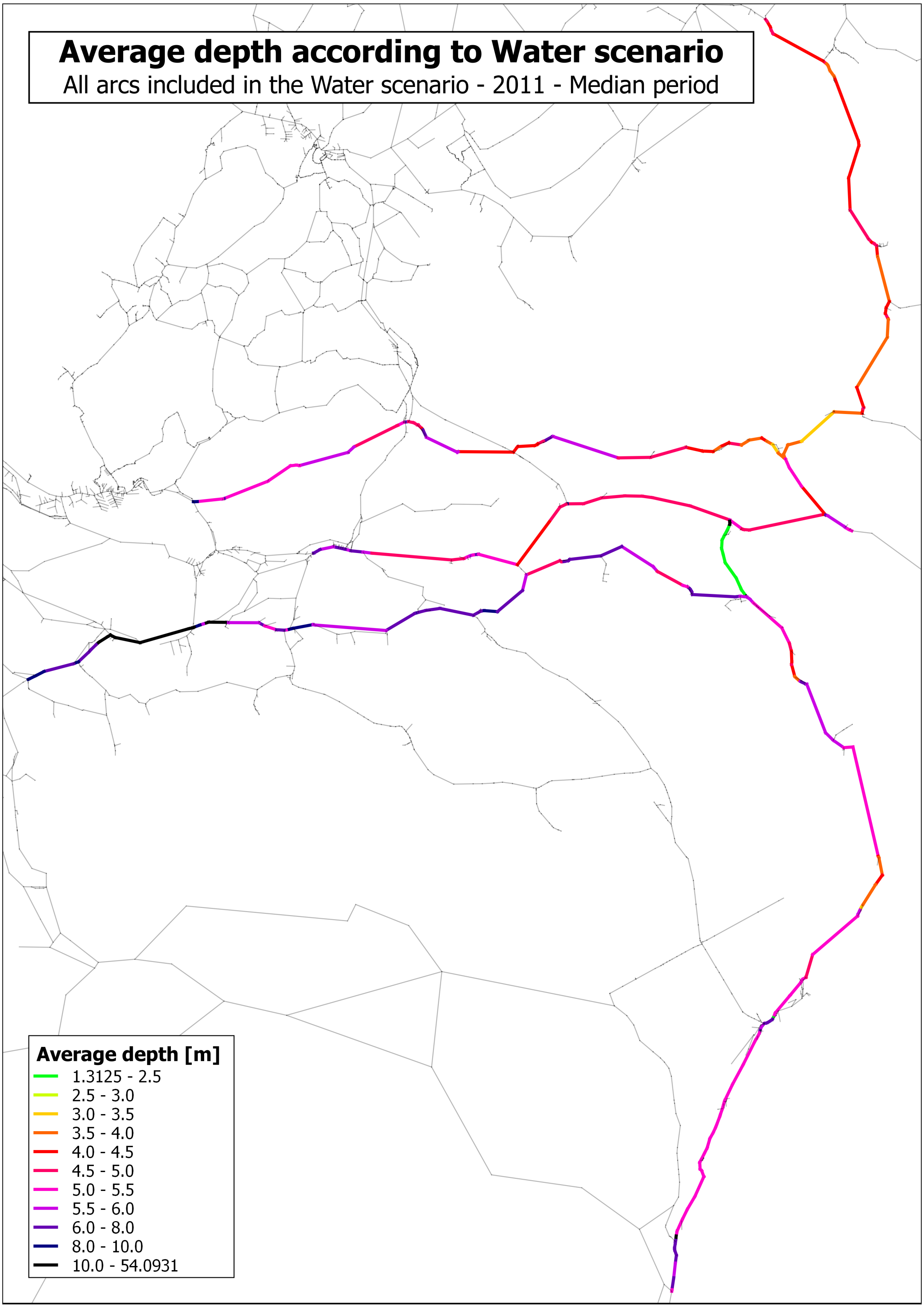


Figure H.22: Water scenario 2011; average water depths of median discharge period on all arcs included in the water scenario.

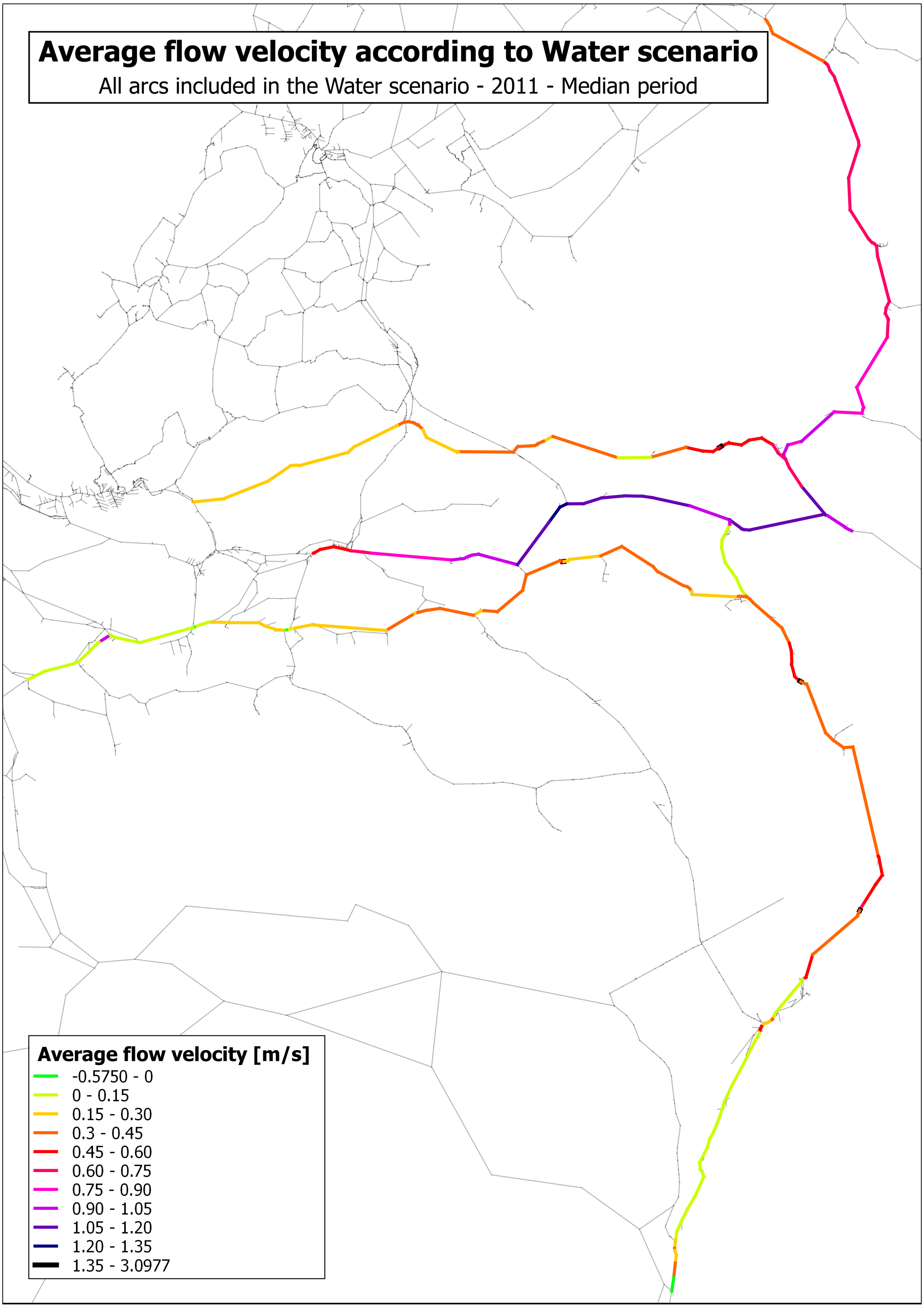


Figure H.23: Water scenario 2011; average flow velocities of median discharge period on all arcs included in the water scenario.

H.3. CORRECTION DEPTHS NIEUWE KOPPELING LSM-BIVAS

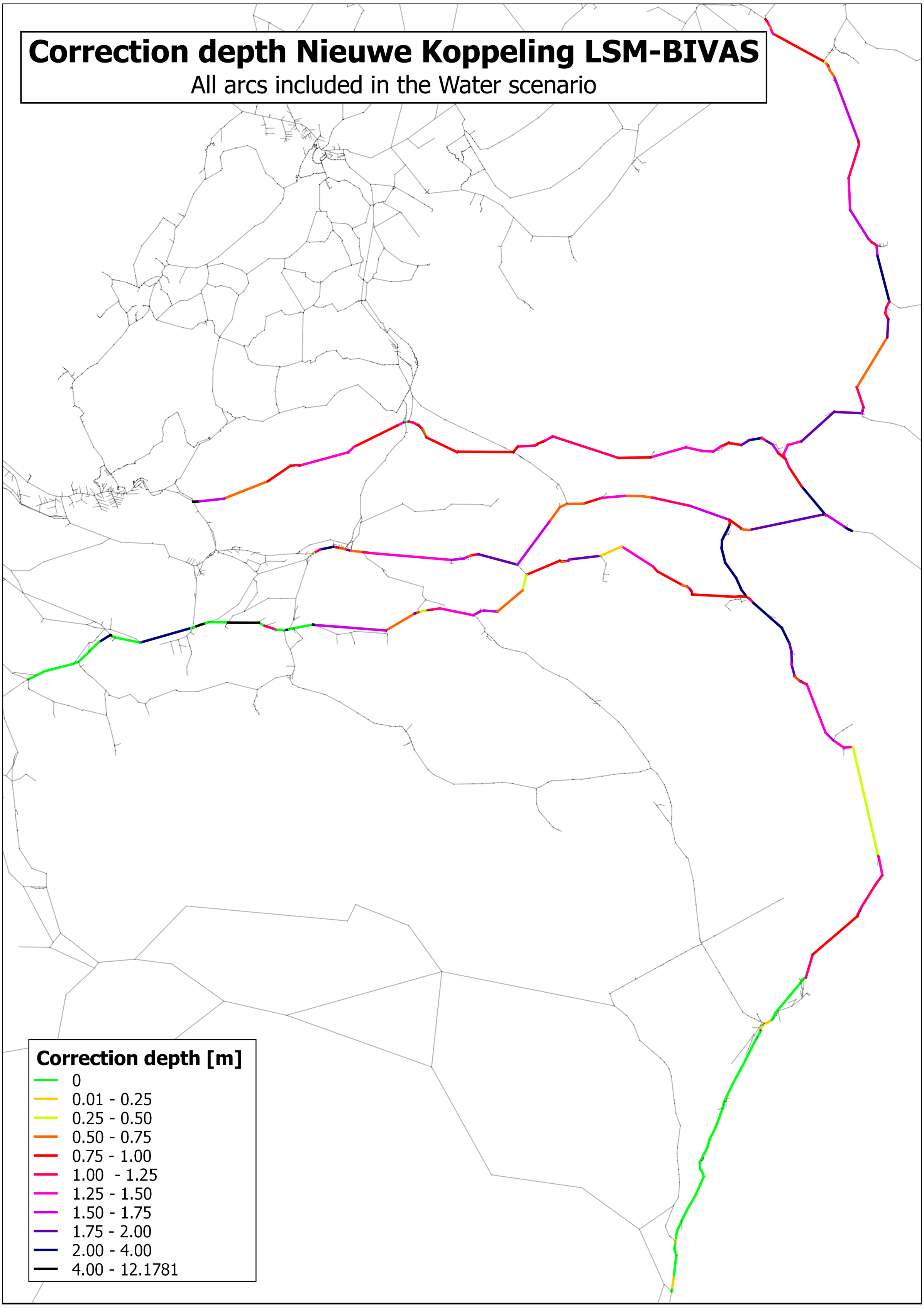


Figure H.24: Correction depths defined in Nieuwe Koppeling LSM-BIVAS; all arcs included in the water scenario.

I
RESULTS BIVAS COMPUTATIONS

I.1. RIJKSWATERSTAAT SCENARIOS

I.1.1. GLOBAL ANALYSIS

Table I.1: Rijkswaterstaat scenarios; number of trips per node and zone where origin = destination.

Traffic scenario 2011 — **Origin of trips where Origin=Destination**

BasGoed zone	Node	No. of trips
Achterhoek		
	5317	3
	5388	1
Agglomeratie Leiden en Bollenstreek		
	5227	1
	5243	4
	5463	1
	5529	1
Agglomeratie 's-Gravenhage		
	5742	1
Alkmaar en omgeving		
	3632	4
Antwerpen		
	21243	1
	21247	12
	21255	410
	21256	1
Arnhem/Nijmegen		
	5995	2
	6855	3
	6902	3
	6903	3
	6906	79
	6921	1
	6929	20
	6930	21
	7193	1
	7341	32
Delft en Westland		
	6045	2
	6070	1
Delfzijl en omgeving		
	355	1
	371	6
	385	84
	394	60
	467	2
	470	2
Flevoland		
	1155	4
	1162	1
	2077	1
	3682	11
	3693	2
	3796	2
	3800	1
	4873	2
Groot-Amsterdam		
	489	1
	1604	1
	1605	1
	1617	1
	3472	75
	3474	1
	3477	3
	3517	3
	3958	2
	4183	3
	4197	53
	4224	34
	4240	588
	4338	2
	4341	93
	5041	1

BasGoed zone	Node	No. of trips
Groot-Rijnmond		
	6093	2
	6195	2
	6199	1
	6221	3
	6269	15
	6348	1
	6415	131
	6677	2
	6685	139
	6722	1
	6729	1
	6754	3
	6765	1
	6833	24
	6847	1
	6851	2
Kop van Noord-Holland		
	723	2
	896	37
	931	3
	947	33
	1242	45
	2284	11
	2536	11
	2836	3
	3322	1
	3443	2
Midden-Limburg		
	8593	13
	8625	2
	8666	14
	8699	7
	8702	3
	8724	15
	8733	36
Midden-Noord-Brabant		
	7138	19
	7470	1
	7483	1
	7984	4
Noord-Friesland		
	195	1
	316	209
	782	1
	793	5
	1313	1
	1770	6
	1799	1
	2042	26
	2128	12
	2202	68
Noord-Limburg		
	7604	1
	7653	3
	7797	4
	8427	1
	8531	9
Noord-Oost Frankrijk		
	21087	1
	21096	2
Noordoost-Noord-Brabant		
	7283	1
	7321	3
	7378	17
	7444	3
	7525	1
	7775	1

BasGoed zone	Node	No. of trips
Noord-Overijssel		
	1512	4
	3175	1
	3450	54
	3846	2
	3895	172
Nordrhein-Westfalen-Noord		
	21400	1
Nordrhein-Westfalen-Zuidwest		
	21465	8
Oost-Zuid-Holland		
	5475	6
	5959	2
	5962	2
Overig Groningen		
	19	15
	34	5
	167	5
	177	1
	220	200
	368	55
	2051	15
Overig Noord-Duitsland		
	21523	3
	21594	1
Overig Vlaanderen		
	8852	1
	21172	3
	21181	10
	21187	1
	21358	1
Overig Zeeland		
	7665	8
	8079	1
	8158	5
	8159	1
	8296	5
	8308	420
	8314	4
	8325	15
	8336	5
	8340	1
	8366	12
	8369	3
	8379	6
	8404	1
Ruhrgebied		
	21467	1
	21468	4
	21476	1
	21480	1
	21482	1
Twente		
	4872	4
	4905	1
Utrecht		
	4840	1
	5335	1
	5610	2
	5627	11
	6030	1
	6046	8
	6106	17
	6116	13
	6174	1
	6283	1
Veluwe		
	4486	1

BasGoed zone	Node	No. of trips
Wallonie en Luxemburg		
	21239	2
	21352	1
West-Frankrijk		
	21025	176
	21053	2
	21139	1
West-Noord-Brabant		
	7459	2
	7530	2
	7550	4
	7722	1
	7739	14
	7933	1
Zaanstreek		
	496	13
	3451	2
	4096	1
	4097	1
	4107	1
	4108	1
Zeeuwsch-Vlaanderen		
	8417	3
	8442	2
	8478	3
	8498	1
	8504	9
	8524	1
	8549	1
Zuid-Duitsland		
	21478	1
	21760	1
Zuid-Frankrijk		
	21756	1
Zuid-Limburg		
	8790	9
	8853	1
Zuidoost-Friesland		
	1194	1
	2744	4
Zuidoost-Zuid-Holland		
	6968	3
	7004	1
	7062	3
	7065	2
	7073	1
	7078	1
	7262	2
	7267	2
Zuidwest-Drenthe		
	710	3
	738	1
Zuidwest-Friesland		
	559	1
	2963	1
Zuidwest-Gelderland		
	6273	1
	6549	7
	6709	2
	6732	2
	6802	3
	7171	35
	7225	1
	7266	32
Zuidwest-Overijssel		
	4932	3

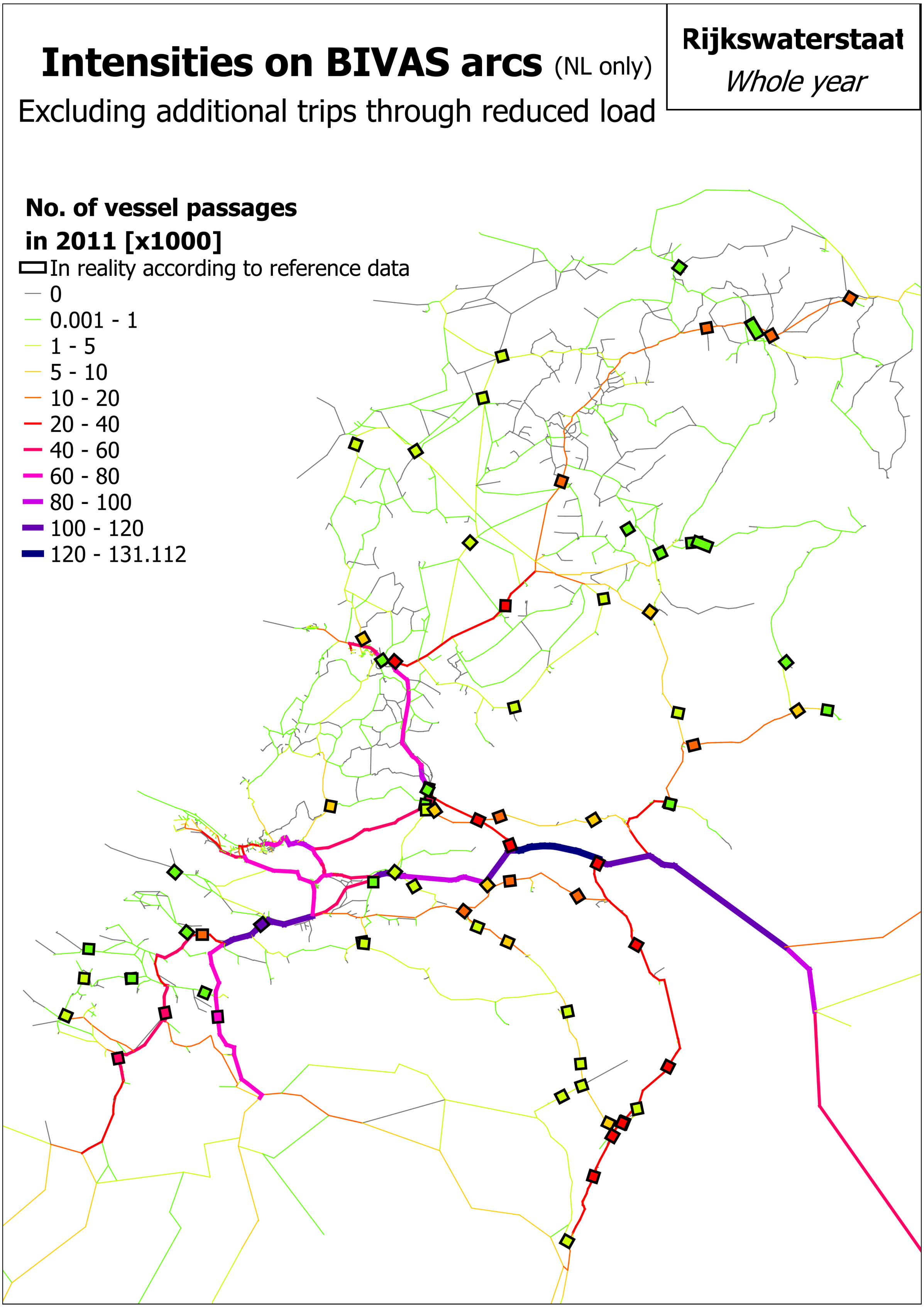


Figure I.1: Rijkswaterstaat Whole year scenario; intensities on the Dutch BIVAS network, and measured intensities in reality

I.1.2. LOCK LEVEL

Table I.2: Rijkswaterstaat scenarios; no. of passages according to the IVS90 and percentage of total no. of trips in the scenario of these passages (counting points).

Rijkswaterstaat		No. of passages in IVS90 Whole year	% of total no. of trips in scenario	Median		Low		High			No. of passages in IVS90 Whole year	% of total (empty + loaded) no. of passages	% of total no. of trips in scenario	Median			Low			High		
Hagestein, Sluis	**East**	5255	1.18%	202	1.17%	176	0.93%	154	1.07%	**Empty**	1640	31%	0.37%	51	25%	0.29%	61	35%	0.32%	36	23%	0.25%
										Loaded	3615	69%	0.81%	151	75%	0.87%	115	65%	0.61%	118	77%	0.82%
	West	2328	0.52%	87	0.50%	84	0.44%	121	0.84%	**Empty**	1307	56%	0.29%	51	59%	0.29%	63	75%	0.33%	69	57%	0.48%
										Loaded	1021	44%	0.23%	36	41%	0.21%	21	25%	0.11%	52	43%	0.36%
Amerongen, Sluis	**East**	7402	1.66%	301	1.74%	264	1.39%	205	1.42%	**Empty**	1124	15%	0.25%	51	17%	0.29%	47	18%	0.25%	51	25%	0.35%
										Loaded	6278	85%	1.41%	250	83%	1.44%	217	82%	1.14%	154	75%	1.07%
	West	4227	0.95%	138	0.80%	252	1.33%	216	1.50%	**Empty**	3688	87%	0.83%	107	78%	0.62%	242	96%	1.28%	126	58%	0.87%
										Loaded	539	13%	0.12%	31	22%	0.18%	10	4%	0.05%	90	42%	0.62%
Driel, Sluis	**East**	5821	1.31%	267	1.54%	104	0.55%	187	1.30%	**Empty**	1670	29%	0.37%	69	26%	0.40%	52	50%	0.27%	68	36%	0.47%
										Loaded	4151	71%	0.93%	198	74%	1.14%	52	50%	0.27%	119	64%	0.83%
	West	2721	0.61%	104	0.60%	87	0.46%	208	1.44%	**Empty**	1594	59%	0.36%	50	48%	0.29%	75	86%	0.40%	94	45%	0.65%
										Loaded	1127	41%	0.25%	54	52%	0.31%	12	14%	0.06%	114	55%	0.79%
Prinses Beatrixsluizen	**North**	24050	5.40%	883	5.10%	1168	6.16%	1004	6.97%	**Empty**	8128	34%	1.82%	305	35%	1.76%	321	27%	1.69%	369	37%	2.56%
										Loaded	15922	66%	3.57%	578	65%	3.34%	847	73%	4.47%	635	63%	4.41%
	South	23906	5.37%	912	5.27%	1042	5.50%	944	6.55%	**Empty**	11099	46%	2.49%	437	48%	2.52%	431	41%	2.27%	443	47%	3.08%
										Loaded	12807	54%	2.87%	475	52%	2.74%	611	59%	3.22%	501	53%	3.48%
Prinses Irenesluis	**North**	17345	3.89%	675	3.90%	807	4.26%	403	2.80%	**Empty**	8270	48%	1.86%	297	44%	1.72%	476	59%	2.51%	160	40%	1.11%
										Loaded	9075	52%	2.04%	378	56%	2.18%	331	41%	1.75%	243	60%	1.69%
	South	18720	4.20%	732	4.23%	878	4.63%	496	3.44%	**Empty**	5242	28%	1.18%	242	33%	1.40%	232	26%	1.22%	171	34%	1.19%
										Loaded	13478	72%	3.03%	490	67%	2.83%	646	74%	3.41%	325	66%	2.26%
Prins Bernhardsluis	**North**	17414	3.91%	690	3.99%	810	4.27%	348	2.42%	**Empty**	6803	39%	1.53%	268	39%	1.55%	393	49%	2.07%	111	32%	0.77%
										Loaded	10611	61%	2.38%	422	61%	2.44%	417	51%	2.20%	237	68%	1.65%
	South	18696	4.20%	712	4.11%	1005	5.30%	428	2.97%	**Empty**	6857	37%	1.54%	296	42%	1.71%	349	35%	1.84%	174	41%	1.21%
										Loaded	11839	63%	2.66%	416	58%	2.40%	656	65%	3.46%	254	59%	1.76%
Grote Sluis, Vianen	**North**	1670	0.37%	69	0.40%	27	0.14%	75	0.52%	**Empty**	1414	85%	0.32%	62	90%	0.36%	24	89%	0.13%	58	77%	0.40%
										Loaded	256	15%	0.06%	7	10%	0.04%	3	11%	0.02%	17	23%	0.12%
	South	1485	0.33%	71	0.41%	30	0.16%	75	0.52%	**Empty**	382	26%	0.09%	22	31%	0.13%	7	23%	0.04%	12	16%	0.08%
										Loaded	1103	74%	0.25%	49	69%	0.28%	23	77%	0.12%	63	84%	0.44%
Grote Merwedesluis	**North**	2448	0.55%	100	0.58%	82	0.43%	93	0.65%	**Empty**	1217	50%	0.27%	51	51%	0.29%	29	35%	0.15%	53	57%	0.37%
										Loaded	1231	50%	0.28%	49	49%	0.28%	53	65%	0.28%	40	43%	0.28%
	South	2205	0.49%	100	0.58%	83	0.44%	102	0.71%	**Empty**	1555	71%	0.35%	70	70%	0.40%	77	93%	0.41%	49	48%	0.34%
										Loaded	650	29%	0.15%	30	30%	0.17%	6	7%	0.03%	53	52%	0.37%

Table I.3: Rijkswaterstaat scenarios; no. of passages in BIVAS and ratio between the passages in BIVAS and the passages according to the IVS90 (counting points).

Rijkswaterstaat		No. of passages in BIVAS - No. of passages in BIVAS/ No. of passages in IVS90: Whole year		Median		Low		High	
Hagestein, Sluis	**East**	11129	2.12	392	1.94	502	2.85	355	2.31
Hagestein, Sluis	**West**	1958	0.84	73	0.84	76	0.90	66	0.55
Amerongen, Sluis	**East**	7644	1.03	252	0.84	404	1.53	205	1.00
Amerongen, Sluis	**West**	3054	0.72	102	0.74	200	0.79	65	0.30
Driel, Sluis	**East**	6259	1.08	221	0.83	260	2.50	181	0.97
Driel, Sluis	**West**	1809	0.66	81	0.78	56	0.64	49	0.24
Prinses Beatrixsluizen	**North**	23453	0.98	870	0.99	987	0.85	944	0.94
Prinses Beatrixsluizen	**South**	24149	1.01	934	1.02	950	0.91	897	0.95
Prinses Irenesluis	**North**	17420	1.00	719	1.07	829	1.03	450	1.12
Prinses Irenesluis	**South**	19345	1.03	730	1.00	938	1.07	558	1.13
Prins Bernhardsluis	**North**	17051	0.98	714	1.03	777	0.96	429	1.23
Prins Bernhardsluis	**South**	23931	1.28	922	1.29	1135	1.13	705	1.65
Grote Sluis, Vianen	**North**	1046	0.63	43	0.62	45	1.67	34	0.45
Grote Sluis, Vianen	**South**	970	0.65	36	0.51	45	1.50	31	0.41
Grote Merwedesluis	**North**	1670	0.68	72	0.72	74	0.90	54	0.58
Grote Merwedesluis	**South**	1625	0.74	61	0.61	73	0.88	60	0.59

Rijkswaterstaat			No. of passages in BIVAS - % of total (empty + Loaded) no. of passages - No. of passages in BIVAS/ No. of passages in IVS90: Whole year			Median			Low			High		
Hagestein, Sluis	**East**	**Empty**	1374	12%	0.84	38	10%	0.75	51	10%	0.84	30	8%	0.83
		Loaded	9755	88%	2.70	354	90%	2.34	451	90%	3.92	325	92%	2.75
Hagestein, Sluis	**West**	**Empty**	745	38%	0.57	32	44%	0.63	39	51%	0.62	28	42%	0.41
		Loaded	1213	62%	1.19	41	56%	1.14	37	49%	1.76	38	58%	0.73
Amerongen, Sluis	**East**	**Empty**	385	5%	0.34	23	9%	0.45	14	3%	0.30	8	4%	0.16
		Loaded	7259	95%	1.16	229	91%	0.92	390	97%	1.80	197	96%	1.28
Amerongen, Sluis	**West**	**Empty**	2745	90%	0.74	84	82%	0.79	191	96%	0.79	58	89%	0.46
		Loaded	309	10%	0.57	18	18%	0.58	9	5%	0.90	7	11%	0.08
Driel, Sluis	**East**	**Empty**	927	15%	0.56	37	17%	0.54	25	10%	0.48	22	12%	0.32
		Loaded	5332	85%	1.28	184	83%	0.93	235	90%	4.52	159	88%	1.34
Driel, Sluis	**West**	**Empty**	692	38%	0.43	32	40%	0.64	31	55%	0.41	18	37%	0.19
		Loaded	1117	62%	0.99	49	60%	0.91	25	45%	2.08	31	63%	0.27
Prinses Beatrixsluizen	**North**	**Empty**	7778	33%	0.96	282	32%	0.92	325	33%	1.01	336	36%	0.91
		Loaded	15675	67%	0.98	588	68%	1.02	662	67%	0.78	608	64%	0.96
Prinses Beatrixsluizen	**South**	**Empty**	11457	47%	1.03	456	49%	1.04	431	45%	1.00	456	51%	1.03
		Loaded	12692	53%	0.99	478	51%	1.01	519	55%	0.85	441	49%	0.88
Prinses Irenesluis	**North**	**Empty**	8483	49%	1.03	310	43%	1.04	479	58%	1.01	198	44%	1.24
		Loaded	8937	51%	0.98	409	57%	1.08	350	42%	1.06	252	56%	1.04
Prinses Irenesluis	**South**	**Empty**	4795	25%	0.91	217	30%	0.90	185	20%	0.80	148	27%	0.87
		Loaded	14550	75%	1.08	513	70%	1.05	753	80%	1.17	410	73%	1.26
Prins Bernhardsluis	**North**	**Empty**	7055	41%	1.04	276	39%	1.03	372	48%	0.95	168	39%	1.51
		Loaded	9996	59%	0.94	438	61%	1.04	405	52%	0.97	261	61%	1.10
Prins Bernhardsluis	**South**	**Empty**	6732	28%	0.98	287	31%	0.97	288	25%	0.83	201	29%	1.16
		Loaded	17199	72%	1.45	635	69%	1.53	847	75%	1.29	504	71%	1.98
Grote Sluis, Vianen	**North**	**Empty**	808	77%	0.57	37	86%	0.60	33	73%	1.38	24	71%	0.41
		Loaded	238	23%	0.93	6	14%	0.86	12	27%	4.00	10	29%	0.59
Grote Sluis, Vianen	**South**	**Empty**	197	20%	0.52	7	19%	0.32	11	24%	1.57	9	29%	0.75
		Loaded	773	80%	0.70	29	81%	0.59	34	76%	1.48	22	71%	0.35
Grote Merwedesluis	**North**	**Empty**	617	37%	0.51	28	39%	0.55	28	38%	0.97	21	39%	0.40
		Loaded	1053	63%	0.86	44	61%	0.90	46	62%	0.87	33	61%	0.83
Grote Merwedesluis	**South**	**Empty**	1346	83%	0.87	53	87%	0.76	59	81%	0.77	44	73%	0.90
		Loaded	279	17%	0.43	8	13%	0.27	14	19%	2.33	16	27%	0.30

I.1.3. ROUTE LEVEL

Table I.4: Rijkswaterstaat scenarios; no. of passages according to the IVS90, in BIVAS and tha ratio between them (remarkable routes)

Rijkswaterstaat	**Whole year** No. of passages in IVS90	No. of passages in BIVAS	No. of passages in BIVAS/ No. of passages in IVS90	**Median**			**Low**			**High**				**Whole year** No. of passages in BIVAS	No. of passages in IVS90	No. of passages in BIVAS/ No. of passages in IVS90	**Median**			**Low**			**High**		
Prinses Irenesluis - Prins Bernhardsluis	14456	15854	1.10	592	632	1.07	650	747	1.15	349	469	1.34	**Empty**	4146	4503	1.09	200	202	1.01	181	180	0.99	110	137	1.25
													Loaded	10310	11351	1.10	392	430	1.10	469	567	1.21	239	332	1.39
Prins Bernhardsluis - Prinses Irenesluis	14073	15308	1.09	586	649	1.11	629	699	1.11	275	392	1.43	**Empty**	5929	6791	1.15	243	267	1.10	333	260	0.78	90	164	1.82
													Loaded	8144	8517	1.05	343	382	1.11	296	339	1.15	185	228	1.23
Hagestein, Sluis - Amerongen, Sluis - Driel, Sluis	2839	3537	1.25	129	130	1.01	46	151	3.28	63	106	1.68	**Empty**	370	128	0.35	13	6	0.46	13	7	0.54	7	0	-
													Loaded	2469	3409	1.38	116	124	1.07	33	144	4.36	56	106	1.89
Hagestein, Sluis - Prins Bernhardsluis	796	6147	7.72	26	216	8.31	63	297	4.71	7	180	25.71	**Empty**	491	535	1.09	23	20	0.87	32	29	0.91	4	10	2.50
													Loaded	305	5612	18.4	3	196	65.3	31	268	8.65	3	170	56.7

I.2. WATER SCENARIO LSM

Table I.5: Water scenario LSM scenarios; growth/shrinkage relative to Rijkswaterstaat scenario, per counting point and direction.

Water scenario LSM		Growth/shrinkage relative to Base scenario *No. of passages and percentage*																
		Whole year		**Median**		**Low**		**High**			**Whole year**		**Median**		**Low**		**High**	
Hagestein, Sluis	**East**	+3198	+29%	+159	+41%	-40	-8%	-249	-70%	**Empty**	-48	-3%	-2	-5%	-3	-6%	-6	-20%
										Loaded	+3246	+33%	+161	+45%	-37	-8%	-243	-75%
	West	-232	-12%	-10	-14%	-16	-21%	+17	+26%	**Empty**	-10	-1%	-1	-3%	-2	-5%	+2	+7%
										Loaded	-222	-18%	-9	-22%	-14	-38%	+15	+39%
Amerongen, Sluis	**East**	+2206	+29%	+53	+21%	-57	-14%	-16	-8%	**Empty**	+13	+3%	-	-	+1	+7%	-	-
										Loaded	+2193	+30%	+53	+23%	-58	-15%	-16	-8%
	West	-102	-3%	-1	-1%	-6	-3%	+21	+32%	**Empty**	-56	-2%	-1	-1%	-	-	+1	+2%
										Loaded	-46	-15%	-	-	-6	-67%	+20	+286%
Driel, Sluis	**East**	+1867	+30%	+48	+22%	-66	-25%	-19	-10%	**Empty**	+5	+1%	-	-	-	-	-	-
										Loaded	+1862	+35%	+48	+26%	-66	-28%	-19	-12%
	West	-439	-24%	-6	-7%	-15	-27%	+18	+37%	**Empty**	-61	-9%	-1	-3%	-1	-3%	+1	+6%
										Loaded	-378	-34%	-5	-10%	-14	-56%	+17	+55%
Prinses Beatrixsluizen	**North**	+3230	+14%	+73	+8%	+175	+18%	+420	+44%	**Empty**	+72	+1%	+1	+0.4%	+5	+2%	-6	-2%
										Loaded	+3158	+20%	+72	+12%	+170	+26%	+426	+70%
	South	+1388	+6%	+60	+6%	+117	+12%	+16	+2%	**Empty**	+23	+0.2%	+1	+0.2%	+7	+2%	-2	-0.4%
										Loaded	+1365	+11%	+59	+12%	+110	+21%	+18	+4%
Prinses Irenesluis	**North**	-481	-3%	-67	-9%	+50	+6%	-12	-3%	**Empty**	-118	-1%	-2	-1%	-2	-0.4%	-4	-2%
										Loaded	-363	-4%	-65	-16%	+52	+15%	-8	-3%
	South	+39	+0.2%	-48	-7%	-12	-1%	+410	+73%	**Empty**	-51	-1%	-3	-1%	+1	+1%	-	-
										Loaded	+90	+1%	-45	-9%	-13	-2%	+410	+100%
Prins Bernhardsluis	**North**	-487	-3%	-72	-10%	+49	+6%	-16	-4%	**Empty**	-72	-1%	-2	-1%	-3	-1%	-4	-2%
										Loaded	-415	-4%	-70	-16%	+52	+13%	-12	-5%
	South	+1155	+5%	+62	+7%	+14	+1%	+177	+25%	**Empty**	-112	-2%	-5	-2%	-2	-1%	-7	-3%
										Loaded	+1267	+7%	+67	+11%	+16	+2%	+184	+37%
Grote Sluis, Vianen	**North**	-8	-1%	-	-	-	-	+2	+6%	**Empty**	-6	-1%	-	-	-1	-3%	+1	+4%
										Loaded	-2	-1%	-	-	+1	+8%	+1	+10%
	South	-15	-2%	-	-	-	-	-11	-35%	**Empty**	-7	-4%	-	-	+1	+9%	-2	-22%
										Loaded	-8	-1%	-	-	-1	-3%	-9	-41%
Grote Merwedesluis	**North**	+10	+1%	-	-	+1	+1%	+7	+13%	**Empty**	-	-	-	-	-1	-4%	+2	+10%
										Loaded	+10	+1%	-	-	+2	+4%	+5	+15%
	South	+6	+0.4%	-	-	+1	+1%	-4	-7%	**Empty**	+1	+0.1%	-	-	+1	+2%	-	-
										Loaded	+5	+2%	-	-	-	-	-4	-25%

Table I.6: Water scenario LSM scenarios; no. of passages in BIVAS/no. of passages in IVS90 compared to results for Rijkswaterstaat scenarios.

Water scenario		No. of passages in BIVAS/No. of passages in IVS90 - Rijkswaterstaat (RWS) - Water Scenario (WS) - Change relative to absolute deviation from BIVAS/IVS90=1.00 of Rijkswaterstaat scenario (CHG)																								
		Whole year			*Median*			*Low*			*High*				*Whole year*			*Median*			*Low*			*High*		
		RWS	**WS**	**CHG**	**RWS**	**WS**	**CHG**	**RWS**	**WS**	**CHG**	**RWS**	**WS**	**CHG**		**RWS**	**WS**	**CHG**	**RWS**	**WS**	**CHG**	**RWS**	**WS**	**CHG**	**RWS**	**WS**	**CHG**
Hagestein, Sluis	**East**	2.12	2.73 (↑)	+0.61	1.94	2.73 (↑)	+0.79	2.85	2.63 (↓)	-0.23	2.31	0.69 (↓)	-0.99	**Empty**	0.84	0.81 (↓)	+0.03	0.75	0.71 (↓)	+0.04	0.84	0.79 (↓)	+0.05	0.83	0.67 (↓)	+0.17
														Loaded	2.70	3.6 (↑)	+0.90	2.34	3.41 (↑)	+1.07	3.92	3.6 (↓)	-0.32	2.75	0.69 (↓)	-1.45
	West	0.84	0.74 (↓)	-0.10	0.84	0.72 (↓)	+0.11	0.90	0.71 (↓)	+0.19	0.55	0.69 (↑)	-0.14	**Empty**	0.57	0.56 (↓)	+0.01	0.63	0.61 (↓)	+0.02	0.62	0.59 (↓)	+0.03	0.41	0.43 (↑)	-0.03
														Loaded	1.19	0.97 (↓)	-0.16	1.14	0.89 (↓)	-0.03	1.76	1.1 (↓)	-0.67	0.73	1.02 (↑)	-0.25
Amerongen, Sluis	**East**	1.03	1.33 (↑)	+0.30	0.84	1.01 (↑)	-0.15	1.53	1.31 (↓)	-0.22	1.00	0.92 (↓)	+0.08	**Empty**	0.34	0.35 (↑)	-0.01	0.45	0.45 (-)	-	0.30	0.32 (↑)	-0.02	0.16	0.16 (-)	-
														Loaded	1.16	1.51 (↑)	+0.35	0.92	1.13 (↑)	+0.04	1.80	1.53 (↓)	-0.27	1.28	1.18 (↓)	-0.10
	West	0.72	0.7 (↓)	+0.02	0.74	0.73 (↓)	+0.01	0.79	0.77 (↓)	+0.02	0.30	0.4 (↑)	-0.10	**Empty**	0.74	0.73 (↓)	+0.02	0.79	0.78 (↓)	+0.01	0.79	0.79 (-)	-	0.46	0.47 (↑)	-0.01
														Loaded	0.57	0.49 (↓)	+0.09	0.58	0.58 (-)	-	0.90	0.3 (↓)	+0.60	0.08	0.3 (↑)	-0.22
Driel, Sluis	**East**	1.08	1.4 (↑)	+0.32	0.83	1.01 (↑)	-0.16	2.50	1.87 (↓)	-0.63	0.97	0.87 (↓)	+0.10	**Empty**	0.56	0.56 (↑)	-0.00	0.54	0.54 (-)	-	0.48	0.48 (-)	-	0.32	0.32 (-)	-
														Loaded	1.28	1.73 (↑)	+0.45	0.93	1.17 (↑)	+0.10	4.52	3.25 (↓)	-1.27	1.34	1.18 (↓)	-0.16
	West	0.66	0.5 (↓)	+0.16	0.78	0.72 (↓)	+0.06	0.64	0.47 (↓)	+0.17	0.24	0.32 (↑)	-0.09	**Empty**	0.43	0.4 (↓)	+0.04	0.64	0.62 (↓)	+0.02	0.41	0.4 (↓)	+0.01	0.19	0.2 (↑)	-0.01
														Loaded	0.99	0.66 (↓)	+0.34	0.91	0.81 (↓)	+0.09	2.08	0.92 (↓)	-1.00	0.27	0.42 (↑)	-0.15
Prinses Beatrixsluizen	**North**	0.98	1.11 (↑)	+0.08	0.99	1.07 (↑)	+0.05	0.85	0.99 (↑)	-0.15	0.94	1.36 (↑)	+0.30	**Empty**	0.96	0.97 (↑)	-0.01	0.92	0.93 (↑)	-0.00	1.01	1.03 (↑)	+0.02	0.91	0.89 (↓)	+0.02
														Loaded	0.98	1.18 (↑)	+0.17	1.02	1.14 (↑)	+0.12	0.78	0.98 (↑)	-0.20	0.96	1.63 (↑)	+0.59
	South	1.01	1.07 (↑)	+0.06	1.02	1.09 (↑)	+0.07	0.91	1.02 (↑)	-0.06	0.95	0.97 (↑)	-0.02	**Empty**	1.03	1.03 (↑)	+0.00	1.04	1.05 (↑)	+0.00	1.00	1.02 (↑)	+0.02	1.03	1.02 (↓)	-0.00
														Loaded	0.99	1.1 (↑)	+0.09	1.01	1.13 (↑)	+0.12	0.85	1.03 (↑)	-0.12	0.88	0.92 (↑)	-0.04
Prinses Irenesluis	**North**	1.00	0.98 (↓)	+0.02	1.07	0.97 (↓)	-0.03	1.03	1.09 (↑)	+0.06	1.12	1.09 (↓)	-0.03	**Empty**	1.03	1.01 (↓)	-0.01	1.04	1.04 (↓)	-0.01	1.01	1 (↓)	-0.00	1.24	1.21 (↓)	-0.03
														Loaded	0.98	0.94 (↓)	+0.04	1.08	0.91 (↓)	+0.01	1.06	1.21 (↑)	+0.16	1.04	1 (↓)	-0.03
	South	1.03	1.04 (↑)	+0.00	1.00	0.93 (↓)	+0.07	1.07	1.05 (↓)	-0.01	1.13	1.95 (↑)	+0.83	**Empty**	0.91	0.9 (↓)	+0.01	0.90	0.88 (↓)	+0.01	0.80	0.8 (↑)	-0.00	0.87	0.87 (-)	-
														Loaded	1.08	1.09 (↑)	+0.01	1.05	0.96 (↓)	-0.00	1.17	1.15 (↓)	-0.02	1.26	2.52 (↑)	+1.26
Prins Bernhardsluis	**North**	0.98	0.95 (↓)	+0.03	1.03	0.93 (↓)	+0.03	0.96	1.02 (↑)	-0.02	1.23	1.19 (↓)	-0.05	**Empty**	1.04	1.03 (↓)	-0.01	1.03	1.02 (↓)	-0.01	0.95	0.94 (↓)	+0.01	1.51	1.48 (↓)	-0.04
														Loaded	0.94	0.9 (↓)	+0.04	1.04	0.87 (↓)	+0.09	0.97	1.1 (↑)	+0.07	1.10	1.05 (↓)	-0.05
	South	1.28	1.34 (↑)	+0.06	1.29	1.38 (↑)	+0.09	1.13	1.14 (↑)	+0.01	1.65	2.06 (↑)	+0.41	**Empty**	0.98	0.97 (↓)	+0.02	0.97	0.95 (↓)	+0.02	0.83	0.82 (↓)	+0.01	1.16	1.11 (↓)	-0.04
														Loaded	1.45	1.56 (↑)	+0.11	1.53	1.69 (↑)	+0.16	1.29	1.32 (↑)	+0.02	1.98	2.71 (↑)	+0.72
Grote Sluis, Vianen	**North**	0.63	0.62 (↓)	+0.00	0.62	0.62 (-)	-	1.67	1.67 (-)	-	0.45	0.48 (↑)	-0.03	**Empty**	0.57	0.57 (↓)	+0.00	0.60	0.6 (-)	-	1.38	1.33 (↓)	-0.04	0.41	0.43 (↑)	-0.02
														Loaded	0.93	0.92 (↓)	+0.01	0.86	0.86 (-)	-	4.00	4.33 (↑)	+0.33	0.59	0.65 (↑)	-0.06
	South	0.65	0.64 (↓)	+0.01	0.51	0.51 (-)	-	1.50	1.5 (-)	-	0.41	0.27 (↓)	+0.15	**Empty**	0.52	0.5 (↓)	+0.02	0.32	0.32 (-)	-	1.57	1.71 (↑)	+0.14	0.75	0.58 (↓)	+0.17
														Loaded	0.70	0.69 (↓)	+0.01	0.59	0.59 (-)	-	1.48	1.43 (↓)	-0.04	0.35	0.21 (↓)	+0.14
Grote Merwedesluis	**North**	0.68	0.69 (↑)	-0.00	0.72	0.72 (-)	-	0.90	0.91 (↑)	-0.01	0.58	0.66 (↑)	-0.08	**Empty**	0.51	0.51 (-)	-	0.55	0.55 (-)	-	0.97	0.93 (↓)	+0.03	0.40	0.43 (↑)	-0.04
														Loaded	0.86	0.86 (↑)	-0.01	0.90	0.9 (-)	-	0.87	0.91 (↑)	-0.04	0.83	0.95 (↑)	-0.13
	South	0.74	0.74 (↑)	-0.00	0.61	0.61 (-)	-	0.88	0.89 (↑)	-0.01	0.59	0.55 (↓)	+0.04	**Empty**	0.87	0.87 (↑)	-0.00	0.76	0.76 (-)	-	0.77	0.78 (↑)	-0.01	0.90	0.9 (-)	-
														Loaded	0.43	0.44 (↑)	-0.01	0.27	0.27 (-)	-	2.33	2.33 (-)	-	0.30	0.23 (↓)	+0.08

J
Vessel speeds in BIVAS

J.1. CEMT Types Va and Lek

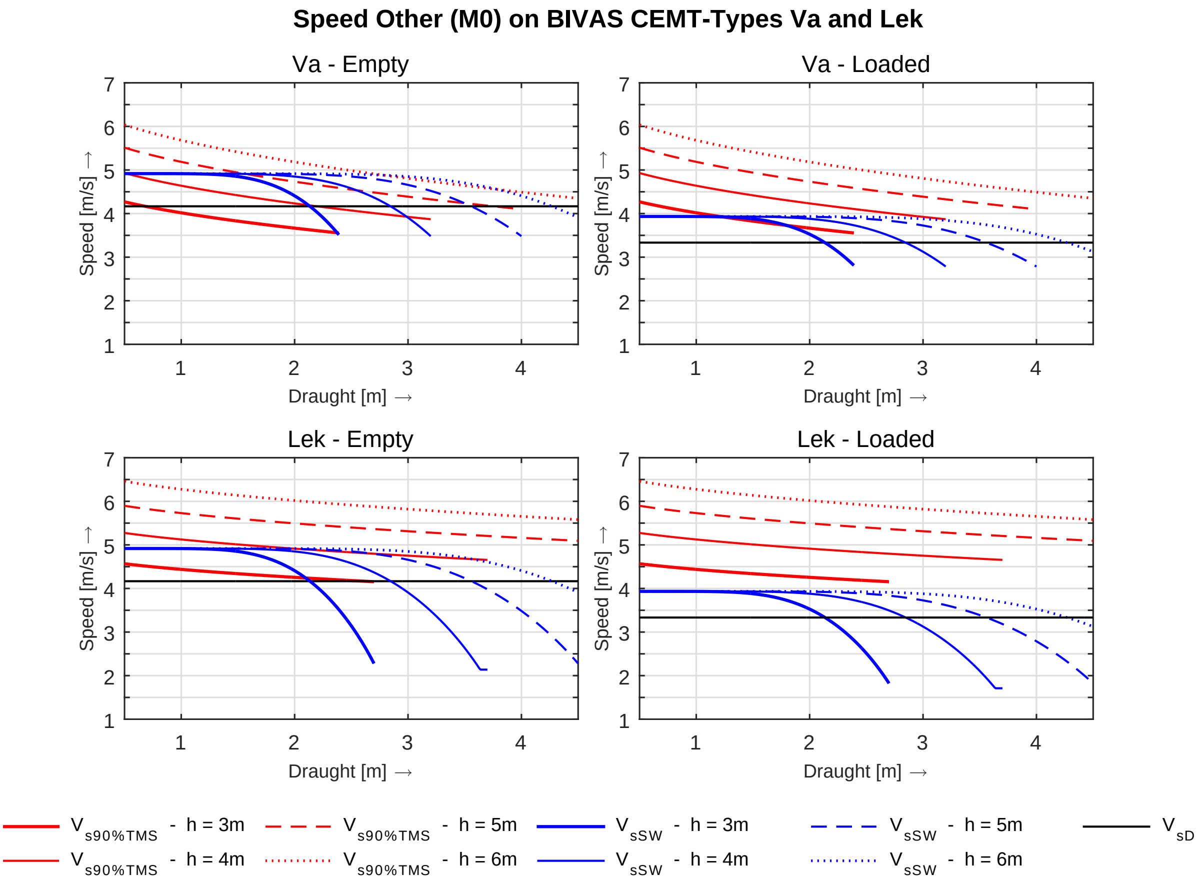


Figure J.1: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for Other vessels (M0) on BIVAS CEMT Types Va and Lek, depending on water depth and draught.

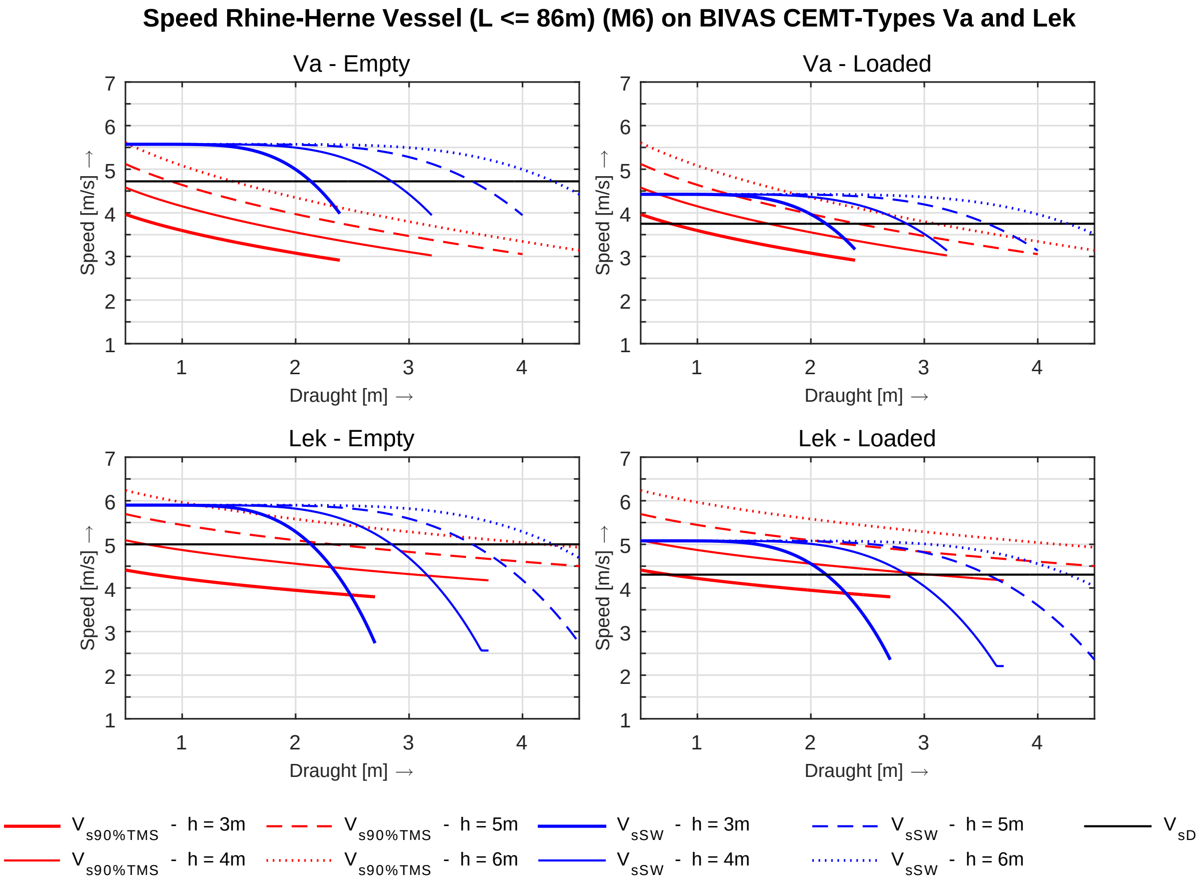


Figure J.2: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Rhine-Herne Vessel (L<=86m) (M6) on BIVAS CEMT Types Va and Lek, depending on water depth and draught.

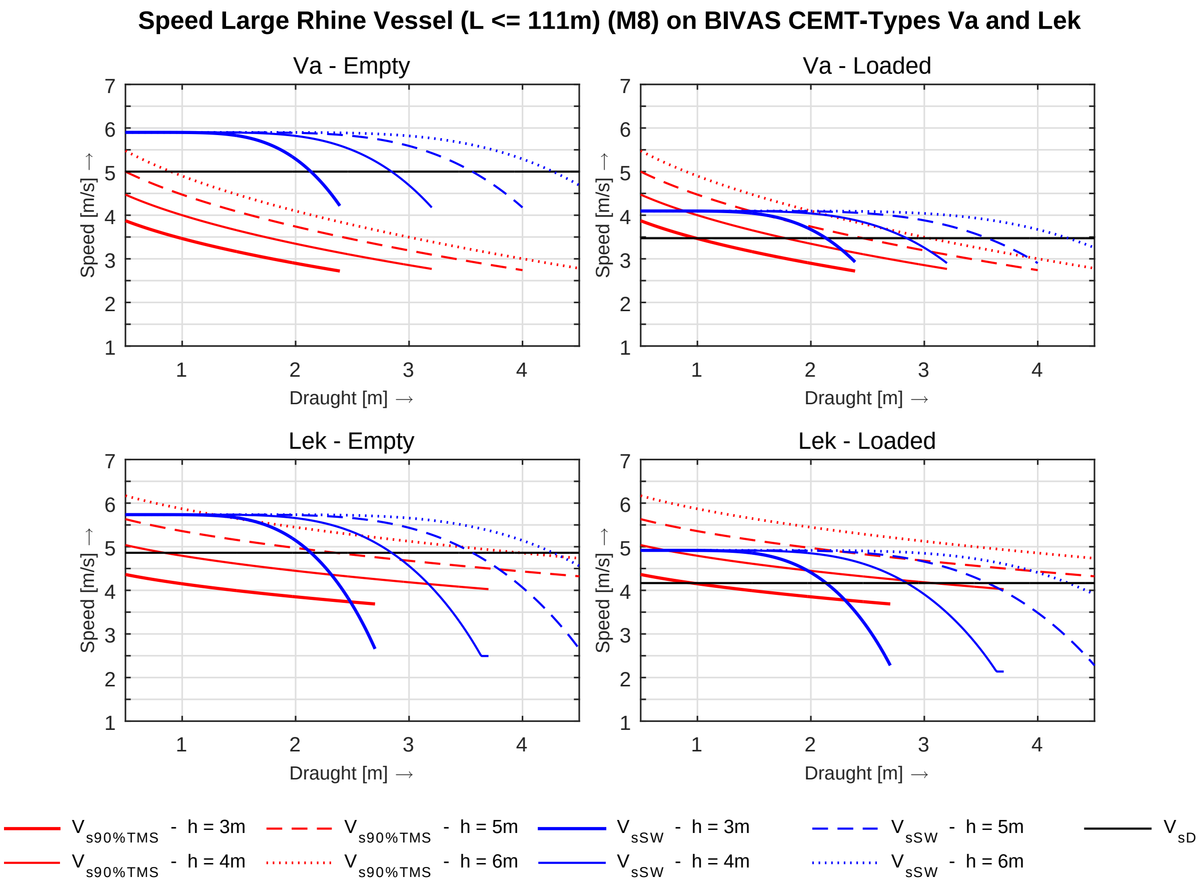


Figure J.3: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Large Rhine Vessel (L<=111m) (M8) on BIVAS CEMT Types Va and Lek, depending on water depth and draught.

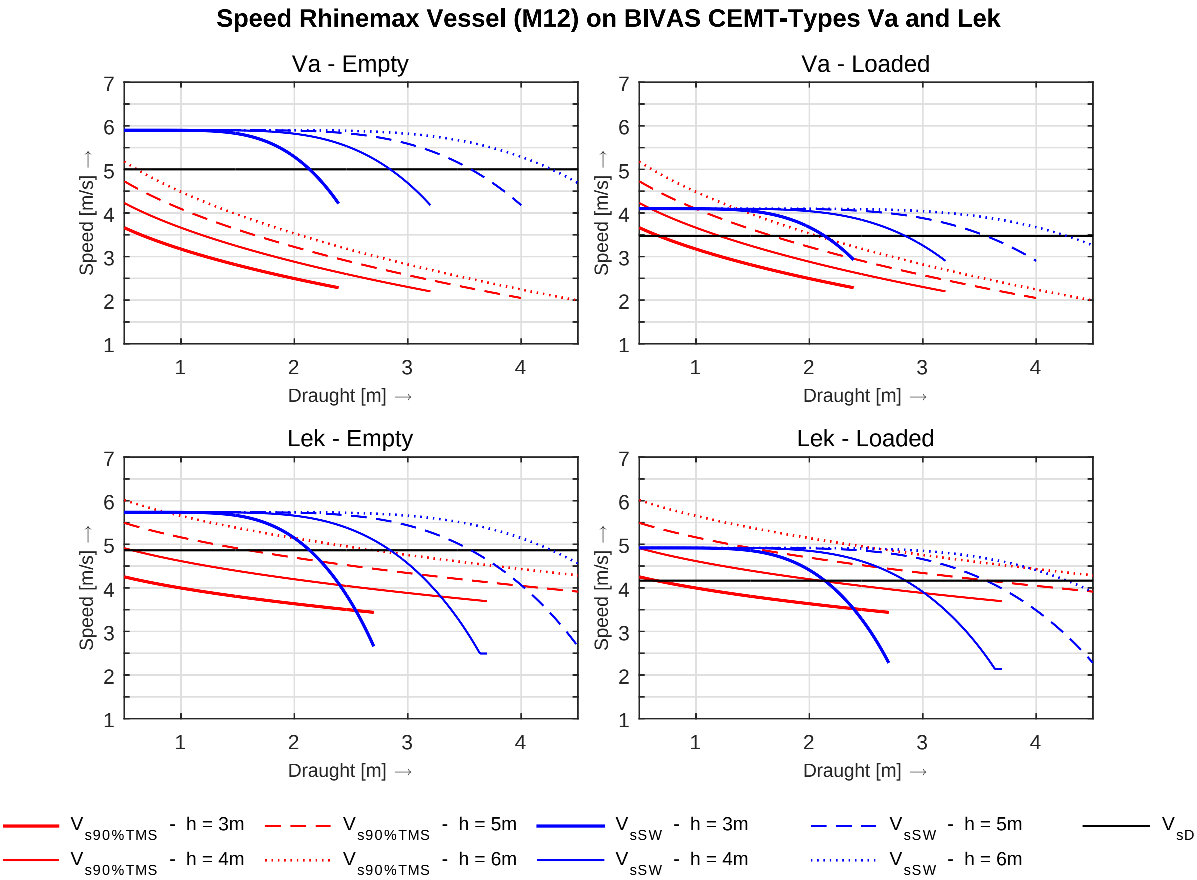


Figure J.4: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Rhinemax Vessel (M12) on BIVAS CEMT Types Va and Lek, depending on water depth and draught.

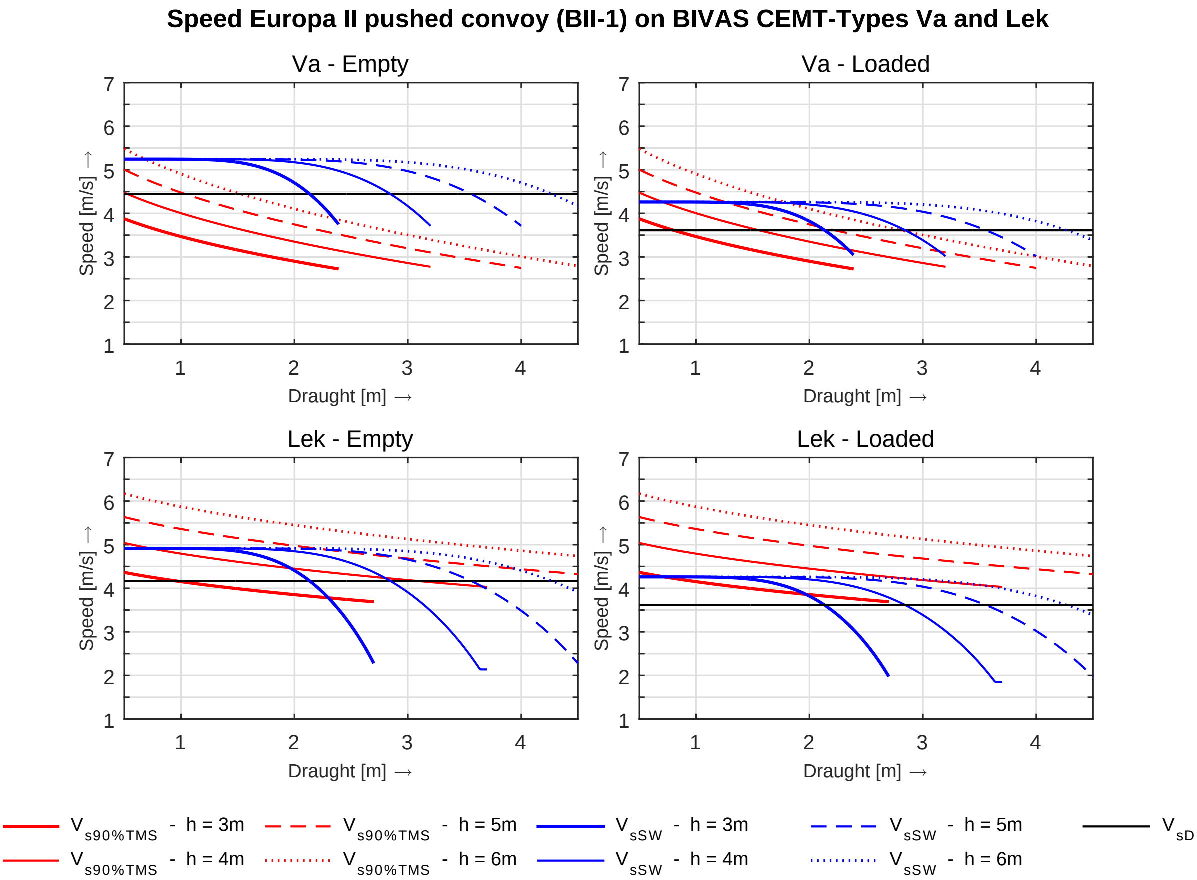


Figure J.5: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Europa II pushed convoy (BII-1)) on BIVAS CEMT Types Va and Lek, depending on water depth and draught.

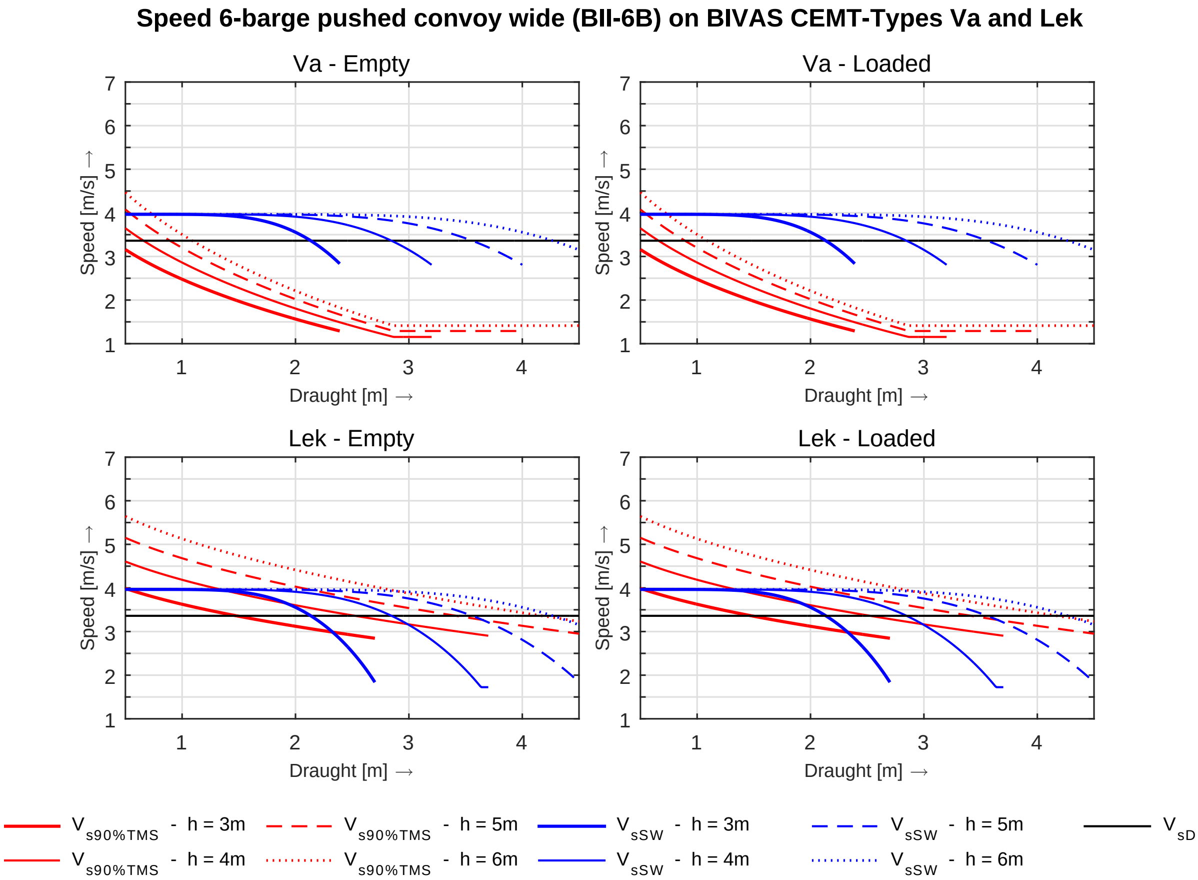


Figure J.6: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a 6-barge pushed convoy wide (BII-6B) on BIVAS CEMT Types Va and Lek, depending on water depth and draught.

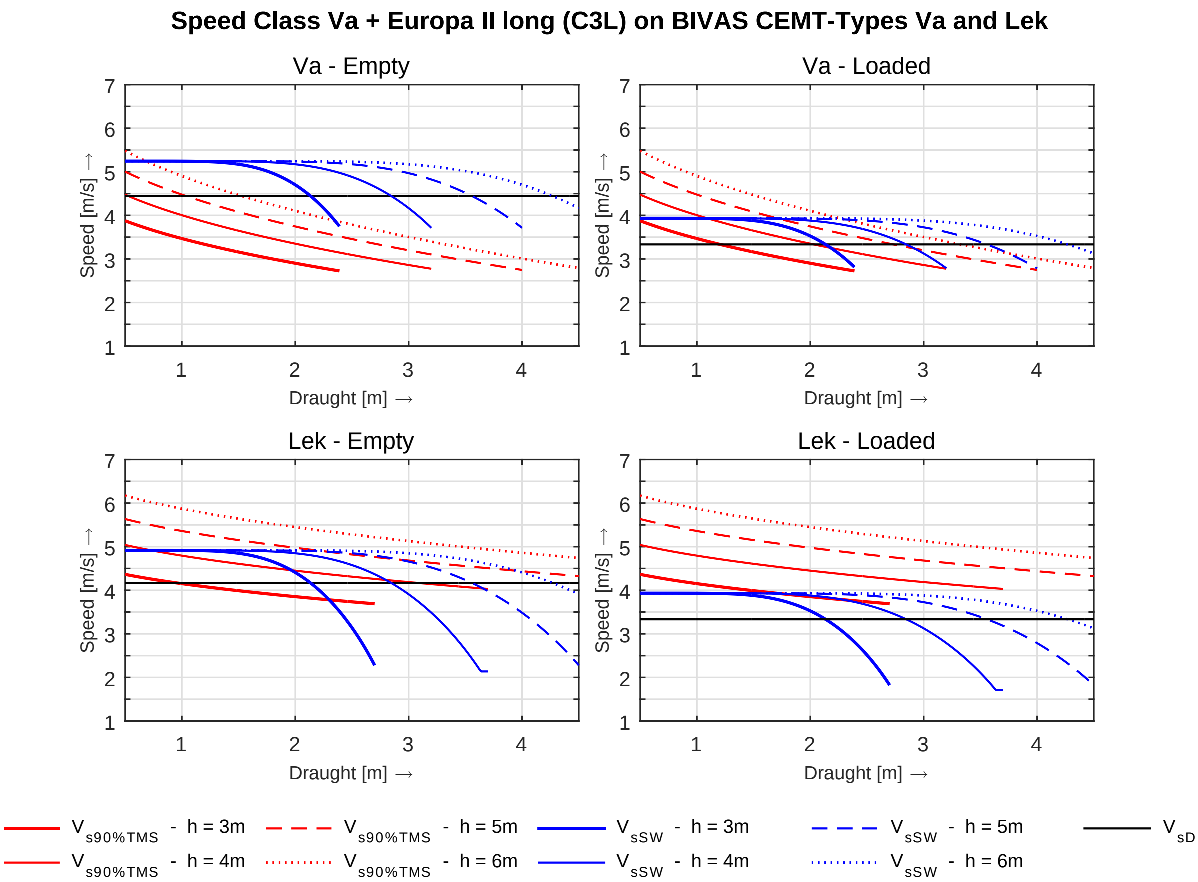


Figure J.7: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Class Va + Europa II long coupled unit (C3L) on BIVAS CEMT Types Va and Lek, depending on water depth and draught.

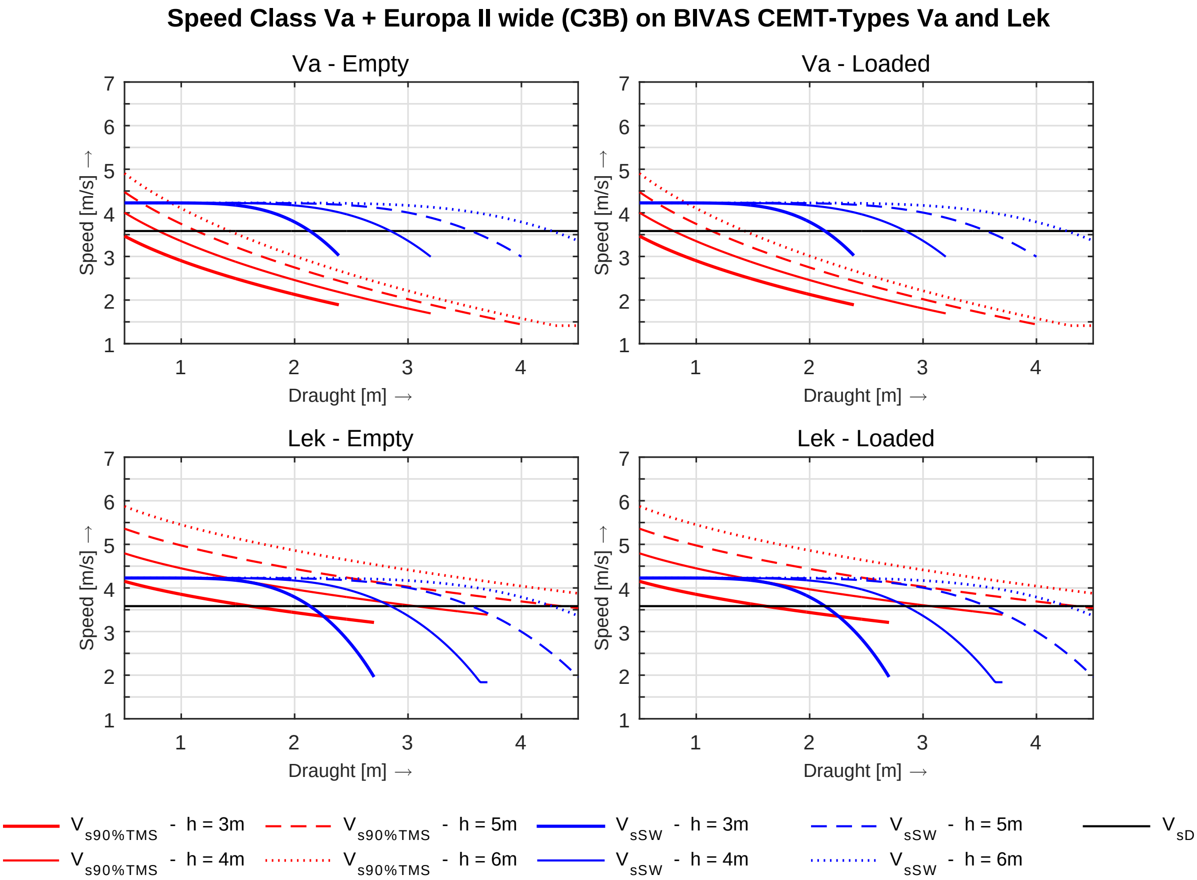


Figure J.8: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Class Va + Europa II wide (C3B) on BIVAS CEMT Types Va and Lek, depending on water depth and draught.

J.2. CEMT TYPES VIC AND WAAL

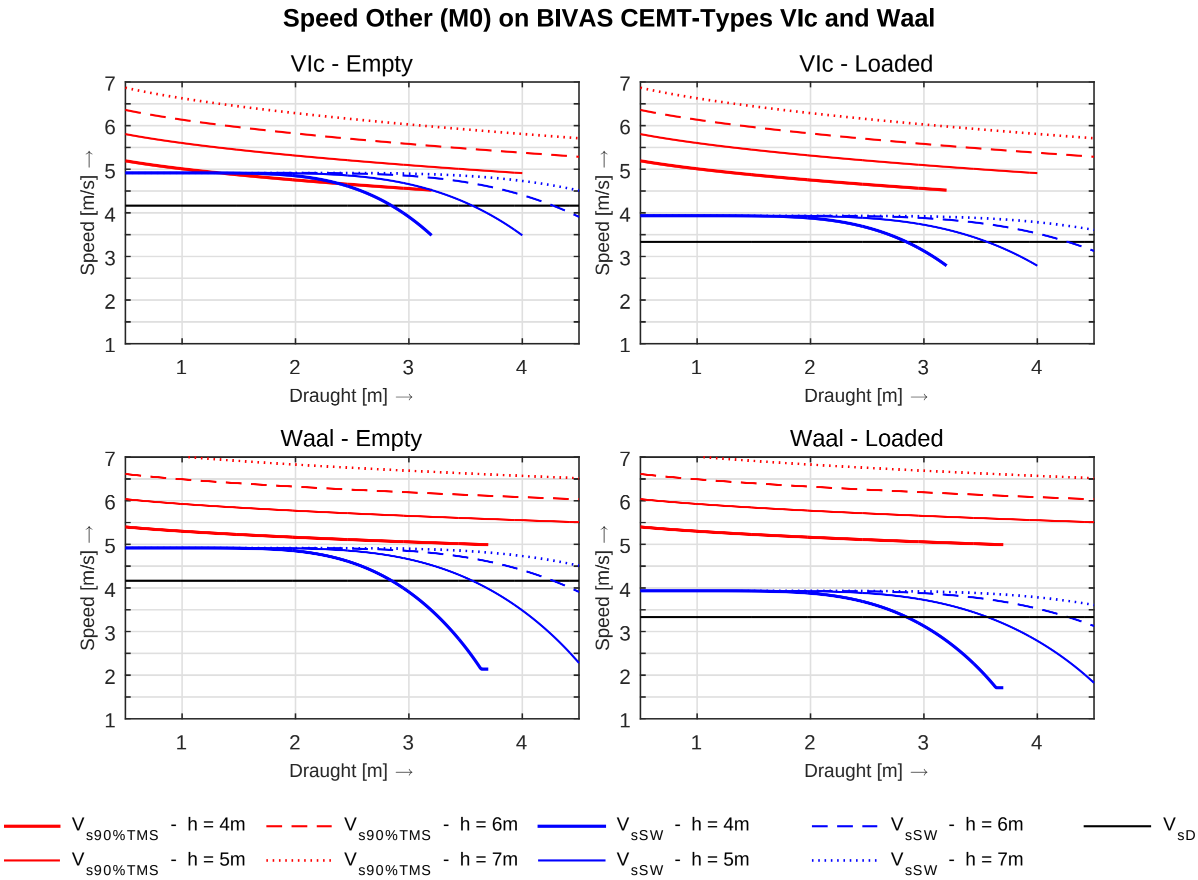


Figure J.9: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for Other vessels (M0) on BIVAS CEMT Types VIc and Waal, depending on water depth and draught.

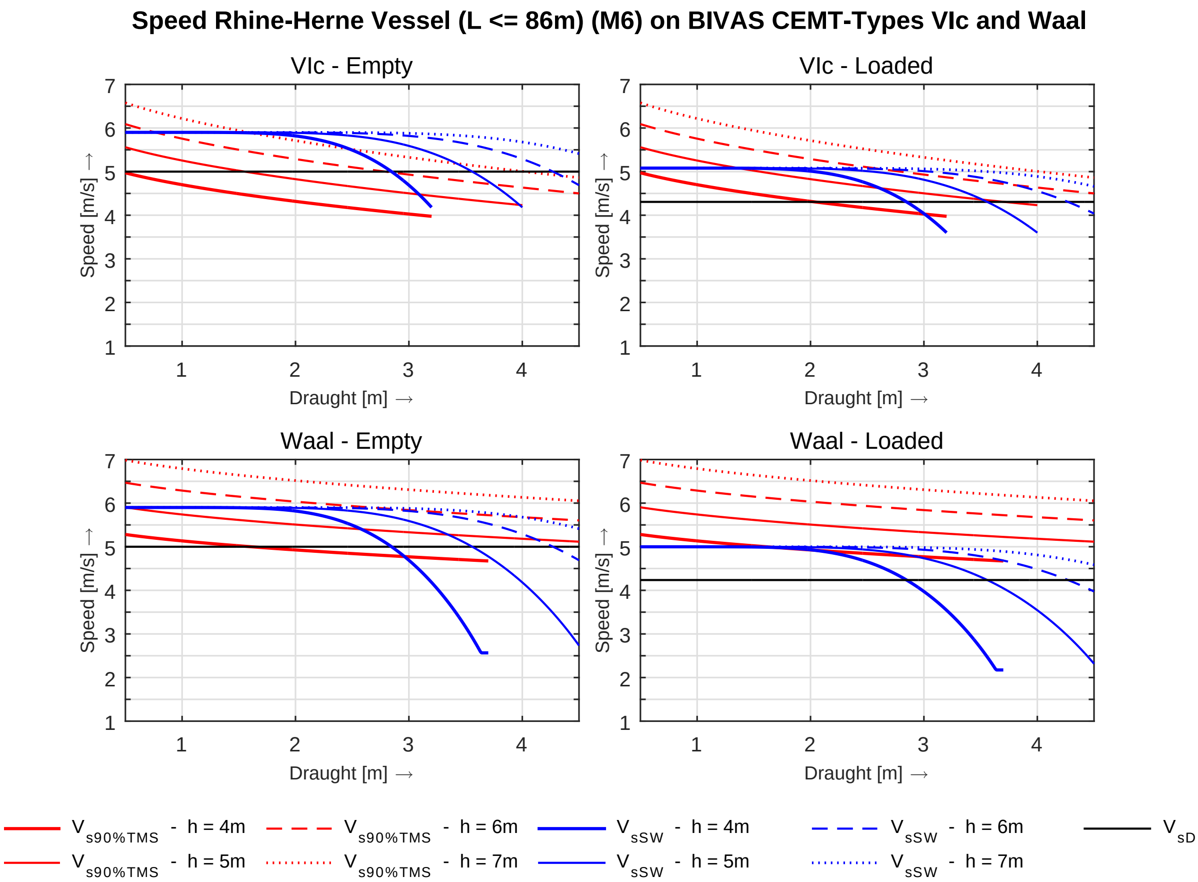


Figure J.10: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Rhine-Herne Vessel (L<=86m) (M6) on BIVAS CEMT Types VIc and Waal, depending on water depth and draught.

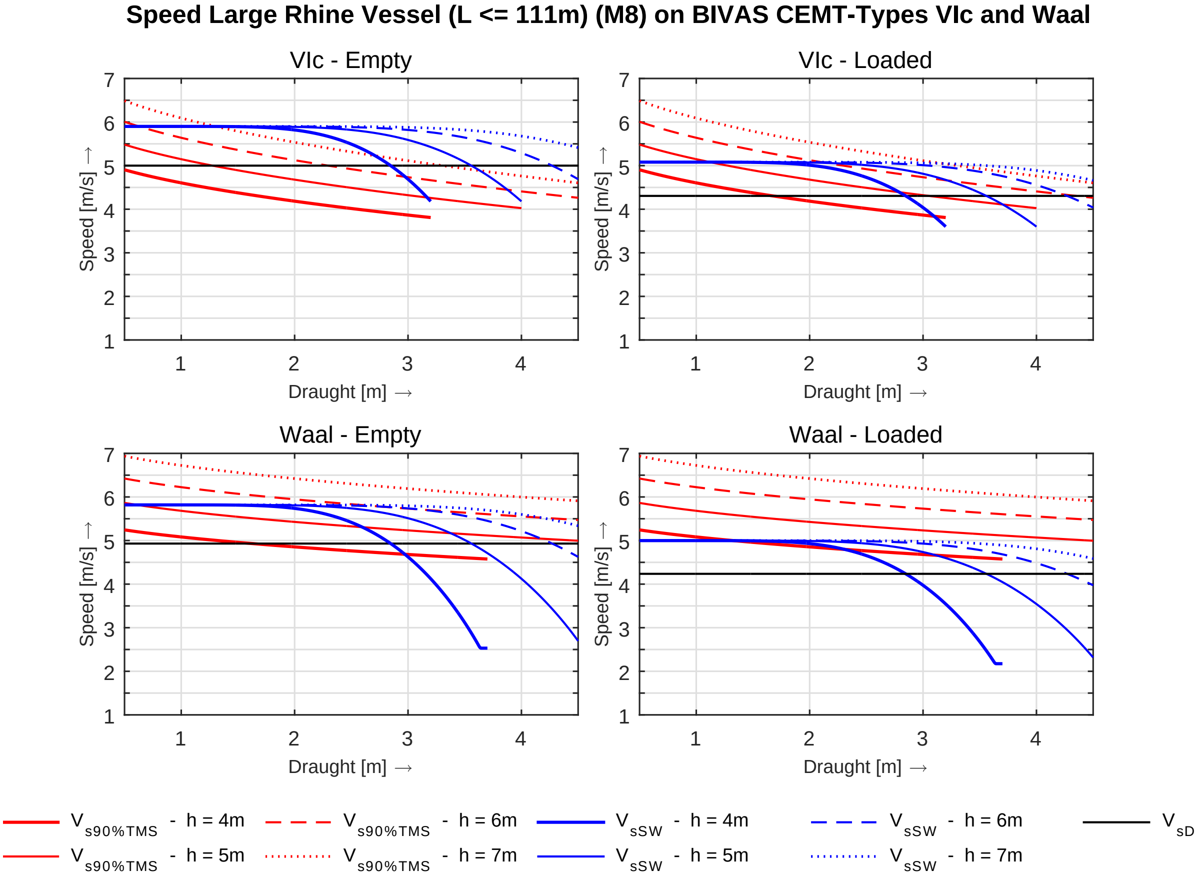


Figure J.11: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Large Rhine Vessel (L<=111m) (M8) on BIVAS CEMT Types VIc and Waal, depending on water depth and draught.

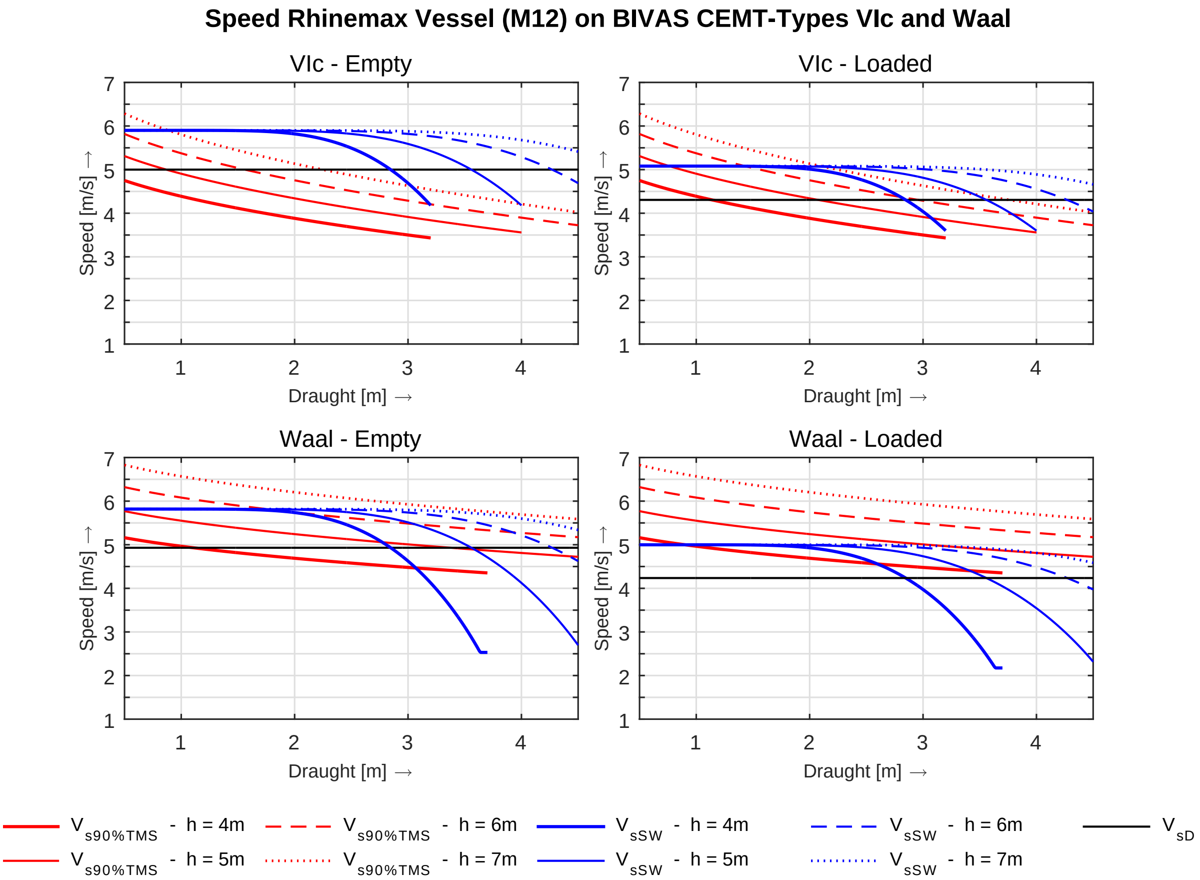


Figure J.12: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Rhinemax Vessel (M12) on BIVAS CEMT Types VIc and Waal, depending on water depth and draught.

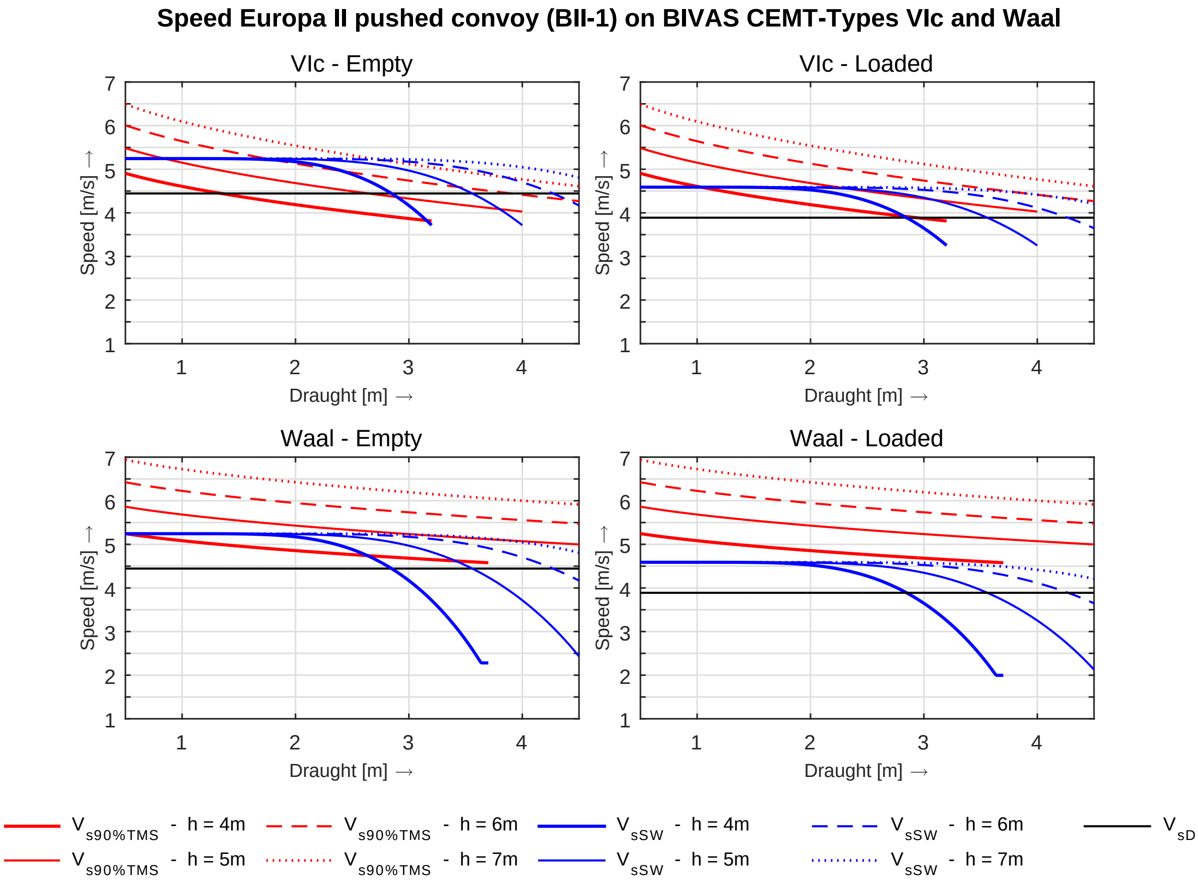


Figure J.13: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Europa II pushed convoy (BII-1)) on BIVAS CEMT Types VIc and Waal, depending on water depth and draught.

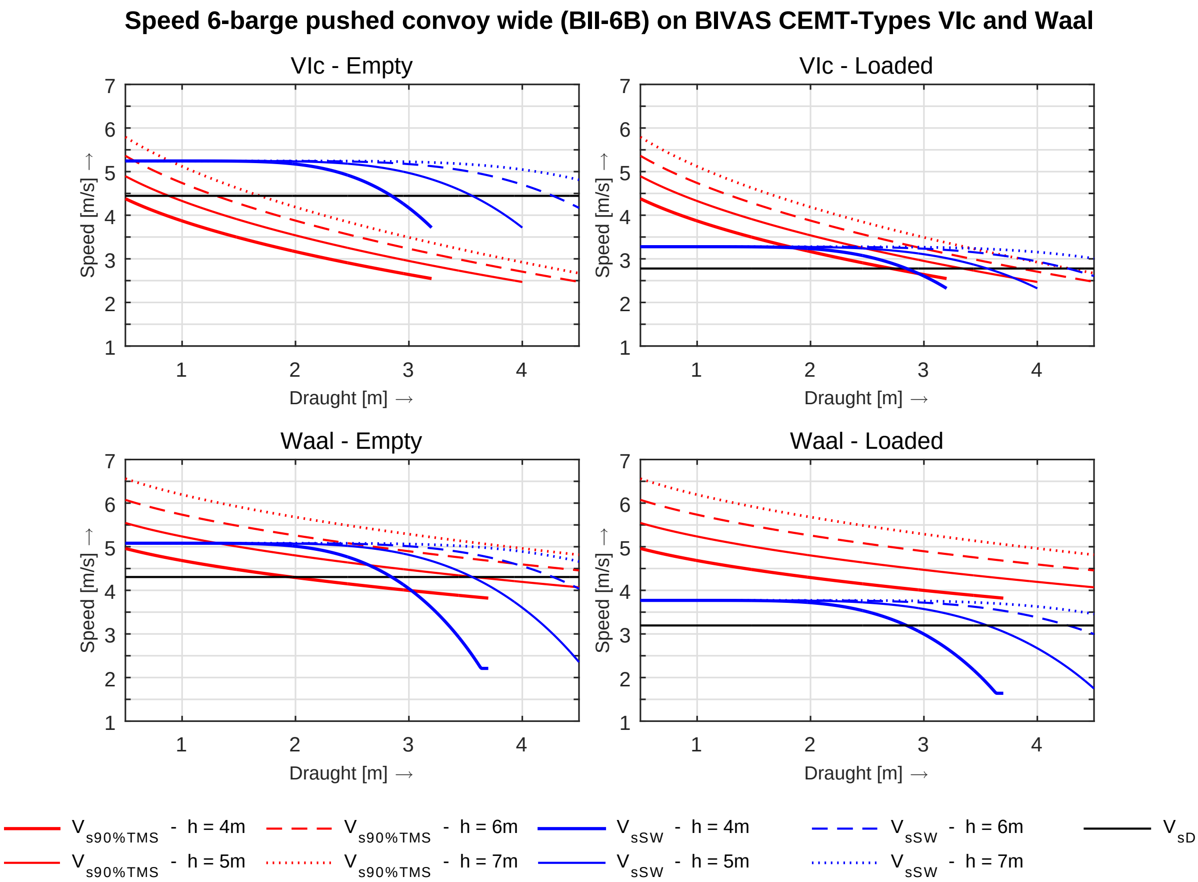


Figure J.14: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a 6-barge pushed convoy wide (BII-6B) on BIVAS CEMT Types VIc and Waal, depending on water depth and draught.

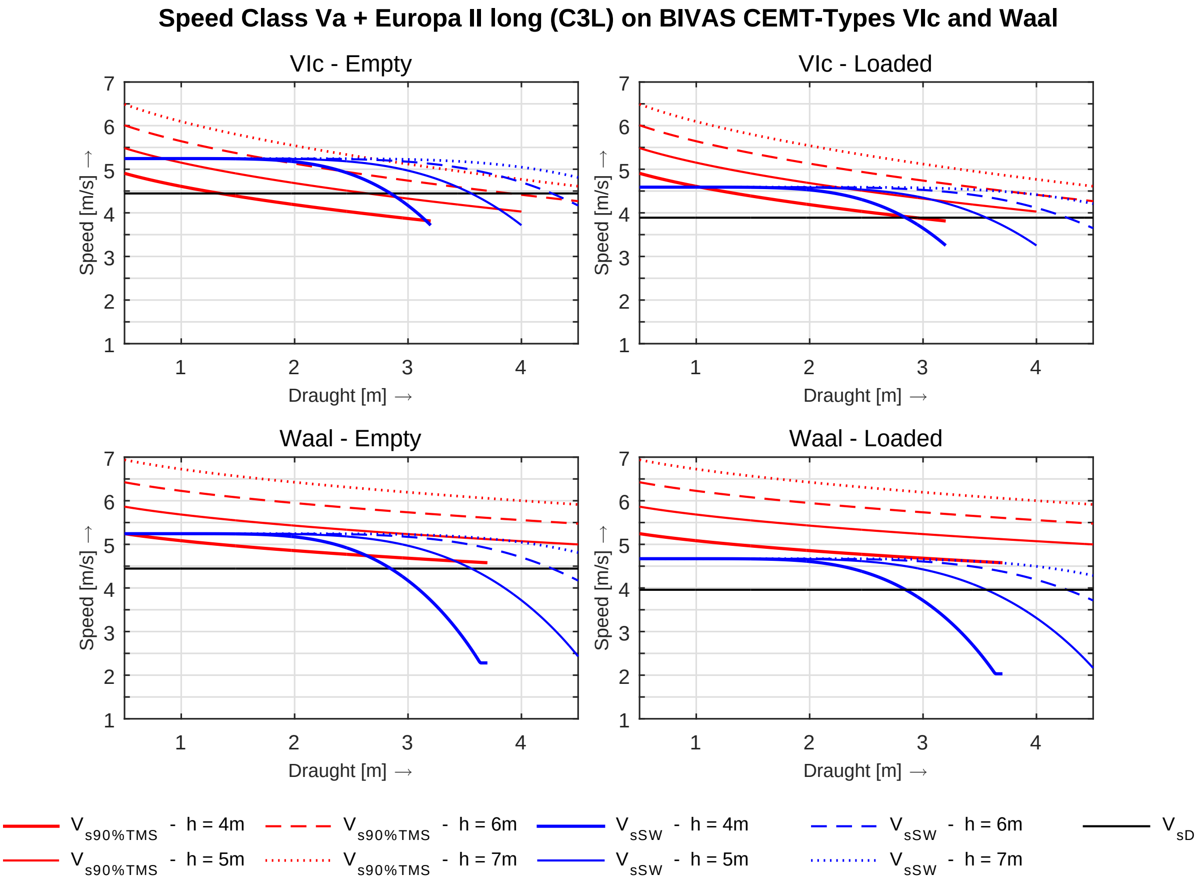


Figure J.15: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Class Va + Europa II long coupled unit (C3L) on BIVAS CEMT Types VIc and Waal, depending on water depth and draught.

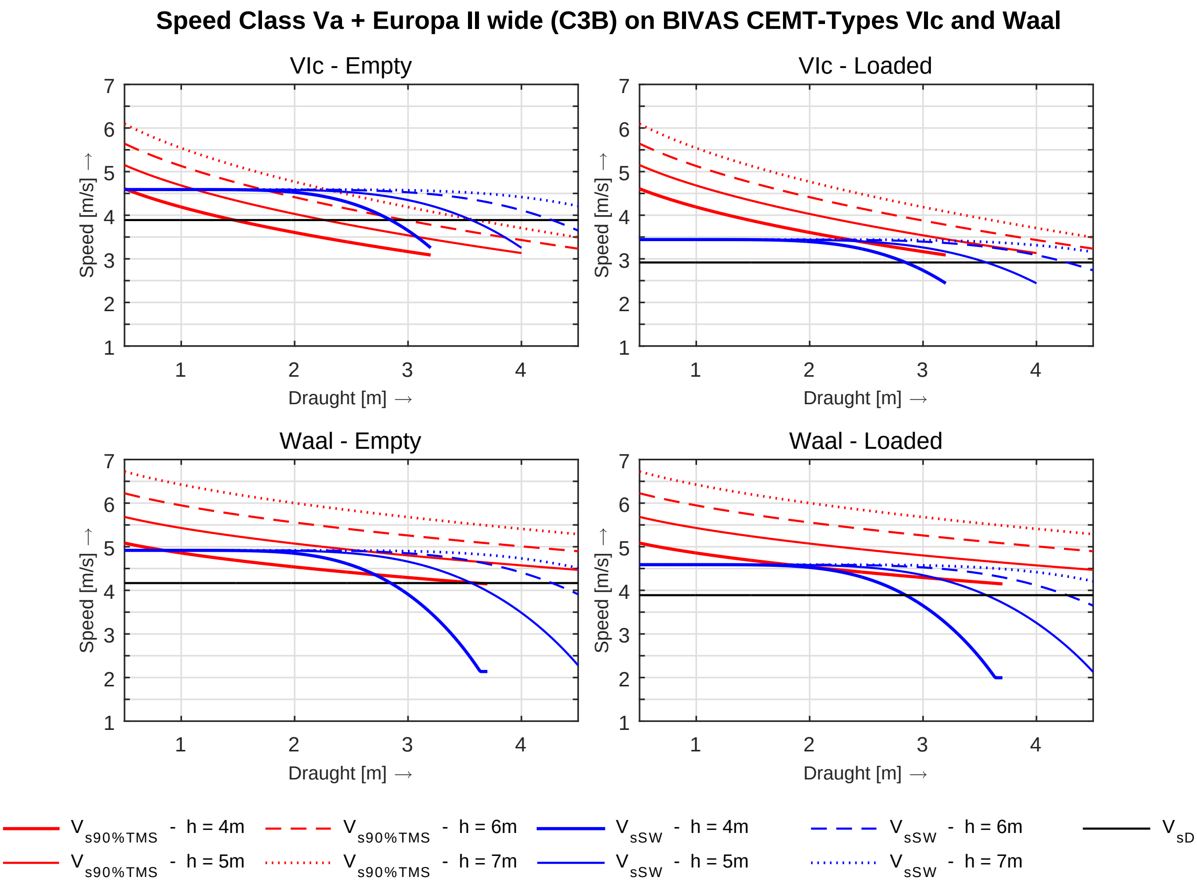


Figure J.16: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Class Va + Europa II wide (C3B) on BIVAS CEMT Types VIc and Waal, depending on water depth and draught.

J.3. CEMT TYPES VIA AND VIB

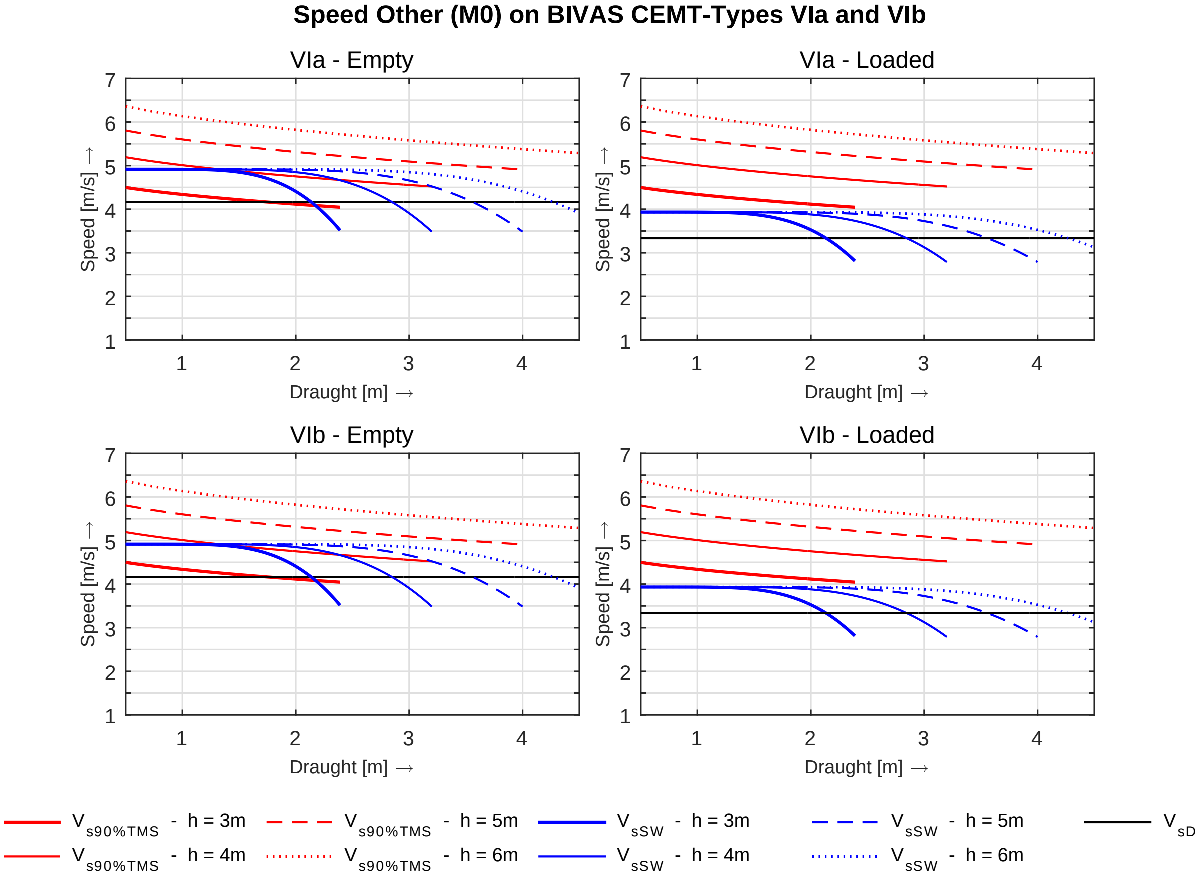


Figure J.17: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for Other vessels (M0) on BIVAS CEMT Types VIa and VIb, depending on water depth and draught.

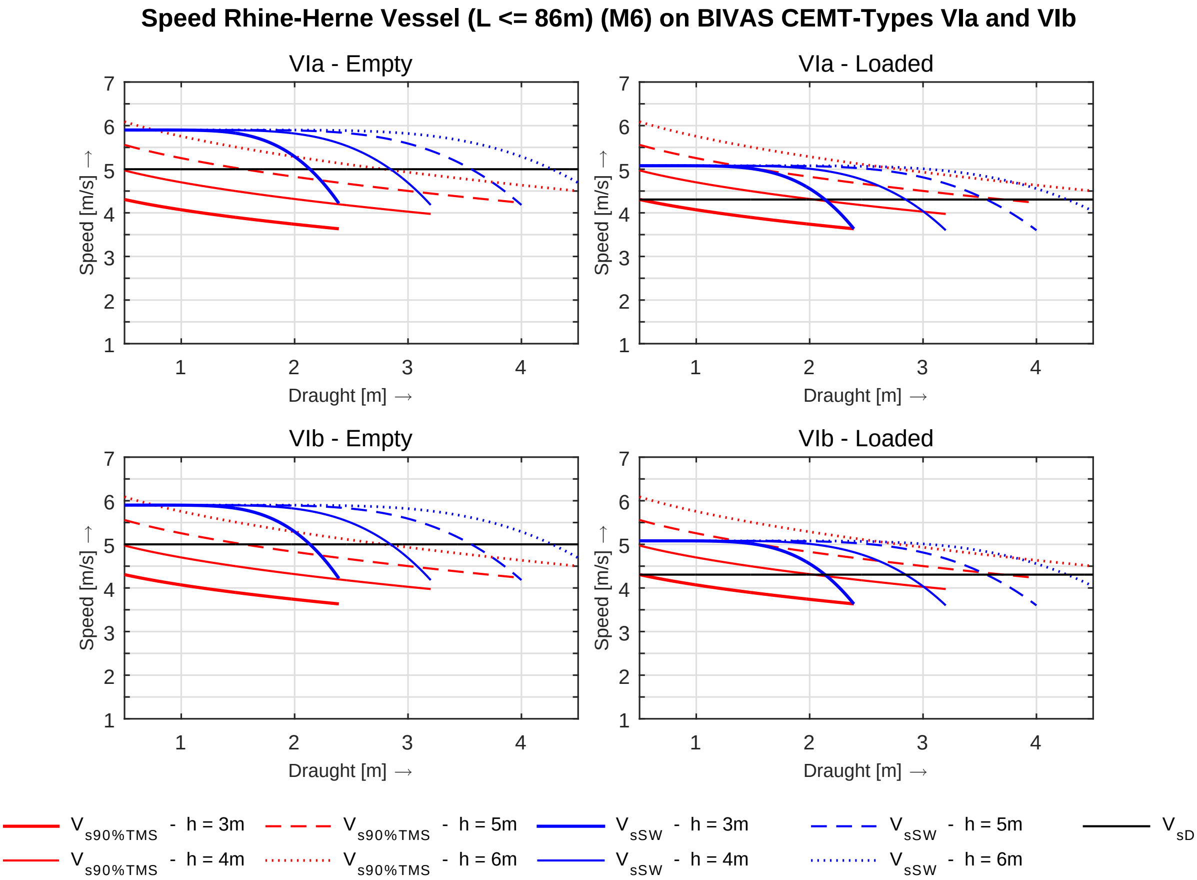


Figure J.18: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Rhine-Herne Vessel (L<=86m) (M6) on BIVAS CEMT Types VIa and VIb, depending on water depth and draught.

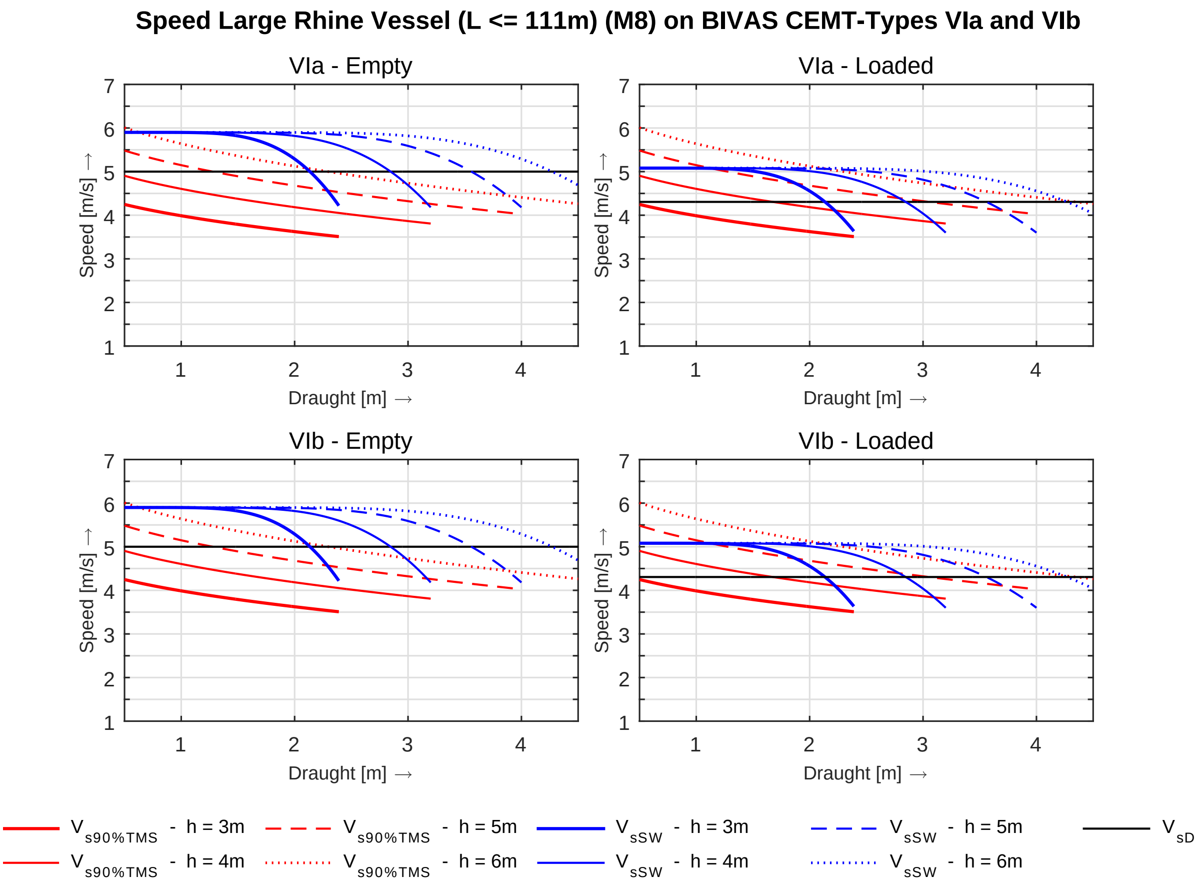


Figure J.19: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Large Rhine Vessel (L<=111m) (M8) on BIVAS CEMT Types VIa and VIb, depending on water depth and draught.

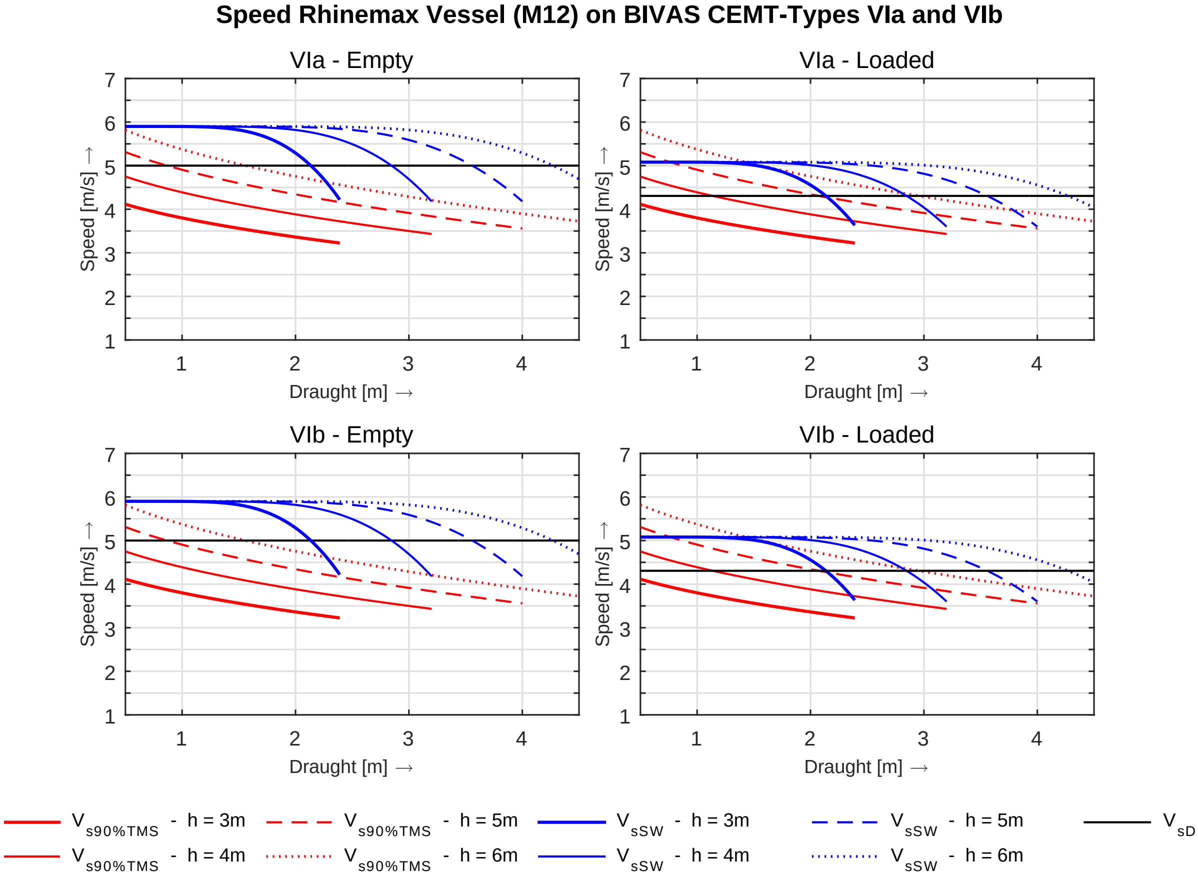


Figure J.20: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Rhinemax Vessel (M12) on BIVAS CEMT Types VIa and VIb, depending on water depth and draught.

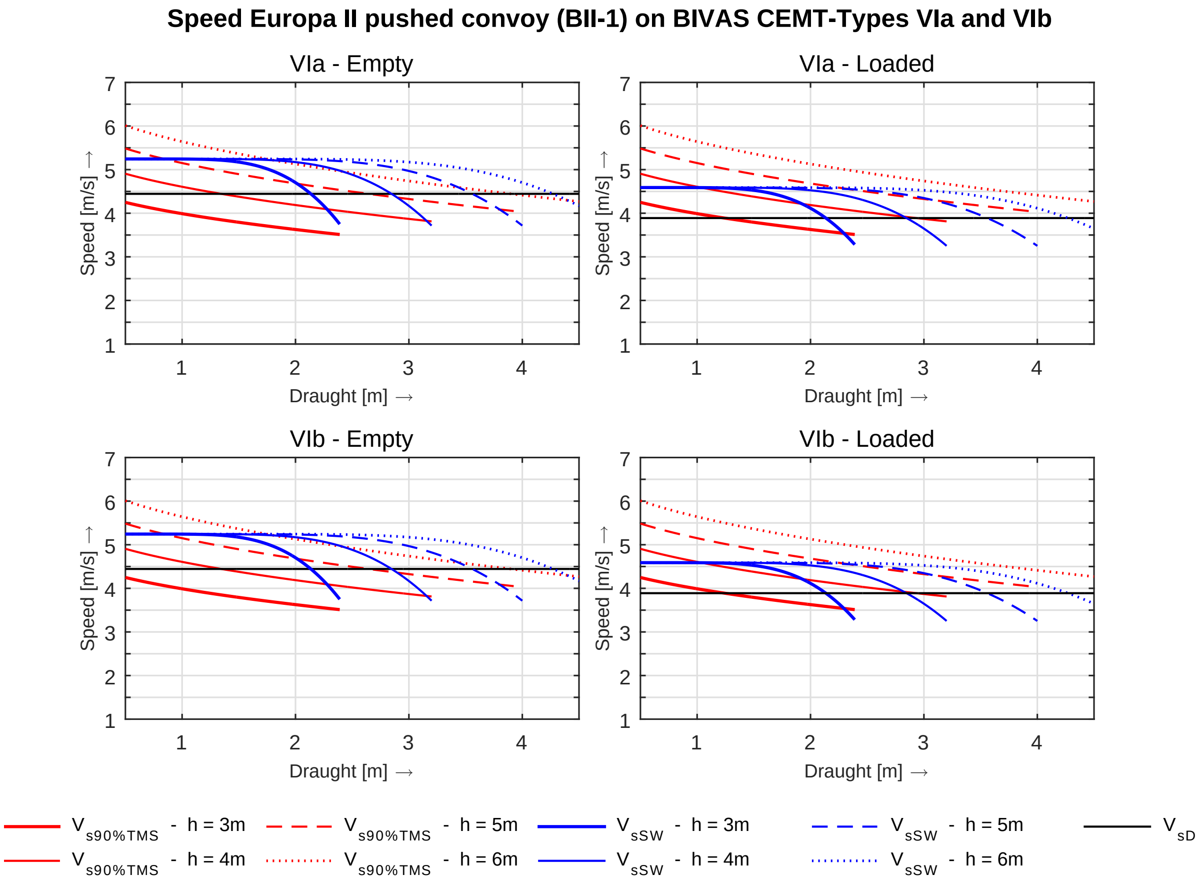


Figure J.21: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Europa II pushed convoy (BII-1)) on BIVAS CEMT Types VIa and VIb, depending on water depth and draught.

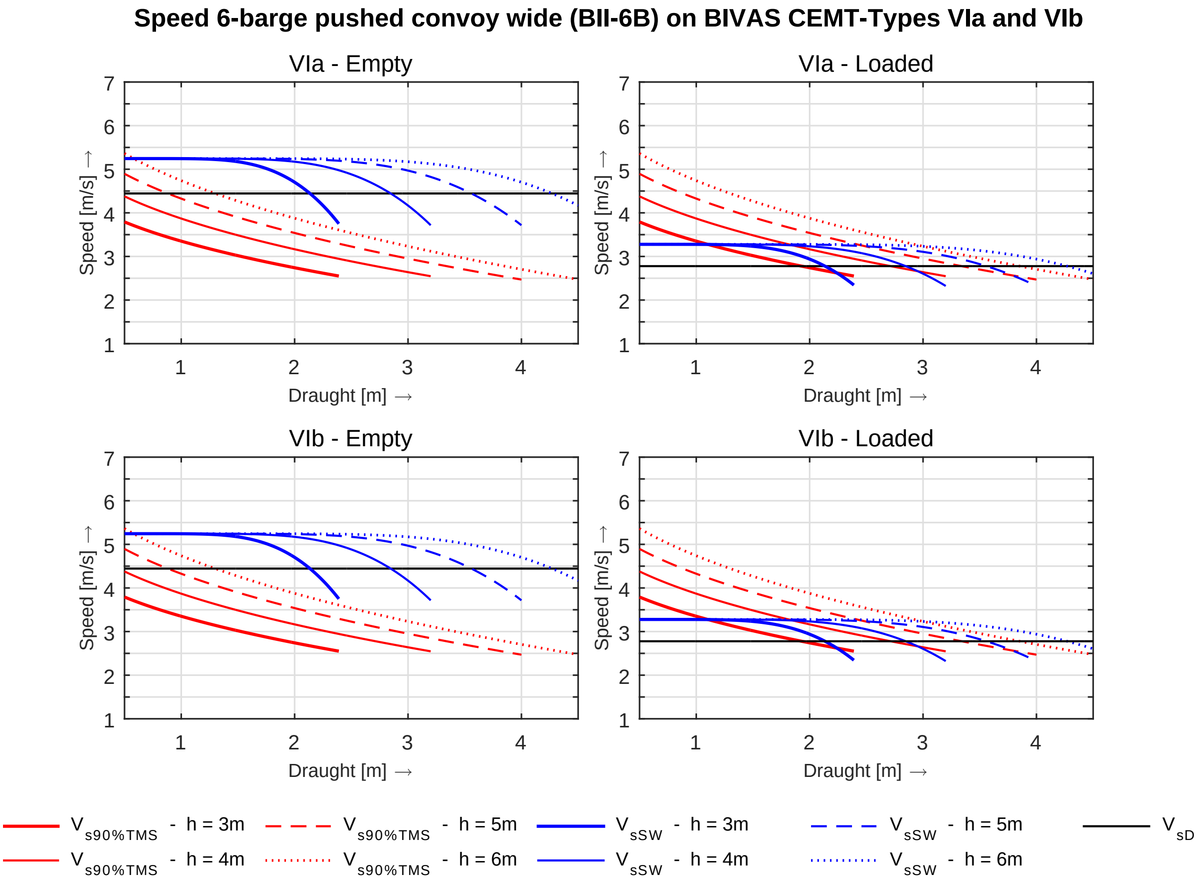


Figure J.22: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a 6-barge pushed convoy wide (BII-6B) on BIVAS CEMT Types VIa and VIb, depending on water depth and draught.

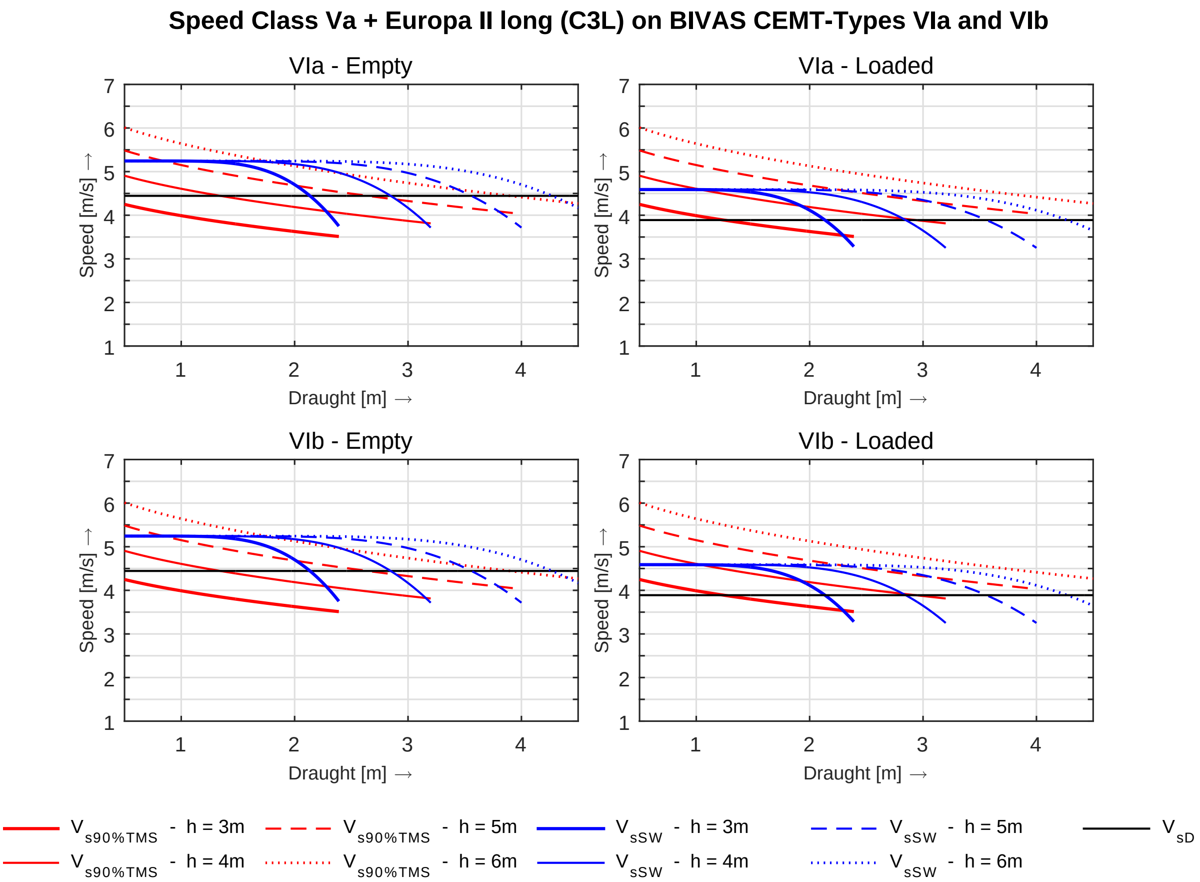


Figure J.23: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Class Va + Europa II long coupled unit (C3L) on BIVAS CEMT Types VIa and VIb, depending on water depth and draught.

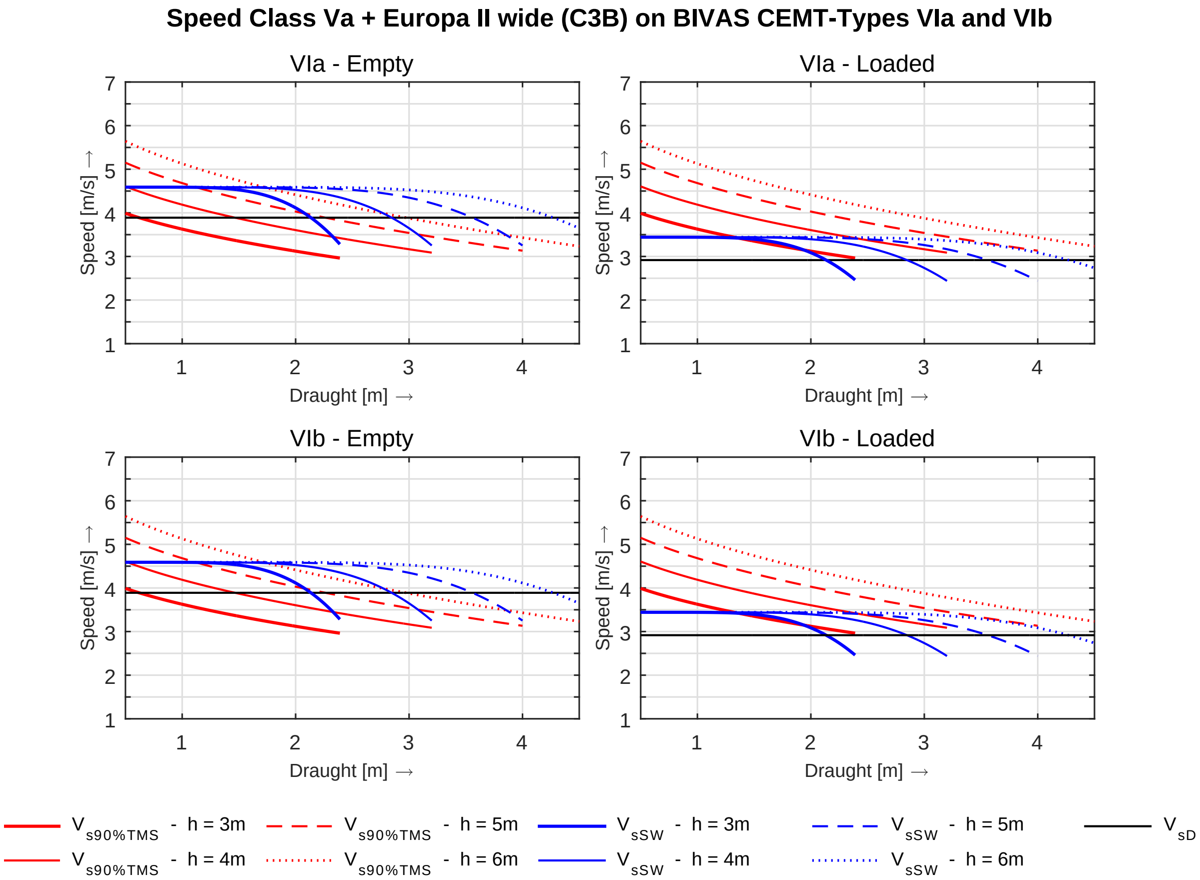


Figure J.24: Desired speed, 90% of the theoretical maximum speed and speed in shallow water for a Class Va + Europa II wide (C3B) on BIVAS CEMT Types VIa and VIb, depending on water depth and draught.

K
TABLES AND FIGURES ABOUT 2013

K.1. DISCHARGE PERIODS 2013

Table K.1: Discharge periods computations 2013; time frames and average discharges.

2013	Time span [dd-mm – dd-mm]	Average discharge [m^3/s]
Whole year	01-01 – 31-12	2580
Median	04-12 – 17-12	1889
Low	26-08 – 08-09	1294
High	01-02 – 14-02	4936

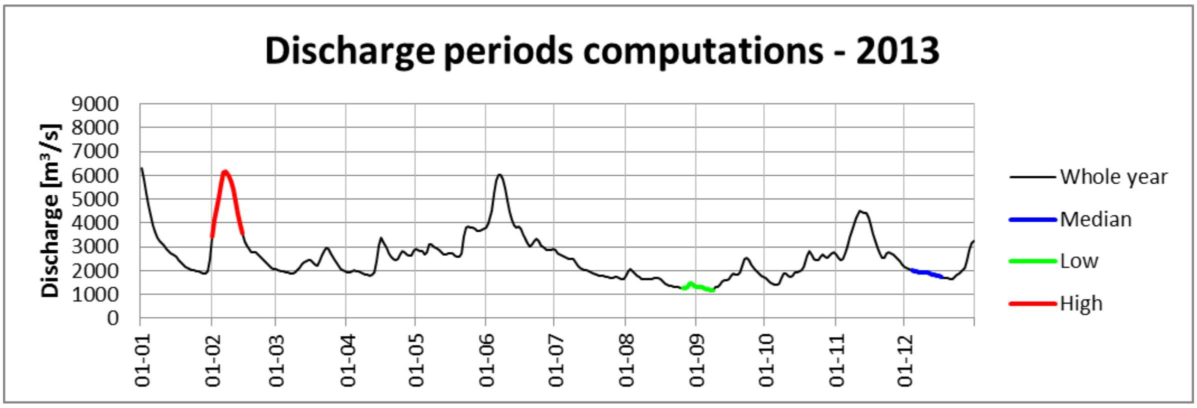


Figure K.1: Discharge at Lobith 2013; periods computations.

K.2. TRAFFIC SCENARIO 2013

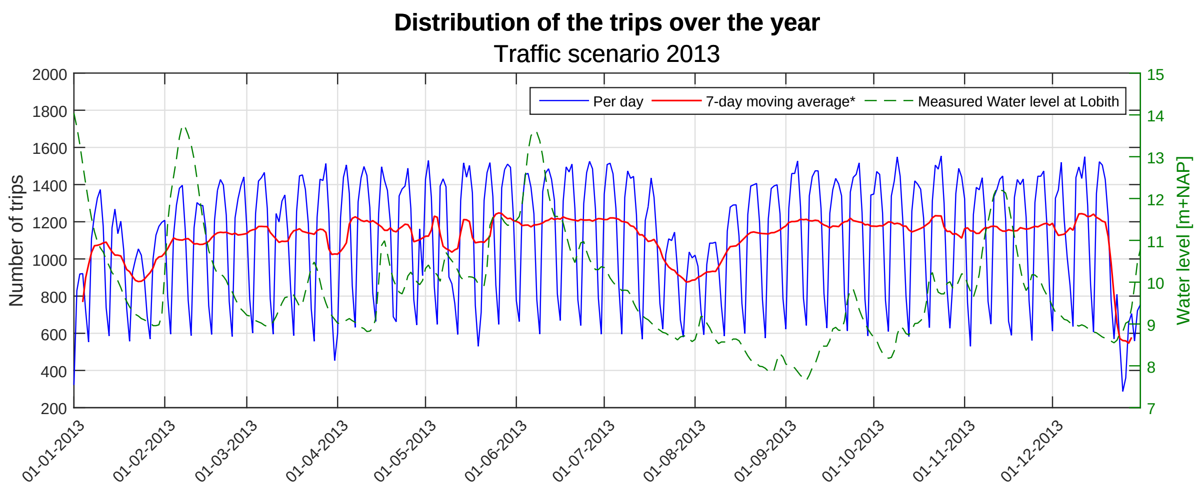


Figure K.2: Traffic scenario 2013;d istribution of the trips over the year.

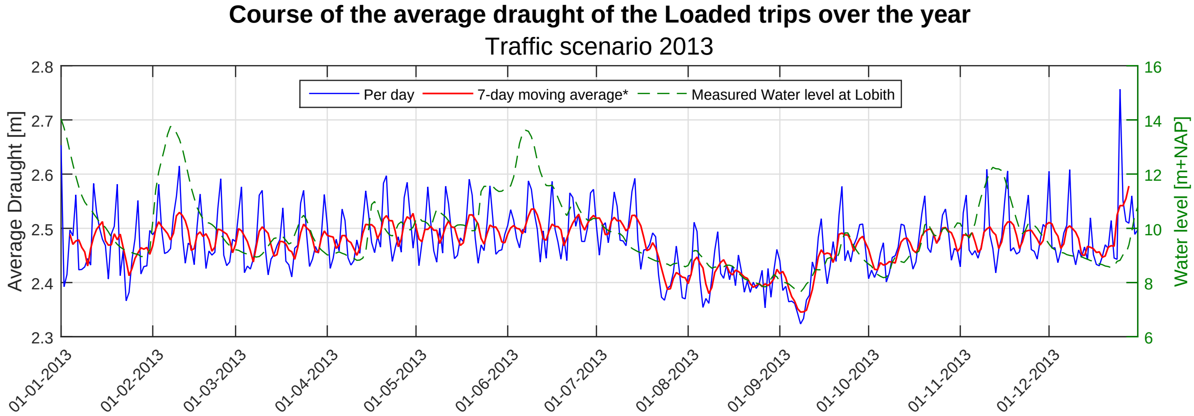


Figure K.3: Traffic scenario 2013; course of the average draught of the loaded trips over the year.