ECONOMIC ANALYSIS OF ADAPTATION MEASURES TO CLIMATE CHANGE FOR INLAND WATERWAY TRANSPORT

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Olaf Jonkeren[1]
Piet Rietveld[1]
Ad van der Toorn[2]

[1]VU University, Amsterdam
[2]TU Delft

Inhoud

1 Introduction

During the last decade discussions on climate change and transport were mainly focused on mitigation strategies. The central question was: in which ways can the greenhouse gas emissions of the transport sector be reduced? More recently another element has been added to the discussion on climate change: it is plausible that the climate is changing rather rapidly, and that raises the issue of what adaptation measures will be called for in the transport sector.

In water transport, climate change impacts may be substantial and even be positive. For example, the increase of global temperatures may make water transport in the Arctic areas possible and economic viable (Johannessen et al., 2004; Somanathan et al., 2007). However, there are also potential negative effects. In particular, inland waterway transport may experience higher volatilities in water levels in rivers which will result in higher transport prices, a decrease of reliability and consequently, a shift of cargo to competing transport modes. The degree to which these negative effects for inland waterway transport occur is extensively discussed in the ‘problem exploration phase’ of the ‘Knowledge for Climate, HSRR08, water and transport’ research project. The current report is part of the ‘solution phase’ of this climate research project and focuses on the economic feasibility of adaptation measures that aim to reduce the potential effects of climate change on inland waterway transport in North West Europe.

The adaptation measures that are discussed in the current report are selected as being ‘most worthwhile to evaluate’ by a group of stakeholders during the workshop ‘Water and Transport’ that was organized in Utrecht by the HSRR08 research consortium on 07/04/2010.

In total eight adaptation measures are selected for research of which three are eligible for economic assessment (in italic) in this report. Below all measures are listed:

- *Higher number of operational house per day*
- *Canalization of river Rhine*
- *Additional storage capacity at production location of shipper*
- Alternative use of modalities in the logistic chain
- Use of ICT in the waterway

- ICT logistics
- Improvement of waterway infrastructure
- New ship types

The non-bold adaptation measures are evaluated by other consortium partners from the point of view of their expertise. In the remainder of this report, each of the three adaptation measures for economic assessment is dealt with in a separate section and the last section will conclude.

2 Higher number of operational hours per day for inland ships

In periods with low water levels, inland ships are restricted in their load factor and transport prices per tonne rise, implying a decrease in the amount of cargo transported by inland waterways in these periods (Jonkeren et al., 2007). A part of this loss of cargo will not be transported by inland waterways because of capacity constraints and another part because it will shift to competing transport modes, road and rail. This implies there is a loss of revenue for inland waterway carriers. The loss of revenue that is caused by a lack of capacity can be regarded as the potential benefits that can be achieved by navigating more hours per day. After all, if (part of) the inland ship fleet navigates more hours per day, this (partly) compensates for the reduction in load factor.

In inland waterway transport in North West Europe three exploitation forms (A1, A2 and B) exist. Waterway carriers can operate on a 14 hours (A1), 18 hours (A2) or 24 hours (B) basis per day. Each exploitation form requires a specific size and composition of the ship crew, which is founded in the “Reglement van Onderzoek voor Schepen op de Rijn” (Regulations of Investigation for Inland Ships on the Rhine). About 25% of all inland waterway carriers operate on a 24-hour basis (Jonkeren, 2009). This implies that about 75% of the fleet (exploitation forms A1 and A2) is able to increase the number of navigable hours per day in periods with low water levels so that fleet capacity will increase. However, increasing the number of operational hours means that extra labor must be hired. So, hourly labor costs increase. Hourly fuel and maintenance costs will not increase but total costs for fuel and maintenance will rise because carriers sail more hours per day. A practical problem that arises when a carrier wants to operate more hours per day is how to obtain extra (sufficiently qualified) personnel. Second, it is difficult to determine for what time period the extra personnel must be hired as it is hard to foresee how long a low water period will last. Therefore, carriers hire so called ‘zzp-ers’, ‘independents without personnel’ which they can lay off in the short term.

The question is if the extra revenue which is generated by navigating more hours per day compensates for the extra costs. To answer this question a few limitations of the cost-benefit approach must be mentioned. First, we only focus on inland waterway traffic for which the location Ruhrort at the Rhine is critical with respect to load factor because for this location we know to what extent the load factor of inland ships is restricted and thus how much cargo cannot be transported.[1] Second, our analysis is limited to the ‘Global Economy’ WLO economic scenario (Centraal Planbureau, 2006). The volume of the annual cargo flow that passes Ruhrort in 2050 is likely to be higher than nowadays. It is therefore assumed that, compared to the year 1997, the flow will have increased by a factor 2.0 by 2050, in line with the assumption made in Deltares (2008). Third, the W+ KNMI’06 (KNMI, 2006) climate scenario is considered in the current study.

2.1 Benefits

In 1997, the inland waterway transport volume that passed Ruhrort was about 151.000 million tonnes (CCR, 1998). Assuming a Global Economy WLO scenario with a growth factor of 2.0 for 2050 compared to 1997 for inland waterway transport demand (Deltares, 2008), about 302.000 million tonnes of cargo will pass Ruhrort in 2050. Assuming that this quantity is equally distributed over the year, the daily volume that passes Ruhrort is 0.83 million tonnes in 2050.

The number of days with, and the intensity of low water levels in the Rhine at Ruhrort in the W+ climate scenario then determine to what extent the load factor of the inland ships passing Ruhrort is restricted. Econometric estimation techniques are applied to determine the extent to which the load factor drops as the water level decreases at Ruhrort. To our disposal we have a rich dataset (called the ‘Vaart Vrachtindicator’) on trips made by inland waterway carriers in North West Europe in the period between January 2003 and January 2007.

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[1] Ideally, the analysis covers the whole of the Rhine area. However, the analysis now applies to the thickest cargo flow on the Rhine, the one between Rotterdam and the Ruhr area. Second, the outcome of this analysis, so for a part of the Rhine area, is likely to be valid for the whole of the Rhine area.

Table 1: Estimation results for load factor

Explanatory Variables	*Coefficient*		*Std. Error*
Water level			
207 – 255	-0.322		0.016
256 – 265	-0.250		0.019
266 – 275	-0.184		0.017
276 –285	-0.153		0.016
286 – 295	-0.148		0.017
296 – 305	-0.092		0.012
306 – 315	-0.115		0.016
316 – 325	-0.057		0.017
326 – 335	-0.026		0.017
≥ 336		Reference	
Log(distance)	-0.049		0.007
Time trend	0.000		0.008
Vessel size			
0 – 1000 tonnes	0.152		0.009
1000 – 1500 tonnes	0.173		0.009
1500 – 2000 tonnes	0.079		0.010
2000 – 2500 tonnes	0.082		0.011
> 2500 tonnes		Reference	
Month dummies			
January		Reference	
February	0.026		0.013
March	0.008		0.016
April	0.016		0.012
May	0.034		0.012
June	0.009		0.012
July	-0.001		0.012
August	-0.003		0.013
September	-0.004		0.011
October	-0.021		0.012
November	0.012		0.012
December	-0.016		0.012
Cargo dummies, 46		Included	
$\mathbf{R^2}$		0.23	
n		6252	

Note: the dependent variable is the logarithm of load factor; the time trend variable is in days and divided by 1000.

The model that is estimated is shown below:

$$Y_i = \alpha + \gamma_2 W_{2i} + \gamma_3 W_{3i} + \gamma_4 W_{4i} + \gamma_5 W_{5i} + \gamma_6 W_{6i} + \gamma_7 W_{7i} + \gamma_8 W_{8i} + \gamma_9 W_{9i} + \gamma_{10} W_{10i} + \beta X_i + \varepsilon_i$$

,

where Y_i denotes the logarithm of the load factor, W_2 to W_{10} refer to water level dummy variables, X_i denotes observed explanatory variables and ε_i is random error.[2]

Each water level dummy represents a water level interval of 10 centimetres. The reference category (W_1) is the group with water levels exceeding 335 centimetres, which measures the threshold level.

We have performed a sensitivity analysis and it appears that the effect of water level on load factor of an inland ship of average size is absent when water levels exceed 335 cm at Ruhrort. The estimation results are presented in Table 1.

Our main result is that the water level has a statistical significant, positive effect on the load factor. The drop in load factor is relative to the situation of 'normal' water levels, which we defined as water levels higher than 335 cm at Ruhrort. Given normal water levels, the average load factor is 0.84. The drop in load factor has to be regarded relative to this percentage. So, if an inland ship of average size passes Ruhrort at a water level between 256 cm and 265 cm, the drop in load factor is 22% compared to the load factor of same ship if its trip took place at a water level higher than 335 cm.[3]

With information on daily water levels at Ruhrort during a year in the W+ climate scenario (kindly provided by Deltares) in combination with the estimation results in Table 1, one can determine the extent to which the load factor of the inland waterway fleet decreases on average (see Table 2) in the low water period. It is assumed that the load factor of both, small and large ships drops to the same extent when the water level drops. This implies that the drop in load factor is overestimated for small ships and underestimated for large ships. Table 2 shows there are 156 days with a water level at Ruhrort lower than 335 cm in the W+ climate scenario implying that inland ships are restricted in their load factor during these days. The weighted average decrease in load factor is then 19.7% resulting in an average load factor of 67.4% during the 156 days.[4]

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[2] The control variables X_i are: the logarithm of distance, a time trend, ship size (4 dummies), 11 month dummies to control for seasonal effects and 46 cargo type dummies because of differences in the mass per volume of each cargo type.

[3] $e^{-0.250} - 1 = -0.221$.

[4] 0.84 – ((1- 0.197)/0.84) = 0.674.

Table 2: Average load factor decrease and average load factor for inland waterway fleet in a W+ year

Interval	Load factor decrease (%)	Load factor	No. of days in W+ year
326 - 335	-0.026	0.818	12
316 - 325	-0.055	0.794	7
306 - 315	-0.109	0.748	11
296 - 305	-0.088	0.766	8
286 - 295	-0.137	0.725	11
276 - 285	-0.142	0.721	10
266 - 275	-0.168	0.699	9
256 - 265	-0.221	0.654	9
207 - 255	-0.275	0.609	79
Total low water level period	*-0.197*	*0.674*	*156*

Due to this reduction in load factor the annual loss of cargo for inland waterway transport that passed Ruhrort is equal to 156 * 0.83 (daily volume) * 0.197 = 25.50 million tonnes. Part of this quantity will be transported by competing transport modes, road and rail. TNO (2010)[5] calculated that 43% of the transport volume that is lost by inland waterways due to low water levels in the W+ climate scenario is expected to accept the higher transport price. The remaining volume is expected to shift to road and rail. We apply this percentage in the current study so that 11.00 million tonnes of cargo is the quantity that can be transported extra by inland waterways by means of navigating more hours a day. Knowing that the average transport price per tonne during the low water level period in 2003 (which is said to be representative for future summers, Beniston, 2004)) for inland ships with a capacity of between 1000 and 2500 tonnes[6] that pass Ruhrort is € 6.83 and that the average distance of an inland waterway trip that passes Ruhrort is equal to 347 km, the loss of 11.00 million tonnes is equivalent to an amount of € 75.13 million and 3,817 million ton-km (the potential benefits). In the next section, the costs that are involved in transporting the additional 11.00 million tonnes by means of navigating more hours a day will be estimated.

2.2 Costs

In this section, we analyse the costs of transporting an extra 3,817 million ton-km by inland waterway carriers that operate in the A1 and A2 exploitation forms, taking into account that

[5] See Figure 5.13 in the report.

[6] Transport capacity of inlands ships in the A1 and A2 exploitation forms is about between 1000 and 2500 tonnes.

transporting these extra ton-km requires extra hours for loading and unloading and that hourly labour costs will rise because more personnel is hired when navigating 24 hours a day instead of 14 or 18 hours a day. In addition, fuel and maintenance costs increase when carriers sail more hours per day. Table 3 informs us on the values of several parameters that are needed to calculate the costs that are involved with transporting the extra 3,817 million ton-km.

It is assumed that representative ship sizes for exploitation forms A1 and A2 are 1150 and 1910 tonnes respectively (an M5 and M7 ship according to the DVS classification). Average speed of those inland ships is equal to 15 and 15.75 km/h respectively (NEA, 2008). From Table 3 it can be calculated that the average number of ton-km per hour in periods with low water levels is 11,626 for an A1 ship and 20,275 for an A2 ship.

Table 3: Parameter values

Parameter	Ship exploitation form A1	Ship exploitation form A2
Representative average ship size	1150 tonnes	1910 tonnes
Average speed (km per hour)	15 km/h	15.75 km/h
Average load factor low water	0.674	0.674
Average load factor normal water	0.840	0.840
Share of exploitation form in total fleet (in ton-km)	0.25	0.35

The question then is how the 3,817 million ton-km are distributed over the exploitations forms. It is reasonable to assume that the proportions are based on the share of each exploitation form in the total fleet (measured in ton-km, not in number of ships). We assume that about 25% of all ton-km made by the inland waterway fleet is performed by A1 ships, 35% by A2 ships and 40% by inland ships operating in exploitation form B. Based on these assumptions, about 1,590 million ton-km (42% of the 3,817 million ton-km) is transported by A1 ships and 2,226 million ton-km (58%) by A2 ships implying navigating an extra 136,792 hours for the A1 fleet and 109,816 extra hours for the A2 fleet.[7]

Transporting an extra 11.00 million tonnes also means that these tonnes must be loaded and unloaded onto and from the inland ships. Correcting for the lower load factor of the inland ships the A1 fleet is confronted with 91,514 extra hours for (un)loading and the A2 fleet with 94,229 extra hours.[8] Table 4 shows the extra number of operational hours needed and Table 5 the

[7] $0.25/(0.25 + 0.35) \approx 0.42$ and $0.35/(0.25 + 0.35) \approx 0.58$.

[8] Because of the lower load factor of inland ships during low water levels, less time per ship is needed for (un)loading.

hourly costs. Multiplying the extra number of hours with the relevant hourly costs results in a total sum of € 67.88 million (see Table 6).

Table 4: Number of extra operational hours needed in case of low water level in W+ scenario

	Hours navigation	Hours loading/ unloading
1150 tonnes ship (A1)	136.792	91.415
1910 tonnes ship (A2)	109.816	94.229

The total number of extra operational hours is about 430,000. The Dutch and German fleet together comprises about 4800 dry and wet bulk ships (CCR, 2009). About 75% of those ships is assumed not to navigate 24 hours per day. The ratio of the total number of extra operational hours and the number of ships not navigating 24 hours per day tells us that every ship has to navigate about 120 hours extra during the low water period (of 156 days). It seems that this is physically possible.[9]

Table 5: Hourly costs on basis of 24-hours per day operation, dry bulk

	Costs one hour navigation	Costs one hour loading/ unloading
1150 tonnes ship (A1)	€ 176.32	€ 77.87
1910 tonnes ship (A2)	€ 239.67	€ 109.57

Source: NEA, 2008 (excel file).

Table 6: Total costs of measure 24-hours per day navigation

	Total costs navigation	Total costs loading/ unloading
1150 tonnes ship (A1)	€ 24.119.233	€ 7.118.507
1910 tonnes ship (A2)	€ 26.319.571	€ 10.324.645

Adding all costs together in Table 6 results in a total cost level of € 67.88 million.

[9] In recent years there is a trend of increasing scale in the inland waterway transport sector. This implies that the share of exploitation form B (continuous navigation) in the total fleet will most likely be larger in 2050 than it is now. As a result, the part of the fleet that is able to increase the number of operational hours per day will be smaller in the future. Together with the expectation that demand for transport will rise in the coming decades the question is if this smaller part of the fleet is still able to navigate enough extra hours.

2.3 Welfare analysis

Subtracting the costs (in section 2.2) from the benefits (section 2.1), it turns out that the net result is €7.25 million. Under the assumption of perfect competition and perfect elastic supply, this positive result will be passed on to the consumers by means of lower transport prices (Jonkeren et al. 2007).[10] If p_0 is equal to €6.83 (see section 2.1), then p_1 is 6.83 – (€7.25 million/ 11.00 million tons) = €6.17. However, as a result of this lower price, demand will slightly increase. The welfare gain from this small increase in demand is equal to the shaded small triangle in Figure x. The total welfare gain (WG) due to the adaptation measure ‘navigating more hours per day’ is equal to the total shaded area in Figure 1.

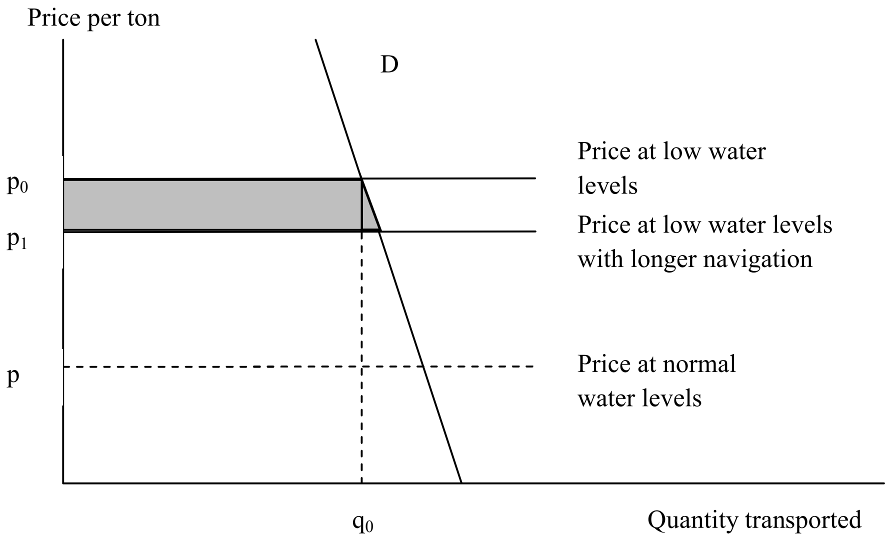

Figure 1: Welfare change due to longer navigation

The size of this area can be approximated with equation (4).
We have:

$$WG = (p_0 - p_1)q_0 + \tfrac{1}{2}(p_0 - p_1)(q_1 - q_0) \qquad (1)$$

and the definition of the price elasticity:

[10] Note that increasing the number of operational hours increases transport supply (a shift of the supply curve to the right) leading to lower unit transport prices.

$$\varepsilon = (\Delta q / q_0)/(\Delta p / p_0) \quad (2)$$

Then, we have for modest changes in p:

$$(q_1 - q_0) \approx \varepsilon q_0 (p_1 - p_0)/ p_0 \quad (3)$$

After substitution of the latter expression in (1) we have:

$$WG = (p_0 - p_1) q_0 (1 + \tfrac{1}{2} \varepsilon (p_1 - p_0)/ p_0) \quad (4)$$

Using a price elasticity of demand for inland waterway transport of -0.5 (Jonkeren, 2009), and a q_0 of 11.00 million tons the resulting welfare gain is equal to €7.44 million.[11] Concluding, navigating more hours per day is an economically feasible adaptation measure in the above assessed case (W+ climate scenario). The question is if this conclusion holds for all climate scenarios. If benefits (transport prices) increase disproportionally when water levels decrease, it may be that in milder climate scenarios benefits do not outweigh costs.

3 Canalization of the river Rhine/ Waal

A possible solution for keeping the River Rhine (including its main Dutch branch, the Waal) navigable during periods of (very) low discharges is canalization: the construction of a few weirs in combination with navigation lock-complexes. The analysis of costs and benefits of canalization is limited to the stretch between Rotterdam and the Ruhr area in Germany because the biggest cargo flows are transported on this part of the Rhine.

In times of normal or high discharges of the river Rhine, the weirs are in upward position, thus making nearly free flow possible for the river discharges and a nearly unrestricted passage for the inland navigation. However, in times of (very) low discharges and associated low water depth, the weirs were partly or nearly completely closed, in order to improve the navigability by means of a so called canalized river. In order to give passage to inland waterway vessels in these periods (several weeks or months per year), the weirs are mostly combined with one or two navigation locks. Although with some delay in the order of 15 - 30 minutes per passage, these

[11] See Jonkeren (2009) for a similar approach for calculating a welfare effect.

locks make it possible to overcome the created differences in heads, here estimated as about 5 meter. The amount of weir- & lock-complexes depends on the total head over the shipping route and the head per weir. For the lower part of the river Rhine the head is about 1 meter per 10 kilometer. So, for a total sailing distance of about 200 kilometer from the Port of Rotterdam to the German Ruhr area a total head of about 20 meter is needed. If for instance one chooses a mean head in the order 5 meter per weir-complex, then 4 complexes will be needed.

Canalization of a part of the river Rhine is not new. Between 1932 and 1977, 10 barrages have been constructed in the upper Rhine between Basle and Iffezheim in order to improve navigation conditions and to generate hydro-electric power. At GIW (Gleichwertige Wasserstand) in this canalized part of the Rhine, a draught of 3 meter is guaranteed. GIW is a statistical determined water level, which is on average reached or underspend at most 20 days a year (Bosschieter, 2005).

Next to the effect canalization has on navigation conditions, there are also effects on the water system. For example, the intrusion of salt water from the North Sea into the Waal may increase due to a decrease in the amount of fresh water in dry periods when barrages decrease the streaming velocity of the Rhine. Another example is that groundwater levels in the direct surroundings of the river will increase which likely have a negative impact on agriculture, nature and local drainage systems (Deltares, 2008). These effects are not included in the analysis.

3.1 Benefits

The benefits are measured in terms of quantity (tonnes) and in terms of €. Canalization implies that inland ships are able to navigate with higher load factors in periods with low water levels compared to a situation without canalization. So, canalization generates a higher annual cargo flow on the Rhine and in the Port of Rotterdam:

$$\textit{Benefits tonnes} = Q_c - Q_{wc} \qquad (5)$$

where Q_c represents the annual quantity transported on the Rhine between Rotterdam and the Ruhr area in a situation with canalization, Q_{wc} denotes the annual quantity transported on the Rhine on the same stretch without canalization.

Currently, shippers pay so called low water surcharges on top of a basic transport price per tonne to inland waterway carriers in order to compensate for the decrease in load factor in periods with low water levels. Due to canalization the transport price per tonne will drop. The benefits in terms of € are then determined by using equation (4) from the previous section. For earlier studies on the benefits of canalization we refer to Appendix C.

In addition to the direct benefits there are indirect benefits, like a higher reliability to deliver the goods on time, and consequently reduced risk of production break downs for the shipper. This may also result in a better image for the inland waterway transport sector. These indirect benefits will not be taken into account in the analysis.

Deltares (2008) focuses on costs and benefits of canalization of the Waal (so the part of the Rhine in the Netherlands). In that study it is assumed that, as a result of canalization, each day of the year there will be enough water in the Waal to prevent the occurrence of a decrease in load factor and thus an increase in the transport price. In the current study we apply the same assumption. The critical location with respect to the load factor of inland ships for the Rhine stretch between Rotterdam and the Ruhr area is Ruhrort. On basis of the difference in daily water levels at Ruhrort between the situations '*2050, W+, no canalization*' and '*2050, W+, canalization*' it is determined what the daily difference in average transport price per tonne is.

By means of an econometric approach it is determined to what extent the transport price per tonne increases when the water level at Rurhort drops below a certain threshold. We use the same data as is used for the analysis in section 2. The model that is estimated is:

$$Y_i = \alpha + \gamma_2 W_{2i} + \gamma_3 W_{3i} + \gamma_4 W_{4i} + \gamma_5 W_{5i} + \gamma_6 W_{6i} + \gamma_7 W_{7i} + \gamma_8 W_{8i} + \gamma_9 W_{9i} + \gamma_{10} W_{10i} + \beta X_i + \varepsilon_i$$

where Y_i denotes the logarithm of the transport price per tonne, W_2 to W_{10} refer to water level dummy variables, X_i denotes observed explanatory variables and ε_i is random error.[12]

Each water level dummy represents a water level interval of 10 centimetres. The reference category (W_1) is the group water levels exceeding 335 centimetres, which measures

[12] The control variables X_i are: the logarithm of distance, the logarithm of travel time, a time trend, ship size (4 dummies), 11 month dummies to control for seasonal effects and 46 cargo type dummies because of differences in the mass per volume of each cargo type.

the threshold level. We have performed a sensitivity analysis and it appears that the effect of water level on transport price per tonne for an inland ship of average size is absent when water levels exceed 335 cm at Ruhrort. The estimation results are presented in Table 7.

Table 7: Estimation results for transport price per tonne

Explanatory Variables	*Coefficient*	*Std. Error*
Water level		
207 – 255	0.493	0.059
256 – 265	0.405	0.035
266 – 275	0.315	0.036
276 –285	0.291	0.027
286 – 295	0.241	0.042
296 – 305	0.176	0.044
306 – 315	0.153	0.036
316 – 325	0.116	0.021
326 – 335	0.029	0.023
≥ 336	Reference	
Log(distance)	0.529	0.057
Log(travel time)	0.159	0.024
Time trend	0.307	0.022
Vessel size		
0 – 1000 tonnes	0.224	0.035
1000 – 1500 tonnes	0.134	0.023
1500 – 2000 tonnes	0.066	0.021
2000 – 2500 tonnes	0.048	0.010
> 2500 tonnes	Reference	
Month dummies		
January	Reference	
February	-0.078	0.015
March	-0.119	0.020
April	-0.100	0.024
May	-0.101	0.016
June	-0.072	0.021
July	-0.039	0.023
August	-0.119	0.020
September	-0.053	0.016
October	0.033	0.018
November	0.082	0.017
December	0.217	0.018
Cargo dummies, 46	Included	
R^2	0.72	
n	6252	

Note: the dependent variable is the logarithm of transport price per tonne; the time trend variable is in days and divided by 1000.

Our main result is that the water level has a statistical significant, negative effect on the transport price per tonne. The increase in transport price is relative to the situation of 'normal' water levels, which we defined as water levels higher than 335 cm at Ruhrort. So, if an inland ship of average size passes Ruhrort at a water level between 256 cm and 265 cm, the increase in transport price per tonne is 50% compared to the transport price of the same ship and trip if it took place at a water level higher than 335 cm.[13]

With information on daily water levels at Ruhrort during a year in the W+ climate scenario in combination with the estimation results in Table 6, one can determine the extent to which the transport price per tonne for inland waterway transport increases on average in the low water period in the W+ scenario (see Table 7). It is assumed that the transport price for both, small and large ships increases to the same extent when the water level drops. This implies that the increase in transport price is overestimated for small ships and underestimated for large ships.

Table 8: Average transport price increase for an inland ship of average size in a W+ year

Interval	**Transport price increase (%)**	**No. of days in W+ year**
326 - 335	0.028	12
316 - 325	0.122	7
306 - 315	0.165	11
296 - 305	0.192	8
286 - 295	0.273	11
276 - 285	0.338	10
266 - 275	0.370	9
256 - 265	0.499	9
207 - 255	0.637	79
Total low water level period	*0.443*	*156*

Table 8 shows that the average transport price increase in a low water period belonging to the W+ climate scenario compared to a year without low water levels for an inland ship of average size is equal to 44.3%. So, the transport price in the low water period is a factor 1.44 higher than the transport price in a situation without low water levels. The transport price decrease as a result of canalization is then 30.7%.[14] However, part of this decrease is undone because of travel time losses due to the passing of inland ships through locks. Deltares (2008) mentions that the extra travel time for an inland waterway trip between Rotterdam and Duisburg (in the Ruhr area) is about 3 hours. With data from NEA (2008) it is calculated that for a dry bulk carrier of about

[13] $e^{0.405} - 1 = 0.499$.

[14] (100 – 144.3)/144.3 = -0.3069.

1900 tonnes, these three extra hours imply a cost increase for the trip of 4.47%. The transport price decrease in the low water level period as a result of canalization for the Rotterdam – Ruhr area route is therefore estimated to be 26.2% (30.7 – 4.5).

The estimated changes in transport price per tonne are applied to the transport cost parameters in the TRANS-TOOLS model for the waterway route Rotterdam – Ruhr area, in order to assess the impact of lower transport prices on modal share for inland waterways and the competitive position of the Port of Rotterdam (in terms of the number of tonnes transshipped in the port). It is assumed that inland waterway transport prices are equal to inland waterway transport costs, in line with Jonkeren et al., (2007). TRANS-TOOLS is a European transport network model. For a thorough description of this model we refer to the study of van TNO (2010) which is also carried out in the framework of the 'Knowledge for Climate, HSRR08, Water and Transport' research project.

Using equation 5, the TRANS-TOOLS model found that, as a result of the adaptation measure 'canalization', about 9.66 million tonnes extra are being transported by inland waterways between Rotterdam and the Ruhr area on the river Rhine (Waal). This is an increase of 3.20% compared to a situation without canalization in 2050.

Welfare analysis

Under the assumption of perfect competition and perfect elastic supply, the change in economic surplus as a result of canalizing the river Waal between Rotterdam and the Ruhr area can be represented as in Figure 2. P_0 is equal to the average (all ship sizes) transport price per tonne during the low water level period in 2003, which is €6.63. As mentioned previously in this section, p_1 is 26.2% lower than p_0, resulting in a price per tonne of €4.89. In 1997, the inland waterway transport volume that passed Ruhrort was about 151.000 million tonnes (CCR, 1998). Assuming a growth factor of 2.0 compared to 1997 for inland waterway transport demand for 2050 (Deltares, 2008), about 302.000 million tonnes of cargo will pass Ruhrort in 2050. In the year 2003 during 154 days inland ships that passed Ruhrort were restricted in their load factor. Assuming that the annually transported quantity is equally distributed over the year, the total volume that passes Ruhrort during low water levels (q_0) is 127.000 million tonnes in 2050.

The welfare gain (WG) due to the adaptation measure 'canalization' can be calculated by means of eq. (4) and is equal to the total shaded area in Figure 2. The price elasticity of demand for inland waterway transport is assumed to be -0.5 (Jonkeren, 2009).

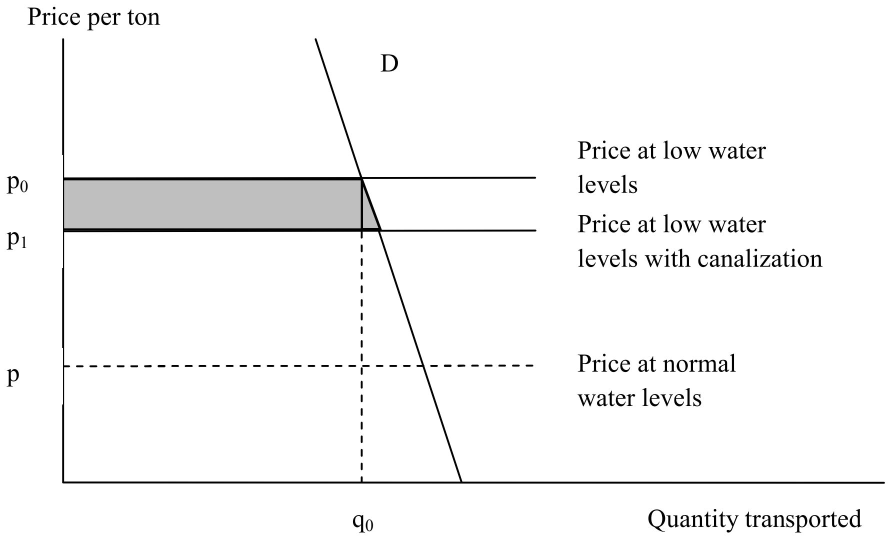

Figure 2: welfare change due to canalization

The size of this area can be approximated with equation (4) from section 2. Using a price elasticity of demand for inland waterway transport of -0.5, the resulting welfare gain is equal to €317 million annually.

3.2 Costs

The number of weirs will be given by an optimization (see Figure 3), taking into account the cost of the total amount of weirs and navigation locks, the cost of raising some local dikes directly upstream of the weirs, the visual damage to the landscape with these massive buildings and extra high dikes, etc.

Because the water depth directly upstream of a (partly) closed weir will be higher than in the case that the weir is in an open position, one has to check if for this specific reason there is a necessity to make these local dikes higher. And if so, the next question will be to what extent and is it possible to heighten them in an easy way against relatively low costs. These costs depend highly on the area, if it is just a simple grass-dike or a much more complex hidden dike through an urban area (see Appendix F).

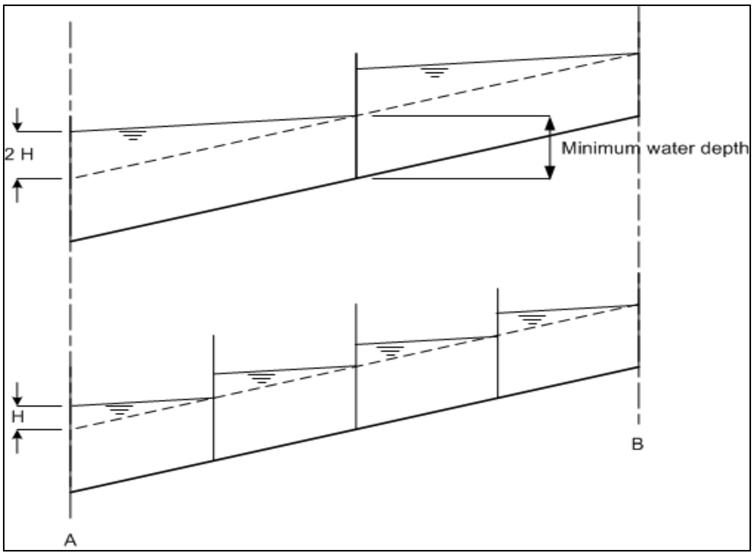

Figure 3: Number of weirs could be optimized

Because dikes along the river Rhine are designed for extreme high discharges with related extreme water depths (in the order of 10 - 12 meters) there is some reserve in dike height in times of low discharges. But in order to create enough water depth (e.g. 5 meter) directly downstream of an upstream weir, the water depth directly upstream of the correspondent downstream weir will be in the order of 5 + 5 = 10 meter (in the above given situation).

Below the first estimate will start with an amount of 4 weir- and navigation-lock-complexes at regular distances of ~ 50 km, with a mean head of about 5 meter per weir and the assumption that in this case little or just a small amount of dikes has to be raised.

Cost estimation method

The costs of a weir- and lock-complex can only be estimated correctly if there is a (pre)design of these four specific complexes and dike raising projects. But in this decision stage of the research project the costs will just be roughly estimated on the basis of so called index-numbers, which are based on scaling and discounting cost figures of existing comparable complexes. However, because in the Netherlands no weir- and lock-complexes of this scale were realized in the last fifty years, the index-numbers will mainly be derived from separate cost figures for weirs and locks. After all, as a rough check, the combined cost of the three weir- and lock-complexes in the river Lek, which have already been build in the fifties, were scaled and discounted.

An estimation of the expected costs

- Weir: Based on a wet cross section in the order of 300 meters in width and 10 meters in depth, a head in the order of 5 meters per weir, and an index number of €30,000 per cubic meter (see Appendix D) the total price of that weir-complex will be €450 million.
- Navigation lock: Based on a lock chamber of 280 * 40 square meter, a head in the order of 5 meter and an index number of about €5,000 per cubic meter (see Appendix E), the total price of that navigation lock-complex will be €280 million.
- Dikes: Based on a restricted amount (~10%) of dike raising in the order of 2 * 5 km = 10 km, and an index number of about €6 million per meter per kilometer grass dike (see Appendix C), the total price of that dike raising will be €60 million.

So all together, for about 200 km canalization, only based on the realization cost of 4 weir- & lock complexes, the total prize will be: 4 * (450 + 280 + 60) = €3,160 million, so the total price will be in the order of €3 billion.

NB 1: Scaling and discounting the three weir- and lock-complexes in the river Lek (1958) gives a total amount of: 2,5 * 2 * $(1,04)^{50}$ * 120 M fl / 2,2 ~ €2 billion. So for four complexes a comparable amount of €2,7 billion. This is still exclusive some raise of the dikes, which gives an extra €240 million, so together ~ €3 billion.
NB 2: In addition to the direct cost of construction there will be inspection and maintenance costs. If well designed and constructed, there will be just periodic inspection needed in the first 10 to 15 years and some preventive maintenance for the mechanical parts. But after this period and often earlier because of “children diseases” more maintenance may be expected, not only for replacement and revision of electrical and mechanical parts, but also to the civil engineering works. Though hard to predict for a specific work under specific conditions, it has been proven from experience, that inspection and maintenance in the long run will take a rough 1% of the realization costs per year. Presenting this as a net-present-value makes a total amount in the order of $(1+r)/r * C_c$ ~ 20% of the construction costs (if the rate is about 5%). This gives a summed amount of 20% * €3 billion, thus in the order of €600 million.

NB 3: Next to these structure related costs, there will be cost for operation, administration and control of the weir gates and navigation locks. When the complex is in operation, the service for these complexes will be needed 7 * 24 hour. So there will be operational costs in the order of 6 * 5 * 0.1 M€ /year ~ 3 Million €/yr, which represents a net present value of about €60 Million €.

NB 4: Such a civil engineering work also causes energy costs, because of the operation activities, like opening and closing of gates and doors, the lighting, heating, etc.

NB 5. The tempered discharge of the river in times the weirs are (partly) closed, will cause extra sediment to settle down and that will need extra dredging activities (costs) to keep the river navigable. And opposite, during opening of the weirs, there could be some scour despite of the local bottom protection around the weirs.

NB 6. Though the closing period is expected to be just a few weeks per year, of course there will be some consequences for the environment, because the natural flow of the river is suddenly artificially disrupted. Though migrating fish could partly pass the complex by means of a fish passage, river banks will change, flood plains and beaches may be drowned, etc.

NB 7. There is an ecological and (thus) social opposition against large scale interventions in the natural environment (see the experience in Germany, weir 11 in the upper Rhine).

NB 8.: A seasonal canalization of the river Waal will have effect on the discharge of the other branches like the IJssel. So something has to be done around the bifurcation point.

3.3 Costs and benefits

Part of the costs are once only, at the start of the project and several costs return annually. All benefits have an annual character. For the calculation of costs and benefits an interest rate (*r*) of 5% and an infinite lifespan (*t*) of the project is assumed, which are generally accepted values when analyzing such infrastructural projects. The present value of the annual costs and benefits therefore have to be multiplied by a factor 20:

$$\sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \approx 20, with\, r = 0.05$$

Table 9 compares the present value of costs and benefits of canalization in the W+ climate scenario.

Table 9: NPV of costs and benefits in €.

Costs		Benefits	
4 weirs	1,800 million (once)	Reduction transport costs	6,340 million (20 x 317)
4 locks	1,120 million (once)		
4 times dike raising	240 million (once)		
Maintenance	600 million (20 x 30 million)		
Operation	60 million (20 x 3 million)		
Total	3,820 million	Total	6,340 million

The cost-benefit analysis shows that benefits outweigh the costs by € 2,520 million. Note that this positive result is due to the fact that canalization does not only offset costs of future climate change, but also costs of present low water periods.

4 Extra storage capacity

Storage capacity gives a first hint as to how vulnerable an inland waterway transport dependent company might be if transport capacity shortages due to high or low water levels occur. How long a company might be able to produce without or with limited transport capacity availability differs by company, industry and location. Whilst companies in the energy industry often have large storage capacities of about a month or more, producers of semi-finished products prefer just-in-time transport and therefore have a storage capacity of only one or two days (Scholten et al., 2009). The authors also mention that enlargement of storage capacity is one of the most often mentioned measures (to adapt to high and low water levels) in their survey under companies along the river Rhine that make use of inland waterway transport. It is therefore interesting to find out more about this adaptation measure. The current section will discuss the results of a survey under industrial companies located in the river Rhine area. More specific, we analyze which company characteristics relate to the decision whether to invest in additional storage capacity for bulk cargo in order to reduce the probability of an out of stock situation during periods with high or low water levels under future climate conditions. The trade off that is being made by a manager when making this decision is whether the cost saving of paying less for inland waterway transport and the reduced risk of production process interruptions in future periods with low water levels outweighs the costs of investing in additional storage capacity. So, we do not assess benefits and costs itself, but the factors that affect the benefits and costs related to the adaptation measure ‘extra storage capacity’.

4.1 Setup of the research

The first task to carry out for analyzing this adaptation measure was to find potential respondents. The Dutch-German Trade Chamber delivered contact details of about 150 firms that are located in the Rhine area. The shortcoming of this list however was that it was not known whether the firms make use of inland waterway transport. In addition, Mrs. A. Scholten (University Wurzburg) was so kind to offer her contacts (about 70 inland waterway dependent shippers). At the start of September 2010 the 220 potential respondents were requested to fill out the German or English online questionnaire and about half October a reminder was sent.[15] This resulted in 12 questionnaires that were (completely) filled out. This number is unfortunately not enough to produce statistically significant results but some descriptives can provide us with valuable information.

As an introduction to the questionnaires, the respondents were reminded about the water level conditions throughout the year 2003, a year with a long and severe low water period. The respondents had to imagine that by the year 2050, the water level conditions like in 2003 will occur every year. Having this water level situation in mind, the respondents were requested to fill out the questionnaire. In the next section, the results will be discussed.

4.2 Results

Eight of the twelve answered ‘yes’ to the question whether they experienced problems during the low water level period on the Rhine in 2003. Table 10 shows the specific problems that are experienced by the eight shippers.

[15] The questionnaire can be found in Appendix A.

Table 10: type of problems experienced due to low water

Type of problem	Frequency
Lack of transport capacity	5
Scarcity of raw materials	1
Decrease of internal stock	2
Delivery problems for outgoing products	2
Higher transport prices	3
Production process hampered	1

Note: a shipper may mention more than one type of problem.

Note that several problems are closely related to the problem of running out of stock like ‘scarcity of raw materials’, ‘decrease of internal stock’, ‘delivery problems for outgoing products’ and ‘hampered production process’. The most often mentioned measures to cope with these problems were ‘we paid the higher transport prices’, ‘we decreased production output’ and ‘use of alternative transport modes’. The cargo types that are transported for the shippers are the major bulks like coal, steel products, chemicals, agricultural products and some non-bulk commodities like steel coils and copper cathode. Those cargos are stored by the shippers on the ground in the open air, in warehouses, silos and tanks. Motor vessels for dry and wet bulk cargo as well as push barges are hired by the shippers to transport the mentioned cargo types. On the question whether the respondents are planning to invest in extra storage capacity, the answers were ‘don’t know’ (4 respondents), ‘no’ (5) and ‘yes’ (3). It is striking that two of the three shippers that answered ‘yes’, mention that they did not experience problems related to low water levels in the year 2003. Now it is interesting to further focus on the characteristics of the shippers that answered ‘yes’.

Critical Rhine kilometer

Based on the answers to question three, it is determined what the ‘most critical Rhine kilometer’ is for every respondent (see Appendix B and Table 11), where the most critical Rhine kilometer is defined as the most upstream located place (the production facility, the customer or supplier) that is visited by a barge which performs transport for the respondent.

Table 11: Critical Rhine kilometer for respondents

Respondent	Rhine kilometer
1	730
2	800
3	850
4	800
5	800
6	450
7	711
8	150
9	500
10	250
11	700
12	300

Note that Rhine kilometer 0 is close to the source of the river. For five of the twelve respondents its critical Rhine kilometer is located upstream of Kaub (Rhine kilometer 550). For the large majority of the trips that pass Kaub, the water depth at Kaub is the bottleneck with respect to the load factor of the inland ships. It is therefore expected that especially stocks of shippers who hire barges that have to pass Kaub are sensitive for low water periods.

Focusing on the three respondents that answered positively to the question whether they are planning to invest in extra storage capacity in the future, it is observed that the critical Rhine kilometer for those respondents is 500 or less (respondents 9, 10 and 12). The route information on the barges that are hired by those shippers reveals that the barges pass Kaub and are therefore relatively sensitive to low water levels concerning their load factor.

Barge size

In question four, the shippers were asked about the size of the barges they hire. It is expected that the larger the barge, the higher the sensitivity of the load capacity of the barge for low water levels, and so, the larger the vulnerability of the stock levels for low water levels. The respondents reported the minimum and maximum barge sizes they hire. One would expect that the shippers who answered yes to the question whether they are planning to invest in extra storage capacity in the future, make use of relatively large barges.

Table 12: Minimum and maximum barge size hired by the shippers that are planning to expand storage capacity

Respondent	Minimum	Maximum
9	800	2000
10	2000	5000
12	1000	2000
Mean	1682	3035

Table 12 shows that respondents 9 and 12 make use of relatively small vessels, which is in contrast with what is expected. It may be that already now relatively small barges are being hired because of the regular frequency of low water level periods.

Mode share of inland waterway transport

Shippers may make use of several transport modes for transporting their cargo to and from their production sites. The respondents in the survey were asked to report the share of inland waterway transport in total transport to and from their storage facility. It is likely that shippers that rely for a large proportion on inland waterway transport may be more willing to invest in storage capacity. See Table 13 for mode shares of inland waterway transport for the shippers that are planning to invest in extra storage capacity in the future. We can observe that the three respondents in Table 13 indeed are for a relatively large proportion dependent on inland waterway transport.

Table 13: dependency on inland waterway transport for the shippers that are planning to expand storage capacity

Respondent	Mode share inland waterways
9	70%
10	100%
12	70%
Mean	60%

5 Conclusion

Given several assumptions, the explorative welfare analysis of the measure *'higher number of operational hours'* demonstrates that the benefits outweigh the costs by €7.44 million. The benefits are determined by estimating the extent to which the load factor of inland ships is restricted in the low water periods in a KNMI W+ climate scenario. The loss of revenue that is caused by a lack of capacity can then be regarded as the potential benefits that can be achieved by navigating more hours per day. The costs are caused by navigating extra hours per day by inland ships that do not already navigate 24 hours a day. Costs for fuel, maintenance and labor will increase whereby it must be noted that labor costs do not only increase because of more hours navigation but also because, according to safety regulations, the ship crew must be increased.

The calculation of costs and benefits is subject to several assumptions and limitations. First, it is assumed that the daily quantity which passes Ruhrort by inland waterways is equal throughout the year. However, if, for example, in summer and autumn there is a peak in demand for inland waterway transport, the 3.817 ton-km that is lost as a result of a lack of capacity is an underestimate. Second, the assumption that the decrease in load factor is equal for all ship sizes may be questioned. However, because for small ships this decrease is overestimated and for large ships underestimated, the error that is made may be small. Third, for the exploitation forms A1 and A2 average ship sizes are assumed. Statistics on this measure are lacking and experts from the field find it very difficult to make a judgment. It may be clear that the results are sensitive for this assumption: the ship sizes affect the number of extra trips needed and therefore the total number of extra hours needed to load, transport and unload the 11.0 million tonnes or 3,817 million ton-km. Fourth, the assumed shares of each exploitation form in the capacity of the fleet may affect the results. If the share of the amount of ton-km made by ships that operate under A1 is higher, the total number of hours for transporting and (un)loading the additional tonnes would also be higher. Therefore, the result in this section must be regarded as an explorative, rough estimate.

The second adaptation measure that is assessed in this report is canalization of the stretch of the river Rhine (Waal) between Rotterdam and the Ruhr area. Annual benefits are calculated by means of a welfare analysis and defined as the reduction of transport costs as a result of canalization. So, benefits are expressed as ‘avoided transport costs’ for shippers. The implicit assumption that is made is that as a result of canalization, under future climate conditions (W+ KNMI’06 scenario), inland ships will be able to navigate without load factor restrictions during the whole year. This results in an average decrease of inland waterway transport costs of 26.2% compared to a situation with future climate conditions (W+) without canalization. Costs occur both initially, at the start of the project (construction costs of weirs and locks), and annually (maintenance and operation of the weirs and locks). Using a discount rate of 5% and infinite *t*, the present value of future annual costs and benefits are calculated. The calculation shows that the benefits amount €6,340 million and the costs €3,820 million. The annual extra amount of cargo transported by inland waterways on the river Rhine (Waal) as a result of canalization is calculated to be about 10 million tonnes.

The last measure that is assessed is *'investing in extra storage* capacity'. Although no statistical significant conclusions can be drawn from the information obtained with the on-line survey (n = 12), some interesting findings can be reported. Eight of the twelve respondents were confronted with low water level problems in 2003 and three respondents indicated that they are planning to invest in extra storage capacity in the future. Strikingly, only two of those three shippers belong to the group of four shippers that did *not* experience low water level problems in 2003. Several characteristics of the shippers are likely to have an impact on the decision whether to invest in extra storage capacity before 2050: the shippers' critical Rhine kilometer, the vessel size hired and the dependency on inland waterway transport. The shippers' 'critical Rhine kilometer' is defined as the most upstream located place (the production facility, the customer or supplier) that is visited by a barge which performs transport for the shipper. The three respondents that are planning to invest in extra storage capacity indicate that the more upstream the critical Rhine kilometer is located and the larger a shippers' dependency on inland waterway transport, the more likely the shipper is to invest in extra storage capacity. The size of the vessels that are hired by the three respondents who are planning to invest in extra storage capacity in the future is relatively small, which is counter-intuitive.

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Appendix A: Questionnaire extra storage capacity

This is a short questionnaire intended for companies that make use of inland waterway transport. If you are such a company, can you please take the effort to fill out the questionnaire? If you are not, I apologize for disturbing you. All questionnaires will be made anonymous.

As a user of inland waterway transport, in recent years your company may have been confronted with periods of high and low water levels in the river Rhine with accompanying negative consequences:

- Higher prices for inland waterway transport
- Lack of sufficient raw materials/ products as input for the production process

In the framework of a Dutch research project on climate change and inland waterway transport ('Knowledge for Climate') we analyse the feasibility of several adaptation measures that aim to prevent the occurrence of the above mentioned negative consequences. This questionnaire focuses on one particular measure namely investing in extra storage capacity. This measure offers shippers the opportunity to longer eat into their stocks in periods with high or low water levels implying lower costs for transportation and reduced risk of interruptions of the production process (benefits). On the other hand, this measure requires an investment in permanent or temporal storage capacity (costs). By means of this short questionnaire we aim to investigate which factors affect the decision whether to invest in additional storage capacity under future climate conditions. Therefore, as a starting point, a scenario for future annual water level conditions for 2050 will be described:

Remember the water level conditions in the year 2003, a year with a long low water period. Now suppose that these water level conditions occur every year around 2050. This implies that during 182 days per year Pegel Kaub is lower than 1.60 m and during 156 days per year Pegel Ruhrort is lower than 3.00 m. For both locations the water level is below the mentioned Pegels during 120 *consecutive* days.

Now please answer the following questions:

1a Did your firm experience problems due to the low water period of 2003?
1b If yes, what were the problems experienced?
1c How did your firm cope with these problems?

2 What is the location of your storage facility/facilities (city/ town/ municipality)?

3 What is/ are the inland waterway route(s) for inland ships visiting your storage facility (mention place of loading, waterways, place of unloading)?
Route 1:
Route 2:
Route 3:

4 What *type* of inland ships is being used for transportation of the cargo/ raw materials and what is the *size* (in tonnes) of those ships?
○ self-propelled barge, dry bulk
○ self-propelled barge, tanker
○ self-propelled barge, containers
○ push boat
○ other namely: ………

Size of ships: …….. tonnes
Remark (optional): ………………………………..

5 What cargo type (e.g. coal, agricultural, ore etc.) is being transported by the inland ships that visit your storage facility?

6 What is approximately the modal share (%) of inland waterway transport in total transport to or from your storage facility?

7 In what kind of storage facility is the cargo placed (silos, tanks, warehouse etc. or just on the ground)?

8 What is the current size of the storage capacity? (m^2, m^3, no. of silos, or another measure).

9 What is approximately the average utilization rate of the storage capacity during a year?

10 Do you think it is economically feasible to invest in extra storage capacity under the described water level conditions for 2050?

○ yes

○ no

○ don't know

11 What is the size of the desired extra storage capacity then?

12 Would you like to receive the results from this research?

○ yes

○ no

Thank you very much for your cooperation!

Appendix B: Rhine area and Rhine kilometers

800

600

400

200

Nether-
lands
Ijssel
Germany
Lippe
Waal
Duisburg
Ruhr
Düsseldorf
Cologne
Sieg
Bonn
Lahn
Belgium
Koblenz
Wiesbaden
Moselle
Main
Lux.
Mannheim
Neckar
France
Karlsruhe
Strassbourg
Lake
Constance
Basel
Austria
Aare
Switzerland

Appendix C: Previous studies on benefits of canalization

1. Investeringsruimte voor toekomstige droogte (Royal Haskoning, 2007):

The expected maximum shipping benefits in the G+ and W+-scenario are estimated at €175 to €280 million per year. For an eternal time horizon and a rate of 5%, this will result in a summed amount in the order of 20 times this yearly value. So the NPV will be in the order of €3.5 to €5.6 billion.

2. Delta Commissie (2008):

In this report the same amount of money is given for the G+ and W+-scenario's, consisting of avoided cost for the inland shipping in the order of €175 respective €280 million as NPV. It looks as if the same source was quoted, but incomplete.

3. Verkenning kosteneffectiviteit van grootschalige maatregelen tegen droogteschade als gevolg van de G+ en W+ scenario's (Deltares, 2008)

Again the same source seems to be quoted here, so for G+ of W+ benefits are foreseen of about €175 resp. €280 million per year. But in this study, because of the expected delays, c.q. waiting time plus passage time of the four navigation locks in the order of 2 - 2,5 hours, at a normal undisturbed sailing time in the order of 10 - 12 hours. Though this is a twenty percent delay in time, a reduction on the benefits side is suggested of 0.45. Here the investments were roughly estimated as 4 * (300 + 350) = €2.600 million.

4. Investeringsruimte voor toekomstige droogte (Rijkswaterstaat 2008)

The common source of all above mentioned sources seems to be Appendix 15 of this report, where Royal Haskoning makes a navigation damage estimation of €90 million per year by means of a 100-years damage series. In Appendix 16 this value is extrapolated for the G+ and W+ scenarios to €175 respectively €280 million per year.

These are the well known and often quoted numbers. They are in fact "just" extra costs for inland navigation, so for sailing, transshipment and waiting hours near locks. But the "real" costs, i.e. risk, which is the probability of low water depth, and related low transport capacity, times consequences for the industry (shortage of energy, loss of production, loss of market share) are not taken into account.

Appendix D: Cost estimation for weirs /barriers by index numbers

The costs of a new weir, barrier or other structure can be estimated by a few steps:

1. Defining a so called index number (= unity price), based on relevant parameters;
2. Discounting the costs of a number of representative structures to present values;
3. Calculation of this index number for that representative existing structures;
4. Extracting a representative mean value out of these index numbers.

In the past these steps are undertaken for the State Public Works for series of tunnels, locks, etc and more recently for the Port of Rotterdam for series of quay walls. The simplest index numbers are linear relations, but of course rather rough. The more parameters are taken into account, the better the fit, but opposite the more data is needed.

In the current study a group of well known weirs / barriers inside and outside the Netherlands are used to come up with enough data. The index number is based on the consideration that the strength and so the costs of a weir or barrier are strongly related with the *width*, the retaining *height* and the *head* over the weir or barrier.

So in this case the index number has the dimension [€/m^3] and is more or less the mean value of the separate calculated index numbers for the different weirs / barriers. Extreme values may be excluded if there is a known special reason (e.g. the storm surge barrier of St.-Petersburg has an opening for normal navigation and a special one for the navy).

That this index number may be seen as a reasonable representative value may appear from the fact that the spread is limited and if not, that there are good reasons for the separate differences to the mean index number. For instance the index number will be relatively low if there are a lot of nearly the same, repeating gates in one big barrier (see for instance the Easternscheldt), and opposite the index number will be relatively high if there are three types of gates in one small barrier (for instance Ems or Thames).

From the analyses of eight well known weirs / barriers (see spreadsheet) the index number based on total price / (width * height * head) turns out to be 30,000 €/m^3.

Table A:

	Name barrier	Type of gate	Year	Width [m]	Height [m]	Head [m]	Constr. Cost [Euro]	nt Constr. Cost [Euro]	Cost / cubic meter [Euro / m.m.m]	Remar
1	Maeslant barrie	Floating sector	1991	360	22	5	450.000.000	945.000.000	23864	strong competiti
2	Hartel barrier	Vertical lifting g	1991	170	9,3	5,5	140.000.000	294.000.000	33811	one big span (~100
3	Easternscheldt	Vertical lifting g	1986	2400	14	5	1.136.000.000	2.910.000.000	17321	strong repetiti
4	Rampspol	Bellow barrier (	1996	240	9	3,2	100.000.000	173.000.000	25029	innovati
5	Ems-barrier	Sector gate + 2	1998	360	8,5	3,8	290.000.000	464.000.000	39904	3 types of gat
6	Thames-barrier	Sector gates +	1980	530	17	7,2	800.000.000	2.600.000.000	40079	2 types of gat
7	Nakdong-river	Vertical lifting g	2010	200	10	2	125.000.000	125.000.000	31250	
8	New Orleans	?	2015?							
9	Venice Mose-pr	Flap gates 78 *	2014?	1560	15 ?	2 ?	3.000.000.000	5E9 ?	~100.000?	very big flap gate
							Cost-index (mean of 1 to 7):		**30.180**	[Euro / m.m.m]

Some remarks should be made on this index number:

- A difference between weirs and (high water) barriers is the fact that the former only have high water at the upstream side of the river, while storm surge barriers may also have a negative head and are more affected by waves, which can be seen as an extra head. In Table A, half of the barriers is situated near the sea, so these costs may be at the high side compared to the others.
- Often costs of existing structures are unclear (for political reasons e.g.) in the sense that cost of additional works, like demolishing earlier structures, access roads, dredging, bottom protection, connections to nearby infrastructure, etc. are included in the price or not. This results in an extra spread in the index numbers.

Appendix E: Cost estimation for navigation locks by index numbers

In Table B some navigation locks are analyzed: first individual costs are discounted, next normalized in square-meter-prizes, then the mean value is determined and finally a cubic-meter-prize is derived.

Table B:

	name	year	build.cost M. Fl	build.cost M. Euro	pres.cost M. Euro	area m * m	unit costs K.Euro/m.m	remark
1	Lith	1992	100	45	91	3600	25	second lock
2	Helmond	1992	26	12	24	1375	17	
3	Oranje	1990	130	59	129	4800	27	
4	Oester	1990	64	29	63	3173	20	
5	Vlaardingen	1986	20	9	23	650	36	also storm barrier
6	Schiedam	1978	25	11	43	720	60	also storm barrier
7	Terneuzen	1962	98	45	296	21160	14	2 chambers
				Total	**669**	**35478**	**19**	
8	Terneuzen	2015?		200 - 300	200 - 300	6 - 27000	11 tot 13	Not build yet! excl. dredging

In the case of a mean head of 4 meter, the unit costs are ~ 5000 Euro / cubic meter

<u>NB1:</u> There are a lot of additional works in the construction stage of a navigation lock, such as demolition of the old lock, dredging, bottom protection, guiding works, etc. Often it is not clear if all these works and related costs are included in the “total” price or not.

<u>NB2:</u>. If navigation locks are situated near the sea or estuaries, the high head door often has a double function, because, in addition to normal water conditions it has to withstand extreme high water conditions. Such a “flood door” will cost extra money and thus raise the total price.

Appendix F: Cost estimation for dike raising by index numbers

Even in the case of estimating the cost of dike raising one may use index numbers, if derived from a rather homogeneous group of realized dike raising projects. In its simplest form the cost of dike raising can be expressed in cost per kilometer in length and per meter dike raising. To make the group more homogeneous one has to distinguish the category pure up stream river dikes and dikes under influence of tides and/or more significant wave attack along estuaries and in coastal zones.

For cost of dike raising there is a data collection by Eigenraam [..], and he already distinguishes dike raising projects in the downstream area (with wide waters, so more wave attack and some tidal influence) and dikes more upstream. In this data there are three dike raising classes, namely per 0.5 – 0.75 – 1.0 meter.

What surprises in the downstream subset of data, which now contains only 6 reference projects, is the rather wide spread of 4,3 to 13,3 million € per km, per meter of dike raising. A comparable spread, but now at a lower cost level, is present in the much bigger (sub)set of 16 upstream dike raising projects.

The big spread of a factor 3 in both categories gives rise to the feeling that in this simple cost index number, there is still an important parameter missing. This could be the difference between simple dike raising projects and dike reinforcement projects. In the first case only ground work is needed, while in the last case the reinforcement in the zone of water and wave attack on the outside of a dike is strengthened as well. Beside this extra cost generating factor, there may be an influence of higher cost at the inner side if some local buildings change simple groundwork into more complex locally specified solutions, like sheet piling walls or even cofferdams. But this point stays unclear, because more detailed information about these projects is not available.

Elaborating this point it is essential to distinguish categories dike raising in rural areas from the ones in urban areas, which can be much more complex, so much more costly.

Therefore six categories are distinguished, increasing from a simple grass-dike to a very complicated hidden road-dike with (historical) buildings at two sides. A good example of this last category is the Voorstraat in Dordrecht which retaining level is just 3.25 meter + NAP.

In the case of dike raising in urban areas with buildings on one side, often sheet piling walls or similar are used and with buildings at two sides, an even more expensive so called cofferdam (a kind of coupled double sheet piling wall) is used.

Deriving index numbers for these categories is a problem, because these are all rather special, i.e. not frequent constructed and rather unique projects, often mixed up with “normal” dikes. In order to find index numbers for these categories, one needs another approach. There are rather reliable index numbers for ground and water retaining structures like quay walls [.] and a cofferdam can be seen as a nearly double quay wall.

In the case of ground retaining structures, like quay walls, index numbers are used in the order of 1200 – 1500 €/m^2. But one has to realize that for a dike elevation of 1 meter in an urban area, there is more retaining height needed than one meter quay wall, because the sheet piling wall will have a higher (sloping) active pressure and a reduced lower (sloping) resistant. For simplicity a factor 4 is used, so 1 meter of raising dikes needs a quay wall with a retaining height of about 4 meters. Besides these direct costs, it is assumed that every building with a width of about 10 m, needed extra reinforcement of about € 100.000, so an extra 10 million Euro per kilometer.

Thus the index number for road dikes with one-sided buildings and some indexation (factor ~ 1,5), comes to K(1-sided) = 4*1,5*1,35E6+10.000.000 ~ 18 million €/km.m.

For road dike raising with (historical) buildings at both sides of the road the double price is estimated, so K(2-sided) ~ 36 million €/km.md. Without further analysis the heightening of a simple “green” grass-dike or park-dike the index number is given by ~ 6 million €/km.m, based on the data of Eigenraam. In the case of a firm road dike or another reinforcement on top, the cost are estimated to double and so their index number will be ~ 12 million €/km.m After these simplifications the index numbers for different dike categories are presented in Figure A.

Figure A: Cost index number for dike raising