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Navigation on the Danube - Limitations by low water levels and their impacts

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Foreword by Alberto Pistocchi

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Foreword

In the context of the work the JRC is conducting in support to the European Union Strategy on the Danube Region[1], and particularly the scientific flagship cluster of the "Danube Water Nexus", the JRC has contracted Anja Scholten, who collaborated with Benno Rothstein, in order to collect information and provide insights on navigation. Navigation can be in principle a useful alternative to road and rail transport despite its impacts on river hydromorphology, and the Danube remains one of the most important European waterways for transport. At the same time, the increasing variability in the hydrological cycle (and consequently in water levels) that may be expected under climate change scenarios suggests the frequency and magnitude of difficulties in navigation related to low flows may increase in the future.

This technical report presents the analyses developed by the experts.

The work has allowed to focus some key messages:

- The Danube River presents bottlenecks, where transport is significantly affected by water levels.
- Rail transport is an important competitor for navigation: if the cost of navigation transport increases, there can be a shift to rail transport.
- Data reveal a clear, although complex, connection between water levels and transport prices.
- This enables some estimates of the impacts of water levels on the total volume of goods transported, on the degree of use of the available transport capacity, and on other related aspects (such as the shift from a lower number of large ships towards a larger number of smaller ships during low water levels, e.g. in Austria).
- The analysis shows these impacts are sizeable. For instance, for every 10cm less of water level at a reference location, the degree of capacity utilization is reduced by 0.6% in average, implying a reduction of capacity of some 1700 t or more.
- Adaptation options exist that may enable limiting the impacts of low levels on navigation. These include management of the fleet in favour of smaller ships (less affected by low water levels), adaptation in ship form and materials, and more traditional hydraulic engineering works to manage the river channel (the latter with a clear potential impact on river hydromorphology).

This report may contribute in the assessment of the water-food-energy-ecosystems nexus in the Danube region, also by providing hydro-economic criteria for the valuation of water for navigation.

Ispra, 24 November 2016

Alberto Pistocchi

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[1] https://ec.europa.eu/jrc/en/research/crosscutting-activities/danube-strategy

Abstract

This report contains two parts: The first part presents an overview on studies concerning the Danube, inland navigation or the impact of climate change on either of those. The second part gives a more detailed analysis of inland navigation on the Danube, partly based on studies presented in part one. Part two covers the current situation along the Danube by covering the topic of bottlenecks and other limitations for shipping along the Danube. Based on these observations, an estimation of the economic impacts of low water periods on inland navigation is made. As a last step, measures to reduce the impact of low water on inland navigations are presented.

The report shows, that inland navigation still is an important transport mode, along the Danube as well as in other European regions. Especially in Romania, inland navigation still has a share of more than 20% and rising in total transport. However, inland navigation depends strongly on the good conditions of its infrastructure. These good conditions are limited mainly by two factors: first are the so called bottlenecks. Those are areas with sub-optimal shipping conditions e.g. due to solid rock formations in the river that lead to reduced water depths. The second factor is the weather (and, on a longer time scale, the climate) which, mostly depending on precipitation and evaporation, can lead to low water levels seasonally. In addition to these two natural factors, laws which regulate the maximum number of barges allowed and human built structures like locks limit the size of vessels as well as the speed they can travel. These limiting factors are identified and located in the first chapter of part two of this report, before the water depth needed by several ship sizes as well as the cargo fleet available along the Danube are presented.

One of the targets of this report is to estimate the economic impact of low water periods. All the factors named above as well as the freight prices charged for connections along the Danube are used to reach this target in chapter II.4. To estimate the impact of low water periods on the freight prices, a method developed by Jonkeren et al. (2007) for the Rhine is transfered to the Danube. By transfering the Jonkeren et al. (2007) method, regression equations for several transport connections along the Danube are identified that give a first estimate for the connection of freight prices and water levels. With the help of these regression equations, an estimation of the total expenses for transport via inland navigation for several years is made possible. The yearly and seasonal variability is identified as well as the additional expenses due to water levels below 280cm.

But additional expenses are not the only impact of changing water levels on inland navigation. Another is that while the demand for transport stays at the same level, sometimes the water levels are not sufficient enough to use the full capacity of the fleet. Therefore, the (theoretical) amount of cargo that could not be transported due to low water levels is calculated as well and presented in chapter II.5.

Finally, some measures to overcome some of the here named problems of inland navigation due to low water levels are presented. These are separated into two general approches: change the ship or change the river. Both methods have their advantages and disadvantages due to technical as well as regulatory and other factors. The list presented here however is incomplete and only gives a few ideas of how some problems can be overcome. In the end, an individual mix for the different regions along the river and sometimes for the individual companies must be found.

1. Introduction

While inland navigation in the EU27 has a share of 6.5% (140707 million tkm) and therefore appears to be a minor way of transport, its importance in areas along big European rivers is far greater. In the Netherlands for example 33% of all transport takes place via inland navigation (Eurostat 2011). In North Rhine Westphalia, a state in Germany, inland navigation transports 25% of all cargo (Hoenemann 2005, Clement 2007) and in Romania 20% (ZKR 2013). This illustrates that inland navigation is an important factor in modern transport chains.

The importance of inland navigation in the Danube region can be highlighted by a comparison of the share of inland navigation in total transport to the share of other modes of transport. While the share of inland navigation in total transport is changing over time, in most countries in the Danube region inland navigation has a steady share of 5-10% in total transport (tkm) in the last years (for more detailed information see annex A). In Serbia it has a (declining) transported total of about 15% of all goods in 2009, (after having a share of 30% in 1998). In Romania however, inland navigation became more important with transporting over 20% of all cargo in 2011, after having a share of 10% or less in the decades before. Locally the share of inland navigation can have a much higher influence and a higher share in total transport though.

Like inland navigation the share of train transport declined from almost 70% in 2001 in Serbia to 50% in 2009 or from 43% in Romania in 2001 to 20% in 2008. At the same time the percentage of truck transport rose over the last decades e.g. from 48% in 2001 in Hungary to 70% in 2009 or from 61% in Slovenia in 2004 to 74% in 2008. As a result, truck transport dominates in all Danube countries, except for Serbia, where trains have the highest share. Figures with more detailed information can be found in annex A.

The transport amounts of the individual transport modes given above show that the importance of inland navigation varies for the different areas of the Danube. While it declines in some areas, it becomes more important in others. With the increasing transport of containerized goods and the rising awareness of companies for their carbon footprint, as well as mitigation projects from many governments, the significance of inland navigation may increase further, as it has, depending on the transport connection, the lowest CO_2 emission per ton of all modern ways of transport (Planco 2007). Because of its ability to transport bulk- and mass-cargo for relatively low freight rates, inland navigation always has been an important way of transport for companies that depend on bulky products and/or have a high transport demand (here called mass-cargo-affine companies; e.g. steel production or coal-fired power plants). Therefore these companies can mostly be found along big waterways throughout Europe (Scholten 2010). But, as on all ways of transport, weather and climate have an impact on inland navigation (Koetse & Rietveld 2009). During low water periods however, the capacity of inland navigation vessels is reduced and therefore the transport amount is limited, while the transport demand stays on the same high level. This affects their security of supply. In order to identify the effects of low water periods on this kind of company, a survey and expert interviews were conducted along the River Rhine in 2007–2009. Detailed results of this survey can be found in Scholten et al. (2011) and Scholten (2010). The analysis of the survey showed that during low water periods companies suffer from a shortage of transport via inland navigation. To keep the production running they have to fall back on short term adaptation measures. But as these short term adaptation options are very limited, companies run the risk of depletion of stock or overflowing warehouses with finished products and, in the worst case scenario, a shutting down of production (Scholten & Rothstein 2012). During low water periods the bearing capacity of ships is reduced, which in the past has led to transport shortages for companies, e.g. in 2003 (Scholten 2010).

As a first step to analyze how future low water periods impact these companies, the impact of climate change on discharge has to be investigated. During the KLIWAS project 4.01 (Nilson et al. 2014) the impact of climate change on the discharge of German rivers was analyzed using a multi-model ensemble containing all available climate change model runs at the time (2012), providing a good foundation for reliable results. This analysis included the Rhine, Elbe and Danube rivers with their tributaries. In total 36 model-chains of global and regional climate models were analyzed. Detailed results for the three rivers can be found in Nilson et al. (2015) for the Rhine, Krahe et al. (2015) for the Elbe and Klein et al. (2015) for the Danube. Nilson et al. (2014) provides a summary of all findings. In addition to this project, other studies have investigated the impact of climate change on said rivers, but those studies used fewer models. Middelkoop et al. (2001), Kleinn (2002), Schwandt (2003), Wagner et al. (2013) and Johst et al. (2013) are just some examples. The impact of low water periods on inland navigation is debated in Bader et al. (2004), VBD (2004), Renner (2005), Scholten (2010) and Scholten & Rothstein (2012) amongst others. The studies of Jonkeren et al. (2007 and 2009) quantify for the first time the financial impact of low water periods on the freight prices of inland navigation for the Rhine and potential impacts of climate change on modal-split.

During the ECCONET project, Beuthe et al. (2012) calculated the impact of water depth on transport amount for the past, present and future, including possible impacts on the modal-split and the impact of better infrastructure. Potential capacity shortages for other ways of transport (e.g. rails, road), however, were not included in the study. Other studies that also include the impact of climate change on inland navigation are from Millerd (2005 and 2007), Koetse & Rietveld (2009), Demirel (2011) and Beuthe et al. (2012). These studies however do not include impacts on the mass-cargo-affine industry that use inland navigation for transport. Interesting calculations concerning adaptation measures for inland navigation (e.g. new ship types or changes in the navigation channel) can be found in Bosschieter (2005) and VBD (2004). Studies that analyze the impact of climate change on companies can be found in Rothstein (2007) and Rothstein & Parey (2011), regarding energy production and consumption. The reduced transport capacity of inland navigation vessels is just one of several aspects investigated here. Studies focusing on this aspect as well as possible adaptation measures are Scholten (2010), Scholten & Rothstein (2012) and Scholten et al. (2014). Studies that contain possible adaptation measures for the industry are amongst others De Vries (2009), Harrison et al. (2012), Eisenach & Stecker (2012), Hemberger & Utz (2013). However, they mostly focus on other vulnerable aspects of the companies, e.g. heat-stress for employees and no or little attention to transport. An overview of studies covering several aspects of the Danube and inland navigation can be found in Part I of this report.

In part II this report focuses on showing the impact of low water periods on inland navigation on the Danube as well as giving a first estimate on the economic impact of low water periods on inland navigation.

Whilst a lot of research for the Danube, its bottlenecks, the impact of climate change on its water levels and the inland navigation on the Danube was performed in the past (a table with some of these studies including a short description can be found in Annex B), the economic impact so far has not been calculated.

To be able to estimate the economic impact of low water periods, freight prices, transport amounts and water levels for several transport connections (e.g. from the Netherlands to Hungary) have been used to find a correlation between those factors on the one hand and use the fitting equations to calculate the (theoretical) economic impact of low water periods on the total transport costs on the Danube on the other hand. However, this method can only lead to a rough estimate of the real effects. For more precise calculations better data (e.g. daily freight-prices) would be needed, as the here used monthly freight data is not only influenced by changing water levels but also by other factors like economic development.

To overcome problems in inland navigation due to low water, several adaptation measures were developed for other rivers already. A summary of these results is shown in chapter II.6.

Part I

The first part of this report gives an overview of studies performed for the Danube, inland navigation in the EU, the impact of climate change on European rivers and inland navigation and possible adaptation levels. This overview is organized in tables, covering the individual topics and giving short summaries of the studies covered. Studies containing several aspects mentioned here are named separately for each topic.

I.1. Studies concerning Danube

Name of the Project/Author	Year	Summary and Source
NEWADA	2009-2012	The project, which was initiated in April 2009 and concluded in March 2012, was financed with funds from 2007-2013 EU budget. Just like previous initiatives, NEWADA intends to highlight the many benefits of inland vessels, increase the efficiency of Corridor VII and foster region-wide coordination of Danube protection efforts, which are still largely confined to the national level. The case is that measures taken by countries further upstream are bound to affect the countries further downstream. It also happens that individual countries launch their own projects in river sections near the border without telling the neighboring state. As a result, such measures often do not have the desired effect - or they are unnecessarily duplicated. To improve the present situation, one important aspect must be to focus on the quality and accessibility of information intended for stakeholders. The primary purpose is to establish a network which allows the project partners to attune their action plans as well as their waterway maintenance, hydrographical and hydrological activities. Much attention is also paid to the exchange of know-how, drawing on best-practice examples. http://www.newada.eu/newada/; http://www.newada-duo.eu/
EUSDR	2010	The EU Strategy for the Danube Region (EUSDR) is a macro-regional strategy adopted by the European Commission in December 2010 and endorsed by the European Council in 2011. The Strategy was jointly developed by the Commission, together with the Danube Region countries and stakeholders, in order to address common challenges together. The Strategy seeks to create synergies and coordination between existing policies and initiatives taking place across the Danube Region. The EU Strategy for the Danube Region, endorsed in June 2011 by the European Council, is the second EU macro-regional strategy after the EU Strategy for the Baltic Sea Region. http://www.danube-region.eu/pages/what-is-the-eusdr

Name of the Project/Author	Year	Summary and Source
Herold, S.	2007	This master thesis discusses the issue of software-based tools for generating intermodal transport chains. On the one hand available tools are identified (Supply side) and will be analyzed with regard to several criteria like performances, applications, technique, quality and quantity of the results. This analysis will be the basis for the evaluation and the following comparison of the software-based tools. After the breakdown of the supply side the analysis of the demand side follows. Therefor potential users of software-based tools for the generation of intermodal transport chains will be identified in a first step and will be analyzed then. The potential users will be identified through an empirical survey with regard to potential applications, requirements and benefits which can be achieved through the usage of the tool. In the final step the results of the analysis of the supply and demand side and the empirical survey will be summarized. Opportunities and threats for the launch and positioning of one ideal software-based tool on the market should be discovered. http://www.th-wildau.de/fileadmin/dokumente/interim/ dokumente/Further_reports/interim_DA_Stefan_HEROLD_ v3.pdf

Name of the Project/Author	Year	Summary and Source
PLATINA I & II	2010 -2016	Manual on good practices in sustainable waterway planning, ICPDR, Vienna:
		This manual offers general advice on organizing and implementing a balanced and integrated planning process. Thereby, project developers must also consider national, regional and local aspects and requirements when developing an inland waterway transport project. The early integration of stakeholders (including those representing environmental interests) and of environmental objectives and wide communication are essential for successful planning process.
		Blue Book:
		Inventory of the main standards and parameters of the waterway E waterway network "Blue Book" Second Revised Edition; UNITED NATIONS New York and Geneva, 2012;
		At its fortieth session in 1996, the UNECE Working Party on Inland Water Transport (SC.3) agreed to proceed with the drafting of the so-called "Blue book" which would contain technical characteristics of European inland waterways and ports of international importance (E waterways and ports) identified in the European Agreement on Main Inland Waterways of International Importance (AGN). The first edition of the Blue book was published in 1998 as TRANS/SC.3/144.
		The objective of the Blue book is to establish an inventory of existing and envisaged standards and parameters of E waterways and ports in Europe and to show, on an internationally comparable basis, the current inland navigation infrastructure parameters in Europe as compared to the minimum standards and parameters prescribed in the AGN Agreement. This would enable member Governments and intergovernmental organizations concerned to use the Blue book as a basic instrument for monitoring the progress made in implementing the AGN.
ICPDR	2007	Development of Inland Navigation and Environmental Protection in the Danube River Basin:
		This joint statement aims to provide guidance to decision makers dealing with inland waterway transport and environmental sustainability as well as to water managers preparing relevant riverine environmental and navigational plans, programs and projects.

Name of the Project/Author	Year	Summary and Source
Inventory	2013	Inventory of Most Important Bottlenecks and Missing Links in the E Waterway Network Resolution No.49; Revision 1; UNITED NATIONS:
		The European Agreement on Main Inland Waterways of International Importance (AGN) in its annex I establishes the network of E waterways including a few portions that do not presently exist and are considered as missing links. In its annex III, the Agreement stipulates the requirements for the classification of E waterways. In total, 29,131 km of European inland waterways have been earmarked by Governments as E waterways. The above length excludes the double counting of sections on which two or more E waterways overlap. In accordance with the AGN Agreement, only waterways meeting the basic minimum requirements of class IV (minimum dimensions of vessels: 80.00m x 9.50m) can be considered as E waterways. The Agreement recommends that the new E waterways to be built (for the completion of missing links) should meet, at least, the requirements of class Vb, while the waterways to be modernized should meet the requirements of at least class Va.
Veichtlbauer, O.	2008	Donau-Strom. Über die Herrschaft der Ingenieure, In: Graue Donau, Schwarzes Meer: Wien Sulina Odessa Jalta Istanbul, Reder C, Klein E (eds), Edition Transfer, Springer Wien New York 2008, ISBN 3211754822
		26 pages of information about barrages along the Danube. Includes general information about the Danube area (e.g. inhabitants, length of the river, energy needed/produced)

Name of the Project/Author	Year	Summary and Source
Sielker, F.	2012	Makroregionale Strategien der EU und Soft Spaces - Perspektiven an der Donau; Diplomarbeit, written at TU Dortmund
		The appearance of macro-regional strategies (MRS) has stimulated discussions regarding new concepts of territorial cooperation in the EU. As a result of ongoing globalization and Europeanization, functional linkages become more and more important, hence leading to new conceptualizations of territory based on functional approaches. MRS constitute an adaptation process and shape spatial development as well as the creation of networks. In the light of the rescaling debate, MRS operate as a new framework for cooperation in the multi-level governance system of the EU. Forming a strategic roof, they link regional policies as a project focused approach with sectoral policies. After the development of the first EU macro-regional strategy for the Baltic Sea Region similar initiatives evolved quickly, leading to the adoption of the EU Danube Region Strategy (EUDRS) in June 2011.
		Driven by the current interest in macro-regional strategies, this thesis focuses on the evaluation of perspectives and expectations towards this new framework for cooperation. Based on the analysis of the EUDRS from a stakeholder perspective, it is on the one hand of interest to improve the understanding of the MRS concept, its underlying developments and to comprehend the coordination. Examining the perspectives on potential added value and challenges of relevant stakeholders in the Danube region, expectations towards a successful implementation are identified. On the other hand, it is of interest to understand the macro-regional approach from a scientific point of view. MRS evolved along with discussions on the possibility of building a new layer of intervention to cope with common challenges in relational geographies. The emergence of soft spaces is one of the most significant contemporarily discussed phenomena. Soft spaces describe informal and fuzzy shaped spaces that emerge from cooperation across various ranges of geographies, scales, sectors and actor-networks operating within the legal set of boundaries. In the light of the rescaling debate it is to be analysed whether MRS, initiated by nation states and thus following mainly a political logic, can build an appropriate framework for governance within fuzzy functional geometries. Part of this work is to examine whether the concept of soft spaces can be applied to further explain processes on the macro-regional level.

Name of the Project/Author	Year	Summary and Source
Hasenbichler, H.-P.	2013	Handbuch der Donauschifffahrt; Via Donau; Wien, ISBN 3-00-009626-4
		Gives a description of inland navigation on the Danube, including its strength and draw backs, a comparison with other modes of transport and information to its relevance. In addition information to politics concerning the Danube is included as well as data concerning its tributaries, harbours, inland navigation vessels, available markets and multimodale transport.
Backalic, T.; Maslaric, M.	2012	Navigation conditions and the risk management in inland waterway transport on the middle Danube; Transport Problems; Vol. 7, Issue 4
		Water transport could be the backbone of the future European combined transport system. The development of the cargo transport in river traffic depends directly on technical-exploitative characteristics of the network of inland waterways. Research of navigational abilities of inland waterways always comes before building ships or making a transport schedule. It is known that the size of the vessel's draught (T) is usually the limiting value in project tasks and it depend on the depth of the waterway or certain ports condition. This is the reason why navigation characteristics of rivers have to be determined as precise as possible, especially from the aspect of determination of the possible draught of vessels. Unfortunately, risks in water transport are perhaps an under researched area and consequently, this article outlines a rationale, why it is necessary to develop competence about risk in water transport. Climate changes require special attention and global monitoring. Current risk assessment methods for water transport just consider some dramatic events. We present a new method for the assessment of risk and vulnerability of water transport where river depth represents a crucial part. The analysis of water level changes in the middle Danube was done during the last sixty years
Donaukomission	2004	Die Donaukommission und die Donauschifffahrt – Zum 150. Jahrestag der Gründung der Europäischen Donaukommission und zum 50. Jahrestag der Sitznahme der Donaukommission in Budapest, Budapest
		http://www.danubecommission.org/uploads/doc/publication/Broschura%202004/DC_150_DE.pdf
		This book was released to celebrate the 150th anniversary of the Danube Commission. It contains information on the history of inland navigation on the Danube as well as important regulations and agreements.

Name of the Project/Author	Year	Summary and Source
Günthner, W. A.; Segerer, H.; Heinecker, M.	2001	Studie Donau-Logistik Technische und logistische Maßnahmen zur weiteren Entwicklung der Verkehre über die deutschen und österreichischen Donauhäfen - Abschlußbericht, LSR Lehrstuhl für Fördertechnik Materialfluß Logistik Technische Universität München, Garching near München
		http://www.binnenhafen.info/download/akt_5024_Deckblatt_Abschlussbericht_S_2_NEU.pdf
		Study on technical and logistic measures to further develop the transport at German and Austrian Dunube harbors.
Austria and/or Austrian Part of Danube:		
NAP	2006	Nationaler Aktionsplan Donauschifffahrt - Endbericht; Bundesministerium für Verkehr, Innovation und Technologie; Wien
		Political measures to strengthen the Austrian inland navigation. Study contains information about the "system inland navigation", targets of the national action plan, the strategy of the Austrian politic for inland navigation, a catalogue of measures and their implementation.
		"The Danube waterway plays an important role in Austria's transport system. With inland navigation as an environmentally friendly means of transport it contributes to "greening" transport and easing the burden on Austria's roads.
		Together with the Federal Ministry for Transport, Innovation and Technology, via donau is responsible for the implementation of the National Action Plan on Danube Navigation.
		The purpose of the Action Plan is to further strengthen the role of inland waterway transport. The combination of individual measures in the fields of infrastructure, ports, information systems, markets, knowledge & awareness and international cooperation aims at strengthening the use of waterways. Important NAP activities to make navigation even more innovative, reliable and environmentally friendly have already been implemented in the first years of the plan's existence.
		http://www.donauschifffahrt.info/index.php?id=149

Name of the Project/Author	Year	Summary and Source
OeAD	2013	"Der Donauraum - Kooperationen in Bildung, Wissenschaft und Kultur", oead news 22 3/88, Österreichischer Austauschdienst, Wien 2013 Contains several short articles about projects in the Danube region (e.g. DREAM "Danube River Research and Management"), as well as facts and figures of the Danube region. https://www.oead.at/fileadmin/oead_zentrale/ueber_den_oead/publikationen/pdf/oead.news/2013/oead-news-88_web.pdf
ÖIR	2006	Flussbauliches Gesamtprojekt Donau oestlich von Wien Strom-km 1921.0 – 1872.7 - Umweltvertraeglichkeitserklärung – Kosten-Nutzen-Analyse. http://www.oir.at/de/node/388 This study contains an analysis of a development project along the river Danube km 1921.0 – 1872.7 with a focus on its impact on the ecology and cargo transport as well as the analysis of the costs-benefit-analysis.
Seitz, M.; Gussmagg, G.; Heiserer, A.; Pusztay, C. Schwanzer, J.; Deußner, R.; Novak, S.; Capatu, A.	2006	COLD - Container Liniendienst Donau - Eine Einschätzung der Chancen und Risiken von Containertransporten auf der Donau zwischen Österreich und dem Schwarzen Meer; Via Donau; Wien http://www.oir.at/de/node/427 A study analysing the chances and risks of developing a system for the transport of containers via inland navigation on the Danube.
Germany and/or German Part of Danube		
Schiller, J.	2010	Variantenunabhängige Untersuchungen und Ausbauplanungen für den Ausbau des Donauabschnittes Straubingen Vilshofen; presentation of WSD Süd; 29.09.2010 Contains information about the conditions for inland navigation on the German part of the Danube and presents plans for further development.
Göttler, H.P.	2011	Variantenunabhängige Untersuchungen zum geplanten Donauausbau zwischen Straubing und Vilshofen Contains information about the conditions for inland navigation on the German part of the Danube, its importance for the local and regional transport structure and presents plans for further development.

Name of the Project/Author	Year	Summary and Source
Günthner, W. A.; Segerer, H.; Heinecker, M.	2001	Technische und logistische Maßnahmen zur weiteren Entwicklung der Verkehre über die deutschen und österreichischen Donauhäfen, Technische Universität München; Untersuchung im Auftrag des Freistaats Bayern; Garching http://www.binnenhafen.info/download/akt_5024_Deckblatt_Abschlussbericht_S_2_NEU.pdf Study on technical and logistic measures to further develop the transport at German and Austrian Dunube harbors.

I.2. Deployment of inland navigation

Name of the Project/Author	Year	Summary and Source
BAG	1998 - 2008	Qualitative and quantitative information about inland navigation in Germany on a yearly and seasonal basis plus several additional publications concerning future perspectives and new developments: • BAG (1998-2007): Marktbeobachtung Güterverkehr - Jahresbericht, Bundesamt für Güterverkehr, Köln • BAG (1998H-2007H): Marktbeobachtung Güterverkehr - Bericht Herbst, Bundesamt für Güterverkehr, Köln • BAG (2006B): Marktbeobachtung Güterverkehr - Sonderbericht: Eineinhalb Jahre streckenbezogene LKW-Maut - Auswirkungen auf das deutsche Güterverkehrsgewerbe, Bundesamt für Güterverkehr, Köln • BAG (2006C): Marktbeobachtung Güterverkehr - Sonderbericht über die Entwicklung in der deutschen Binnentankschifffahrt, Bundesamt für Güterverkehr, Köln • BAG (2006D): Marktbeobachtung Güterverkehr - Karbotage auf deutschen Binnenwasserstraßen, Bundesamt für Güterverkehr, Köln • BAG (2006E): Marktbeobachtung Güterverkehr - Zwei Jahre EU-Osterweiterung - Auswirkungen auf das deutsche Güterverkehrsgewerbe, Bundesamt für Güterverkehr, Köln • BAG (2006F): Marktbeobachtung Güterverkehr - Internet gestützte Frachtvermittlung, Bundesamt für Güterverkehr, Köln • BAG (2007B): Marktbeobachtung Güterverkehr - Sonderbericht zur Entwicklung des Seehafen - Hinterlandverkehrs, Bundesamt für Güterverkehr, Köln • BAG (2008): Marktbeobachtung Güterverkehr - Strukturentwicklungen auf dem Schienengüterverkehrsmarkt, Bundesamt für Güterverkehr, Köln

Name of the Project/Author	Year	Summary and Source
CCR/ZKR	1998 - 2002 2004 - 2007	Qualitative and quantitative information about inland navigation along the River Rhine or in Europe on a yearly and seasonal basis: • ZKR (1998-2002): Wirtschaftliche Entwicklung der Rheinschifffahrt - Statistiken, ed. Zentralkommission für die Rheinschifffahrt, Strasbourg • ZKR (2004-2007): Marktbeobachtungen der europäischen Binnenschifffahrt, ed. Zentralkommission für die Rheinschifffahrt, im Auftrag der Europäischen Kommission, Generaldirektion für Energie und Verkehr, Strasbourg
BDB	2007	Short information concerning the numbers of ships available in Germany, amount of cargo, share of transport etc.: BDB (2007): Daten und Fakten 2006/2007, ed. Bundesverband der Deutschen Binnenschifffahrt e.V., Duisburg
DESTATIS	2002 - 2014	Quantitative information about inland navigation in Germany on a yearly and monthly, e.g. amount of cargo per harbour, number of ships by age...: • DESTATIS (2002-2014): Fachserie 8 Reihe 4 - Verkehr - Güterverkehrsstatistik der Binnenschifffahrt, ed. Statistisches Bundesamt, published monthly and annually, Wiesbaden • DESTATIS (2003B-2014B): Binnenschifffahrt - Umschlagstruktur der wichtigsten Häfen, ed. Statistische Ämter des Bundes und der Länder, published annually, Wiesbaden

I.3. Number of ships available and their capacity

Name of the Project/Author	Year	Summary and Source
ELWIS	2007	Development of the German fleet http://www.elwis.de/Verkehrsstatistik/zbbd/2007/ Entwicklung-Binnenflotte.pdf
BDB	2007	Short informations concerning the numbers of ships available in Germany, amount of cargo, share of transport etc.: BDB (2007): Daten und Fakten 2006/2007, ed. Bundesverband der Deutschen Binnenschifffahrt e.V., Duisburg
DESTATIS	2002 - 2014	Quantitative information about inland navigation in Germany on a yearly and monthly, e.g. amount of cargo per harbour, number of ships by age...: • DESTATIS (2002-2014): Fachserie 8 Reihe 4 - Verkehr - Güterverkehrsstatistik der Binnenschifffahrt, ed.

Name of the Project/Author	Year	Summary and Source
		Statistisches Bundesamt, published monthly and annually, Wiesbaden • DESTATIS (2003B-2014B): Binnenschifffahrt - Umschlagstruktur der wichtigsten Häfen, ed. Statistische Ämter des Bundes und der Länder, published annually, Wiesbaden
CCR/ZKR	1998 - 2002 2004 - 2007	Qualitative and quantitative information about inland navigation along the River Rhine or in Europe on a yearly and seasonal basis: • ZKR (1998-2002): Wirtschaftliche Entwicklung der Rheinschifffahrt - Statistiken, ed. Zentralkommission für die Rheinschifffahrt, Strasbourg • ZKR (2004-2007): Marktbeobachtungen der europäischen Binnenschifffahrt, ed. Zentralkommission für die Rheinschifffahrt, im Auftrag der Europäischen Kommission, Generaldirektion für Energie und Verkehr, Strasbourg
Verkehr in Zahlen	2006	Verkehr in Zahlen, ed. Bundesministerium für Verkehr, Bau- und Stadtentwicklung, 35. Jahrgang, Deutscher Verkehrs-Verlag GmbH, Hamburg Handbook concerning all modes of transport, giving quantitative information about cargo amounts and passenger numbers, average traveling distance...
De Vries, C.J.	2009	Inlandshipping an outstanding choice - Die Zukunft des Gueterverkehrs und der Binnenschifffahrt in Europa 2010-2011, ed. Bureau Voorlichting Binnenvaart, Rotterdam
Transport capacity and degree of capacity utilization		
BAG	2003	Qualitative and quantitative information about inland navigation in Germany on a yearly and seasonal basis plus several additional publications concerning future perspectives and new developments: • BAG (2003): Marktbeobachtung Güterverkehr - Jahresbericht, Bundesamt für Güterverkehr, Köln • BAG (2003H): Marktbeobachtung Güterverkehr - Bericht Herbst, Bundesamt für Güterverkehr, Köln

I.4. Impact of low water periods

Name of the Project/Author	Year	Summary and Source
BUWAL, BWG, MeteoSchweiz	2004	Auswirkungen des Hitzesommers 2003 auf die Gewässer, Schriftenreihe Umwelt Nr. 369, ed. Bundesamt für Umwelt, Wald und Landwirtschaft, Bern This report provides an overview of how the extremely hot and dry summer of 2003 affected Switzerland's waterbodies. Having examined the causes and pattern of the weather conditions and the immediate consequences for the Alpine glaciers, it describes the effects on waterbodies themselves and on their utilization. An account is given of the impacts on the hydrology and condition of surface waters, groundwater, wetlands, water withdrawals and inflows, fish and fisheries, bathing waters, supplies of drinking water, hydropower generation and inland navigation. Wherever possible, comparisons are made with two previous dry years – 1976 and 1947. From a comprehensive view of the events, key conclusions are drawn.
VBD	2004	Technische und wissenschaftliche Konzepte fuer flussangepasste Binnenschiffe, Versuchsanstalt fuer Binnenschiffbau e.V., Duisburg Study on the possibility to adapt ships to the rivers instead of the other way around
Renner, V.	2005	Der Entwurf eines Schiffes orientiert sich immer an den gegenwaertig gueltigen gesetzlichen Vorgaben, Binnenschifffahrt, ZfB, Nr. 6, Juni 2005
BAG	1998 - 2007	Qualitative and quantitative information about inland navigation in Germany on a yearly and seasonal basis plus several additional publications concerning future perspectives and new developments: • BAG (1998-2007): Marktbeobachtung Güterverkehr - Jahresbericht, Bundesamt für Güterverkehr, Köln • BAG (1998H-2007H): Marktbeobachtung Güterverkehr - Bericht Herbst, Bundesamt für Güterverkehr, Köln
Scholten et al.	2010 2012 2014	• Scholten, A. (2010): Massenguttransport auf dem Rhein vor dem Hintergrund des Klimawandels - Eine Untersuchung der Auswirkungen von Niedrigwasser auf die Binnenschifffahrt und die verladende Wirtschaft, 361p, Wuerzburger Geographische Arbeiten 104, Wuerzburg The thesis "Transport of Mass-Cargo on the River Rhine in Context of Climate Change" deals with the interactive structure Rhine - inland navigation - commercial transport - mass-cargo affine industries - and, in this context, especially regards the effects of

Name of the Project/Author	Year	Summary and Source
		low water on the different aspects of this (interactive) chain. In order to achieve this, statistic analyses of data-sets are conducted. The effects on mass-cargo affine industries are examined through a survey, interviews and media-analyses. Based on the results of this examination, an index of vulnerability was developed, with which not only the vulnerability of several companies but also the effects of possible adaptation measures could be compared.
		• Scholten, A. & Rothstein, B. (2012): Auswirkungen von Niedrigwasser und Klimawandel auf die verladende Wirtschaft, Binnenschifffahrt und Haefen entlang des Rheins, 352 p, Wuerzburger Geographische Arbeiten 107, Wuerzburg
		This book contains 5 main chapters of closely interlinked analysis: 1.Analysis of the impact of climate change on mass cargo affine companies, based on surveys; 2. Media-analysis of the impact of low water events since 1998, an accident, blocking the River Rhine for several days and a strike of train drivers; 3. Impact of low water events on inland navigation; 4. Impact of low water on harbors; 5. Development of an index to calculate the vulnerability of mass-cargo-affine companies due to low water events.
		• Scholten, A., Rothstein, B. & Baumhauer, R. (2014): Mass-cargo-affine industries and climate change; Climatic Change Volume 122, Issue 1-2, pp. 111-125 http://link.springer.com/article/10.1007%2Fs10584-013-0968-0
		The impact of low water periods on inland navigation and companies is well known by ship-operators and companies that rely on this mode of transport but it is rarely a topic of climate impact research. As climate change might affect the frequency and intensity of low water periods, quantifying the impact of climate change on companies and the effects of possible adaptation measures is vital. In this study, we present a model for quantifying the impact of low water events on companies which rely on inland navigation and apply that model to three anonymous iron and steel companies along the River Rhine. The deviation of optimal storage, the storage level that evens out risk vs. fixed capital, is used in the model to measure the vulnerability of companies. The results show that, depending on the climate scenario, the companies might have to deal with either one or five additional days of empty storage in the near future (2021-2050) and up to nine more days by the 2071-2100 period. Seasonal analysis shows that, consistent with the change in the river discharge, the biggest deviations from optimal storage level occur in the late

Name of the Project/Author	Year	Summary and Source
		summer/early autumn. Analysis of adaptation options shows that companies would need to increase storage capacity by 2.5% for the 2021–2050 period, and by 25% by the 2071-2100 period. A reduction of ship sizes is not an adaptation option for the three companies in this study, because these companies already use relatively small vessels. This is however an efficient adaptation option for companies which employ larger vessels for transport. Another adaptation option would be to reduce the share of transportation via inland waters, but the feasibility of this option depends on the availability and cost of other modes of transport.
Beuthe, M.; Jourquin, B.; Urbain, N.; Bruinsma, F.; Lingemann, I.; Ubbels, B.; Van Heumen, E.	2012	Estimating the impacts of water depth and new infrastructures on transport by inland navigation: a multimodal approach for the Rhine corridor, in: Procedia - Social and Behavioral Sciences, Volume 54, pp. 387-401 http://www.sciencedirect.com/science/article/pii/S187704 2812042206
Holtmann B.; Scholten, A; Baumhauer, R. Rothstein, B.; Gründer, D, Renner, V; Nilson, E.	2012	Analyses of the Impact of Climate Change on Inland Waterway Transport and Industry on the Rhine, Weißensee Verlag, Bonn Forwarding companies (consignors) depend on low-costs and reliable freight transport. This applies to mass cargo dependent sectors with a focus on bulk cargo, for instance energy, coal and steel, and chemical industries, as well as to the transport of containers. In the Rhine Corridor, big parts of this demand for freight transport are covered by inland waterway transport. Because of the good infrastructure conditions on the Rhine, this mode is characterized by a high level of cost effectiveness and efficiency. In this context, the impact of climate change on the availability of water resources, discharge and water depths (cf. paper by Nilson et al., this volume) may have an impact on various aspects, such as cost structures, transport capacity and reliability of inland waterway transport and, as a function of this, forwarding companies. As part of the KLIWAS project entitled "Water Balance, Water level and Transport Capacity" (KLIWAS 4.01), this paper addresses the effects of possible climate change on cost structures and transport capacity of inland waterway transport on the Rhine and its impact on forwarding companies, taking selected companies from various sectors as examples. It implements and evolves the approaches presented by Holtmann & Bialonski (2009) and Scholten & Rothstein (2009) at the first KLIWAS status conference.

I.5. Impact of low water periods on transport costs

Name of the Project/Author	Year	Summary and Source
Jonkeren et al.	2005 2007 2009	• Jonkeren, O. (2005): An explorative study to inland waterway transport: the Rhine market, Paper to be presented at the 45th Congress of the European Regional Science Association 23-27 August 2005, Department of Spatial Economics, Vrije Universiteit, Amsterdam Climate change is likely to affect many sectors in the economy. The agricultural sector, for example, may be confronted with lower yields and quality of harvested products, and, in the tourist sector, new holiday destinations at higher latitudes may become more popular at the expense of the traditional sun-holiday destinations. This study has addressed the impact of climate change on the transport sector, or, more specifically, on the inland waterway transport sector in North West Europe. Plausibly, the inland waterway transport sector is more vulnerable to climate change than other transport sectors. After all, the quality of the waterway infrastructure is directly dependent on the amount of precipitation and evaporation in the river basins in North West Europe. As more than 63 per cent of all cargo moved by inland waterways in Europe is transported on the River Rhine, we mainly focus on this waterway. The River Rhine is a combined rain-snow river. As a result of climate change, it is expected that the Rhine will be more rain-oriented in the future. More specifically, it is expected that, in winter, precipitation will increase, and higher temperatures will cause a smaller proportion of precipitation to be stored in the form of snow in the Alps. As a result, in winter, more precipitation directly enters rivers, average and peak water levels will be higher, and the number of days with low water levels will decrease. However, as low water levels hardly occur during winter, the reduction of days with low water levels in winter will be small. In summer, besides a reduction in meltwater contribution, there will be less precipitation and more evaporation due to higher temperatures. As a consequence, inland waterway vessels on the Rhine are expected to experience lower water levels, as well as an increase in the number of days with low water levels in summer and autumn (Middelkoop et al., 2000; 2001). Low water levels imply restrictions on the load factor of inland ships. This suggests that the capacity of the inland waterway transport fleet is (severely)

Name of the Project/Author	Year	Summary and Source
		reduced in periods with low water levels. Because low water levels occur far more often than high water levels, this study only focuses on the economic consequences of low water levels.
		• Jonkeren, O.; Van Ommeren, J. & Rietveld, P. (2005): Welfare Effects of Water level Variation on the Rhine through the Inland Waterway Transport Market, In: F. Witlox, W. Dullaert & Vernimmen, B. (ed.): Proceedings of the BIVEC-GIBER Transport Research Day 2005 P II
		• Jonkeren, O.; Rietveld, P. & Van Ommeren, J. (2007): Climate Change and inland waterway transport - welfare effects of low water levels on the River Rhine, Journal of Transport Economics and Policy, Volume 41, Part 3, pp. 387-411
		The authors derive the annual welfare effects of low water levels on the River Rhine employing detailed trip data reported by bargemen between January 2003 and July 2005. They find a considerable effect of water levels on freight price per ton and load factor, but the effect on the price per trip is close to zero. Using water level information over a period of almost 20 years, the average annual welfare loss due to low water levels is estimated to be about €28 million. In years with extremely low water levels, such as in 2003, the loss amounts to about €91 million, about 13 per cent of the market turnover in the part of the Rhine market considered.
		• Jonkeren, O.; Jourquin, B. & Rietveld, P. (2009): Modal-split effects of climate change: The effect of low water levels on the competitive position of inland waterway transport in the River Rhine area, Transportation Research Part A: Policy and Practice, doi:10.1016/j.tra.2009.01.004
		Future climate change is expected to affect inland waterway transport in most main natural waterways in Europe. For the River Rhine it is expected that, in summer, more and longer periods with low water levels will occur. In periods of low water levels inland waterway vessels have to reduce their load factors and, as a result, transport prices per ton will increase. One possible consequence of these higher transport prices is a deterioration of the competitive position of inland waterway transport compared with rail and road transport, and thus a change in modal split. We study this issue using a GIS-based software model called NODUS which provides a tool for the detailed analysis of freight transportation over extensive multimodal networks. We assess the effect of low water levels on the costs of transport operations for inland waterway transport in North West Europe under several climate

Name of the Project/Author	Year	Summary and Source
		scenarios. It turns out, that the effect on the modal split is limited. Under the most extreme climate scenario, inland waterway transport would lose about 5.4% of the quantity that is currently being transported annually in the part of the European inland waterway transport market considered. The very dry year of 2003 can be seen as an analogue for this scenario. • Jonkeren, O.; Van Ommeren, J. & Rietveld, P. (2009 B): Low water levels and trade imbalances in inland waterway transport revisited: interaction effects on transport prices, Beitrag zum BIVEC-GIBER Transport Research Day 2009 The paper focuses on the interaction effect of an imbalance in trade flows and low water levels on transport prices in the inland waterway transport sector. As a result of climate change, in periods with low water levels barges have to reduce their load factor in order not to hit the river ground. As a consequence, barge operators receive a low-water surcharge, a price mark-up per ton transported, to be compensated for the reduction in load factor. According to theory on imbalance in trade flows, transport prices in the high demand direction exceed those in the low demand direction in order to attract carriers to return to the high demand region without cargo. An interesting question that arises from these topics is: will the effect of an exogenous change in transport costs on transport prices depend on the level of imbalance? The question is relevant in the light of climate change as it may be expected that an imbalance in trade flows can enforce or weaken the effect of low water levels on inland waterway transport prices. We employ data from an inland waterway carrier survey, which contains detailed information about trips made by these in North West Europe (about 15,000 observations). The carriers report information (via Internet) about their trips, such as the transport price, region and date of (un)loading, capacity of the ship, number of tons transported, type of cargo, etc. We find indeed that an increase in the transport price due to an exogenous increase in transport costs (in this case: low water levels) is higher if the trip takes place in a high demand direction than if the trip takes place in a low demand direction. We even find that, in some extreme cases, the increase in transport price in the high demand direction may be almost twice the size of the increase in transport price in the low demand direction.

Name of the Project/Author	Year	Summary and Source
Beuthe, M.; Jourquin, B.; Urbain, N.; Bruinsma, F.; Lingemann, I.; Ubbels, B.; Van Heumen, E.	2012	Estimating the impacts of water depth and new infrastructures on transport by inland navigation: a multimodal approach for the Rhine corridor, in: Procedia - Social and Behavioral Sciences, Volume 54, pp. 387-401 http://www.sciencedirect.com/science/article/pii/S1877042812042206
Frachtenspiegel	2001-2014	BS Frachtenspiegel, in: Zeitschrift für Binnenschifffahrt und Wasserstraßen (ZFB), published ten times per year
Case, L.S.; Lave, L.B.	1970	Cost functions for inland waterways transport in the united states, Journal of Transport Economics and Policy; May 1970

I.6. Recent trends in inland navigation

Name of the Project/Author	Year	Summary and Source
Engelkamp, P.	2000	EU-weit eine Spitzenstellung, Entwicklung und Bedeutung von Binnen- und Rheinschifffahrt, Der Rhein, 50. Jahrgang, Heft 2 2000, Landeszentrale für politische Bildung Baden-Württemberg, Stuttgart http://www.buergerimstaat.de/2_00/rhein.pdf

I.7. Future Perspectives of inland navigation

Name of the Project/Author	Year	Summary and Source
Petersen, R.; Pastowski, A.; Lelowski, P.	1993	Entwicklungsperspektiven der Binnenschifffahrtvor dem Hintergrund einer klimagerechten Verkehrspolitik, Endbericht einer Untersuchung im Auftrag der ISA Consult, Wuppertal
PLANCO	2003 2006	• PLANCO (2003): Potentiale und Zukunft der deutschen Binnenschifffahrt - Schlussfolgerungen und Empfehlungen, erstellt im Auftrag des Bundesministeriums für Verkehr, Bau- und Wohnungswesen, Essen • PLANCO (2006): Entwicklungspotenziale von Güterschiffen über 110m Länge (Langfristprognose 2025) und Bewertung erwogener Ausbaumaßnahmen am Neckar (Schleusenkammerverlängerung) - Schlussbericht, erstellt im Auftrag der Wasser- und Schifffahrtsdirektion Südwest, Essen
PINE	2004	PINE (2004): Prospect of Inland Navigation within enlarged Europe

Name of the Project/Author	Year	Summary and Source
		Between February 2003 and June 2004, a consortium consisting of four experienced organisations, i.e., Buck Consultants International (The Netherlands), ProgTrans (Switzerland), VBD European Development Centre for Inland and Coastal Navigation (Germany) and via donau (Austria) carried out the project 'Prospects for Inland Navigation within the enlarged Europe' (PINE). The PINE study dealt primarily with freight transport. The consortium has analysed and compared the situation above all in the four main Inland Waterway Transport (IWT) corridors: the Rhine and its tributaries (Netherlands, mid-western Germany, north of Belgium, Luxembourg, France and Switzerland); the East-West corridor (northern and eastern Germany, Poland and Czech Republic); the Danube corridor (south-eastern Germany, Austria, Slovakia, Hungary, Romania, Bulgaria) and the North-South corridor (parts of the Netherlands and Belgium, France). Furthermore, isolated waterway systems in the United Kingdom, Finland, Sweden, Lithuania, Italy, Spain and Portugal have been analysed. In addition to a comprehensive and up-to-date overview of the inland navigation sector, the study has mapped the potentials and indicated possibilities for promoting the growth of IWT against the background of EU-enlargement. http://ec.europa.eu/transport/sites/transport/files/modes/inland/studies/doc/2004_pine_report_summary_en.pdf
Jonkeren, O.; Van Ommeren, J.; Rietveld, P.	2005	Welfare Effects of Water level Variation on the Rhine through the Inland Waterway Transport Market, In: Witlox, F., Dullaert, W. & Vernimmen, B. (ed.): Proceedings of the BIVEC-GIBER Transport Research Day 2005 Part II The annual welfare effects of low water levels on the river Rhine employing detailed trip data reported by bargemen between January 2003 and July 2005 are derived. A considerable effect of water levels on freight price per ton and load factor is identified, but the effect on the price per trip is close to zero. Using water level information over a period of almost 20 years, the average annual welfare loss due to low water levels is estimated to be about € 28 million. In years with extremely low water levels, such as in 2003, the loss amounts to about € 91 million, about 13% of the market turnover in the part of the Rhine market considered.
Wiegmans, B. W.; Konings, R.	2007	Strategies and innovations to improve the performance of bargetransport, European Journal of Transport and Infrastructure, 7, No. 2 The extended competitive forces model is a tool for analysing the barge transport market in Europe. This paper examines several sub-sectors in the barge transport market with the aim of identifying potentially successful

Name of the Project/Author	Year	Summary and Source
		innovations and strategies for improving competitiveness. Barge transport faces some tough challenges if it is to significantly enhance its competitive position.
Millerd, F.	2005	The economic impact of climate change on Canadian commercial navigation on the Great Lakes, Waterloo, Ontario

The decrease in water depths facing commercial navigation in the Great Lakes–St. Lawrence River system is likely the greatest potential impact of climate change on freight transportation in Canada. This water transportation system is an efficient means of transporting bulk and other commodities through a heavily industrialized part of North America. Great Lakes vessels, however, often have to limit their loads to maintain minimum under-keel clearances when water depths are restricted in harbours and connecting channels. Climate change due to increasing atmospheric concentrations of greenhouse gases is expected to bring about lower water levels and further reduced depths in the Great Lakes, with consequent reductions in vessel cargo capacities and increases in shipping costs. The lower water levels predicted as a result of a doubling of the atmospheric concentration of carbon dioxide could increase annual transportation costs by 29 percent, more moderate climate change could result in a 13 percent increase in annual shipping costs, based on current prices. The impacts vary between commodities and routes.

http://pubs.nrc-cnrc.gc.ca/cwrj/cwrj3004269.html |
| **Millerd, F.** | 2007 | Global Climate Change and Great Lakes International Shipping, Transportation Research Board Special Report 291, Waterloo, Ontario

This study examines the potential impacts of climate change on Great Lakes international commercial navigation and on nonindigenous species. For the Great Lakes climate change is expected to result in lower water levels, shorter times of ice cover, and higher surface water temperatures, affecting both shipping and nonindigenous species. Great Lakes international commercial navigation is defined here as shipping to or from an American or Canadian Great Lakes port and a country other than the United States or Canada. Great Lakes international commercial navigation includes cargo originating in the Great Lakes which moves to another country after being transshipped at ports in the lower St. Lawrence River and Gulf of St. Lawrence. International shipping will be affected by lower lake water levels and less ice cover. Lower water levels will require that, in order to maintain sufficient under-keel clearances, vessels may have to reduce the tonnage of cargo carried on each voyage. Transporting a given tonnage of a commodity will require |

Name of the Project/Author	Year	Summary and Source
		additional trips, thus increasing total shipping costs. This impact is estimated by simulating a typical annual pattern of cargo movements under various climate change and water level conditions. The qualifications to this analysis, typical of analyses of this type, are discussed. The second impact, reduced ice cover, could result in an extension of the navigation season. This impact is discussed in terms of the adjustments season extension may require. Currently, because of ice formation, the locks in the Great Lakes - St. Lawrence River system are closed for at least two months a year. Higher surface water temperatures and reduced ice cover will alter the environment for all species, including nonindigenous species. The changed environment may favour nonindigenous species, compared to native species, encouraging the spread and abundance of nonindigenous species. The altered environment may also facilitate the introduction of further nonindigenous species. After an overview of the effects of climate change on the Great Lakes, the impacts on commercial navigation and nonindigenous species are examined in detail.
Koetse, M.J.; Rietveld, P.	2009	The impact of climate change and weather on transport: An over-view of empirical findings, Transportation Research Part D 14 (2009) 205-221
		This paper presents a survey of the empirical literature on the effects of climate change and weather conditions on the transport sector. Despite mixed evidence on many issues, several patterns can be observed. On a global scale especially shifts in tourism and agricultural production due to increased temperatures may lead to shifts in passenger and freight transport. The predicted rise in sea levels and the associated increase in frequency and intensity of storm surges and flooding incidences may furthermore be some of the most worrying consequences of climate change, especially for coastal areas. Climate change related shifts in weather patterns might also cause infrastructure disruptions. Clear patterns are that precipitation affects road safety by increasing accident frequency but decreasing severity. Precipitation also increases congestion, especially during peak hours. Furthermore, an increased frequency of low water levels may considerably increase costs of inland waterway transport. Despite these insights, the net impact of climate change on generalised costs of the various transport modes are uncertain and ambiguous, with a possible exception for inland waterway transport.
Demirel, E.	2011	Economic Models for Inland Navigation in the Context of Climate Change; Tinbergen Institute Research Series; no. 495; ISBN 978 90 3610 227 8
		The inland navigation market of North-Western Europe faces potential problems due to climate change. Different

Name of the Project/Author	Year	Summary and Source
		measures may be taken by governments, carriers, and customers to cope with the negative effects of climate change. The effects of climate change on the inland navigation market may also be different for regions with different demand for transport by inland navigation. The research carried out in this dissertation can be seen as an investigation into adaptation strategies and the interaction-effects of imbalance and climate change on the inland navigation market. This gives rise to the following two main research questions for this dissertation: (1) What is the optimal barge-size adjustment for barge operators to cope with climate change, and what are the implications of climate change for investments in inland waterway infrastructure by the public sector?; (2) What is the impact of climate change on freight prices in the inland navigation market in the presence of direction dependent freight imbalances? By taking the imbalance issue into account, this study gives insights into how to achieve a fair division of the costs of potential infrastructural investments on an international level. In Chapter 2, Research Question (1) is addressed by formulating a micro-economic model and deriving optimality conditions for instruments to cope with climate change. In addition, numerical results are given for the case of the Rhine market. Research Question (2) is addressed in Chapter 3 by a mainly theoretical investigation into imbalance and its implications for climate change impacts, and then by an empirical analysis of the Rhine market in Chapter 4.
Harrison, P.A.; Holman, I.P.; Cojocaru, G.; Kok, K.; Kontogianni, A.; Metzger, M.J.; Gramberger, M.	2012	Combining qualitative and quantitative understanding for exploring cross-sectoral climate change impacts, adaptation and vulnerability in Europe, Regional Environmental Change, doi10.1007/s1113-012-0361-y

Climate change will affect all sectors of society and the environment at all scales, ranging from the continental to the national and local. Decision-makers and other interested citizens need to be able to access reliable science-based information to help them respond to the risks of climate change impacts and assess opportunities for adaptation. Participatory integrated assessment (IA) tools combine knowledge from diverse scientific disciplines, take account of the value and importance of stakeholder 'lay insight' and facilitate a two-way iterative process of exploration of 'what if's' to enable decision-makers to test ideas and improve their understanding of the complex issues surrounding adaptation to climate change. This paper describes the conceptual design of a participatory IA tool, the CLIMSAVE IA Platform, based on a professionally facilitated stakeholder engagement process. The CLIMSAVE (climate change integrated methodology for cross-sectoral adaptation and vulnerability in Europe) Platform is a user-friendly, interactive web-based tool that allows stakeholders to |

Name of the Project/Author	Year	Summary and Source
		assess climate change impacts and vulnerabilities for a range of sectors, including agriculture, forests, biodiversity, coasts, water resources and urban development. The linking of models for the different sectors enables stakeholders to see how their interactions could affect European landscape change. The relationship between choice, uncertainty and constraints is a key cross-cutting theme in the conduct of past participatory IA. Integrating scenario development processes with an interactive modelling platform is shown to allow the exploration of future uncertainty as a structural feature of such complex problems, encouraging stakeholders to explore adaptation choices within real-world constraints of future resource availability and environmental and institutional capacities, rather than seeking the 'right' answers.

I.8. Future perspectives of transport demand

Name of the Project/Author	Year	Summary and Source
PLANCO	2003	Potentiale und Zukunft der deutschen Binnenschifffahrt - Schlussfolgerungen und Empfehlungen, erstellt im Auftrag des Bundesministeriums für Verkehr, Bau- und Wohnungswesen, Essen http://www.binnenhaefen.de/fileadmin/user_upload/download_alteSeite/all/planco_gutachten_schlussfolgerungen_und_empfehlungen.pdf This report shows the (future) potentials of inland navigation in Germany.
BMVBS	2007	Prognose der deutschlandweiten Verkehrsverflechtungen 2025, FE-Nr. 96.0857/2005,Studie im Auftrag des Bundesministeriums für Verkehr, Bau- und Stadtentwicklung (BMVBS), München, Freiburg
Ickert, L.; Matthes, U.; Rommerskirchen, S.; Weyland, E.; Schlesinger, M.; Limbers, J.	2007	Abschätzung der langfristigen Entwicklung des Güterverkehrs in Deutschland bis 2050, Im Auftrag des Bundesministeriums für Verkehr, Bau und Stadtentwicklung, Basel, 2007, Projekt-Nr. 26.0185/2006 http://dvpi.de/downloads/eu-kraftfahrer/Gueterverkehrs-prognose-2050.pdf This study estimates the long term development of cargo transport in Germany till 2050.
Capros, P.; Mantzos, L.; Papandreou, V.	2008	European Energy and Transport - Trends to 2030 - Update 2007, European Commission - Directorate-General for Energy and Transport, ISBN 978-92-79-07620-6, Luxembourg

Name of the Project/Author	Year	Summary and Source
		http://www.e3mlab.ntua.gr/reports/energy_transport_trends_2030_update_2007_en.pdf

Update 2013:

http://ec.europa.eu/transport/sites/transport/files/media/publications/doc/trends-to-2050-update-2013.pdf |
| **Mann, H.-U.; Ratzenberger, R.; Schubert, M.; Kollberg, B.; Gresser, K.; Konanz, W.; Schneider, W.; Platz, H.; Kotzagiorgis, S.; Tabor, P.** | 2001 | Verkehrsprognose 2015 für die Bundesverkehrswegeplanung, Studie im Auftrag des Bundesministeriums für Verkehr, Bau- und Wohnungswesen, FE.Nr. 96.578/1999, München, Freiburg, Essen

https://www.bmvi.de/SharedDocs/DE/Anlage/VerkehrUndMobilitaet/2001/verkehrsprognose-2015.pdf?__blob=publicationFile

This study contains a prognosis for transport amounts up to 2015 in Germany. |
| **Ickert, L.; Matthes, U.; Rommerskirchen, S.; Weyland, E.; Schlesinger, M.; Limbers, M.** | 2007 | Abschätzung der langfristigen Entwicklung des Güterverkehrs in Deutschland bis 2050, im Auftrag des Bundesministeriums für Verkehr, Bau und Stadtentwicklung, Basel, 2007

http://dvpi.de/downloads/eu-kraftfahrer/Gueterverkehrs-prognose-2050.pdf

This study estimates the long term development of cargo transport in Germany up to 2050. |

I.9. Analysis of discharge development

Name of the Project/Author	Year	Summary and Source
Middelkoop, H.; Daamen, K.; Gellens, D.; Grabs, W.; Kwadijk, J.C.J.; Lang, H.; Parmet, B.W.A.H.; Schaedler, B.; Schulla, J.; Wilke, K.	2001	Impact of climate change on hydrological regimes and water resources management in the Rhine basin, Climatic Change 49, pp. 105-128

The International Commission for the Hydrology of the Rhine basin (CHR) has carried out a research project to assess the impact of climate change on the river flow conditions in the Rhine basin. Along a bottom-up line, different detailed hydrological models with hourly and daily time steps have been developed for representative sub-catchments of the Rhine basin. Along a top- down line, a water balance model for the entire Rhine basin has been developed, which calculates monthly discharges and which was tested on the scale of the major tributaries of the Rhine. Using this set of models, the effects of climate change on the discharge regime in different parts of the Rhine basin were calculated using the results of UKHI and XCCC GCM-experiments. All models indicate the same trends in the changes: higher winter discharge as a result |

Name of the Project/Author	Year	Summary and Source
		of intensified snow-melt and increased winter precipitation, and lower summer discharge due to the reduced winter snow storage and an increase of evapotranspiration. When the results are considered in more detail, however, several differences show up. These can firstly be attributed to different physical characteristics of the studied areas, but different spatial and temporal scales used in the modelling and different representations of several hydrological processes (e.g., evapotranspiration, snow melt) are responsible for the differences found as well. Climate change can affect various socio-economic sectors. Higher temperatures may threaten winter tourism in the lower winter sport areas. The hydrological changes will increase flood risk during winter, whilst low flows during summer will adversely affect inland navigation, and reduce water availability for agriculture and industry. Balancing the required actions against economic cost and the existing uncertainties in the climate change scenarios, a policy of 'no-regret and flexibility' in water management planning and design is recommended, where anticipatory adaptive measures in response to climate change impacts are undertaken in combination with ongoing activities. http://www.adbarno.it/rep/biblio/Impact%20of%20climate%20change%20on%20hydrological%20regimes.pdf
Kleinn, J.	2001	Climate change and runoff statistics in the Rhine basin: a process study with a coupled climate-runoff model, Dissertation, ETH Zürich The consequences of extreme runoff and extreme water levels are within the most important natural hazards induced by weather. The question about the impact of global climate change on the runoff characteristics, especially on the frequency of floods, is of utmost importance. To assess the influence of a warmer climate upon the hydrologic cycle, the pertinent processes are studied using a regional climate model and a distributed hydrologic model. To this end, a model interface is developed to couple the two mode is in a one-way mode. The coupled modelling system consists of two model components: the regional climate model CHRM and the distributed hydrologic model WaSiM. CHRM is driven by ECMWF reanalysis and is ran in a nested mode in 56 km and 14 km horizontal grid spacing (CHRM56 and CHRM14). WaSiM is operated at a horizontal grid spacing of 1 km for the Rhine basin down to Cologne, a basin of about 145'000km2. Such a large basin was chosen to have the spatial variability well represented by the regional climate model within the basin. The hydrologic model uses a time step of 1 hour and is driven by the Output of CHRM56and CHRM14with an appropriate model interface. The model interface accomplishes the scale transition for

Name of the Project/Author	Year	Summary and Source
		the driving fields of the hydrologic model: downscaling of precipitation and temperature, bias corrections for precipitation and winterly surface air temperature, and bilinear interpolation of wind, relative humidity, and radiation. Five winters (1989/90 -1993/94), each from November until January, are considered in the analysis. http://e-collection.library.ethz.ch/eserv/eth:26192/eth-26192-01.pdf
Schwandt, D.	2003	Abflussentwicklung in Teileinzugsgebieten des Rheins - Simulation fuer den Ist-Zustand und fuer Klimaszenarien, Dissertation, PIK Report No. 88, Universitaet Potsdam https://core.ac.uk/display/40584082 This report ''development of runoff in subcatchments of the River Rhine -simulations of the current state and for climate change scenarios'' investigates the impacts of possible future climate changes on runoff and runoff regime in selected subcatchments of the River Rhine. The regional climate in the selected subcatchments Mosel (up to gauge Cochem), Sieg (gauge Menden 1) and Main (gauge Kemmern) is affected by the middle mountain ranges. In a first step, important model processes are parameterized according to catchment characteristics. A representation of the regional hydrology is then produced by using the hydrological model HBV-D. Based on time series of daily measurements (temperature, precipitation) at stations within the catchment, this representation can be used to realistically simulate time series of runoff and discharge. In all examined areas, the quality of simulations of the calibration and validation periods for the current state (standard period of measurements 01/01/1961-12/31/1999) can be regarded as good to excellent. To aid the catchment-specific, extensive and time-consuming data processing, a working environment for the hydrological model HBV-D has been developed. In a second step, the current states of areal precipitation, areal temperature and simulated mean discharge (MQ) are compared to the corresponding states for two scenarios of future climate changes (100 years later, 2061-2099). These scenarios are based on simulated global circulations of one model run for each of two global circulation models (GCM). These global circulations are regionalized (downscaled) using a statistical approach into scenario time series of daily values (temperature, precipitation - input for the hydrological model) at control stations within the individual catchments.
Krahe, P.; Eberle, M.; Richter, K.-G.; Wilke, K.	2004	Simulationen des Wasserhaushalts für das Rheingebiet, KLIWA Berichte Heft 4, Klimaveränderungen und Konsequenzen für die Wasserwirtschaft, ISBN 3-937911-16-2

Name of the Project/Author	Year	Summary and Source
		This study shows the results of simulations of the hydrological balance for the Rhine area with a focus on climate change and its consequences for water supply and distribution.
Goergen, K.; Beersma, J.; Brahmer, G.; Buiteveld, H.; Carambia, M.; de Keizer, O.; Krahe, P.; Nilson, E.; Lammersen, R.; Perrin, C.; Volken, D.	2010	Assessment of Climate Change Impacts on Discharge in the Rhine River Basin, CHR report, I-23, 229 pp., Lelystad. Regional climate change modifies hydrological processes, the water balance and discharge in the Rhine River basin and its tributaries. This has variable impacts, depending on respective sectors, sensitivities and vulnerabilities. Decision makers need suitable information for adequate adaptation strategies. Often the focus is only on sub-catchments, a small regional climate change projection ensemble size or there is a missing link to stakeholders (i.e. water managers). Need for common coordinated discharge projections for the complete catchment. Coordinating role of CHR in hydrological research in the Rhine River catchments. Linkage to and cooperation with the ICPR / AG-H / EG Klima. Goals: Development of a common, consistent research framework. Creation (acquisition, pre-processing, evaluation, bias-correction) of state-of-the-art regional climate change projection ensemble for analyses and as forcing data to hydrological models to generate specific discharge projections (macro-scale). Compilation of partly heterogeneous information into applicable information (synchronized with stakeholders) and quantifiable statements through scenario bandwidths and tendencies of future changes in meteorological and hydrological key diagnostics (mean, low and high flow statistics) for time-spans up to 2050 and 2100, "meta" project, based on existing ongoing projects, results and data of the partners (e.g. KLIWAS)

I.10. Future perspectives of inland navigation

Name of the Project/Author	Year	Summary and Source
De Vries, C.J.	2009	Inlandshipping an outstanding choice - Die Zukunft des Gueterverkehrs und der Binnenschifffahrt in Europa 2010-2011, ed. Bureau Voorlichting Binnenvaart, Rotterdam
Petersen, R.; Pastowski, A.; Lelowski, P.	1993	Entwicklungsperspektiven der Binnenschifffahrt vor dem Hintergrund einer klimagerechten Verkehrspolitik, Endbericht einer Untersuchung im Auftrag der ISA Consult, Wuppertal
PLANCO	2003 2006	• PLANCO (2003): Potentiale und Zukunft der deutschen Binnenschifffahrt - Schlussfolgerungen und Empfehlungen, erstellt im Auftrag des Bundesministeriums für Verkehr, Bau- und

Name of the Project/Author	Year	Summary and Source
		Wohnungswesen, Essen
		• PLANCO (2006): Entwicklungspotenziale von Güterschiffen über 110m Länge (Langfristprognose 2025) und Bewertung erwogener Ausbaumaßnahmen am Neckar (Schleusenkammerverlängerung) - Schlussbericht, erstellt im Auftrag der Wasser- und Schifffahrtsdirektion Südwest, Essen
PINE	2004	Prospect of Inland Navigation within enlarged Europe
		Between February 2003 and June 2004, a consortium consisting of four experienced organisations, i.e., Buck Consultants International (The Netherlands), ProgTrans (Switzerland), VBD European Development Centre for Inland and Coastal Navigation (Germany) and via donau (Austria) carried out the project 'Prospects for Inland Navigation within the enlarged Europe' (PINE). The PINE study dealt primarily with freight transport. The consortium has analysed and compared the situation above all in the four main Inland Waterway Transport (IWT) corridors (see illustration on the next page): the Rhine and its tributaries (Netherlands, mid-western Germany, north of Belgium, Luxembourg, France and Switzerland); the East-West corridor (northern and eastern Germany, Poland and Czech Republic); the Danube corridor (south-eastern Germany, Austria, Slovakia, Hungary, Romania, Bulgaria) and the North-South corridor (parts of the Netherlands and Belgium, France). Furthermore, isolated waterway systems in the United Kingdom, Finland, Sweden, Lithuania, Italy, Spain and Portugal have been analyzed.
		In addition to a comprehensive and up-to-date overview of the inland navigation sector, the study has mapped the potentials and indicated possibilities for promoting the growth of IWT against the background of EU-enlargement.
Jonkeren, O.; Van Ommeren, J.; Rietveld, P.	2005	Welfare Effects of Water level Variation on the Rhine through the Inland Waterway Transport Market, In: F. Witlox, W. Dullaert & B.Vernimmen (ed.): Proceedings of the BIVEC-GIBER Transport Research Day 2005 Part II
Wiegmans, B. W.; Konings, R.	2007	Strategies and innovations to improve the performance of barge transport, European Journal of Transport and Infrastructure, 7, No. 2
		The extended competitive forces model is a tool for analyzing the barge transport market in Europe. This paper examines several sub-sectors in the barge transport market with the aim of identifying potentially successful innovations and strategies for improving competitiveness. Barge transport faces some tough challenges if it is to significantly enhance its competitive position.

Name of the Project/Author	Year	Summary and Source
BfG	2007	Verkehrswirtschaftlicher und ökologischer Vergleich der Verkehrstraeger Straße, Schiene und Wasserstraße, performed by BfG and PLANCO, ==ed==. Wasser- und Schifffahrtsdirektion Ost, Magdeburg
Platina Project	2010 2016	• Platina I: http://platina1.naiades.info/platina/page.php?id=1 • Platina II: http://www.naiades.info/platina/page.php?id=1

I.11. Impacts of climate change on discharge and inland navigation

Name of the Project/Author	Year	Summary and Source
Grabs, W.; Daamen, K.; Gellens, D.; Kwadijk, J. C. J.; Lang, H.; Middelkoop, H.; Parmet, B. W. A. H.; Schädler, B.; Schulla, J.; Wilke, K.	1997	Impact of Climate Change on hydrological regimes and water resources management in the Rhine basin, CHR-report No. I-16, Lelystad The International Commission for the Hydrology of the Rhine basin (CHR) has carried out a research project to assess the impact of climate change on the river flow conditions in the Rhine basin. Along a bottom-up line, different detailed hydrological models with hourly and daily time steps have been developed for representative sub-catchments of the Rhine basin. Along atop-down line, a water balance model for the entire Rhine basin has been developed, which calculates monthly discharges and which was tested on the scale of the major tributaries of the Rhine. Using this set of models, the effects of climate change on the discharge regime in different parts of the Rhine basin were calculated using the results of UKHI and XCCC GCM-experiments. All models indicate the same trends in the changes: higher winter discharge as a result of intensified snow-melt and increased winter precipitation, and lower summer discharge due to the reduced winter snow storage and an increase of evapotranspiration. When the results are considered in more detail, however, several differences show up. These can firstly be attributed to different physical characteristics of the studied areas, but different spatial and temporal scales used in the modelling and different representations of several hydrological processes (e.g., evapotranspiration, snow melt) are responsible for the differences found as well. Climate change can affect various socio-economic sectors. Higher temperatures may threaten winter tourism in the lower winter sport areas. The hydrological changes will increase flood risk during winter, whilst low flows during summer will adversely affect inland navigation, and reduce water availability for agriculture and industry. Balancing the required actions against economic cost and the existing

Name of the Project/Author	Year	Summary and Source
		uncertainties in the climate change scenarios, a policy of 'no-regret and flexibility' in water management planning and design is recommended, where anticipatory adaptive measures in response to climate change impacts are undertaken in combination with ongoing activities.
Middelkoop et al.	2001 2000	• Middelkoop, H.; Daamen, K.; Gellens, D.; Grabs, W.; Kwadijk, J.C.J.; Lang, H.; Parmet, B.W.A.H.; Schaedler, B.; Schulla, J. & Wilke, K. (2001): Impact of climate change on hydrological regimes and water resources management in the Rhine basin, Climatic Change 49, pp. 105-128 • Middelkoop, H. & Kwadijk, J.C.J (2000): Towards integrated Assessment of the implications of global change for water management - the Rhine experience, Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, Volume 26, Issues 7-8, 2001, Pages 553-560
Stock, M.	2005	KLARA: Klimawandel Auswirkungen Risiken Anpassung, Stock, M. (ed.): KLARA - Klimawandel - Auswirkungen, Risiken, Anpassung, Potsdam Institute for Climate Impact Research, PIK Report 99, Potsdam
Zebisch, M.; Grothmann, T.; Schröter, D.; Hasse, C.; Fritsch, U.; Cramer, W.	2005	Klimawandel in Deutschland - Vulnerabilität und Anpassungsstrategien klimasensitiver Systeme, Umweltforschungsplan des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit, Förderkennzeichen (UFOPLAN) 201 41 253
Bates, B.C.; Kundzewicz, Z.W.; Wu, S.; Palutikof, J.P.	2008	Climate Change and Water, Technical Paper VI of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Genf
PIANC	2008	Climate Change and Navigation - Waterborne transport, ports and waterways: A review of climate change drivers, impacts, responses and mitigation, PIANC - EnviCom - Task Group 3 The main goal for EnviCom Task Group 3 "Climate Change and Navigation" was to discuss the climate change related issues for the navigation sector, and how to understand and to deal with the knowledge about climate change and the various projected scenarios. The assumptions, definitions and findings of the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007) represent a peer-reviewed body of knowledge that identifies changes in climate and projected future changes. Projections for 2100 suggest a global mean sea level rise of a few decimetres and a greater frequency and intensity of extreme weather events. Even if emissions of greenhouse

Name of the Project/Author	Year	Summary and Source
		gases (especially carbon dioxide CO_2) stop today, these changes would continue for many decades and in the case of the sea level for centuries. This report reviews climate change impacts on maritime and inland navigation including sea level rise, wind conditions, wave action, tidal and surge propagation and range, ocean circulation, storms, coastal hydrodynamics, sea chemistry, environmentally protected areas, ice conditions, icing, water supply and quality in inland rivers, extreme hydrological conditions, and coastal, estuarine and river morphology. Potential adaptation and mitigation responses are identified. Navigation contributions to greenhouse gas (GHG) emissions are discussed, along with opportunities for navigation to contribute both to overall decreases in anthropogenic GHG, and, through use of alternative fuels, to decreases in other pollutants.
Schweighofer, J.	2014	The impact of extreme weather and climate change on inland waterway transport; Natural Hazards; May 2014, Volume 72, Issue 1, pp. 23-40
		Similarly to other modes of transport, inland waterway transport has to deal with weather events, affecting navigation conditions and the infrastructure on inland waterways. Most significant extreme weather events result from high precipitation, droughts and temperatures below zero degrees Celsius. Heavy rainfall, in particular in association with snow melt, may lead to floods resulting in suspension of navigation and causing damage to the inland waterway infrastructure as well as the property and health of human beings living in areas exposed to flooding. Long periods of drought may lead to reduced discharge and low water levels, limiting the cargo-carrying capacity of vessels and increasing the specific costs of transportation. Temperatures below zero degrees Celsius over a longer period may cause the appearance of ice on waterways, leading to suspension of navigation and possible damage to infrastructure, for example, buoys. Neither extreme weather events as well as climate change are new phenomena nor is their general occurrence expected to change suddenly. However, due to climate change, extreme weather events may change positively or adversely in severity and frequency of occurrence, depending on the respective weather event and the location of its occurrence. This paper gives an overview of the impact of extreme weather events on inland waterway transport in Europe, focused on the Rhine–Main–Danube corridor, followed by a discussion on how climate change will change these events and their impacts.

I.12. Adaptation options

Name of the Project/Author	Year	Summary and Source
Bosschieter, C.G.	2005	Klimaatverandering en binnenvaart - Effecten op de binnenvaart van meer extreem lage (en hoge) waterstanden op de Rijn, Port Research Centre Rotterdam-Delft, ISBN 90-5638-142-3
Petersen, R.; Pastowski, A.; Lelowski, P.	1993	Entwicklungsperspektiven der Binnenschifffahrtvor dem Hintergrund einer klimagerechten Verkehrspolitik, Endbericht einer Untersuchung im Auftrag der ISA Consult, Wuppertal
VBD	2004	Technische und wissenschaftliche Konzepte fuer flussangepasste Binnenschiffe, Versuchsanstalt fuer Binnenschiffbau e.V., Duisburg

I.13. Information on waterways, harbours etc.:

Name of the Project/Author	Year	Summary and Source
WESKA	2006	Europaeischer Schifffahrts- und Hafenkalender, Ausgabe 2006, Verein fuer europaeische Binnenschifffahrt und Wasserstrassen e.V., Duisburg
Zigic, B.	undated	Particularities of navigation on inland waterways; *www.factline.com/download/136365.1*

Part II

II.1. Shipping limitations in the Danube region

In the Danube region several factors limit inland navigation. One of them are the so called 'bottlenecks areas' with difficult shipping conditions (mostly stretches of lower water due to rock formations in the river beds). In addition, laws limit the use of inland navigation in the region. Both limitations define which ship sizes can be used. The limiting factors, as well as how much cargo vessels can transport at certain water levels are presented in the following chapter.

II.1.1 Locations of bottlenecks along the Danube

While low water levels have an impact on inland navigation along the whole river, it is most severe at the so called bottlenecks. At these bottlenecks the water is especially low then (e.g. due to massive rock formations in the river beds). The water depth at those bottlenecks therefore defines the amount of cargo a ship can carry on its journey, if it has to pass one (or several) of them. To be able to caculate how much cargo a ship can transport during low water periods and thereby the economic impact low water has due to limiting the amount of cargo, the location of bottlenecks as well as their water depth during low water periods, have to be identified.

Bottlenecks can be found along the whole Danube, in some areas limiting the draft of inland navigation vessels by a maximum water depth of 150cm during low water periods, in others at water depth of 2m or 220cm. The maximum draft of the vessels is roughly 30cm less, as free water under the vessel is needed to navigate it safely. Depending on the country and area they are in, those bottlenecks are either smaller patches or longer stretches of the Danube River. Some bottlenecks, like the area between Straubingen and Vilshofen in Germany, will be hard to remove due to environmental reasons. Table 1 illustrates the most important bottlenecks along the Danube. It can be seen that the bottlenecks are more or less spaced out evenly.

Table 1: Bottlenecks along the Danube; Source: NEWADA (undated); WESKA 2006, UN 2013

Country	Danube kilometer	Name	Problem	fairway depth (cm)	Depth of fairway in fords at RNW (cm)	Number of days/year with low water
Germany	Straubing to Vilshofen		low fairway depth	155		
	2,412.72	Kehlheim	bottleneck		120	
	2,402.2 to 2,402		discontinuity		35	
	2,381.5 to 2,381.28		discontinuity		185	
	2,355 to 2,354.92		discontinuity		77	
	2,330.6 to 2,330.48		discontinuity		60	
	2,321.31	Straubingen	bottleneck		170	
	2,318.73		bottleneck		200	
	2,311.27		low height (5.0m)			
	2,285.87	Deggendorf	low height (4.70m)			
	2,285.87	Deggendorf	bottleneck		200	
	2,249.85	Vilshofen	bottleneck		210	
	2,230.28		low height (6.3m)			
	2,225.75		low height (5.15m)			
Austria	2,037.0 to 2,005.0		low fairway depth	down to 220		
	2,027.7	Aggsbach	bottleneck		210	
	2,022.2	Schwallenbach	bottleneck		250	
	2,018.8	Hofarnsdorf	bottleneck		260	
	2,013.8	Weißenkirchen	bottleneck		230	
	1,921.0 to 1,873.0		low fairway depth			
	1,898,6 to 1,898	Regelbrunn	bottleneck		210	
	1,896,2 to 1,895.7	Rote Werd	bottleneck		190	
	1,883.2 to 1,882.4	Wendeplatz Theben	bottleneck		240	
	1.873.2 to 1.872		bottleneck		210	
Hungary	1,810,0 to 1,708.2		low maximum draught during dry season	150		
	1,806.35		low height (8.85m)			
	1,770.4		low height (8.65m)			
	1,767.8		low height (9.08m)			

	1,735.5 to 1,733.7		narrow point			
	1,708.2 to 1,433.0		low maximum draught	150		
	1,651.55 to 1,648.9		one way only			
Slovakia	1,880.26 to 1,867.0		Insufficient depth at low water level			
	1,868.14		low height (8.59m)			
	1,819.3		low height (8.90m)			
	1,810,0 to 1,708.2		insufficient depth at low water level and insufficient height under the bridges			
Serbia	1,405.6 to 1,227.9		narrow fairway conditions.			
	1,393.2 to 1,391.3		sharp turn			
	1,379 to 1,368.5		sharp turn			
	1,366.5		low height (8.15m)			
	1,254.25		low height (6.82m)			
	863 to 845.5		low fairway depth during dry season	220–230		7 to 15
Romania	863 to 175		low fairway depth during dry season	below 250 at several critical sections		
	863 to 845.5		low fairway depth during dry season	220–230		7 to 15
	845.5 to 610		low fairway depth during dry season	210-220		10 to 15
	610 to 375		low fairway depth during dry season	180–200		20 to 40
	375 to 300		low fairway depth during dry season	160–220		30 to 70
	300 to 175		low fairway depth during dry season	190–210		15 to 30
	170 to the Black Sea		low fairway depth during dry season	below 730		10 to 20

II.1.2 Ship sizes in the Danube Region

In the Danube region two kinds of shipping limitations exist, which are closely connected: those given by natural conditions (e.g. natural bottlenecks) and those fixed by rules and laws. The later ones mostly only regulate the limitations given by natural factors or buildings (like bridges or locks). These regulations do not only limit the size of the ships, but also the number of barges allowed in each part of the river.

The allowed ship sizes in on river determain the amount of goods transported on the river.

According to Donaukommission (2004), each pushing boat is allowed to push the following number of barges in the named area of the river (Table 2):

Table 2: Number of barges each pushing boat is allowed to push in the named area of the river, Donaukommission (2004)

Area	Length of river stretch (km)	Number of barges allowed
Kehlheim- Regensburg	32	2
Regensburg – Devin	500	4
Devin – estuary of Save	704	6
Estuary of Save – Sulina	1175	9

These sizes are (amongst others) limited by the lock sizes in the area. Table 3 gives the lock sizes as recommended by the Donaukomission (2004).

Table 3: Lock sizes in the named area of the river, Donaukommission (2004)

Area of the locks	Danube kilometer	length (m) of the locks	width (m) of the locks	depth (m) of the locks
Kehlheim-Regensburg	2414.7-2379.0	190	12	4
Regensburg – Wien	2379.0-1920.3	230	24	4
Wien – Gönyü	1920.3-1791.0	230	24	4.5
Gönyü – Budapest	1791.0-1646.5	260-310	34	4.5
Budapest – Braila	1646.5-170	310	34	4.5

In addition to these recommendations, Germany and Austria have regulations concerning the maximum ship size allowed on their parts of the river (Segerer 2001). While on the German part of the Danube the maximum width of ships is 11.45m the width is Austria is 23m. The length differs as well with 110m on Germany and 230m in Austria. In addition to that, the maximum gauge on the German part of the Danube is 2.8m. The sizes in Germany are in huge parts determained by the size of the locks along the River Main and Main-Danube Channel (MDK; Segerer 2001).

II.1.3 Minimum water level required for different vessels

The minimum water level required depends on the chosen vessel. Long before a ship is unable to pass a certain bottleneck, its bearing capacity is limited. Therefore the water level at which the bearing capacity starts to be limited is more important than the minimum water level a ship is able to pass a bottleneck (empty). Due to economic reasons, most shippers decide to switch to rivers with higher water levels or wait in a harbour long before their ship is not able to pass bottlenecks anymore (see e.g. Scholten 2010).

The bearing capacity of different ship types for different drafts is shown in table 4. Especially interesting are those drafts where the first limitations of the bearing capacities occur. These are marked in red. For bigger ships the limitations start at a gauge of 3.5m

(so a water level of at least 3.70m or 3.80m is needed), while smaller ships are limited at water levels below 2.70m or 2.80m (draft of 2.50m). From the same table also the share of the maximum bearing capacity that can be transported at certain water levels can be calculated, as can be seen in table 5.

In table 6 water levels at low water along the Danube are given. The combination of these two tables allows to calculate the bearing capacity of certain ship types during low water events. If in addition to this the number of ships per size is included in the calculation, the bearing capacity of the fleet passing this point during low water situations can be calculated.

Table 4: Bearing capacity of different ship types at different water levels; WESKA 2006

gauge	Large inland freight vessel (135m*11.45m)	Large inland freight vessel (110m*11.40m)	Large inland freight vessel (100m*14.18m)	Large inland freight vessel (105m*9.5m)	„Johann Welker" (85m*9.50m)	„Johann Welker" (80m*9.50m)	„Gustav Koenigs" (80m*8.20m)	„Gustav Koenigs" (67m*8.20m)	„Karl Vortisch" (57m*7.04m)	„Oskar Teubert" (53m*6.29m)	„Theodor Bayer" (48m*5.05m)	„Theodor Bayer" (38.5m*5.05m)
3.5	3700	3000	2000	1850	1350	1280	1100	1000	560	550	370	270
3.4	3520	2850	2000	1850	1350	1280	1100	1000	560	550	370	270
3	2936	2377	2000	1850	1350	1280	1100	1000	560	550	370	270
2.5	2225	1800	2000	1684	1350	1280	1100	1000	560	550	370	270
2.4	2060	1667	1815	1591	1262	1212	1040	924	545	517	359	260
2	1475	1200	1302		950	940	800	670	460	390	300	220
1.5	750	603	662		570	600	500	420	285	240	190	130

Table 5: Share of bearing capacity of different ship types at different water levels; WESKA 2006

gauge	Large inland freight vessel (135m*11.45m)	Large inland freight vessel (110m*11.40m)	Large inland freight vessel (100m*14.18m)	Large inland freight vessel (105m*9.5m)	„Johann Welker" (85m*9.50m)	„Johann Welker" (80m*9.50m)	„Gustav Koenigs" (80m*8.20m)	„Gustav Koenigs" (67m*8.20m)	„Karl Vortisch" (57m*7.04m)	„Oskar Teubert" (53m*6.29m)	„Theodor Bayer" (48m*5.05m)	„Theodor Bayer" (38.5m*5.05m)
3.5	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
3.4	95%	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
3	79%	79%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
2.5	60%	60%	100%	91%	100%	100%	100%	100%	100%	100%	100%	100%
2.4	56%	56%	91%	86%	93%	95%	95%	92%	97%	94%	97%	96%
2	40%	40%	65%		70%	73%	73%	67%	82%	71%	81%	81%
1.5	20%	20%	33%		42%	47%	45%	42%	51%	44%	51%	48%

But not only high water limits inland navigation. During periods of high water above a certain level, inland navigation on the Danube is stopped by law as waves caused by inland navigation vessels might damage the infrastructure. In addition, stronger currents might endanger the vessels or limit their navigability and/or bridges might be too low to be safely passed. However, high water periods only last a few days, while low water is a longer lasting limitation for inland navigation (Rothstein 2007). Therefor the following chapters focus on the impact of low water periods on inland navigation. The table that shows the water levels and/or discharge at which inland navigation on the Danube has to stop can be seen in Annex C.

Table 6: Low water levels (RNW) and low water discharge (RNQ), impacting inland navigation; Source: WESKA 2006

Gauge	Danube km	RNQ (m³/s)	RNW (cm)
Kehlheim	2414.84	218	250
Oberndorf	2397.38	182	170
Schwabelweis	2376.49		292
Pfatter	2350.7		310
Pfelling	2305.53	214	290
Deggendorf	2284.43		218
Hofkirchen	2256.86	360	207
Passau	2226.7	700	415
Achtleiten	2223.21	898	258
Wilhering	2144.3		240
Linz	2135.17	730	316
Mauthausen	2110.98		380
Grein	2079.4		669
Kienstock	2015.21	918	177
Dürnstein	2009		258
Korneuburg	1941.3		191
Wien	1941	976	191
Wildungsmauer	1894.72		162
Hainburg	1883	975	121
Bratislava	1868.75		233
Komarno	1767.05		98
Nagymaros	1694.6		-10
Budapest	1646.5		80
Paks	1531.3		-6
Mohacs	1446.8		144
Bezdan	1425.5		30
Novi Sad	1255.3		80
Zemun	1173		223
Gruia	851		34
Lom	743.3		174
Turnu-Magurele	597		34
Oltenita	430		9
Silistra	375.5		86
Calarasi	370.5		-1
Cernavoda	300		-35
Hirsova	253		19
Braila	170		46
Galati	150		52
Reni	127.23		46
Isacea	103.8		42

II.2. Capacity of the Danube fleet and the amount of cargo transported

In addition to the natural limitations and the limitations of inland navigation by law, the capacity of inland navigation for a certain river is defined by its fleet and the bearing capacity of said fleet. Therefore in the following chapter the number of vessels per country for solid and fluid cargo as well as their bearing capacity is shown.

II.2.1 Number of vessels per sector of the Danube

While Germany has a comparatively big fleet of inland navigation vessels (compared to other Danube countries), only a relatively small share of those vessels is employed on the Danube on a regular basis. Most of the German ships travel on the Rhine and other waterways most of the time. Therefore the German fleet is excluded from the following figures. Figures including the German fleet can be found in Annex D.

With roughly 800 ships in 2012, Romania has the second biggest share in total number of ships, followed by Ukraine, Serbia and Hungary (roughly 400 vessels each) (figure 1). Compared to the number of ships for dry cargo, the number of barges for fluids are very small (figure 2), which has an impact on the ability to transport fluids like crude oil, chemicals or liquid gas via inland navigation.

Especially in combination with the question of the impact of low water on the bearing capacity of the ship fleet, the sizes of the individual ships within the fleet are important. The sizes of the ships for the Danube fleet (sum over all countries) is shown in figure 3. It can be seen that most ships on the Danube are of medium size of about 1000 to 1500t per ship. This ship size is limited in its bearing capacity at water levels below 2.70m (gauge of 2.50m plus 20cm of free water underneath).
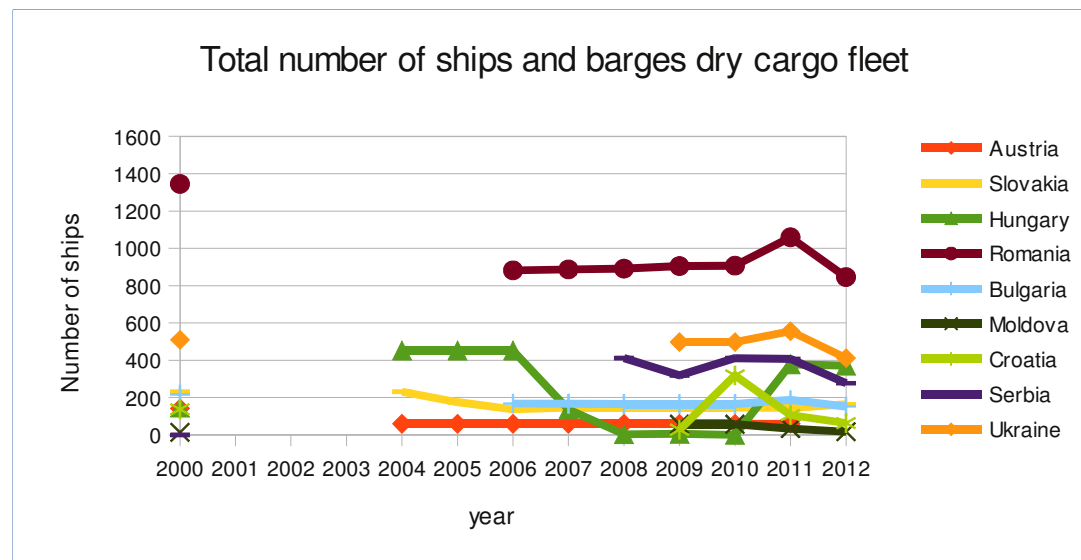
Figure 1: Total number of ships and barges for dry cargo – without German fleet; Source: ZKR Marketobservations 2005-2012; WESKA 2006; Donaukommission (2014)
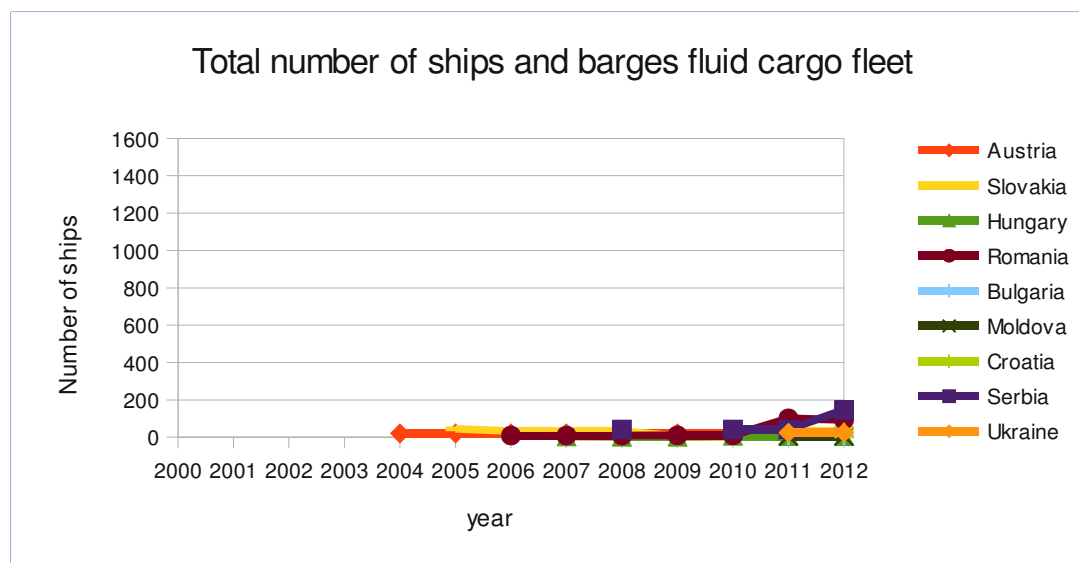
Figure 2: Total number of ships and barges for fluid cargo – without German fleet; Source: ZKR Marketobservations 2005-2012; WESKA 2006; Donaukommission (2014)
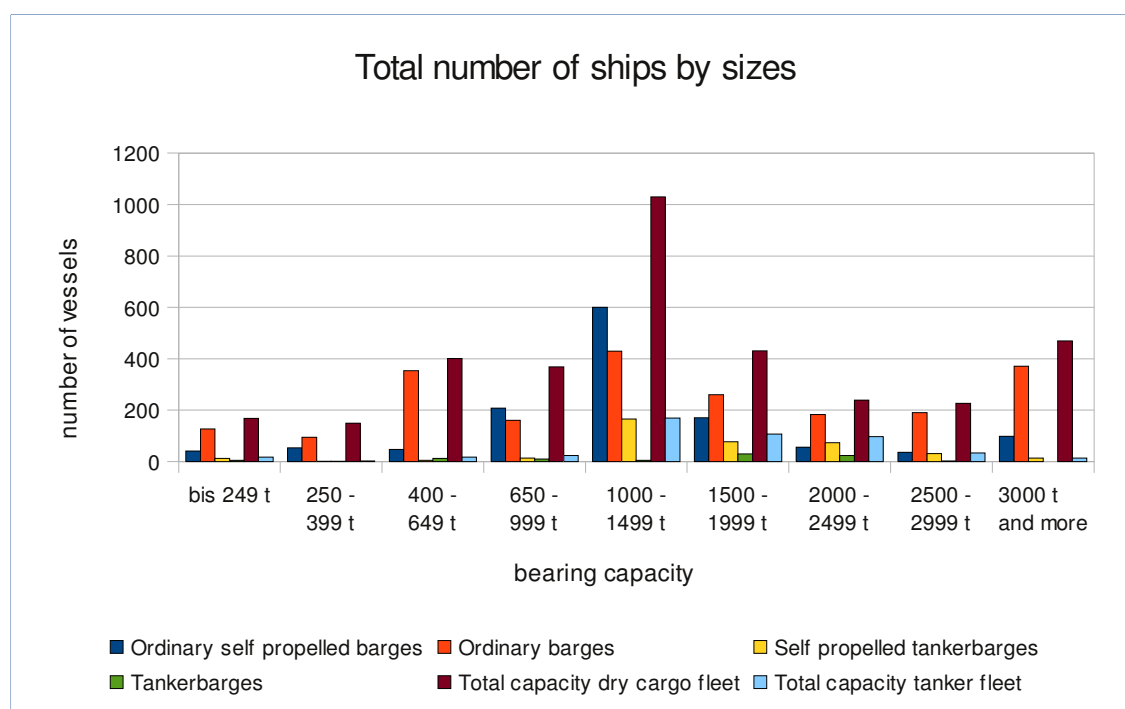
Figure 3: Total number of ships by sizes; Source: ZKR Marketobservations 2007

II.2.2 Amount of goods per sector of the Danube

The amounts of cargo by category can be seen in figure 4. As can be seen which goods are transported most varies hugely from country to country. While e.g. in Bulgaria crude and manufactured minerals and building materials are transported most by inland navigation, in Rumania and Austria ore for the iron and steel industry has the highest share. In Hungary agricultural products have the highest share in transport via inland navigation.
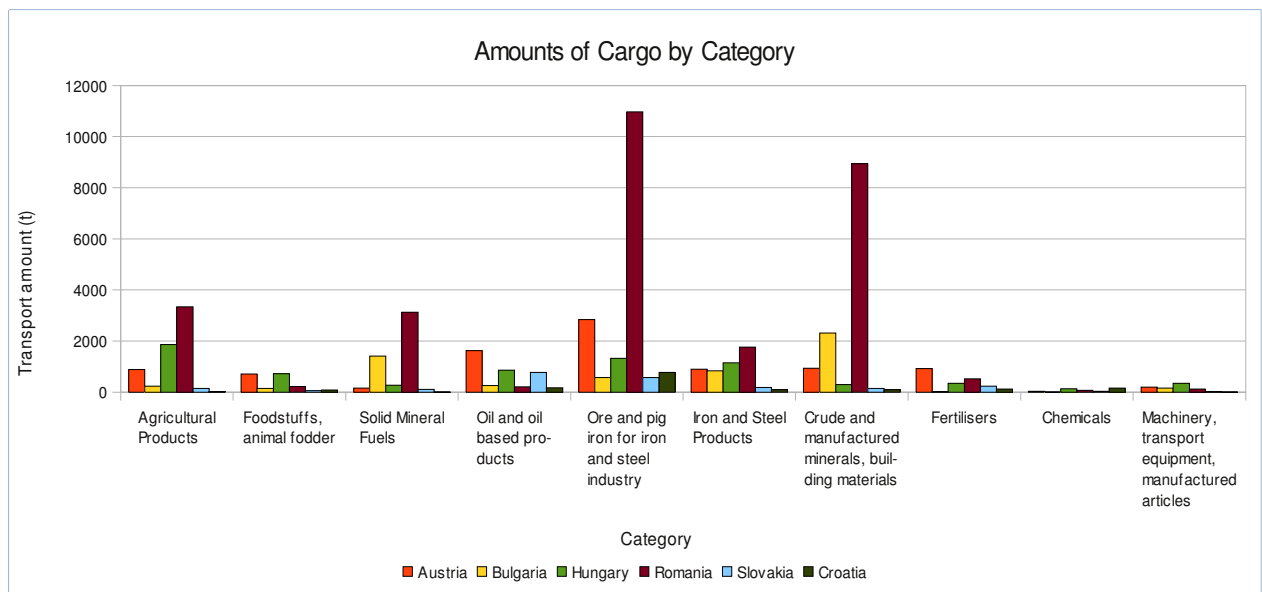
Figure 4: Amounts of Cargo by Category and Danube Countries without Germany in 2006; Source: ZKR Marketobservations 2007-1; 2005-1

Figure 5 illustrates the cargo transport on the Danube for different areas and different years. Two items become obvious region- and time-wise: the transport-amount via inland navigation is highest in the Lower Danube, especially in Romania, Bulgaria and Ukraine, while the transport amounts in the Upper and Middle Danube are similar. In 2004 the absolute maximum of transport via inland navigation on the Danube was reached. In Austria, inland navigation had the highest share in 2007. In general in the years after 2000, the cargo-amounts transported via inland navigation were higher than in the decades before. Only in Hungary the 1980's have a greater transport-amount via inland navigation than in the last decade.
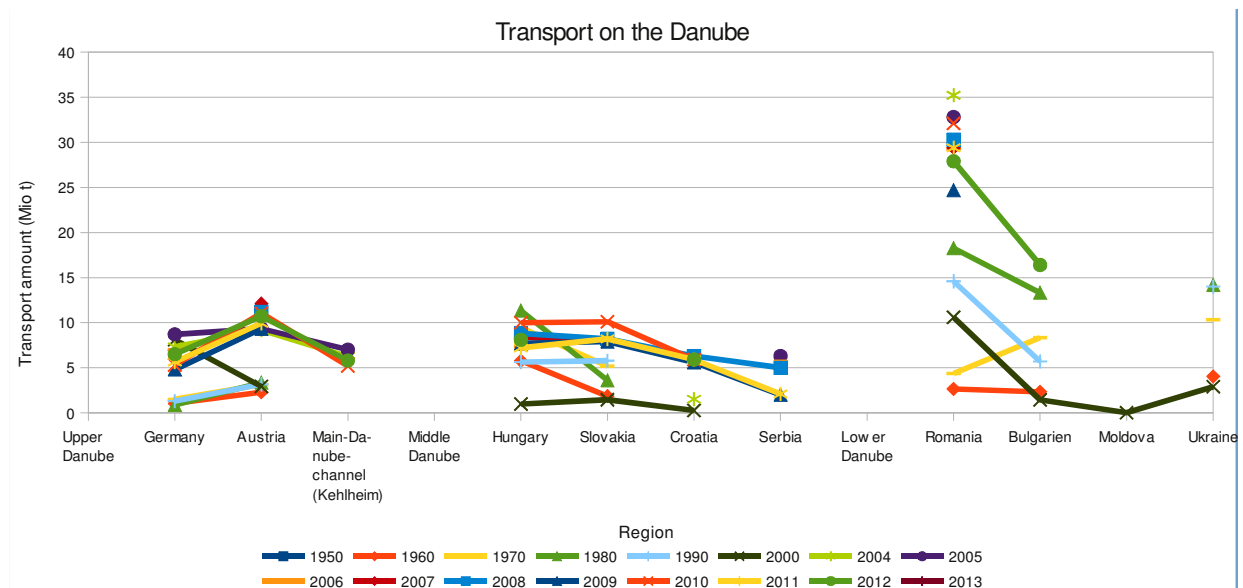
Figure 5: Cargo transport on the Danube (Mio t); Source: ZKR Marketobservations 2006-2; Donaukommission (2014), Donaukommission 2004

II.3. Data sets used for the following analysis

To analyze the economic impacts of low water periods on inland navigation, mostly to kinds of data are needed: water levels of gauges near the identified bottlenecks and inland navigation data. Both will be presented in the following chapter.

II.3.1 Inland navigation data

Historic data on inland navigation on the Danube in and from Germany can be found in published statistics. These contain information on a yearly basis for individual German harbors which transport cargo to the Danube region. This information is categorized into cargo groups, transport within Germany, trans-boundary receipt and distribution and transit. In addition to the German harbors, the ARA harbors (Amsterdam, Rotterdam, Antwerp) are covered as well as data on country level. In total, the following areas/harbors are covered in the data-set:

Table 7: Available data sets – harbours and years covered; Source: Statistik Austria (2008-2012), Destatis (2002-2010)

Area	years covered
ARA harbors:	
Amsterdam	2002-2010
Rotterdam	2002-2010
Antwerp	2002-2010
Harbors within Germany:	
Duisburg	2002-2010
Düsseldorf	2002-2010
Karlsruhe	2002-2010
Köln	2002-2010
Krefeld	2002-2010
Ludwigshafen	2002-2010
Mainz	2002-2010
Mannheim	2002-2010
Passau	2002-2010
Regensburg	2002-2010
Countries in the Danube area	
Bulgaria	2002-2010
Croatia	2002-2010
Austria	2002-2010
Rumania	2002-2010
Slovakia	2002-2010
Slovenia	2002-2010
Czech Republic	2002-2010
Hungary	2002-2010

For this analysis, a summarized set of tables of these years and harbors including the cargo groups transported and from where they are transported was set up. It also contains tables giving information which cargo groups are transported in which country and which German and international harbors have connections to which countries in the Danube region. This data-collection allows to identify transport routes from and to the Danube region and therefore which bottlenecks have to be passed by on the route.

Another set of tables, referred to as Statistik Austria (2008-2012), contains additional information concerning Austrian harbors and transit transport through Austria on a monthly basis. Of special interest in this context is the information about 'Auslastung' = degree of capacity utilization, separated for transport within Austria, trans-boundary receipt and distribution and transit. The Austrian data-set also contains information about the country in which cargo was loaded and which country it was transported to. Of special interest here are the countries Germany, Netherlands, Slovenia and Hungary, which are covered by the data-set. In addition to that, amounts of cargo handled in several Austrian harbors by cargo group are given on a monthly basis. Covered harbors are: Wien, Linz, Krems and Enns. The data is available on a monthly basis for the years 2008 to 2013. This statistic only gives the information as 'transport services' (in tkm), while for some calculations (e.g. in chapter II.4.4) the 'transport amount' (in t) is needed. But, as the transport connection (e.g. Hungary to ARA) is known the data can be transferred into the needed unit t by dividing it with the average distance. If, for example, the connection Hungary to ARA is used, the given tkm are divided by the distance the ship has to travel from ARA to the Main (511km) plus the distance it has to travel on the Main to the MDK (384km) plus the length of the Main-Danube Channel (MDK; 171km) and finally the distance the ship travels on the Danube. As several destinations in Hungary exist, a destination of medium distance within Hungary was chosen. This leads to a distance of 832km and therefore to a total distance from the ARA harbors of 1898km. The same exercise was performed for all connections needed to gain information about the tons transported on each connection.

II.3.2 Water level condition data

In chapter II.1.1 the following bottlenecks have been identified for Austria: Rötelstein-Rothe Werd (Danube km 1883.2-1896.2) and Aggsbach (Danube km 2027.7). In the data-set the following gauges could be identified to contain information about the water level at those bottlenecks: Kienstock, Wildungsmauer, Bad Deutsch Altenburg and Hainburg. Monthly data for all four gauges was published by BMLFUW (2002-2012) with their monthly mean, minimum and maximum. Daily data can be found for the gauges Kienstock, Wildungsmauer and Hainburg. Kienstock and Hainburg are given with their daily water levels, while Wildungsmauer is given with discharge data. Discharge data for Kienstock and Hainburg can be found as well though, while no water level information for Wildungsmauer can be obtained. In total, information about water levels at several gauges in Austria on a monthly and daily basis for the years 2002 to 2012 are published by BMLFUW (2002-2012).

Figure 6 shows the water level at the gauge Passau for the years 2001 to 2013. A yellow line marks the highest water level that still allows navigation for this gauge, a red line marks the water levels at low water for this gauge. While the water level is too high for navigation on 35 days in this 13 year period, the water level drops below the low-water-mark on 408 days, which shows that low water potentially has the much bigger impact on inland navigation. While during periods of high water after a certain water level inland navigation has to stop (to protect infrastructure etc.), during low water periods at least in Germany, the operator of the ship is responsible for its safe navigation. There is no lower limit at which inland navigation becomes illegal on the rivers. However, if the ship is not able to be operated safely anymore (risk of accidents/destruction of the vessel), the ship operator will decide to either wait in a safe harbor or take cargo on another river with higher water levels. Same is true if the amount of cargo a vessel can carry is so limited that the trip is not economical anymore. The Frachtenspiegel states in several

publications that ship operators have trouble getting additional money for transporting cargo during low water periods on the Danube (while this is usually the case on other rivers like the Rhine). This is an indicator that companies do not depend on (timely) transport via inland navigation because the can either switch to train transport or delay the transport till after the low water period.
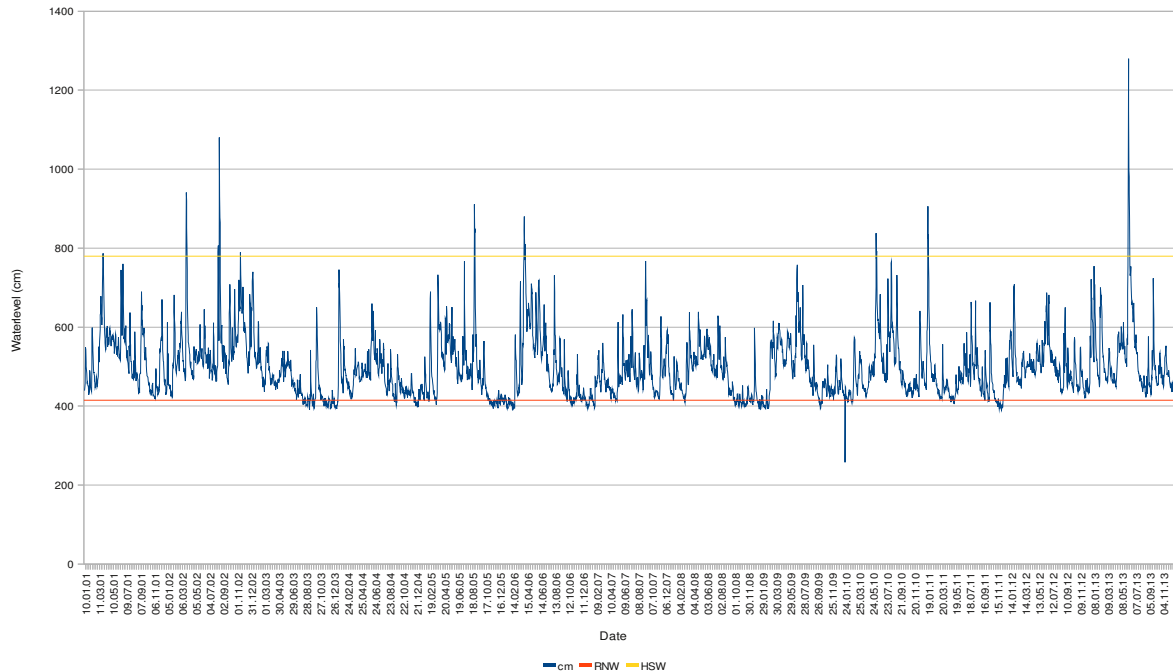

Figure 6: Water level at gauge Passau, including highest navigable water level and low water level; Source: own figure based on Wetteronline (2000-2013)

II.3.3 Freight cost data

Freight cost data for the Danube was published in the magazine "Zeitschrift für Binnenschifffahrt und Wasserstrassen" which is released on a monthly basis by the "Bundesverband der Deutschen Binnenschifffahrt e.V." in Duisburg. It contains information about freight costs on the River Rhine as well. Data from December 1999 till June 2013 were collected for this analysis (longer time series are available).

However, due to technical problems as well as other, not always named reasons, not all months of the magazine contain the freight cost information. Especially December and/or January of the years is often missing. On top of that, even if the magazine contains the freight cost table, not all connections are always covered – no reasons given. A table in Annex E shows which months were covered by the magazine (yellow crosses indicate missing data for that month/connection). These data-sets were collected to analyze a possible correlation of the freight costs with the water level at the bottlenecks.

As can be seen in figure 7, the price per ton (€) for transports from or to the ARA harbors from or to Austria vary over time. The water level on Danube and Rhine is one factor that triggers these variations, but there are several other factors, influencing the prices. While the Frachtenspiegel often gives low water situations as a reason for rising prices (e.g. in August 2001, July 2003, January 2004 etc.), other reasons are given as well. Some should be named here. In October 2002 a faltering economy is given as a reason for falling prices. In March 2004, prices get reduced because many ships searching for cargo arrive form the lower Danube in Austria. In September 2003 a blockage of the Main leads to a huge jump in prices. While the prices for transport in

both directions often show a similar development, sometimes one direction shows a more intense impact (e.g. in case of the Main blockage) than the other direction.
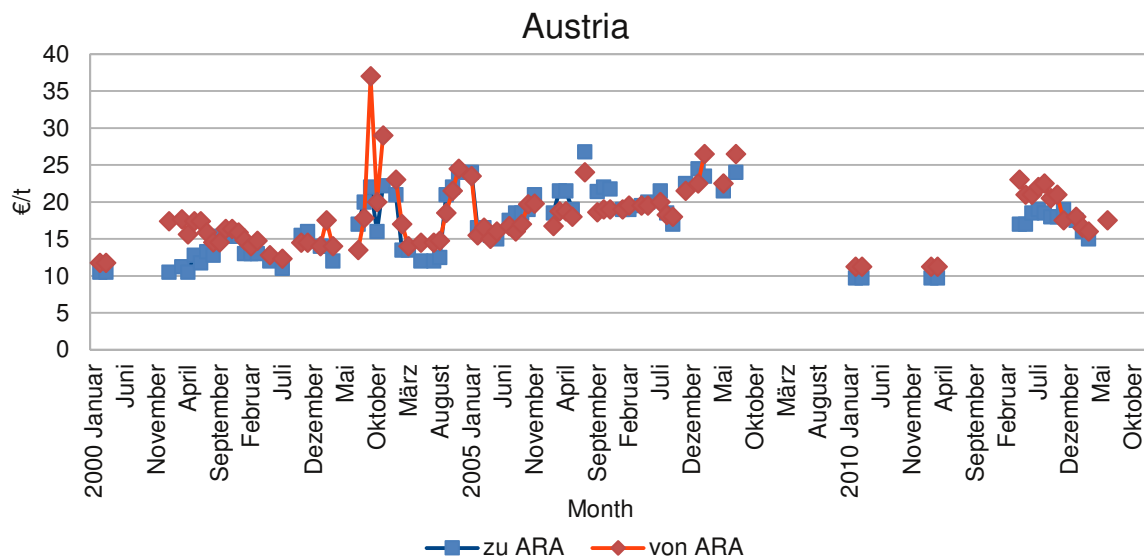
Figure 7: Frachtenspiegel, Euros per ton from 2001 to 2013; Connection of Austria from or to the ARA harbors; Source: Frachtenspiegel 2001-2013

In addition to low water periods, ice can lead to shipping limitations or rather the blockage of certain parts on a ships route. This is especially the case in slow flowing rivers with many gauges and channels. For the Danube, one of the areas where ice might cause a problem for transport is the Main-Danube channel. For example in January and February 2005 ice in the Main-Danube channel lead to more than 300 ships waiting in the upper Danube (ZKR 2006). In 2006 shipping on the Danube was impossible for 15 days due to high water levels and 10 days due to ice. Low water levels lead to delayed transports as well, especially in the areas of bottlenecks (ZKR 2007). 2007 had comparatively good water levels. The draft never dropped below 180cm and only 20% of the year the draft was below 240cm. High water did not restrict the inland navigation transport either (ZKR 2008).

Impact of competition with train transport on the price level along the Danube

In general, the train is a strong competitor along the Danube. A study from Seitz et al. (2006) analyzed the competition in container transport by inland navigation and train in the Danube region, analyzing several ship sizes and possible harbors. With the current (2006) fleet, not made to carry containers, using inland navigation vessels for transport of containers to Vienna is about the same price as using train transport while being 2 days slower and having a higher risk of more delays due to low and high water. This leads to many companies being critical about using inland navigation for shipping and prefer to use the well-known train connections. But, calculated with ships that are (newly) made to transport containers, like many vessels on the Rhine are, the price for shipping containers via inland navigation to Vienna is almost half the price the train offers for those connections. Seitz et al. (2006) claim that most shippers would be willing to try using inland navigation, if the price is competitive and someone else sets the system (a regular container transport on the Danube with round trips several times a week) up and proofs that it works first. Though the situation is different for different harbors/countries in this area, the current preference for train transport until someone else sets up a working container line on the Danube, is true for most stakeholder included in the study. For more detailed information see Seitz et al. (2006).

When it comes to the question of economic losses due to low water periods the important information in this study is, that, at least when it comes to container

transport, the train offers about the same prices as inland navigation is able to offer. This means that switching from one mode of transport to the other means little or no additional expenses and explains the unwillingness of customers to pay additional fees during low water periods.

II.4 Statistical and economic analysis

To estimate the economic loss due to low water periods, a connection of economic factors like the freight price or the bearing capacity and the water level has to be identified. The possible transport amount of inland navigation vessels - and therefore its degree of capacity utilization - is, amongst other factors, a function of the water depth of the river. If the maximum draft of the individual vessel cannot be reached due to low water, its bearing capacity and therefore the amount of goods it can transport as well as its degree of capacity utilization is reduced. As described above, this can have a direct impact on the mass-cargo-affine companies, as their transport demand stays high while the amount of cargo that can be transported with the same number of ships is reduced. Therefore companies try to employ additional ships if possible. As a result, the transport amount per ship, the number of ships and the degree of capacity utilization are, within limits, functions of the water level. With a high demand, but reduced transport capacities due to low water, the prices should rise as well and therefore also be a function of the water level. How strong this connection is, is shown in this chapter. Therefore a correlation analysis for several transport factors is performed.

In addition, the results for each transport factor for the Danube are compared to an analysis done for the River Rhine. This comparison was important as Jonkeren et al. (2007) developed a concept to calculate the additional costs due to low water levels of the Rhine. If the transport factors for both rivers (Rhine and Danube) show a similar development with the water levels, a transfer of this method from one river to the other is valid.

II.4.1 Identifying the gauge

As can be seen in chapter II.1.1, the Danube has several bottlenecks that have to be passed for transport along the river. For several of these bottlenecks datasets of water levels at nearby gauges were available. To identify which dataset should be used for the following analysis, a correlation of the water levels at several gauges with the degree of capacity utilization is performed first. For this analysis, not only the monthly means of the water level at the gauges is used, but, if available, also their maximum and minimum.

In a first step, a correlation of the degree of capacity utilization and the water level at several gauges (Kaub, Passau, Kienstock (mean, minimum, maximum), Wildungsmauer (mean, minimum, maximum), Bad Deutsch (mean, minimum, maximum) and Hainburg (mean, minimum, maximum)) was calculated for transport within Austria, trans-boundary receipt and distribution and transit (figure 12). The Rhine gauge Kaub has been included in these calculations as all transport to and from the big sea harbors in the Netherlands and Belgium (Amsterdam-Rotterdam-Antwerp, the so called ARA harbors) have to pass by this bottleneck along the River Rhine.

As can be seen in figure 12 the highest correlation occurs for the monthly means and minimum water levels for transit traffic, which shows a strong connection (0.73), followed by trans-boundary receipt (0.69). The Austrian gauges Kienstock, Bad Deutsch and Hainburg hereby lead to a higher correlation with the degree of capacity utilization than the German Danube or Rhine gauges Kaub and Passau. Only the trans-boundary distribution shows a strong correlation with the Rhine gauge Kaub which could be an indicator that the cargo transported is on its way to harbors along the River Rhine or the ARA sea harbors. As in average the gauge Kienstock shows the strongest correlation for all transport connections given here, this gauge will be used as a reference for all following analysis for all transport factors.
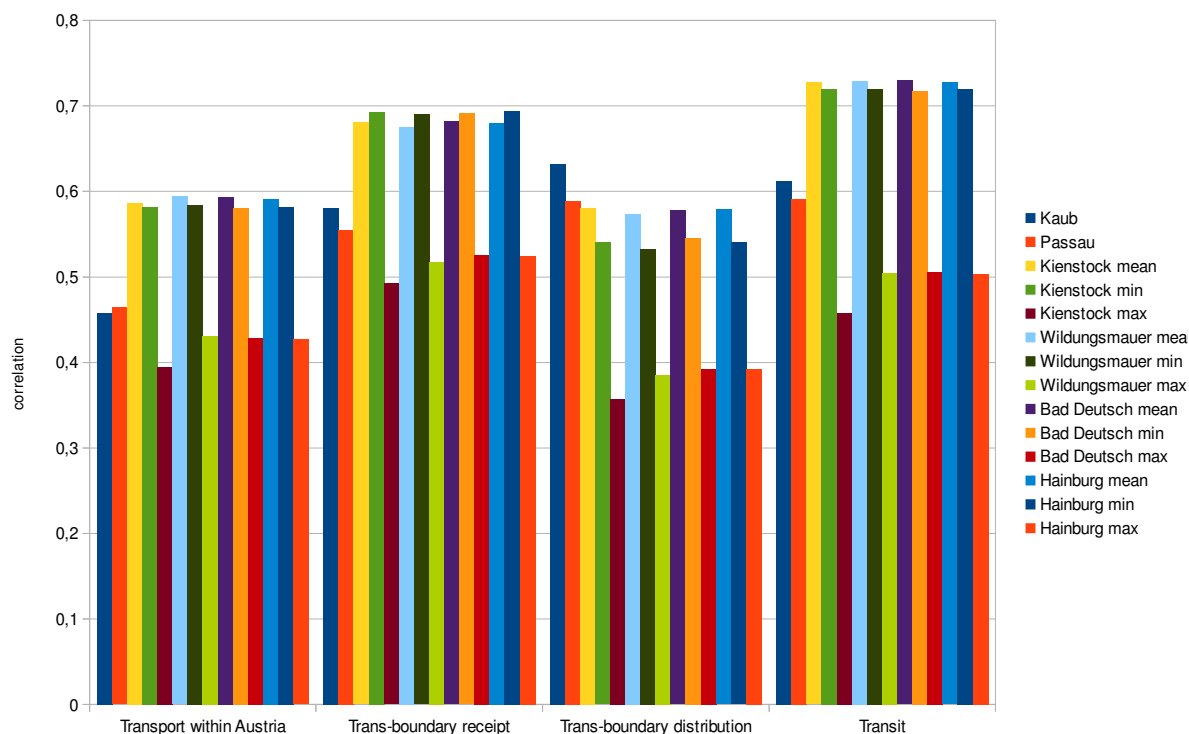
Figure 8: Correlation of water levels and degree of capacity utilization for several transport connections for the years 2008 to 2013; Source: own calculations based on Wsd (1998-2006); Wetteronline (2000-2012); BMLFUW (2002-2012); Statistik Austria (2008-2013)

II.4.2 Strength of connection between changing water levels and transport factors

To find out if it is valid to transfer Jonkeren et al. (2007) method from the Rhine to the Danube, a comparison of the transport-factors for both rivers and the strength of their connection to the water levels was performed.

As the dataset Jonkeren et al. (2007) used for their analysis was not available for a direct comparison, another dataset for the Rhine was used that shows the same results as Jonkeren et al. (2007) data. Daily data from the harbor Mannheim (Upper Rhine) proved to be the best data-set available (Mannheim 2008). This dataset will be compared to monthly averages in Austria described above.

The transport factors compared are:

- the transport amount per ship,
- the number of ships per day and
- the degree of capacity utilization.

The data-sets are analyzed concerning their strength of connection with the water levels at local gauges. For the Rhine the gauge Kaub is chosen, as that is the same gauge Jonkeren et al. (2007) use in their analysis and the main bottleneck for the Upper Rhine. In addition to Kaub, also data from the gauge at Worms was used, as this is the gauge closest to Mannheim available. Based on the results presented above, for the Danube the gauge of Kienstock was used to represent the Austrian bottlenecks.

Danube

Rhine

Transport amount per ship

f(x) = 368,6728944725 ln(x) - 1061,9706181272

f(x) = 1,1660581516x + 680,0893361478

(Danube chart — Transport amount per ship (mean) (t) vs Waterlevel (cm))

f(x) = 1,8656164091x + 768,4242482032

f(x) = 388,2067558213 ln(x) - 888,5365975981

(Rhine chart — Transport amount per ship (mean)(t) vs Waterlevel (cm))
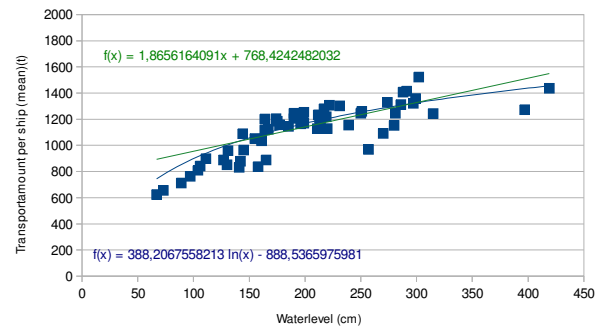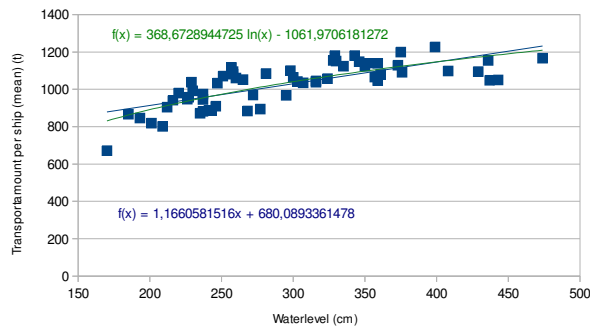
Linear-Correlation with water level at Kienstock: 0.74

Linear-Correlation with water level at Kaub: 0.51
Linear-Correlation with water level at Worms: 0.72
Rank-Correlation with water level at Kaub: 0.77
Rank-Correlation with water level at Worms: 0.83

Number of Ships

f(x) = -4,1557897652 ln(x) + 52,0413122544

f(x) = - 0,0153347199x + 33,055882317

(Danube chart — number of ships per day vs Waterlevel (cm))

f(x) = - 0,0106699734x + 20,0414715308

f(x) = 41,5693631935 x^-0,1666816779

(Rhine chart — Number of ships per day vs Waterlevel (cm))
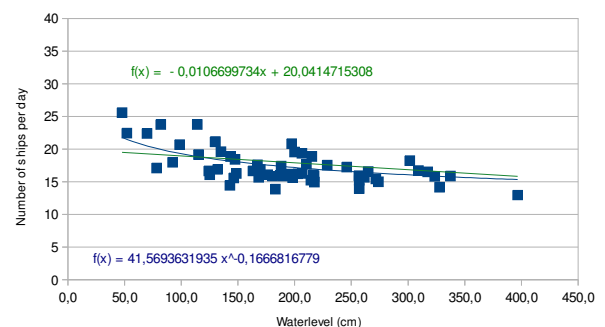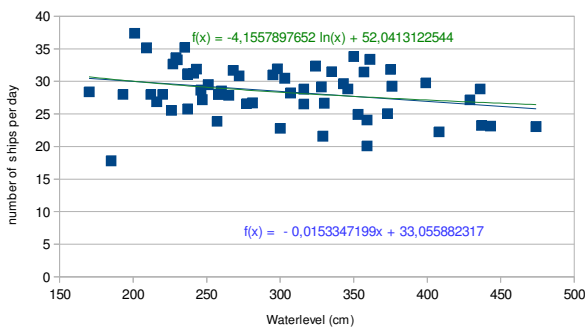
Correlation with water level at Kienstock (mean): -0.20

Linear-Correlation with water level at Kaub: -0.40
Linear-Correlation with water level at Worms: -0.16
Rank-Correlation with water level at Kaub: -0.57
Rank-Correlation with water level at Worms: -0.51

Degree of Capacity Utilization

f(x) = 0,1893856327 ln(x) - 0,4635857063

f(x) = 0,0005999692x + 0,4310141729

(Danube chart — degree of capacity utilization (%) vs Waterlevel (cm))

f(x) = 0,0007252882x + 0,4973055542

f(x) = 0,1565378435 ln(x) - 0,1762601707

(Rhine chart — degree of capacity utilization (%) vs Waterlevel Kaub (cm))
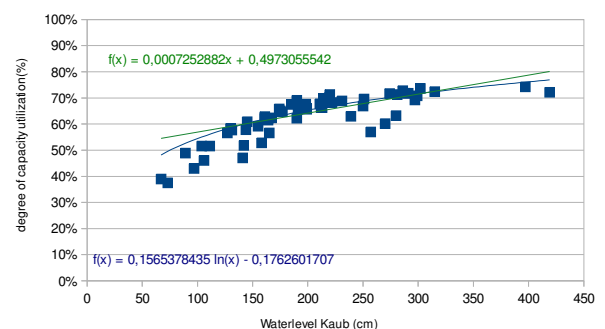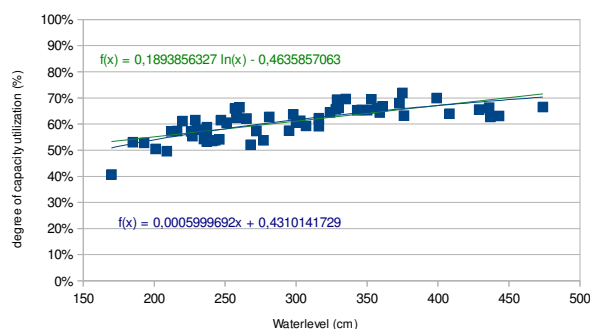
Correlation with water level at Kienstock (mean): 0.73

Linear-Correlation with water level at Kaub: 0.38
Linear-Correlation with water level at Worms: 0.61
Rank-Correlation with water level at Kaub: 0.80
Rank-Correlation with water level at Worms: 0.81

Figure 9: Comparison of key variables of the Rivers Rhine (right) and Danube (left) and their correlation with local water levels; Source: own calculation based on Statistik Austria (2008-2013); Mannheim (2008); Lebensministerium (2002-2012); BfG (2008)

For the Rhine data from 2003 to June 2008 were available for this analysis, for the Danube monthly data for 2008 to November 2013 were obtainable. This means, that the data-files overlap for one year only. This should however not have a big impact on the analysis of the monthly means over several years. That the data of one single harbor at the Rhine is compared to the data collected all over Austria might have a bigger impact. However, a data-set similar to the Danube data-set from Austria is not available for the Rhine. While the data-set for Austria was divided into the transport factors: transport within Austria, cross border receipt and distribution as well as transit, this separation was not available for the Rhine. Therefore an average and/or total was calculated for Austria and used here. The individual connections can show slightly different results. For each data-set a linear and a logarithmic trend curve including its equation is shown.

As can be seen in figure 13, the transport amount per ship in general is higher on the Rhine. Here, average transport amounts per ship of about 1500t can be found, while on the Danube the maximum average is below 1300t. Higher transport amounts for individual ships could be found on both rivers of course. For both rivers the transport amount per ship increases with increasing water levels. For the Rhine this development follows a logarithmic curve, while for the Danube the difference between the logarithmic and linear trend curve are minimal. The minimal average transport amount per ship is almost identical (about 600t) for both rivers. The linear connection of water level and average transport amount per ship is, depending on the Rhine gauge used, (slightly) stronger for the Danube (correlation: 0.74) than for the Rhine (correlation with the gauge Kaub: 0.51; correlation with the closer-to-Mannheim gauge Worms: 0.72). However, as the connection is non-linear for the Rhine, a rank correlation was also performed. This rank-correlation shows a strong connection for the Rhine (rank-correlation with Kaub: 0.77, with Worms: 0.83). All in all, a similar development with changing water levels can be seen for both areas. So for this aspects (transport amount per ship), it seems to be reasonable to transfer findings for the Rhine seem to the Danube.

The number of ships per day has a much weaker connection to the water levels on both rivers and at maximum reaches the level of a medium connection (max 0.57 for the Rhine). This might be partly due to the number of ships available for transport. If no additional vessels can be employed because none are available, the number of used ships cannot rise. Nonetheless it can be noticed, that the number of ships deployed per day increases with sinking water levels. Like for the transport amount per ship, the connection for the Rhine is more non-linear, while for the Danube, a more linear connection can be noted. Interestingly, the number of ships per day for one single harbor at the Upper Rhine is only about a third lower than the number of ships for the Danube in Austria. This might be seen as an indicator for the importance of this way of transport in both regions. The number of ships on the Danube has a higher variability however.

The development of the degree of capacity utilization with changing water levels also is very comparable for both rivers, although again the Rhine shows a more logarithmic connection while the Danube has a more linear development. For both rivers the minimal degree of capacity utilization is about 40%, the maximum around 75%. Both rivers show a strong connection between the degree of capacity utilization with changing water level (linear-correlation for the Danube: 0.73, rank-correlation for the Rhine: 0.80 for Kaub, 0.81 for Worms).

The similarities for both rivers for this parameter also seems to be strong enough to allow a transfer of the findings of Jonkeren et al. (2007) based on those parameters at the Rhine to the Danube. Therefore, their analysis will be transferred as described in the next chapters.

II.4.3 Connections of water- and freight-price levels for the Danube

Mathematically, a strong connection between the degree of capacity utilization and water level should lead to rising prices with lower water levels. But, as stated above, other factors impact the price development as well. The Frachtenspiegel for example states that customers along the Danube often refuse paying higher prices and 'Kleinwasserzuschläge' (low water fees). On top of that, many other aspects influence the freight prices (like a blockage of the Main, ships searching for cargo and economic development). This leads to a rather weak direct connection of freight prices and water levels as can be seen in figure 14 for the Rhine and Danube alike for the connection of freight prices for transports from and to the ARA harbors with the water levels at the bottlenecks. Figure 15 shows the correlations for other transport connections along the Danube. The highest correlation can be found for the connection from Slovakia to Hungary and the gauge Bad Deutsch with a medium correlation (0.43). Only the freight prices for the transport from ARA to Mannheim show a similar strong correlations, all other correlation are weaker.

Danube   **Rhine**

To ARA
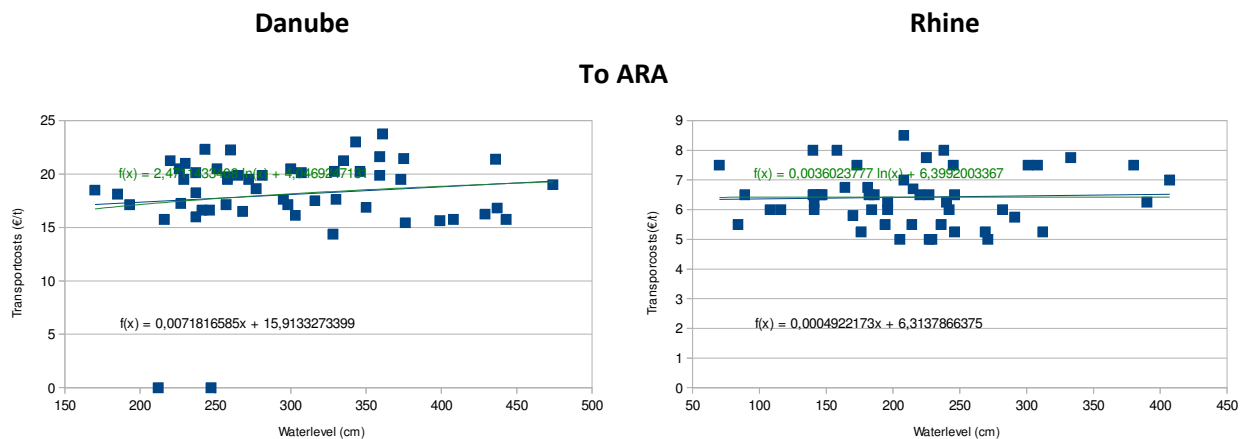
Correlation with water level at Kienstock (mean): Correlation with water level at Kaub: 0.04
0.13

From ARA
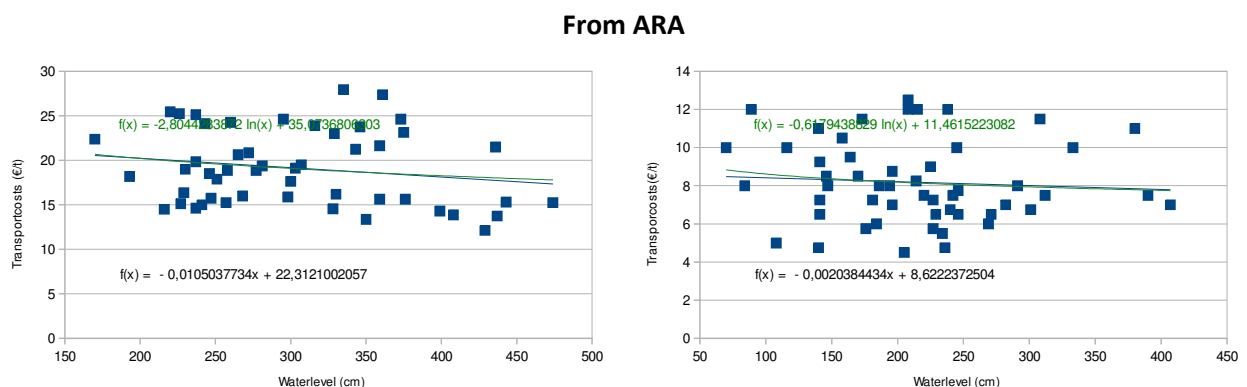
Correlation with water level at Kienstock (mean):   Correlation with water level at Kaub: -0.07
-0.11

Figure 10: Comparison of correlations of the freight-prices with local water levels from an to ARA of the Rivers Rhine (right) and Danube (left); Source: own calculation based
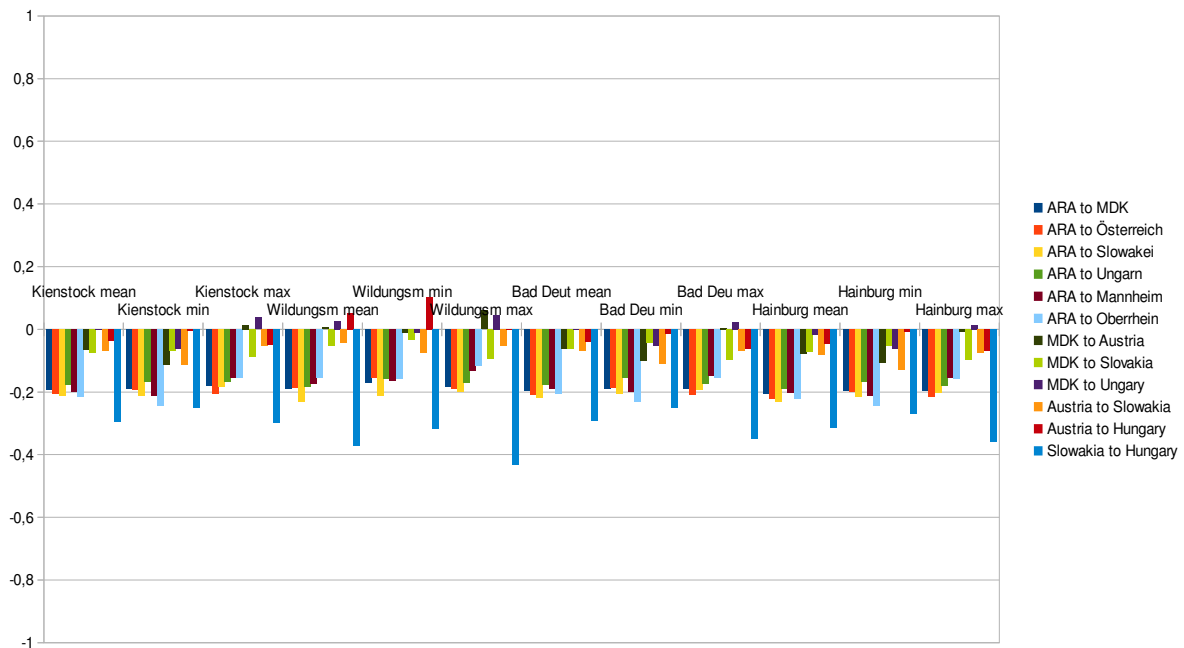
Figure 11: Correlation of freight prices (for transport up river) with water levels along the Austrian Danube; Source: own calculations based on Frachtenspiegel (2000-2013) and Statistik Austria (2008-2012)

Therefore, instead of trying to find a direct connection of freight prices and water levels, the method of Jonkeren et al. (2007), who identified a strong connection of freight prices and water levels, was used for the following calculations.

As done by Jonkeren et al. (2007) for destinations to the Upper Rhine, the freight prices for the trips to destinations at the Danube were put in order by the connected water levels. Unlike Jonkeren et al. (2007), no daily, only monthly data was available. Nonetheless, all monthly freight-prices (2000 to 2013) were connected to the fitting average monthly water level and then ranked by the water level. Jonkeren et al. (2007) used the bottleneck at Kaub as a reference. As described above, here the bottleneck Kienstock in Austria was used as a reference. While not all transports included in this study have to pass this bottleneck (e.g. transports from Slovakia to Hungary) it can be expected that - with possibly some days delay - if low water conditions are recorded at Kienstock, other gauges along the Danube will also experience lower water levels in the same month. Therefore not the absolute water depth is of interest here, but the changes of water levels.

As in Jonkeren et al. (2007) study the water levels at Kienstock were put in 10cm categories and the average freight-price for each water level was calculated (in most cases about 7 freight prices for each 10cm step of water level were available). This was done for transports upstream (of the Danube) and downstream separately. As a comparison, some of connection included in Jonkeren et al. (2007) study along the Rhine (Mannheim and Upper Rhine) are also included in this analysis. Although the number of items is very small for a correlation analysis, a correlation analysis after Spearman was performed. This correlation coefficient is relatively resistant to outliers and therefore also usable for small data-sets.

Figure 16 presents the results for the upstream transport, figure 17 for the downstream transport. As can be seen, not for all connections the freight prices have the same

sensitivity concerning water levels. The strongest correlation can be found for the connection Austria to MDK (upstream: -0.901) and MDK to Hungary (downstream: -0.868). But except for the connections MDK to ARA, Slovakia to Austria and Hungary to Slovakia (upstream) and Slovakia to Hungary and Austria to Slovakia (downstream) all other connections show correlations above 0.7 (upstream) or 0.6 (downstream). For all transport connections an increase of freight prices with decreasing water level is visible, even though the connection is not strictly linear. This might be partly due to the data-base (monthly instead of daily data; comparatively small data-sets per water level) used, but also due to economic impacts (the transport demand and/or the availability of free ships have an impact on the prices paid). Interestingly, even the connections that do not use the Danube for transport (like Mannheim to ARA) and are only included in this study as a comparison to Jonkeren et al. (2007) show a strong increase for the transport from the ARA harbors (upstream Rhine, but here in the downstream Danube figures), while prices increase only slightly for transports the other way around. This indicates that the demand for one direction is higher and therefore the prices increase faster with reduced water levels than the other way around where most likely enough empty vessels are available which leads to lower prices.

In total it can be stated that, as was found in the study from Jonkeren et al. (2007), there is a (strong) connection between freight prices and water levels. Therefore the regression equation for each connection could be used to estimate average freight prices depending on the water levels. These equations also could be used to build in a model to estimate the total economic impact of changing water levels.
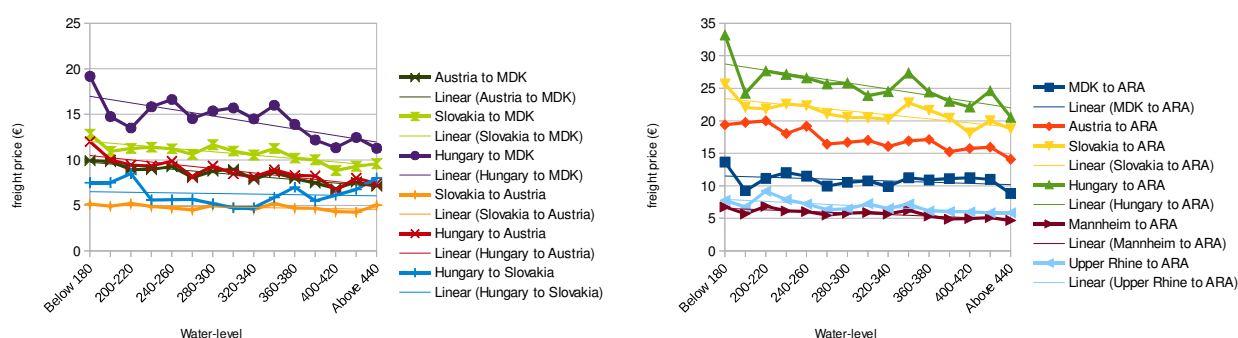
Figure 12: Connection of freight-prices and water levels (gauge Kienstock, Austria) on a monthly basis – upstream Danube; Source: own calculations based on Frachtenspiegel (2000-2013) and BMLFUW (2002-2012)
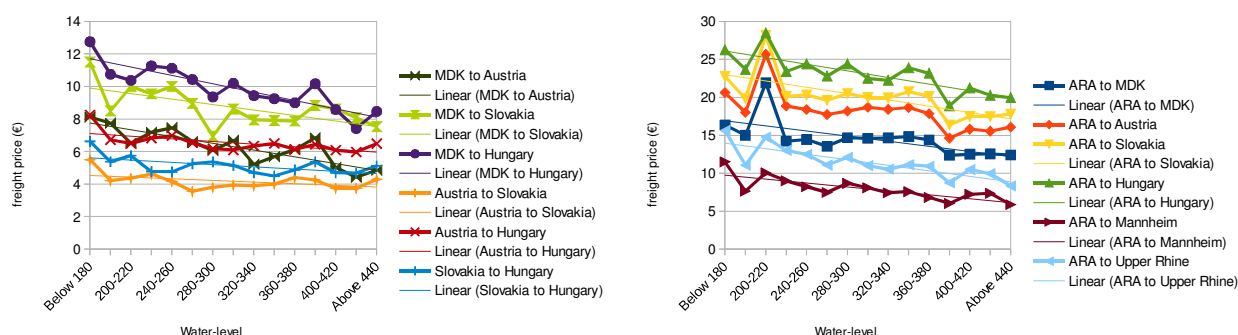
Figure 13: Connection of freight-prices and water levels (gauge Kienstock, Austria) on a monthly basis - downstream Danube; Source: own calculations based on Frachtenspiegel (2000-2013) and BMLFUW (2002-2012)

II.4.4 Estimation of economic losses due to low water levels

After a connection between water level and freight-prices has been proven above, an estimation on the impact of changing water levels on the economy can be performed.

This will be done step by step to emphasize the different impact factors as good as possible.

The first factor needed is the price per transported ton as known through Frachtenspiegel (2000-2013). This price is connected to a water level as is described above. Figure 12 and 13 show the freight prices per ton as will be used in this chapter.

The second factor needed the water level. To include the impact of the water level (data that was available on a daily basis) the number of days with water levels in the above given 10cm categories was calculated for each month (e.g. how many days a month the water level was below 180cm, between 180 and 190cm etc.) From this the share of each water level per month was calculated (e.g. 0.2% of month the water level was between 180 and 190cm) as can be seen in figure 14.
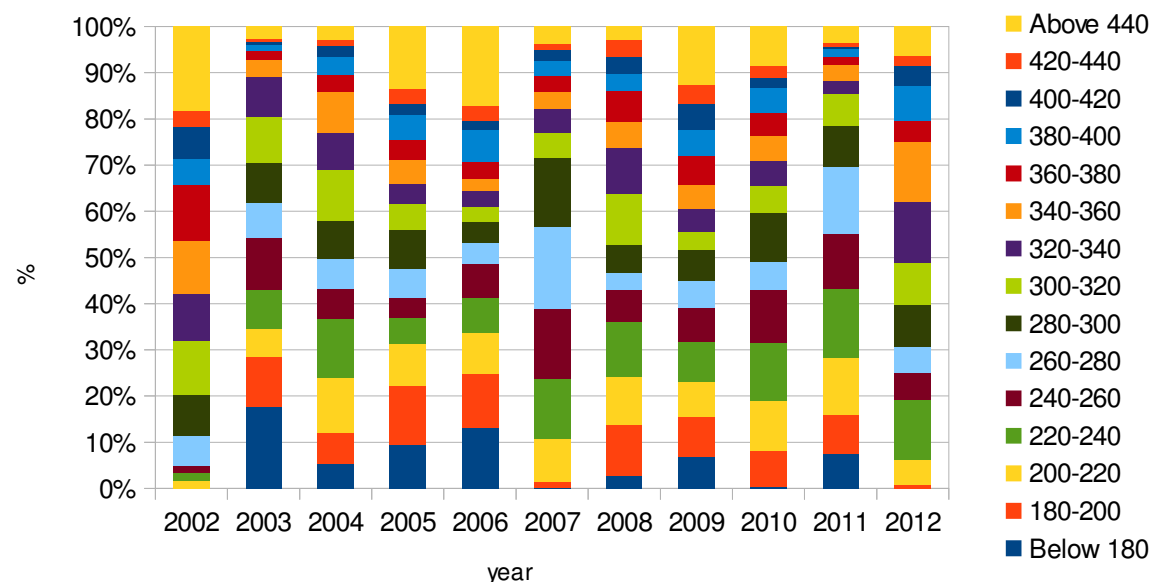
Figure 14: Percentage of days with a certain water level at the gauge Kienstock for the years 2002 to 2012; Source: own calculation based on BMLFUW (2002-2012)

The third factor needed is the transport amount (in tons t) from one destination to another as can be seen in figure 15 for the destination from Hungary to the Netherlands (ARA) and back. Figure 16 illustrates the transport amounts for the transport connection from Germany to Austria. These two connections were chosen to as examples for long and short distance transport that pass the bottleneck Kienstock. As can be seen, the transport amounts vary from month to month and year to year. These variations have several impacting factors like the economic development, but also the water level.
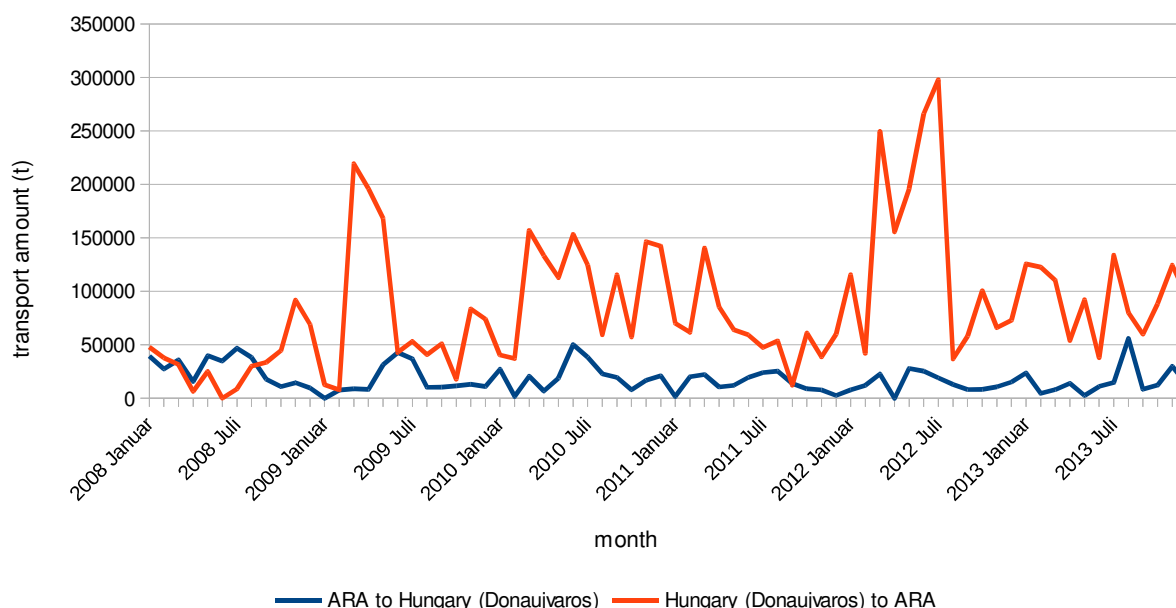
Figure 15: Transport amounts on the Danube from Hungary (Donaujvaros) to the Netherlands (Amsterdam and Rotterdam, here marked as ARA) and vice versa in tons (t); Source: Statistik Austria (2008-2012)
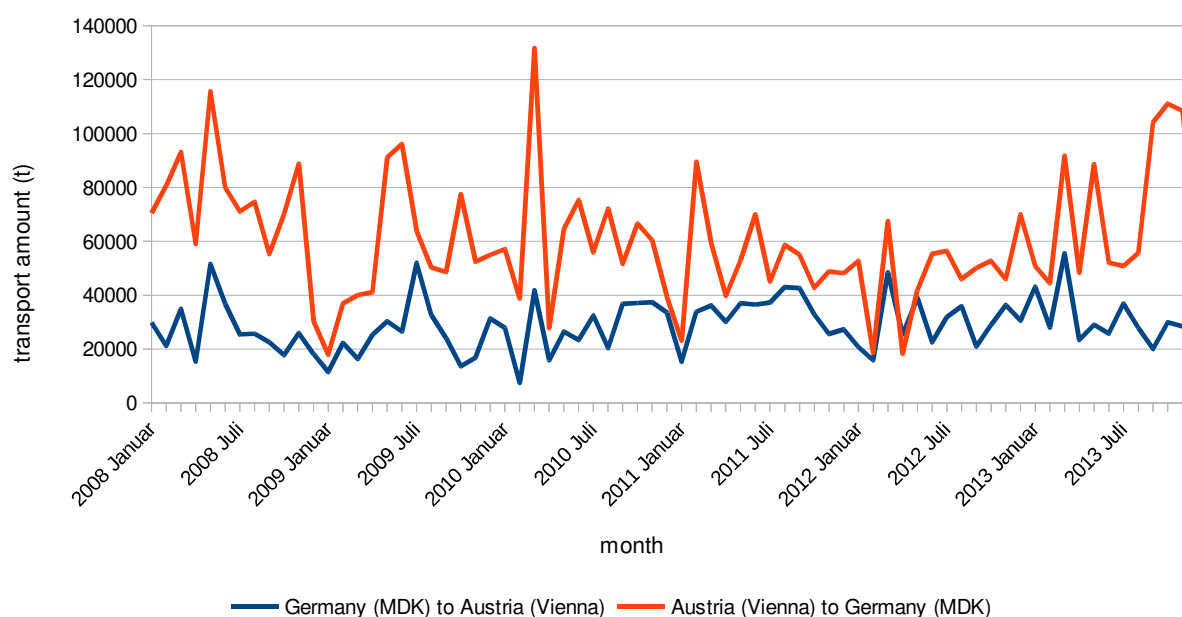
Figure 16: Transport amounts on the Danube from the Main-Danube channel (MDK) to Austria, Vienna and vice versa in tons (t); Source: Statistik Austria (2008-2012)

The next step is to combine these data-sets:

- Multiplying the transport amount (t) with the share of the water level categories per month gives information of how many tons were transported at which water levels on a monthly basis.

- Multiplying the results with the freight-prices per water level leads to how many Euros had to be spend for those transports in those month (for real transport amounts and real water levels while the freight prices are averages over several years for certain water levels).

The fleet of the Danube is only indirectly included in this analysis. As freight-prices for single ship types are not published, only the average for the fleet could be used. This means that the different ship sizes are included in these calculations indirectly by average prices for the fleet.

To be able to analyses the impact of these factors separately, as a first step only the impact of the water level will be analyzed. This is done by **fixing the transport amount** to the average transport amount for the whole time frame covered here (2008-2012).

The results can be seen in figure 17. The figure shows the sum of the total costs as beams as well as the water level (thick blue line). To make the scale more comparable, the water level was multiplied with 10000. The beams that represent the costs are separated into categories of costs caused by certain water levels. These are marked by different colors. The costs purely depend on changing water levels as the transport amount is fixed (thick grey line). The different colors marking the share of certain water levels show that the mean water level is less important than the number of days with water levels in each category. When many days with water levels above 440cm occur in a month (like between March and July 2009), the costs are much lower than in months with many days below 180cm like in November 2011. For the connection from Hungary to the Netherlands the difference between the month with the lowest costs and the one with the highest costs is 28%, only driven by changing water levels. However, this is just one of many connections that were included in this study. Table 9 shows how big the difference between the month with the lowest and highest costs is for other connections, only depending on changing water levels and their connected freight prices.
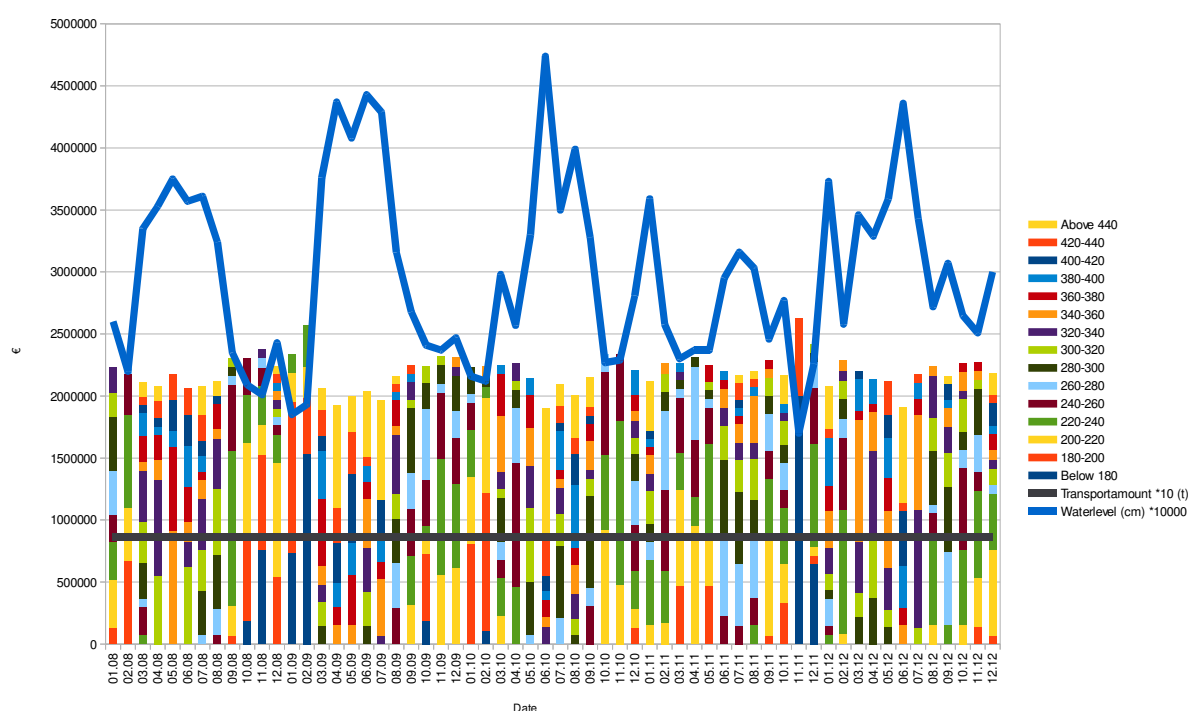
Figure 17: Expenses for transport via inland navigation from Hungary to Netherlands by month and year; transport amounts fixed on the average over the years 2008 to 2012, total costs only depending on freightprices per water level and changing water levels (gauge Kienstock); Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)

Due to missing data for some connections, the costs could not be calculated for all connections included in the Frachtenspiegel (see Annex E). Nevertheless, table 8 gives a first impression of the impact of the water level on the freight prices on the Danube. The

smallest impact of changing water levels on the total expenses for shipping can be seen for the connection from Slovakia to Austria with 9% difference between the maximum and minimum of total expenses. The highest impact with 37% is for a connection from the Main-Danube Channel (MDK) to Austria. The biggest impact (37%) of changing water levels on the expenses for inland navigation transport can be found for the connection MDK to Austria. It is important to note that the direction of the transport is important. For example, while the impact of the water level on the freight price from Slovakia to Austria shows a relatively low impact of 9%, the transport the opposite direction shows a difference of 25%. This might be due to a higher demand on the transport downstream the Danube and therefore lower water levels have a higher impact on the prices, while the demand for transports upstream is less. This would mean there is enough free capacities in ship transport and the prices therefore would increase less during low water periods.

Table 8: Difference in expenses between the month with the lowest and highest costs for inland shipping connections in the Danube region between 2008 and 2012, only depending on changing water levels and their connected freight prices, transport amounts fixed o fixed on the average between 2008 and 2012; Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)

Connection	difference between highest and lowest expenses for shipping based on water levels
ARA to MDK	
ARA to Austria	25%
ARA to Slovakia	23%
ARA to Hungary	20%
MDK to Austria	37%
MDK to Slovakia	27%
MDK to Hungary	30%
Austria to Slovakia	25%
Austria to Hungary	20%
Slovakia to Hungary	
MDK to ARA	
Austria to ARA	24%
Slovakia to ARA	21%
Hungary to ARA	28%
Austria to MDK	26%
Slovakia to MDK	22%
Hungary to MDK	33%
Slovakia to Austria	9%
Hungary to Austria	34%
Hungary to Slovakia	

Not only the difference of total transport costs per year purely influenced by water levels is of interest, but also when those costs appear. Therefore the impact of changing water

levels on the total expenses were calculated on a yearly (figure 20) and monthly (figure 21) level. The changes are shown for the connection MDK/Germany to Austria, as it shows the highest impact of the water level. The figures for all other connections (under scenario 1 with changing transport amounts) can be found in the appendix. While the yearly data is a sum of all transport expenses in that year, the monthly data is an average over the years 2008-2012.
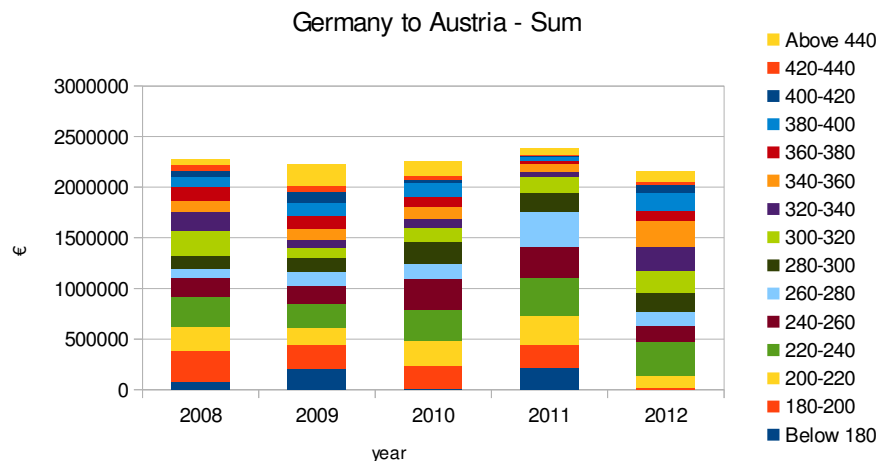
Figure 18: Total costs for transport from Germany to Austria on a yearly basis based on freight costs by water level (gauge Kienstock) and fixed transport amounts (average from 2008 to 2012); Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)

From 2008 to 2011 the most expensive year for inland water transport on the Danube was 2011. While days with water levels above 320cm occur rather rarely, 2011 has the highest share of days with water levels below 180cm. The year with the second lowest costs in this time-period however, 2009, has a similar high share of days with water levels below 180cm. But 2009 also has a much higher number of days with water levels above 320cm, and, on top of that, the highest number of days with water levels above 440cm which reduces the total costs for transport. The year with the lowest costs, 2012, has almost no days with water levels below 200cm. And while it also does not have as many days with water levels above 440cm, most of the days of the year have water levels between 240 and 440cm. Most inland navigation vessels on the Danube, especially on the connection from Germany to Austria due to the limitations of the shipping channel, have a maximum gauge of 250cm. In addition to that, they need about 30cm of free water underneath, which means that at water levels above 280cm these ships are unlimited in their transport capacity. This is true most of the year in 2012.

Figure 19 shows the seasonal average of the expenses for inland navigation during the years 2008 to 2012. To further emphasize the impact of the water level, the monthly average of the water levels in those years is shown as a green line. As can be seen, the expenses for transport in June, where the best water levels can be found, are lowest, while in the two month with minimum water levels, February and November, the expenses are highest. This is of special interest if combined with the transport demand in those months, as is done in the following sub-chapter.
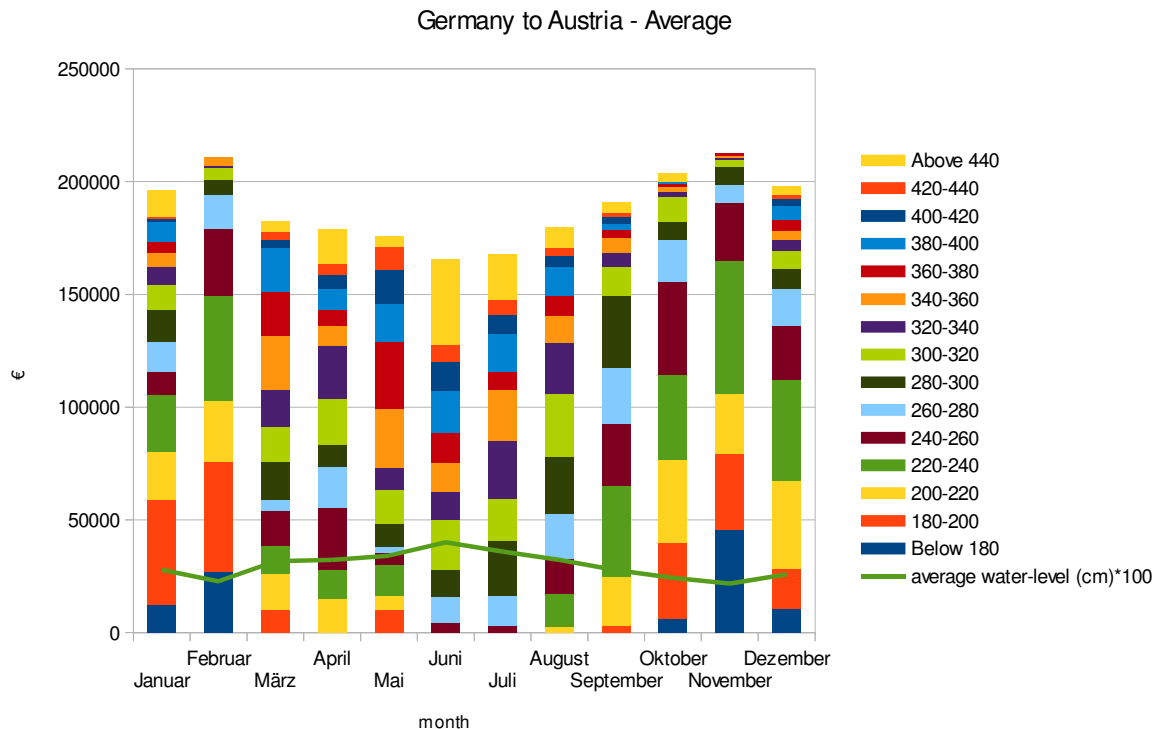
Figure 19: Total costs for transport from Germany to several countries - monthly average over several years (2008-2012) based on freight costs by water level (gauge Kienstock) with fixed transport amounts (average from 2008 to 2012); Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)

To show a more realistic picture of the transport expenses along the Danube, in the next step the **real transport amounts** per month from 2008 to 2012 are included in the calculation. Here it has to be taken into account that transport demands are not only impacted by economic factors. As has been shown in earlier chapters, a strong connection between the transport amounts and the water levels exists.

Figure 20 presents the total expenses for the transport from Hungary to the Netherlands harbors (mostly Amsterdam and Rotterdam) with varying transport amounts on a monthly basis. Obviously the costs vary from month to month and year to year. This is partly due to the changing transport amounts – shown here as a fat grey line to emphasize their impact – and partly due to the changing freight costs based on changing water levels – shown as a fat blue line. The transport amount here is multiplied with 10, the water level with 10000, so its variation becomes more obvious at this scale. The different colors in each bar show how much cargo is transported in which price-category.

As can be expected the total costs increase with the increasing transport amount. At the same time, often the transport amount increases with increasing water levels, most likely due to better transport conditions. But, on a closer look, the impact of the water level on the total costs shows as well. For example the transport amount from November to December 2008 decreases by 33%. At the same time, the water level increases (monthly mean) by 17%. This leads to a decrease of total costs by 11% only, instead of 33% as one might suspect based on the reduced transport amount. This difference can be explained by higher prices due to the lower water levels.
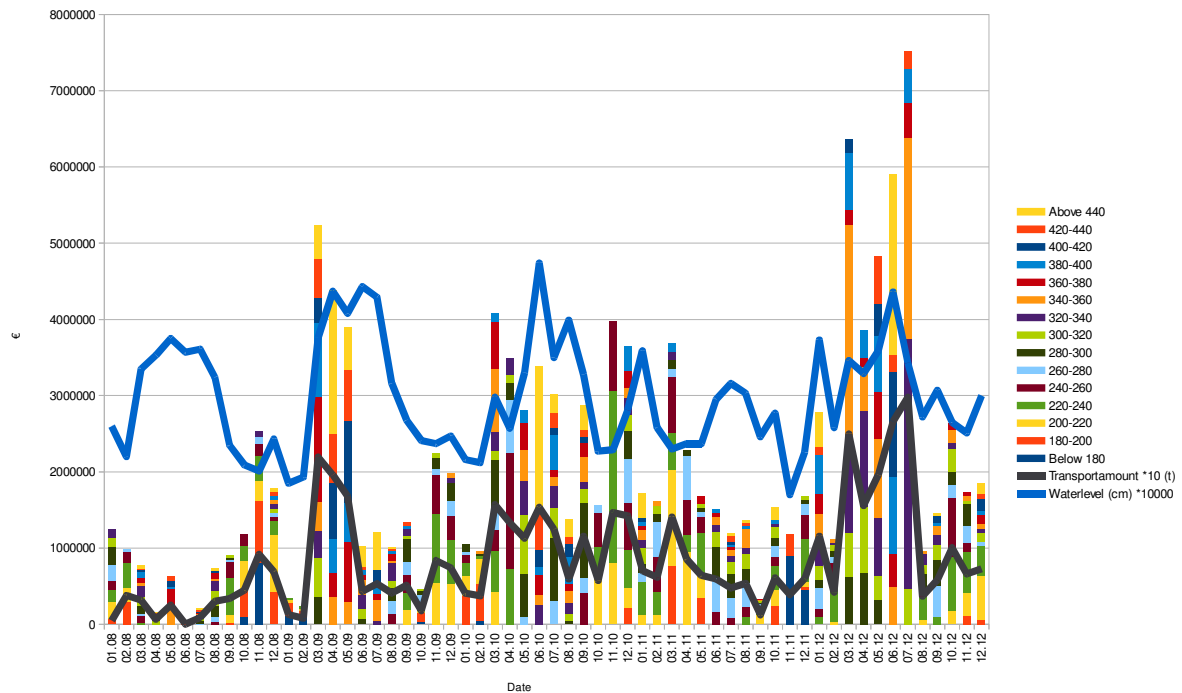
Figure 20: Expenses for transport via inland navigation from Hungary to Netherlands by month and year; total costs depending on shipping amounts and freightprices per water level and changing water levels (gauge Kienstock); Source: own calculation based on Fracht

For a more detailed analysis of changes with time, figure 20 shows the impact of changing transport amounts from year to year. Figure 21 shows the impact of seasonally changing transport amounts for the connection MDK to Austria. This connection was chosen, as it shows the highest impact of changing water levels. The figures for all other connections can be found in the appendix.

Like in the analysis with fixed transport amounts the most expensive year for transport via inland navigation in total is still 2011. The cheapest year, however is not 2012 anymore due to its comparatively high transport amounts, but 2009, which does not only have a low share of low water levels, as explained above, but also a low transport demand. Interestingly 2008, which has the second highest transport expenses if only water levels are taken into account, has the second lowest expenses for transport, if also the transport demands are included into the calculations. This shows that both factors play an important role for the total expenses for transport and neither can be used alone.

This can also be seen if the monthly average instead of the yearly sum is shown, as is done in figure 22. While the costs mostly followed the water levels when the transport amounts were fixed, now the month with the highest water levels, June, while still having comparatively low expenses, is by far not the month with the lowest expenses anymore, but only the fourth cheapest. Same is true for the two month with the lowest water levels February and November. While November is still the third most expensive month in average, February which is the most expensive month of the year, if only water levels are taken into account, is now the month with the third lowest expenses, as the transport amount in this month is so low.
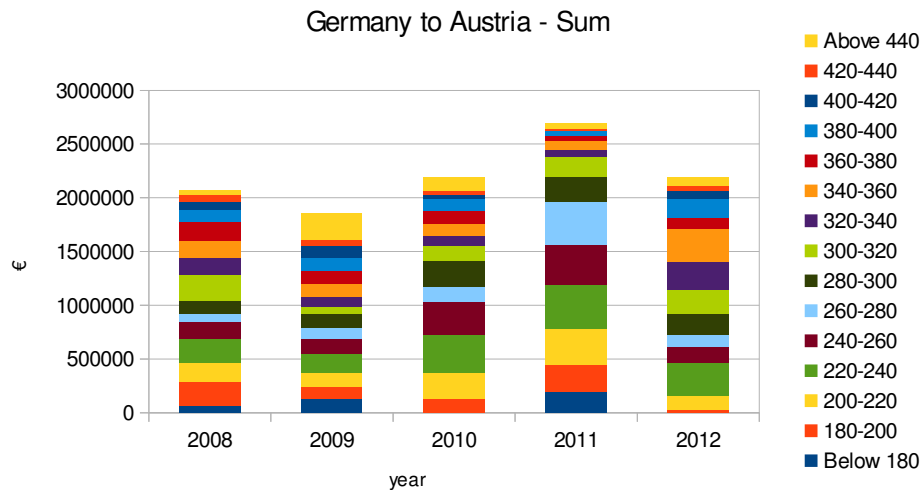
Figure 21: Total costs for transport from Germany to Austria on a yearly basis based on freight costs by water level (gauge Kienstock) and changing monthly transport amounts; Source:own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)
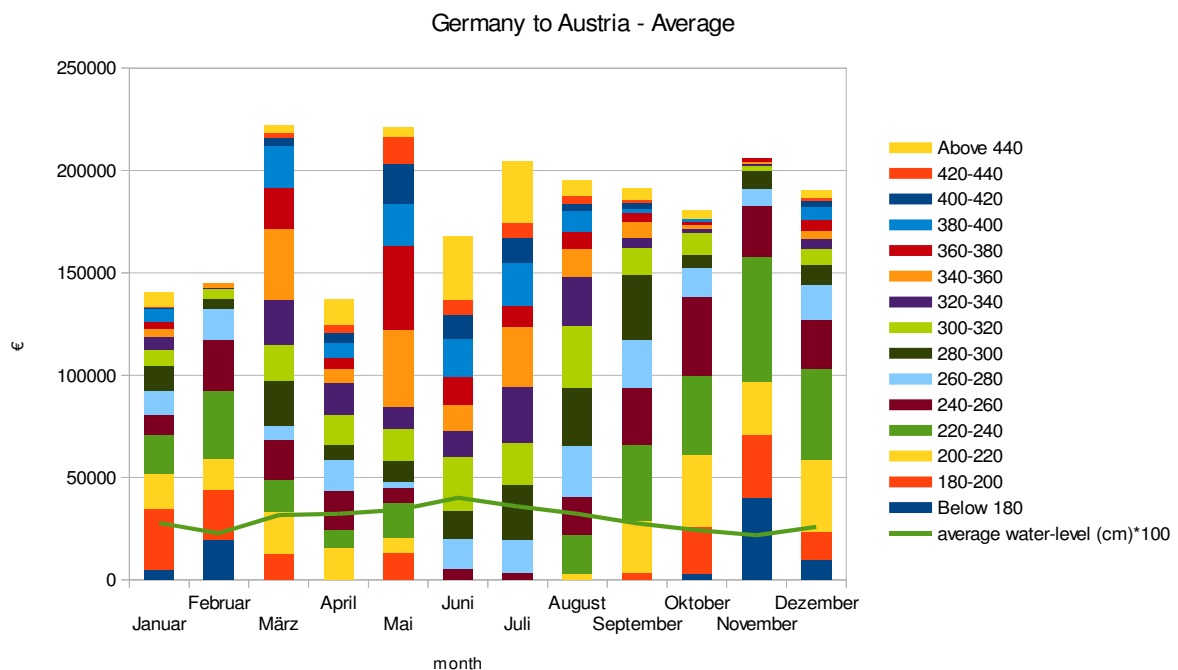
Figure 22: Total costs for transport from Germany to Austria - monthly average over several years (2008-2012) based on freight costs by water level (gauge Kienstock) and changing monthly transport amounts; Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)

To calculate the **additional expenses due to low water levels** instead of the total expenses per year, the expenses during periods of sufficient water levels and periods with low water need to be separated. In average the ships of the Danube fleet that are able to pass the Main Danube channel start to be limited at water levels below 280cm (see chapter II.1.3). To calculate the losses made due to reduced water levels the average freight-prices for water levels above 280cm were calculated for each connection given here. As a reverence, for each year the total costs were calculated for a theoretical

year with water levels above 280cm on 365 days, using individual transport amounts for each year. Those expenses are then used as a base line. The additional costs due to lower water levels are shown in figure 23 to figure 25.

As can be seen in figure 23 in most years additional costs arise due to water levels below 280cm which can reach up to 455000€ per month (in November 2010) for the transport from Hungary to the Netherlands. However, in some month the transport is mostly performed at water levels above 280cm. The prices per ton therefore are slightly lower than the average price per ton above 280cm. By this, up to 490000€ per month (June 2012) can be saved compared to the average prices. But those months – where expenses are below those theoretical expenses with fixed average freight-prices for water levels above 280cm – are rare.
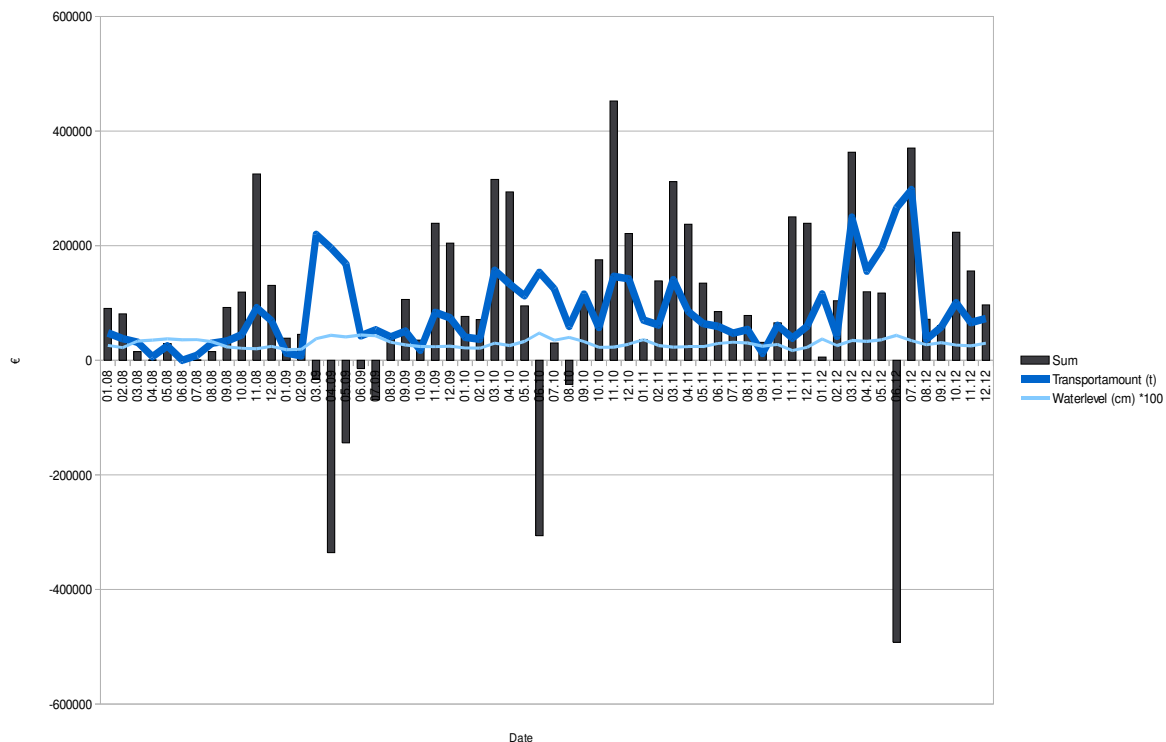
Figure 23: Additional expenses for transport via inland navigation from Hungary to Netherlands by month and year compared to a reference year with average freight prices for water levels above 280cm; depending on shipping amounts and freightprices per water level and changing water levels (gauge Kienstock); Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)

Figure 24 shows the additional expenses for transport from Germany to Austria on a yearly basis (sum over all month), while figure 25 shows the additional expenses on an average monthly basis. It is obvious that 2011 is the year with the most additional expenses (roughly 450000€) compared to a theoretical year with prices fixed at the average of freight costs above 280cm. 2011 was identified to be the most expensive year for freight transport via inland navigation in figure 18 already, while 2009 was the cheapest year. In figure 18 the difference in total expenses in 2009 and 2011 was roughly 100000€. Here, where additional costs of both years compared to a year with optional water levels above 280cm is calculated, the difference between 2009 and 2011 is almost 300000€. This emphasizes the influence of the freight prices for real water levels influence this calculation.

On a monthly level (figure 25) it can be seen that for the month June and July almost no additional expenses occur. For November, the month with the highest average costs, 45000€ have to be paid additionally.
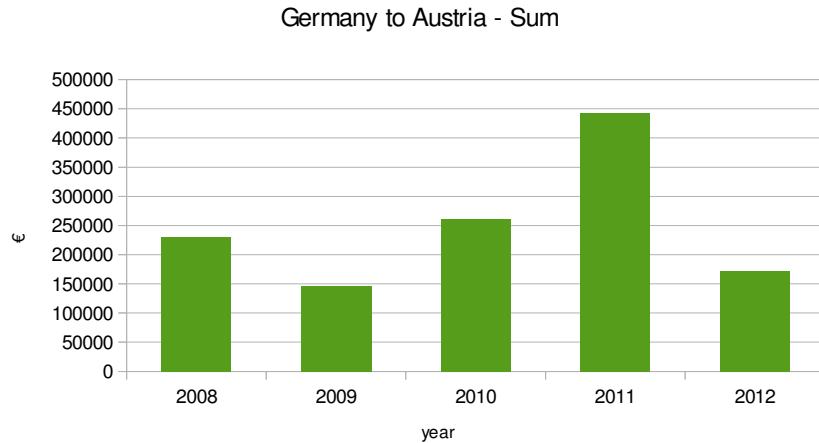
Figure 24: Total additional costs for transport from Germany to Austria on a yearly basis compared to a reference year with average freight prices for water levels above 280cm; depending on shipping amounts and freightprices per water level and changing water levels (gauge Kienstock); Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)
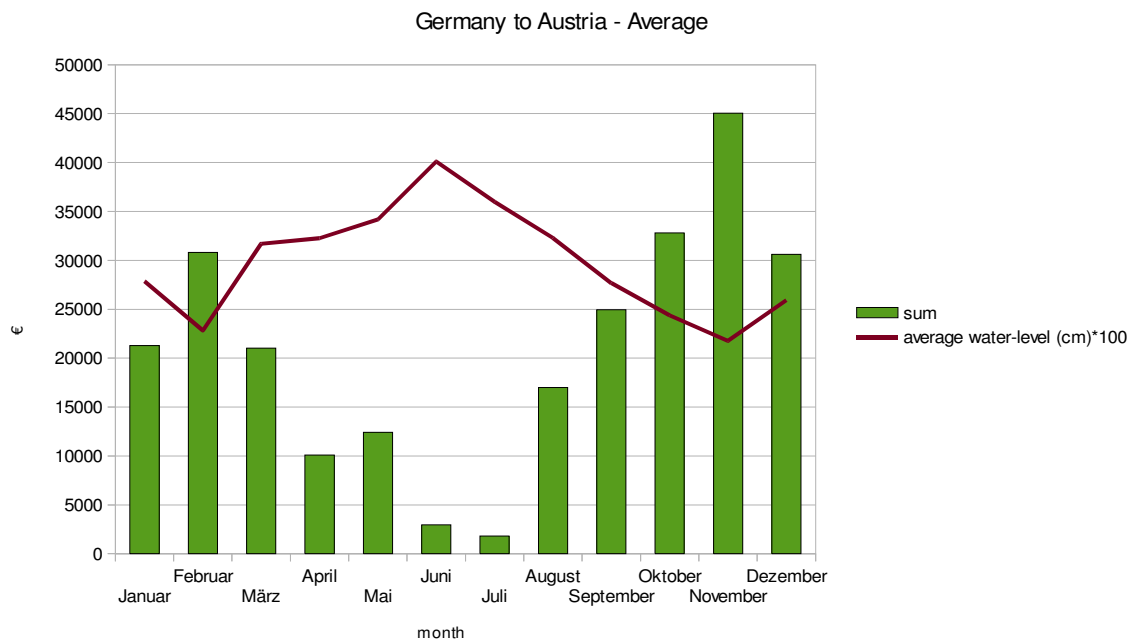
Figure 25: Additional costs for transport from Germany to Austria compared to a reference year with average freight prices for water levels above 280cm - monthly average over several years (2008-2012); depending on shipping amounts and freightprices per water level and changing water levels (gauge Kienstock); Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)

II.5 Estimation of reduced transport amounts due to low water levels

Additional expenses are not the only economic impact of low water periods. As shown in chapter II.4.2 the bearing capacity is reduced with sinking water levels. Because the number of vessels remains unchanged, the capacity of the fleet is reduced as well. While the fleet has some additional capacity, if the transport demand stays at the same level, some cargo cannot be transported due to the reduced capacity. And estimation of how much cargo is not transported during periods of low water is made in this chapter.

II.5.1 Impact of changing water levels on transport factors

To estimate the impact of water levels on all available transport factors (degree of capacity utilization, transport amount per ship, total transport amount, number of ships per day) the available data for those factors was put in a xy-diagram. Then the water levels and the fitting regression curve was calculated (see figure 26 to figure 29, here shown as the anomalies (from the average) in connection with the water levels). This was done for all available transport connections (transport within Austria, trans-boundary receipt, trans-boundary distribution and transit) as the impact of the water level on the transport factors slightly varies for each transport connection.
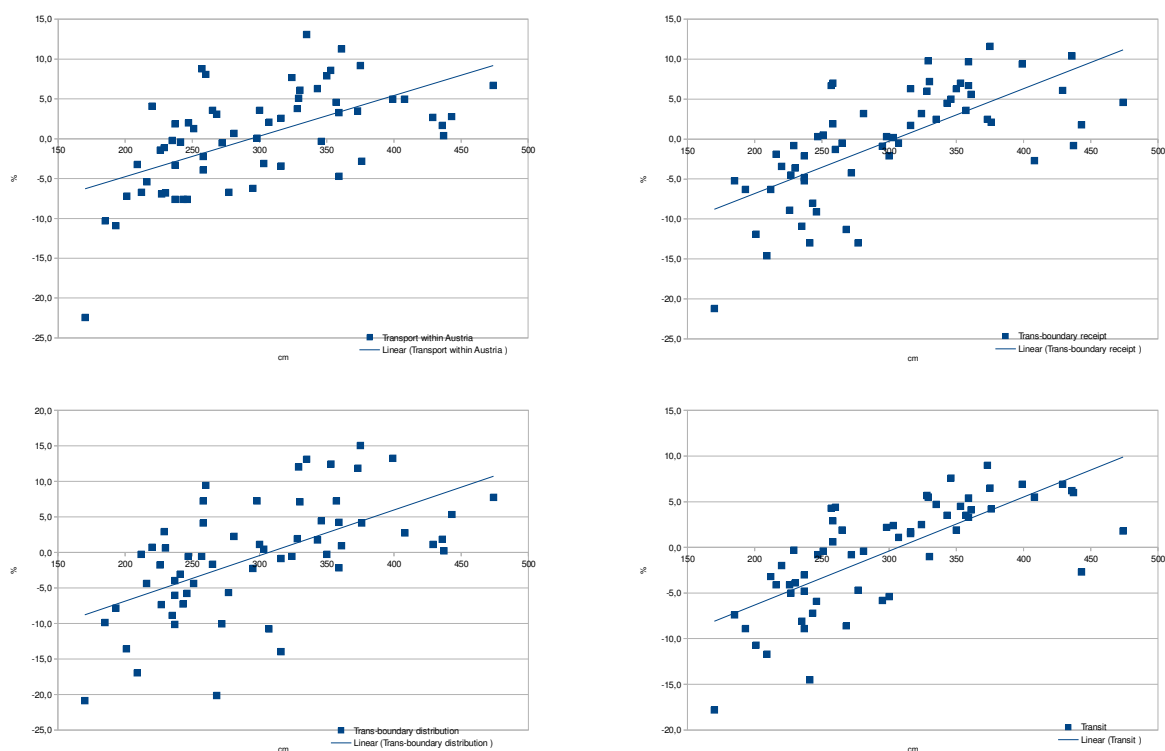
Figure 26: Connection between water level and anomalies in degree of capacity utilization for the gauge Kienstock, Austria; Source: own calculations based on BMLFUW (2002-2012); Statistik Austria (2008-2012)
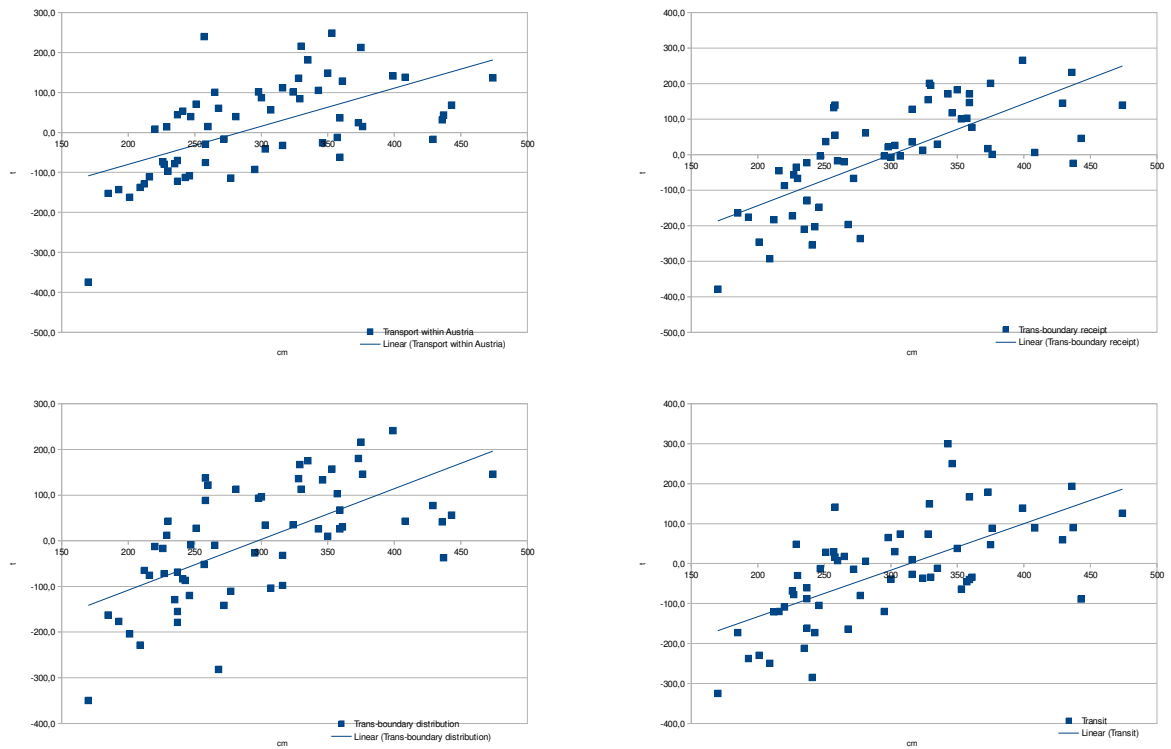
Figure 27: Connection between water level and anomalies in transport amount per ship for the gauge Kienstock, Austria; Source: own calculations based on BMLFUW (2002-2012); Statistik Austria (2008-2012)
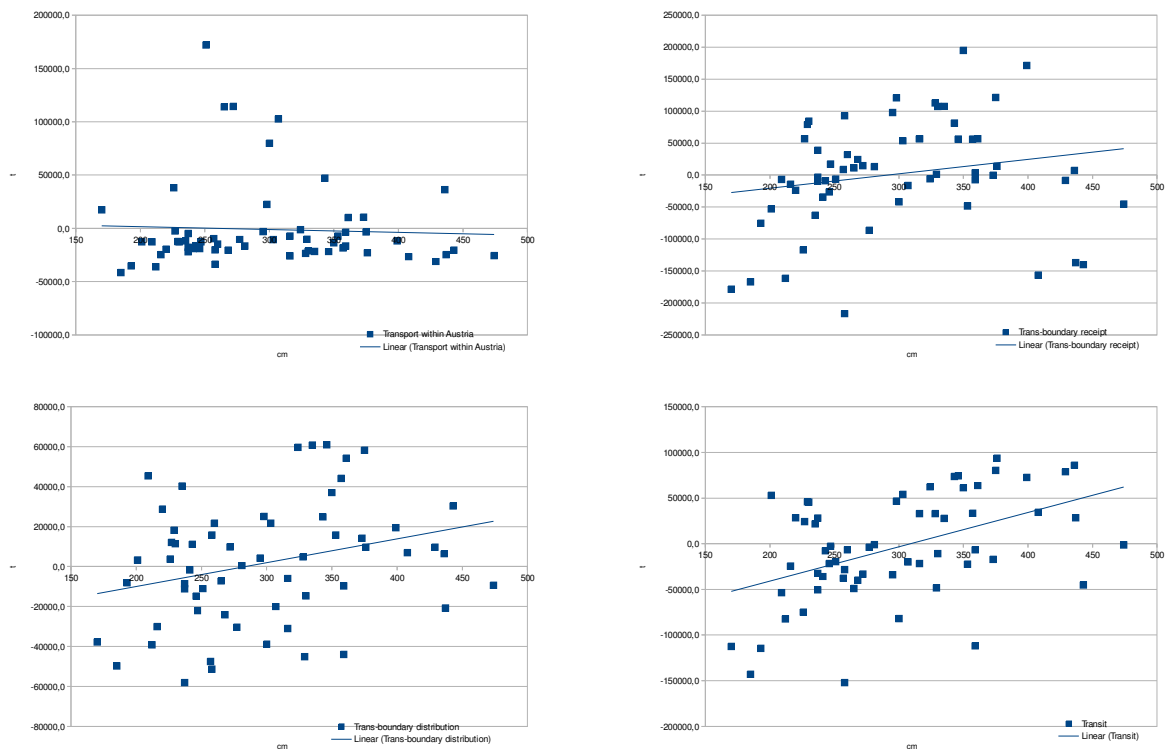
Figure 28: Connection between water level and anomalies in total transport amount for the gauge Kienstock, Austria; Source: own calculations based on BMLFUW (2002-2012); Statistik Austria (2008-2012)
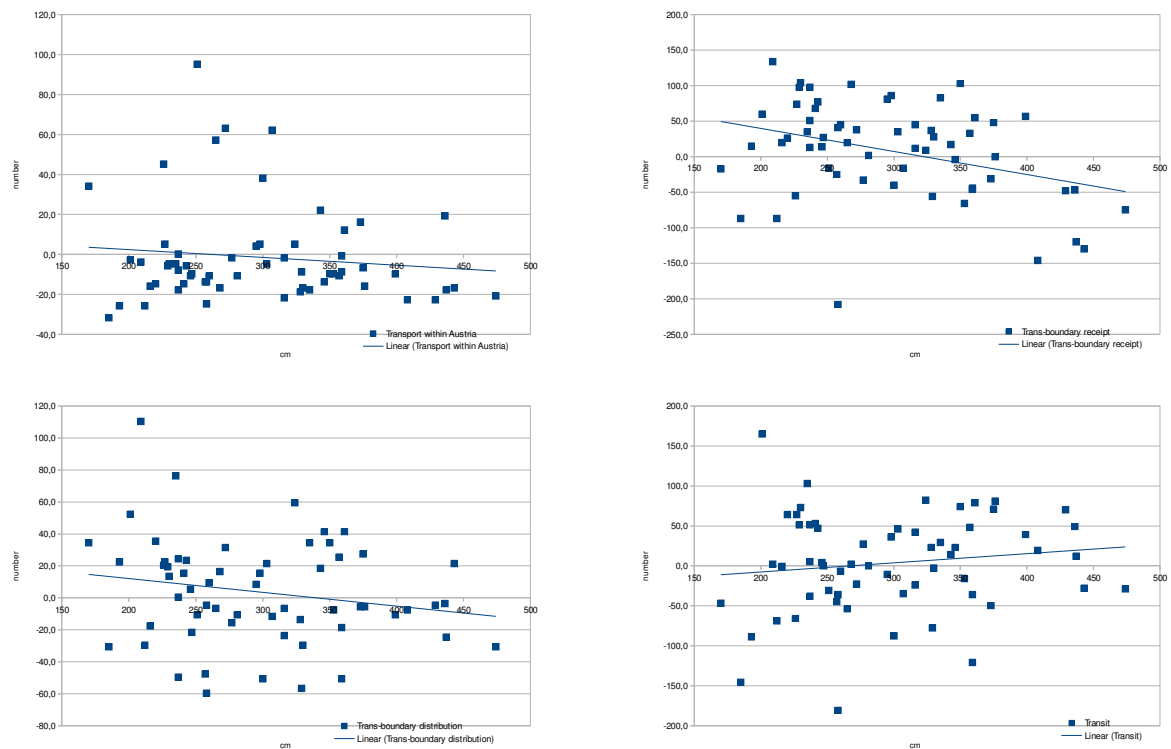
Figure 29: Connection between water level and anomalies in number of ships for the gauge Kienstock, Austria; Source: own calculations based on BMLFUW (2002-2012); Statistik Austria (2008-2012)

Based on the regression-equation, it was calculated which impact a changing water level has on these transport factors. The results are given in table 9. It can be seen that for every 10cm less of water level at the gauge Kienstock the degree of capacity utilization is reduced by 0.6% in average. The transport amount per ship is reduced by 12t in average and the total amount of transport on the Danube is reduced by 1733t for every 10cm less water. Except for the transit through Austria, additional ships are used to perform this transport though. In average 0.84 additional ships are needed if the water level decreases by 10cm. However, this varies hugely with the transport-connection. While for trans-boundary receipt 3.24 more ships are used for transport, 1.15 ships less are used for transit transport. This might be an indicator for the different importance of the transport connections. Most likely the available additional ships are used for the most important transport-connections, while for other, less important transport connections, no additional or even less ships are available. The transit transport for example, has the biggest reduction in total transport amount for 10cm less water level as well as is the only connection for which less ships are employed during periods with lower water. At the same time, in trans-boundary receipt the ships have the highest impact on their degree of capacity utilization (-0.66%) and transport amount per ship (-14t), but as the most additional ships are employed for this connection (3.24) the total transport amount suffers only the second biggest reduction (-2254t). Of course this is only based on average changes. As can be seen in figure 26 to figure 29 above, depending on the transport factor the average numbers given here vary much more in reality due to other impact factors (e.g. development of economy).

Table 9: Changes in transport-factors with every 10cm reduced water level for the gauge Kienstock, Austria; Source: own calculations based on BMLFUW (2002-2012); Statistik Austria (2008-2012)

Transport-factor	Changes for every 10cm less in water levels (average)			
	Transport within Austria	Trans-boundary receipt	Trans-boundary distribution	Transit
Degree of capacity utilization (%)	-0.51	-0.66	-0.64	-0.59
transport amount per ship (t)	-10	-14	-11	-12
total transport amount (t)	268	-2254	-1188	-3760
number of ships	0.39	3.24	0.86	-1.15

II.5.2 Impact of changing water levels on total transport amounts

To identify how much cargo could not be transported due to low water levels the water levels measured at the gauge which were used so far had to be transferred into usable water depth (usable for inland navigation) (for more information see Scholten 2010 and Donaunachrichten 2000). This was done by using the following equation:

$t_2 = P_{act} - RNW + t_1$

Herein t_2 is the water depth usable for the ships, P_{act} is the water level recorded at the gauge, RNW is low water level at the gauge (see table 6) and t_1 is the water level guaranteed below RNW. t_1 at this gauge is 200cm, RNW is 177cm for gauge Kienstock for the time frame in question here (changed in 2012).

As stated above, most ships on passing the bottleneck of Kienstock are limited below usable water depth (t_2) below 280cm. To calculate how much cargo could not be transported due to lower water levels, in a first step the average total transport amount for water depth above 280cm was calculated. For months with average water depth below 280cm the average transport amount for water depth above 280 was subtracted from the actual monthly transport amounts in those months. The results for several connections can be seen in figure 20 for the transport from the Netherlands (mostly Amsterdam and Rotterdam) to the Danube region. Figures for other connections can be found in the appendix.

In tune with the seasonal discharge, most months with water depth below 280cm mostly occurs in winter. In most of the months with a water depth below 280cm, less is transported: for the transport connection shown here up to 123000t less. In total in the years from 2008 to 2012 for the connections shown here 397000t were transported less than average during months with water depth below 280cm. However, in some months, like in autumn 2008, more than the average of water depth above 280cm is transported. This might have economic reasons or other reasons combined with a high transport demand. The mean water depth with 232cm (October) to 266cm (December) allowed the biggest ships employable on this connection (Large inland freight vessels) a degree of capacity utilization of 65% at those water levels, smaller vessels (Theodor Bayer) could use up to 81% of their capacity. The shipping limitations were not too severe during these months.
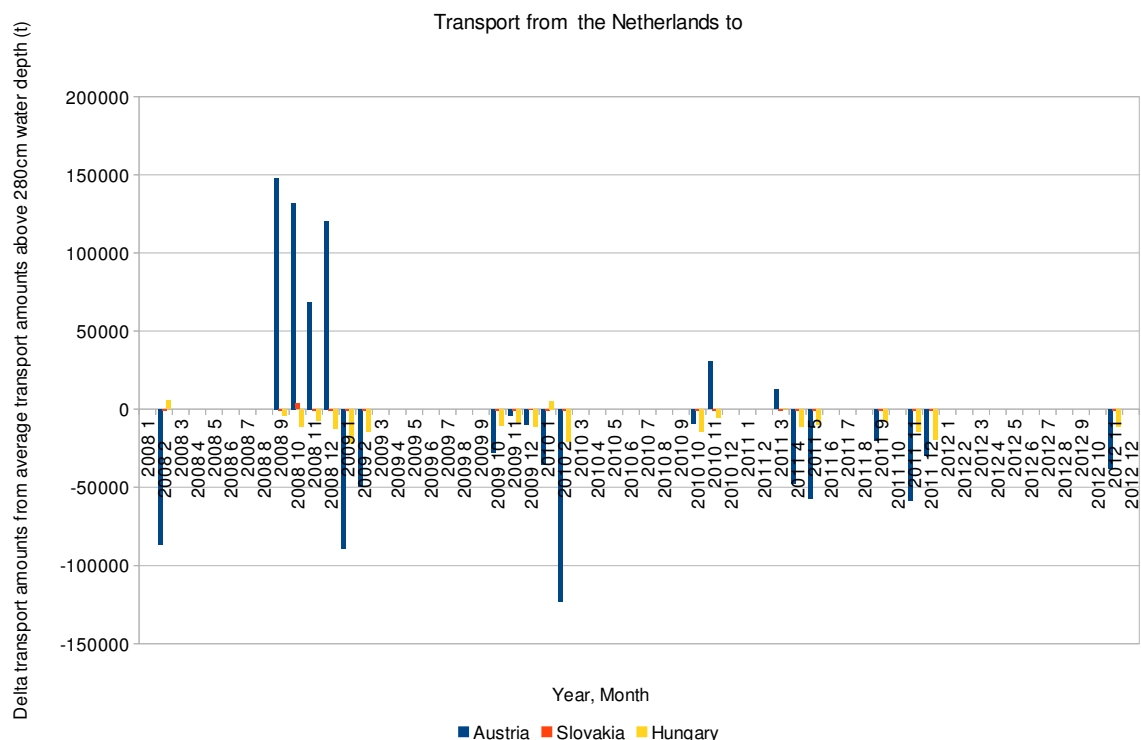
Figure 30: Delta in transport amounts from average transport amounts at water levels above 280cm for the transport from the Netherlands to the Danube region; reference gauge: Kienstock; Source: own calculation based on Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012)

II.5.3 Additional information on the impacts of low water levels on inland navigation on the Danube

As has been stated above, the RNW (low water level) at Kienstock is at 177cm. This means the usable water depth for inland navigation vessels is 200cm. With 30cm of water below the vessel needed, this allows a gauge of 170cm for inland navigation vessels. Even small(er) vessels can only use about 50% of their bearing capacity at that water depth, bigger vessels 20 to 30% (see table 5). The bearing capacity of the ships starts to be limited far above that level. Table 10 shows the average degree of capacity utilization, transport amount per vessel, total transport amount, number of ships per day and transport costs in Austria at water levels above and below 177cm. These values are given on a monthly basis, based on the data available in Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012).

Table 10: Average degree of capacity utilization, transport amount per vessel, total transport amount, number of ships per day and transport costs in Austria at water levels above and below 177cm at gauge Kienstock. calculations based on the data available in Frachtenspiegel (2000-2013), BMLFUW (2002-2012) and Statistik Austria (2008-2012).

	Average degree of capacity utilization (%)				
	Transport within Austria	Trans-boundary receipt	Trans-boundary distribution	Transit	Average
above 177cm	67	70	55	53	61
below 177cm	44	49	35	36	41
Difference	23	21	21	18	21

	Average transport amount per vessel (t)				
	Transport within Austria	Trans-boundary receipt	Trans-boundary distribution	Transit	Average
above 177cm	1185	1155	933	859	1033
below 177cm	791	773	577	549	673
Difference	394	382	356	310	360
	Average total transport amount (t)				
	Transport within Austria	Trans-boundary receipt	Trans-boundary distribution	Transit	Average
above 177cm	51246	467508	143205	214543	219125
below 177cm	70125	284308	103193	104692	140580
Difference	-18879	183200	40012	109851	78546
	Average number of ships per day				
	Transport within Austria	Trans-boundary receipt	Trans-boundary distribution	Transit	Average
above 177cm	41	419	150	252	215
below 177cm	77	393	181	201	213
Difference	-36	26	-31	51	2
	Average transport costs to/from Austria (€/t)				
	To ARA (average of costs to MDK, Austria, Slovakia, Hungary)	From ARA (average of costs to MDK, Austria, Slovakia, Hungary)	To ARA	From ARA	
above 177cm	16.47	15.82	16.90	18.00	
below 177cm	18.50	22.38	15.00	21.50	
Difference	-2.03	-6.55	1.90	-3.50	

It can be seen that the average degree of capacity utilization is 20% lower than in average for water levels above 177cm, if the water level drops below this threshold. The average transport amount per vessel gets reduced by 360t in average. As a comparison: This amount is a full ship load for a "Theodor Bayer" vessel of 48m length and 5m width. The total average transport amount is reduced by 78546t and the average number of ships increases by 2 per day. The price at the same time, depending on the transport connection, increases by up to 6.55€/t in average from several destinations in the Danube area to the ARA harbors. For single destinations the prices might increase even more.

As can be noted, also, not all transport connections react the same way. While for trans-boundary connections the prices increase while the capacity of utilization degree as well as the transport amounts decrease, for transports within Austria low water can have a positive effect in some regards. The number of ships and therefore the total amount of

transported goods increases during low water periods, even though the transport amount per ship is reduced.

II.6. Possible scenarios to overcome problems of navigation – Adaptation Options

As presented above, one of the main problems of inland navigation is its reduced bearing capacity during low water periods. This in exchange leads to higher freight prices during these periods as well as reduced transport capacities. The following chapter gives some examples of how inland navigation can be adapted to reduce the impact of low water periods.

However, some remarks of the problems of adaptation options need to be made first. Two main problems occur when adaptation measures for inland navigation should be implemented:

- On the one hand innovations take a long time to change the fleet structure (BMU 2007, Jaegers 2009) as:

    - The vessels have a very long life time and aren't replaced as often as e.g. trucks are (PINE 2004).

- Inland navigation companies are often run as family businesses which often own one or two vessels only (Jonkeren 2005, Jaegers 2009, Peijs 2009). These businesses do not have the financial capacity to invest in new vessels before the end of their life span or provide an over capacity to be used during low water events (Jaegers 2009, Peijs 2009). However, this is less true for the Danube fleet of some countries (like Serbia) where the share of bigger businesses running inland navigation companies is higher (ZKR 2011).

- On the other hand it has to be possible to rise the fright costs to cover the investments for the adaptation measures to ensure economical sound transport (Jaegers 2009, Welsch 2009). But:

    - Inland navigation has to be competitive with train and truck transport (BfG 2007, Welsch 2009), which is explicitly difficult in the Danube region where e.g. container transport by train already is as cheap or even cheaper than by ship, unless a new fleet is build (Seitz et al. 2006)

    - Depending on the branch, the willingness of companies which use inland navigation for transport to pay additionally all year to ensure the reliability of transport (e.g. by investing in over-capacities or innovative ship types), is very limited (Ham & Muilermann 2002)

    - Innovations are quickly regarded as the new standard by customers, so charging extra for this is not accepted (Bieringer 2009, Jaegers 2009)

Therefore long term investments only make sense, if low water periods occur often and severe while the demand for inland navigation transport stays at a high level (Bosschieter 2005). At the same time, if more and longer lasting low water periods occur an investment in an adapted fleet structure is essential, as otherwise customers might permanently use other modes of transport (Welsch 2009).

II.6.1 Fleet Structure

The bearing capacity of ships has an almost linear connection with its draft. The maximum draft of smaller ships is 2.50m, while bigger ships have a maximum draft of 3.50m. Therefore bigger ships cannot use their maximum bearing capacity anymore if the water depth is below 3.80m (3.50m draft plus 30cm free water under the ship), while smaller ships are only affected at water depth below 2.80m. This means that smaller ships are less affected by low water periods (and bottlenecks) than bigger ships. Therefore a higher share of smaller ships in a fleet makes the whole fleet more resistant to low water and bottlenecks. In the last years however a tendency to an increasing share of bigger ships in European fleets is registered (Scholten 2010). In the KLIWAS

project one research aspect was how the current (Rhine) fleet is affected by climate change (see e.g. Nilson et al. 2014). In a second step the impact of climate change on adapted fleet was studied. The fleet is adapted in two ways: in one version the tendency to build bigger ships is reversed – smaller ships have a higher share in the total fleet again. In the other version in addition to smaller ships, new, innovative ships are also included in the calculation. The study shows that a higher share of smaller ships as well as new, innovative ships which are less impacted by low water periods are possible adaptation measures. Some of the results are presented in Holtmann et al. (2012).

II.6.2 Innovative Ship Forms

Especially after low water periods some politicians, NGOs and media recommend to better adapt inland navigation vessels to the river they use instead of changing the river (VBD 2004, BfG 2007). Here, several adaptation options for inland navigation which have been recommended by various sources are presented including their advantages and disadvantages:

- To adapt vessels to low water periods a main focus is to **reduce** their **draft**. In principle there are two ways to reach this goal:

  New, lighter materials: If new materials could make a ship lighter while not reducing its stability its draft would be reduced while the ship would still have the same bearing capacity. In the past mixed materials like a combination of steel and polyuretal in three layers were discussed. While this material offers the same security as a double hull (as is used for tank ships), it is lighter. Other parts of the ship, which are not necessary for its stability like the on board flat could be made of plastic or aluminium (BfG 2007). If more sturdy steel would be used, it could be thinner and therefore lighter than the one used now (Bosschieter 2005). But these new materials most likely are more expensive than those used so far (Bieringer 2009). In addition to that, while the new three layered material is lighter than a double hull, it is not lighter than one hull made out of steel. As long as European law demands tanks to have a double hull, no matter the material, using the new material would not lead to any advantages. Exchanging flat and other parts not important for the stability by lighter materials would have a very small impact on the draft of the vessel, as these parts only have a share of 5% of the total weight of the ship (BfG 2007).

  New, lighter and/or better distributed engine: One possibility to change the engine would be to have four light engines in each corner of the ship instead of one heavy one in the back as is done now. That would reduce the stern trimming and by that reduce the gauge. But most likely those ships would have to be wider than the current ones which might lead to problems in harbors and in some smaller rivers and channels. Engines that run faster are also lighter – but the reduction in weight (5-10 t) would be next to nothing compared to the weight of the ship (BfG 2007). Research on an "Azimuthing Electric Propulsion Drive" is on-going. This would reduce the gauge of the ship (BfG 2007). The Whale Tail on the other hand has lots of power even in low water, while using less fuel (VBD 2004, Bosschieter 2005, BfG 2007). The Whale tail could actually lead to a Win-Win situation: less fuel consumption, less CO_2 Emission, higher speed and more efficient during low water events (Joeris 2009). But, as most changes of the engine, this engine could only be built in in new vessels due to its specific construction needs and therefore as most innovations needs lots of time to have a significant market share.

- **Provision of over-capacity** is one way to reduce the impact of low water periods on the security of transport. During low water periods the additional capacity can be used to compensate the loss of transport capacity in the main fleet. For example the Dutch policy sees the importance of such a measure (Peijs

2009). However in other countries political activities lead to a reduction of overcapacity. But as said above: providing an over-capacity leads to increase of fright rates throughout the year.

- **Deploying (more) small vessels** is an alternative to reduce the impact of low water periods without needing expensive innovations. The bearing capacity of small vessels (of up to 85m length) is – compared to bigger vessels – less reduced percentage wise during low water periods. However, during normal water levels small vessels are more expensive than big ones (economy of scale), especially if they have to be newly build.

- Another way to increase the capacity of the fleet during low water periods is to **use all vessels 24 hours a day** (most smaller vessels are only used 8 to 14 hours a day) Bosschieter (2005). This of course would demand additional crew, which in most cases is not available. In addition to that, harbors also need to work 24 hours, to ensure this method to be effective (Bosschieter 2004). As most measures, this as well leads to higher costs (Bieringer 2009).

- To reduce the risk of accidents and to increase the use of the full width and depth of the river when possible, **radars in combination with GPS and maps** enable better navigation and an optimal amount of cargo for the maximum possible gauge (Bosschieter 2005, Joeris 2009, Bieringer 2009).

- To lift the ships with the help of **additional lifting bodies** used only during low water periods is debated, as well as **floating docks or hover cushions** to be used at critical bottlenecks (BfG 2007, Joeris 2009, Bosschieter 2005). But especially the last one can only be used for short distances (BfG 2007).

The higher costs for these innovations however lead to new ship types/fleets which are economically not competitive with older ship types/fleets or train transport, as the more complex technique not only leads to higher investments, but also a higher demand for maintenance and repairs (VDB 2004). Longer and wider vessels, which have roughly the same weight as smaller vessels, are difficult to develop, as the stability has to be insured without increasing the weight. But these ships again are not able to compete with normal vessels at normal water levels, as using them for transport would be much more expensive (BfG 2007). In addition to that, the design of the vessels also defines the design of the terminals which then also would need to be adapted (Grabs et al. 1997). Another problem is, that to be economical sound ships need to be able to serve on different waterways and with different products. Though some ships exist which are perfectly adapted to a certain waterway, they are also restricted to it. While this might be economically sound in some special cases, it is not for commercial cargo (BfG 2007).

II.6.3 Hydro Engineering

In addition to changes in the fleet, changes of the river are also viable adaptation options. Following, some of the most debated measures are presented:

- Building **additional barrages** can regulate the water level constantly, but is a rather expensive measure (Zebisch et al. 2005). To regulate a whole river, several barrages as well as several locks are needed. Even huge locks add waiting time for inland navigations and thereby reduce its efficiency (Bosschieter 2005). In addition to that, new barrages might lead to conflicts, e.g. with the EU water framework directive (Bosschieter 2005, Zebisch et al. 2005). As barrages slow down the discharge, high water levels are reduced slower (Rothstein 2007) and more accumulations appear (Zebisch et al. 2005).

- New **storage basins** to collect water during periods of high or normal water could be build, to release the water during periods of low water (Geenhuizen et al. 1996, Grabs et al. 1997, Bosschieter 2005, BMU 2007). To have a lasting effect those basins would need to be huge though. Bosschieter (2005) calculated, that to catch water during a high water period (16 000m³/s for 3 days) the basin

would need to be able to hold 260 000 000m³ of water, which demands a basin of 16*16km at 3m depth (267km²). To increase the discharge during a low water period (24 days per year at a discharge of 800m³/s) to 1000m³/s 414 000 000m³ of water would be needed, so almost double the amount caught during the named high water period (Bosschieter 2005).

- To **deepen the navigable channel** is a method often mentioned during low water periods. But this would not lead to more water within the river, unless the navigable channel is more narrow as well – a method that is debated as well. In addition to that, for the River Rhine 1.8m³ of earth would need to be moved to deepen the navigable channel by 15cm with the resulting costs (Bosschieter 2005).

- **Spur dykes** are used to lead the water to the navigable channel of the river during low water periods. But their effect during high water periods has to be studied in the individual cases (Bosschieter 2005). They might lead to higher water levels during floods and it is questionable if they are in line with the water framework directive of the EU (Bosschieter 2005). Therefore the idea of semi permanent or flexible spur dykes is debated, which are only used during low water periods.

7 Conclusion

This report contains two parts: The first part presents an overview on studies concerning the Danube, inland navigation or the impact of climate change on either of those. The number of studies emphasises the importance of the Danube region and inland navigation. The second part gives a more detailed analysis of inland navigation on the Danube, partly based on studies presented in part one. Part two covers the current situation along the Danube by covering the topic of bottlenecks and other limitations for shipping along the Danube. Based on this information, an estimation of the economic impact of low water periods on inland navigation is made. As a last step, measures to reduce the impact of low water on inland navigations are presented.

The major findings of this report can be summed up as follows: The report shows that inland navigation still is an important transport mode along the Danube as well as in other European regions. Especially in Romania, inland navigation still has a large share of more than 20% and rising in total transport. However, inland navigation depends strongly on good conditions of its infrastructure. These good conditions are limited mainly by two factors: one are the so called bottlenecks. Those are areas with sub-optimal shipping conditions e.g. due to solid rock formations in the river that lead to a reduced water depths. Bottlenecks can be found in all segments of the Danube. The other factor is the weather (and, on a longer time scale, the climate) which, mostly depending on precipitation and evaporation, can lead to low water levels as well. The later one is a mostly seasonal factor. In addition to these two natural factors, laws which regulate the maximum number of barges allowed and human built structures like locks also limit the size of vessels and the speed they can travel. These limiting factors are identified and located in the first chapter of part two of this report. Then the water depth needed by several ship sizes is presented, as well as the number of vessels available along the Danube for dry and fluid cargo. Based on this information the maximum bearing capacity that can be transported at certain water-levels can be calculated. Most ships of the Danube fleet are of medium size (1000 -1499t bearing capacity per ship). The bearing capacity of this ship size is only limited at water levels below 2.80cm. But bigger ships with bearing capacities of more than 3000t also exist. The bearing capacity of these ships is already limited at water levels below 3.80cm. Therefore these ships are far more vulnerable during low water periods than smaller vessels. These findings as well as statistical data of transport amounts via inland navigation on the Danube, of water levels and freight prices, are used to estimate the economic impact of low water periods. To estimate the impact of low water periods on the freight prices, the strength of the connection of transport factors like the degree of capacity utilization or the transport amount per ship in tons with the water level is analyzed using correlation analyzises. A strong connection (correlation factor of 0.74) of the degree of capacity utilization or the transport amount per ship in tons with the water level is identified here. As this connection influences the freight prices as well, a method developed by Jonkeren et al. (2007) for the Rhine is transfered to the Danube, to identify the strength of the impact. First however, it had to be proven, that this transfer is valid by showing that the transport factors for both rivers show a similar connection to the water levels. By transfering the Jonkeren et al. (2007) method, regression equations for several transport connections along the Danube are identified that represent the connection of freight prices and water levels. With the help of these regression equations, an estimation of the total expenses for transport via inland navigation for several years is possible. These are calculated for several transport connections. As one example the transport of goods from Germany to Austria is used. Here, yearly expenses up to 2.7 million € are calculated with the maximum costs appearing in March and May. Additional expenses due to water levels below 280cm for this transport connection sum up to about half a million € with the maximum additional expenses in winter. Additional expenses for transport due to water levels below 280cm from the Netherlands to Hungary can sum up to about half a million € per month.

But additional expenses are not the only impact of changing water levels on inland navigation. Another is that while the demand for transport stays at the same level, sometimes the water levels are not sufficient enough to use the full capacity of the fleet. Therefore, the (theoretical) amount of cargo that could not be transported due to low water levels is calculated as well. For example in February 2010, roughly 123000t less than average were transported from the Netherlands to Austria.

Finally, some measures to overcome some of the here named problems of inland navigation due to low water levels are presented. These are separated into two general approches: change the ship or change the river. Both methods have their advantages and disadvantages due to technical as well as regulatory and other factors. The list presented here however is incomplete and only gives a few ideas of how some problems can be overcome. In the end, an individual mix for the different regions along the river and sometimes for the individual companies must be found.

In total, this report can only give a brief overview of studies performed, impact factors on the Danube as well as a rough estimation of the economic impact of low water levels and a brief overview of possible adaptation measures. Especially the estimation of the economic impact is limited by the data sets available. Except for the water levels, monthly data from published statistics of several countries along the Danube was used in most cases. Average freight prices per month and average transport amounts per ship per month are just two factors to be named here. However, the impact of water levels is more visable on a daily scale as has been proven by Jonkeren et al. (2007) and Scholten & Rothstein (2012) for the Rhine. Therefore only a rough estimate of the economic impact could be provided. Never the less, this estimate gives a first idea of the economic impact of changing water levels in the Danube region and a motivation for additional research with data on a daily basis.

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Annex A: Importance on inland navigation and other modes of transport along the Danube
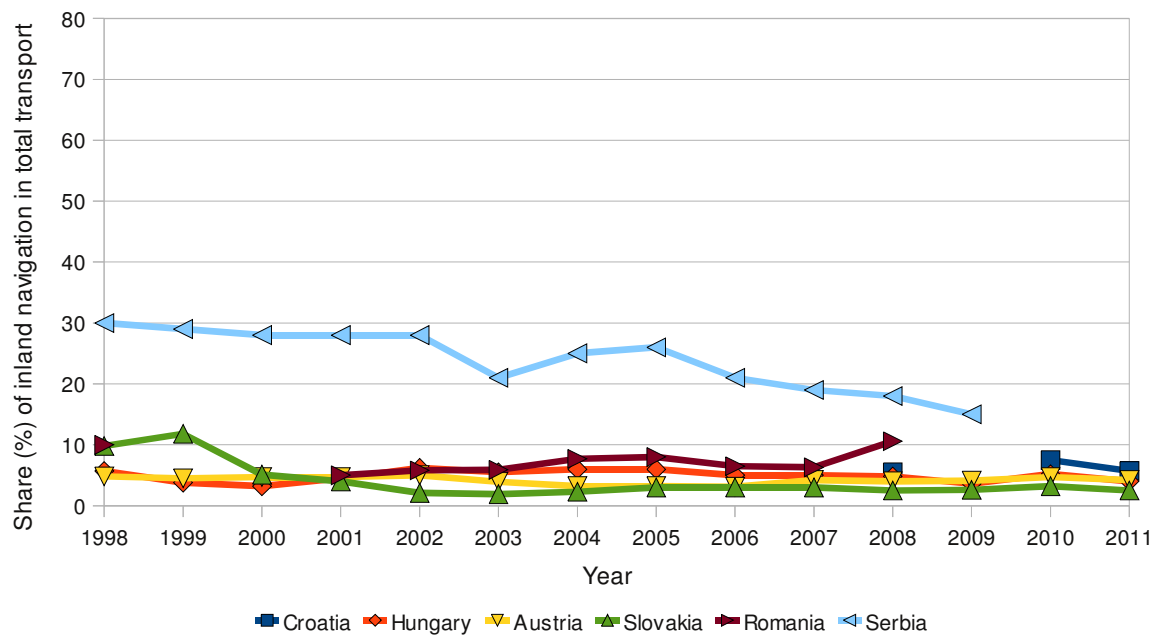
Figure A-31: Share of inland navigation in the Danube area in total transport (tkm); Source: ZKR Marketobservations 2010-2013
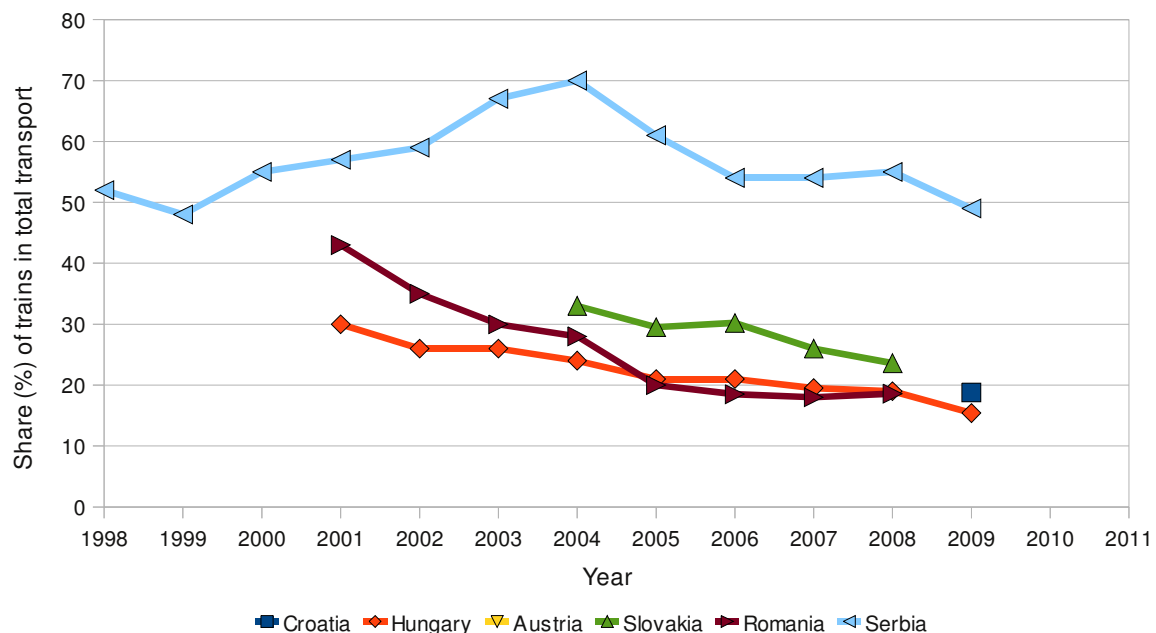
Figure A-32: Share of trains in total transport (tkm) in the Danube area; Source: ZKR Marketobservations 2010-2013
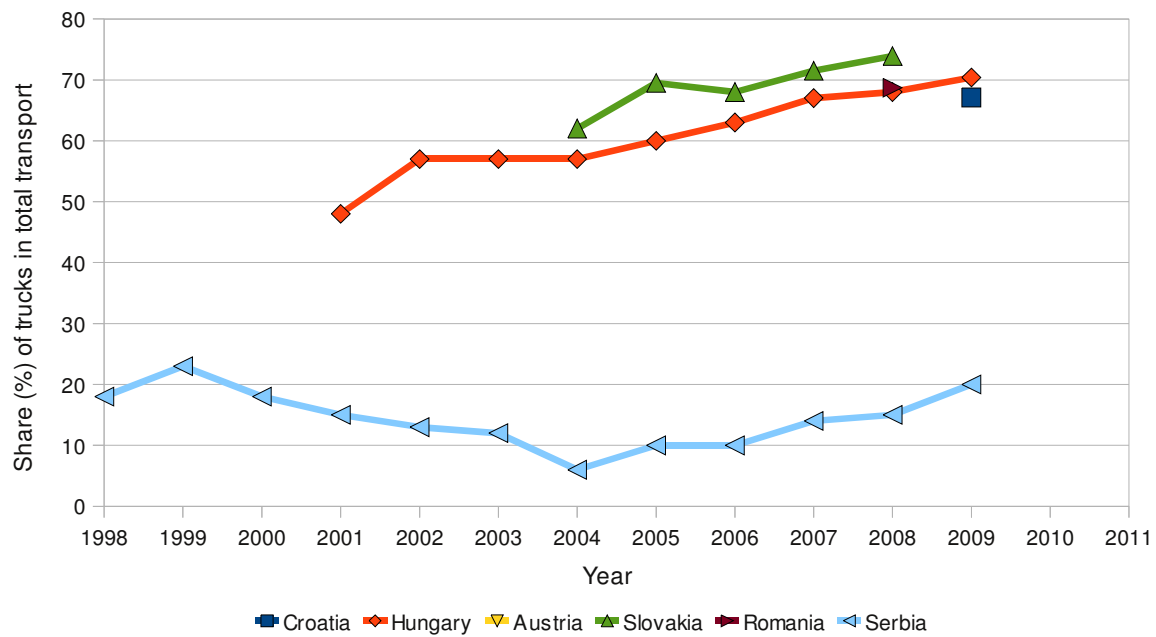
Figure A-33Share of trucks in total transport (tkm) in the Danube area; Source: ZKR Marketobservations 2010-2013

Annex B: Maximum water level and discharge along the Danube and main tributaries, which still allows navigation

Table B-11: Maximum water level and discharge along the Danube and main tributaries, which still allows navigation; HSW (highest navigable water level); Source: WESKA 2006, NEWADA undated; HNR undated

Gauge	Danube km	HSQ (m³/s)	HSW (cm)
Kehlheim	2414.84	1110	540
Oberndorf	2397.38	1160	480
Schwabelweis	2376.49	1560	520
Pfatter	2350.7		600
Pfelling	2305.53	1230	620
Deggendorf	2284.43		540
Hofkirchen	2256.86	1550	480
Passau	2226.7	4210	780
Achtleiten	2223.21	3670	510
Wilhering	2144.3		628
Linz	2135.17	3342	545
Mauthausen	2110.98		510
Grein	2079.4		898
Kienstock	2015.21	4621	624
Dürnstein	2009		638
Korneuburg	1941.3		549
Wien	1941	4707	537
Wildungsmauer	1894.72		576
Hainburg	1883	4652	602
Bratislava	1868.75		643
Komarno	1767.05		747
Nagymaros	1694.6		510
Budapest	1646.5		668
Paks	1531.3		720
Mohacs	1446.8		815
Bezdan	1425.5		596
Novi Sad	1255.3		599
Zemun	1173		636
Gruia	851		748
Lom	743.3		795
Turnu-Magurele	597		614
Oltenita	430		714
Silistra	375.5		717
Calarasi	370.5		639
Cernavoda	300		604
Hirsova	253		644
Braila	170		578
Galati	150		553
Reni	127.23		485
Isacea	103.8		458

Annex C: Amount of goods per sector of the Danube including Germany
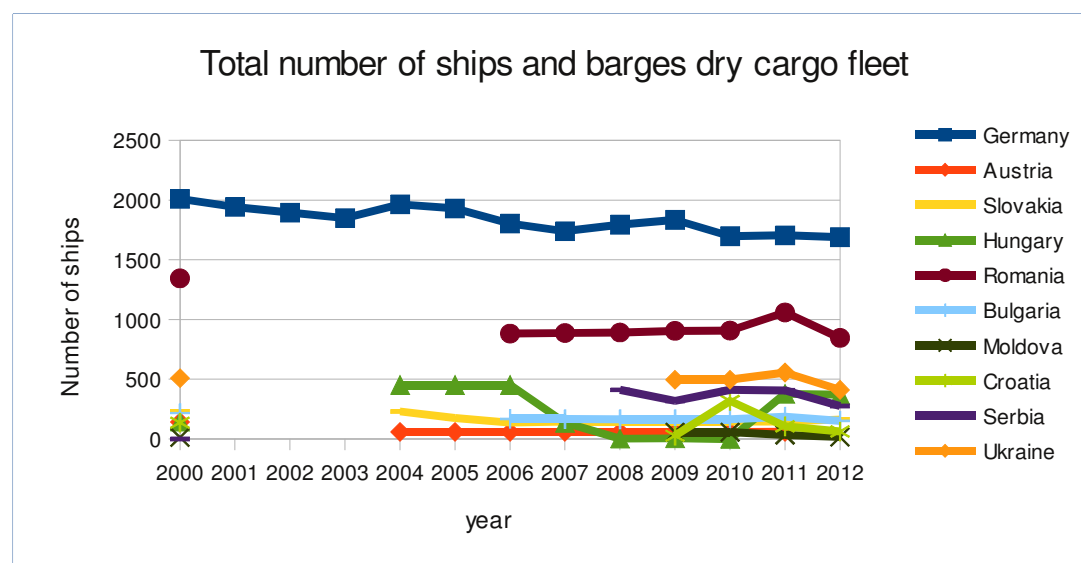
Figure C-34: Total number of ships and barges for dry cargo - with German fleet; Source: ZKR Marketobservations 2005 - 2012; WESKA 2006; Donaukommission Anlage zu DK 5/I-2014
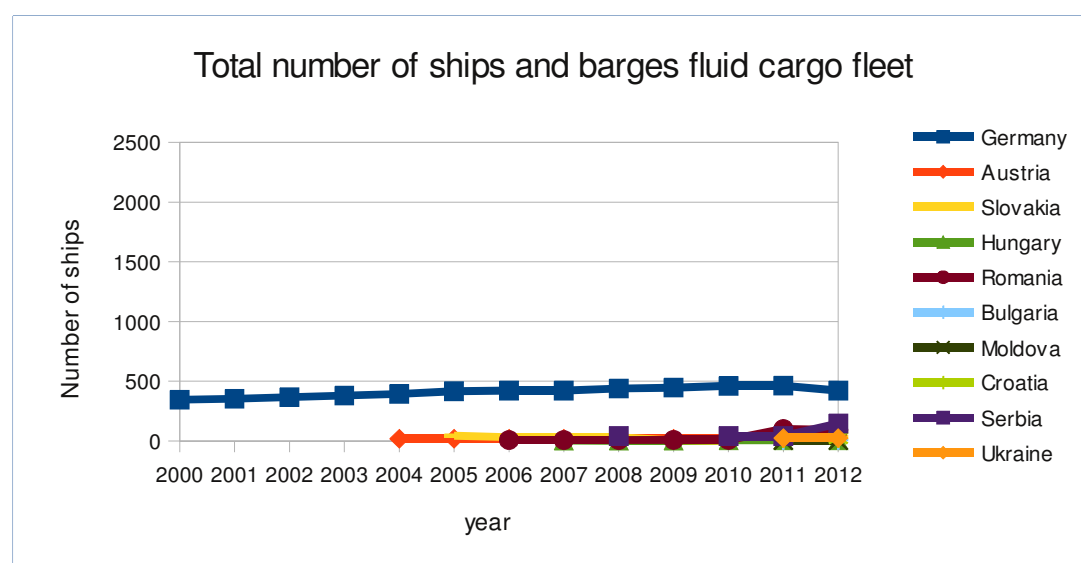
Figure C-35: Total number of ships and barges for fluid cargo - with German fleet; Source: ZKR Marketobservations 2005 - 2012; WESKA 2006; Donaukommission Anlage zu DK 5/I-2014
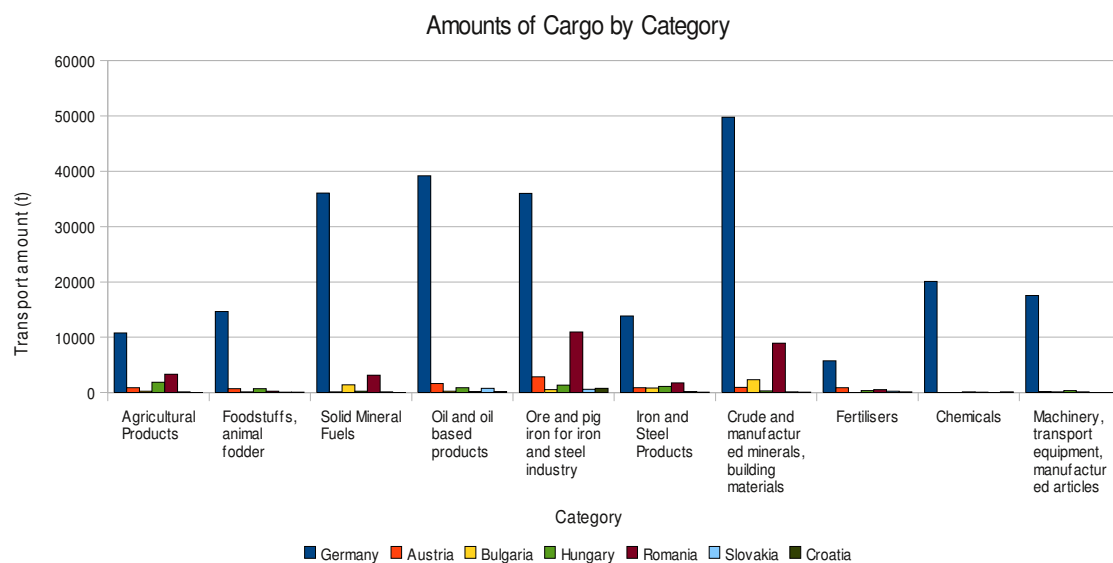
Figure C-36: Amounts of Cargo by Category and Danube Countries with Germany in 2006; Source: ZKR Marketobservation 2007-1; 2005-1

Annex D: Available freight cost data by connection and month

Table D-142: Available freight cost data by connection and month. Missing data is marked by crosses; Source: Frachtenspiegel (2000-2013)

		ARA to MDK	ARA to Österreich	ARA to Slowakei	ARA to Ungarn	ARA to Mannheim	ARA to Oberrhein	MDK to Austria	MDK to Slovakia	MDK to Ungary	Austria to Slowakia	Austria to Hungary	Slowakia to Hungary
2000	Januar	x	x	x	x	x	x	x	x	x	x	x	x
	Februar								x		x		x
	März								x		x		x
	April								x		x		x
	Mai								x		x		x
	Juni								x		x		x
	Juli								x		x		x
	August								x		x		x
	September								x		x		
	Oktober								x				x
	November								x		x		
	Dezember	x	x	x	x	x	x	x	x	x	x	x	x
2001	Januar								x		x		x
	Februar								x		x		x
	März								x	x	x		x
	April								x		x		x
	Mai								x		x		x
	Juni								x		x		x
	Juli								x		x		x
	August								x		x		x
	September										x		x
	Oktober												x
	November												x
	Dezember												x
2002	Januar												x
	Februar								x	x			x
	März								x	x	x		x
	April												
	Mai												
	Juni	x	x	x	x	x	x	x	x	x	x	x	x
	Juli												
	August												
	September	x	x	x	x	x	x	x	x	x	x	x	x
	Oktober												
	November												
	Dezember	x	x	x	x	x	x	x	x	x	x	x	x
2003	Januar												
	Februar												
	März												
	April												
	Mai	x	x	x	x	x	x	x	x	x	x	x	x
	Juni	x	x	x	x	x	x	x	x	x	x	x	x
	Juli										x		x
	August												
	September												
	Oktober												
	November												
	Dezember	x	x	x	x	x	x	x	x	x	x	x	x
2004	Januar												
	Februar							x		x			
	März								x	x			
	April	x	x	x	x	x	x	x	x	x	x	x	x
	Mai												
	Juni	x	x	x	x	x	x	x	x	x	x	x	x
	Juli												
	August												
	September							x	x	x	x	x	x
	Oktober												
	November												
	Dezember	x	x	x	x	x	x	x	x	x	x	x	x
2005	Januar												
	Februar												
	März												
	April												
	Mai												
	Juni	x	x	x	x	x	x	x	x	x	x	x	x
	Juli												
	August												
	September												
	Oktober												
	November												
	Dezember	x	x	x	x	x	x	x	x	x	x	x	x
2006	Januar	x	x	x	x	x	x	x	x	x	x	x	x
	Februar								x				
	März								x				
	April								x				
	Mai								x				
	Juni	x	x	x	x	x	x	x	x		x		x
	Juli								x		x		
	August	x	x	x	x	x	x	x	x		x	x	x
	September								x		x		
	Oktober								x		x		x
	November								x		x		x
	Dezember	x	x	x	x	x	x	x	x	x	x	x	x

Table D-15: Available freight cost data by connection and month. Missing data is marked by crosses; Source: Frachtenspiegel (2000-2013)

Year	Month	ARA to MDK	ARA to Österreich	ARA to Slowakei	ARA to Ungarn	ARA to Mannheim	ARA to Oberrhein	MDK to Austria	MDK to Slovakia	MDK to Ungary	Austria to Slovakia	Austria to Hungary	Slowakia to Hungary
2007	Januar								x		x		x
	Februar												
	März										x		x
	April										x		x
	Mai										x		x
	Juni	x	x	x	x	x	x	x	x		x	x	x
	Juli								x		x		x
	August								x		x		x
	September						x	x	x		x		x
	Oktober	x	x	x	x	x	x	x	x		x	x	x
	November										x		
	Dezember	x	x	x	x	x	x	x	x		x	x	x
2008	Januar										x		x
	Februar										x		x
	März										x		x
	April	x	x	x	x	x	x	x		x	x	x	x
	Mai						x		x		x		
	Juni	x	x	x	x	x	x	x	x		x	x	x
	Juli						x		x		x	x	x
	August	x	x	x	x	x	x	x	x	x	x	x	x
	September	x	x	x	x	x	x	x	x	x	x	x	x
	Oktober	x	x	x	x	x	x	x	x	x	x	x	x
	November	x	x	x	x	x	x	x	x	x	x	x	x
	Dezember										x		x
2009	Januar								x				x
	Februar								x				
	März								x				
	April								x				
	Mai								x				
	Juni								x				
	Juli								x				
	August	x	x	x	x	x	x	x	x	x	x	x	x
	September								x				
	Oktober								x				
	November								x				
	Dezember								x				
2010	Januar								x				x
	Februar	x	x	x	x				x				
	März										x		x
	April												
	Mai							x	x	x			
	Juni							x	x	x			
	Juli								x				
	August								x	x	x		x
	September								x	x			x
	Oktober										x		
	November												
	Dezember												x
2011	Januar							x	x	x			x
	Februar							x	x	x			
	März												
	April			x				x	x				x
	Mai												x
	Juni							x		x			x
	Juli									x			
	August									x			
	September							x			x		
	Oktober							x			x		
	November							x		x			
	Dezember												x
2012	Januar									x			x
	Februar	x	x	x	x	x	x	x	x	x	x	x	x
	März							x	x	x	x		x
	April									x			x
	Mai							x	x	x	x		
	Juni							x	x	x	x		
	Juli							x	x	x	x		
	August			x				x	x	x	x		
	September			x							x		
	Oktober										x		
	November										x		
	Dezember												
2013	Januar							x	x	x	x		x
	Februar							x	x	x	x		
	März			x				x	x	x	x		
	April	x	x	x	x	x	x	x	x	x	x	x	x
	Mai	x	x	x	x	x		x	x	x	x		x
	Juni			x	x			x	x	x	x		
	Juli	x	x	x	x	x	x	x	x	x	x		x
	August	x	x	x	x	x	x	x	x	x	x	x	x
	September	x	x	x	x	x	x	x	x	x	x	x	x
	Oktober	x	x	x	x	x	x	x	x	x	x	x	x
	November	x	x	x	x	x	x	x	x	x	x	x	x
	Dezember	x	x	x	x	x	x	x	x	x	x	x	x

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