Future of weir Linne

Appendix

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1 The Meuse

1.1 Introduction

The river Meuse originates from the plateaus of Langres in northern France, about 100 km northward from Dijon. The Meuse flows from a height of 384 m through a 935 km long river trough France, Belgium and the Netherlands to the Hollands Diep and the Haringvliet. Near the Hollands Diep the Meuse is connected with the Nieuwe Merwede, which is a branch of the river Rhine. Due to this connection and the low flow velocities of the Hollands Diep is the Hollands Diep usually chosen as the river mouth. The Meuse has a couple of tributaries who discharge water from watersheds to the river. The most important tributaries are:

- France: Chiers, Semois
- Belgium; Viroin, Lesse, Sambre, Ourthe, Ambiève, Vesdre
- The Netherlands: Roer, Niers, Dieze, Dommel

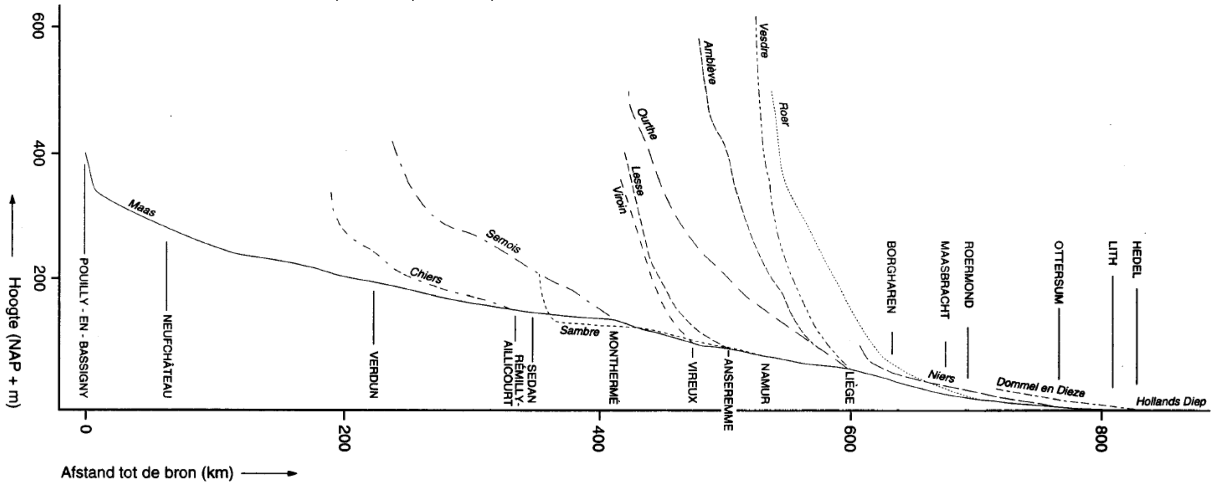


Figure 1 - Profile of the Meuse (source: Rijkswaterstaat)

The water of the Meuse mainly originates from rainwater. This type of river is often referred as rain river. The characteristics of this type of river are the strong changes between discharges and water levels. During wet periods there will be high water levels which can cause floods of nearby areas. The wet periods of the Meuse are usually between December and January (Rijkswaterstaat, Hoogwater op de Rijn en de Maas, 2007).

1.2 Development of the Meuse until 1900

In the first centauries of the modern era, the Meuse flowed at Heusen in westerly direction and mouthed in the North Sea. In the next ages the Meuse changed its direction and was moving northward which resulted in a connection with the Waal at Woudrichem. Whether this change was caused by nature of human intervention is not known.
Even during the Middle-Ages when parts of the Meuse where diked there were problems with discharges downstream of Cuijk. This part of the Meuse was very winding and the dikes were placed too close to the river. Due to the winding character downstream Cuijk the flow velocities decreased which resulted in high water levels and eventually dike failure. During these situation the Meuse took an alternative route. This route went from Grave along the village of Beers to Den Bosch. This alternative route during high discharges was called the Beersche Overlaat. This spillway functioned

also as a safety measure because due to this spillway the water level of the Meuse downstream of Cuijk remained low. Because of this reason the Beersche Ovelaat existed for centuries.

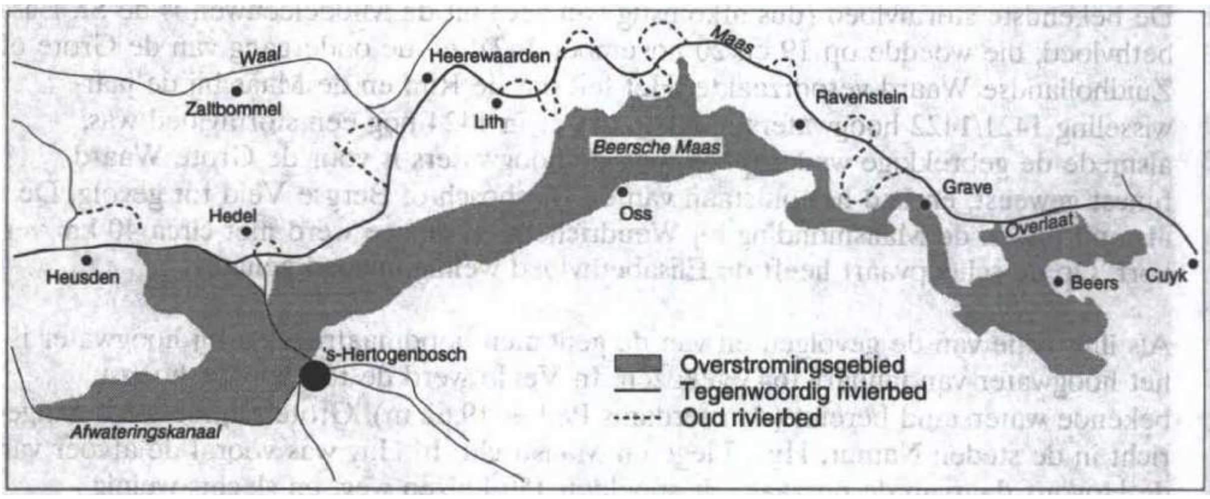


Figure 2 - Beersche Overlaat (source: Rijkswaterstaat)

Besides the Beersche Overlaat more spillways were formed at Bokhoven, Vlijmen and Heerewaarden. At high waters on the Meuse the water could flow over the spillway at Heerewaarde to the Waal and vice-versa. However the spillway at Heerewaarde caused a lot of problems. The water levels at the Waal were often higher than the water levels on the Meuse which resulted in flow from the Waal to the Meuse. The discharges over the spillway at Heerewaarden in the direction of the Meuse were larger than the discharge capacity of the Meuse itself. Together with the low gradient of the downstream Meuse problems arose with the discharge capacity which resulted in long during high water levels. These long during high water levels caused floods and problems with drainage of the nearby areas. This problem has decreased since the Waal discharge became a larger share of the Rhine discharge. After the extension of the Pannerdensch Kanaal to Arnhem in 1707 a share of the Rhine discharge was discharged by the Nederrijn and the IJssel. This caused a lowering of the Waal discharge so a decrease in the problems of the Meuse discharge. However a lower Waal discharge caused sedimentation of the Merwede which resulted in problems with the discharge capacity of the Waal. To avoid this problem the Nieuwe Merwede was constructed in 1860.
After the floods of 1855 the spillway at Heerewaarde has been closed in 1856 by construction of a high dike. To maintain the connection between Maas and Waal for navigation a navigation lock was constructed in the Kanaal van Sint Andries. In the course of time most spillways were closed and in 1883 was decided to a complete separation of the Meuse and Waal. The connection at Woudrichem was closed at Andel, nowadays this part is called the Afgedamde Maas. By construction of the Bergsche Maas in 1904 a new connection was created between the Meuse and the Haringvliet. The Beersche Overlaat was partly unnecessary however it would take until 1942 before the Beersch Overlaat was completely closed (Berger & Mugie, 1994).

1.3 Sections of the Meuse

1.3.1 Maasvallei

The Maasvallei is the part of the Meuse from the Ardennes in France and Belgium until Cuijk so the whole part of the Meuse in the province of Limburg is part of the Maasvallei. The Maasvallei is the part of the Meuse which has not been embedded by dikes but by terraces. Due to continue transitions between Ice ages and warm periods the Meuse cut into the landscape and has formed the characteristic Meuse traces. The Dutch part of the Maasvallei is divided into four parts, the Bovenmaas, Grensmaas, Plassenmaas and Noordelijke Maas. Each of these parts has its own character and feature.

1.3.1.1 *Bovenmaas*

The Bovenmaas is a part of the Meuse between Eijsden where the Meuse enters the Netherlands. In the area of the Bovenmaas the Meuse has created an incised valley in the higher Pleistocene soil layer. These the top layers mainly consisted of loam placed on the deeper gravel layers. Over the years the valley has trough the loam and gravel layers. In this way a river arose which is low-lying in the landscape. (Expertise Netwerk Waterkeren, 2008).

1.3.1.2 *Grensmaas*

The section of the Meuse between Borharen en Roosteren is called the Grensmaas. The Grensmaas forms the natural boundary between Belgium and the Netherlands. Together with the Bovenmaas the Grensmaas is the only gravel river in the Netherlands. Due to dynamical character the Grensmaas developed gullies and gravel banks. However nearly no gravel is transported from upstream regions because the presence of weirs in the Belgian part of the Meuse. This lack of gravel from upstream regions and the gravel excavations from the summer bed in the 20th century has leaded to high flow velocities in the Grensmaas. This resulted in a summer bed without fine gravel and sand, only the coarse gravel fractions remained (Smart Rivers, De Grensmaas - Stromend water over grind, 2012). With widening of the Grensmaas it is attempted to lower the flow velocities and restore the dynamical character of the Grensmaas for ecological purposes. Just like the Bovenmaas the Grensmaas is characterized by a river bed which has incised in the higher soil layers from the Pleistocene. The Grensmaas in not used for navigational transport. Vessels in this section of the Maas are using the Julianakanaal. The Julianakanaal is a cannel parallel to the Grensmaas. It starts at Borgharen and end near Maasbracht.

1.3.1.3 *Plassenmaas*

Plassenmaas forms the transitions between the Grensmaas and sandy terrace shaped Noordelijke Maas of northern Limburg. The upstream part of the Plassemaas has as strong meandering character. Halfway the gradient of the Plassenmaas became lower which resulted in sedimentation. In this way large gravel packs have been formed. By the placing of weirs at Linne and Roermond in the 1920s and the intensive gravel excavation in the 1950s the character of the Plassenmaas had changed strongly. The characteristic meanders and gullies from the past have been transformed to a river part which is characterized by deep meanders and gravel holes which are separated by dams (Everts, Jansen, Maas, Bouwman, Eysink, & Takman, 2012). Between Linne and Buggenum parallel to the Plassenmaas is the Lateraalkanaal. Navigational transport uses this channel because of the meandering character of the upstream part of the Plassenmaas. In this way a shorter route for navigation has been formed.

1.3.1.4 *Noordelijke Maas*

The Noordelijke Maas is the section of the Meuse between Roermond and Cuijk. This part of the Meuse is called the Noordelijke Maas because this is the most northern part of the Meuse in the povince of Limburg. The Noordelijke Maas is the only sandy terrace river in the Netherlands. This terrace river consists of old river terraces and rests of seepage gullies which are filled by groundwater. The Noordelijke Maas is relatively straight as compared to the meandering Grensmaas and Plassenmaas. The Maas has cut the terrace landscape by erosion of the upper clay layers and the lower laying sand layers. The sandy terraces are important for the ecological value of the Noordelijke Maas because it forms the habitat for lots of animals (Smart Rivers, De Zandmaas - Unieke Terrassenrievier met Kwelgeulen, 2012).

1.3.2 Bedijkte Maas

The Bedijkte Maas is the Meuse part which is embedded by floodplains and dikes. These dikes have been constructed by humans to protect land and properties against floods risk. The Bedijkte Maas is the Meuse section from Cuijk to the Haringvliet. Even as the Maarvallei is the Meuse separated in different parts with their own characteristics.

1.3.2.1 *Benedenmaas*

The Benendenmaas also known Slibmaas is in contrary to upstream parts of the Maas embedded by foodplanes dikes and not by natural boundaries. These dikes and floodplains have a important function for the protection of the hinterland and discharging of floods.
Before the canalizations of the Maas in the 1920s the Benedenmaas had a meandering character what resulted in difficulties of the water discharge in this part of the river. Since the canalization and normalization of the Meuse in the 1920s the discharge capacity has been improved and the occurrence of floods decreased. (Everts, Jansen, Maas, Bouwman, Eysink, & Takman, 2012)

1.3.2.2 *Getijdenmaas*

The Getijdenmaas is the undammed part of the Maas. In this part the water can flow freely so that that the Meuse becomes a free discharging sand river. In this part of the Maas tide effects are influencing the water levels. The effect of tide on the Getijdenmaas strongly decreased after construction of the Bergsche Maas, the closure of the connection between the Maas and Waal and the closure of the Haringvliet. Before these works were done the amplitude at the Getijdenmaas was around 1 to 1,5 m, after the work was done the tide effect was around 30 cm (Smart Rivers, De Getijdenmaas - Kleine Zandrivier met Scala aan Geulen, 2012). In the second halve of the 20th century the floodplains are lowered due to excavation of sand.

1.3.3 **Zandmaas**

The areas of the Noordelijke Maas, Benedenmaas and Getijdenmaas together are often mentioned as the Zandmaas. The Zandmaas starts at Venlo and ends at Den Bosch. This part of the river is called Zandmaas because in comparison with the upstream parts of the river the river bottom consists of sand instead of gravel.

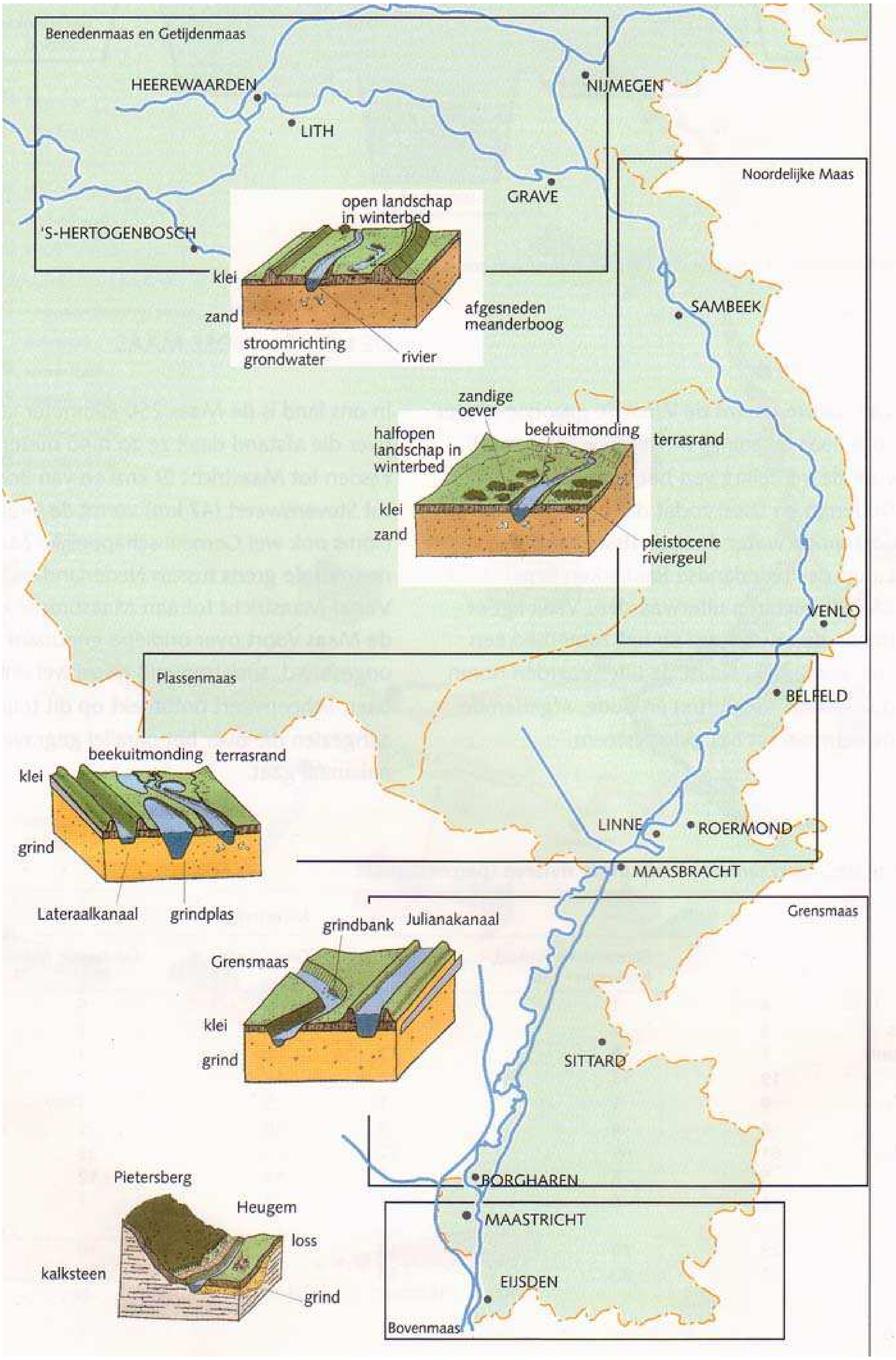


Figure 3 - Meuse (source: Rijkswaterstaat)

1.4 Functions

The Meuse has al lot of functions including:

- Discharge of water
- Navigation
- Clay and gravel extraction
- Water supply for drinking water
- Cooling water for the industry
- Agriculture
- Environment
- Living
- Ecological purposes
- Landscape
- Irrigation water
- Security
- Border function between countries (Belgium and the Netherlands)
- Border function between provinces (Brabant and Limburg)
- Water to feed channels in and along the Meuse

1.5 Water discharge

1.5.1 Current discharge

The water which is discharged by the Meuse originates mainly from rain water. This type of river is called a rain river. Characteristic for this type of river are the strong changes in discharge. During wet periods high discharges can cause floods and during dry periods low discharges can cause water shortages. This strong fluctuation has two reasons:

- Most of the water from the Meuse comes from the Ardennes. The Ardennes forms the biggest part of the watershed of the Meuse. The bottoms in the Ardennes are hard and impermeable so that the rain water runoff from land to the river takes less time. So heavy rain in the Ardennes causes a quick raise of the water levels of the Meuse (Rijkswaterstaat, Hoogwater op de Rijn en de Maas, 2007).
- The watershed of the Meuse is relatively small comparable to for example the watershed of the Rhine. The watershed of the Meuse has an area of about 35000 km^2. Due to the small watershed there is a relative high probability that at the same moment rain will fall over the entire watershed (Rijkswaterstaat, Hoogwater op de Rijn en de Maas, 2007).

Discharges of the Meuse are in the Netherlands measured in southern Limburg nearby Borgharen. These measurements have resulted in the following numbers:

- Mean annual discharge 230 m^3/s
- Mean high discharge in wet periods 480 m^3/s
- Mean low discharge in dry periods 89 m^3/s
- Mean annual flood peak 1500 m^3/s
- Extreme low discharges < 18 m^3/s
- Extreme high discharges >3000 m^3/s
- Design discharge (1/1250) 3800 m^3/s

1.5.2 Future discharges

Until 2006 the WB21 climate models were used as starting point for water management in the Netherlands. In the WB21 model is based on three scenarios a low, middle and high scenario. For practical reasons the middle scenario is usually used in the Netherlands. The KNMI has based on results from research programs all over the world created new climate scenarios. This are called the KNMI06 scenarios. Th KNMI 06 model consists of four scenarios:

- Moderated (G)
- Moderated with changing airflow (G+)
- Warm (W)
- Warm with changing airflow (W+)

The changes from to the KNMI06 scenarios are calculated according to the hydrological model for the Meuse basin. In Figure 4 are the mean discharges according to the WB21 scenarios and the KNMI06 scenarios represented for the year 2050. All scenarios refer to a increasing discharge in the winters and a decreasing discharge in the summers.

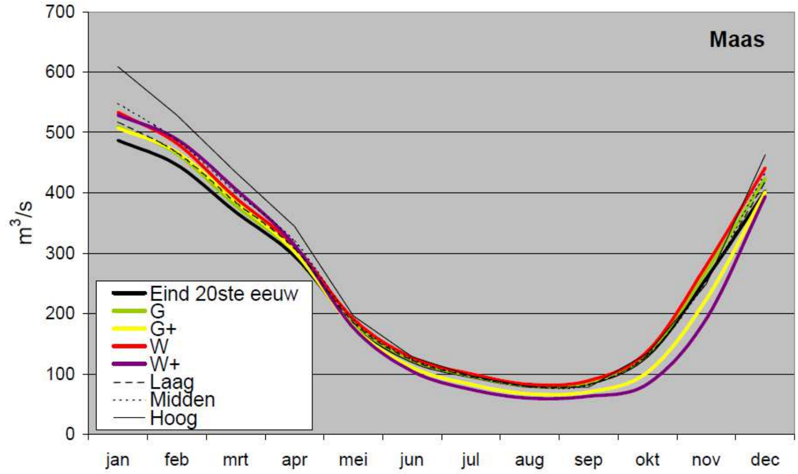


Figure 4 - Climate scenarios according to WB21 and KNMI06 (source: KNMI)

The influence of climate changes on the occurrence low discharges is not totally clear. The decreasing rainfall in the summer months and the increase of evaporation leads to a decreasing discharge in the summer. However the increase of rainfall in the winter months results in an increase of the groundwater level which leads to a higher base flow. At the moment there is not a clear answer for the combined effects.

The discharges in Table 1 are the design discharges of different scenarios for a repetition time of 1/1250 year. The A in the table stands for values which are obtained according to the rule of thumb. According to this rule of thumb is the increase of the design discharge proportional to de increase of the 10-day precipitation in the winter months. The B values in the table are determined according to a compassion between changes in discharge of the WB21 and KNMI06 scenarios. In most sources a design discharge of 4600 m^3/s for the year 2100. According to the climate models this turns out to be correct for mean situations, not for extreme situations.

Table 1 - Design discharges according to WB21 and KNMI06

	WB21			KNMI06			
	Laag	Midden	Hoog	G	G+	W	W+
2050 A				3952	4028	4104	4256
2050 B	4000	4200	4550	4000	4000	4200	4200
2100 A				4104	4256	4408	4712
2100 B	4200	4550	5300	4200	4200	4550	4550

1.6 Gradient and width

The dimensions of the river are not constant along the Meuse. The gradient of the bottom slope becomes smaller when the river approaches the Haringvliet. The Meuse has in the Belgian and French part of the river a relative steep slope. In the Netherlands the slop of the river becomes smaller. This can be seen in gradient of the bottom slope, after the Meuse has left the hilly terrain of southern Limburg the gradient decreases three times. The decrease of the gradients results in a decrease of the flow velocities in the downstream part of the Meuse. These low flow velocities result in a wider river downstream as represented in
Table 2 (Semmekrot & Vries, 1992).

Table 2 - With and gradient per section

Section	Mean Width [m]	Bottom gradient [‰]
Lixhe (België) - Borgharen	120	0.34
Borharen - Linne	120	0.3
Linne - Roermond	120	0.15
Roermond - Belfeld	140	0.08
Belfeld - Sambeek	140	0.10
Sambeek - Grave	160	0.12
Grave - Lith	160	0.10

1.7 Flood protection

Flood protection in the Netherlands consist out of dike ring areas. To protect all vulnerable areas in the Netherlands the country is spitted in 95 dike ring areas. A dike ring is an area that is protected against floods by a system of connected flood defenses. A system can be consisted out dikes, dunes, locks etc. The size of the dike ring areas is very different. There are large dike ring areas like those of Noord- or Zuid Holland but there are also small dike ring areas like the areas along the Meuse in the province of Limburg. For every dike ring area a safety level is determined. Densely populated areas or areas with a high economic value have a higher safety level than sparsely populated and economical unimportant areas (Weijers & Tonneijck, 2009). The safety levels differ from 1/10000 year for dike rings 13 and 14 (Noord- and Zuid Holland) to a safety lever of 1/250 year for the dike rings 54 to 95 (rings along the Meuse). The dike rings 54 to 95 are located in the Maasvallei. These areas are not defended by dikes but by quays. These quays were constructed in the past around villages and not around lager areas like in other parts of the Netherlands. However the safety levels of the dike rings along the Meuse are low they are a part of the primary flood defense of the Netherlands.

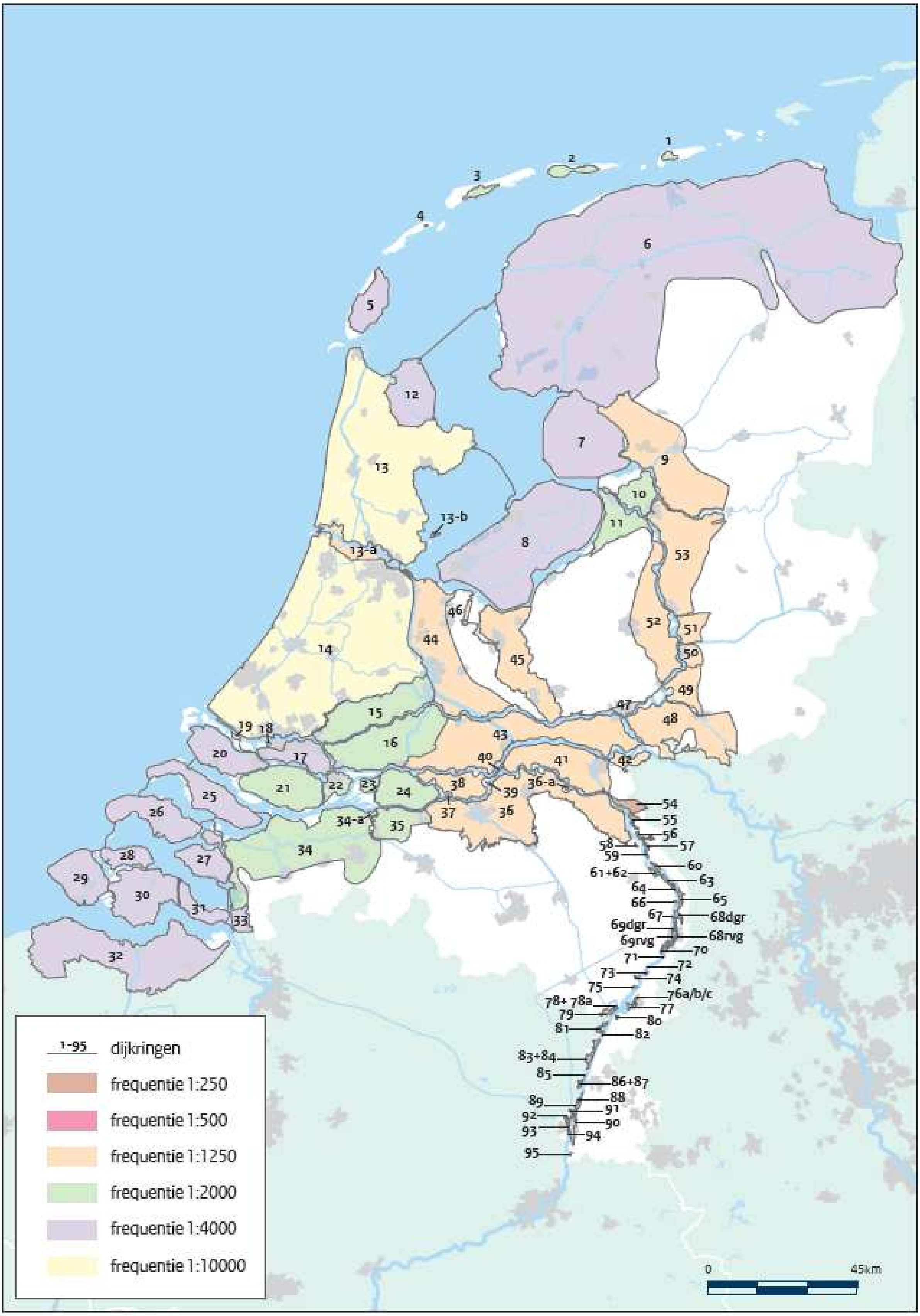


Figure 5 - Dike ring areas in the Netherlands (source: Rijkswaterstaat)

1.8 Sediment transport

1.8.1 Sand

The sand transportation on the Meuse is a hard to determine because the amount of transported sand varies along the river. At the Grensmaas large differences in transport occur. Normally the sediment transport on the Grensmaas will be low however the transport capacity can increase with a factor 100.
From measurements near Linne mean annual transports of 26000 m^3 sand and gravel are known. However in dry year this can decrease to 5000 m^3 and in wet years increase to 90000 m^3. The average transport at Linne first decreases to 19000 m^3 nearby Kessel and than increases to 70000 m^3 in the direction of Grave (Breukel, Silva, van Vuuren, Botterweg, & Venema, De Maas - Verleden, heden en toekomst, 1992).

1.8.2 Silt

The transport of silt has strongly increased in the last hunderd years. This is the result from increased bottom erosion, urbanization and increasing industrialization along the Meuse. Transport of silt is more than sand transport dependent on the discharges of the Meuse. Mainly the occurrence of high water determines the amount of silt transport. This explains the differences in silt transport for years with the same mean annual discharge. Because discharge of the Meuse is varying the silt transport is also varying. The mean annual transport the period 1970 to 1990 was about 559 kton/yr with a minimum of 79 kton in 1976 and a maximum of 1287 kton in1984 (Breukel, Silva, van Vuuren, Botterweg, & Venema, De Maas - Verleden, heden en toekomst, 1992).

2 Canalized Meuse

2.1 Canalization and normalization of the Meuse

The canalization and normalization of the Meuse was done for two purposes:

- Making the Meuse navigable for large ships
- Better discharge of water in the Benedenmaas en Getijdemaas to prevent floods

The demand to optimize the Dutch rivers for navigational purposes increased in around 1900. Led by the industry and trading companies the pressure on the government to optimize the rivers increased quickly. In particular for the Meuse the demand became larger and larger. Because new techniques were developed to win coal on a large scale from the mines in the south of Limburg. These coals had to be transported to the industrialized areas in the western part of the Netherlands. Transport by ship was a good option because it was the cheapest solution. However the Meuse had to be canalized.

However the most attention was focused on the navigability of the Meuse also the discharge problems in the downstream part of the Meuse remained important. Mainly the part downstream of Grave was problematic. Because of the winding character and the low gradient of the river, were the flow velocities low which resulted in high water levels. During extreme high waters in 1920 some dikes along the Bedijkte Maas failed at some spots which caused floods. Also during high waters in 1926 major problems were encountered due to high waters on the Meuse and Waal. Large parts of the Land van Maas en Waal flooded. Due to the long periods of high water at the Bedijkte Maas also problems with drainage of the areas along the Meuse arose because during high water it was not possible to drain the polders.

In this period new techniques were developed in to hydraulic engineering. However the Nederlands had no experience with these new techniques the developments played an important role in the decision to canalize the Meuse. Due to a lack of experience there was a lot discussion about the type

of weirs which should be used. An proven but old fashioned design like the Poirée weir or a modern weir like a weir with Stoney gates. Chosen was a combined weir which consisted partly out of a Poirée weir and partly out of Stoney gates.
It took during 1919 until the canalization of the Meuse started. It was not only the discussion about the weir type but also the difficult negotiations with Belgium of the canalization of the Grensmaas and the start of the First World War delayed the process. In 1919 decided the Dutch government to start with the canalization of the Meuse on Dutch territory. Started was with the construction of the weirs near Linne, Roermond, Belfeld, Sambeek and Grave.
Because no agreement could be reached with Belgium about the canalization of the Grensmaas the Dutch government decided to construct a channel parallel to the Grensmaas on own territory. This is the current Julianakanaal. To maintain the water depth until the Julianakanaal a weir near Borgharen was constructed

In total was the cannibalization of the Meuse divided into four parts.

- Part 1: Canalization of the Meuse from Maasbracht to Grave by means of five weirs near Linne (1921), Roermond (1921), Belfeld (1924), Sambeek (1925) and Grave (1926).
- Part 2: Construction of the Julianakanaal between Borgharen and Maasbracht (1926 to 1936) and construction of a weir near Borgharen (1928).
- Part 3: Canalization of the Meuse from Grave to Lith by constructing a weir nearby Lith (1936).
- Part 4: Normalization of the Meuse between Grave and Blauwesluis to obtain a better discharge though this part of the river.

From (Berger & Mugie, 1994) and (Heezik, 2008)

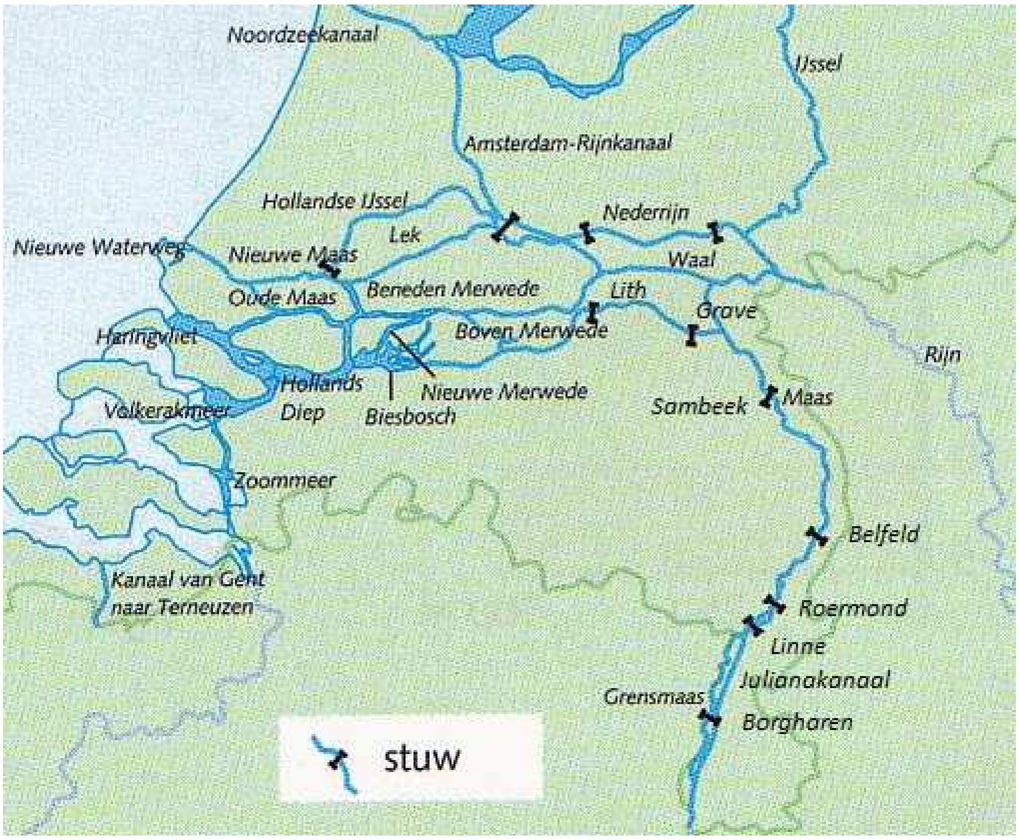


Figure 6 - Locations of the weirs (source: Rijkswaterstaat)

2.2 Meuse corridor

There are in total seven weir in the Meuse. The Meuse corridor is represented in Figure 7. In this figure the location and the weir heights are shown.

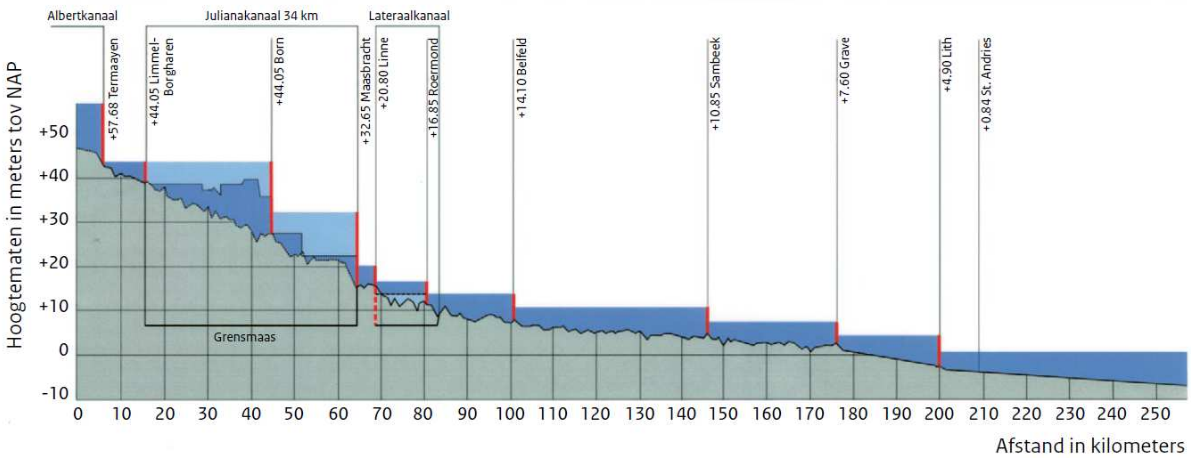


Figure 7- Meuse corridor (source: Rijkswaterstaat)

During current works on the Meuse the water level in some channel sections will be changed from the water levels in Figure 7. This is done for two reasons (Maaswerken, Peilopzetplan, 2003):

- In order to create enough draught for vessels of the CEMT Vb class
- In order to increase ground water levels to prevent drying of natural areas

The changes in water levels is represented in Table 3.

Tracé-deel	Stuwpand	Stuwpeil huidige situatie (m + NAP)	Stuwpeil na peilopzet (m + NAP)	Peilopzet (cm)
1	Eijsden-stuw Borgharen	44,05	44,05	0
2	Stuw Borgharen-Maasbracht	-	-	-
3	Sluis Limmel-sluis Born	44,05	44,05	0
4	Sluis Born-sluis Maasbracht	32,65	32,90	25
5	Maasbracht-stuw Linne	20,80	20,80	0
6	Stuw Linne-stuw Roermond	16,85	16,85	0
7	Lateraalkanaal	14,00	14,10[1]	10
8	Stuw Roermond-stuw Belfeld	14,00	14,10[1]	10
9	Stuw Belfeld-stuw Sambeek	10,85	11,10	25
10	Stuw Sambeek-stuw Grave	7,60	8,10	50
11	Sluis Heumen-sluis Weurt	7,60	8,10	50
12	Stuw Grave-stuw Lith	4,90	4,90	0
13	Stuw Lith-Hedel	-	-	-

[1] *dit is de 10 cm peilopzet die enkele jaren geleden, conform de WM-vergunning voor Proefproject 2, voorafgaand aan de zomerbedverbreding is gerealiseerd*

Table 3 - Changes in water levels (source: Rijkswaterstaat)

2.3 Basic principles of the Meuse weirs

The weirs from Linne to Grave are constructed according to the principle of Stoney and/or Poirée. Before the Meuse weirs are described the principle of the Stoney and Poirée weirs will be discussed.

2.3.1 Poirée weir

The needle weir of the French engineer Poirée is for the first time used in France. The Poirée weir consists of yokes which are connected by hinges with the bottom of the weir. Between the yokes partitions are place so that a wall is formed which will push up the water. The first step of lowering of

the weir is the removal of the partitions between the yokes. After the partitions are removed the yokes will be lowered to the bottom of the weir (Berger & Mugie, 1994).
The Poirée weir was a large improvement in weir construction because this type of weir was able to accommodate on changing conditions. The disadvantage of this weir type was that the regulation was very inaccurate.

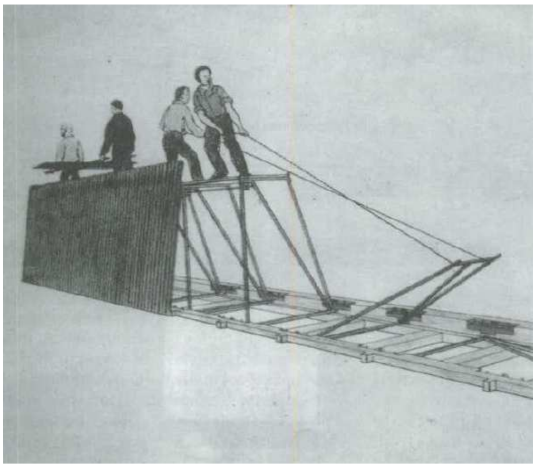


Figure 8 - Principle of the Poirée weir (source: Rijkswaterstaat)

2.3.2 Stoney weir

The Stoney weir was developed by the British engineer Francis Stoney. The Stoney weir consist of mechanically operating gates which are placed between two pillars. The gate consists of two slides, a higher and a lower slide which can be operate separately. This gives the opportunity to use a free surface flow or a submerged flow. The big advantage of this type of weir in comparison with the Poirée weir is the possibility of accurate discharge regulation (Berger & Mugie, 1994).

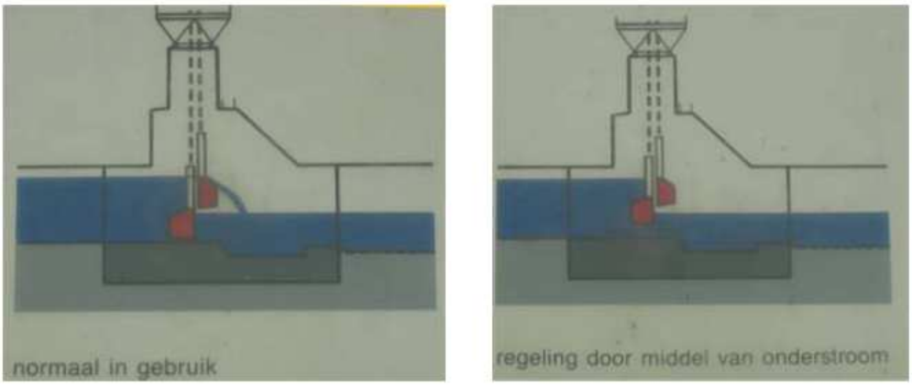


Figure 9 - Principle of the Stoney weir (source: Rijkswaterstaat)

2.3.3 Combined weirs

The weirs of Linne, Roermond, Belfeld and Sambeek are constructed partly as Poirée weir and partly as Stoney weir. At discharges lower than 200 m^3/s will the discharge be fully regulated by the Stoney gates. The Poirée part is completely closed in this situation. At discharges higher than 200 m^3/s also the Poirée part is used for water discharge. The partitions will be removed row by row, starting from the middle. After every series of removed partitions the Stoney gates have to be constantly adjusted in height until the next series of partitions should be removed. By decreasing discharges are the partitions places row by row back into the yokes.
In the openings between two yokes three partitions can be placed. The removal of the partitions is of the Poirée weir is done by using a special crane. The crane is able to move over the weir by use of the rail on top. After removing of the partition between the yokes they are stored in a special storage next to the weir. The removal and placing of the partitions is a very labour-intensive because at least two people are needed to handle a partition. This work is not without risks for these people so they

have to work very carefully. The minor advantage of this combined weirs is the ability of accurate discharge regulation by the Stoney gates during low river discharges and the ability of transmission of vessels during high water by the Poirée part.

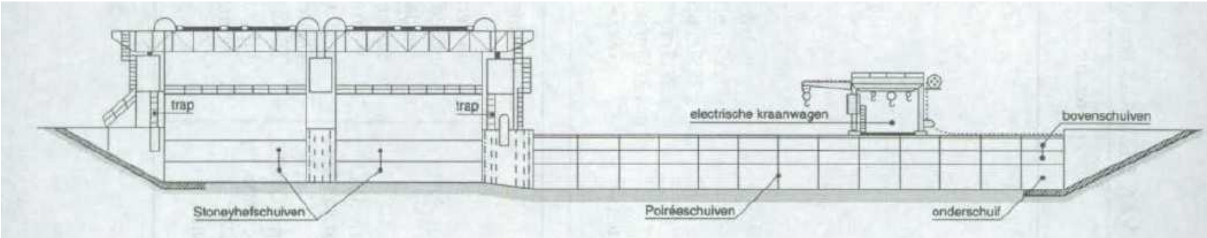


Figure 10 - Front view of a combined weir construction (source: Rijkswaterstaat)

2.4 Description of the current weir management

2.4.1 Weir of Borhgaren

The weir of Borgharen is most upstream weir in the Dutch part of the Meuse. The weir of Borgharen is constructed as a weir with sliding gates. This weir has four discharge openings, three openings of 23 m and one opening of 30 m. The weir has besides maintaining the water level also the task to discharge water to the Julianakanaal and the Zuid-Willemsvaart (Berger & Mugie, 1994). At low discharges a water level of NAP + 44.05 m is maintained with tolerances between NAP + 43.90 m and NAP + 44.10 m. For discharges up to 230 m^3/s the regulation is done by the remote controlled flaps on top of the sliding gates. When the discharges increase up to 300 m^3/s the gates are lifted 0.20 m. Until a discharge of 1200 m^3/s is reached is the gate is lifted by steps of 0.10 m. At discharges above 1200 m^3/s the gates are totally removed from the water (Kranenbarg & Kemper, 2006).

2.4.2 Weir of Linne

The weir of Linne is the second weir in the Meuse. The weir of Linne is a combined Poirée Stoney system. The Poirée part consists of fifteen openings of 4 m which resulted in a total width of 60 m. The Stoney part consists of three discharge openings of 17 m each (Berger & Mugie, 1994). The navigation lock is not placed next to the weir but near Heel. This is done because vessels use the Lateraalkanaal between the Linne and Roermond. At low discharges a water level of NAP + 20.80 m is maintained with tolerances between NAP + 20.70 m and NAP + 20.90 m. For discharges up to 200 m^3/s the water discharge is managed by the hydroelectric power station next to the weir and the Stoney gates. For increasing discharges up to 1000 m^3/s partitions of the Poirée weir are removed. The weir will be entirely opened at discharges higher than 1000 m^3/s (Kranenbarg & Kemper, 2006).

2.4.3 Weir of Roermond

The Poirée part of the weir near Roermond consists of 17 openings between the yokes of each 4 m wide which results in a width of 60 m for the Poirée part. The Stoney part consist of two openings of 17 m each (Berger & Mugie, 1994). At low discharges a water level of NAP + 16.85 m is maintained with tolerances between NAP + 16.75 m and NAP + 16.95 m. During discharges up to 200 m^3/s the flow is controlled by the Stoney gates. For discharges up to 1000 m^3/s parts of the Poirée part will be removed to increase the discharge of the weir. At discharges higher the 1000 m^3/s the total weir is opened (Kranenbarg & Kemper, 2006).

2.4.4 Weir of Belfeld

The weir of Belfeld is the fourth weir in the Dutch part the Meuse. The Poirée part of the weir consists of thirteen openings of 4.85 m wide so the total width of the Poirée part becomes 63.05 m. The Stoney part has two openings of 17 m wide. In situations of low discharge a water level of NAP + 14.10 m is maintained with tolerances of NAP + 13.90 m and NAP + 14.20 m (Berger & Mugie, 1994). The water level is maintained by the Stoney gates for discharges up to 200 m^3/s. Partitions of the Poirée weir will be removed for increasing discharges up to 800 m^3/s. In this way the water level can be maintained in an accurate way by the combination of the Poirée part and theStoney gates. For discharges higher than 800 m^3/s the weir will be opened completely. In this situation vessels do not have to use the sluice complex next to the weir but can pass the weir through the opening of the Poirée weir (Kranenbarg & Kemper, 2006).

2.4.5 Weir of Sambeek

The weir of Sambeek is the fifth Meuse weir and the last weir in the Meuse which is constructed according the combined principle . The weir Poirée part. The Stoney part consists just like the weir of Belfeld of two openings each of 17 m wide (Berger & Mugie, 1994). For discharges up to 200 m^3/s is the water level maintained by the use of only the Stoney gates. In this situation a water level of at least NAP + 10.85 m is maintained with tolerances of NAP + 10.80 m and NAP + 11.00 m. Discharges up to 1070 m^3/s will be handled by removing partitions of the Poirée weir. For discharges higher than 1070 m^3/s the weir complex is totally opened. In this situation vessels do not have to use the sluice complex near the weir but can pass the weir through the gap of the opened Poirée weir (Kranenbarg & Kemper, 2006).

2.4.6 Weir of Grave

The weir of grave is a special type in the Netherlands. This type is in the Netherlands only used at the weir of Grave. The construction at Grave consists of a combined bridge-weir structure. The bridge connects the cities of Nijmegen and Den Bosch. The weir consists of two discharge openings which are separated by a bridge pier. Each opening can be closed by partitions between yokes just like the Poirée weir. The hinged yokes are in comparison with the weir Linne, Roermond, Belfeld and Sambeek not connected to the bottom but to the bridge, in this way a turned around Poirée system arises. The yokes will not be lowered to the bottom but will be lifted up and stored under the bridge. This is done by chains which are connected to a hoist on the underside of the bridge deck.
Each discharge opening consists of nine openings of 5.45 m between the yokes and one opening with a width of 5 m so in total there are in twenty openings between the yokes. Between two yokes three partition can be placed. By removing a partition from the upper row a flow of about 20 m^3/s extra could be discharged. At low discharges a water level of NAP + 7.60 m is maintained with tolerances between NAP + 7.55 m and NAP + 7.65 m (Kranenbarg & Kemper, 2006). This is not only important for navigation on the Meuse but also for the possibility to enter the Maas-Waalkanaal. Up to a discharge of 400 m^3/s the highest partitions are removed one by one. When discharges increase until 1000 m^3/s also the lower partitions will be removed. For discharges higher than 1000 m^3/s all partitions will be removed. In this situation vessels do not have to use the sluice complex near the weir but can use the discharge openings of the weir (Kranenbarg & Kemper, 2006).

2.4.7 Weir of Lith

The weir of Lith is the last weir in the Meuse. In 1934 the construction of weir started and in 1936 the weir was ready to operate. Because this weir has built at a later moment then the other weirs more and better technologies were available. For this reason the weir was constructed as a (for those times) modern weir with sliding gates. The sliding gates have been executed as rotatable wheel slides with a remote controlled flap on top. The flaps are controlled by means of chains and winches which are connected with the hoisting equipment on top of the lifting tower. The flap are used to obtain an accurate discharge management. The weir of Lith consists of three discharge openings of each 38 m wide between four lifting towers. Each opening has a maximum discharge of 400 m^3/s. During low discharges at least a water level of NAP + 4.90 m is maintained. For discharges up to 230 m^3/s the water discharge is managed by the hydroelectric power station next to the weir. At increasing discharges up to 300 m^3/s also the flap on top of the gates are used. For higher discharges than 300 m^3/s the gates lifted 0.20 m and hereafter by steps of 0.10 m. Discharges up to 1200 m^3/s will result in a total lifting of the gates (Kranenbarg & Kemper, 2006). In the opened situation vessel can use the discharge openings of the weir. The gates will be lifted to a height of NAP + 13.60 m to create sufficient navigation height for vessels. This situation occurs about 22 days a year.

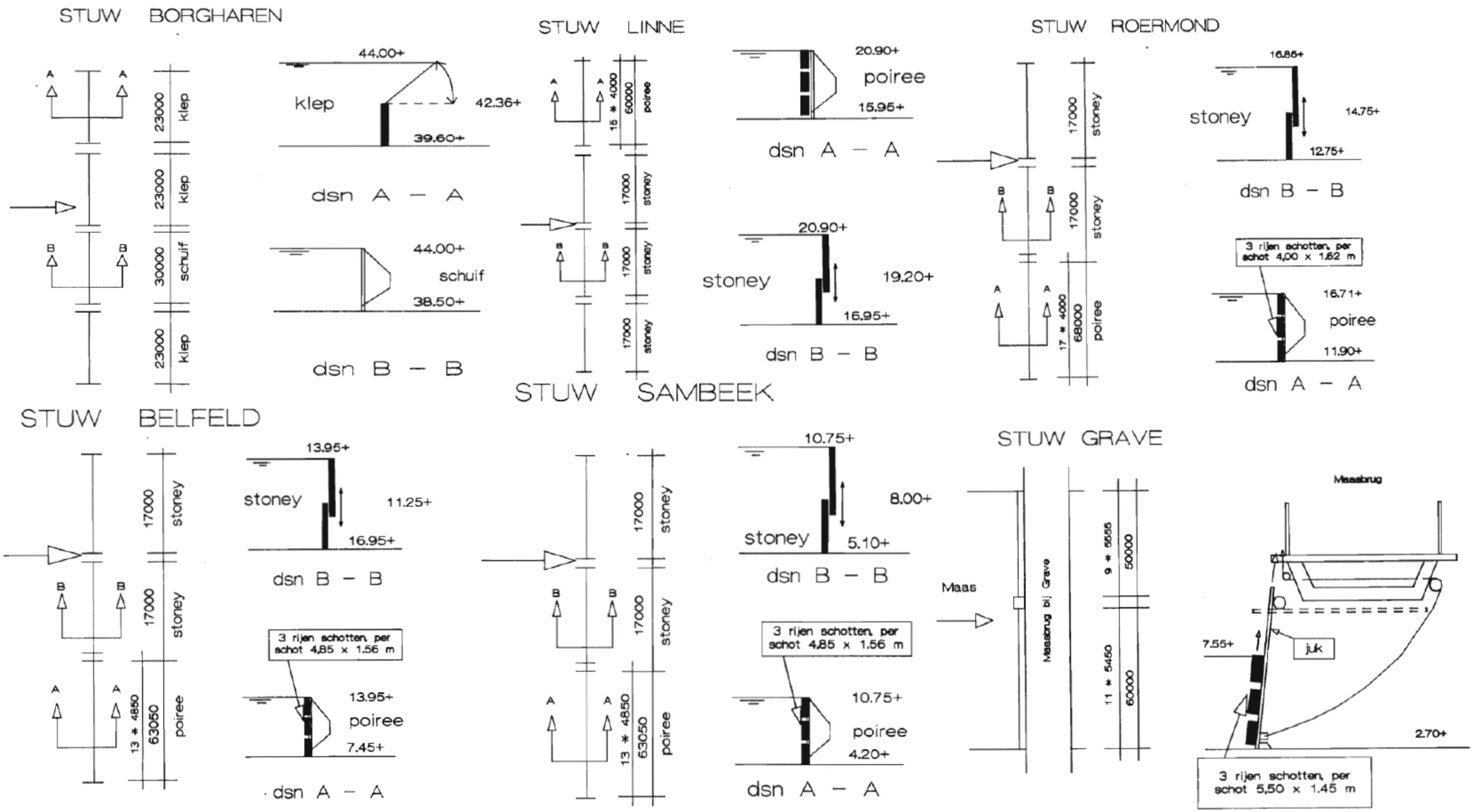


Figure 11 - Layout of the weir near Borgharen, Linne, Roermond, Belfeld, Sambeek and Grave (source: Rijkswaterstaat)

2.5 State of the Weirs

The seven weirs in the Meuse are situated near Borharen, Linne, Roermond, Belfeld, Sambeek, Grave and Lith. They have been build between 1921 and 1936 for a lifespan period of 80 to 100 years. This means that the weirs will in the period between 2020 to 2030 reach their technical lifespan. The main shortcomings of the weirs are related to aging of materials, operability and lack in the discharge capacity. In 2010 the Dutch ministry of public works (Rijkswaterstaat) started the RINK project. The project started due to doubts about the state of the art of hydraulic structures in the Netherlands after problems with some bridges. Also the aging of lots of hydraulic structures all over the Netherlands were an reason. The purpose of the RINK project is to make an inventory of the state of hydraulic structures. The total result should be an overview of the state of the art of hydraulic structures in the Netherlands. The weirs in the Meuse have also be investigated. Rijkswaterstaat has investigated the risk of these weirs, there results are shown in Figure 12. It can be seen that according to the RINK project the risks of the Meuse weirs are rather high. These risks are the result of changing circumstances and aging of materials.

Stuwen	Bouwjaar	Risico
Borgharen	1928	Hoog / Zeer hoog
Linne	1921	Hoog / Zeer hoog
Roermond	1921	Hoog / Zeer hoog
Belfeld	1924	Hoog / Zeer hoog
Sambeek	1925	Hoog
Grave	1926	Hoog / Zeer hoog
Lith	1936	Zeer hoog

Figure 12 - Results of the RINK project for the weirs of the Meuse

2.5.1 Overview of the state of the weirs

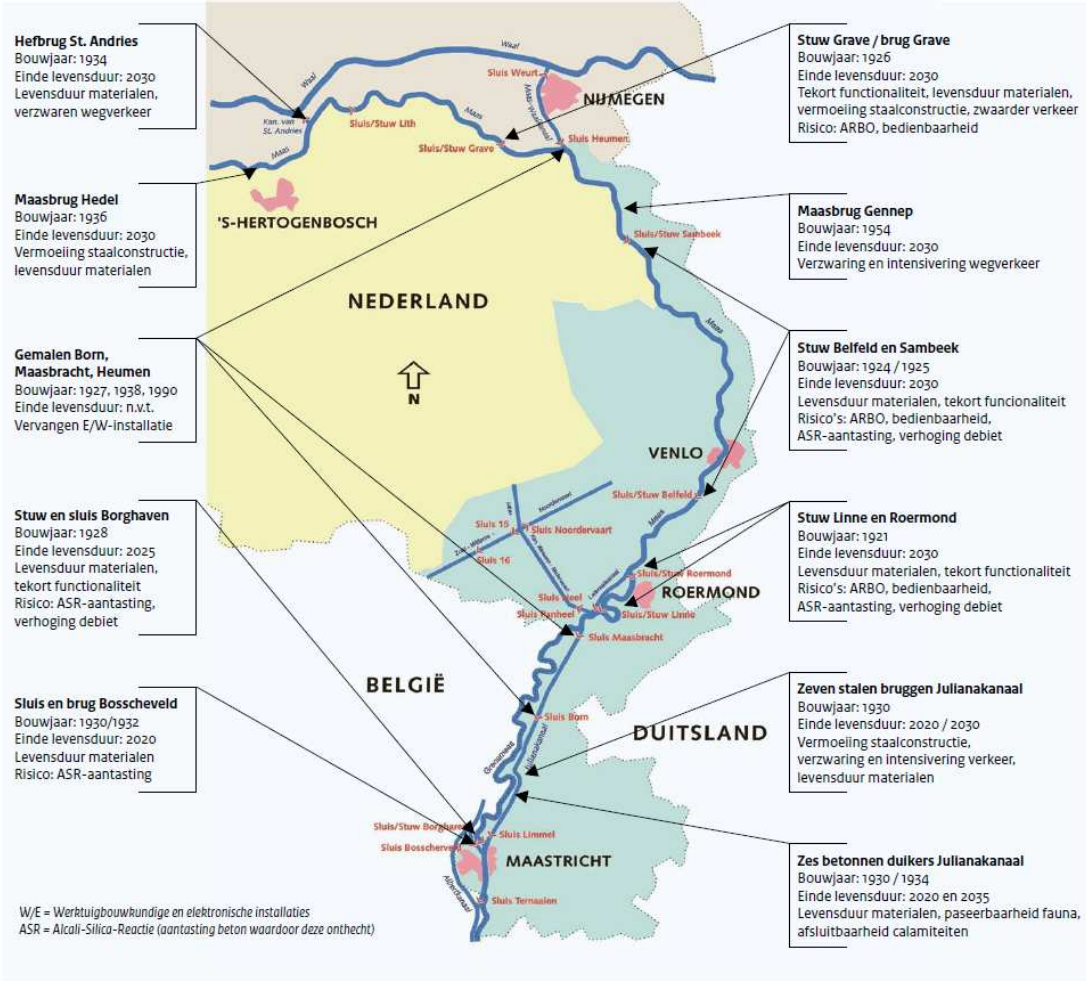


Figure 13 - Results of the VONK project for the Meuse structures (source: RIjkswaterstaat)

2.5.2 Lifespan of materials

The lifespan of the weir materials is nearly reached, the first traces are already noticeable. One of the problems is the ASR degradation of the concrete. The acronym ASR stands for alkali-silica reaction, this is a chemical reaction what causes an expansion of the altered aggregate by the formation of a swelling gel. The gel increases in volume with water and exerts an expansive pressure inside the concrete. The inside pressure causes spalling and loss of strength and finally leads to failure. At a certain moment the weirs are not able to fulfill their function due to constructive risks. However the weirs have been over dimensioned because the lack of construction rules in the past. So the lifespan of materials do not cause really large problems at the moment but good monitoring is important to keep an eye on the state of the materials. Moreover, the maintenance of structures suffering from ASR degradation is very expensive (Bakker, Kaptijn, & Appels, 2002).

2.5.3 Operability

When removing or placing the parts of the Poirée weir, the partitions should be removed or placed one by one. This affects the operability of the weirs during high discharges. For discharges below 200 m^3/s only the Stoney gates are used. For higher discharges some partitions of the Poirée part have to be removed and the discharges will be accurately managed by the Stoney gates until discharges become too high. Now more partitions will be removed and again is tried to regulate the discharges more accurately by the Stoney gates.This will go on until all partitions have been removed. This process is difficult, very labor intensive and inefficient. Because a flood wave needs about 12 to 24 hours to reach the Dutch border so a fast and efficient controlled is important. In the case of the weirs at Linne, Roermond, Belfeld, Sambeek and Grave this is not the case.

2.5.4 Lack of discharge capacity

The increase of the discharges in the future will become problematic. The weir forms a bottleneck in the river. For increasing high discharges the bottleneck problem becomes even large which will led to higher water levels near the weir.

2.5.5 ARBO requirements

The weirs which contain a Poirée part are very labour intensive because the weirs have to be placed or removed by hand. Over the years several changes have been made to meet the requirements for a responsible working environment according the ARBO law. For exampele, the renovation of the cranes which are used to lift the partitions of the Poirée weirs. Because the old weir constructions and the the continuously changes of the ARBO law, the weirs have to be adapted continuously to the new requirements.

3 Weir design

3.1 Weir types

Weirs can be classified in various ways. Classifications could for example be made according to function or mechanism. However, all weirs can be divided into two main types, the fixed weir and the movable weir.

3.1.1 Fixed weir

The fixed weir is a weir type which cannot be adjusted to changing situations. A fixed weir should be designed in such a way that the relation between discharge and the water push up fulfils the requirements. By means of the probability distribution of the discharge maximum and minimum discharges could be determined that are associated with the shorter and exceedance frequency. For minimum discharges the water levels should not be lower than the minimum required water levels. For maximum discharges the water levels should not be lower than the minimum required water levels (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Inleiding Waterbouwkunde, 2009).

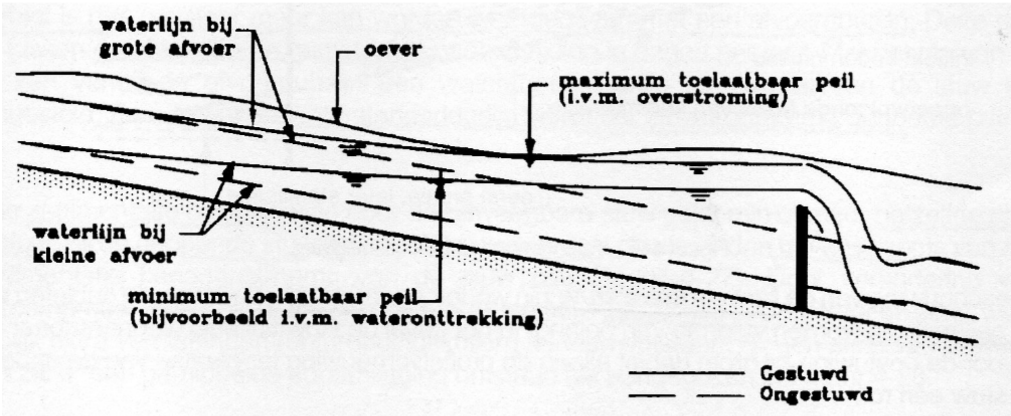


Figure 14 - Fixed weir (source: TU Delft, lecture notes CT5313)

3.1.2 Moveable weir

Just like the fixed weir it is important that the required water levels and discharges will be met. The height of the weir is dependent on the minimum and maximum design discharge and the minimum required water levels. For a movable weir gates that can be completely removed out of the wateronly the narrowing of the waterway due to the fixed superstructure is important. This narrowing could cause some water push up. The gates will be opened a bit for increasing discharges, this results in a decrease of the water push up. This opening operation continues until a constant water level arises that fulfils the requirements for minimal water levels (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Inleiding Waterbouwkunde, 2009).

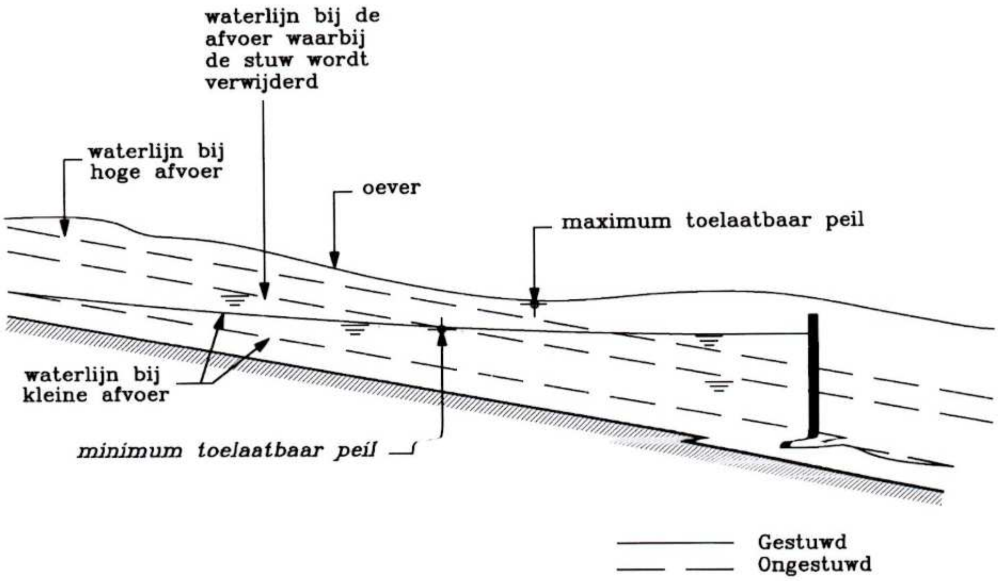


Figure 15 - Movable weir (source: TU Delft, lecture notes CT5313)

3.2 Types of moveable weirs

3.2.1 Flap gate

The flap gate is gate type which consist of a torsionally rigid gate. Flap gates can be divided into two types, a flap gate which is lifted by chains (Figure 16, left) and a gate which is lifted by hydraulic systems (Figure 16, right). The first type is hingedly connected to the bottom a super structure. The opening of this type of gate will be done by means cables and hoisting equipment. This is a very old principle, in Roman times this principle was already used (Schuiven met mogelijkheden, 1996). For the second type the gates are also hingedly connected to the bottom floor of the weir. When the weir is opened the gates are stored on the bottom of the super structure. The opening and closure of the gates is done by means of hydraulic pistons or cables. In the modern versions are the flaps gates hingedly connected to a yoke just below the middle of the gate. The retaining height of the downward rotating flap gate is limited because the moment near the hinge becomes larger for increasing retaining heights. Because the moment is proportional to the third power of the water height will the moments near the bottom become very high by increasing water heads. Sometimes counterweights or opposing moments are used to relieve the moment near the hinges. An opposing moment can be created by means of the water on the upstream side of the weir (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009). The downward rotating gate has the disadvantage that large parts of the construction are under water. This makes possibilities for maintenance more difficult. Also the occurrence of large moments near the hinges can be problematical. However the advantage of this type of gate is the unlimited vertical clearance for the passage of vessels.

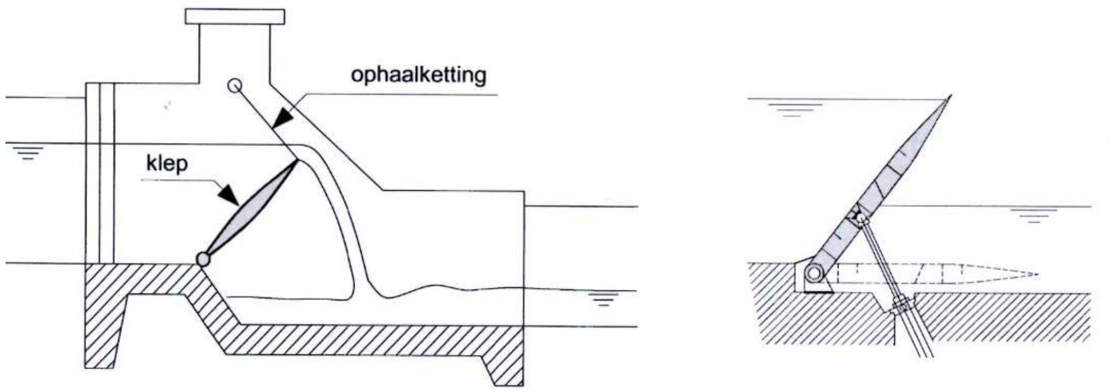


Figure 16 - Flap gate; left the first type and right the second type (source: TU Delft, lecture notes CT2320)

Examples:

- Lagan stuw in the Lagan river (Belfast, Northern Ireland)
- Libcice-Dolany weir in de Vltava river (Roztoky, Czech Republic)
- Veselí weir in the Morava river (Veselí Nad Moravou, Czech Republic)
- Wier in the Weser river (Bremen, Germany)
- Denouval weir in the Seine (Andrésy, France)

3.2.2 Tainter gate

The tainter gate consist of a plate which is constructed on a stiff halve open steel frame. This steel frame provide support to the plate and distributes the water pressure acting on the gate to the arms connected at the sides of the frame. The arms are hingedly connected to the piers of abutments of the super structure so that the resulting force will go through the point of the hinge. The hinges can be constructed either on the upstream or the downstream side of the weir (Schuiven met mogelijkheden, 1996). For the reason of maintenance are the hinges mostly places on the downstream side of the weir. For the piers and abutments it recommended that the resulting forces act as low as possible on the gates. It is also recommended that the resulting forces in the arms and hinges are always pointed in the downward direction to avoid tensile stresses in the concrete piers. The segment gate is rotated around the horizontal axis. During opening of the gate is rotated in the upward direction. It is possible to construct a flap on top of the tainter gate to obtain a more accurate discharge management. The tainter gate can be moved by different systems like cables and winches or hydraulic systems. In most cases a counterweight is used to lighten the moving mechanism of the weir (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009).

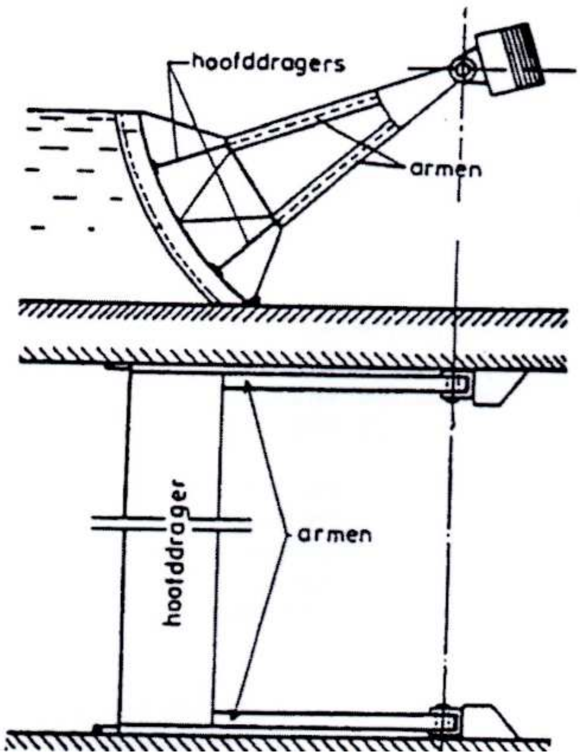


Figure 17 - Taintor gate (source: TU Delft, lecture notes CT2320)

Examples:

- Weir in the Labe (Štětí, Czech Republic)
- Eidersperrwerk in the Eider (Tönning, Germany)
- Braddock Dam in the Monongahela River (Braddock, United States)
- Dam in the Olt river (Izbiceni, Romania)
- Haringvlietsluizen in the Haringvliet (Hellevoetsluis, the Netherlands)

3.2.3 Roof weir

The roof weir consists of two flaps, a long flap also known as bearing flap and a short flap. The long flap is downstream hingedly connected to the bottom and the short flap on the upstream side. The two flaps are hingedly connected with each other on the top by means of sliding elements. In this way the flaps can role or slide freely with respect to each other. Water will be pumped in or out the triangular space between the flaps and bottom by means of drains. In this way the height of the weir can be lifted or lowered. In opened conditions will the flaps be stored in a special stock area in the bottom floor. The flaps will lay horizontally on the bottom of the fixed structure. Roof weirs are often sedimentation of the stock area which can result in problems during closing operations (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009).

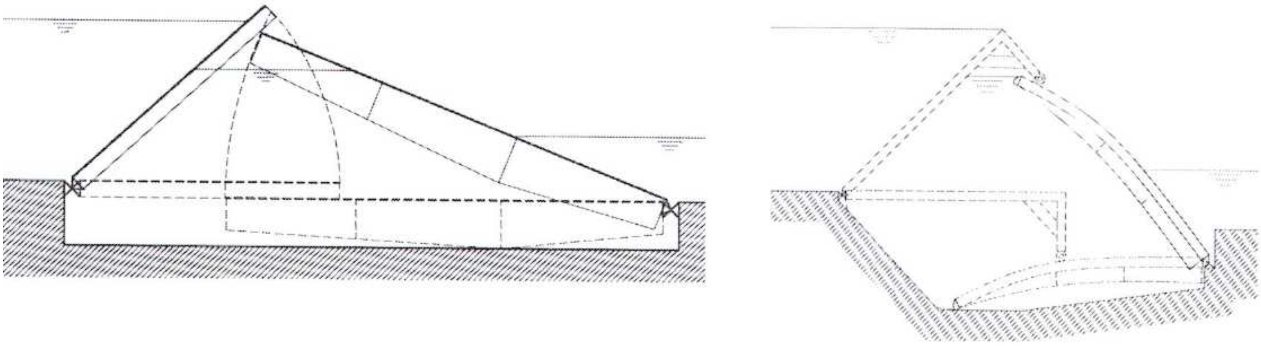


Figure 18 - Principle of roof weirs (source: TU Delft, lecture notes CT2320)

Examples:
• Tees Barrage in the Tees (Stockton - on-Tees , England)

3.2.4 Sector gate

The principle of a sector gate is a variant of the roof weir. The difference with the roof gate is that the two flaps of the roof weir are connected and will act like one element. The sector gates can be divided into two types, a gate which rotates around the horizontal axis and a gate which rotates around the vertical axis. At the first type are the hinges connected on the downstream part of the weir. Just like the roof weir will the gate be stored in a stock area in the bottom. The gate is lifted and lowered by pumping water in and out of the stock. The disadvantage of the sector gate is the construction and maintenance of the gate stockings. Just like the roof weir the sedimentation of the stocking area below the gate is a major problem (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009).
The second type of sector gate rotates around the vertical axis. The gate is hingedly connected with the abutments and will be opened or closed by a role or floating construction.

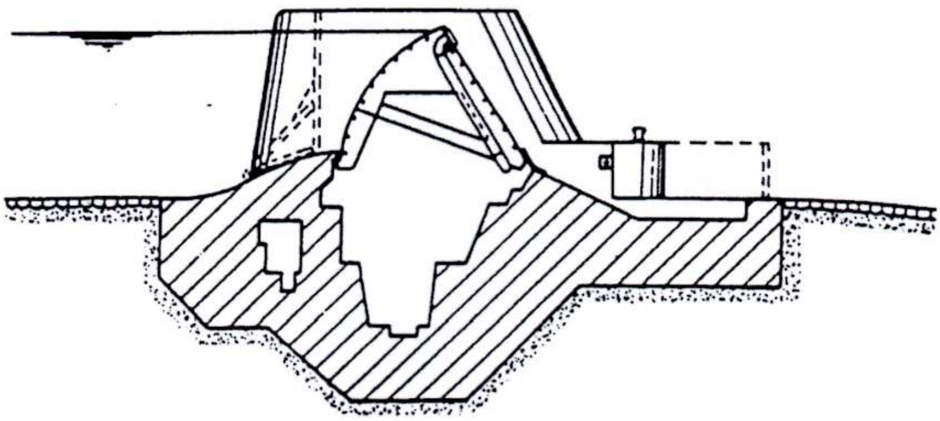


Figure 19 - Sector gate (source: TU Delft, lecture notes CT2320)

Examples:
- Maeslandkering in the Nieuwe Waterweg (Rotterdam, the Netherlands)
- Sluice in the bay of Osaka (Amagasaki, Japan)

3.2.5 Visor gates

The visor gate a curved retaining wall which are mainly used to push the local water level up. The principle and also the name of the visor gate comes from a medieval knight helmet. The gates are placed and connected between abutments or pillars. These pilars could contain discharge openings with small gates to obtain a accurate discharge over the weir complex. The gates are connected to the abutments or pillars by means of hinges. These hinges allow the gate to rotate over it horizontal axis just like the segment gate. Because the hinges are placed on the upstream side of the weir what results in hydraulic forces which are directed from the middle of the gate. This results in a gate that is only loaded on tension forces. In the middle of the gate a hinge is places so that small deformations, due to temperature changes do not cause extra tension forces on the construction (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009).

The gate can be rotated by means of cables which are guided over a curved concrete structure to the engines on top of the structure. How high the gates have to be lifted depends on the required clearance for navigation. However in most cases is rotation over an angle of 60 degree enough. A disadvantage of this type of gate is that the clearance is not equal over the width of the gate (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009).

The advantage of the visor gate is the water flow perpendicular to the arched gate during lifting of the gate. This creates a spread flow over the width of the gate which is beneficial for the bottom protection behind the weir construction. Furthermore can this type of gate be used for spans up to about 50 m. When a relative large gate is lifted a little bit high discharges can be reached. However, this has the disadvantage of unwanted vibrations during opening of the gate due to the water flow (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009).

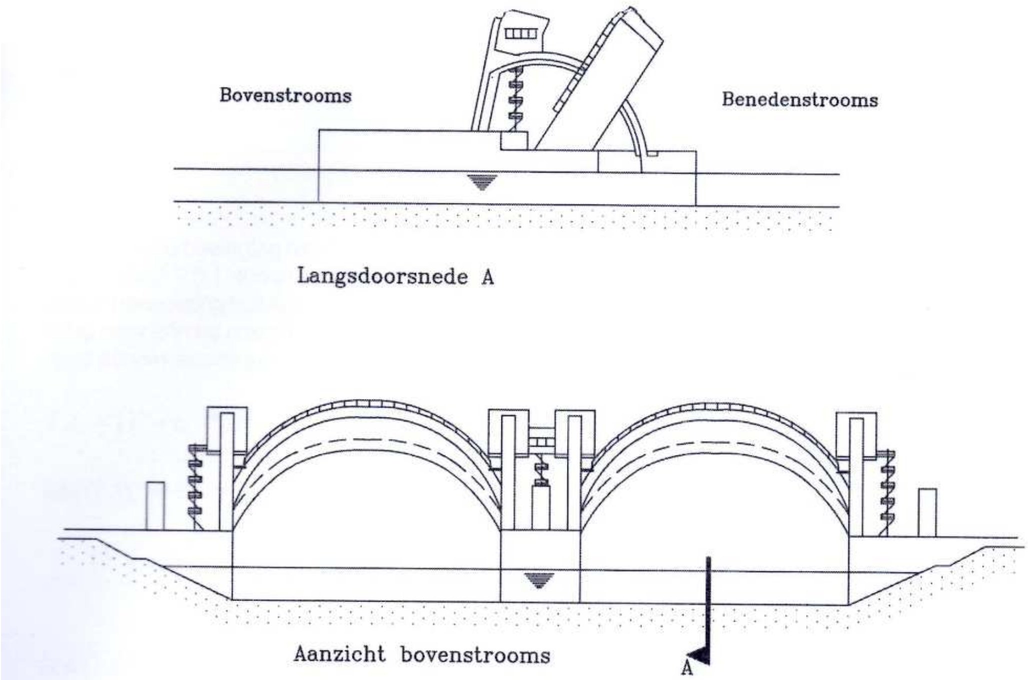


Figure 20- Visor gate (source: TU Delft, lecture notes CT2320)

Examples:

- Wei in the Rijn near Hagestein, Amerongen en Driel(The Nederland)
- Kizukawa Gate in the Kizukawa river (Osaka , Japan)

3.2.6 Stop lock weir

The stop lock weir blocks the waterway by piled up plates or beams between yokes, pillars or abutments. The elements should be placed or removed by crane or hand. By large spans of the waterway the plates or beams will be placed between yokes so that the partitions can be constructed as light simple constructions (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009). Stop lock weir have been frequently used in France and Belgium. In the Netherlands this type of weir has been used to canalize the Meuse by means of Poirée weirs. The disadvantage of this type of weir is that the discharge regulation can only be done by steps due to placing or removing of a plate or beam. In this way a accurate discharge is impossible.

Examples:

- Poirée weirs in the Meuse nearby Linne, Roermond, Belfeld en Sambeek (The Netherlands)
- Needle weir in the Reuss (Luzern, Switzerland)
- Needle weir in the Spree (Neubrück, Germany)
- Poirée weir in the French Meuse (Revin, France)

3.2.7 Weir with sliding gates

The sliding gate is a more developed version of the stop lock weir. The sliding gate is located between to hoisting towers. Hoisting installations are placed on top of the hoisting towers so that the gates can be lifted of lowered. In the sides of the towers guiding notches have been constructed so that the gates can only be lifted or lowered. The hoisting equipment is connected by chains or cables to the gates. With the use of counterweight can the capacity of the hoisting installation kept low. The forces due to the water pressure will become large for gates with large spans or high water heads. These high forces will result in high friction forces between towers and gates during opening or closing operations. To avoid this problem most doors are fitted with wheel which makes the gates able to ride over a rail during lifting and lowering. The highest lifting forces have to be supplied by the hoisting equipment when the door is put in motion during the lifting operation because first the friction forces have to be overcome. To reduce the horizontal force is the notches of the doors are places under an angel (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Bijlage C: Stuwtypen, 2009).
If a accurate discharge is required a flap could be places on top of the gate. By means of this flap the discharge and the water height can be managed very accurately and be changed if the situation changes. There are lots of variations of weirs with sliding gates possible like a wheel slide or Stoney gates. The advantage of the sliding gate is the absence of a point of rotation. The disadvantage of this type is the limited vertical clearance.

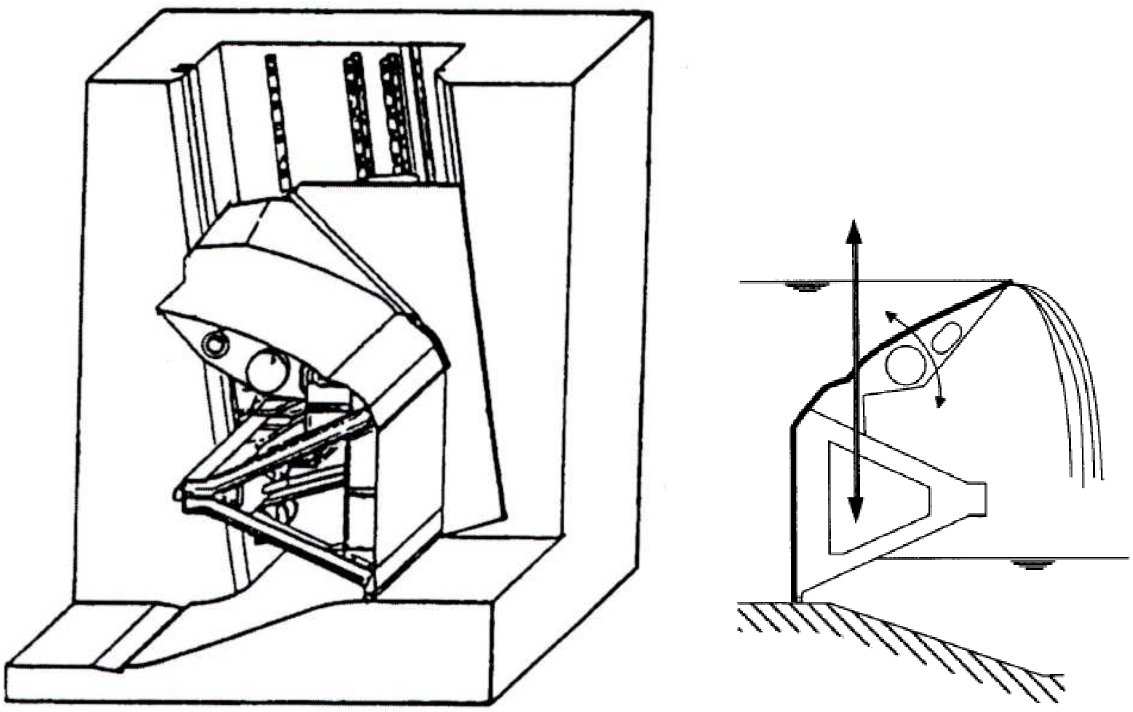


Figure 21 - Sliding gate with flap on top (source: TU Delft, lecture notes CT2320)

Examples:

- Weir in the Gent-Brugge channel (Beernem, Belgium)
- Weir near Ivoz Ramet in the Meuse (Ivoz Ramet, Belgium)
- Stop lock in the Canal du Centre (La Louvière, Belgium)
- Stoney gates in the Meuse near Linne, Roermond, Belfeld en Sambeek (the Netherlands)
- Weir in the Meuse near Lith (the Netherlands)

3.2.8 Weir with roller gates

A roller gate is a gate that is rolled in horizontal direction into the profile of the waterway. At the bottom of the gate wheels are connected, that make the gate able to move over a rail which is places in transverse direction on the bottom of the waterway. To avoid high pressure forces on the wheels sometimes air compartments are incorporated in the door. By means of the upward forces, the resulting vertical forces become smaller. When the gate is removed it will be stored in a special socket. This socket is constructed in one of the riverbanks. For wide waterways a long socket is needed. When there is not enough space for the socket the gate can be divided into two parts. For this variant sockets on both river banks have to be constructed. However these sockets can be kept small. The disadvantage of this variant is the lack of stability when gates with large spans are used (Schuiven met mogelijkheden, 1996).

Examples:

- Sluice near Selby in the Selby channel (Selby, England)
- Sluice near the Schelde (Berendrecht, Belgium)

3.2.9 Inflatable weirs

The inflatable weir does not consist out of concrete of steel but out of rubber blankets. The blankets are connected with the concrete bottom construction of the weir. In closed condition, the inflatable weir is filled with air and water, so that an overpressure in the construction exists. Due to the overpressure the construction will take a cylindrical shape. When the weir is removed the air and water is pumped out of the bellow a weak rubber bag remains. The bag is stored in a socket in the floor construction.

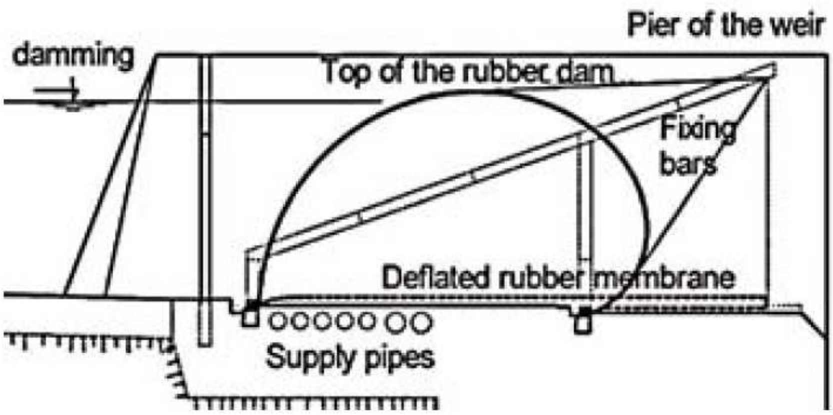


Figure 22 - Inflatablw weir (source: TU Delft, lecture notes CT2320)

Examples:

- Inflatable weir between the Ketelmeer and the Zwarte Meer (Ens, the Netherlands)
- Inflatable weir in the Dinkel (Denekamp, the Netherlands)
- Inflatable weir in the Bornsebeek (Borne, the Netherlands)
- Inflatable weir in the channel of Haarthelemmermeer (Aalsmeer, the Netherlands)
- Inflatable weir in the Loucna river (Pocaply, Czech Republic)

3.2.10 New concepts

Weirs and barriers can be combined with a bridge. In this constructions the foundations and the pillars are used by the weir and bridge construction. A new concept for this situation is developed by Dijk and van der Ziel. In this concept is called the bridge barrier. The deck of the bridge can be used as bridge and as barrier. The bridge deck can be rotated over its horizontal axis so that the bridge can be rotated into the waterway to block this waterway. A strong point of this design is that the largest component of this construction is intertwined in the bridge and barrier function. Due to the double function costs can be reduced. The disadvantage of this construction is the temporary closure of the bridge when de deck is used as barrier (Dijk & van der Ziel).

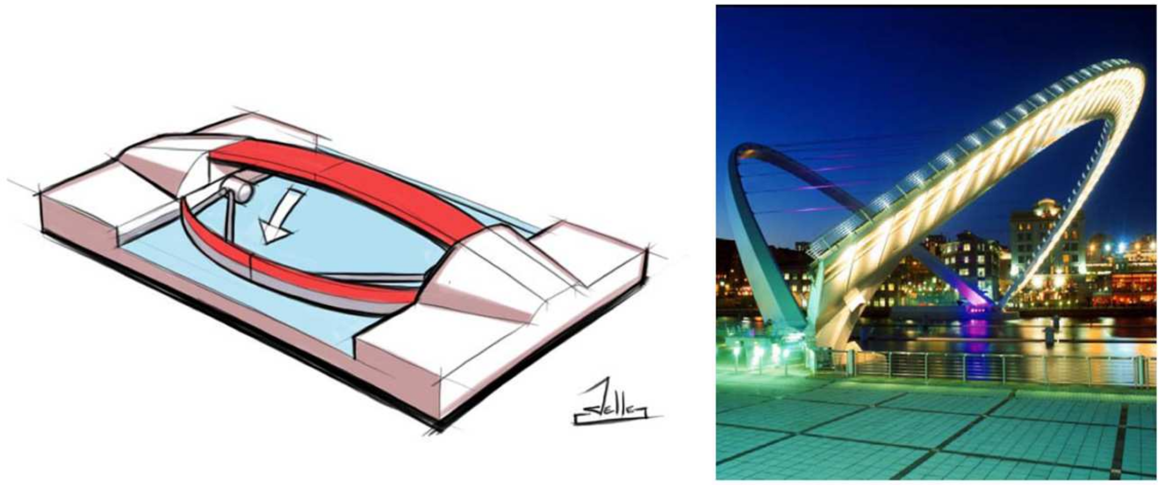


Figure 23 - Left: The principle of a bridge barrier; Right: Millennium bridge in Newcastle (source: Dijk & van der Ziel)

3.3 Elements of a weir

3.3.1 Fixed super structure

The fixed super structure is the basis of the weir. The fixed structure can be an object in itself but can also be part of a water retaining system. Usually the fixed structure is made of concrete but there are also examples of fixed structures made up of bricks, steel or wood. The fixed structure is mostly constructed as a single or multiple U-shapes. The construction consists out of:

- Two abutments
- Pillars
- Floor slab
- Sill beam
- Foundation
- Cut off screens

The main functions of the fixed structure are (de Gijt & van de Toorn, 2012):

- Resist the hydraulic loads on the gates in closed situation
- Resist wind loads in opened situation (especially for lifting gates)
- Carrying and guiding the movable parts of the weir
- To convey external loads, the self weight of the fixed structure and the self weight of the movable parts to the foundation
- Reduction of groundwater flows under and along the structure
- Reduction of the flow velocities of the water to reduce erosion of the bottom behind the weir.

- Prevent wear and tear due to high flow velocities when the gates are removed.

3.3.2 Movable closure elements

The movable closure elements are the parts of the weir which are able to be adjusted to changing conditions. Among the movable closure elements are understood:

- Gates
- Control system

The gates are usually made of steel but also doors out of high strength concrete or FRP are possible. The main function of the closure elements are (de Gijt & van de Toorn, 2012):

- To provide variable discharge opening to control the water discharge
- Resist the resulting hydraulic loads in closed and halve opened condition
- Resist the wind loads in open condition (especially for lifting gates)
- Reduce leakage between the gates and the fixed structure
- Reducing of the flow velocities between the gates and the fixed structure so that erosion of the bottom behind the weir

3.3.3 Bottom protection

The bottom construction is situated in the front, on the back and sometimes along the weir construction. There are different types of bottom protections, there are for example protections made of concrete blocks, stone-asphalt constructions of mattresses. The main function of the bottom protection is:

- Preventing soil erosion of the bottom near the structure so that weir instability is prevented.

3.4 Series of weirs

When the requirements for the canalization of a river cannot met by the use of one weir, more weirs are needed. In this case the weirs are placed in series so that different channel parts are formed. The water level of a channel part is controlled by the downstream weir. The determination of the number and the place of weirs in series is a difficult task. The number of weirs will be determined according to (de Gijt & van de Toorn, 2012):

- The total water head over the waterway
- The maximum water head over a single weir
- The height of the flood protection along the river
- Function of the weir
- Construction costs and costs of adjustment of the flood protection
- Maintenance costs

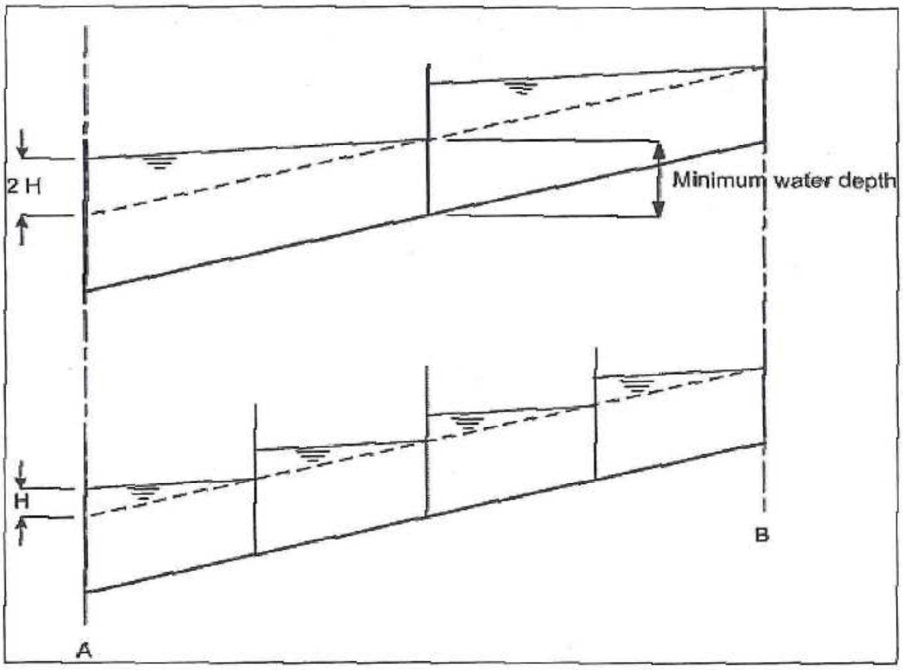


Figure 24 - Weirs in series (source: TU Delft, lecture notes CT5313)

An important aspect of the construction of weirs in series are the locations of the weirs. When searching for a good location the following aspects should be considered:

- The number of weirs
- The layout of the weirs
- The construction methods

3.5 Water level regulation

Water level regulation is often the main priority of weirs. Water level regulation means to dominate water levels of a water way. In the Netherlands the main purpose of water level regulation is usually creating enough draught for shipping. A way to regulate the water level of a river is to canalize the river by means of weirs. The weirs are able to regulate discharges to obtain a certain water level in a channel section. The weirs influence the water level of a river by lowering the gradient in the downstream part of a channel section (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Inleiding Waterbouwkunde, 2009).

The dimensions of a weir will be determined by the required minimum and maximum water levels of a channel section. For higher gdischarges weirs will be lowered which results in less push up of water until the weir gates are removed. In this situation a river in non pushed state arises.
The water level in a channel section depends on the height of the weir and of the discharge which enters the channel section on the upstream side. Because discharges are not constant over a year they will be represented by means of a discharge-duration-line. This line represents the relation between the discharge and the mean number of days a certain discharge is exceeded. By means of a Q -h curve of certain location the water-level-duration-line can be constructed out of the discharge-duration-line. The water-level-duration-line gives the relation between the water level and the mean number of days a certain water level is exceeded. This line is also called the weir program, an example of a weir program is represented in Figure 25 (Bezuyen, Stive, Vaes, Vrijling, & Zitman, Inleiding Waterbouwkunde, 2009).

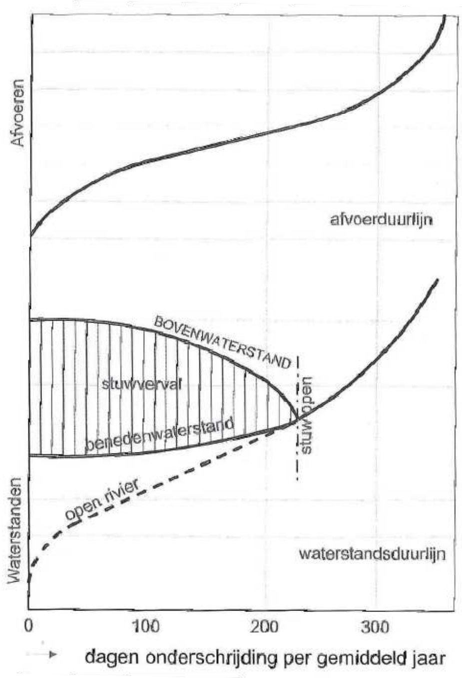


Figure 25 - Weir program (source: TU Delft, lecture notes CT2320)

3.6 Effect of the water level

The effect of an intervention in the water level in a river is noticeable upstream and downstream of the location of the intervention. This effect is called the push up effect. The measure of the distance over which the push up effect is noticeable is called the halve-length. The halve-length is the length over which the maximum water level has halved. The halve-length is represented according to the following expression:

$$L_{1/2} = 0.24 * \frac{h_e}{i_b} * \left(\frac{h_0}{h_e}\right)^{4/3}$$

Where: $L_{1/2}$ halve-length
h_e equilibrium depth
i_b gradient of the river bottom
h_0 water level downstream (boundary condition)

Water depth and discharge are related with each other, a required water level demands a certain discharge and vice versa. This relations is described by the so called Chézy formula, for a rectangular cross section the expression becomes:

$$Q = B * h * C * \sqrt{h * i_b}$$

Where Q = Discharge
B = Width of the cross section
C = Chézy coefficient
h = Local water depth

The water level for a free discharging river will approach the equilibrium depth. The equilibrium water depth for a free discharging river comes out of the Chézy formula. This formula is represented as:

$$h_e = \left(\frac{Q^2}{C^2 * B^2 * i_b}\right)^{1/3}$$

The former motioned push up effect can be approximated according the method of Bresse. The formula for this method is represented as:

$$h(x) = h_e + (h_0 - h_e) * \left(\frac{1}{2}\right)^{\left(\frac{x-x_0}{L_{1/2}}\right)}$$

Where x-x_0 = Lengte van het te beschouwen rivier deel

3.6.1 Shape of the waterline

The shape of the waterline depends inter alia on the Froude number. When the Froude number is lower than 1 a subcritical flow arises and for Froude numbers larger than 1 a supercritical flow arises. A measure for the transition between the subcritical and supercritical flow is the critical water depth. The critical water depth is the water dept which occur during critical flows. This critical flow arises when the Froude number is equal to 1. The critical depth is also motioned as the boundary depth and is represented as:

$$h_g = \left(\frac{Q^2}{B^2 * g}\right)^{\frac{1}{3}}$$

Where: g = gravitational acceleration

The relative bottom slope determinates whether a uniform flow is subcritical or supercritical. In natural waterways in most cases B >> d is valid so that the expression for the Froude number becomes:

$$Fr_e^2 = \frac{i_b}{c_f}$$

As can be seen in the formula above the Froude number also depends on the bottom slope. The subscript e indicates that it is a Froude number for a uniform flow. As already said the value of Fr_e indicates the situation of the flow pattern.

- If $Fr_e^2 < 1$ (approximately $i_b < c_f$) it refers to an mild slope (M-type). The uniform flow which arises for $Fr_e^2 < 1$ is subcritical ($h_e > h_g$).
- If $Fr_e^2 > 1$ (approximately $i_b > c_f$) it refers to an steep slope (S-type). The uniform flow which arises for $Fr_e^2 < 1$ is supercritical ($h_e < h_g$).

There are three types of energy lines recognizable:

- Type 1: if $d > d_e$ and $d > d_g$ so also $i_w < i_b$ and $Fr^2 < 1$. In this way the lines M1 and S1 arise. The dept will monotonically increase in downstream direction until the water level becomes horizontal ($i_w = 0$ en $Fr^2 \approx 0$).
- Type 2: if $d_g < d < d_e$ the lines M2 and S2 will arise.
- Type 3: if $d < d_e$ and $d < d_g$ so also $i_w > i_b$ en $Fr^2 < 1$. In this way the lines M3 and S3 will arise.

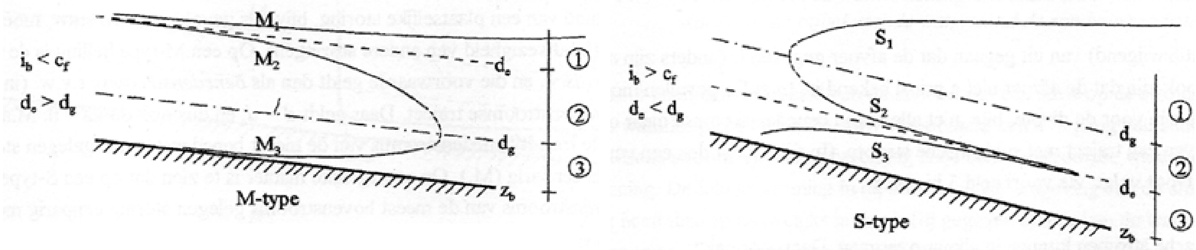


Figure 26 - Different forms of the energy lines (source: TU Delft, lecture notes CT2100)

Besides the M-type and S-type also other type of energy lines can be distinguished:

- The C-type ($i_b = c_f$, Critical slope)
- The H-type ($i_b = 0$, Horizontal slope)
- The A-type ($i_b < 0$, Adverse slope)

For downstream river sections these types of energy lines do not apply. Because in the Netherlands only downstream parts of rivers can be found the C, H, and A types are of minor importance.

Sources: (de Vriend, Havinga, van Prooijen, Visser, & Wang, 2011) en (Battjes, 2002)=

3.7 Sediment transport in channel parts

A weir has a great impact on the morphology of a river. The impact region of a weir in closed state can be divided into three areas:

- Upstream of the weir outside the catchment area of the weir. In this part of the river the flow of the river is free. The discharge in this situation causes a current that drives the sediment transport. The total amount of the sediment transport can be calculated according to the following formula:

$$V_0 = \int_0^{\infty} S(Q) * p(Q) * dQ$$

- Upstream of the weir inside the catchment area of the weir. In part the flow velocity decreases in the direction of the weir because the weir blocks the water flow. The decrease in flow velocity results in sedimentation near the weir.
- Downstream of the weir. The water passes the weir whereby the water drops from a certain height. This causes erosion downstream of the weir. However also sedimentation can occur if it is possible for sediment to pass the weir.

When the weir is opened there will appear erosion upstream of the weir and sedimentation downstream of the weir. In this way the bottom profile formed in closed situation will be compensated like represented in Figure 27. Since a weir is usually a constriction in the waterway, turbulence will appear behind the weir during high discharges. Because of the turbulence scour holes can arise behind the construction of the weir.

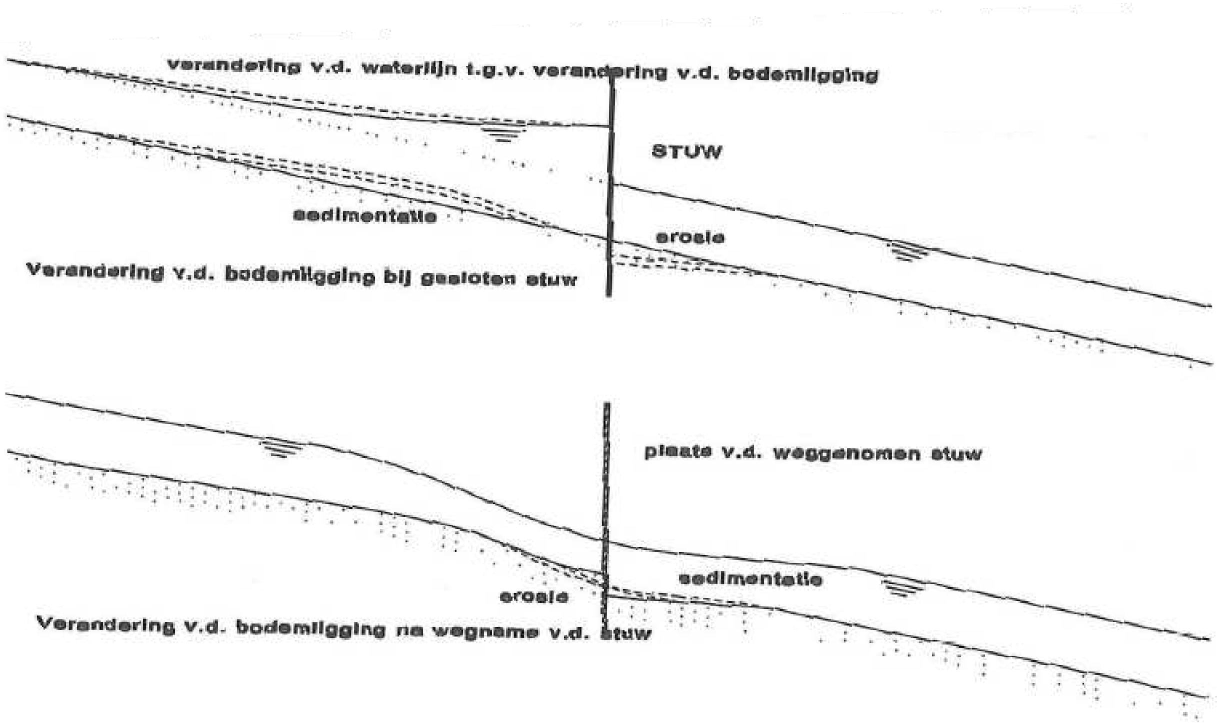


Figure 27 - Sedimentation pattern near a weir (source: TU Delft, lecture notes CT5313)

4 Adaptive Delta Management

4.1 Introduction

In the future circumstances will be different than in the current situation. To be prepared for the future, in the coming decennia measures should be taken which match the long term. The measurements should be able to adapt to obtain a better response to extreme an changing situations. Examples is the Room for the River project or strengthening of coastal areas by stand beach nourishments. In most cases it is difficult and usually not desirable to nail measurements for the coming fifty to hundred years down. Solutions should be able to adapt on new insights and circumstances. On the other hand it is also in these days important to look for new opportunities. After all solutions should be ready by the time they are needed.

Due to climate change the need for better protection against floods becomes necessary. The challenge is increases by disadvantages of delta areas which makes the area vulnerable. Delta areas have to deal with sea level rise, strong river increases during winter, less precipitation in the summer and land subsidence by extraction of groundwater and agriculture.

Because uncertainties are large on the part of climate change and social-economic developments they are hard to predict. So a good and durable solution for the coming hundred years is hardly possible because this will lead to draconian measures and extreme costs. To anticipate on changing conditions like climate change Rijkswaterstaat has developed the Adaptive Delta Management approach. By use of Adaptive Delta Management Rijkswaterstaat tries to responds on changing conditions. The key issues of Adaptive Delta Management are:

- Short term decisions should be connected to long term challenges for flood protection and protection of fresh water

- To install flexibility in solutions
- To work with several strategies so that there can be an switch of strategy

To apply Adaptive Delta Management three steps are required:

1. Analyze what short term developments from other fields influence the policy on the flood protection and the freshwater supply.
2. To obtain an overview of possibilities on flexibility. For example are the solutions able to be implemented one by one and are they be able to be adjusted when the situation changes.
3. To analyze which decisions are needed to be able to use the method of Adaptive Delta Management.

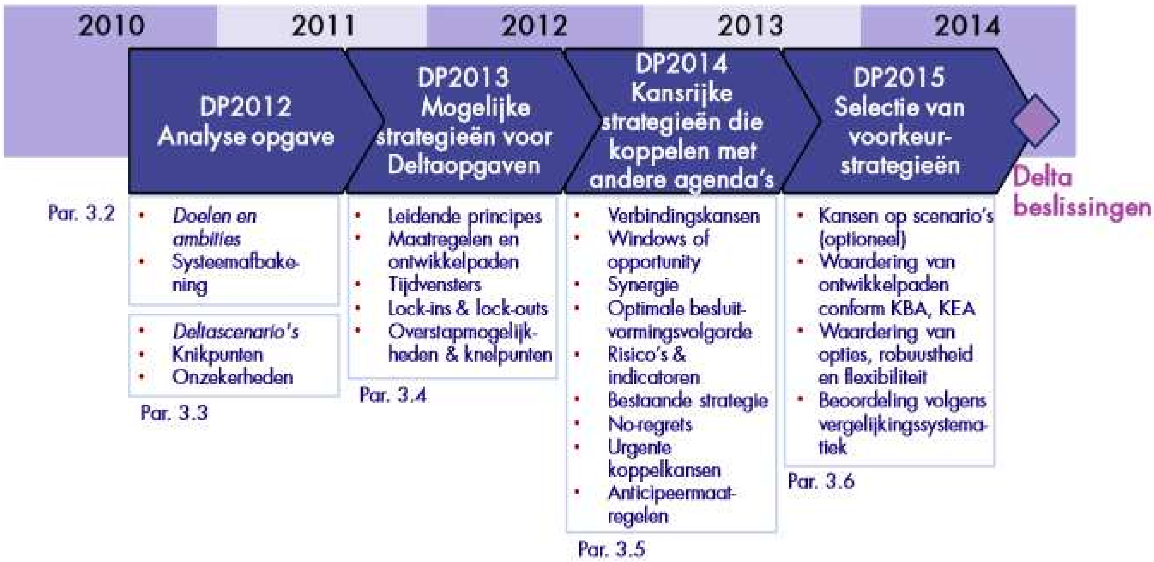


Figure 28 - Steps of Adaptive Delta Management (source: Rijkswaterstaat)

4.2 Example of Adaptive Delta Management

A good example of the approach of Adaptive Delta Management is the VONK project. VONK stands for *Vervangings Opgave Natte Kunstwerken*. In the VONK project is specified on the replacing of locks, weirs and storm surge barriers. These constructions aging not only in terms of wear and tear but also in a more technical sense. In the VONK project Rijkswaterstaat indicated for the next fifty to hundred years which structure have to be replaced and when this has to be done. By connecting the replacement of a hydraulic structure with developments in the Delta program it can be avoided that after a couple of years the structure has to be replaced or adapted to new regulations. The Meuse corridor is also subjected to the VONK project.

Appendix B: Area Analysis

1 Meuse in the Netherlands

1.1 The Meuse

The Meuse is a river in the western part of Europe. The Meuse rises in France about 100 km north of Dijon. Besides France flows the Meuse trough Belgium and the Netherlands where the water flows into the North Sea. The total length of the Meuse from the source to the North Sea is 935 km. The watershed of the Meuse has an area of about 33000 km^2, of this watershed is 10000 km^2 located in France, 13000 km^2 in Belgium, 6000 km^2 in the Netherlands and 4000 km^2 in Germany. However the Meuse does not flow through Germany is a part of the watershed located in Germany. This area contains the watershed of the Meuse tributary the Roer, which is located mainly on German territory. The flow of the Meuse is represented in Figure 29.

The Meuse in France arises on a height of 40 9 m + NAP on the Plateau of Langres. From her flows the Meuse in northerly direction trough a valley in the Plateau of Lotharingen. In this stretch is the width of the Meuse very narrow. The Meuse in France has two important tributaries, the Chiers and the Semois. Via the Ardens Plateau enters the Meuse the Belgian territory. From Sedan is the French part of the Meuse partly navigable for recreational boating and Class I vessels.

The Meuse enters Belgium at a height of 98m +NAP. The Meuse flows in northerly direction to the city of Namur and from there in easterly direction until Liege. At this point Meuse has fallen to a height of 60 m + NAP. After Liege flows the Meuse in norterly direction to the Dutch border. After a small section on Dutch territory forms the Meuse between Borgharen and Maasbracht the natural border between Belgium and the Netherlands. In Belgium is the Meuse totally canalized and suitable for navigation. The canalization is done by means of 12 weirs. From the Belgian-French border is the river suitable for vessels of the IV class and from Namur for vessels of the Va class.

Although the Meuse does not flow trough Germany is a part of the Meuse watershed located in Germany. The Roer, the Niers and the Swalm are Meuse tributaries which discharge their water on the Meuse. The watersheds of these rivers are located in Germany of which the watershed of the Roer is the largest (Breukel, Silva, van Vuuren, Botterweg, & Venema, De Maas - Verleden, heden en toekomst, 1992).

The Meuse enters the Netherlands near Eijsden, the water level of the Meuse has at this location a height of 57.68m +NAP. The river flows across the province of Limburg via Maastricht, Roermond and Venlo to Cuijk. The Meuse acts as natural border in this part of the Meuse. Between Borgharen and Maasbracht as a border between the Netherlands and Belgium and between Maashees to Cuijk as the natural border between the provinces Limburg and North Brabant. At Cuijk the Meuse leaves Limburg and enters the provinces of North Brabant and Gelderland. The Meuse flows via Cuijk via Ravenstein, Maasbommel and 's-Hertogenbosch to Heusden. In this part the river is the natural border between the provinces of North Brabant and Gelderland. From Heusen turns the Meuse into the Bergsche Meuse and flows to Raamsdonksveer. At Raamsdonksveer turns the Bergsche Meuse into the Ammer and flows until Moerdijk. At this point the Ammer confluences with the New Merwede. The New Merwede is a canal which is connected to the Waal and has the purpose to discharges a part of the Waal water. From the confluence the water flows via the Hollands Diep and the Haringvliet to the North Sea. The described trajectory of the whole water flow from Eijsden to the North Sea has a length of about 315 km.

It is important to notice that the part of the Meuse which is called in the Netherlands *"the Meuse"*, is the river part from Eijsden until Heusden. When in this report is spoken about the Meuse, the section between Eijsden and Heusden is meant.

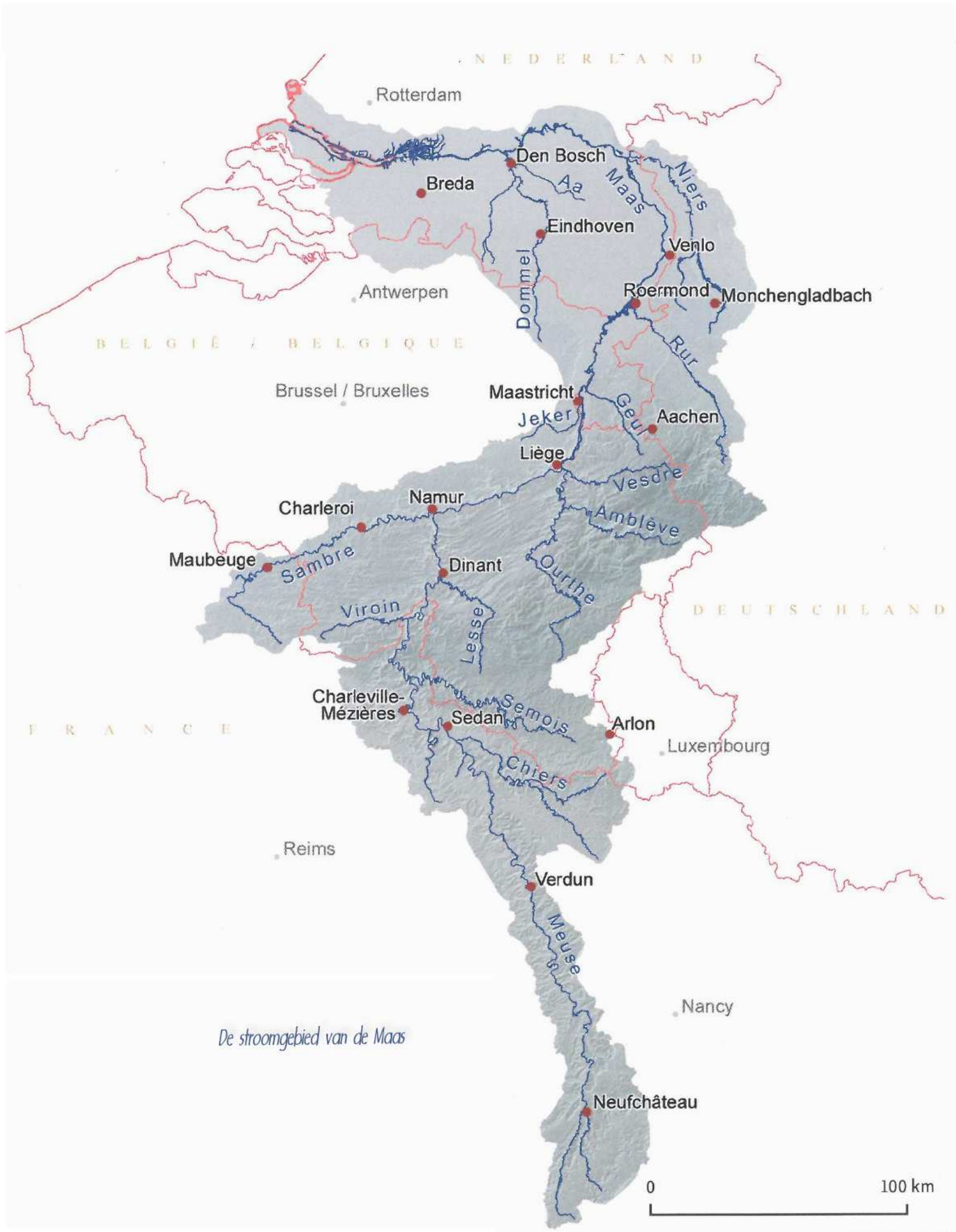


Figure 29 - Flow of the Meuse (source: Maascommissie)

1.2 Meuse in the Netherlands

The Dutch part of the Meuse can be divided in several ways. In this report the river is divided on two levels. The first level divides the Meuse in higher and lower grounds of the Meuse basin. The second level has to do with the geological characteristics of different Meuse sections.

At the first level can the Meuse be divided in an undiked and a diked section:

- Undiked Meuse
- Diked Meuse

The Undiked Meuse is the Meuse section on the higher grounds in the south of the Netherlands. This part is of the river is also called the Meuse Valley because the areas around the river are on a higher level than the river itself. Due to changes between ice ages and warm periods has the Meuse cut itself into the landscape of the province of Limburg. This has resulted in the so called Meuse terraces. In Figure 30 a height card of Limburg is represented, the red areas are the higher grounds and the yellow and green areas the lower grounds. Especially from the Meuse Lakes area to Cuijk is the Undiked Meuse clearly visible.

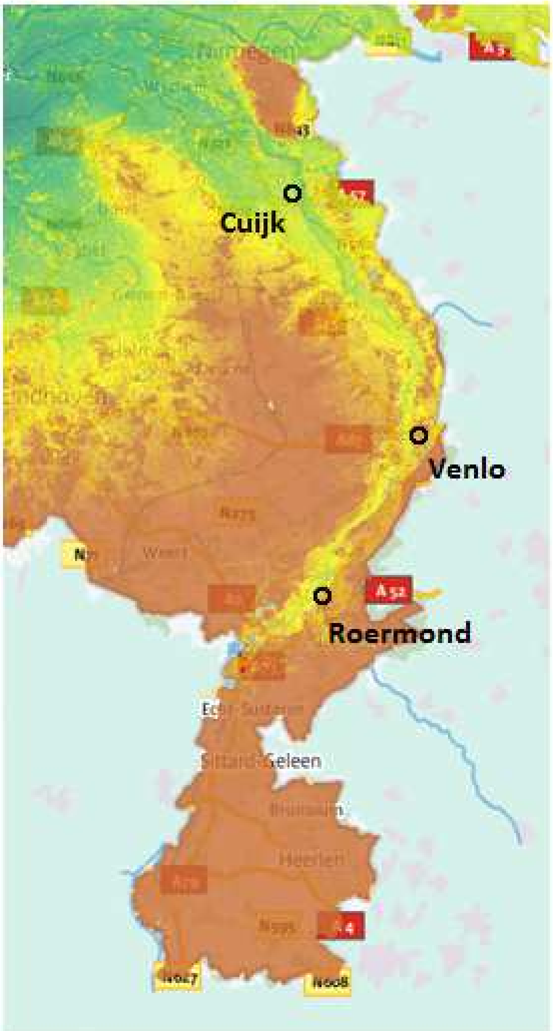


Figure 30 - Height card Undiked Meuse (source: Algemeen Hoogte Bestand)

The Diked Meuse is the Meuse section located on lower grounds. In this section has the Meuse not cut itself into the landscape but, is in comparison with the Undiked Meuse completely enclosed by floodplains and human made dykes.

On the second level are the Undiked Meuse and the Diked Meuse divided in smaller parts. The part are divided by means of their geological character. The Undiked Meuse contains:

- Border Meuse
- Meuse Lakes
- Peelhorster Meuse
- Venloslenk

The Diked Meuse contains:

- Lower Meuse
- Tidal Meuse

In some literature are the Peelhorster Meuse and the Venloslenk mentioned as the Northerly Meuse. However, in this report the partition according to Rijkswaterstaat is used. More information about the different sections can be found in Appendix a
The Upper Meuse is the most steep section of the Meuse in the Netherlands. The height in this part decreases over a length of nearly 18 km from ca. 50m +NAP near Eijsden to ca. 40m +NAP near Borgharen. The areas of the border Meuse and the Meuse Lakes are not as steep as the Upper Meuse. However, compared with lower parts of the Meuse is the fall relatively large, from ca. 40m +NAP near Borgharen to ca. 9m + NAP near Roermond over a length of about 68 km. After Roermond, the slope of the Meuse flattens and so the fall of the river decreases. However, the slope increases a little bit halve away the Venloslenk. The length profile of the Dutch part of the Meuse is represented in Figure 7.

The lower Meuse is the first part of the Meuse outside the province of Limburg. The slope of the Lower Meuse is relatively flat in the beginning but increases a bit in the direction of Lith. This results in a height decrease from ca. 3m +NAP to 2m -NAP near Lith. After Lith starts the Tidal Meuse, in this section are small tide effects noticeable from the North Sea. The slope in this section of the Meuse is very small. More information about the different part can be found in Appendix A

The division of the Meuse in different parts is represented in Table 4. In the table all the sections are measured from Lixhe to the North Sea. Lixhe is the most southern location were the Meuse enters the Netherlands. Also the lengths of the different sections are represented.

Table 4 - Meuse sections

		Name	Beginning	End	Distance From Lixhe [km]	Length [km]
The Meuse	Undiked Meuse	Upper Meuse	Lixhe	Borgharen	17.81	17.81
		Border Meuse	Borgharen	Maasbracht	60.91	43.10
		Meuse Lakes	Maasbracht	Neer	85.29	24.38
		Peelhorster Meuse	Neer	Venlo	107.37	22.08
		Venloslenk	Venlo	Cuijk	161.39	54.02
	Diked Meuse	Lower Meuse	Cuijk	Lith	200.05	40.12
		Tidal Meuse	Lith	Heusden	229.85	29.79
Bergsche Meuse			Heusden	Geertruidenberg	253.76	23.91
Amer			Geertruidenberg	Moerdijk	267.23	13.49
Hollands Diep			Moerdijk	Numansdorp	284.33	17.10
Haringvliet			Numansdorp	North Sea	312.65	28.47

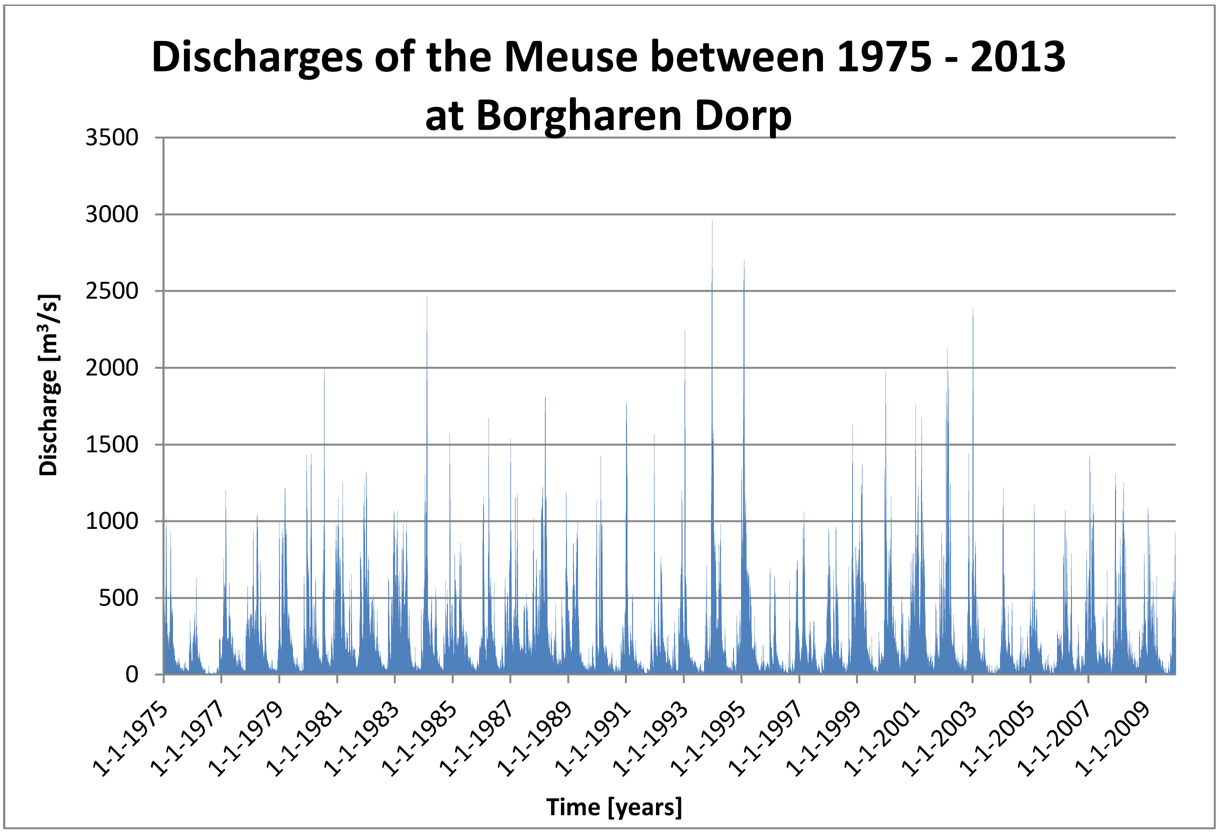
1.3 Discharge

The Meuse is a typical rain-fed- river, this means that the discharge is fed by rain water. The watershed of the Meuse is compared to other rivers in the world very small, the total watershed has a surface of about 36000 km^2. The watershed is located in France (29%) , Belgium (40%), Germany (6%), Luxembourg (1%) and the Netherlands (24%) (Berger & Mugie, 1994). Due to the small watershed it is able that rain will fall over the whole area of the water shed, this can lead to a quick raise of the discharge. However the small watershed can also lead to very low Meuse discharges during dry periods in western Europe. So the discharges of the Meuse can be very high which leads to floods but also very low which leads to drought. The high discharges occur during the winter months (December-March) and the low discharges during the summer months (July-September).The discharge of the Meuse are represented in Table 5.

Table 5 - Meuse discharges

Type	Discharge [m^3/s]
Mean annual discharge	230
Mean high discharge in wet periods	480
Mean low discharge in dry periods	89
Mean annual flood peak	1500
Extreme low discharges	< 18
Extreme high discharges	> 3000
Design discharge (1/1250)	3800

In Graph 1 are the discharges of the Meuse between 1975 and 2013 represented. The floods between 1993 and 1995 are clearly visible by the high peaks. Also the extreme dry year of 1976 are visible. The discharge-water level (Q-h curve) of Borharen Dorp is represented in Figure 31. In the figure are the current and the future Q-h curves represented. The new curve is valid from 2015 when the Grensmaasproject has finished.



Graph 1 - Discharge of the Meuse between 1975 and 2013

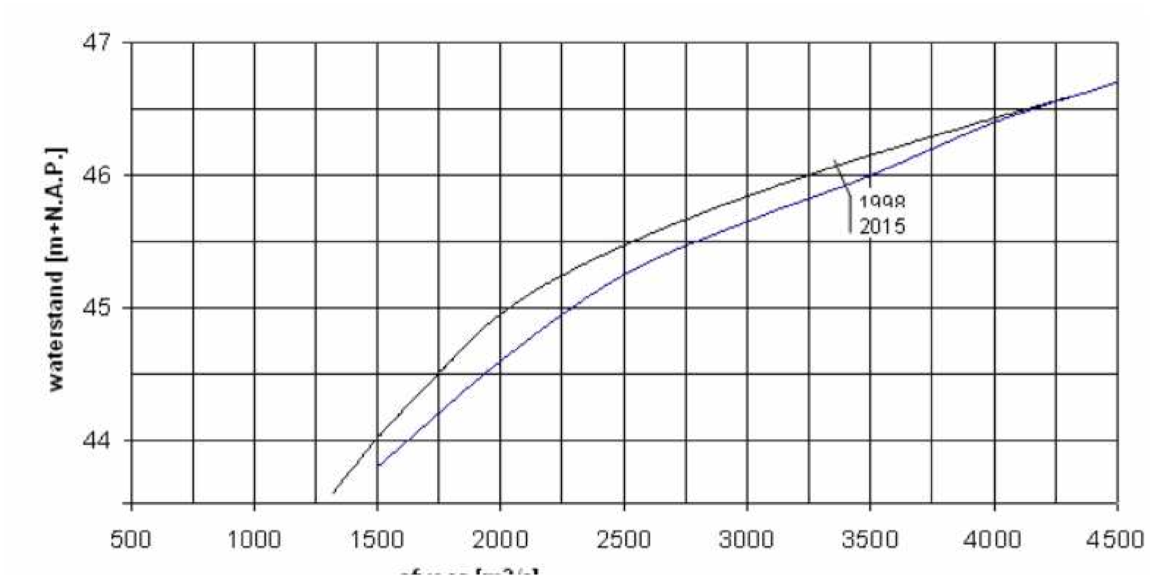


Figure 31 - Q-h curve at Borgharen Dorp ((Barneveld, 2004) & (Ministerie van Verkeer en Waterstaat, Controle Maas 2015, Controle, analyse en een herberekening van de afvoerstatistiek 2015 voor de Maas, 2006)

Discharges of the Meuse were in the past related to the water levels at Borgharen Dorp, this was the reference point for the Meuse discharges. However, due to widening and deepening of several Meuse parts are the measurements of Borgharen Dorp not accurate enough. The reference point is since 2009 displaced to the measure point Maastricht St. Pieter. This was necessary because the interventions on the Meuse have no effect on this measure point. The new location is situated 5 km upstream of the Borgharen Dorp. However there is a new reference point are the measurements of Borgharen Dorp still relevant.

1.3.1 Low discharge

There is spoken of low discharges if the discharge of the Meuse in the Netherlands becomes lower than 30 m^3/s. This is mainly between the months July and September. When discharges become lower the 50 m^3/s near Liège can the normal distribution of water not longer be guaranteed. During low discharge occur water should be saved by the Netherlands as in Belgium as well. The water saving plan which is agreed between the Netherlands and the Flemish Region has three steps:

- The first phase is called the run-up phase. In this phase are the Meuse discharges between 100 m^3/s and 60 m^3/s. In this situation are the Netherlands and Belgium restricted to use a maximum of 25 m^3/s.
- The second phase is the alarm phase. The discharges in this phase are between 60 m^3/s and 30 m^3/s. In this situation will both countries start with evenly balanced saving of water. In this phase the 10 m^3/s to the Border Meuse is still restricted.
- The third phase is the crisis phase. In this phase are the discharges of the Meuse lower than 30 m^3/s. In this phase further savings of water are needed in the Netherlands and Belgium. Also the decrease of the 10 m^3/s to the Border Meuse is allowed. If in one of the countries an emergency situation arises both governments will consult.

The low discharges are mainly problematic upstream the mouth of the Roer near Roermond. There reason is that the reservoir in the Roer near Heimbach always a minimum discharge of 10 m^3/s.
For extreme low discharges is the Meuse not able to fulfill the requirements for:

- Navigation
  There is limited navigation possible on the Meuse and vessels cannot be fully loaded
- Agriculture
  Less water is available for irrigation. In the last years have lots of famers invested in installation to save water and to catch and store rain water.

- Industry
  Industry cannot use Meuse water to cool the installations, the cooling tower have to be used.
- Ecological environment of the Border Meuse
  The ecology of the Border Meuse needs water, in short periods of drought there will be no problems but for longer periods the ecology will be affected.
- Water quality
  The nickel concentration increased due to limited dilution and the oxygen concentrations decease due to a combination of high water temperatures and low discharges. The first influences the water quality for drink water purposes and the second influences fish population of the Meuse.

1.3.2 High discharge

High discharges occur during periods of much precipitation on the watershed. There is spoke about high discharges as the boundary of 1450 m^3/s at measure point Maastricht St. Pieter (formerly Borgharen Dorp) is exceeded. The discharge of 1450 m^3/s is reached by a discharge of 45.55 m +NAP at measure point Maastricht St. Pieter (44.00 m +NAP at Borgharen Dorp)

The side rivers in the Ardennes react quickly on the precipitation so that the water levels in the Ardennes raise very fast. Not every storm in the Ardennes is noticeable in the Netherlands. For high discharges is, depending on the type of precipitation at least 30 to 40 mm per square meter necessary during a couple of days. A couple of days are necessary to saturate the bottom in the Ardennes hereafter a quick rise of the Meuse water levels and a flood wave can occur. The floods can become severe when the high discharges of side streams and tributaries coincide with high water levels on the Meuse. The streams and tributaries cannot discharge the water so more inland regions will flood (Berger & Mugie, 1994).

The flood wave arise in the Ardennes. Because the Ardennes are not far from the Netherlands will a flood wave reach the Netherlands in a day and the North Sea in two days. However, when the floodplains are not saturated a flood wave needs about five days to reach the North Sea. The discharge times until the Dutch border are represented in Figure 32 (Rijkswaterstaat, Hoogwater op Rijn en Maas, 2007).

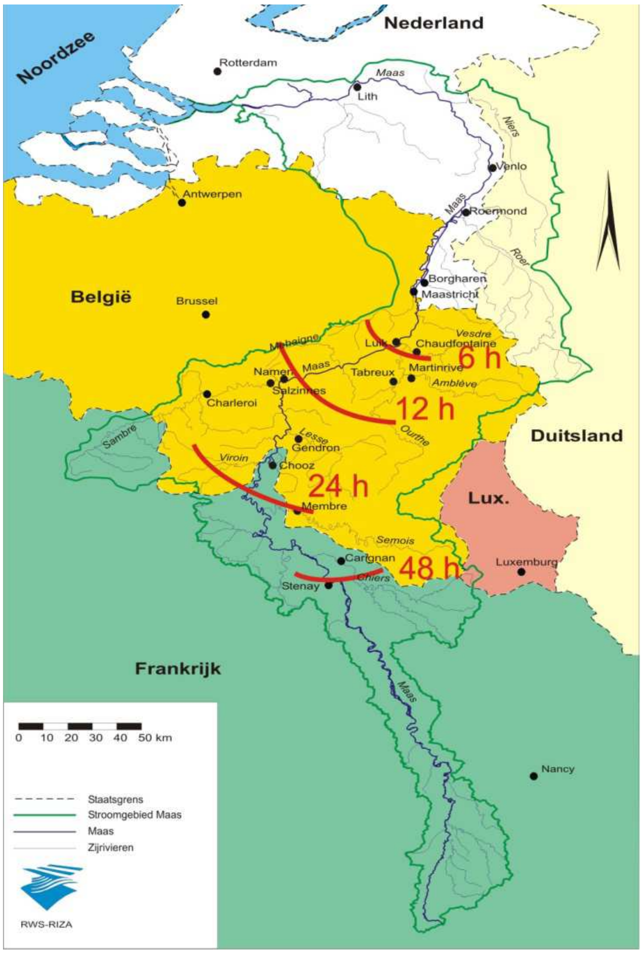


Figure 32 - Discharge times until the border (Rijkswaterstaat)

1.4 Side rivers

The water in of the Meuse is not only the water which enters the Dutch territory near Eijsden, the Meuse is also fed by water from stream, tributaries and drainage canals. The streams can be divided into three types:

- Hill streams (green area)
- Terrace streams (orange area)
- Low land streams (yellow area)

Figure 33 - Different areas of streams in Limburg (van den Brink, 2002)

The hill streams can be found in the South of Limburg and are fed by springs in the hilly terrain of Belgium, Germany and South Limburg. The most important hill streams are:

- The Voer
- The Jeker
- The Geul

The terrace streams can be found in the northern area of the Meuse Lakes and in areas of the Peelhorster Meuse and Venloslenk, this area is also known as the Meuse terraces. The steams are meanly located on the east side of the Meuse terraces. Because the transitions between different Meuse terraces are very abrupt become the flow velocity relatively high. The streams are fed by springs on the terrace edges. The most important terrace streams are:

- The Swalm

The low land streams are mainly located on the west side of the Meuse in the provinces of North Brabant and Limburg. These streams are not fed by springs but by groundwater. The most important low land streams are (van den Brink, 2002):

- The Groote Molenbeek
- The Graafse Raam

The tributaries along the Meuse have a higher discharge than the streams and the lengths of the waterways are larger. The main tributaries are:

- The Roer
- The Niers
- The Dieze

According to Table 6 is the length of the Dieze much smaller than the other tributaries. The the reason of this is that the last part of the Dommel is called the Dieze. The Dommel itself has a length of 120 km. The Roer has its largest watershed in Germany. In Germany is near Heimbach a dam constructed in the Roer. The purpose of the dam is to generate hydro power, the advantage of the dam is that also during dry periods the Roer has a discharge of at least 10 m^3/s (van den Brink, 2002).

The drainage channels can be mainly found in the Lower Meuse and the Tidal Meuse. The canals discharge water coming from the polders along the lower parts of the Meuse. The discharge capacities of these canals are dependent on the rainfall in the area and the polder management. For that reason are the discharges hard to determine, however the discharges are very small compared to the tributaries and streams so not taken into account in this report.

The discharges and the share of the Meuse discharge of the different tributaries are represented in Table 6. In this table are only the most important tributaries and streams presented which are directly connected with the Meuse. Also the distance from Lixhe are represented.

Table 6 - Most important tributaries and streams along the Meuse (Vermulst, 2002)

Name	Place	Mean discharge [m^3/s]	Distance from Lixhe [km]	Length [km]	Share of Meuse discharge
Voer	Eijsden	0.28	2.12	12	<1%
Jeker	Maastricht	1.5 - 2.0	9.90	60	<1%
Geul	Voulwames	0.8 - 3.5	20.13	58	1%
Roer	Roermond	23	77.82	165	6%
Swalm	Swalmen	1.8	84.24	45	<1%
Groote Molenbeek	Wanssum	1.5	127.22	33	<1%
Niers	Gennep	7.5	151.78	114	2%
Graafse Raam	Grave	0.5 -2.6	176.43	30	1%
Dieze	Den Bosch	25	220.90	5	6%

1.5 Water levels

Water level are determined for different discharges and represented in so called 'reference lines' (Dutch: betrekkingslijn 1991.0). The reference lines are representations of water levels of waterways. The water levels have been determined for different discharges including water levels for exceedance frequencies, average yearly discharges and average winter and summer discharges. Reference lines have been produced for the Meuse on several locations. In Table 8 the locations near the weirs of Linne, Roermond, Belfeld, Sambeek, Grave and Lith are represented. The water levels near near Borgharen are chosen at Borgharen Dorp and the Juliana Canal. The water levels downstream of Lith are not represented because downstream Lith are the water levels not only determined by the Meuse discharge but also by the tides at the North Sea. The water levels downstream of Lith are represented in Table 7.

In the time between the publishing of the reference lines and the current situation is the exceedance frequency of 1/1250 adjusted. For this reason are in Table 8 two different water levels represented.

The first is the water level for the old discharge as motioned according to the document 'betrekkingslijn 1991.0'. The second represents the adjusted design discharge according to the last Delta report.

Table 7 - Water levels downstream of Lith

Discharge Lith	Water level + NAP					
	Average tide		Spring Tide		Neap tide	
	High water	Low Water	High water	Low Water	High Water	Low Water
[m^3/s]	[cm]					
0	47	7	54	13	51	12
35	57	18	64	24	60	22
100	65	31	72	37	67	34
320	84	68	91	74	86	70
670	135	124	138	126	138	127
1100	230	222	231	223	232	224
1450	Nearly no influence of the tide					
2250						

Table 8 - Water levels at different exceedance frequencies (Rijkswaterstaat, Referentie waterstanden, 2012)

Exceedance frequencies	Discharge Borgharen Dorp	Water level + NAP													
		Borgharen		Linne		Roermond		Belfeld		Sambeek		Grave		Lith	
		Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	[m³/s]	[m]													
Highest known discharge	3039	46.40	45.90	22.80	21.30	20.90	20.50	19.30	19.00	13.90	1370	10.50	10.40	6.55	
1/1250 old	3650	46.40	46.30	23.25	22.15	21.80	21.50	20.10	19.90	14.50	14.30	11.65	11.50	8.00	
1/1250 new	3800														
1/100	2800	46.15	45.65	22.60	20.85	20.25	20.00	18.75	18.50	13.60	13.40	10.20	10.00	6.30	
1/10	2000	45.55	45.05	22.00	19.95	19.20	18.80	17.70	17.40	12.85	12.55	9.45	9.10	5.50	
1/2	1450	44.55	44.05	21.30	19.05	18.20	17.60	16.35	15.95	11.85	11.55	8.40	8.10		
1/1	1200	44.15	43.40	21.00	18.60	17.10	16.95	15.60	15.30	11.40	11.00	8.00	7.60		
Average yearly discharge	230	44.00	39.55	20.85	16.90	16.80	14.30	14.05	11.60	10.80	8.00	7.60	5.20	4.90	
Average summer discharge (September)	89	43.95	38.65	20.85	16.90	16.80	14.10	14.05	11.05	10.80	7.75	7.60	5.00	4.90	
Lowest known discharge	0	43.90	37.40	20.85	16.90	16.80	14.05	14.05	10.90	10.80	7.65	7.60	4.90	4.90	

1.6 Water distribution

Water is extracted of discharged on the Meuse. The canals, industry or drink water companies extract and discharge on the Meuse. In Belgium should 20 m^3/s be transported to the Albert Canal of which nearly 10 m^3/s is coming back into the Meuse near Maastricht. In the Netherlands is the distribtion over the different waterways (Berger & Mugie, 1994) & (Breukel, Silva, van Vuuren, Botterweg, & Venema, De Maas - Verleden, heden en toekomst, 1992):

- A discharge of 14-16 m^3/s is transported to the Zuid-Willemsvaart with a minimum of 10 m^3/s according to the Tractate of 1863. Of this discharge a minimum of 2 m^3/s is destined for the Dutch part of the Zuid-Willemsvaart and a minimum of 8 m^3/s for the Kempsche Canals in Belgium.
- To maintain the water levels of the Juliana Canal is 16 m^3/s of the Meuse discharges needed for the canal.
- For navigational purposes has 8-7 m^3/s to pass the lock of Heel.
- A discharge of a maximum of 6 m^3/s is going to the Canal Wessem Nederweert by the pumping station of Panheel.
- A minimal discharge of 10 m^3/s is needed for the Border Meuse.

The water of the Border Meuse and the Juliana Canal comes again together at Maasbracht. The destitution is visualized in Figure 34. The discharge of 10 m^3/s to the Border Meuse is a restriction what has been agreed in 1995 by the Dutch government and the Flemish Region (Wet- en regelgeving, 1995). During high discharges will the discharge over the canals will not change because the slope of the canal bottoms is just a few centimeters so he canals are not able to discharge large amounts of water. The discharge of the Border Meuse will increase strongly during high discharges because the Border Meuse has a steep slope, so a lot of water can be discharged.

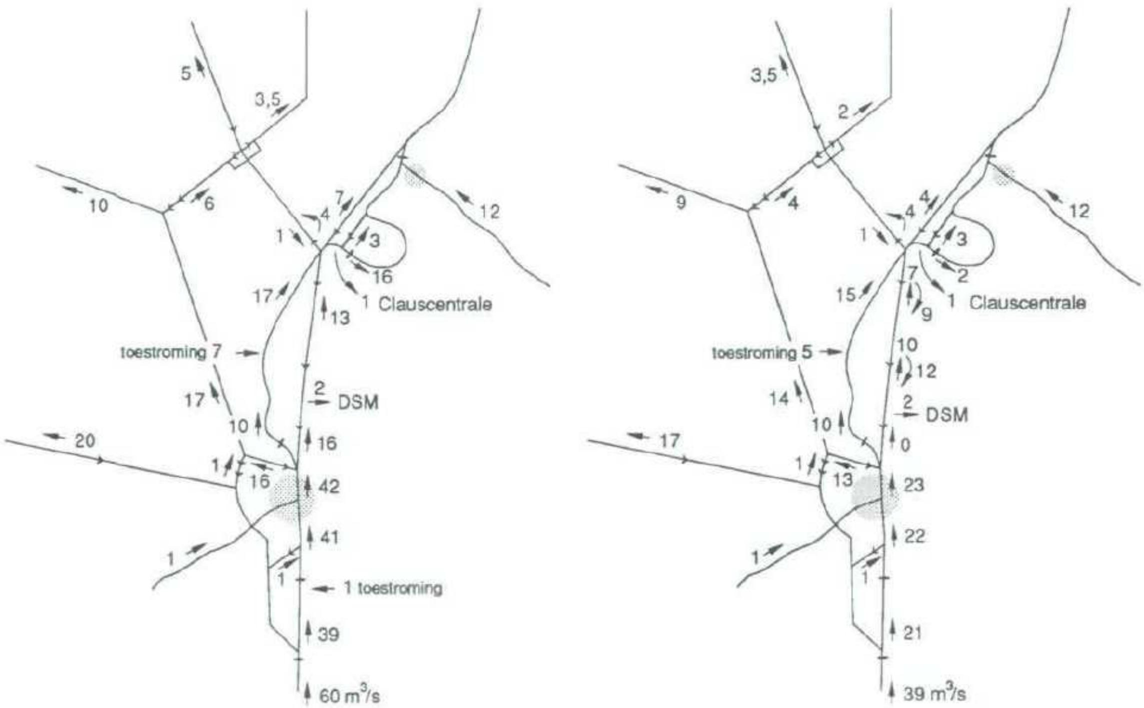


Figure 34 - Discharge distribution; left: situation without discharge shortage; right: situation with low discharge (Breukel, Silva, van Vuuren, Botterweg, & Venema, De Maas - Verleden, heden en toekomst, 1992)

Besides the Canals along the Meuse are there also other sources which extract or discharge water from or to the Meuse (Berger & Mugie, 1994).

- Along the Meuse are factories and power plants which use water from the Meuse as cooling water. After cooling the water is discharged back to the Meuse. The temperature of this water has a higher temperature than the original Meuse water which results in more evaporation, so a decrease of the discharge. Together with factories and power plants in France and Belgium is the evaporation about 1 m^3/s. The main warm water dischargers along the Dutch Meuse are the Clauscentrale near Maasbracht and the Maascentrale near Buggenum. The power plants have to use the cooling towers during low discharges.
- The DSM factories of Sittard and Geleen extract approximately 1.5 - 2 m^3/s from the Juliana Canal downstream of Bunde. Approximately 75% of this water is discharged back to the Border Meuse. These number are of the year 1981, it was expected that the extracted discharges will be doubled in the future.
- Near Roosteren and Heel are water treatment installations which use Meuse water to produce drinking water. The drink water plants extract 1 m^3/s to 2 m^3/s from the Meuse.

1.7 Canalized Meuse

The largest part of the Meuse is canalized by weirs. The weirs are not only located in the Netherlands but also in France and Belgium. The main reason is to increase the navigational depth of the river. The weirs are also important for stockpiling of water, to feed side canals, recreation and to supply water for the industry or energy generation. In the Netherlands is the Meuse canalized from Eijsden, where the Meuse enters the Netherlands to Lith from where the Meuse is a free discharging river.

In the Dutch part of the Meuse is divided in 9 navigational canal sections (Dutch: stuwpanden), 7 are controlled by weirs and 2 by navigation locks. The weirs are located near Borgharen, Linne, Roermond, Belfeld, Sambeek, Grave and Lith. The controlling locks are located in the Juliana Canal near Born and Maasbracht. The weirs and locks are located on the downstream side of the canal sections. In is a cross section of the canalized Meuse represented. In this figure are also the locations of the weirs are presented.

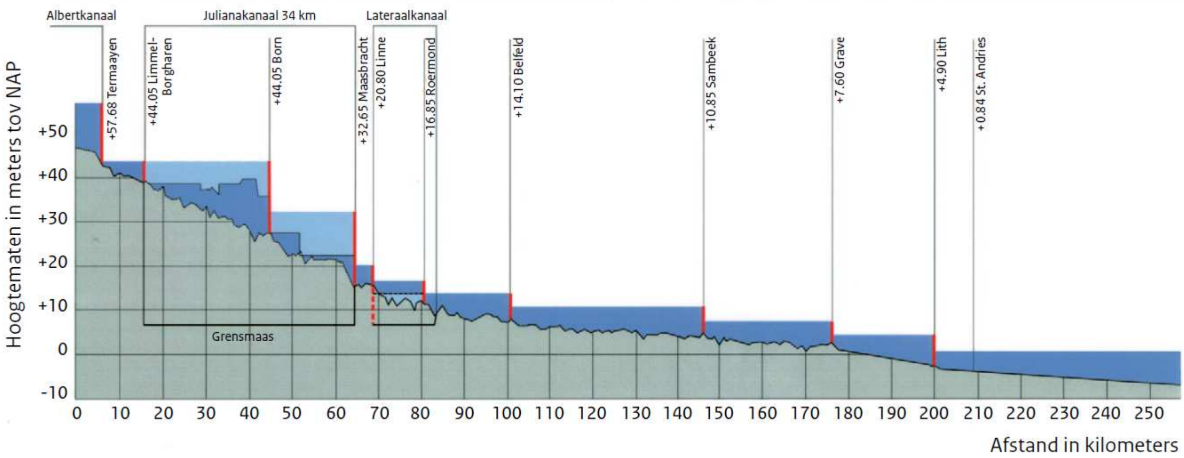


Figure 35 - Profile of the Meuse (Rijkswaterstaat)

1.8 Weirs

In the Dutch part of the Meuse are 7 weirs located, in Table 9 are the target water levels and the distance from Lixhe represented. The Target water levels for the canal sections of Sambeek and Grave differ from the water levels in Figure 35. Since 1997 is Rijkswaterstaat working on the project the Maaswerken. One of the targets of the project is to make the Meuse suitable for vessels of the

Vb class. In the canal sections of Sambeek and Grave is for this purpose the water level increased by changing the target water levels. In 2015 should the Meuse be ready for class Vb vessels.

Table 9 - Weirs of the Meuse

Place	Distance From Lixhe [km]	Target water level + NAP	Year of construction
Borgharen	16	44.05	1928
Linne	68	20.80	1921
Roermond	81	16.85	1921
Belfeld	101	14.10	1924
Sambeek	146	11.10	1925
Grave	176	8.10	1926
Lith	200	4.90	1936

There is a certain relation between the type of weir and the year of construction. The weirs which are built before 1926 contain a Poiree part which is an old fashioned type of weir. The weirs build after 1928 are of a more modern type. More information about the different weirs in the Meuse can be found in Appendix A.

The weir management contains measurements that are needed to control the water levels and discharges. It is tried to retain a certain water level on the upstream side of the weir, this water level is called the target water level (Dutch: streefpeil). For most of the weirs of the Meuse is the target water level not constant but a function of the discharge. In the Dutch part of the Meuse are the target water levels of all canal sections kept constant by the upstream side of the weirs. The only canals section for which this is not case is the canal section that is regulated by the weir of Grave. For this canal section is the water level on the entrance of the Meuse-Waal Canal governing. To avoid problems for the weir master (Dutch: stuwmeester) of a downstream connected canal section should the weir master try to change as little as possible to keep the discharge continues. For accurate discharge management does a weir master not only use data from up and downstream canal sections but also the discharge data of measuring stations, weather forecasts and discharge data of tributaries of the Meuse.

Because navigation has a high priority on the Meuse is it important to retain this function also during periods of low discharges. During periods of low discharges measurements can be taken at the weirs and locks to save water.

- When low discharges are expected can the buffer capacity of the canal sections be raised by increasing the water levels of the canal sections.
- The Poirée parts of the weirs in the Netherlands have a leakage of about 30 m^3/s. This leakage varies strongly fluctuates in time. The most problematic weir is the weir of Linne, to decrease the leakage are rubber seals used. The leakages of the weirs of Linne, Roermond, Belfeld and Sambeek could be decreased by sealing the Poirée parts by sheets of cotton waste. In this way the leakage can be decreased to 2 m^3/s. At the weir of Grave are wooden beams placed between the partitions of the Poirée system. The leakage of the weirs of Borgharen and Lith are small, no measurements are needed.
- The discharge via the navigation locks can be limited by only rising the lock when it is completely filled with vessels. It is also possible when two lock chambers are present to pump the water from the one to the other lock or to the upstream side of the lock, in this way the leakage can be decreased with 40%.

1.9 Waterway Dimensions

The dimensions of the river are not constant along the Meuse. The gradient of the bottom slope becomes smaller when the river approaches the Lower and Tidal Meuse. The Meuse has in the Belgian and French part of the river a relative steep slope. In the Netherlands the slop of the river becomes smaller. This can be seen in gradient of the bottom slope, after the Meuse has left the hilly terrain of southern Limburg the gradient decreases. The decrease of the gradients results in a decrease of the flow velocities in the downstream part of the Meuse. These low flow velocities result in a wider river downstream as represented in
Table 2 (Semmekrot & Vries, 1992).

Table 10 - With and gradient per section

Section	Mean Width [m]	Bottom gradient [‰]
Lixhe (België) - Borgharen	120	0.34
Borharen - Born	100	0
Born - Maasbracht	100	0
Maasbracht - Linne	120	0.3
Borharen - Linne (Borde Meuse)	120	0.3
Linne - Roermond	120	0.15
Roermond - Belfeld	140	0.08
Belfeld - Sambeek	140	0.10
Sambeek - Grave	160	0.12
Grave - Lith	160	0.10

1.10 Locks

The transition of vessels between to canal sections is done by navigation locks. The locks transport the vessels from the water level on the upstream side to the water level on the downstream side and vice versa by means of an vertical displacement. The transitions between the different canal sections are represented in Table 11. In Table 12 are the lock dimensions and the governing vessel class represented. The classes between the brackets is the governing class from 2015. The locks with a star behind their names are the locks which are used by vessels who use the Meuse route.

The locks of Born and Maasbracht fulfill an important role. These locks do not only transport vessels between two canal section but are also manage the target water levels of their canal sections.

Table 11 - Locks between canal sections

Transition	Lock	Waterway
Borgharen - Born	Guard Lock of Limmel	Juliana Canal
Born - Maasbracht	Lock complex of Born	Juliana Canal
Maasbracht - Linne	Lock complex of Maasbracht	Juliana Canal
Linne - Roermond	Lock of Linne	Meuse
Roermond - Belfeld	Lock of Roermond	Meuse
Linne - Belfeld	Lock of Heel	Lateral Canal
Belfeld - Sambeek	Lock of Belfeld	Meuse
Sambeek - Grave	Lock of Sambeek	Meuse
Grave - Lith	Lock of Grave	Meuse
Lith -	Prinses Maximasluizen	Meuse

Table 12 - Details of the Meuse locks

Locks in the Meuse						
Structure	Distance from Lixhe	Length	Width	Sill height +NAP	Height difference	Class
	[km]	[m]				
Guard Lock of Limmel*	13.98	136.00	16.00	39.05	0	Va (Vb)
Lock complex of Born*	41.29	225.00	16.00	27.65	11.40	Va (Vb)
Lock complex of Maasbracht*	61.48	142.00	16.00	16.70	11.85	Va (Vb)
Lock of Heel*	70.19	150.00	12.60	11.45	6.70	Va (Vb)
Lock of Linne	70.19	267.80	14	11.85	2.75	Va
Lock of Roermond	79.46	266.50	14	11.75	2.75	Va
Lock of Belfeld*	101	260	14	6.75	3.00	Va (Vb)
Lock of Sambeek*	146	260	14	3.50	3.00	Va (Vb)
Lock of Grave	176	142	16	1.90	3.20	Va (Vb)
Prinses Maximasluizen	200	200	180	-4.00	Variable	Va (Vb)

To enter the canals connected to the Meuse vessels have also to use locks. The locks of Heumen and Macharen are only operational during very low or high waters, in a normal situation are these lock open so that vessels can pass without using the lock. The locks to the connecting canals are represented inTable 13.

Table 13 - Locks to connecting waterways (Rijkswaterstaat, Vaarwegen in Nederland, 2013)

Locks to additional canals							
Structure	Distance from Lixhe	Length	Width	Sill height +NAP	Height difference	Class	Waterway
	[km]	[m]					
Lock Boschpoort	12.56	127.80	14.00		3.80	II	Zuid-Willemsvaart
Lock Panheel	65.18	150.00	12.60	18.15	7.85	II	Canal Wessem Nederweerd
Guard Lock Heumen*	161.39	270	16	2.80	0	Vb	Meuse- Waal Canal
Lock Macharen	193.43	90	13.50	0.05	0	Va	Burgemeester Delen Canal
Lock Sint Andries	209.23	110	14	-2.00	Variable	Va	Canal of Sint Andries
Henriëtte Lock	220.9	92	13	-2.20	Variable	IV	Canal Henriëttewaard-Engelen

1.11 CEMT Classes

Waterways in Europe are divided in classes, the CEMT classes. CEMT stands for *Conférence Européenne des Ministres de Transport* and is the organization who determined the class system. The classes are represented in Table 15.

Table 14 - CEMT Classes (Rijkswaterstaat, Waterway Guidelines 2011, 2011)

Class	Name	Length	Width	draught	Clearance
		[m]			
I	Péniche Barge	38.50	5.05	1.80 - 2.20	4.00
II	Euro Barge	50 - 55	6.60	2.50	4.00 - 5.00
III	Gustav Koenigs	67 - 80	8.20	2.5	4.00 - 5.00
IV	Johan Welker	80 - 85	8.20	2.50	5.25 - 7.00
Va	Large Rhine Vessels	95 - 110	11.40	2.50 - 2.80	5.25 - 7.00
Vb	1x2 convoy	172 - 185	11.40	2.50 - 4.50	9.10
VIa	2x1 convoy	95 - 110	22.80	2.50 - 4.50	9.10
VIb	2x2 convoy	185 - 195	22.80	2.50 -4.50	9.10
VIc	2x3 convoy	270 - 280	22.80	2.50 - 4.50	9.10
	3x2 convoy	193 - 200	33.00 - 34.20	2.50 - 4.50	9.10
VII	3x3 convoy	285	33.33 - 34.20	2.50 - 4.50	9.10

1.12 Canals

There are eight main channels connected with the Meuse, this are the Zuid-Willemsvaart, the Juliana Canal, the Canal Wessem Nederweert, the Lateral Canal, the Meuse-Waal Canal, the Burgemeester Delen Canal, the Canal of Sint Andries and the Canal Henriëttewaard-Engelen

- The Zuid-Willemsvaart is a lateral canal between Maastricht and 's Hertogenbosch and is one of the seven Kempische kanalen between the Meuse and the Schelde. Just after Maastricht enters the Zuid-Willemsvaart Belgium and near Weert again the Netherlands. The canal has a length of 123 km and has a total height difference of 40 m. To bridge this height 21 sluices have been built in the canal. Just after Maastricht is the normal water level of the canal is 40.30m +NAP. The depth of the Zuid-Willemsvaart varies from 1.90 m at Maastricht to 2.70 m near 's Hertogenbosch. Due to varying depth different types of vessels can use the canal, from class II near Maastricht to class IV near 's Hertogenbosch (Rijkswaterstaat, Vaarwegenoverzicht - Zuid-Willemsvaart).

- The Juliana Canal is a lateral canal between Borgharen and Maasbracht. The Juliana Canal is parallel to the Border Meuse. The canal was constructed when no agreement could be reached with Belgium about canalization of the Border Meuse, so was decided to make the Juliana Canal to obtain a good transport route between the south of Limburg and the western part of the Netherlands. The canal has a length of 35 km. Because the Border Meuse bridges a height of more than 23 m two sluices have been constructed, one near Born and one near Maasbracht. The two sluiced divide the Juliana Canal in two parts, until the sluice of Born has the normal water level a height of 44.05m +NAP and until the sluice of Maasbracht a height of 32.65m +NAP. The canal has a maximum depth of 5.5 m. In the current state is the canal suitable for class Va vessels, however, in the year 2017 the Juliana Canal should be suitable for vessels of the Vb class (Rijkswaterstaat, Vaarwegenoverzicht - Julianakanaal).

- The Canal Wessem Nederweert is a 17 km long canal between Wessem and Nederweert. The canal connects the Meuse near Wessem with the Zuid-Willemsvaart and the Noordervaart near Mederweert. Vessels have to use the sluice of Panheel to enter the canal which has a normal water level of 28.65 m +NAP. This canal is important connection for recreational boating between the inland canals of Noord Brabant and the recreational area of the Meuse Lakes. The depth of the canal varies between 2.5 m and 2.7 m so class II vessels are able to use this canal (Rijkswaterstaat, Vaarwegenoverzicht - Kanaal Wessem-Nederweert).

- The Lateral Canal is a 8 km long lateral canal which is located between Linne and Buggenum. The canal offers a shorter way in the Meuse Lakes area because the he strong meandering character of the Meuse is avoided. A second advantage of this canal is the passages of just one sluice instead of two. The sluices of Linne and Roermond are avoided, the only sluice which have to be passed is the sluice near Heel in the Lateral Canal. The normal water level in the canal is 14.00m + NAP and the canal has a depth of 4.50 m. Class Va vessels are able to use the canal but in the nearby future vessels of the class Vb should be able to use the Lateral Canal as part of the project the Maaswerken.

- The Meuse-Waal Canal is located between Heumen, which is situated on the Meuse and Weurt which is situated on the Waal. So the canal connects the Meuse with the Waal and offers in this way a shorter route to Germany. Before the canal was opened, the route from Heumen and Weurt was more than 100km longer than in the present situation. The canal has a length of 13.3 km and contains two sluices, one near Heumen and one near Weurt. In most case is the sluice of Heumen open, when the water level becomes higher than 8.30m +NAP is the sluice closed and can ships use the sluice. The normal water level of the canal is 7.60m +NAP. Because in normal situation is the sluice of Heumen opened so the water level of the canal becomes the same as the canal section influenced by the weir of Grave (ANWB, Wateralmanak - Vaargegevens, 2007). The maximum depth is 4.90m so the canal is suitable for vessels of the Vb class.

- The Burgemeester Delen Canal is a 5 km long canal which connects Oss with the Meuse. The canal is made to obtain a better connection to the Meuse for the industry of Oss. The canal is separated of the Meuse by a sluice, however most of the time is the sluice open. When the water level becomes higher than 5.50m +NAP is the sluice closed and should ships use the sluice (ANWB, Wateralmanak - Vaargegevens, 2007). The normal water level of the canal is 4.90m +NAP. The canal is suitable for vessels of the Va class.

- The Canal of Sint Andries is a 2.13 km long canal which connects the Meuse and the Waal. The canal is located near Rossum and contains one sluice. The sluice is crossing the road N322 which goes from Niewendijk to Ewijk. The normal water level of the canal is influenced by the water level on the Meuse. Because the canal is downstream Lith is the water level influenced by the tide at the North Sea. In normal situations should the normal water level be around 0.50m +NAP. The canal is suitable for vessels of the Va class (Rijkswaterstaat, Vaarwegenoverzicht - Kanaal van Sint Andries).

- The Canal Henriëttewaard-Engelen or also called the Dieze Canal is a canal in 's Hertogenbosch on the north side of Engelen. The canal is made to obtain a good navigational connection between the Meuse and the Dieze. This connection is needed to reach the harbors of 's Hertogenbosch In the canal is one sluice situated on the north side of Engelen. The normal water level of the canal is 2.25m +NAP. The canal is suitable for vessels of the IV class.

In Table 15 below are the canals and their specifications represented.

Name	CEMT class	Length [m]	Width [m]	Loaded draught [m]	Clearance [m]
Meuse	Va (Vb)	172-185	11.40	2.50-4.50	9.1
Juliana Canal	Va (Vb)	172-185	11.40	2.50-4.50	9.1
Lateral Canal	Va (Vb)	172-185	11.40	2.50-4.50	9.1
Meuse-Waal Canal	Vb	172-185	11.40	2.50-4.50	9.1
Canal Wessem-Nederweert	II	50-55	6.60	2.5	4-5
Burgemeester Delen Canal	Va	50-55	6.60	2.5	9.1
Canal of Sint Andries	Va	95	110 11,4 2,5	4,5	5.25-7
Canal Henriettewaard-Engelen	IV	80-85	9.5	2.5	5.25-7

Table 15 - CEMT classes for the different waterways in and along the Meuse (Rijkswaterstaat, Vaarwegen in Nederland, 2013)

1.13 Meuseroute

The Meuse route connects the province of Limburg on the international network of waterways. The Meuse is connected to the Trans European Network of waterways by means of the Meuseroute. The route runs from Ternaaien to Heumen and is the main route for cargo vessels. Shipping takes partly place on the Meuse and partly on the Juliana Canal, the Lateral Canal and the Meuse-Waal Canal, this route is called the Meuseroute.

The Meuseroute forms together with the Albert Canal, the Scheldt-Rhine Canal and the Waal the so called " the Big Rhombus". Due to the Rhombus forms the Meuseroute an important transport connection between the Netherlands, Belgium, Germany and France. The Meuseroute is suitable for vessels of the CEMT Va class but from 2015 for Vb class vessels. The route does not only connect Limburg to the Big Rhombus but also to the canals of the inside the rhombus. These canals are mainly located in the middle of Limburg and the Dutch and Belgian part of Brabant. Via the Zuid-Willemsvaart and the Canal Wessem-Nederweert is the Meuseroute connected to the canals inside the rhombus. Due to the limited depth, low clearance heights of bridges and small locks are the inside canals only accessible for vessels of the CEMT II class.

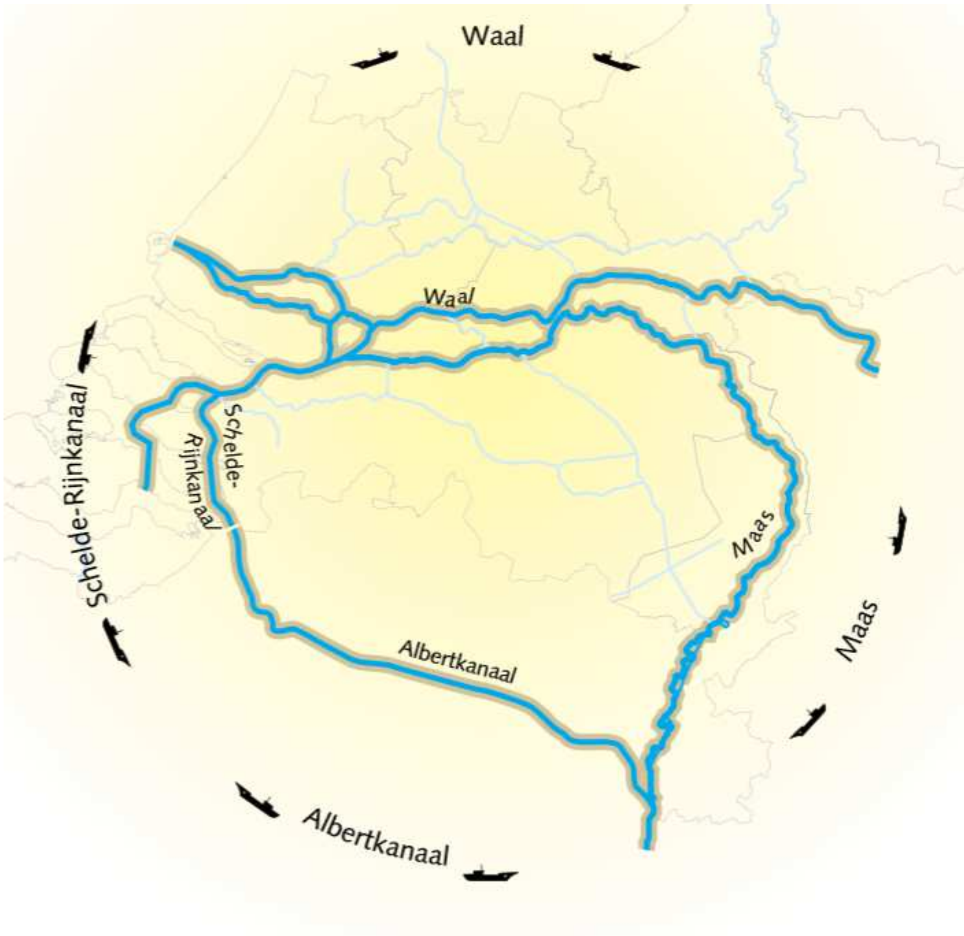
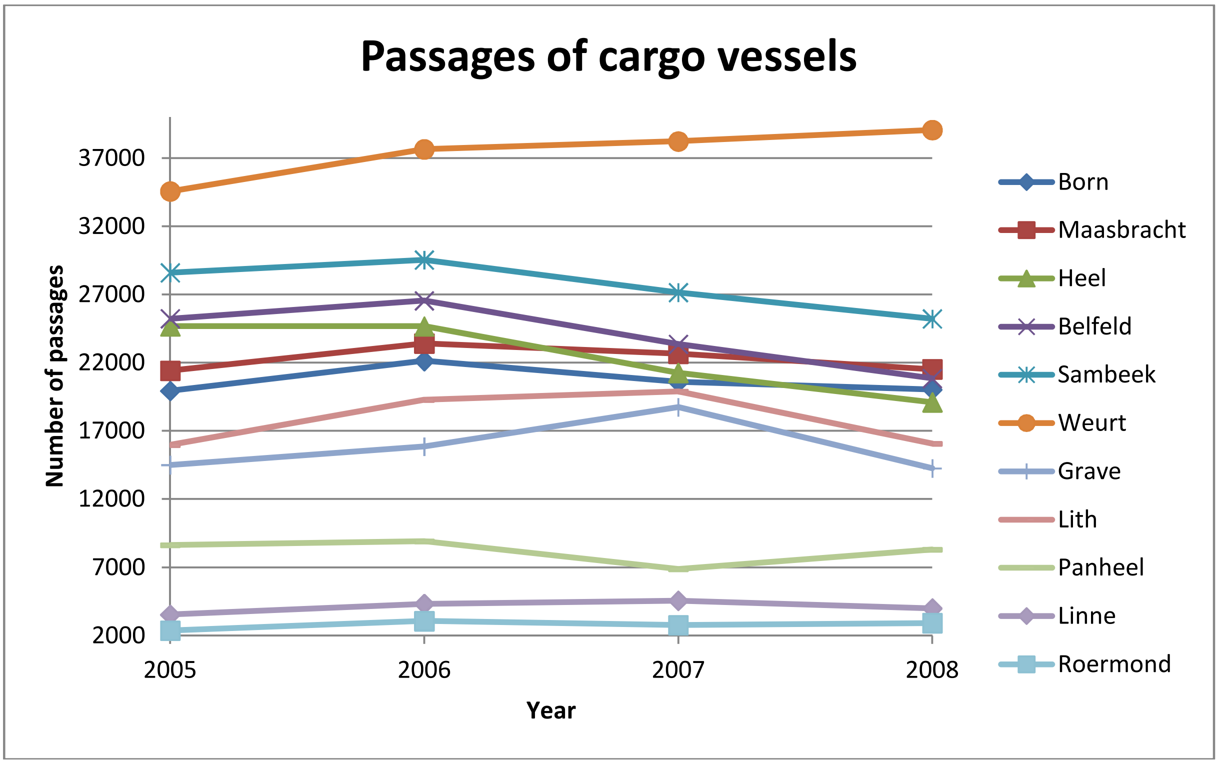


Figure 36 - The Big Rhombus (Maaswerken, Tracébesluis Zandmaas/Maasroute, 2002)

1.14 Navigation

The navigation on the Meuse can be divided in two types, commercial transport and recreational boating. These two types are both using the Meuse which makes the Meuse a combined waterway for navigation.

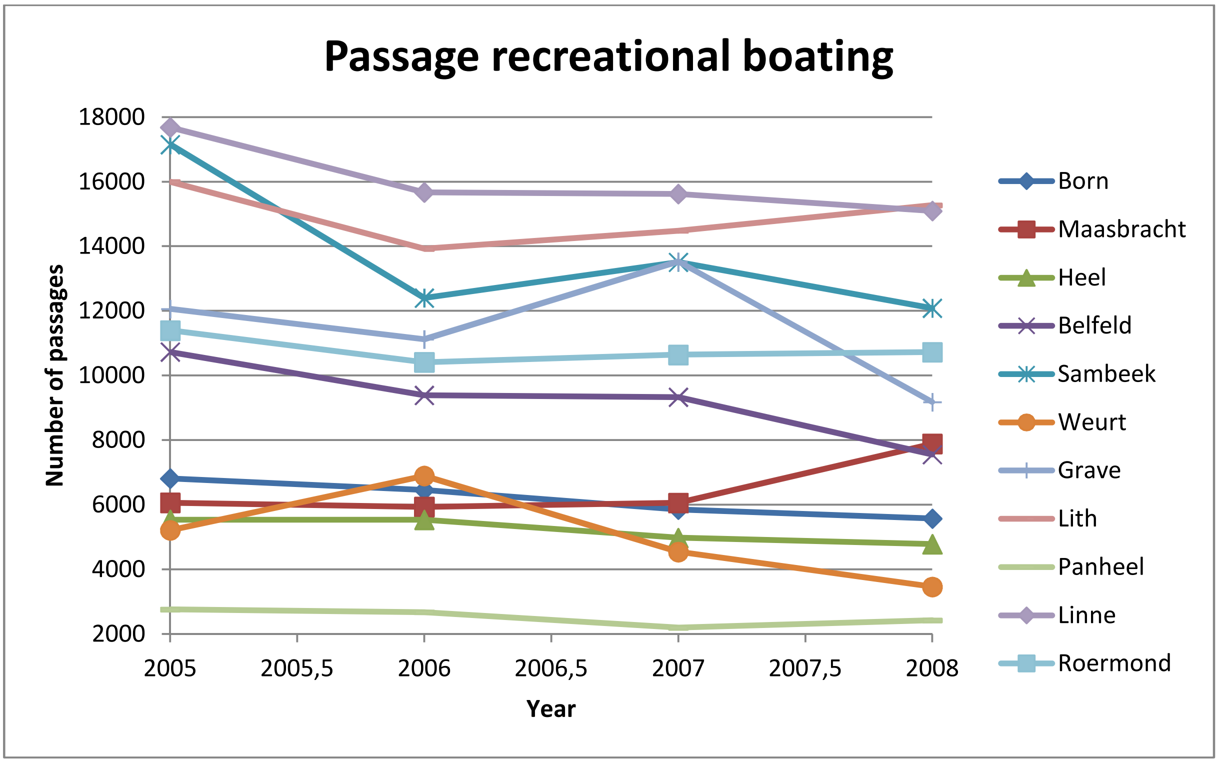
Bulk transport was the most important part of transport since the canalization of the Meuse. However the biggest part of transport over the Meuse still consists of bulk has transport of containers substantially increased. The transport is not equally distributed over the Meuseroute. The largest part of the transport is going over the northern part because of the connection with the Waal via the Meuse-Waal Canal. The transport is considerably smaller on the southern part of the Meuseroute. A large part of this transport is going to destinations in Belgium and France, a smaller part is going to the canals of North Brabant. The amount of shipping on the Meuse is measured by means of lock passages. In this chapter no difference is made between the direction of the lock passage. In Graph 2 are the number of lock passages between 2005 and 2008 are represented.



Graph 2 - Passages of commercial shipping per lock

The distribution of transport on the Meuse is represented in Graph 2, the data between the years 2005 and 2008 are represented (Rijkswaterstaat, Scheepvaartinformatie Hoofdvaarwegen, 2009). It can be seen that the intensity of passages of locks decreases from Heumen to Born. The lock of Heumen is located in the Meuse-Waal Canal and part of the Meuseroute. The intensity of passages is much higher than for the other locks. The number passages of the lock of Panheel is low comparable to the other locks. The reason is that the lock of Panheel is located in the Canal Wessem Nederweerd which is only accessible for vessels of the CEMT II class. Most vessels on the Meuse are of a higher class. The locks of Linne and Roermond are not frequently used by vessels because along this part of the Meuse use vessels the Lateral canal and the lock of Heel. Most vessels which use the locks of Linne and Roermond are going to the harbor of Roermond.

Besides commercial shipping also recreational boating takes place on the Meuse. The passages of the locks by recreational boating are represented in Graph 3. Remarkable are high number of passages of the locks of Linne and Roermond compared to passages of commercial shipping. The reason is that the two locks are located in the Meuse Lakes area, which is an important recreational and water sports area in the Province of Limburg. In the graph can be seen that there is a relative high rate of recreational boating from and to the Meuse Lakes area. The number of passages at Heumen is relative low compared with the passages of commercial shipping. This means that recreational boating on the Meuse to or from upstream destinations is going over the Lower Meuse and Tidal Meuse and not over the Waal like commercial shipping. The reason is probably because the Lower and Tidal Meuse counts less intensive commercial shipping compared to the Waal. More upstream of the Meuse in the direction of Born is the number of passages lower, the recreational boating in this direction is going to or is coming from Maastricht or further upstream.



Graph 3 - Passages of recreational boating

1.15 Harbors

The Meuse contains two types of inland harbors, harbors for commercial shipping and harbors for recreational boating. Most are stand alone harbors, however, some harbors contain a commercial and a recreational part.

The commercial inland harbors along the Meuse are situated in the provinces of Limburg and North Brabant. Limburg contains nine Meuse harbors of importance and North Brabant contains three important harbors along the Meuse. Inland harbors have an important logistical function for the industries in the province of Limburg. The harbors are situated near:

- Maastricht
- Stein
- Born
- Maasbracht
- Roermond
- Buggenum
- Venlo
- Wanssum
- Gennep.

In the harbors transloading takes place from ship to road or railway transport. The harbors a centers of economical activities, besides transloading are also logistical service providers and other companies present near the harbor. In 2006 more than 17.3 million tons of cargo were transported over the Meuse in the province of Limburg. In most of the harbors is the transloading of sand and gravel the largest share of total harbor transloading. Only in the harbors of Born and Stein is this not the case, in Born are containers and in Stein are chemical products the main transloading products. About 50% of the total transloading of the harbors in the province of Limburg contains the transloading of sand and gravel. The other 50% contains containers, oil, agricultural products or iron ore (Limburg, 2008). In Table 16 are more details presented of the harbors.

The harbors along the Meuse in the province of North Brabant are located near:

- Cuijk
- Oss
- 's Hertogenbosch

The harbor of Cuijk is, just like the harbors in Limburg mainly focused on the transloading of sand and gravel. The harbor of 's Hertogenboschis on the contrary is mainly focused on the transloading of agricultural products and food products. This harbor also contains a container terminal which is mainly used by Heineken. The harbor of Oss is mainly focusing on both bulk and container transloading. In Table 16 are more details presented of the harbors (Gedeputeerde Staten van Noord-Brabant, 2008).

Table 16 - Commercial harbors along the Meuse

	Place	Ships per year	Trans-loading [ton]	Containers (TEU)	Water-way	Class	Quay height +NAP [m]	Distance from Lixhe [km]
Limburg	Maastricht		800000-1200000	-	Juliana Canal	Va	46	16.39
	Stein		2416037	15000	Juliana Canal	Va	46	32.22
	Born		1616478	100000	Juliana Canal	Va	34	39.95 - 41.91
	Maasbracht/ Wessem		4597026	-	Juliana Canal	Va	23	64.07
	Roermond	1600	3024266	-	Meuse	Va	19	78.20
	Buggenum		722523	-	Lateral Canal	Va	20	80.51
	Venlo	600	440000	-	Meuse	Va	18.5	107.17
	Wanssum	1750	900000	95000	Meuse	Va	15.5	124.37
	Gennep	2400	1501519	-	Meuse	Va	13	147.93
North Brabant	Cuijk		6192000	-	Meuse	Va	11	162.42
	Oss	2314	2136100	42593	Meuse	Va	6.5	193.42
	's Hertogen-bosch		2820000	105000	Meuse	Va	6.5	221.32

The Meuse has 78 recreational harbors (ANWB, Jachthavens, 2013). There are a lot of harbors in the Meuse Lake area as can be seen in Table 17. The reason is that this part of the Meuse is a popular recreational area in the province of Limburg. Remarkable is the low number of harbors upstream of Meuse Lakes.

Table 17 - Recreational harbors along the Meuse

Meuse section	Place	Number
Upper Meuse	Eijsden	3
	Maastricht	6
Border Meuse	Maaseik	1
	Ohé en Laak	1
	Stevensweert	1
	Ophoven	1
Meuse Lakes	Maasbracht	3

	Heel	1
	Herten	1
	Roermond	10
	Swalmen	1
	Wessem	1
	Thorn	1
Peelhorster Meuse	Neer	1
	Beesel	1
	Kessel	1
Venloslenk	Venlo	2
	Boxmeer	1
	Middelaar	1
	Plasmolen	2
	Wanssum	1
	Well	2
	Gennep	1
	Mook	1
Lower Meuse	Katwijk	1
	Heumen	1
	Linden	2
	Grave	1
	Niftrik	2
	Ravestein	1
	Batenburg	1
	Maasbommel	4
	Helmond	1
	Lithoijen	2
Tidal Meuse	Lith	1
	Heerewaarden	1
	Alem	1
	Kerkdriel	5
	's Hertogenbosh	3
	Hedel	2
	Heusden	3

1.16 River crossings

A river crossing is the connection between two or more points which are separated by a waterway. The crossing ensures a safe connection for traffic, cyclists or pedestrians between two sides of the waterway. A connection can be achieved in three ways: over the waterway by means of a bridge, on the waterway by means of a ferry or boat and under the waterway by means of a tunnel. In this part the different crossings of the Meuse will be considered.

In total forty-three bridges are crossing the navigation route of the Meuse. The bridges result in height restriction for the navigation on the Meuse. The bridges cross the Meuse, the Julianakanaal and the Lateraalkanaal. Twenty-six of the forty-three bridges are crossing the Meuse. The Julianakanaal contains fifteen channel crossings. Twelve of the crossings are individual bridges and three crossings are combined with a sluice. The Lateraalkanaal contains two channel crossings. One of the crossings is an individual bridge and the other is combined with the sluice of Heel. The heights and the locations of the bridges are represented in Table 18, Table 19, Table 20 and Table 21.

Table 18- Bridges over the Meuse (Nederlandse Bruggen Stichting, 2014)

Bridge over the Meuse								
Name	Road	Place	Distance from Lixhe	Height + NAP	Length	Largest span	Type of bridge	Year
			[km]	[m]				
John F. Kennedy brug	N278	Maastricht	9.84	57	588	112	Fixed	1968
Hoge Brug		Maastricht	10.37	57	261	164	Fixed	2003
Sint Servaas brug		Maastricht	10.74	52	57	54.5	Movable	1280
Wilhelmina Bridge		Maastricht	11.00	54	237.8	50.6	Fixed	1932
Spoorbrug		Maastricht	11.78	52	200	66	Movable	1957
Noorderburg		Maastricht	11.93	57	1000	110	Fixed	1985
Scharbergbrug	A76	Stein	26.85	55	1310	115	Fixed	1973
Pater Sangersbrug	N296	Maaseik	49.79	35	150	?	Fixed	1952
Maasbrug Wessem	A2	Wessem	63.65	34	506	100 (2x)	Fixed	1962
Roermond	N280	Roermond	77.82	26	270	80	Fixed	1959
Spoorbrug		Buggenum	80.81	30	248	45	Fixed	1916
Zuiderbrug	A73	Venlo	101.27	27	320	85	Fixed	1995
Stadsbrug Venlo		Venlo	103.07	25	216	61.44	Fixed	1960
Spoorbrug		Venlo	104.13	25	170	55	Fixed	1964
Noorderbrug	A67	Venlo	107.37	27	388	116	Fixed	1968
Koninginnenbrug	N270	Well	125.80	24.5	944	95	Fixed	1978
Maasbrug Boxmeer	A77	Boxmeer	146.85	23	780	157.5	Fixed	1985
Maasbrug Gennep	N264	Gennep	149.20	20	313	47	Fixed	1955
Spoorbrug		Mook	159.83	19	360	75	Fixed	1958
Maasbrug Heumen	A73	Heumen	163.15	20.5	658	157.5	Fixed	1981
John S. Thomsongbrug	N324	Grave	176	17.5	520	61	Fixed	1929
Maasbrug Ravenstein	A50	Ravenstein	182.13	19	435	139.4	Fixed	1975
Spoorbrug Edithbrug		Ravenstein	183.13	15	332	43	Fixed	1937
Maasbrug Empel	A2	Empel	217.24	21	625	117	Fixed	1970
Spoorbrug		Hedel	219.43	12.5	500	100	Fixed	1946
Maasbrug Hedel		Hedel	219.83	14.5	436	124.8	Fixed	1937
Brug Heusden	N267	Heusden	229.43	11.5	540	80	Fixed	1989
Keizersveerbrug	A27	Geertruiden-berg	249.18	10.2	310	90	Fixed	1968

Table 19 - Bridges over the Julianakanaal (Nederlandse Bruggen Stichting, 2014)

Bridges over the Juliana Canal								
Name	Road	Place	Distance from Lixhe	Height + NAP	Length	Largest span	Type of bridge	Year
			[km]	[m]				
Lock Limmel		Limmel	13.98	53	39	16	Fixed	1932
Brug Itteren		Itteren	16.65	53	58.79	46.5	Fixed	1933
Brug Bunde		Bunde	20.05	53	58.59	46.5	Fixed	1933

Brug Geule		Geule	22.42	53	58.59	45	Fixed	1933
Brug Elsloo		Elsloo	26.00	55	77.40	46.5	Fixed	1963
Scharbergbrug	A76	Stein	26.85	55	1310	48	Fixed	1973
Brug Stein		Stein	31.82	53	76.59	46.5	Fixed	1930
Brug Urmond		Urmond	34.70	53	76.59	46.5	Fixed	1930
Brug Berg		Berg	36.24	53	76.59	46.5	Fixed	1930
Brug Obbicht		Obbicht	38.18	53	76.59	46.5	Fixed	1930
Sluice Born		Born	41.29	41				
Brug Illikhoven		Illikhoven	45.51	44	113.90	55.00	Fixed	1965
Brug Roosteren	N296	Roosteren	49.34	44	114	55	Fixed	1965
Echterbrug		Echt	56.23	44	114	55	Fixed	1965
Sluice Maasbracht		Maasbracht	61.48	32				

Table 20 - Bridges over the Lateral Canal (Nederlandse Bruggen Stichting, 2014)

Bridges over the Lateral Canal								
Name	Road	Place	Distance from Lixhe	Height + NAP	Length	Largest span	Type of bridge	Year
			[km]	[m]				
Sluice Heel		Heel	70.19	26	20	16	Fixed	1967
Hornerbrug	N280	Horn	76.94	29	255	80	Fixed	1967

Table 21 - Bridges over the Meuse-Waal Canal (Nederlandse Bruggen Stichting, 2014)

Bridges over the Meuse-Waal Canal								
Name	Road	Place	Distance from Lixhe	Height + NAP	Length	Largest span	Type of bridge	Year
			[km]	[m]				
Sluis Heumen		Heumen	161.39	19.7		16.30	fixed	
Neerbossche Brug		Nijmegen	161.39	20.6	205	100	fixed	1982
Graafsebrug	N326	Nijmegen	161.39	20	187	100	fixed	1974
Dukenbrugse-brug		Nijmegen	161.39	20	187	100	fixed	1973
Hatersebrug		Nijmegen	161.39	20	187	100	fixed	1973
Maldensebrug		Malden	161.39	19.6	217	92	fixed	1986
Sluis Weurt			161.39	19.6			Fixed	

In the Meuse thirty ferry connections are present. The ferries in the upstream parts of the Meuse are important for the numerous walking and bicycle routes of South Limburg. In the middle and lower part of the Meuse most of the ferries are also suitable for cars. The ferries are important for citizens of villages without and far away from a bridge connection. Twenty-eight ferries form a connection between two points. Two ferries connect more than two points along the Meuse. The ferry connections of the Meuse are represented in
Table 22 and Table 23.

Table 22 - Ferry connections between two points (Vrienden van de Voetveren, 2011)

From	To	Distance from Lixhe [km]	Users
Eijsden	Lanaye (Belgium)	2.51	Bike, pedestrian
Maastricht St. Pieter	Heugem	8.01	Bike, pedestrian
Geulle aan de Maas	Uikhoven (Belgium)	25.83	Bike, pedestrian
Berg	Meeswijk	36.24	Car, bike, pedestrian
Grevenbicht	Rotem (Belgium)	41.29	Bike, pedestrian
Ohé en Laak	Ophoven	56.90	Bike, pedestrian
Maasbracht	Wessem	62.43	Bike, pedestrian
Ool	Marina Oolderhuuske	74.85	Bike, pedestrian
Neer	Rijkel	85.36	Bike, pedestrian
Kessel	Beesel	90.34	Car, bike, pedestrian
Baarlo	Steyl	100.53	Car, bike, pedestrian
Grubbenvorst	Velden	110.25	Car, bike, pedestrian
Lottum	Lomm	115.12	Car, bike, pedestrian
Arcen	Broekhuizen	118.53	Car, bike, pedestrian
Blitterserswijk	Wellerlooi	123.20	Bike, pedestrian
Vierlingsbeek	Bergen	139.85	Car, bike, pedestrian
Afferden	Sambeek	144.37	Car, bike, pedestrian
Cuijk	Middelaar	156.92	Car, bike, pedestrian
Batenburg	Demen	184.86	Bike, pedestrian
Appeltern (N329)	Megen (N329)	189.74	Car, bike, pedestrian
Maasbommel	Megen	192.65	Car, bike, pedestrian
Alphen	Oijen	195.78	Car, bike, pedestrian
Alphen	Lith	200.95	Car, bike, pedestrian
Heerewaarde	Lithse Ham	205.71	Bike, pedestrian
Alem	Maren	209.92	Car, bike, pedestrian
Herpt	Bern	226.23	Car, bike, pedestrian
Waalwijk	Drongelen	234.97	Car, bike, pedestrian
Sprang Capelle	Dussen	239.77	Car, bike, pedestrian

Table 23 - Ferry connections with stops (Vrienden van de Voetveren, 2011)

From	Stops	To	Distance from Lixhe [km]	User
Baarlo	Blerick, Grubbenvorst, Arcen, Blitterswijck, Well	Afferden	100.53 to 144.37	Bike, pedestrian
Boxmeer	Gennep, Oeffelt, Cuijk, Mook, Overhasselt	Grave	147.31 to 174.47	Bike, pedestrian

There are no tunnels under the Meuse to form a connection between two riversides. Under side rivers like the Roer or the Swalm are tunnels present but not under the Meuse itself.

1.17 Flood defenses

The flood defense of the Meuse can be separated into two types. In the undiked Meuse are areas protected by means of walls and in the diked Meuse by dikes.

1.17.1 Undiked Meuse

The area of the Undiked Meuse is div ded in forty-two dike ring areas. Because the Undiked Meuse does not contain any fiscal borders likes dikes are areas along this part of the Meuse protected in another way. The cities and villages in these dike ring areas are instead of the other dike ring areas in the Netherlands not protected by dikes but by walls. The walls in the Undiked Meuse have a safety level of 1/250 year. More about the dike rings in the Netherlands can be found in Appendix A.

The places along the Undiked Meuse are build on the different terraces. Places on low terraces on lower terraces are completely surrounded by walls, places on higher terraces are sometimes partly surrounded by walls.
The walls can have different forms like the green wall, the wall and the detachable walls, the walls are represented presented in Figure 37. Walls are not always clearly visible because it is tried to adapt the walls to the landscape. A good example are the green walls. However, also walls and detachable walls are implemented into the landscape like the wall around the monastery of Steyl as represented in Figure 38.

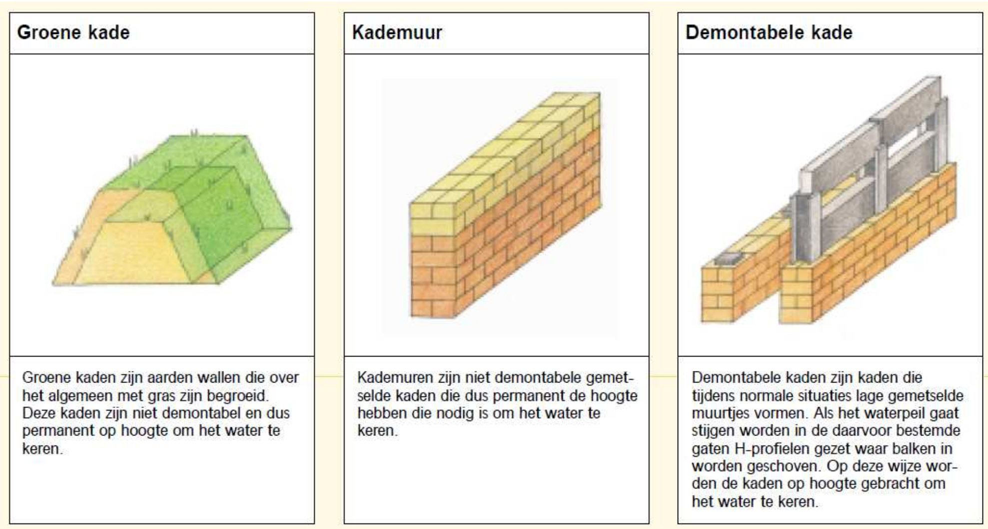


Figure 37 - Different types of walls (De Maaswerken, 2007)

The most dike ring areas of the Undiked Meuse are situated inside the influence zone of the floodplains. During extreme high waters (1:1250) will the water level of the Meuse be higher than the height of the walls so most dike ring areas will flood. In practice municipalities will take measures to keep the dike ring areas dry by using pumps and sandbags

Figure 38 - Wall of the monastery of Steyl

1.17.2 Diked Meuse

The diked Meuse is the river part between Cuijk and Geertruidenberg. The Meuse is totally enclosed by flood plains and dikes. The dikes protect the villages along the Meuse. The dikes have a higher safety level than the walls around dike ring areas in the Undiked Meuse. There reason is that the dike ring areas along the Diked Meuse are larger, have more economical value and are inhabited by more people. The dike ring areas along the Diked Meuse have a safety level of 1/1250 year (Strootman Landschapsarchitecten bv. & Acacia Water, 2013). The width of the flood plains of the Lower Meuse changing as can be seen in Figure 39. The reason is the normalization of the Meuse. Before the normalization was river meandering but already be diked. The dikes followed the river but after the normalization this changed and around the locations of the meanders large flood plains arose.

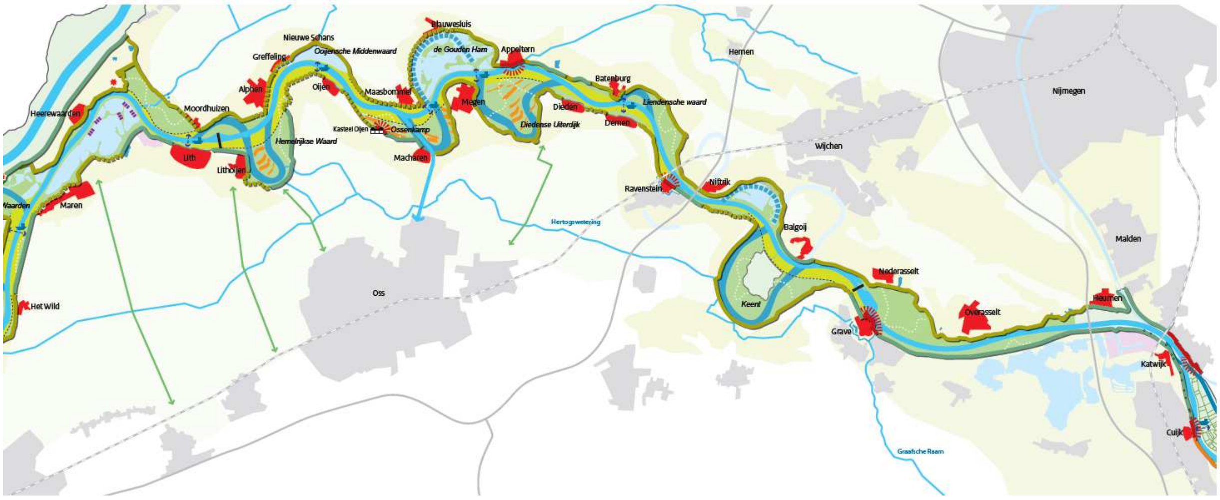


Figure 39 - Section of the Diked Meuse with dikes and flood plains (Strootman Landschapsarchitecten bv. & Acacia Water, 2013)

1.18 Drinking water

Water of the Meuse is used for drink water for a lot of people. It can be seen in Figure 40 that only in Limburg Meuse water is used for the drink water production, the two locations are near Heel and Roosteren. There are three other plants in the western part of the Netherlands which also use Meuse water for drink water production. The plants are located in the western part of the Netherlands near Brakel, Gat van Kerksloot and Scheelhoek. However, these plants use Meuse water but are not connected with the Meuse itself. So the water quality of the Meuse is important for the plants but the weirs in the Meuse have no effect on the height of the intake locations of the plants. The water intake near Brakel is coming from the Afgedamde Meuse, the intake near the Gat van Kerksloot from the Ammer and the intake at Scheelhoek from the Hollands Diep.

Figure 40 - Intake points along the Meuse for drink water production (RIWA, 2012)

The intake points which are of importance in this report are located in the province of Limburg. The drink water distribution in the province of Limburg is provided by the Waterleiding Maatschappij Limburg (WML). Before 2002 only groundwater was used as source of drinking water in Limburg. However, due to drought of the bottom in the southern part of the Netherlands it was decided to decrease the groundwater extraction and to increase water extraction from the Meuse (de Moel, Verberk, & van Dijk, 2005). At two locations along the Meuse are inlet constructions situated.

At the first location is water extracted from the Lateral Canal near Beegden, the water level at the inlet is at 14.10m +NAP. The intake from the Lateral Canal is around 8.7Mm^3 per year. The water is pumped to the Lange Vlieter, this is a 120 ha excavated gravel lake. It is also possible to pump water from the adjacent Bosmolenplas into the Lange Vlieter. So the Lange Vlieter has the function of a retention basin. By means of bank infiltration and the water treating station will the Meuse water be cleaned. Hereafter the water is ready to enter the distribution network.
The treatment plant is restricted to pump maximal 5600 m^3/hour from the Lateral Canal and 2300 m^3/hour from the Bosmolenplas if necessary.
The quality of Meuse water decreases during low discharges. For this reason it is not allowed to transport Meuse water from the intake to the Lang Vlieter, this situation takes about thirty days (Hoogeveen & Witjes, Gebiedsdossier Oppwervalktewaterwinning Heel, 2014).

Figure 41 - Water treating station Heel (source: Google Maps)

The second location of Meuse water extraction is near Roosteren. The water is pumped from wells in the river banks of the Border Meuse. The water treating station near Roosteren has a capacity of 6.7 Mm^3 water per year. After cleaning the water can be distributed to the water supply network of Limburg. Just like the plant of Heel is it not allowed to use Meuse water if the quality is not sufficient. This occurs during low discharges and will take about thirty days (Hoogeveen & Witjes, Gebiedsdossier Oevergrondwaterwinning Roosteren, 2014).

Figure 42 - Water treating station Roosteren (Google Maps)

1.19 Nature

There are several natural areas along the Meuse which are Natura 2000 areas. Natura 2000 is the name for the European network of natural areas which are important for flora and fauna in Europe. The purpose of Natura 2000 is a durable protection of special plant and animal species. In the Netherlands is Natura 2000 included in the "Natuurbeschermingswet". Most of these areas along the Meuse are located in the province of Limburg. The area's are:

- Sint Pietersberg & Jekerdal
- Bunder- en Elslooërbos
- Grensmaas
- Leudal
- Swalmdal
- Maasduinen
- Boschhuizerbergen
- Oeffelter Meent

1.20 Agriculture

The floodplains of the Meuse are during low average discharges used for cattle breeding. When the floodplains flood is the cattle removed to safe locations. The floodplains are not only used for cattle breeding but also for agricultural purposes. The type of crop depends on the time of harvest, this moment must be before the wet season starts.

The Meuse does not only have influence on agriculture of the floodplains but also on agriculture further away from the river. The Meuse influences the ground water levels of regions along the river, low water levels of the Meuse mean low ground water levels. The low ground water levels have effect on the crops especially during dry periods.

2 Area of Linne

2.1 Canal section of Linne

The weir of Linne has are relative short canal section. About 15 km of the Meuse is under influence of the weir of Linne, this is less than 7% of the Meuse in the Netherlands. The canal section of the weir of Linne contains a part of the Border Meuse. The Border Meuse is mainly a free flowing river, however is the last 11 km of the Border Meuse influenced by the Weir of Linne. The influence zone ends somewhere nearby Maaseik. The water level at this point are for low discharges (Q = 50 m^3/s) of the Border Meuse 20.80 m +NAP, for average discharges (Q = 250 m^3/s) a water level of 21.80 m^3/s) and for high discharges a water level (Q = 1250 m^3/s) of about 27.00 m + NAP (Rijkswaterstaat Limburg, 2009). The influence zone of the weir of Linne is represented in Figure 43.

The boundaries of the canal section are on the northern and southern side of the section. The boundaries on the north side of the canal section are formed by:

- Weir of Linne
- Lock of Linne
- Lock of Heel in the Lateral Canal
- Lock of Panheel in the Canal Wessem Nederweert.

The boundaries on the southern side of the canal section are:

- Lock of Maasbracht in the Juliana Canal
- Border Meuse at Maaseik

The last part of the Border Meuse, where the influence of the weir of Linne is noticeable, is called the Laakerweerd. In this part of the Border Meuse are the river dynamics during high water considerably high. The Laakerweerd contains several lakes which have an open connection with the Meuse. These lakes have been created by the excavation of sand and gravel. The lakes are mainly used for recreational purposes like water sports. The lakes can also function as water storage during low discharges of the Meuse. The lakes who have an open connection with the Meuse are represented in Table 24.

Table 24 - Lakes influenced by the water level of the weir of Linne

Name	Meuse part	Country
Schroevendaalseplas	Border Meuse	Belgium
Herenlaak	Border Meuse	Netherlands
De Steenberg	Border Meuse	Belgium
Koningssteen	Border Meuse	Belgium
Huyskensplas	Border Meuse	Netherlands
De Kis	Border Meuse	Netherlands
Oude Maas	Meuse Lakes	Netherlands
De Grote Hegge	Meuse Lakes	Netherlands
Thornerbeek	Meuse Lakes	Netherlands
Molengreend	Meuse Lakes	Netherlands
De Slaag	Meuse Lakes	Netherlands
Polderveld	Meuse Lakes	Netherlands
Tesken	Meuse Lakes	Netherlands

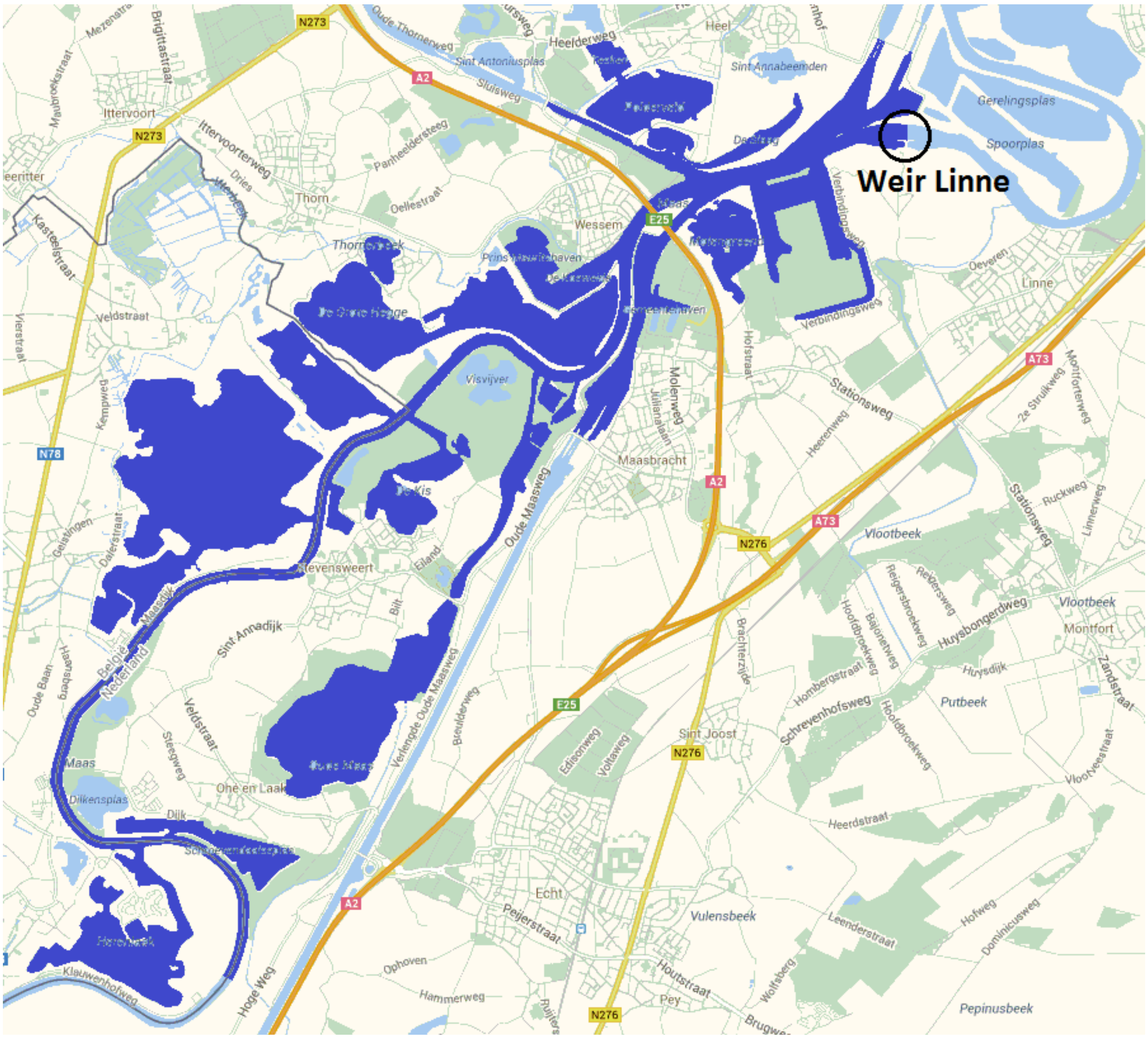


Figure 43 - Influence zone of the weir of Linne (source: Google Earth)

2.2 Discharge

Most of the discharged water in the canal section of Linne is entering the section by the Border Meuse and leaves the canal section near the weir of Borgharen. Discharges of the Border Meuse are (Rijkswaterstaat Limburg, 2009):

- Yearly average discharge 236 m^3/s
- Average winter/spring 397 m^3/s
- Average summer/autumn 116 m^3/s
- Required minimum 10 m^3/s
- Bank full 1500 - 1600 m^3/s
- Maximum measured 3050 m^3/s

2.3 Side streams

The canal section of Linne contains two streams which discharge water on the canal section.

- Geleenbeek

The watershed of the Geleenbeek is totally located in the Neterlands. The watershed has a surface of about 20300 ha and contains 28 small side streams. The stream rises at 120m +NAP as source near Heerlen. The Geleenbeek flows in a 37 km long stream to Ohé en Laak where the mouth of the stream is located at a height of 27m +NAP. The mouth of the stream is not directely connected with the Meuse but with an old gravel excavation hole on the north side of Ohé en Laak which is called the Oude Maas. The mean discharge varies between 0.2 and 2.8 m^3/s but can increase during heavy rainfall to 55 m^3/s. The Geleenbeek flows for a large part trough urbanized areas like Heerlen or Sittard. In these areas is the soil covered by asphalt, concrete or other materials that increase the amount of water and discharging time from land to the stream. So during heavy rainfall can the discharge of the Geleenbeek increase very fast (op den Kamp, 2012).

- Thornerbeek

The Thornerbeek is a stream which discharges its water on the Meuse near Wessem. The stream rises in Belgium in the municipality of Guitrode, the stream is here called the Itterbeek. The stream flows in easterly direction over Belgian and Dutch territory. On the south side of Thorn confluences the Itterbeek with the Wittebeek, from this confluence is the stream called the Thornerbeek. The Thronerbeek flows to Wessem were the mouth of the stream on the Meuse is located. The discharge of the Thornerbeek is between 0.3 and 1.0 m^3/s (Maasbekken, 2008).

2.4 Water levels

The water levels in the of the Border Meus are strongly varying during the year, maximum differences of 7 m can be occur. During the summer months are the differences in the water levels are smaller. In most cases smaller than 4 m. These strong fluctuations of the water level have impact on the canal section of Linne. Water levels of measuring points along the canal section are represented in Table 25. It can be seen that the differences between the high and low water levels decreases very fast in the direction of the weir. The reason is that due to the lakes along the canal section of Linne. The lakes increase the storage of the canal section which decreases the high water peak. During extreme high are the riverbanks flooded which results in a wide discharging area.

Table 25 - Water levels of the canals section Linne (Rijkswaterstaat, Referentie waterstanden, 2012)

Exceedance frequencies	Discharge Borgharen Dorp	Water level + NAP			
		Maaseik	Stevensweerd	Heel Upstream	Linne Upstream
	[m^3/s]	[m]			
Highest known discharge	3039		25.35	22.80	22.80
1/1250 old	3650		2580	23.25	23.25
1/1250 new	3800				
1/100	2800		25.10	22.60	22.60
1/10	2000		24.55	22.00	22.00
1/2	1450		23.90	21.30	21.30
1/1	1200		23.40	21.00	21.00
Average yearly discharge	230		21.10	20.85	20.85
Average summer discharge (September)	89		20.90	20.85	20.85
Lowest known discharge	0		20.85	20.85	20.85

2.5 Water distribution

The canal section of Linne is mainly fed by discharges from the Border Meuse. Also the Juliana Canal discharges at the canal section, however compared to the discharges of the Border Meuse is the discharge of the Juliana Canal small. During dry periods is not always enough water available in the canal section of Borgharen to feed the Juliana canal. To feed the Juliana Canal is water from the canal section of Linne pumped in the Juliana Canal by the pumping station of Maasbracht. During low discharges a negative discharge of the Juliana Canal to the canal section of Linne can occur.
The pumping station of Panheel pumps water into the Canal Wessem Nederweert to keep navigation possible, 1 m^3/s is going back to the Linne canal section due to leakage of the Lock of Panheel. The discharges of the locks of Linne and Heel are also the result of leakage. The Clauscentrale uses Meuse water for cooling, if not enough water is available in the canal section are the cooling towers used.

Table 26 - Extraction and drainage on the canal section of Linne (Berger & Mugie, 1994) & (Breukel, Silva, van Vuuren, Botterweg, & Venema, De Maas - Verleden, heden en toekomst, 1992)

		In			Out		
		Low	Mean	High	Low	Mean	High
		[m^3/s]					
Border Meuse		10	236	3050			
Juliana Canal	Lock Maasbracht	7	13	13			
	Pumping station Maasbracht				9		
Canal Wessem Nederweert	Lock Panheel	1	1	1			
	Pumping station Panheel				4-6	4-6	4-6
Lateral Canal	Lock Heel				4	7-9	7-9
Meuse	Lock Linne				3	3	3
	Weir Linne				Variable	Variable	Variable
Clauscentrale						1	1
Geleenbeek			0.2-2.8	55			
Thorenbeek			0.3-1.0				

2.6 Flood protection

In the influence zone of the weir of Linne are five dike ring areas. The flood protection consist of walls with a probability of exceedance of 1/250 year. Because the considered part of the Meuse is located in a valley is it not nessecary to enclose all dike rings by walls. The higher parts of these dike rings are located high enough that no flood protection is needed. Only the low lying dike ring areas like dike ring 81 are totally enclosed by walls. In Table 27 are the dike ring areas and heights of the walls represented.

Table 27 - Dike ring areas in canal section Linne (Witteveen+Bos, 2013) & (Waterschap Peel en Maasvallei, 2013) & (van de Velde, 2013)

Dike-ring area	Location	Freeboard	Design water level +NAP	Height +NAP	Safety level	Water Board
		[m]				
78	Heel	0.70	23.10	23.80	1/250	Peel en Maasvallei
79	Thorn - Wessem			24.00	1/250	Peel en Maasvallei

80	Clauscentrale (80.1)	0.50	23.07	23.57	1/250	Roer en Overmaas
	Brachterbeek (80.2)	0.50	22.89	23.39	1/250	
81	Ohé en Laak Stevensweert			25.80	1/250	Roer en Overmaas
82	Aasterberg			28.69	1/250	Roer en Overmaas

Figure 44 - Dike-ring areas in the canal section of Linne (Google Maps)& (Rijkswaterstaat, Helpdesk water - Maas)

2.7 Meuseroute

The section of the Meuseroute in the canal section of Linne is relatively short, about 5 km of the Meuseroute is going through the canal section of Linne. On the south side can vessels enter or leave the canal section of Linne by the lock of Maasbracht and on the north side by the lock of Heel. On the south side is the canal section connected with the Julian Canal and on the north side with the Lateral Canal so the Meuse section of Linne is a connection between two canals of the Meuseroute. In Figure 45 is the Meuseroute accentuated by a dark blue line, the red areas are the harbors of Maasbracht which are accessible for vessels on the Meuseroute. These blue and red parts are in the current situation accessible for vessels of the Va class and from 2015 for class Vb vessels, all the other waterways are suitable for smaller vessels and recreational boating.

2.8

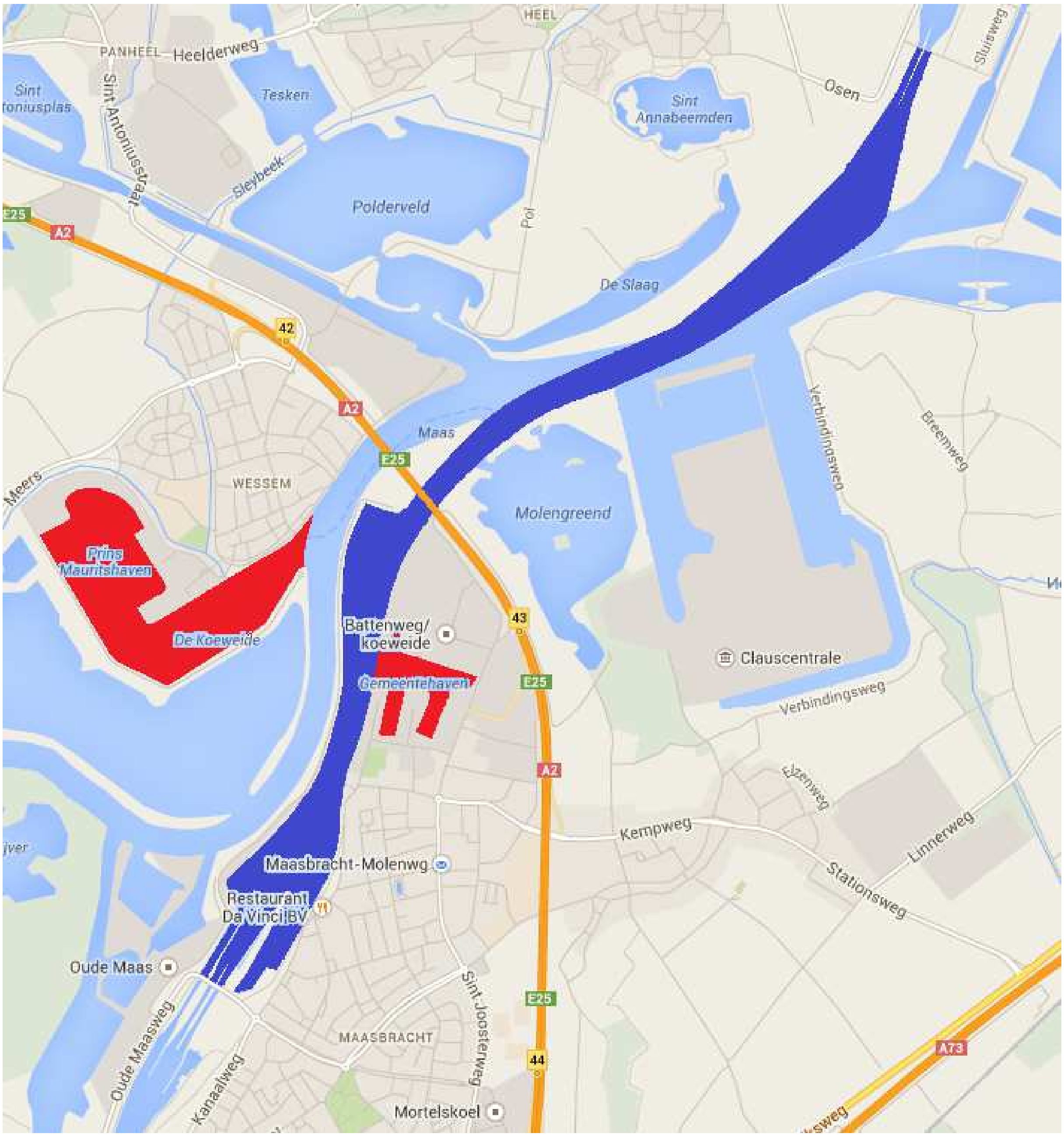


Figure 45 - Meuseroute in canal section of Linne (Google Maps)

2.9 Navigation

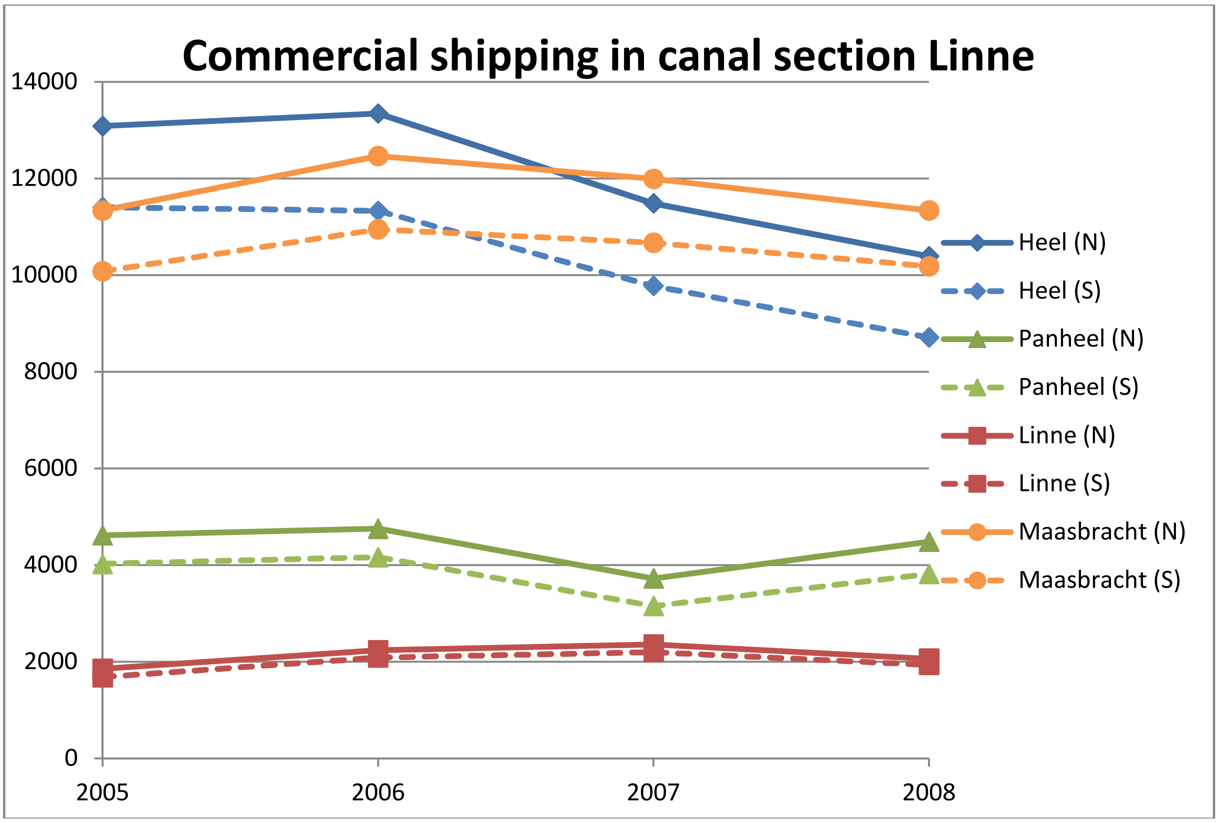
Ships are able to enter the canal section of Linne by four entrances, lock Heel, lock Panheel, lock Linne and lock Maasbracht. The passages of cargo vessels of the four locks are represented in Table 28. The letter N stands for a passage in the northerly direction, S for a passage in the southerly direction and the T for the total number of passages. The total number of passages is represented in Graph 2 and the passages in the northerly and southerly direction are represented in Graph 4.

Table 28 - Lock passages of cargo vessels (Rijkswaterstaat, Scheepvaartinformatie Hoofdvaarwegen, 2009)

Year	Commercial											
	Heel			Panheel			Linne			Maasbracht		
	N	S	T	N	S	T	N	S	T	N	S	T
2005	13082	11404	24670	4616	4023	8639	1852	1679	3531	11334	10078	21412

2006	13343	11327	24670	4751	4161	8912	2236	2086	4322	12464	10946	23410
2007	11484	9775	21259	3723	3153	6876	2354	2199	4553	11990	10668	22658
2008	10390	8709	19099	4484	3816	8300	2060	1932	3992	11338	10181	21519

In Graph 4 can be seen that most of the cargo transport in the canal section of Linne is using the Meuseroute. The number of cargo passages by the locks of Panheel or Linne are much smaller. Vessel who pass the lock of Linne are going from or to the harbor of Roermond. A second remarkable observation is the higher number of passages in northern direction so in the direction of the western part of the Netherlands.



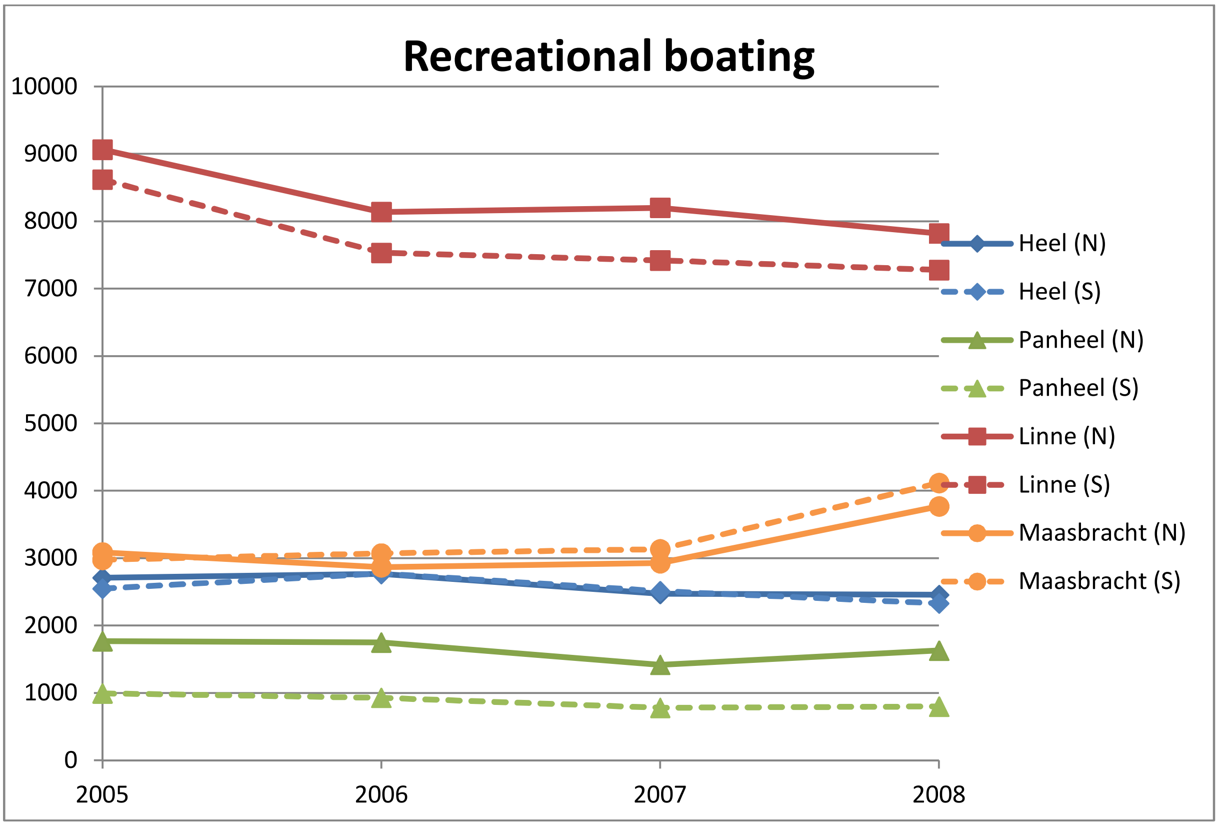
Graph 4 - Passages of cargo vessels in canal section Linne

In Table 29 and Graph 5 are the lock passages for recreational boating represented. Compared to commercial shipping are the locks of the Meuseroute less frequently used. In Graph 5 can be seen that on the north side of the canal section boats do not use the lock of Heel but the lock of Linne. This lock brings the boats to the canal section Roermond which contains a lot or recreational facilities. Due to the usage of different locks on the north side of the canal section, a kind of natural splitting between commercial and recreational shipping occurs. Recreational boating takes place on the Meuse in the canal section Roermond and commercial shipping on the Lateral Canal. In the canal section of Belfeld the waterway is again combined. By comparing Graph 2 and Graph 5 can be concluded that most of the recreational boating is not going further than the canal section of Linne.

Table 29 - Lock passages of cargo vessels (Rijkswaterstaat, Scheepvaartinformatie Hoofdvaarwegen, 2009)

Year	Recreational boating											
	Heel			Panheel			Linne			Maasbracht		
	N	S	T	N	S	T	N	S	T	N	S	T
2005	2709	2547	5538	1768	993	2761	9063	8619	17682	3086	2976	6062

2006	2767	2771	5538	1748	928	2676	8139	7531	15670	2866	3068	5934
2007	2470	2508	4978	1418	780	2198	8201	7419	15620	2926	3132	6058
2008	2455	2329	4784	1628	797	2425	7820	7276	15096	3769	4116	7885



Graph 5 - Passages of recreational boating in canal section Linne

2.10 Harbors

The commercial harbors in the canal section of Linne are the harbors of Maasbracht and Wessem. In 2007 were the municipalities of Maasbracht, Thorn and Heel brought together in a new municipality called Maasgouw. The harbors of Maasbracht and Wessem are since that moment property of the municipality of Maasgouw. The harbors are represented in the red in Figure 45.

The Gemeentehaven is the name of the harbor of Maasbracht. The harbor is one of the biggest inland harbors in the province of Limburg and the largest harbor for sand and gravel transloading in Limburg. The transloading of sand and gravel has decreased over the years because the gravel excavation along the Meuse decreased. On the other hand have ship maintainance and reparation become an important part of the harbor activities. Another important type of transloading is the transloading of agricultural products. The harbor has a surface of 37 ha. which is divided in 61 parcels. The height of the quays are at 23.75 m +NAP.

The harbor of Wessem is called the Mauritshaven. Along the harbor are building, trading and sand and gravel companies located. Also commercial boating is an important aspect of the harbor. The harbor has a surface of 10 ha. and the height of the quays is at 23.75 m +NAP.

In 2013 decided the municipality that all commercial activities in the harbor of Wessem should be moved to the harbor of Maasbracht. The harbor of Wessem should become a recreational harbor instead of a combined harbor. There are plans on the long terms to develop a new harbor and industrial area next to the Clauscentrale. The development depends on the economical situation in the future (Provincie Limburg, 2008).Besides the commercial harbors are there several marinas, they are represented in Table 30.

Table 30 - Recreational harbors

Location	Marina name	Jetty height	Accessibility
Ohé en Laak	De Maasterp	Varying (floating)	Public
Maaseik (Belgium)	Heerenlaak	Varying (floating)	Public
Stevensweert	Jachtaven Stevensweert	Varying (floating)	Public
Ophoven (Belgium)	De Spaanjerd	Varying (floating)	Public
Thorn	Thorner Zeilclub	Varying (floating)	Private
Wessem	Comfortparc Jachthaven	Varying (floating)	Public
Maasbracht	Van der Laan Shipping	Varying (floating)	Public
	Maasbrachter Watersportvereniging	Varying (floating)	Private
	Gemeentehaven	21.50 m +NAP	Public
Heel	Jachthaven Boschmolenplas	Varying (floating)	Public

2.11 River crossings

- Maasbrug Wessem

The bridge over the Meuse near Wessem is an important connection between the north and south part of the Netherlands. The bridge is a part of the high way A2 between Amsterdam and Maastricht. The bridge is also of importance for cargo transport to and from the harbor of Maasbracht.

- Bridge lock Maasbracht

The bridge over the lock of Maasbracht is the shortest connection between Maasbracht and Wessem. The brige contains a two-lane road and is suitable for a bikes, pedestrians and cars.

- Lock Heel and lock Linne

The bridge over the lock of Heel is suitable for cars, cyclists and pedestrians. The bridges of the lock of Heel is mainly used by the staff of the lock control room the bridge. Also the resort Marina Oolderhuuske can be reached by using the bridge. The bridge over the lock of Linne is mainly used by the staff to reach the weir of Linne.

- Bridge weir Linne

The Bridge over the lock and weir of Linne are only suitable for cyclists and pedestrians. The bridge is, together with the bridges over the weir of Linne and the lock of Heel a short cycling connection between Heel and Linne. This route is frequently used by walking and cycling tours in the province of Limburg.

2.12 Natural areas

- Laakerweerd/Schroevendaalse Plas
- Dilkensweerd/Teggerse Plas
- Stevol
- Brand (Molensteense Plas)
- Brand (Visplas)
- De koningsteen
- Overlaat van Ossen

Figure 46 - Natural areas in the canal section of Linne

3 Weir Linne

The weir of Linne is the second weir in the Dutch part of the Meuse. The weir contains two weir types, the Poirée weir and the Stoney weir. The weir is build between two banks, the bank on the side of the Poirée part has a height of 24.00 m +NAP and the bank on the side of the Stoney part has a height of 24.66 m +NAP. The total weir complex between the two banks has a length of 125 m.

The function of the weir is to set up the water level in the canal section of Linne to obtain sufficient navigation depth. At average discharges is on the upstream part of the weir a water level of NAP + 20.80 m maintained with tolerances between NAP + 20.70 m and NAP + 20.90 m. On the downstream side are the water levels dependent on the weir of Roermond. At Roermond vary the water levels between 16.75 m +NAP and 16.95 m +NAP for mean discharges. The mean water level of the canal section of Roermond has a height of 16.85 m +NAP.

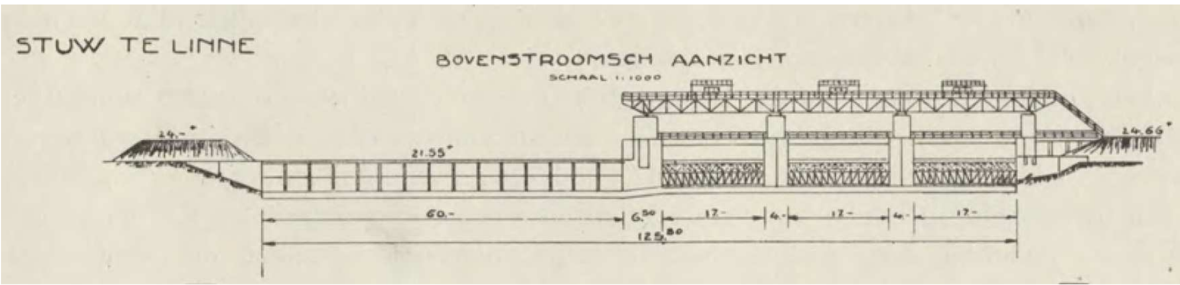


Figure 47 - Front view of the upstream part of the weir of Linne (Rijkswaterstaat, Kanalisatie van de Maas in Nederland - Verslag over de vorderingen van de werken in ther jaar 1921 en balans per 31 december 1921, 1921)

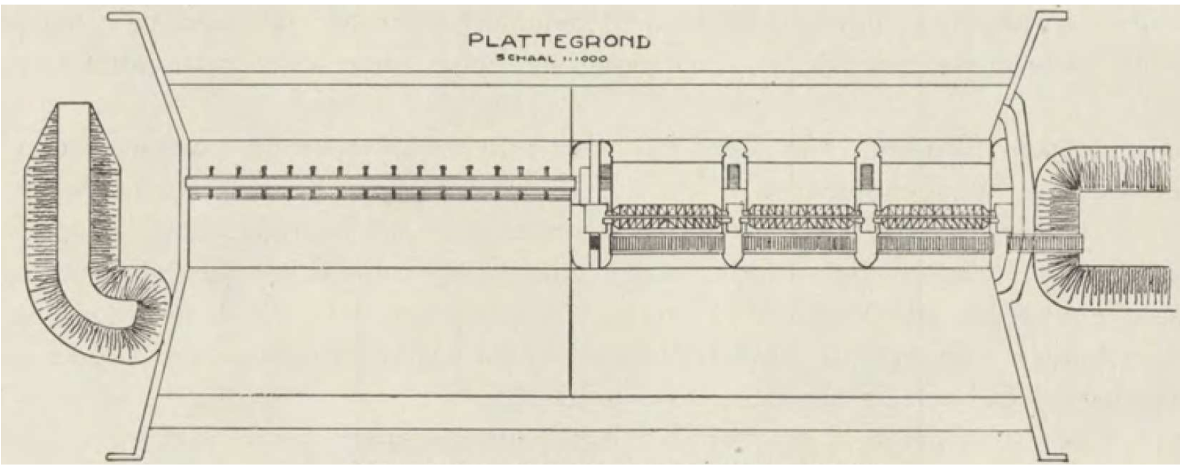


Figure 48 - Top view of the weir of Linne (Rijkswaterstaat, Kanalisatie van de Maas in Nederland - Verslag over de vorderingen van de werken in ther jaar 1921 en balans per 31 december 1921, 1921)

3.1.1 Poirée weir

The bottom of the Poirée weir consist of a thick unreinforced concrete slab. The top of the bottom slab is located on 15.95 m +NAP and has a thickness of 2.65 m. The slab has been founded on a shallow foundation because the subsoil consist mainly of sand and gravel. The slab has a width of 20 with leakage screens on both ends. The leakage screens have been placed until 9.05 m +NAP so have a length of 4.25 m.

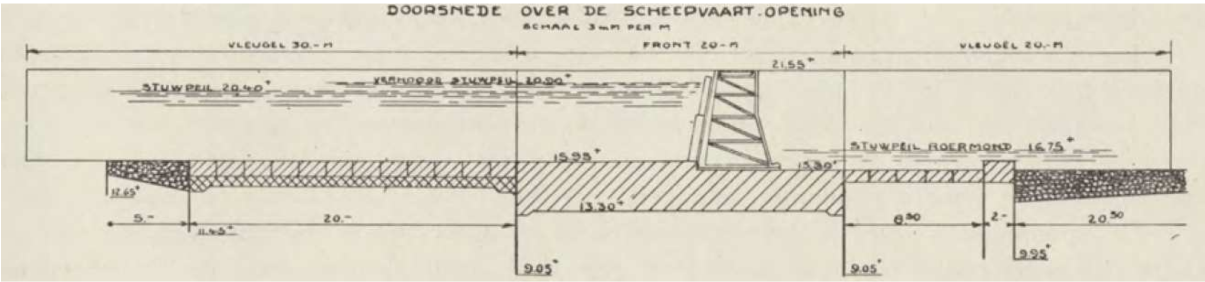


Figure 49 - Cross section of the Poirée part of weir Linne (Rijkswaterstaat, Kanalisatie van de Maas in Nederland - Verslag over de vorderingen van de werken in ther jaar 1921 en balans per 31 december 1921, 1921)

The Poirée weir consists of fifteen opening of each 4 m wide, which make a total width of 60 m. The openings are separated by metal frames, the yokes. On the top of the jokes are demountable bridge parts placed which connects the yokes with each other. In this way a framework between the yokes and the bridge parts occurs. The top of the bridge parts are on 21.55 m + NAP. The yokes are hingedly connected to the bottom so that the yokes can be rotated sideways to the bottom. The connection between the yokes and the bottom construction is represented in Figure 50. On the upstream side of the weir is the bottom slab 0.65 m thicker so that the yokes are lying behind the step when they are rotated to the bottom.

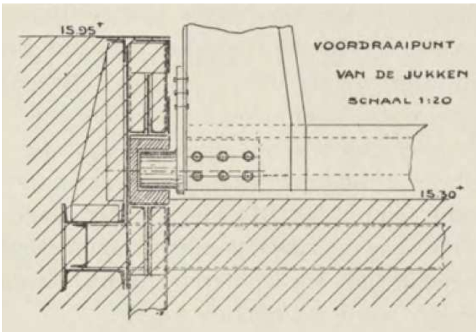


Figure 50 - Detail of the connetion between yoke and bottom (Rijkswaterstaat, Kanalisatie van de Maas in Nederland - Verslag over de vorderingen van de werken in ther jaar 1921 en balans per 31 december 1921, 1921)

On the upstream side of the weir are partitions placed against the yokes, these partitions cause the water setup in the canal section of Linne. Due to the water pressure are the partitions hold in place and no locks have to be used. Three partitions are placed on each other to obtain a sufficient weir height. The partitions are made of steel and are placed or removed one-by-one by means of a crane. The amount of partitions which are removed depends on the required discharge over the weir. The crane that removes or places the partitions moves on the rail on the bridge parts on top of the yokes.

It is possible for navigation to pass the Poirée part of the weir when the yokes are on the bottom. However, in practice will ships still use the weirs of Linne and Heel during high discharges because these are the shortest navigation routes.

3.1.2 Stoney weir

The weir of Linne contains three Stoney gates of each 17 m wide. The gates are placed between four hoisting towers. The top of the hoisting towers is at 31.30 m +NAP and the towers have a height of 14.35 m. The hoisting between the Stoney and Poirée part has a width of 6.5 m and the other towers a width of 4.0 m. During discharges higher than 1000 m^3/s are the gates completely lifted from the water to a height between 24.65 m +NAP and 28.00 m +NAP. The towers are placed on a 20 m wide bottom slab made of reinforced concrete. The top of the slab is at 16.95 m +NAP and the bottom at 13.65 m +NAP. On the downstream side of the weir is a stilling pool created with a depth of 1.2 m and a length of 15 m. On both sides of the floor slab are leakage screens placed up to a depth of 9.65 m +NAP.

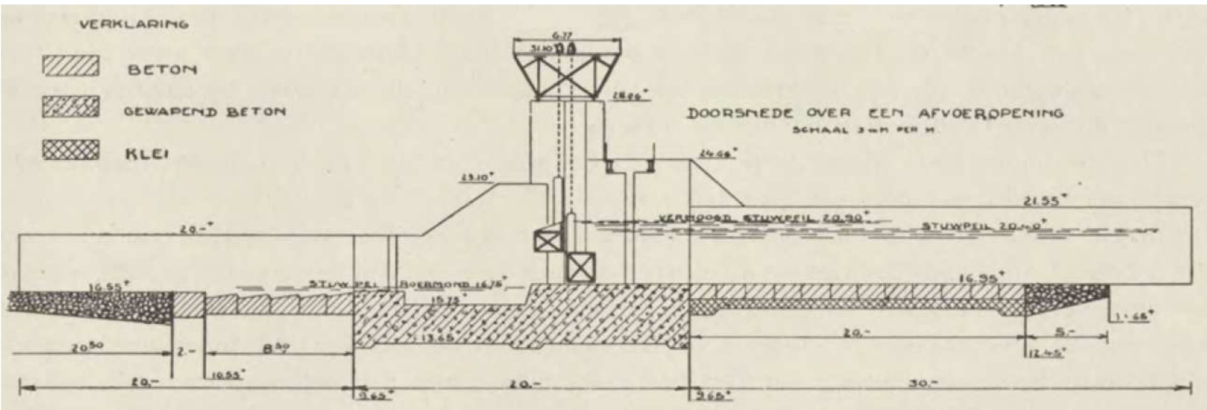


Figure 51 - Cross section of the Poirée part of weir Linne (Rijkswaterstaat, Kanalisatie van de Maas in Nederland - Verslag over de vorderingen van de werken in ther jaar 1921 en balans per 31 december 1921, 1921)

The gates are inclined between two hoisting towers. One opening contains two gates, a lower and a higher gate which can move independently. The gates are lifted by chains that are connected with the hoisting installations on top of the weir. The gates are place between guides in the hoisting towers. Because there are two gates the hoisting towers also contain two guides, a detail of the guides and gates is represented in Figure 52.

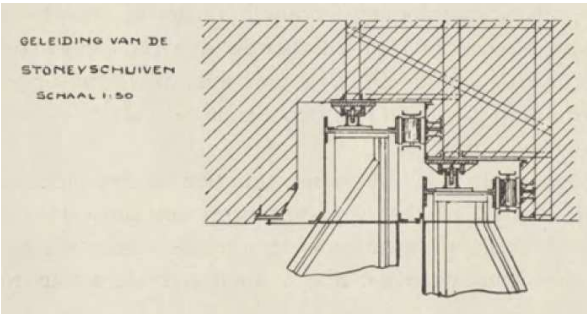


Figure 52 - Detail of the guidance of the Stoney gates (Rijkswaterstaat, Kanalisatie van de Maas in Nederland - Verslag over de vorderingen van de werken in ther jaar 1921 en balans per 31 december 1921, 1921)

On the upstream and downstream side of the weir are water guidance constructions made to create straight streaming lines over the weir. Straight streamlines over the weir are necessary to measure the discharge over the weir. In the guidance constructions are sleeves created to place beams, in this way maintenance on the weir construction can be done.

The discharge regulation of the Poirée weir has a stepped course. Every time when a partition is removed a the discharges increases by a certain amount of water so a precise control of the water level is not possible for a Poirée weir. To obtain a more precise control of the water level in the cala section of Linne are the Stoney gates used.

3.2 Fish ladder

The fish ladder is located on the south side of the weir complex and offers the opportunity for fish to pass the weir complex. The attracting stream of the fish ladder leads fish to the ladder. The ladder has a length of 215 m and a height difference of 4.05 m. The ladder is divided in 17 steps, the steps have been made of natural materials like rocks and gravel. The mean discharge of the fish ladder is about 3 m^3/s during average discharges, during high discharges will this be higher and during extreme discharges will the fish ladder be totally submerged.

Figure 53 - Fish ladder of weir Linne

3.3 Hydropower plant

On the south side of the weir is the hydropower plant of Linne situated. The plant is constructed between 1987 and 1989. The plant has a maximum head difference of 4 m. During average discharges is the discharge going through the plant to generate energy. The plant can handle a maximum discharge of 500 m^3/s, by higher Meuse discharges is also water discharged by the Stoney part of the weir. For discharges higher than 800 m^3/s is the power plant closed because the head difference between the up and downstream side becomes too small by higher discharges. About 287 days a year is the discharge lower than 500 m^3/s, 45 days between 500 - 800 m^3/s and about 33 days a year larger than 800 m^3/s. The power plant contains 4 turbines, each turbine is able to generate 2.87 MW so that the total 11.50 MW can be generated. With energy of the power plant are more than 100000 households served with sustainable energy (Bruijs, 2004).

The guidance system of the power plant has been constructed to prevent mortality of fishes near the hydropower plant. When fishes approach the hydropower plant will they be alarmed by the noise and vibrations of the turbines. The fishes react by swimming back along the bank. On each side of the banks are from water level to bottom fish entrances created. The entrances are connected to tubes which guides the fish around the hydropower plant and ends on the downstream side 4 m lower. The guidance system can only be used by fish going from upstream to downstream (FishFlow Innovations).

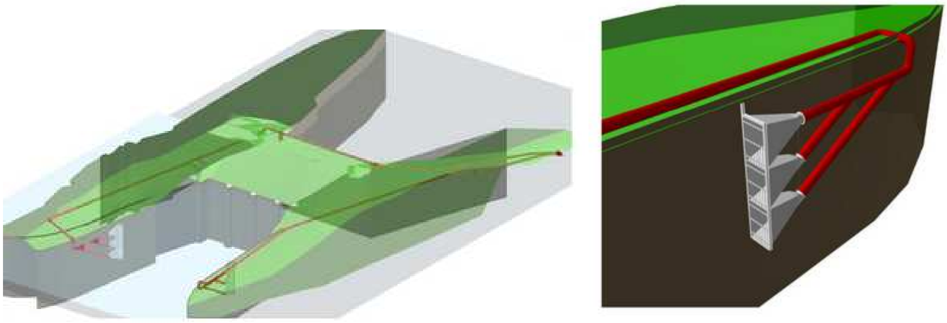


Figure 54 - Left: guidance system of the hydropower plant of Linne ; Right: detail of the entrances (FishFlow Innovations)

3.4 Spillway

The loop of the river behind the weir is called the Lus van Linne. The area functions as a floodplain during high discharges so that a higher discharge profile is created. During construction of the weir in is also a spillway next to the weir created. For higher discharges than about 1550 - 1650 m^3/s is water flowing over the spillway. In this way is the floodplain function of the Lus van Linne maintained. The top of the spillway is located on 21.30 m + NAP (Kurstjens, Peters, & Calle, 2008).

Figure 55 - Spilway of Linne, left: reconstruction of spilway; right: spillway during high discharges (beeldbank Rijkswaterstaat)

3.5 Weir management

Near the weir of Linne are different constructions used to discharge the water. For discharges lower than 500 m^3/s is no water flowing over the weir but is discharges by the hydropower plant. By discharges higher than 500 m^3/s is the Stoney weir activated to discharge the water together with the hydropower plant and the fish ladder. For higher discharges than 800 m^3/s are partitions removed from the Poirée weir so that the Poirée part takes a part of the total discharge. At this time also the hydropower plant is closed because the head difference between up and downstream becomes too low. At discharges higher than 1000 m^3/s are all the partitions of the Poirée part removed and the yokes lowered. In this way can water be discharged over the full 60 m of the Poirée weir. Also the Stoney gates are lifted out of the water. When discharges become larger than 1550 m^3/s also the spillway discharges water. A short summary is given in Table 31.

Table 31 - Weir management of weir Linne

Discharge [m^3/s]	Discharge construction
< 500	Hydropower plant + Fish ladder
500 - 800	Hydropower plant + Stoney weir + Fish ladder
800 - 1000	Stoney weir + Poirée weir (Poirée weir partly removed) + Fish ladder
1000 -1550	Stoney weir + Poirée weir (both removed from the water) + Fish ladder
> 1550	Stoney weir + Poirée weir (both removed from the water) + Fish ladder + Spillway

Appendix C: Stake holder analysis

1 Stake holders

1.1 Government (Rijksoverheid)

Two ministries are involved with the project, the ministry of Infrastructure and Environment and the ministry of Economical Affairs.
The ministry of Infrastructure and Environment focuses on livability and accessibility. The ministry is responsible for good infrastructural connections by road, rail, water and air, flood protection and improve the quality of air and water. The ministry has three primary tasks regarding the policy, this are: making and developing, implementing and inspection. The Royal Dutch Meteorological Institute (KNMI), Rijkswaterstaat and the Inspection of Environment and Transport are the agencies of the ministry.
The ministry of Economical Affairs has to deal with matters of the Dutche economy like trade, industry, communication, energy supply, innovation and agriculture. The intention of the ministry is to create a good and sustainable business environment by creating the right conditions and create possibilities for entrepreneurs. The possibilities have to focus on innovation, growth, focusing on nature and environment and cooperation of entrepreneurs and researchers. Also a creating a leading position for agriculture, industry, services and energy are of importance for the ministry.

1.2 Rijkswaterstaat

Rijkswaterstaat is the implementing organization of the ministry of Infrastructure and Environment and manages and develops the road network and waterways. The organization is responsible for the development, management and maintenance of the national network of roads and waterways. The organization is spitted up in seven districts, the sections are: Noord-Nederland, Oost-Nederland, Midden-Nederland, West-Nederland Noord, West-Nederland Zuid, Zee en Delta and Zuid-Nederland. The Meuse is located in the district Zuid-Nederland. The Meuseroute is not totally located in the district Zuid-Nederland, the Meuse-Waal Canal is located in the district Oost-Nederland. The tasks of Rijkswaterstaat for waterways can be split up in three groups:

- Basic functions
    - Safety against floods
    - Sufficient fresh, clean and healthy water
- Navigational functions
    - Safe and reliable traffic on the waterways for commercial navigation and recreational boating.
- Usage functions
    - Energy
    - Industry
    - Drinking water
    - Agriculture
    - Fishery (commercial and recreational)
    - Mining
    - Nature

1.3 Inspectorate for Environment and Transport (Inspectie voor Leefomgeving en Transport (ILT))

The Inspection for Environment and Transport is an agency of the ministry of Infrastructure and Environment. The task of the inspection is to ensure that companies, organizations and the government meet the laws and regulations in the fields of fiscal safety and environment. Since the first of January 2014 has the inspection the supervision of the primary flood defenses. Plans about the primary flood defenses have to be approved by the inspection on basis of the Wet op de Waterkeringen. The inspection wants a safe environment for people who live along the Meuse so measurements have to satisfy the safety levels.

1.4 Provinces

The provinces are the supervisors of the water boards. The provinces determine where roads, waterways or natural area will come. Therefore the province makes structural plans, municipalities and water boards take these plans into account by making their own plans. The province is also responsible for the construction and maintenance of provincial roads and bridges. The project area is located in three provinces, Limburg, Noord-Brabant and Gelderland.

1.5 Water Boards

The water boards are governmental organizations like the government, provinces or municipalities. Water boards are responsible for the flood defenses, water quality, water quantity and waterway management. The board consists of a Dijkgraaf, a general board and a daily board. The water boards have two tasks, the first task is to, maintain the water system including the water quality, quantity, flood defenses and barriers. The second task is the water treatment of wastewater.
The water boards involved in the project are: Roer en Overmaas, Peel en Maasvallei, Aa en Maas and Rivierenland. The water boards would like a safe environment for inhabitants and a good water management system.

1.6 Municipalities

The municipalities along the Meuse are important when changes along the Meuse are made. When making changes the so call 'bestemmingsplannen' of the municipalities should taken into account, the bestemmingsplannen are based on the structural plans of the provinces. The plans contain a description about the use of certain areas. Along the Meuse are several municipalities which have harbors, marinas, locks, weirs, quay walls or connections with other canals located on their territory. The municipalities are responsible for the management of commercial harbors along the Meuse. The municipalities benefit from good accessibility of the harbors and sufficient dept of waterways and harbors. Inhabitants of the municipalities use the Meuse and areas along the Meuse for recreation and profession. Municipalities have the task to server their inhabitants by for example creating opportunities for recreation.

1.7 Inhabitants

The people who live along the Meuse are maybe the most vulnerable for changes of the current situation. In general inhabitants want to live in a good, safe and pleasant environment with sufficient possibilities for employment and recreation. Exact wishes are hard to determine because different people have different interests. Sometimes people with the same interest organize themselves in organization to practice more influence on the decision makers like municipalities, water boards or companies.

1.8 Koninklijke Schuttevear

The Koninklijke Schuttevaer looks after interests of the commercial shipping in the Netherlands. The interests are in the field of nautical engineering and the infrastructure for inland navigation. This means in practice:

- More influence on waterway policy and budgets
- Provide in time maintenance and budgets
- Widening and deepening of waterways and harbors
- Optimal operation of locks and bridges
- Enough overnight, resting and waiting areas and influence on the layout of these areas.

1.9 Land- en Tuinbouw Organisatie Nederland (LTO Nederland)

LTO Nederland is a partnership of LTO Noord, ZLTO and LLTB and represents the farmers in the Netherlands. The partnership represents more than 50000 farmers and is committed to their ecomomical and social position. Important matters for LTO Nederland are:

- Durable water supply for farmers
- Innovation by means of improvement of crop which can better deal with drought
- High quality products
- Welfare by means of enough employment and production for farmers

1.10 Cascade (Cascade, 2011)

Cascade is the association of sand and gravel excavators. For the association and its members it is important to excavate gravel and stand in a durable manner. Excavation can be the basis for development of nature, recreation, water storage or safety by river widening. The goals of Cascade are:

- Represent the members by focusing on policy, regulations and technical aspects.
- To create a good environment for companies so that they can do their work in a proper way.

Along the Meuse are several excavation sides for sand and gravel, most of the projects are along the Border Meuse.

1.11 Energy companies

Several energy companies have installation along the Meuse. NUON owns two hydropower installations, one near the weir of Lith and one near the weir of Roermond. Essent owns a hydropower plant near the weir of Linne and the Clauscentrale near Maasbracht. The Clauscentale in an plant which uses gas or oil to raise energy. The power station uses Meuse water to cool the installation but contains also cooling towers to cool the installation during low discharges. The energy companies benefit from a sufficient discharge to maintain the energy production. Mainly the hydropower plants are influenced by the discharge, to low and to high discharges are not beneficial. Also an as high as possible height difference between up and downstream is beneficial for hydropower plants.

1.12 Enterprises

Many enterprises use the Meuse to transport their products by vessels. The enterprises are mainly located in the vicinity of harbors, the harbors are presented in Table 16. Also the commercial harbors itself are exploited by private parties but the management is in hands of the municipalities. Most of the marinas are in private hands. The enterprises benefit from a good accessibility of the harbor during the year. Also the possibility to enter the harbors with large ships is beneficial for enterprises because larger ships mean lower transport costs for their products. The marinas benefit just like commercial harbors from a good accessibility.

1.13 Nature conservators

The natural areas along the Meuse are managed by several organizations. The organizations are: Staatsbosbeheer, Natuurmonumenten, Het Limburgs Landschap and ARK. The ornaizations protect and maintain the different natural areas. Because some of these areas are located in the floodplains or just along the river can these areas be affected by changes on the Meuse. The organizations should do everything possible to protect special plants and animals living in the natural areas along the Meuse. Every operation should be tested according the Flora- en Faunawet.

Appendix D: KNMI'14 Scenario's

1 Climate scenarios

The KNMI06 represented four scenarios for the future. The scenarios are based on uncertainties in climate change and uncertainties is the economical development. The climate has a influence precipitation, because the Meuse is a rain river has the a change of precipitation a direct influence o the discharge of the Meuse. The economical development is one of the influencing factors which determines the rate of transport on the Meuse.

The KNMI divided four scenarios to describe possible scenarios for the future, the scenarios are called Druk, Stroom, Rust and Warm. The scenarios do not only present fiscal and social economical enviromental condition but also changes in the use of land, water and space. In Table 32 are the indicators for the different scenarios represented.

1.1 Druk

The scenario Druk focuses on moderate climate change and a strong economical growth. The points of interest of this scenario are:

- The population of the Netherlands increases to 25 million in 2100
- Concentration of urbanization in climate adaptive cities
- Intensivation of agriculture and a decrease of grassland
- High quality and connected natural areas get more attention
- International transport over water increases over seas and oceans as well for inland navigation
- Moderate climate change leads to a minimum change of low and high discharges on the major river in the Netherlands

The higher economical interests and the increasing population demand higher requirements on the flood protection against flood of cities along the Meuse. However due to the moderate change of the discharges should this not be a hard task because the cities along the Meuse are already prepared to situation of high water. Innovation increases the possibility for different sectors to use water more effectively. In this way have the agricultural sector enough water and are less dependent of water from the river. The economical growth increases the international navigation, also on the Meuse. This requires an expansion of the waterway network. Because of the moderate climate changes should there be no problems with the navigational depth on the rivers.

1.2 Stroom

The scenario Stroom focuses on strong climate change and a strong economical growth. The points of interest of this scenario are:

- The population of the Netherlands increases to 25 million in 2100
- A strong increase of the spreading of urbanization
- Intensivation of agriculture and a decreasing of the agricultural are
- Nature for recreation becomes more important
- International transport over water increases over seas and oceans as well for inland navigation
- Extreme low and extreme high discharges become more frequent due to climate change. Extreme drought and intensive rainfall occur more and more

A strong growth of the population and economical situation of the Netherlands combined with a fast climate change results in a decrease of safety. The intensive agriculture requires permanent and high quality water, also the demand of water for other purposes increases. The management of water levels in rivers becomes difficult due to the spreading of urbanization. Navigation experiences trouble from the climate change because the number of navigable days decreases due to more high and low waters.

1.3 Rust

The scenario Rust focuses on moderate climate change and a low economical growth. The points of interest of this scenario are:

- The population of the Netherlands decreases to 12 million in 2100
- Urbanization decreases gradual and lots of villages disappear
- Number of agricultural areas does not change.
- Increase of natural areas
- New technologies improves the increases of a sustainable economy
- Transport over water creases after 2050, the share of inland navigation increases due to the accent on durable transport.
- The moderate climate change causes limited changes in the occurrence of high and low discharges of the rivers.

The decreasing population and decreasing economy causes lower safety levels of the flood protection along rivers and coastal areas. The agriculture and nature demands for fresh water decreases, also the demands for water level management decreases. The small-scale navigation on the rivers keeps the maintenance of the water levels for navigation easier. The increase of multimodal transport sets requirements on the network of waterways. The probability of floods and water shortage decreases.

1.4 Warm

The scenario Rust focuses on strong climate change and a low economical growth. The points of interest of this scenario are:

- The population of the Netherlands decreases to 12 million in 2100
- Urbanization decreases gradual and lots of villages disappear
- Decrease of agricultural areas until 2050
- Increase of natural areas
- Transport over water decreases after 2050 in by meaning and intensity
- Fast climate change leads to extreme low and extreme high discharges of the large rivers. Navigation experience troubles.

The decrease of the population and the decrease of economical environment sets lower restrictions on the safety level along the rivers and coastal areas. Navigation is hindered by the increasing number of days of low water levels on the rivers. By separation of functions of the rivers becomes the fresh water supply less complicated. Due to the strong climate change is the number and height of the water high water levels increasing. Besides the number of days of low water does this phenomena also affects navigation on rivers.

Table 32 - Deltascenarios for the Meuse (de Wit, Buiteveld, & van Deursen, 2007) & (Bruggeman, et al., 2013)

	2000	Druk		Stroom		Rust		Warm	
		2050	2100	2050	2100	2050	2100	2050	2100
Average discharge in Februari [m^3/s	480	500	520	500	590	500	520	530	590
Average discharge in September m^3/s	89	92	94	48	30	92	94	48	30
Extreme high discharge 1/100 year m^3/s	2900	3000	3200	3200	3600	3000	3200	3200	3600
Extreme low discharge 1/10 year m^3/s	18	18	18	10	6	18	18	10	6
Repetition time of the Meuse discharge > 3.600 m^3/s [/year]	1250	1000	400	400	100	1000	400	400	100
Design discharge m^3/s [1/1250 year]	3800	4000	4200	4200	4600	4000	4200	4200	4600
Dry periods (50 connected days of discharges lower than 30 m^3/s): repetition time [year]	300	300	300	20	4	300	300	20	4
Economical growth [bbp, %/year]		2.5	2.5	2.5	2.5	1.0	0.5	1.0	0.5

Appendix E: Requirements analysis

1 Level 1: the Meuse

1.1 Customer Requirements

The customer requirements define the expectations and wishes of the customer. The purpose is to determine what the requirements of the costumer are for a well functioning system and in which way each function should be fulfilled. The main costumer in the project is Rijkswaterstaat. Rijkswaterstaat wants a well functioning and manageable Meuse system. The requirements of the customer have to be taken into account by in the project. As can be read in the stakeholder analysis are the expectations of Rijkswaterstaat divided into three groups.

- Basic functions:
    - A well functioning river system has to deal in the right way with the river discharges. The discharge sets requirements on the flood defense system because discharges vary not only throughout the year but can also change over the years. During these changing situation should the area along the river be a safe environment. The requirements for the flood defense are:
        - Protecting the hinterland against flooding
        - Protecting the hinterland by a certain safety level
        - Discharging water from Eijsden to the Haringvliet
        - A manageable and safe discharge of water through the Meuse system.
    - The supply of clean and healthy water is required because Meuse water is used for several purposes and activities. The proposes and activities require a certain level of water quality. However the quality of different purposes can be varying is water of a good quality important. The requirements for the water quality are:
        - Supplying water with a sufficient quality according the Kaderrichtlijn Water (KRW)
        - Maintaining and restoring the natural environment of the Meuse
        - Maintaining recreational activities along the Meuse.
- Navigational functions
    - Navigation is an important function of the Meuse. The system has to be suitable for navigation, in these days and the future. The requirements of navigation to the project are:
        - Sufficient draught should be available for navigation on the river
        - Sufficient width should be available for navigation on the river
    - The weirs of Borgharen and Linne must be present in the new design.
- Usage functions
    - All users are welcome on the river however not all factions can be fulfilled, the basic functions and navigational functions are priority.

1.2 Constraints

Constraints can be internal or external. The internal constraints are the constraints of the system itself and the external constraints coming from outside and affect the system. The internal constraints of the Meuse have to do with:

- The discharge capacity of the Meuse must be equal to the discharge from the upstream boundary, tributaries and streams.
- A minimum discharge over the Border Meuse is restricted.
- Side canals should be fed with water from the Meuse

The external constraints are:

- The water which enters at the upper boundary plus the water from tributaries and streams must leave the lower boundary.

1.3 Operational scenarios

Four operational scenarios are taken into account in this project. The scenarios are defined by the KNMI and are called the KNMI06 scenarios.

1.4 Functional requirements

The functions a specific process, action or task that the system is able to perform. The requirements are described as a set of inputs, the behavior and the outputs. Functional requirements can be calculations, technical details, process data or other requirements that define what the system should be accomplish. The functional requirements are described for the different river sections, canals and tributaries and streams.

- River sections
  - Upper Meuse — discharge & navigation
  - Border Meuse — discharge & navigation (only recreational)
  - Meuse Lakes — discharge & navigation & recreation
  - Peelhorster Meuse — discharge & navigation
  - Venloslenk — discharge & navigation
  - Lower Meuse — discharge & navigation
  - Tidal Meuse — discharge & navigation
  - Bergsche Meuse — discharge & navigation
  - Amer — discharge & navigation
  - Hollands Diep — discharge & navigation
  - Haringvliet — discharge & navigation
- Canals
  - Julian Canal — navigation
  - Lateral Canal — navigation
- Tributaries and streams
  - Voer — discharge
  - Jekker — discharge
  - Geul — discharge
  - Swalm — discharge
  - Roer — discharge & navigation (only recreational)
  - Grootte Molenbeek — discharge
  - Niers — discharge
  - Graafsche Raam — discharge
  - Dieze — discharge & navigation

1.5 Performance requirements

The performance requirements describe in which way the system is functioning well. The performance requirements are expressed in rate, quality, quantity, degree etc.

1.6 Utilization environments

The utilization environments like temperature or weather conditions are not defined on this level.

1.7 Effectiveness requirements

The effectiveness requirements should be determined to define how well the system acts according to the expectations and wishes of the costumer.

- De amount of water the river has to discharge during high waters

1.8 Operational life cycle

Operational life cycles can be determined for every part, object, construction, verification etc. of the project. The operational life cycle gives requirements about how long the system or system parts should be operable.

1.9 Technical performance

The technical performance are the measurements which are used during the design. The values of the measurements can be used to check if the design fulfills the technical requirements. Measurements like a minimal discharge through the Meuse or the tension strength of steel can be verified.

- Maximum discharges for the Meuse
- Minimum discharges for the Meuse

1.10 Operation modes

The Meuse is a dammed river so has different modes of operation. Three modes can be defined:

- Fully dammed situation
    - A small amount of water is discharged, in this situation are all weirs closed to maintain the water level
- Partly dammed situation
    - Discharges are higher than normal, in this situation are the weirs partly removed
- Undammed situation
    - Discharges are high, in this situation are weirs removed so the river is undammed.

1.11 Interfaces

The interfaces have been spitted into two group, the first group contains interfaces in relation to discharges and the second group interfaces related to navigational connections. Both groups of interface requirements are just like the Constraints divided in two types, internal and external. The internal interfaces are the interfaces inside the boundary conditions and the external interfaces are the interfaces from outside of the boundary conditions. The internal interfaces are:

- Water is flowing from the Upper Meuse into the Border Meuse.
- Water is flowing from the Upper Meuse into the Juliana Canal
- Water is flowing from the Border Meuse into the Meuse Lakes
- Water is flowing from the Meuse Lakes into the Peelhorster Meuse
- Water is flowing from the Peelhorster Meuse into the Venloslenk
- Water is flowing from the Venloslenk into the Lower Meuse
- Water is flowing from the Lower Meuse into the Tidal Meuse
- Water is flowing from the Tidal Meuse into the Bergsche Meuse
- Water is flowing from the Bergsch Meuse into the Amer
- Water is flowing from the Amer into the Hollands Diep
- Water is flowing from the Hollands Diep into the Haringvliet
- Water is flowing from the Haringvliet into the North Sea

External

- Water is flowing from the upper boundary into the Upper Meuse
- Water is flowing from the Tidal Meuse to the lower boundary.

- Water from the Voer is flowing into the Upper Meuse
- Water from the Jeker is flowing into the Upper Meuse
- Water From the Geul is flowing into the Border Meuse
- Water from the Swalm is flowing into the Border Meuse
- Water from the Roer is flowing into the Meuse Lakes
- Water from the Groote Molenbeek is flowing into the Peelhorster Meuse
- Water from the Niers is flowing into the Peelhorster Meuse
- Water from the Graafsche Raam is flowing into the Lower Meuse
- Water from the Dieze is flowing into the Tidal Meuse

2 Level 2: Configuration of the Canalized Meuse

2.1 Customer requirements

The customer requirements define the expectations and wishes of the customer. The purpose is to determine what the requirements of the costumer are for a well functioning system and in which way each function should be fulfilled. The main costumer in the project is Rijkswaterstaat. Rijkswaterstaat wants a well functioning and manageable Meuse system. The requirements of the customer have to be taken into account by in the project. The expectations of Rijkswaterstaat are:

- Basic functions:
    - Safety
        - Protecting the hinterland along the canalized Meuse against flooding
        - Protecting the hinterland by a certain safety level
    - The supply of fresh, clean and healthy water
- Navigational functions
    - Navigation
        - Sufficient draught should be available for navigation on the river
        - Sufficient width should be available for navigation on the river
        - Less hindrance and delays by passing locks or bridges
- Usage functions
        - Energy
        - Industry
        - Drinking water
        - Agriculture
        - Fishery (commercial and recreational)
        - Mining
        - Nature
- Other requirements
    - Maintenance should be easily applied
    - The configuration must be adaptable on the changing conditions in the future
    - The configuration must be adaptable to changing situations in the future

2.2 Constraints

Constraints can be internal or external. The internal constraints are the constraints of the system itself and the external constraints coming from outside and affect the system. The internal constraints of the canalized Meuse have to do with:

- Navigation on the Meuseroute may not be totally blocked during construction
- The Juliana Canal and the Lateral Canal must be accessible during construction
- Discharge over the present weirs may not be hampered
- Harbors must be accessible during construction

- Drink water plants must be operable during construction
- Water level changes along the canalized Meuse should be avoided during construction
- The discharge capacity of the river may not be affected during winter periods.
- Water inlets along the canalized Meuse must be operable during construction
- Pumping stations along the canal sections of Grave and Lith must be able to discharge water from the polders into the river during construction

External constraints

- The connecting canals must be accessible for navigation during construction
- Solutions must be in accordance with laws and treaties:
    - European
        - Kaderrichtlijn Water
        - Natura 2000
        - Floods Directive (Hoogwaterrichtlijn)
        - Directive fishing water (Viswaterrichtlijn)
        - Dirrective swimming water (Zwemwaterrichtlijn)
    - National
        - Waterwet
        - Environment maintaining law (Wet milieubeheer)
        - Flora and Fauna law (Flora en Faunawet)

2.3 Operational scenarios

The operational scenarios give a clear view about possible situations in the future. It has to be clear that operational scenarios are no future predictions but possible situation based on the knowledge of today. The scenarios can be related to climate changes, economical changes, political environment etc. The scenarios give handles to a design so that a design will also be operable in the future. The four aspects are represented by the KNMI in the Deltascenarios for 2050 and 2100. Four scenarios are distinguished namely, Druk, Stroom, Rust and Warm. More information about the scenarios can be found in Appendix D. The requirements that the different scenarios prescribe are:

- Druk
    - The corridor must be suitable for an increase of navigational transport
    - Locks must be suitable for the increasing navigational transport
    - Harbor has to be adopted to the increasing economical situation
    - Decreasing demand of river water for agriculture
    - Flood protection becomes more important due to urbanization
    - Nature should have more attention
- Stroom
    - Flood protection becomes more important due to urbanization
    - Nature must have a more important recreational function
    - The corridor must be suitable for an increase of navigational transport
    - Locks must be suitable for the increasing navigational transport
    - The water depth must be maintained during low discharges for navigational purposes
    - Leakage of weirs and locks must be as low as possible during periods of low discharge
    - Harbor has to be adopted to the increasing economical situation
    - The must be able to discharge higher amounts of water during wet periods
    - Weirs must be able to discharge higher amounts of water during wet periods
- Rust
- Warm
    - The must be able to discharge higher amounts of water during wet periods

- Weirs must be able to discharge higher amounts of water during wet periods
- During low discharges must navigation be able on the river

2.4 Functional requirements

The functional requirements describe the functions of the different canal sections. The canal sections can have one of more functions. The functions of the different canal sections are:

- Canal sections
  - Borgharen — discharge & navigation
  - Born — navigation
  - Maasbracht — navigation
  - Linne — discharge & navigation
  - Roermond — discharge & navigation & recreation
  - Belfeld — discharge & navigation & recreation
  - Sambeek — discharge & navigation
  - Grave — discharge & navigation
  - Lith — discharge & navigation

2.5 Performance requirements

The performance requirements describe in which way the system is functioning well. The performance requirements are expressed in rate, quality, quantity, degree etc. The preformance requirements for the canalized Meuse are:

- Discharge of 3800 m^3/s in 2015
- Discharge between 4000 and 4200 m^3/s in 2050
- Discharge between 4200 and 4600 m^3/s in 2100
- Meuseroute must be accessible for class Vb vessels.
- Transport of sediment must be able during high discharges
- The flood protection along the Undiked Meuse should have a safety level of 1/250
- The flood protection along the Undiked Meuse should have a safety level of 1/1250
- Vessels must be able to navigate underneath the bridges over the river and canals
- The required water levels to the canal sections
  - Canal section Borgharen
    - Maintain a water level of 44.05 m + NAP during normal situations
  - Canal section Born
    - Maintain a water level of 44.05 m + NAP during all situations
  - Canal section Maasbracht
    - Maintain a water level of 32.65 m + NAP during all situations
  - Canal section Linne
    - Maintain a water level of 20.20 m + NAP during normal situations
  - Canal section Roermond
    - Maintain a water level of 16.85 m + NAP during normal situations
  - Canal section Belfeld
    - Maintain a water level of 14.10 m + NAP during normal situations
  - Canal section Sambeek
    - Maintain a water level of 10.85 m + NAP during normal situations
  - Canal section Grave
    - Maintain a water level of 7.60 m + NAP during normal situations
  - Canal section Lith
    - Maintain a water level of 4.90 m + NAP during normal situation

2.6 Utilization environments

The utilization environments like temperature or weather conditions are not defined on this level

2.7 Effectiveness requirements

The effectiveness requirements should be determined to define how well the system acts according to the expectations and wishes of the costumer and important stakeholder. The effective requirements are:

- Number of navigable days during the year

2.8 Technical performance

The technical performance are the measurements which are used during the design. The values of the measurements can be used to check if the design fulfills the technical requirements. Measurements like a minimal discharge through the Meuse or the tension strength of steel can be verified.

- The minimum navigable days in a year

2.9 Operation modes

There are three modes of operation for the canalized Meuse, namely a closed situation, a partly opened situation and a fully opened situation. The close situation is when the discharges of the river are smaller than 200 m^3/s. In this situation maintenance of the required water level is the most important during low discharges so that navigation can go on. The partly closed situation arises when the discharge is between 200 m^3/s and 1000 m^3/s. The weirs in the river are partly opened, maintenance of the required water levels and water discharge are both important during this situation. When discharges become higher than 1000 m^3/s are all weirs open, this is the fully opened situation. In this situation is the discharge of the river the most important requirement.

2.10 Interfaces

The interfaces are split in internal and external interfaces. The internal interfaces are the connections between the elements inside the system and the external interfaces are the connections with elements outside the system. The internal interfaces are:

- Navigation
  - Navigational connection between the canal sections of Borgharen and Born
  - Navigational connection between the canal sections of Born and Maasbracht by the lock of Born
  - Navigational connection between the canal sections of Maasbracht and Linne by the lock of Maasbracht
  - Navigational connection between the canal sections of Linne and Roermond by the lock of Linne
  - Navigational connection between the canal sections of Linne and Belfeld by the lock of Heel
  - Navigational connection between the canal sections of Roermond and Belfeld by the lock of Roermond
  - Navigational connection between the canal sections of Belfeld and Sambeek by the lock of Belfeld
  - Navigational connection between the canal sections of Sambeek and Grave by the lock of Sambeek
  - Navigational connection between the canal sections of Grave and Lith by the lock of Grave
  - Navigational connection between the canal section of Lith and the Tidal Meuse by the Prinses Maximasluizen.

    - Navigational connection between the tidal Meuse and the Waal by the lock of Sint Andries
- Dimensions of the Locks of the canals along the system
- Passage for fish and other species to travel through the system
- Water levels in the harbors along the system caused by the weirs
- Transport of sediment through the canal sections of the system

External:

- Navigation
    - Navigations enters and leaves the system
    - Navigational connection between the upper boundary and the canal section of
    - MaasbrachtNavigational connection between the weir of Lith and the lower boundary
    - Navigational connection between the canal sections of Maasbracht and the Zuid-Willemsvaart by the lock of Boschpoort
    - Navigational connection between the canal section of Linne and the Canal Wessem-Nederweert by the lock of Panheel
    - Navigational connection between the canal section of the canal section of Grave and the Waal by the lock of Heumen
- Dimensions of the locks between the canal sections of the system
    - Height of the sill
    - Width of the lock
- Water levels
    - The water levels in the connecting canals
- Inlets
    - Height of the inlets
    - Intake of the inlets
- Fish must be able to entering and leaving the system

3 Level 3 weir Linne

3.1 Customer Requirements

The customer requirements define the expectations and wishes of the customer. The purpose is to determine what the requirements of the costumer are for a well functioning weir and in which way each function should be fulfilled. The main costumer in the project is Rijkswaterstaat. The main customer requirements are:

- The design of the weir must be innovative
- Changing design principles
    - The weir must be adaptable to the different scenarios
        - The construction should be adaptable to changing discharges
        - The construction should be adaptable to larger ships
- Maintainability
    - An easy and good maintainable solution is preferred
- Use and control
    - The weir should be able to be controlled from the central control room in Maasbracht
    - A variable dam regime must be possible
- The weir must meet the latest standards and design guidelines

3.2 Constraints

Constraints can be internal or external. The internal constraints are the constraints of the system itself and the external Constraints coming from outside and affect the system. The internal constraints of the canal section of Linne have to do with:

- The gates must be high enough to obtain enough water setup
- The weir have to be adaptable in case of changing situations in the future
- Navigation may not be blocked during construction
- The harbors of Maasbracht and Wessem must be accessible during construction
- The solution should agree the requirements according the Eurocodes

External constraints:

- Minimum water levels have to be maintained to create enough navigable depth
- The weir must have sufficient capacity to discharge the water during high water levels on the river

3.3 Operational scenarios

The operational scenarios and the associated requirements as described in Level 2 are still valid for the design of the weir.

3.4 Functional requirements

- Upstream side
    - Sufficient capacity of the approach canal for the discharge of water
    - The bottom on the upstream side of the weir should be defended against scour and erosion
- Downstream side
    - Sufficient capacity for the discharge of water
    - The bottom on the downstream side of the weir should be defended against scour and erosion
- Gates
    - Have to regulate the discharge
    - Have to regulate the water level in the canal section
    - Transferring the hydrostatic and hydro dynamical forces to the columns
    - Withstand collisions with vessels
- Columns
    - The columns have to transfer the loads on the gates to the foundation
    - Construction to connect the hoisting installation
    - Landmark in the landscape
- Bottom plate and foundation
    - Transferring loads to the subsoil
    - Preventing piping under the construction
    - Ensure the stability of the construction
    - Preventing lift up of the construction

3.5 Performance requirements

- Upstream side
    - Discharge 3800 m^3/s in 2015
    - Discharge between 4000 and 4200 m^3/s in 2050
    - Discharge between 4200 and 4600 m^3/s in 2100
    - Bottom is defended against erosion
- Downstream side

    - Discharge 3800 m^3/s in 2015
    - Discharge between 4000 and 4200 m^3/s in 2050
    - Discharge between 4200 and 4600 m^3/s in 2100
    - Bottom is defended against erosion
    - Bottom behind the construction should be defending against scour holes
- Gates
    - Maintaining a water level of at least 20.80 m +NAP
    - Less leakage in the closed situation than in the current situation
- Columns
    - Load transfer between gate and bottom
    - Landmark
- Foundation
    - Load transfer between constructin and bottom

3.6 Utilization environments

The utilization environments has to do with the environmental situation of the system like temperature or weather conditions.

- The weir must be operable 24 hours a day
- The weir has to withstand all the weather conditions in the area

3.7 Effectiveness requirements

The effectiveness requirements should be determined to define how well the system acts according to the expectations and wishes of the costumer and important stakeholder. The effective requirements are:

- Number of days that the weir is totally opened

3.8 Technical performance

The technical performance are the measurements which are used during the design. The values of the measurements can be used to check if the design fulfills the technical requirements. Measurements like a minimal discharge through the Meuse or the tension strength of steel can be verified. The technical requirements are:

- Horizontal, vertical and rotational stability of the construction
- Length of the screens against piping
- Allowable soil pressure under the weir construction
- Stability of the bottom protection
- Discharge which passes the weir complex
- Deformations
- Allowable stresses in all parts of the weir construction (depending on the materials)

3.9 Operation modes

The modes of operation are the same as for Level 2.

3.10 Interfaces

The interfaces are split in internal and external interfaces. The internal interfaces are the connections between the elements inside the system and the external interfaces are the connections with elements outside the system. The internal interfaces are:

- Water flow from the upstream side to the downstream side of the weir
- Connection between the gates and columns
- Connection between the columns and the bottom slab
- Connection between the bottom slab an foundation

- Connection between the hoisting machine and the gates
- Transition between the bottom slab and the bottom protection on the upstream and downstream sides of the weir

External:

- Water is entering and leaving the weir
- Connection of the weir with the banks

Appendix F - Canalized Meuse

1 Canal section Borgharen

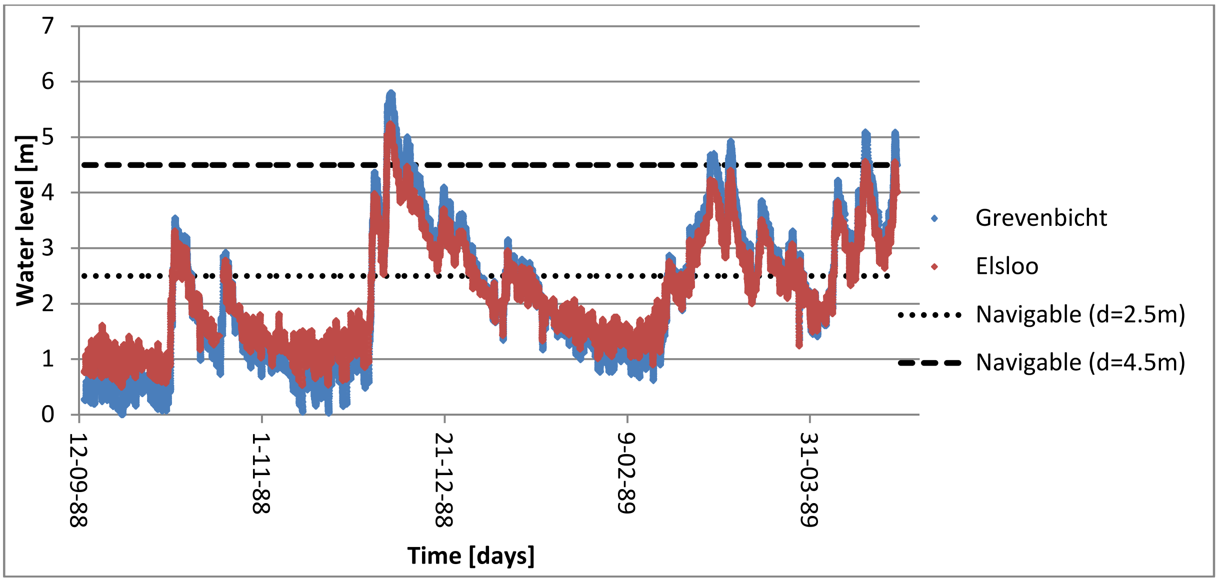
1.1 Situation

The canal section of Borhargen is the most upstream canal section in the Netherlands. The section starts at the Belgian Ternaaien and ends at Borgharen in the Netherlands. The normal water level in the canal section is 44.05 m + NAP and is determined by the weir at Borgharen. The weir forms a border between the dammed Upper Meuse and the free flowing Border Meuse. By removing the weir of Borgharen will the Meuse until Ternaaien also become a free flowing river.

1.2 Navigation

By removing the weir of Borgharen will navigation of large vessels on the Upper Meuse become impossible during large periods of the year. The required vessel class on the Meuse requires a minimum draught between 2.5 m and 4.5 m.

The water levels of two measuring points along the Border Meuse are represented in Graph 6. It can be seen that navigation on the Border Meuse is nearly not possible for vessels with a draught of about 4.5 m. Vessels with a draught of 2.5 m are able to navigate during periods of the year over the Border Meuse. However due to the high steepness of the Border Meuse profile are the flow velocities on relatively high, the flow velocities can differ between 0.4 and 5.5 m/s (Ministerie van Verkeer en Waterstaat, Beheerplan Natura 2000 Grensmaas 2009-2015, 2009).



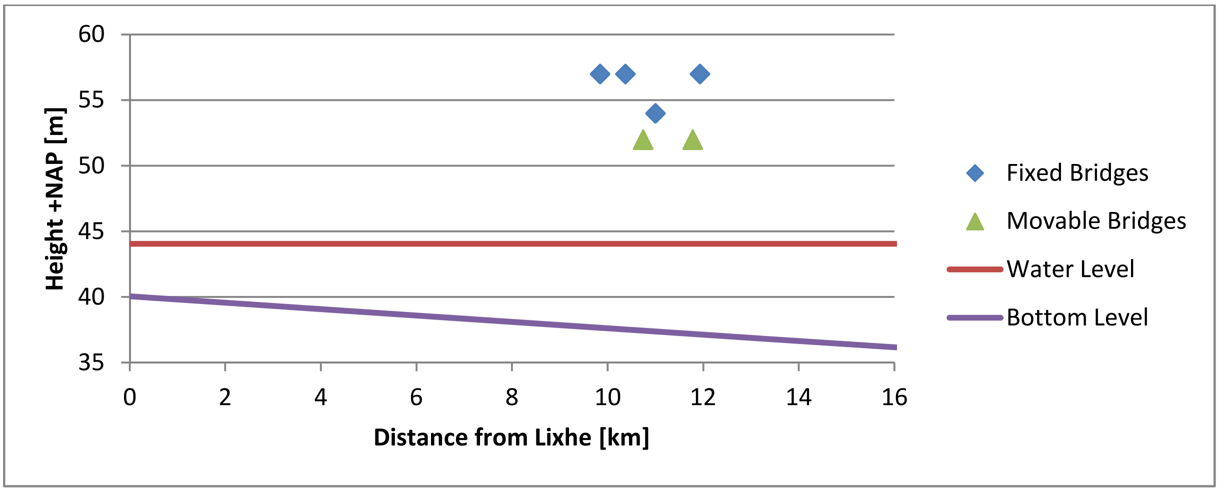
Graph 6 - Water level changes at the Border Meuse

By removing the weir of Borgharen will the free flowing river regime from of the Border Meuse will extended until Ternaaien. T he water level in this canal section will drop, which means that the Meuse from Ternaaien until Limmel (starting of the Juliana Canal) will become unnavigable for commercial shipping.

An alternative route in this situation could be over the Albert Canal, the Zuid-Willemsvaart and the Canal Wessem-Nederweert to the Meuse near Wessem. However the Zuid-Willemsvaart is partly suitable for CEMT II and partly for CEMT IV class vessel. The Canal Wessem-Nederweert is only suitable for vessels of the CEMT II class vessels. Both canals and locks should be renovated and have to be made suitable for CEMT Vb class vessels which will cost lots of money. This route is also much longer than the traditional route over the Meuse and Julian Canal which is not beneficial for shipping companies because it will cost them more fuel.

1.3 Bridges

As Europeans standard for international connections is the CEMT Vb class taken. For this class a minimal vertical clearance of 7.0 m is required for the transportation of containers (Ministerie van Infrastructuur en Milieu, 2011). In the Netherlands is a minimum vertical clearance for container vessels of the Vb class required (Rijkswaterstaat, Scheepvaartinformatie Hoofdvaarwegen, 2009). In Graph 7are the bridges over the Meuse in canal section Borgharen represented. Only the bridges over the navigational part are represented, the bridge near the weir of Ternaaien is not represented because there is no navigational transport in that part of the Meuse. Navigation is using in this part of the Meuse the parallel located Albert Canal. At Eijsden is a connection between the Albert Canal and the Meuse created so that vessels are able to enter the Dutch part of the Meuse. The bridges represented are all located in and around Maastricht.

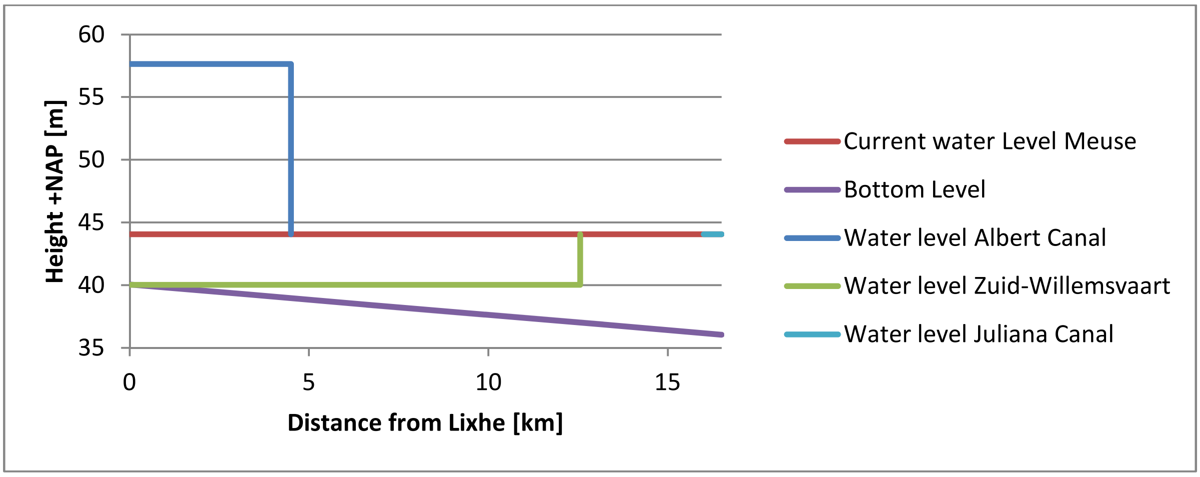


Graph 7 - Canal section Borgharen

The drop of the water level due to the removal of the weir has an positive effect on the clearance under bridges over the Meuse in the canal section of Borgharen. However nearly no navigation is possible after removing the weir.

1.4 Locks

The water levels of the canal section of Borgharen, the Albert Canal and the Zuid-Willemsvaart around Maastricht are represented in Graph 8.



Graph 8 - Connecting channels to canal section Borgharen

In the Canal section of Borgharen are three locks located. The first lock is located near Eijsden (on Belgian territory) and enables a navigational connection between the Albert Canal and the Meuse. The lock complex consists of 3 lock chambers, two lock chambers have miter gates directed to the Albert Canal and one lock has lifting gates. The water level in the Albert Canal is 57.65 m +NAP and the current water level in the canal section of Borgharen 44.05 m +NAP. When the water level in canal section Borgharen drops it will be discussable if the gates are able to resist the larger water head. Maybe the doors have to be replaced for stronger ones.

The second lock is lock Boschpoort. The lock is located just above Maastricht and enables a connection between the Meuse and the Zuid-Willemsvaart. The water level in this part of the Zuid-Willemsvaart 40.30 m +NAP so lower than the current water level of canal section Borgharen. The lock consists of one chamber with lifting gates. The drop of the water level by removing the Borharen weir could have a positive effect on lock Bosschpoort because the water head over the gates become smaller so also the hydraulic loads. However when the water in the canal section drops below the water level of the Zuid-Willemsvaart will the hydraulic loads turn around, the question is if the doors are able to handle this change of load direction.

The third lock is located at the beginning of the Juliana Canal. This lock is actually a guard lock which is opened under normal conditions. When the water in the canal section Borgharen becomes too high will the guard lock be closed. The lock consists of two chambers with lifting gates. When the weir of the Borgharen is removed should the guard lock permanently be closed to maintain the water level on the Juliana Canal until Born.

1.5 Flood protection

The removal of weir Borgharen has little influence on the flood protection along this canal section because during high discharges is the weir removed and the water can flow freely from canal section Borgharen to the Border Meuse. However the flood protection is calculated based on a governing discharge of 3800 m^3/s. Because the governing discharges in the future will become higher should the high water protection in the future be raised.

1.6 Harbors

The canal section of Borgharen contains one commercial harbor near Maastricht. By removal of weir Borgharen will the harbor of Maastricht be inaccessible for large vessels. The companies in the harbor of Maastricht should move to other locations on the Meuse. An option could be an new harbor on the west side of Maastricht along the Albert Canal. However this harbor should be created on Belgian territory.

The canal section contains two yacht harbors, one near Eijsden and one near Maastricht. Because recreational boating is also on the Border Meuse is assumed that recreational boating should also be possible in the canal section Borgharen after removing of the weir. The two recreational harbors are equipped with floating jetties so a drop in the water level should be no problem.

2 Canal section Born

2.1 Situation

The canal section of Born is the second canal section of the main navigation route. The canal section of Born is not located at the Meuse but on the Juliana Canal. The canal section ends at Born, here is only a lock located and no weir. The reason is that the Juliana Canal is only used for navigation and not for discharging of water, the water discharge is managed by the Border Meuse. The water level in this canal section is normally the same as the water level in canal section Borgharen so 44.05 m +NAP. The canal sections are divided by a guard lock that can be closed when the water level in canal section Borgharen becomes too high. By removing the locks of Born will the water level in the canal section Born be managed by the locks of Maasbracht at the end of the Juliana Canal. So the canal section of Born is now part of the canal section Maasbracht.

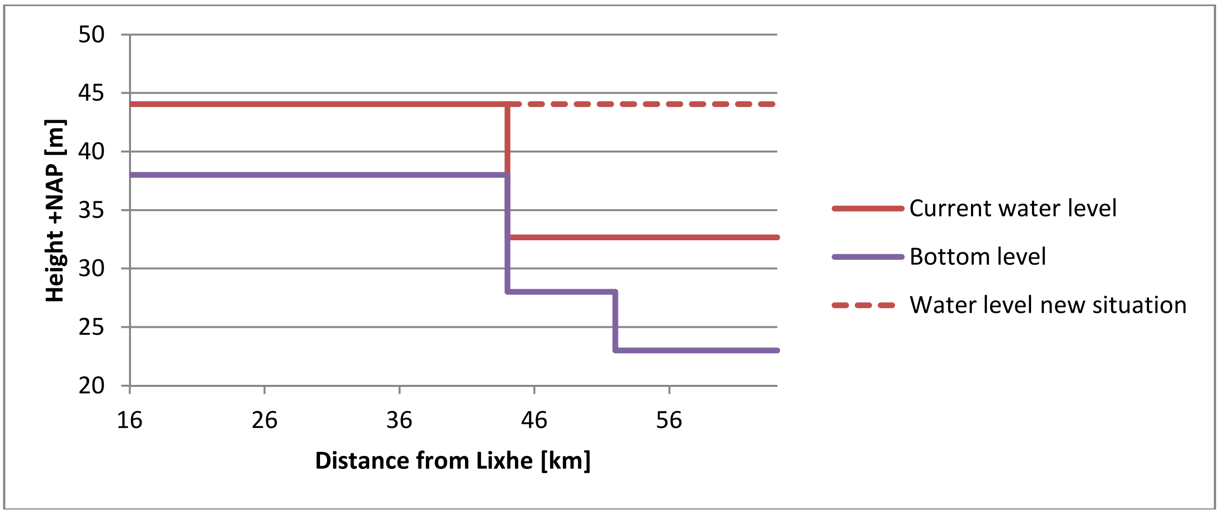
Two possible new options can be distinguished for a new situation. In the first option will the water level in the former canal section of Maasbracht raised with more than 11 m from 32.62 m +NAP to 44.05 m +NAP. In this situation is the guard lock of Limmel kept open and the water level in the former canal section Born is managed by the weir of Borgharen, just like the current situation. The only difference in this situation for the water level is that not only the former canal section of Born but also the former canal section Maasbracht is managed by the weir of Borgharen.

In the second option will the water level in the former canal section Born be lowered from 44.05 m +NAP to 32.65 m +NAP. The bottom of this former canal section from 38 m +NAP to 28 m +NAP to obtain sufficient navigational depth. In this situation has the guard lock of Limmel to be closed permanently. In 2015 will be started with the construction of a new guard lock near Limmel (Rijkswaterstaat, Maas: aanleg nieuwe keersluis Limmel, 2010). The change in water and bottom level between canal section Borgharen and Born/Maasbracht can be taken into account in this design.

2.2 Navigation

2.2.1 Option 1

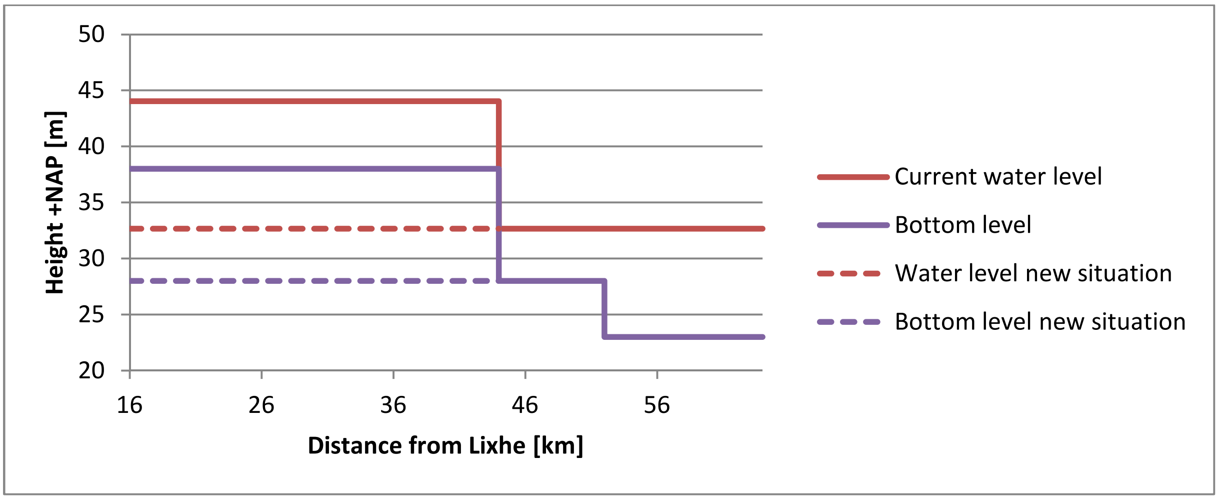
The first option could be favorable for navigation, mainly in the former canal section Maasbracht. This option is represented inGraph 9. Due to the extensive raise of the water level in this former canal section is the draught larger so larger vessels could use this part of the Julian Canal. The navigational possibilities for the former canal section of Born stay the same as the current situation. If in this section larger vessels are required should the river bottom be lowered.



Graph 9 - Canal section Born: option 1 navigation

2.2.2 Option 2

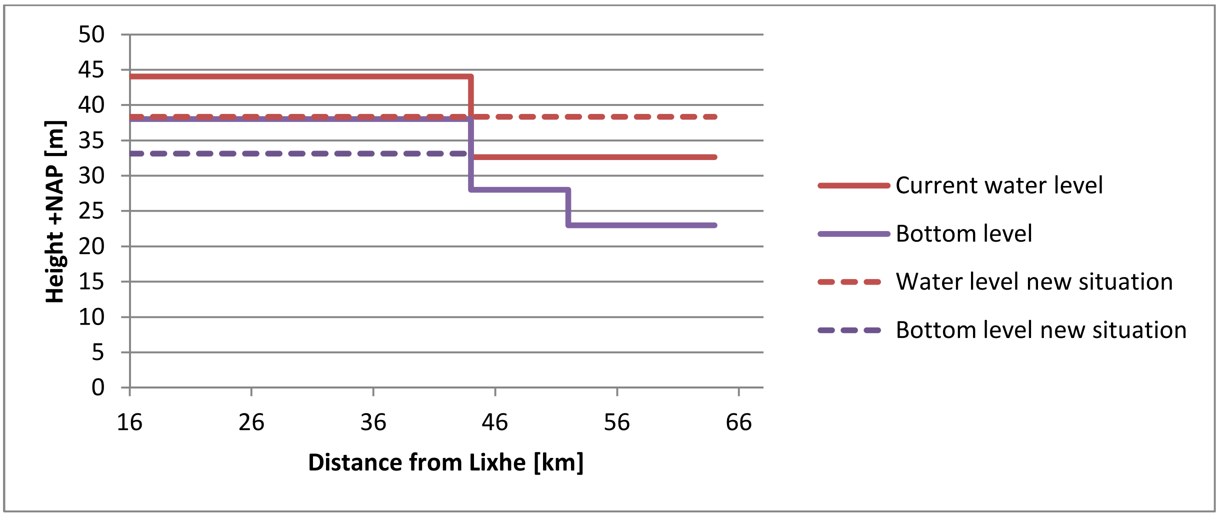
In the second situation is navigation on the Juliana Canal also possible despite the extensive lowering of the water level in former canal section Born. However has the bottom level in the this former canal section be lowered with at least 10 m to obtain enough navigational depth for the required vessel class Vb. Navigational situation in the former canal section Maasbracht stays the same as in the current situation. The second option is represented in Graph 10.



Graph 10 - Canal section Born: option 2 navigation

2.2.3 Option 3

The third situation results in a lowiering of the Julianakanaal along canal section Born, also a large water level fall in canala section Born will be the result.

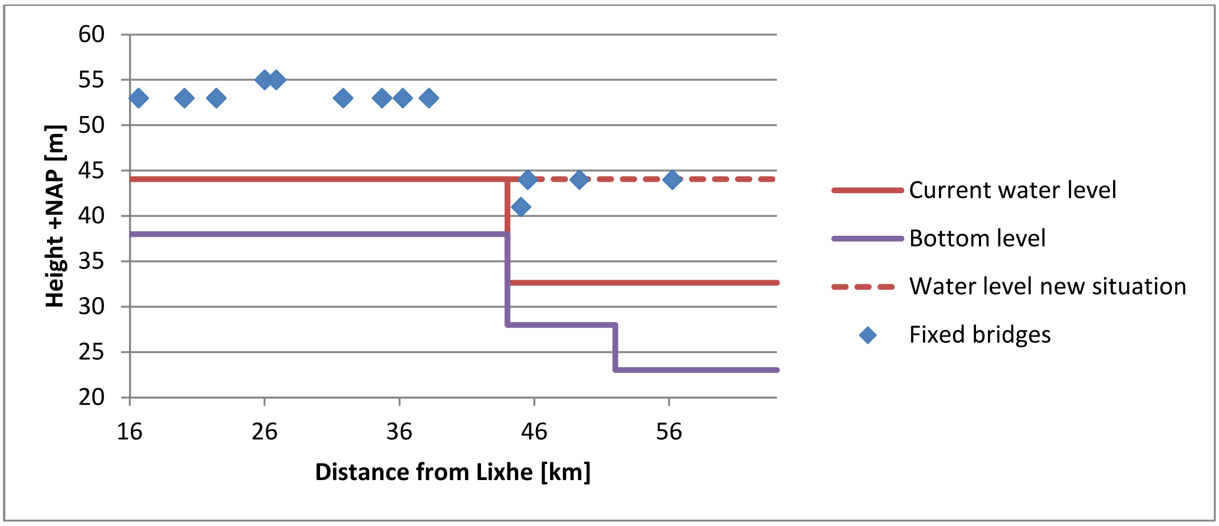


Graph 11 - Canal section Born: option 2 navigation

2.3 Bridges

2.3.1 Option 1

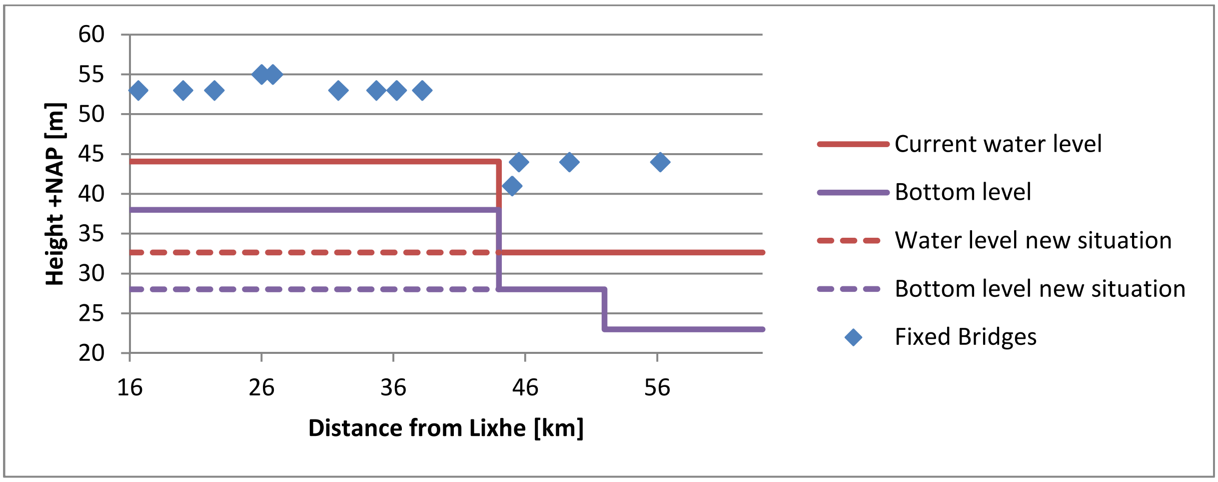
In the first option is clearance under the bridges in the former canal section of Born the same as the current situation as can be seen in Graph 12. The water level in this former canal section is not changed so the vertical clearance does also not change. Problems arise in the former canal section Maasbracht, due to the extensive increase of the water level will 3 bridges be on the same height as the water level and one bridge under the water level. These bridges have to be replaced for new ones when this option is chosen. The bridge which lies under the water level is the bridge over the lock of Born so when the lock of Born is removes will this bridge also disappear. Because the bridge of Illikhoven is located just next to the lock of Born (Table 19 from Appendix B) so it is not necessary to replace the bridge over the lock of Born. So only the bridges of Illikhoven, Roosteren and Echt have to be replaced to obtain enough navigational clearance.



Graph 12 - Canal section Born: option 1 bridges

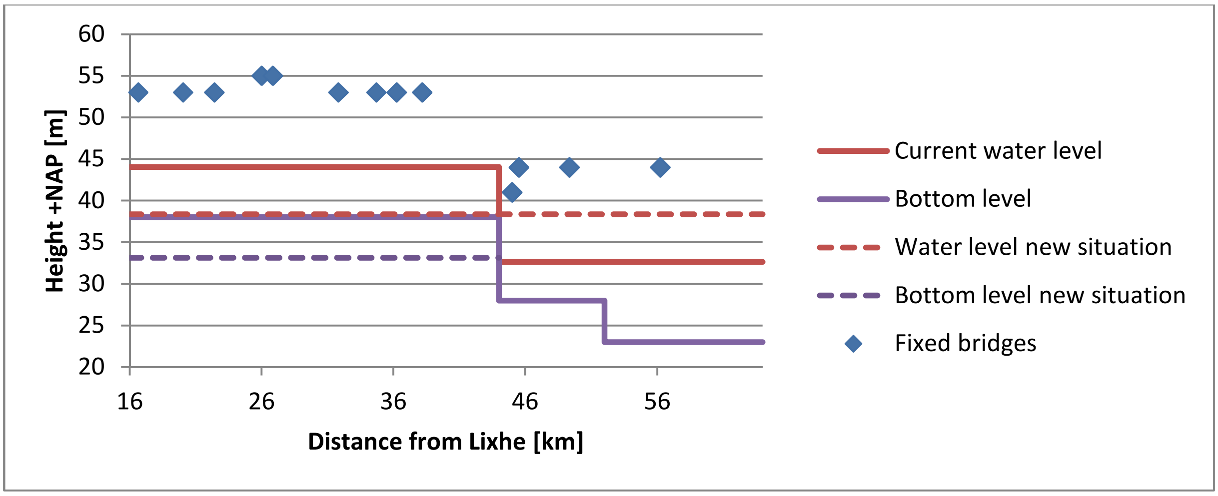
2.3.2 Option 2

Lowering the water level by more than 11 m in the former canal section Born is beneficial for the vertical clearance in this section. The vertical clearance is automatically increased by 11 m. The vertical clearance under the bridges in the former canal section Maasbracht stays the same because the water level remains the same as the current situation. For the aspect of vertical clearance is this option a better solution than option 1. The situation is represented in Graph 13.



Graph 13 - Canal section Born: option 2 bridges

2.3.3 Option 3



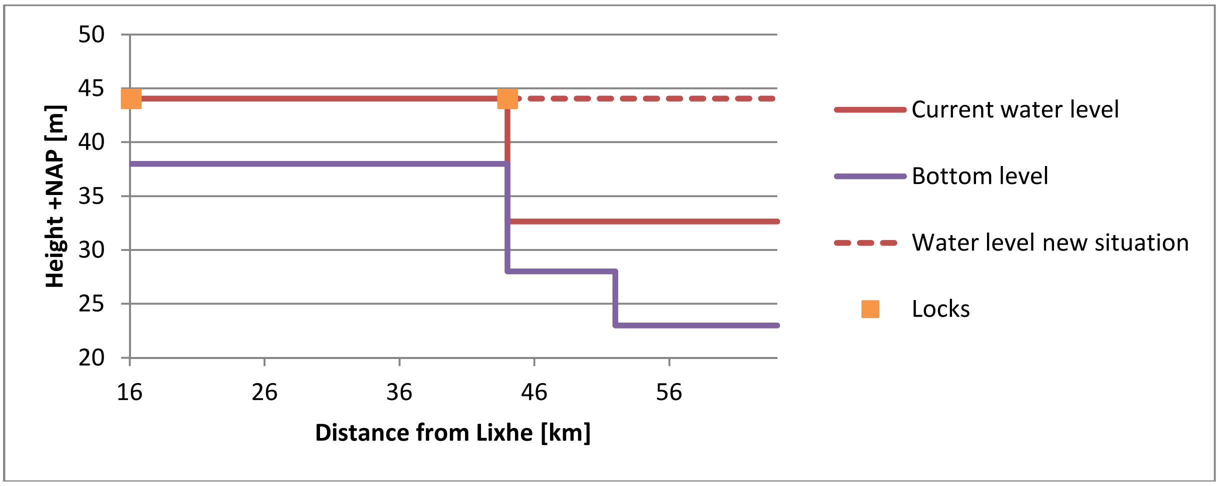
Graph 14 - Canal section Born: option 3 bridges

2.4 Locks

In the new situations contains the new canal section two locks, the guard lock near Limmel and the navigation lock near Maasbracht.

2.4.1 Option 1

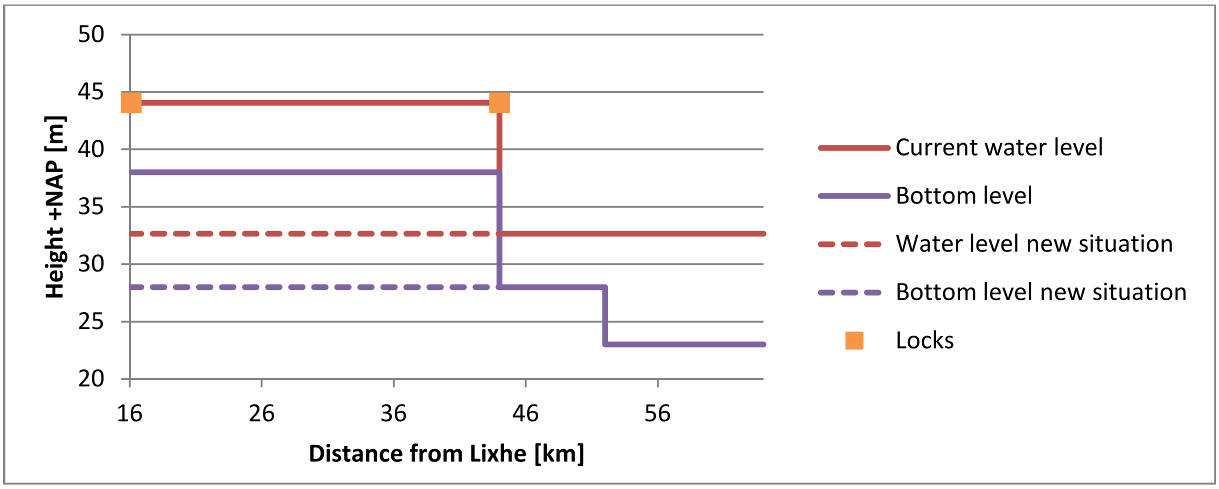
At the first option can the guard lock near Limmel act as is the current situation. The lock will only be closed during high water levels on the Upper Meuse. The lock of Maasbracht has in this situation be adapted to the new situation. The lock has to be heightened from 32.65 m +NAP to at least 44.05 m +NAP, this is an increase of more than 11 m. The lock should have a height from bottom to top of more than 21 m high. The water level on the outside part of the lock (canal section Linne) is 20.80 m +NAP so the lock has to resist a water column of 23.25 m. The current lock of Maasbracht has the highest fall in the Netherlands, this is a fall of 12 m. For this option a lock with a fall of 23.25 m has to created, however this relatively large for a navigation locks in the Netherlands.



Graph 15 - Canal section Born: option 1 locks

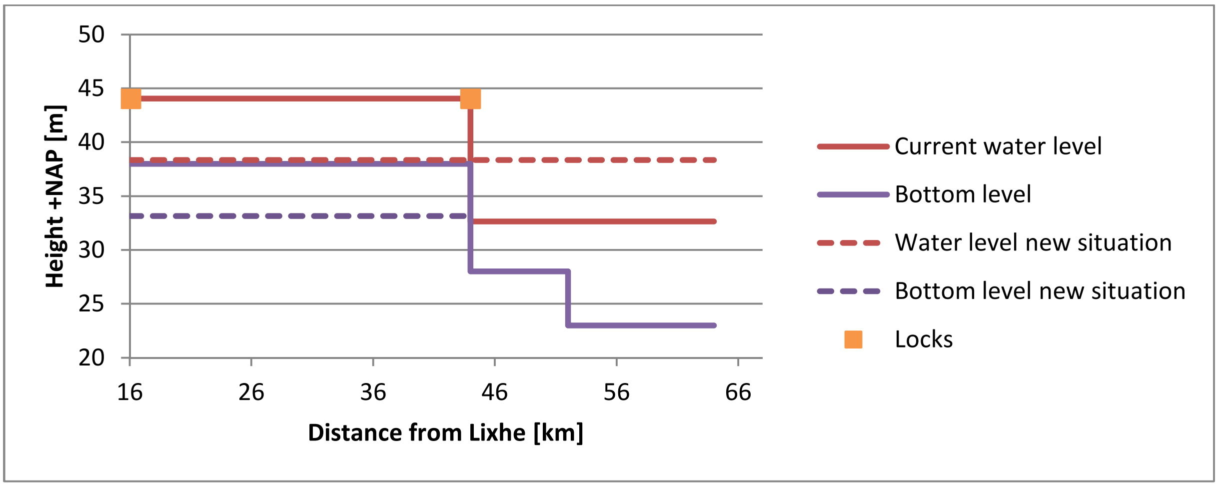
2.4.2 Option 2

In the second option can the navigation lock of Maasbracht act as the in the current situation because the water level in the former canal section Maasbracht is kept at the same level. At Limmel should a new navigation lock be constructed because the water level in the former canal part Born is lowered. The bottom of the navigation lock should be placed at 28 m +NAP and the top at 44.05 m +NAP.



Graph 16 - Canal section Born: option 2 locks

2.4.3 Option 3



Graph 17 - Canal section Born: option 3 locks

2.5 Flood protection

2.5.1 Option 1

The Juliana Canal has actually no real flood protection because during high water levels on the Meuse the guard lock of Limmel is closed. In this way is prevented that high water levels on the Juliana Canal could occur. However when the water level on the former canal section Maasbracht is raised is a protection needed to prevent the area along the Juliana Canal. This protection should have a height of at least 11.4 m along nearly halve of the Juliana Canal. It is questionable if this is a realistic solution.

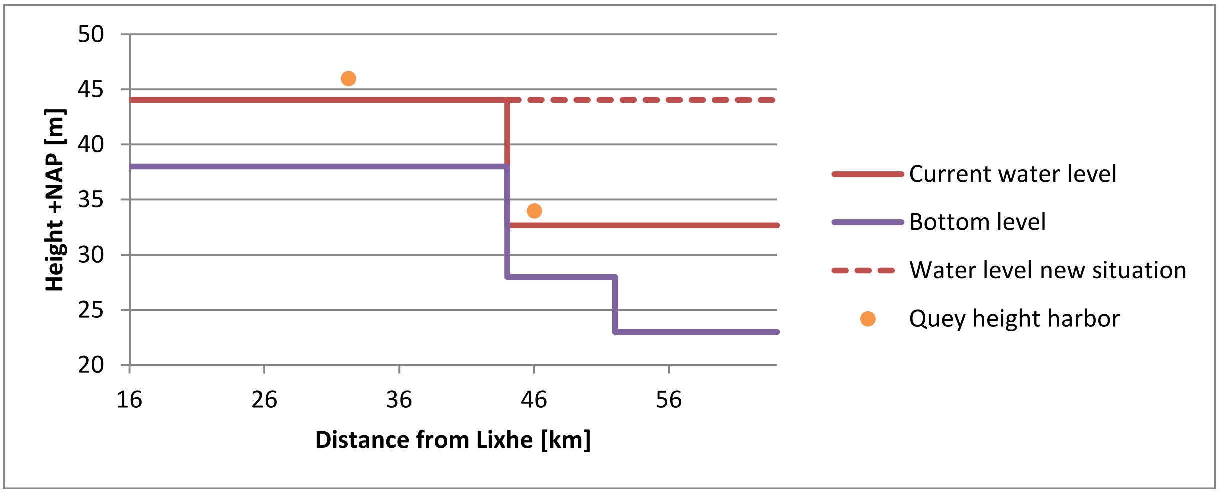
2.5.2 Option 2

In the second solution will the water level and bottom in the former canal section of Born be lowered. This results in high canal walls which are not subjected to hydraulic pressure, the walls will end 11.4 m above the water level in the canal. These walls have to be prevented to collapse and blocking of the waterway for navigational purposes. This interference has to be done over the whole former canal section of Born which is nearly halve of the Juliana Canal.

2.6 Harbors

2.6.1 Option 1

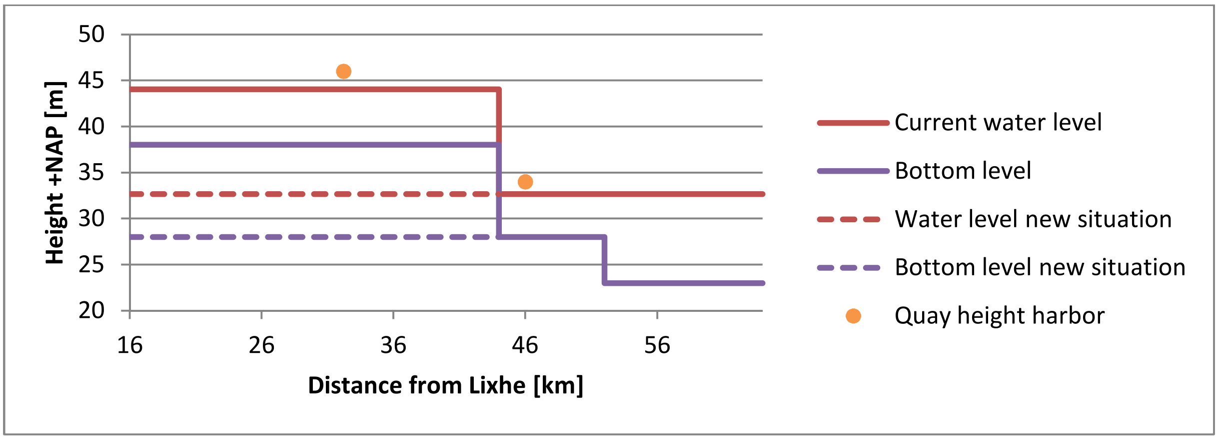
Along the Juliana canal are two harbors located, the harbor of Stein in the former canal section of Born and the harbor of Born in the former Canal section of Maasbracht. The harbor of Stein can act in the same way as in the current situation because the water level in the former canal section Born stays the same as in the current situation. The quays of the harbor of Born will become under water in this situation. To keep the harbor operable the quays of the harbor should be increased.



Graph 18 - Canal section Born: option 1 harbors

2.6.2 Option 2

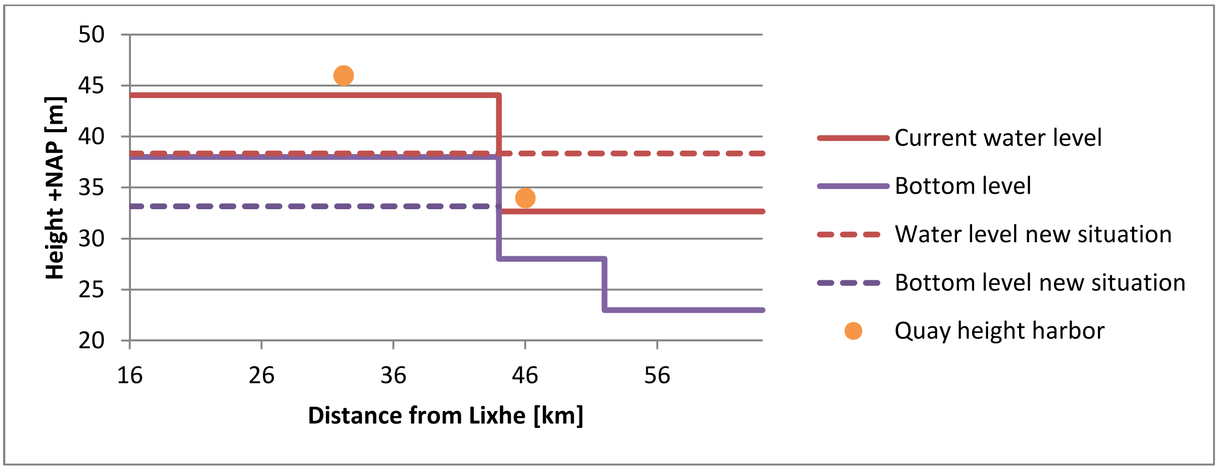
In the second situation is the water level in former canal section Born lowered. Due to the water level fall will the harbor of Stein become unavailable for navigation. For harbor Born will change nothing in this situation.



Graph 19 - Canal section Born: option 2 harbors

2.6.3 Option 3

In the third situation is the water level in former canal section Born lowered and raised in former canal section Maasbracht. Due to the water level fall will the harbor of Stein become unavailable for navigation. Also harber Born will become unavailable because the water level will become higher than the harbor quay height



Graph 20 - Canal section Born: option 2 harbors

3 Lock Maasbracht

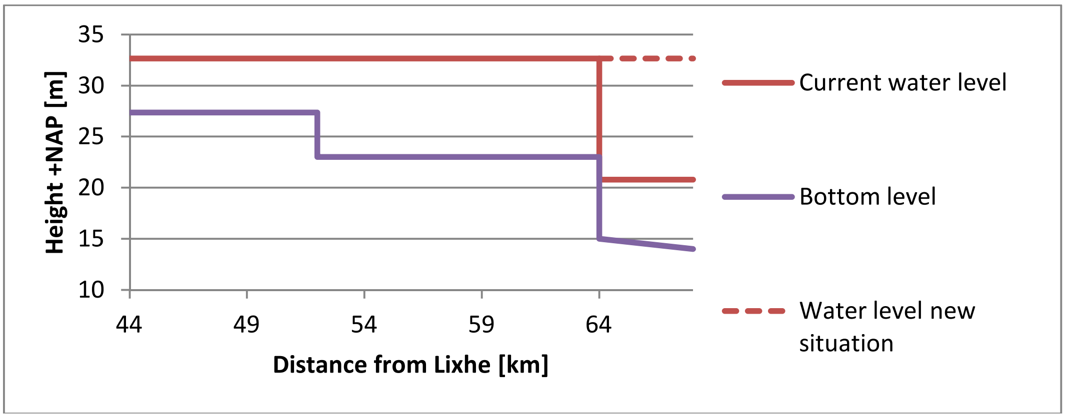
Three possible situation will be discussed after removing of the lock of Maasbracht. In the first option will the water level in the former canal section Linne be raised from 20.80 m + NAP to 32.65 m +NAP so the water level in the former canal section of Linne will be raised to the water level of the former canal section of Maasbracht. In this situation can the lock of Born act as in the current situation.
In the section option will the water level in the former canal section Maasbracht be lowered to the water level of the former canal section Linne, so from 32.65 m +NAP to 20.80 m +NAP. In this situation has the bottom of the Julianal Canal be lowered from 23 m +NAP to 15 m +NAP, a lowering of at least 8 m. In this situation will act the harbors, locks or flood protection in the former canal section Linne as in the current situation. Because the water level difference between the canal sections of Maasbracht and Linne are relatively high will a third option be represented. In this third option will a water level be suggested which lies between 32.65 m +NAP and 20.80 m +NAP. In this situation has the former canal section of Maasbacht as well Linne be adopted but not in the rigorous ways as the first and the second options. The water level is assumed at 23 m +NAP, which is the same as the bottom level of the Julian Canal in canal section Maasbracht.

It is important to notice that the water level in the canal section of Linne also influences the water level in the Border Meuse until Ohé en Laak. By changing the water level in the canal section Linne also the water level in the downstream section of the Border Meuse is changed. So a water level change in this canal section has not only influence on the locks, bridges or flood protection but also on these topics along the Border Meuse

3.1 Navigation

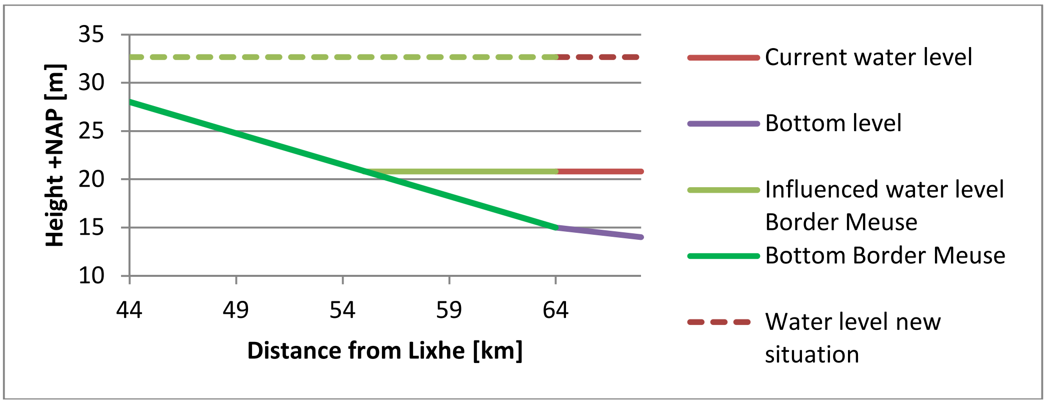
3.1.1 Option 1

The first option is very beneficial for navigation in the former canal section Maasbracht and Linne, especially in the canal section Linne will a large draught be created. The smallest draught in the new canal section will be in the beginning the canal section, the first 8 km from Born as can be seen in Graph 25. By lowering this section a large draught over the whole new canal section can be created. However the lock of Born should be adapted to the lowering of the bottom.



Graph 21 - Canal section Maasbracht: option 1 navigation

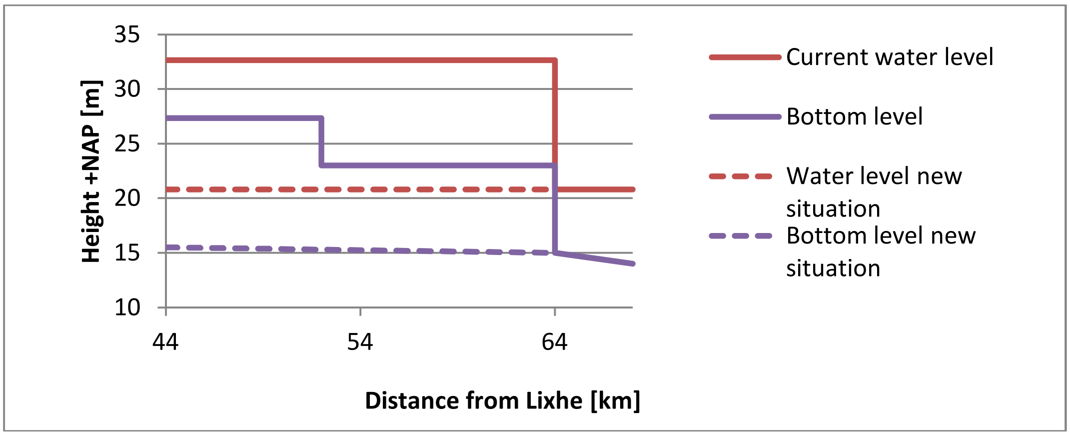
The water level raise has also a positive effect for navigation on the Border Meuse. In the current situation was only recreational boating possible on the Border Meuse and no commercial transport as can be seen in Graph 21. Due to the raise in water level becomes the water level on the Border Meuse, to at least Grevenbicht not below the maximum required 4.5 m. So even at Grevenbicht becomes the Border Meuse based on draught not suitable for vessels larger than class Vb.



Graph 22 - Border Meuse: option 1 navigation

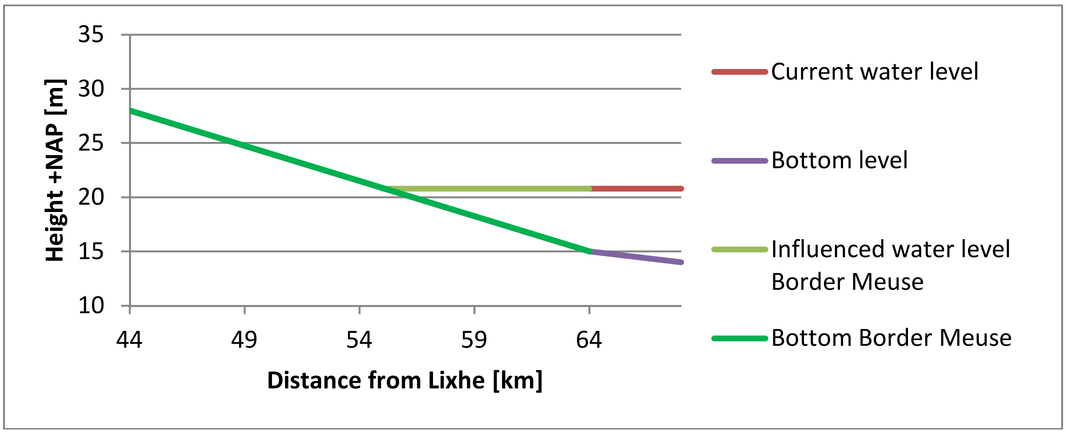
3.1.2 Option 2

In the second option will the water level in the former canal section of Maasbracht be lowered to 20.80 m +NAP, the water level of the former canal section of Linne. The canal section of Linne can act as in the current situation but from Born has the Juliana Canal to be adapted to the new situation to maintain the navigational purpose of the canal. Because the water level in the former canal section Maasbracht is lowered to 20.80 m +NAP has the bottom also be lowered to maintain enough navigational draught. The Bottom near the lock of Born has to be lowered from 28 m +NAP to 15.5 m +NAP to meet the requirement of enough depth of the waterway. The bottom near the removed lock of Maasbracht has to be lowered from NAP 23 m +NAP to 15 m +NAP to obtain a smooth connection with the bottom of the former canal section Linne. The situation is represented in Graph 23.



Graph 23 - Canal section Maasbracht: option 2 navigation

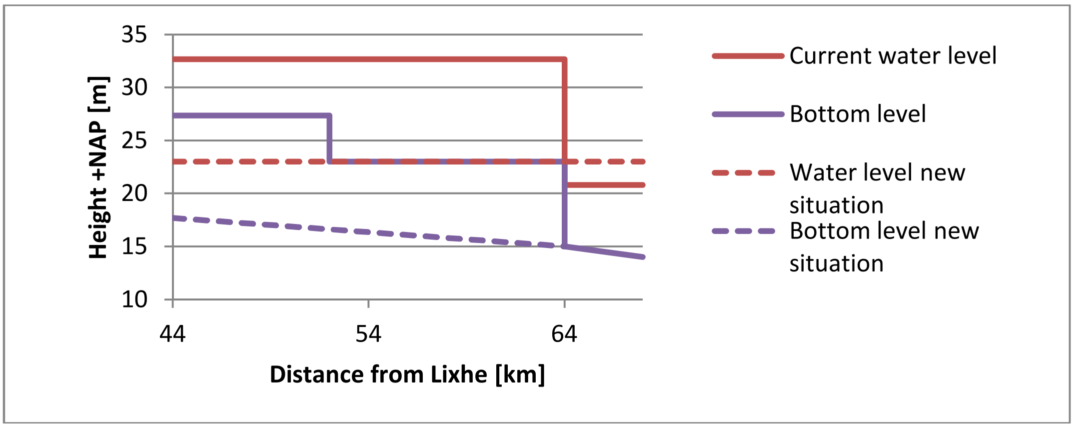
This option has no influence on the navigational opportunities of the Border Meuse. As can be seen in Graph 24 does the water level not change so just like in the current condition is only recreational boating possible on the Border Meuse.



Graph 24 - Border Meuse: option 2 navigation

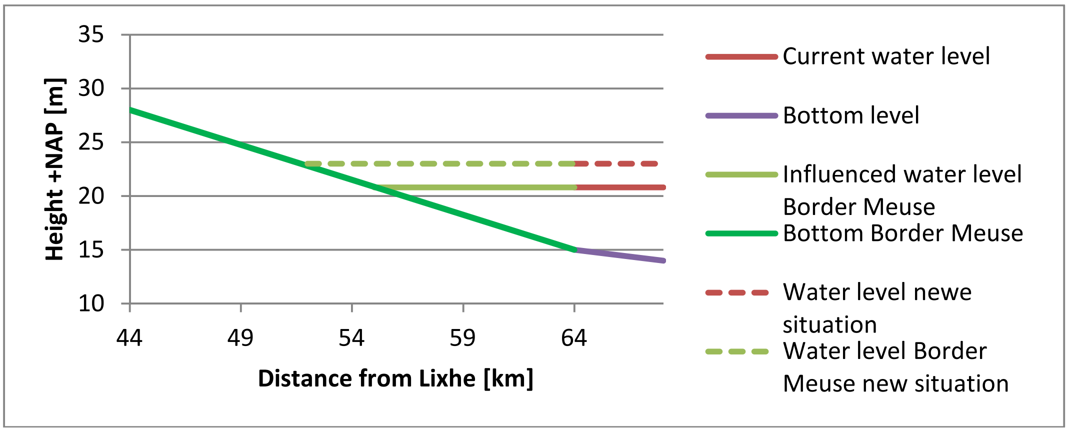
3.1.3 Option 3

The third option is an intermediate solution, in the former canal section will the water level be lowered and in the former canal section of Linne will the water lever be raised. The water level in the new canal section will be raised from 20.80 m +NAP and set at 23 m + NAP as can be seen inGraph 25. This water level could possible raised or lowered but the 23 m +NAP is here taken as example to check this situation. This new situation results in an increase of the draught in the former canal section of Linne, which is beneficial for navigation in this section. The water level in the former canal section of Maasbracht has to be lowered from 32.65 m + NAP to 23 m + NAP. To obtain sufficient draught should the canal bottom be lowered from 28 m + NAP to NAP 17.7 m +NAP at lock Born and from 23 m +NAP to 15 m +NAP near Maasbracht. This situation is represented in Graph 25.



Graph 25 - Canal section Maasbracht: option 3 navigation

Due to the water level raise of the new canal section is navigation possible on a small part of the Border Meuse. Navigation could be possible until somewhere between Stevensweert and Ohé en Laak. However this has not any advantage with respect to the current situation. The situation is represented in Graph 26.

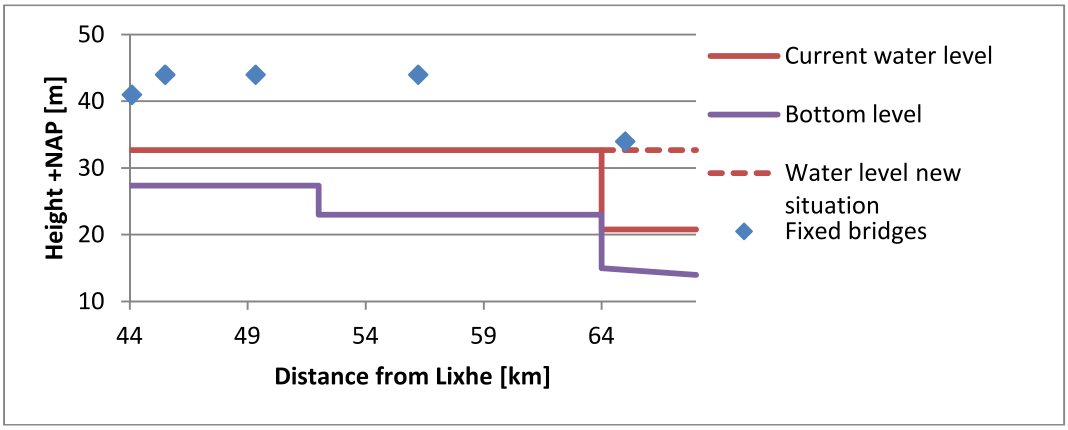


Graph 26 - Border Meuse: option 3 navigation

3.2 Bridges

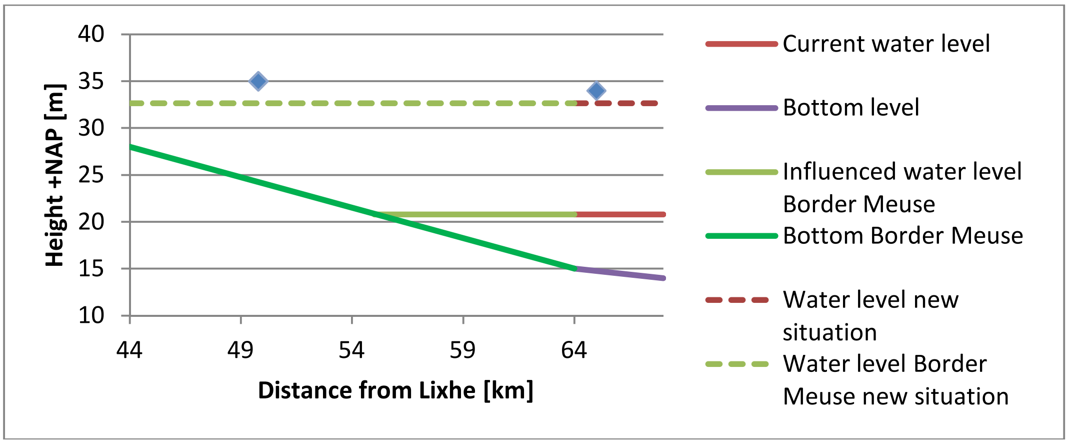
3.2.1 Option 1

In this new canal section are five bridges over the Juliana Canal and one bridge over the Border Meuse. In the first option will the vertical clearance under the first four bridges be as in the current situation. The bridge in the former canal section of Linne will still be above water level however the vertical clearance of under this bridge will become too small as can be seen in Graph 27. This is the highway bridge in the A2 nearby Wessem. This bridge has to be heightened with more than 7 m to a height of at least 41 m +NAP to obtain the minimum required vertical clearance.



Graph 27 - Canal section Maasbracht: option 1 bridges

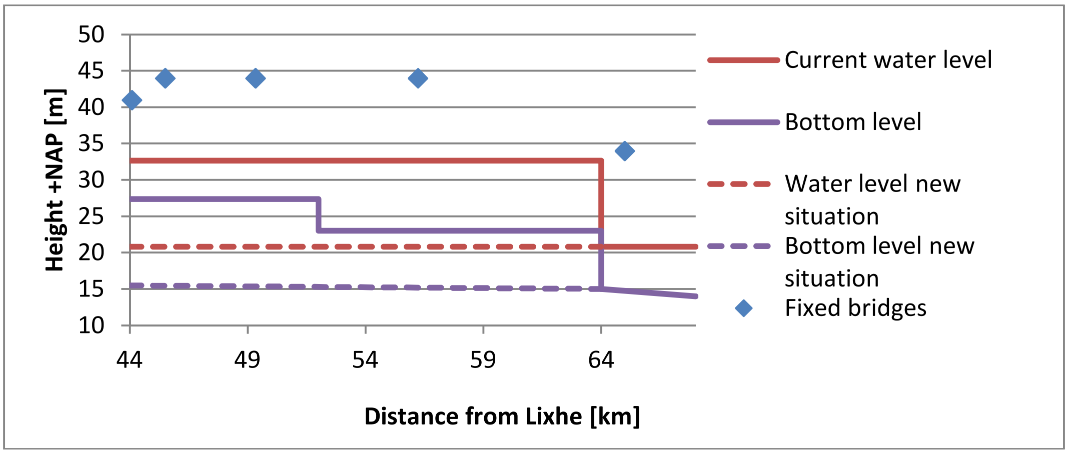
As already said is there one bridge over the Border Meuse. In are two bridges represented, the bridge downstream is the highway bridge over the A2 as also represented in Graph 28. The bridge over the Border Meuse is the bridge near Maaseik in road N296, this is a bridge which connects Belgium and the Netherlands. The vertical clearance under this bridge is too small for navigation. How large the clearance under this bridge should be is questionable, it depends if this part of the Border Meuse will be used for only recreational boating or also for commercial shipping.



Graph 28 - Border Meuse: option 1 bridges

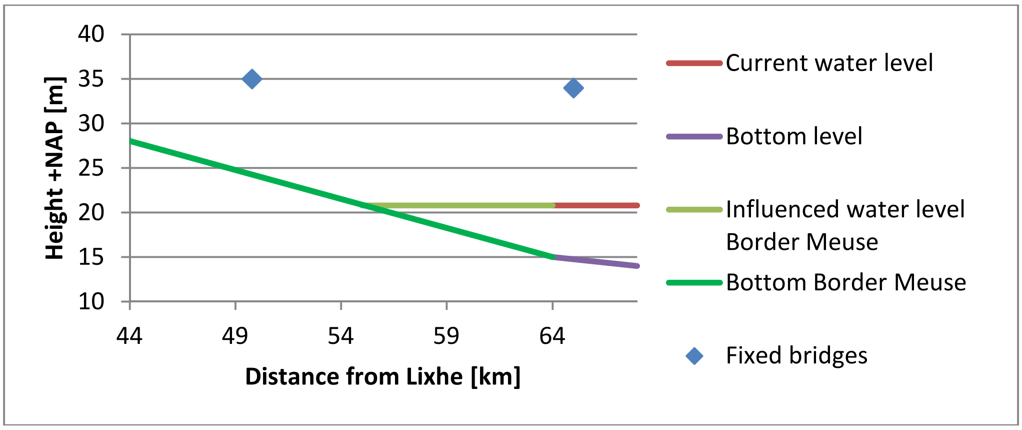
3.2.2 Option 2

By lowering the water level in the Juliana Canal as in option two will the clearance under all the bridges be sufficient for navigation on the Meuse. It is not necessary in this option to adopt any of the bridges in this new canal section.



Graph 29 - Canal section Maasbracht: option 2 bridges

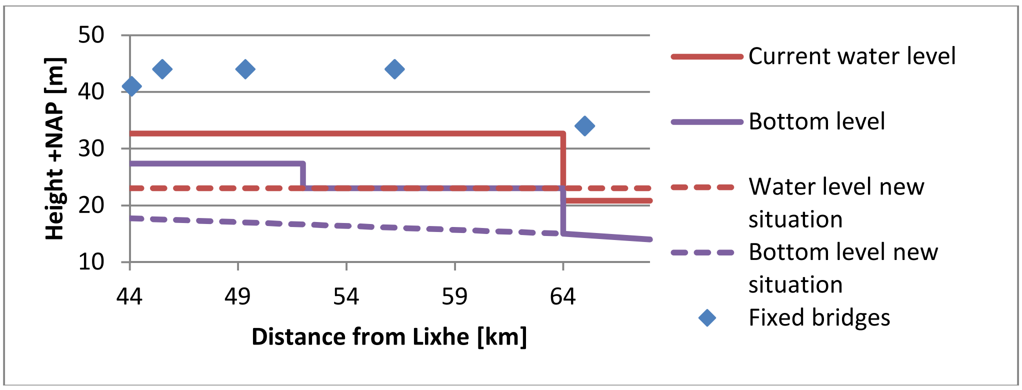
For the bridges over the Border Meuse holds the same as for the bridges over the navigational route in this canal section. This is represented in Graph 30.



Graph 30 - Border Meuse: option 2 bridges

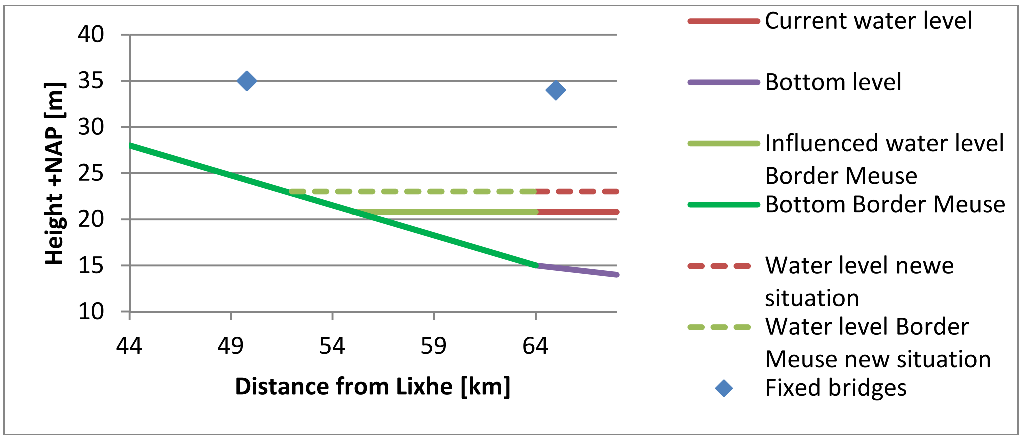
3.2.3 Option 3

In option 3 is the water level in the former canal section Maasbracht lowered and in former canal section Linne raised. By a water level of 23 m +NAP will the vertical clearance under all bridges be sufficient. However when water levels will rise during high discharges could problems be occur at the highway bridge of Wessem . The vertical clearance is during low discharges is for this bridge is 11 m so when the water levels increases with 1.9 m will the vertical clearance also be sufficient. This situation is represented in Graph 31.



Graph 31 - Canal section Maasbracht: option 3 bridges

For the bridges over the Border Meuse has the raise of water level no effect, the vertical clearance will be sufficient as can be seen in Graph 32.



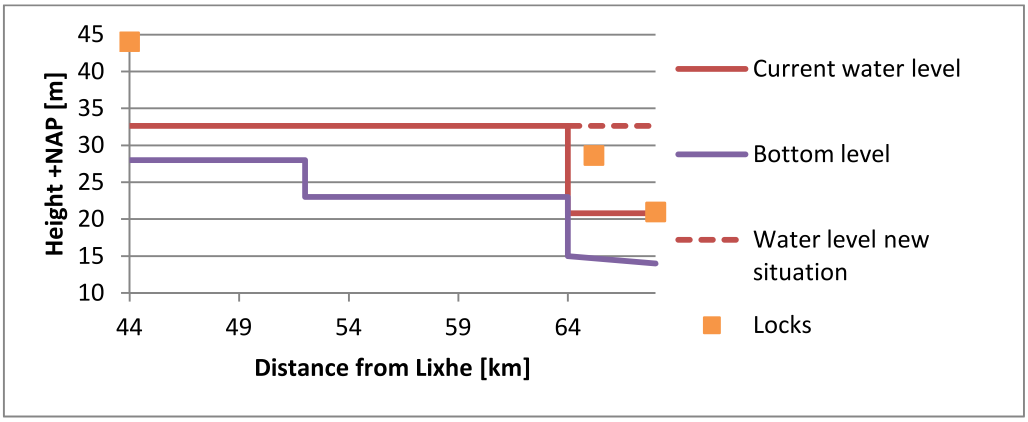
Graph 32 - Border Meuse: option 3 bridges

3.3 Locks

3.3.1 Option 1

In the new created canal section are in total four locks created. The first lock is located near Born, this is at the beginning of the new canal section. The other three locks are located in the former canal section Linne, the lock of Linne and Heel are located at the end of the canal section at the same distance of Lixhe. The last lock is the lock of Panheel, this lock provides access to the Canal Wessem-Nederweerd. This canal is connected to the Kempische Canals so that the inland cities of Brabant and Belgium inside the Big Rhombus can be reached. In this option can the locks of Born, Linne and Heel act as in the Current situation.

The lock of Panheel however will be to low in this option, also will the high and low water side change in this situation. In the current situation is the water level in the Meuse 20.80 m +NAP and in the Canal Wessem-Nederweert 28.65 m +NAP. A new lock has to be created, it should be imagined that in normal situations the water high level is on the Meuse side but that during high discharge the water level will be lower so that the high water side is on the canal side. A new lock with the right type of gates has to be chosen. The current lock has miter gates, this will in the new situation not the best option.

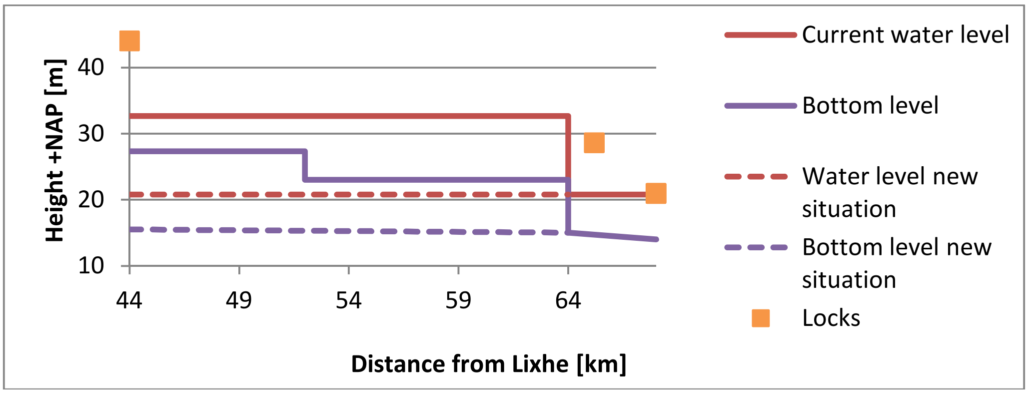


Graph 33 - Canal section Maasbracht: option 1 locks

3.3.2 Option 2

In the second option can the locks of Panheel, Linne and Heel can act as in the current situation because the water level in these sections will not be changed. The lock of Born has to be adapted. By lowering the water level in the former canal section of Maasbracht will the water head over lock

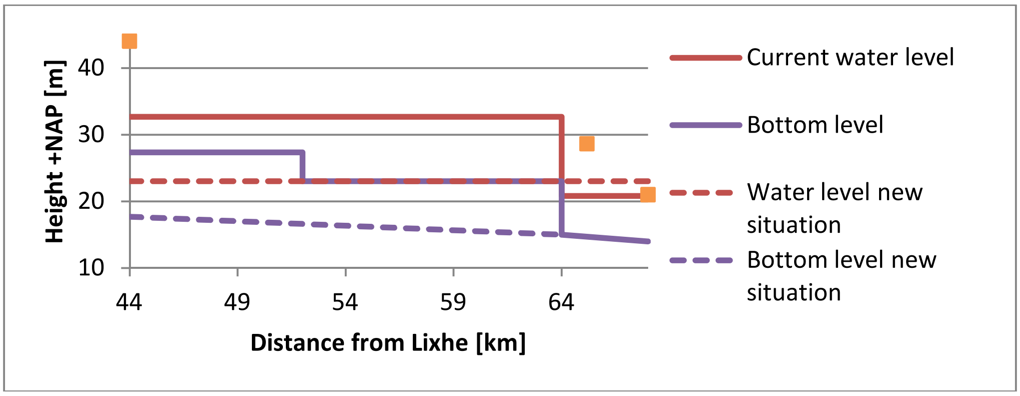
Born be increased. By lowering the water level will the water head be increased from 11.4 m to 23.25 as can be seen in Graph 34. For this option has lock Born to be adapted so that it will resist the larger water head.



Graph 34 - Canal section Maasbracht: option 2 locks

3.3.3 Option 3

In the third option can the lock of Panheel act as in the current situation. The locks of Linne and Heel have to be raised with about 2 m to adapt the locks to the new water level. Also the lock of Born has to be adapted to the lowering in the former canal section of Maasbracht. The water head over the lock will be larger but smaller than in option 2. The water head in this situation will 21.05 m, more than 2 m lower than in option 2. The raise of water level in the former canal section Linne is beneficial for the lock of Panheel, the water difference between both sides of the lock becomes smaller so also the resulting water pressure on the gates.



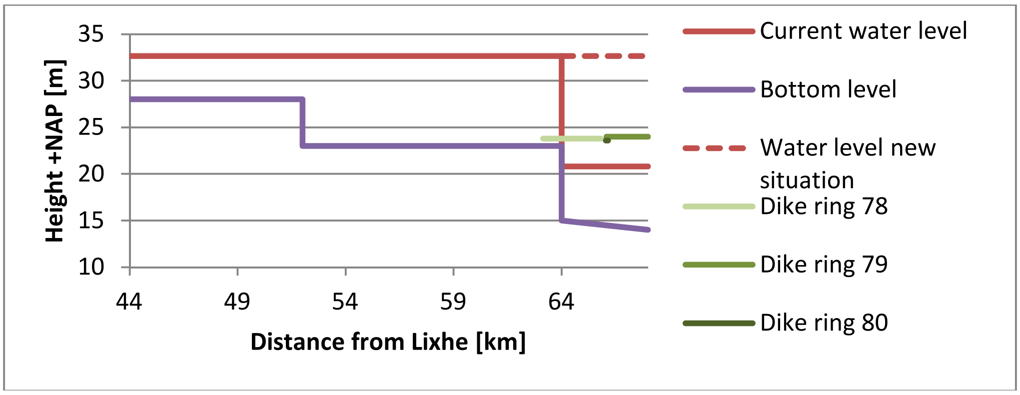
Graph 35 - Canal section Maasbracht: option 3 locks

3.4 Flood protection

The dike ring areas along the new canal section are located along the former canal section of Linne. Dike ring 78 has to protect Heel, dike ring 79 has to protect Wessem and Thorn and dike ring 80 has to protect the Clauscentrale, a power plant nearby Maasbracht. Along the Juliana Canal is no flood protection present because the canal has only a navigable function and no discharging function. The Border Meuse has this discharging function which resulted in flood protection along the Border Meuse. In the considered part of the Border Meuse are the dike ring areas 78, 81 and 82 located. Dike ring area 81 has to protect Stevensweerd and Ohé en Laak and dike ring 82 has to protect Aasterberg.

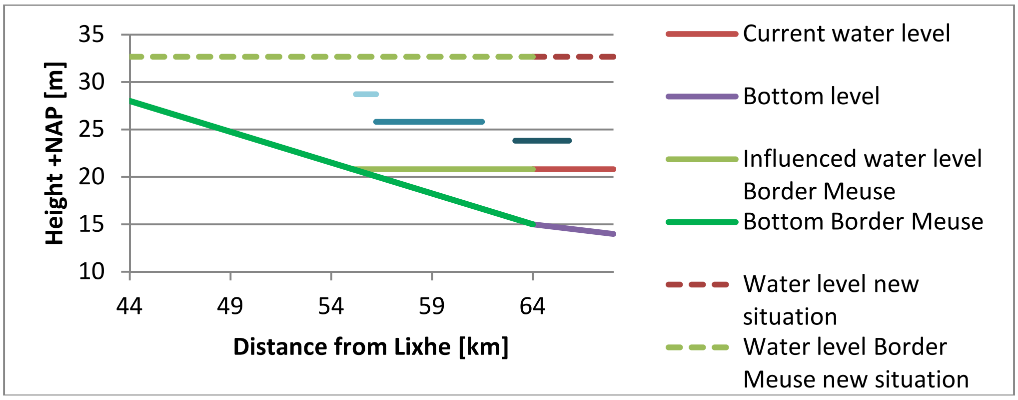
3.4.1 Option 1

In the first option will all the flood protections along the former canal section Linne be under the water level. To adapt the current flood protection to the new situation has the flood protection be raised by nearly 10 m. This flood protection is not only necessary during floods but also as permanent protection for the raised water level in the new canal section. This flood protection are no dikes but walls which are sometimes located in the middle of the village centers. By raising the flood protection should large wall arise in village centers or back yards of citizens. It is questionable if this is in the best interest of the villages along the Meuse. The situation is represented in Graph 36. The Juliana Canal has not to be adapted in this situation.



Graph 36 - Canal section Maasbracht: option 1 flood protection

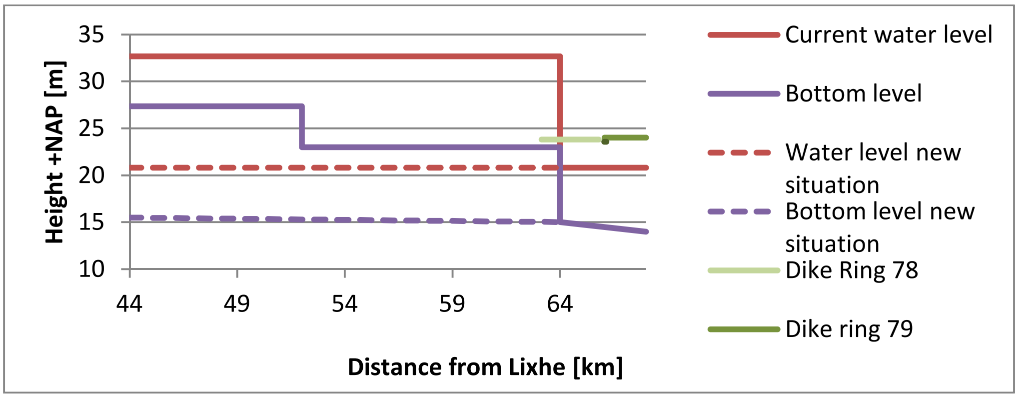
By raising the water level will also the water level in the downstream part of the Border Meuse rise. As can be seen in Graph 37 will all the dike rings be under water in this new situation. All the dike ring areas have to be raised with at least 10 m to maintain a sufficient flood protection along the Border Meuse.



Graph 37 - Border Meuse: option 1 flood protection

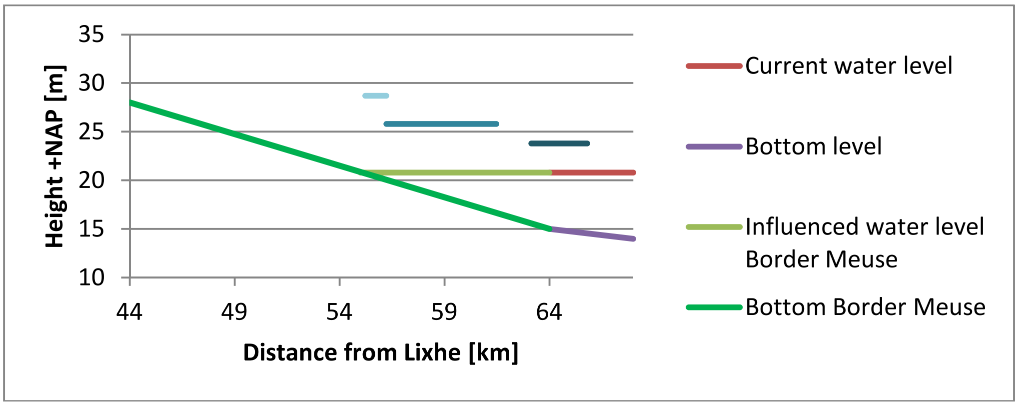
3.4.2 Option 2

In the second option will the water level in the former canal section of Linne not be raised as can be seen in Graph 38. This is beneficial for the flood protection because it means that the current flood protection is high enough so has not to be raised. The new water level means a reduction of the water level in the Julian canal. It has to be ensured that the walls of the canal will be stable in the new situation. It has to be investigated if and how this should be done.



Graph 38 - Canal section Maasbracht: option 2 flood protection

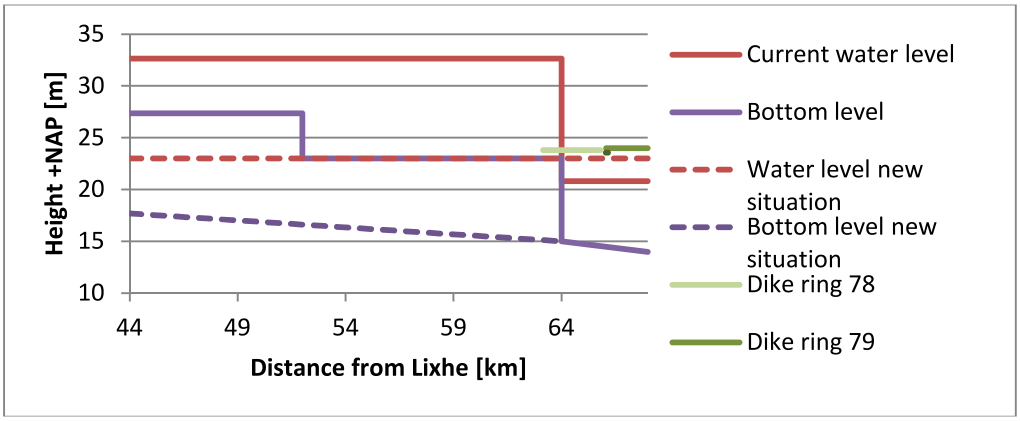
The maintenance of the water level in the former canal section Linne is beneficial for the flood protection along the Border Meuse. As can be seen in Graph 39 are the dike ring areas high enough for the new situation. So for this option has no adaption to be made for the current dike ring areas along the Border Meuse.



Graph 39 - Border Meuse: option 2 flood protection

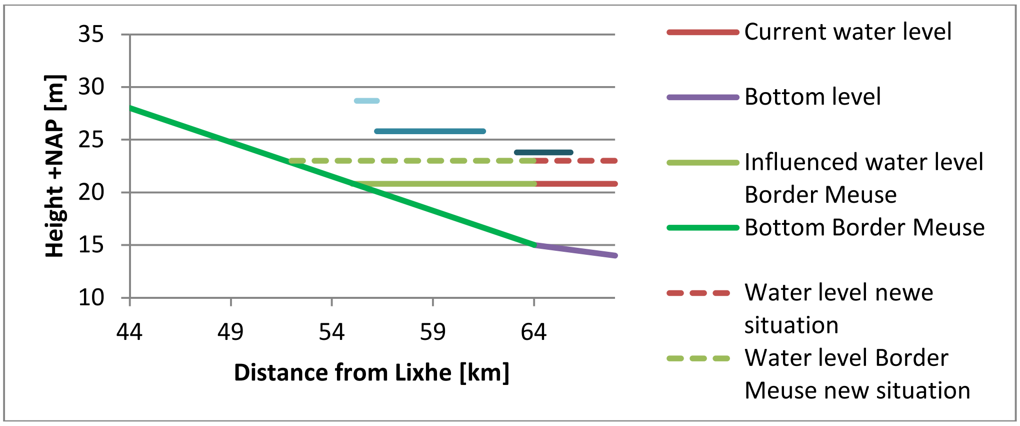
3.4.3 Option 3

In the third option will the flood protection of the former canal section Linne be just above water level as is represented in Graph 40. However, when the water level will rise during high discharges will the water level probably higher than the current flood protection. In this situation should the high water protection be raised but not as rigorous as in option 1. Just as in option 1 will the water level in the Juliana Canal be lowered so the walls of the canal have to be checked on stability.



Graph 40 - Canal section Maasbracht: option 3 flood protection

The small raise in water level in the former canal section of Linne ensured that the flood protection along the Border Meuse. However the water level will be nearly as high as dike ring 78 and also the over height of dike ring 81 becomes smaller. Probably dike ring 78 will be to low and should be raised, it has to be investigate if dike ring 81 have to be raised. Dike ring area 82 will probably be high enough because when discharge become higher will water level rise but with a maximum of about 2 m.

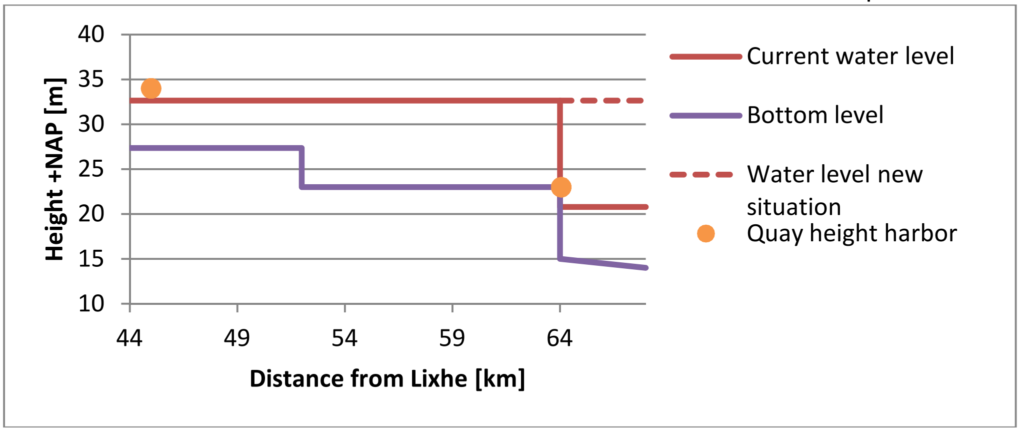


Graph 41 - Border Meuse: option 3 flood protection

3.5 Harbors

3.5.1 Option 1

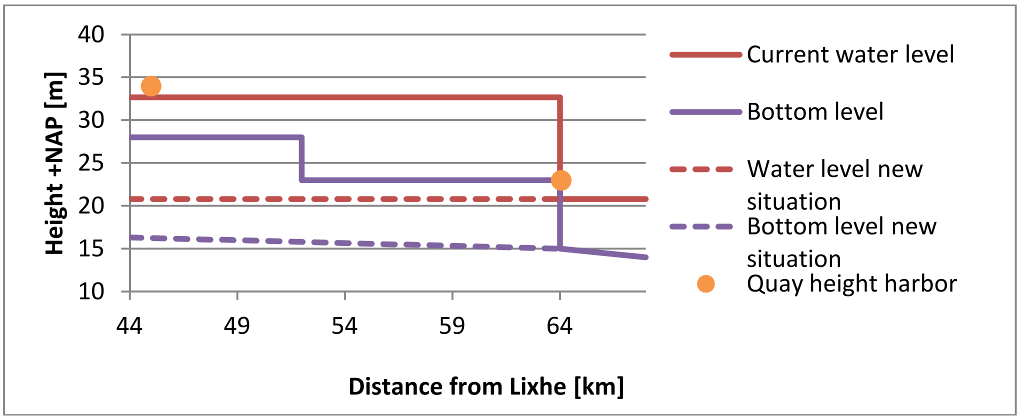
In the new considered canal section are in two harbors located as can be seen in Graph 42. The upstream harbor is the harbor of Born and the downstream harbor is the combined harbor of Wessem/Maasbracht. By the rise of the water level in the former canal section of Linne will the harbor of Wessem/Maasbracht become below water level because the quays are by far not high enough. To maintain this harbor should the quay walls be heightened from 23 m +NAP to at least 34 m +NAP, this is an increase of 11 m. The harbor of Born can in this situation act as in the current situation because the water level in the former canal section of Maasbracht is kept at the same level.



Graph 42 - Canal section Maasbracht: option 1 harbors

3.5.2 Option 2

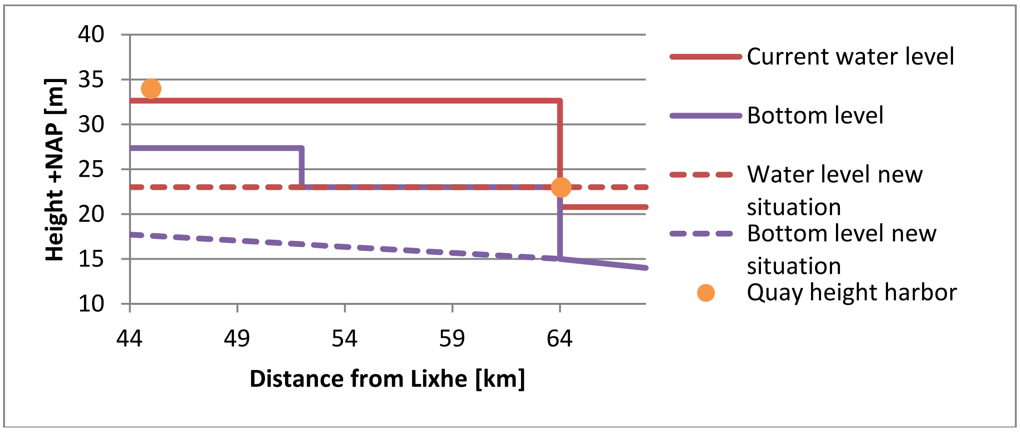
In the second option is the water level in the former canal section of Maasbracht extensively lowered, which resulted in too high quay walls at the harbor of Born as can be seen in Graph 43. The quay wall are more than 13 m to high and will probably fail if no adoptions are been made. If nothing is been done can this harbor not been used in the new situation. The water level in the former canal section of Linne is not changed so the harbor of Linne can be act as in the current situation.



Graph 43 - Canal section Maasbracht: option 2 harbors

3.5.3 Option 3

By the lowering of the water level in the former canal section of Maasbracht will the quay walls of the harbor of Born far too high, just as in the second option. In this situation becomes the harbor unusable for transloading of commercial vessels. The water level in the former canal section is slightly raised to 23 m +NAP, the same height as the quay walls of the harbor of Wessem/Maasbracht. The keep this harbor in operation should the quay walls be heightened otherwise will the harbor flood is the water level rises slightly during high discharges. The situation is represented in Graph 44.



Graph 44 - Canal section Maasbracht: option 3 harbors

4 Weir Linne

Three possible options will be discussed after the removal of the weir of Linne. In the first situation will the water level in the former canal section of Roermond be equalized with the water level of the former canal section of Linne. The water level in the former canal section of Roermond will rise from 16.85 m +NAP to a height of 20.80 m +NAP. The new weir of Roermond should be heightened to maintain the water level in the new canal section.

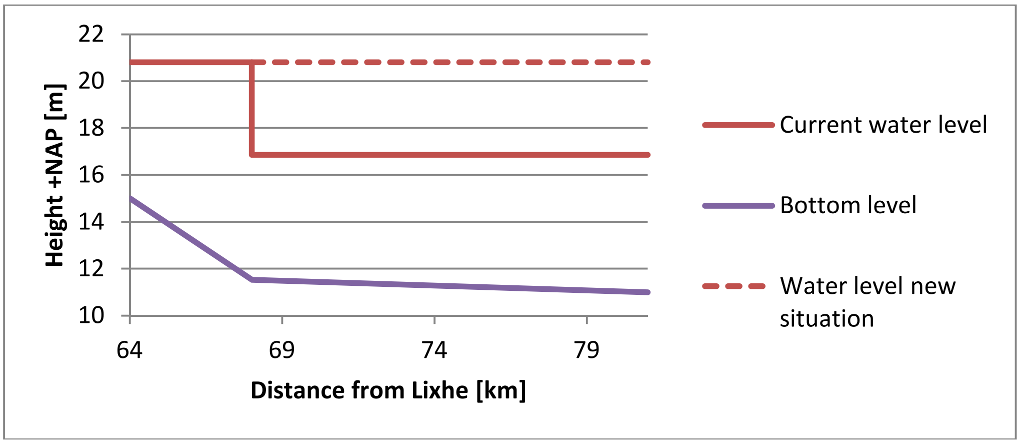
In the second option will the water level in the former canal section of Linne be equalized to the water level in the former canal section of Roermond. The water level will fall from 20.80 m +NAP to a height of 16.85 m +NAP. The new weir of Roermond can stay at the same height as in the current situation.

In the third option will the water level in the former canal section be lowered and in the former canal section be heightened. The water level in this new canal section will be set at 18.80 m +NAP. This is the mean between the former water levels in the canal sections Linne of 20.80 m +NAP and the canal section Roermond of 16.85 m +NAP. To obtain this situation has the new weir of Roermond to be higher than the current weir.

4.1 Navigation

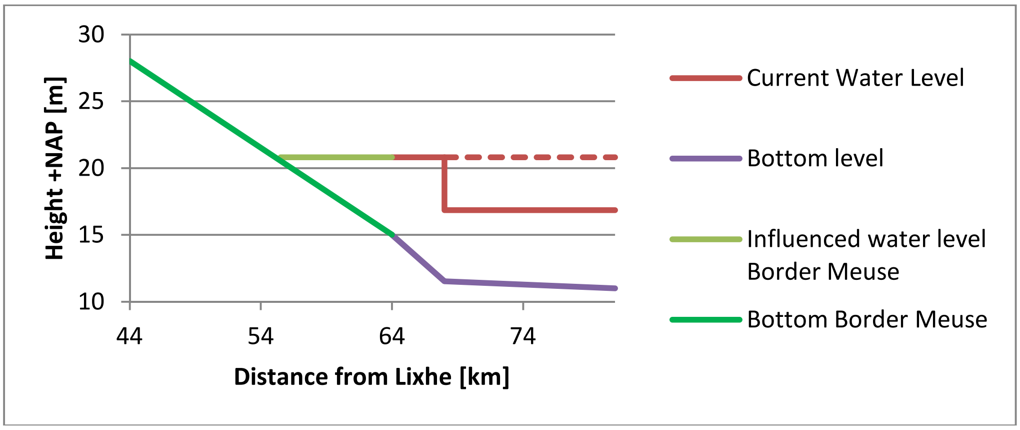
4.1.1 Option 1

The first option is does not influence for the navigation because the current navigational situation has not to be changed. The main navigable route is going over the former canal section Linne and not over the former canal section Roermond. The water level in the former canal section Linne is not lowered so navigation until the lock of Heel will not be disturbed. Beneficial in this option is that the harbor of Roermond would be better reachable for navigation because the lock of Linne is no longer necessary.



Graph 45 - Canal section Linne: option 1 navigation

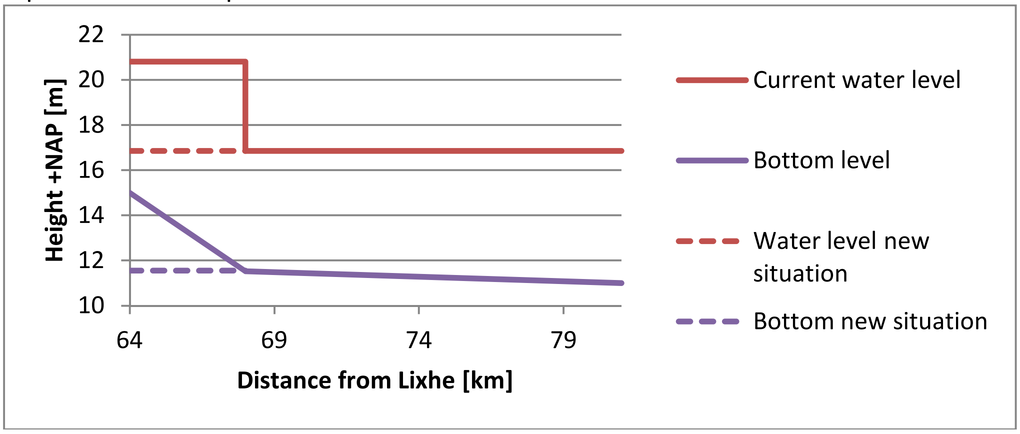
Because the water level of 20.80 m +NAP of the former canal section of Linne is maintained will for the water level on the Border Meuse also nothing change. The only difference is in this situation that the water level in not any longer maintained by the weir of Linne but by the weir of Roermond. For navigation of recreational boating on the Border Meuse does this option make no sense. The current influenced water level of 20.80 +NAP will be maintained.



Graph 46 - Border Meuse: option 1 navigation

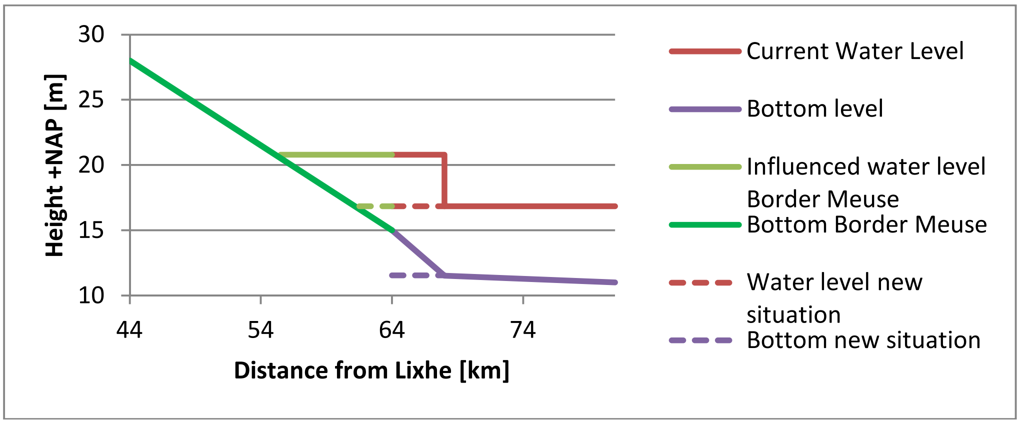
4.1.2 Option 2

The second option is less beneficial for the navigation on the Meuse. By lowering the water level in the former canal section of Linne from 20.80 m +NAP to 16.85 m +NAP will the former canal section Linne have not enough draught for the required CEMT Vb class. To obtain sufficient draught is a lowering of the river bottom from the lock of Maasbracht until the locks of Heel and Linne necessary. The bottom has to be lowered to 11.55 m +NAP to obtain sufficient depth, at least a depth of 5.3 m is ecessary for the Vb class. The lowering of the bottom and the water level in the former canal section Linne is represented in Graph 46.



Graph 47 - Canal section Linne: option 2 navigation

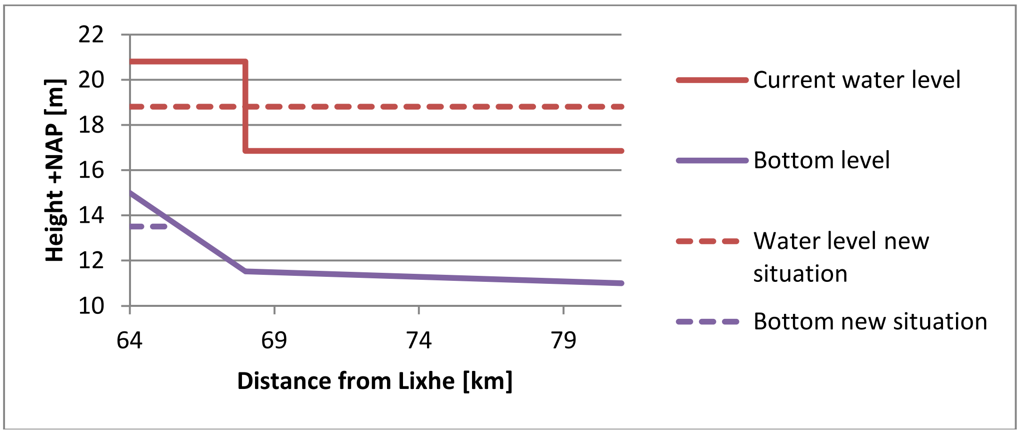
By lowering the water level in the former canal section of Linne to 16.85 m +NAP will the influence zone of the new canal section on the Border Meuse become smaller. For the commercial transport over the Border Meuse does this not make any sense however for recreational boating may this interference cause problems. Around Stevensweert are several recreational harbors, it has to be investigated what the lowering of the water level means for these harbors. However along the Border Meuse are more recreational harbors so probably will the shortening of the influence zone have a small effect on recreational boating on the Border Meuse.



Graph 48 - Border Meuse: option 2 navigation

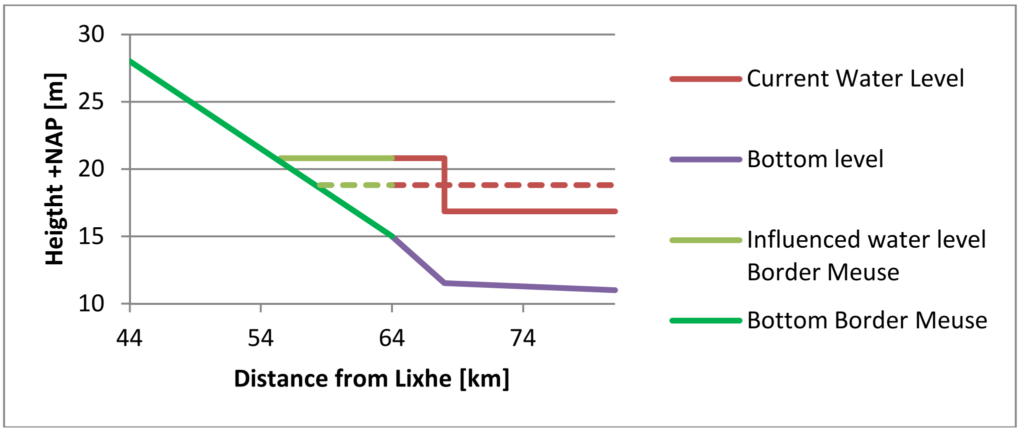
4.1.3 Option 3

In the third situation is the water level in the former canal section Linne lowered with 2 m and in the former canal section Roermond raised with 1.95 m. For the purpose of navigation in the new canal section has this little effect on the upstream side of the section. By as small lowering of the river bottom to 13.50 m +NAP will the water depth be sufficient to maintain the transport by class Vb vessels.



Graph 49 - Canal section Linne: option 3 navigation

The effect of the third option on the influence zone on the Border Meuse is smaller than in option 2. The influence zone will for this option be 300 m shorter compared with the current situation. For navigation, recreational as commercial will this probably have not influence.

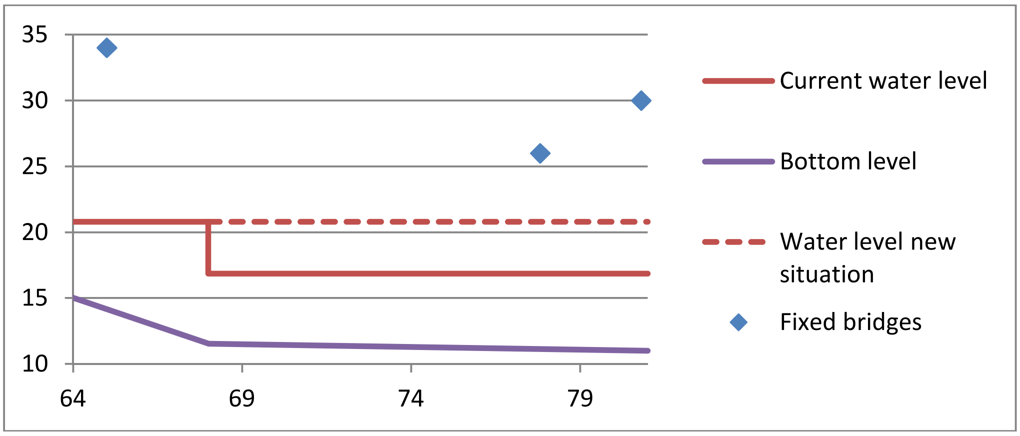


Graph 50 - Border Meuse: option 3 navigation

4.2 Bridges

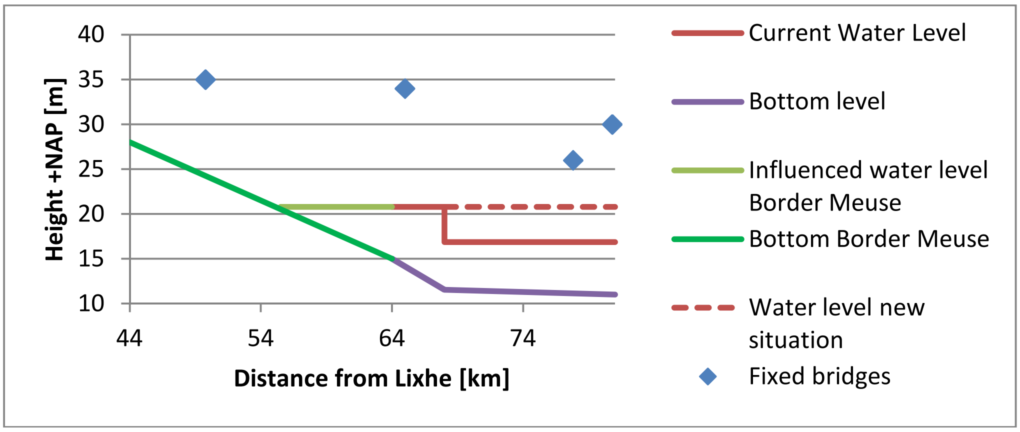
4.2.1 Option 1

In the considered canal section are three bridges located, one in the former canal section Linne and two in the former canal section Roermond. By increasing the water level in the former canal section Roermond will the vertical clearance of the first bridge in the canal section Roemond not be sufficient, this is the bridge in the N280 near Roermond. The second bridge in the canal section Roermond will be high enough the vertical clearance is in the new situation 9.2 m where a vertical cleance between 7.0 and 9.1 m is restricted for the governing vessel class on the Meuse. The current bridge in the A2 over the former canal section Linne is high enough and needs no adaption as can be seen in Graph 51.



Graph 51 - Canal section Linne: option 1 bridges

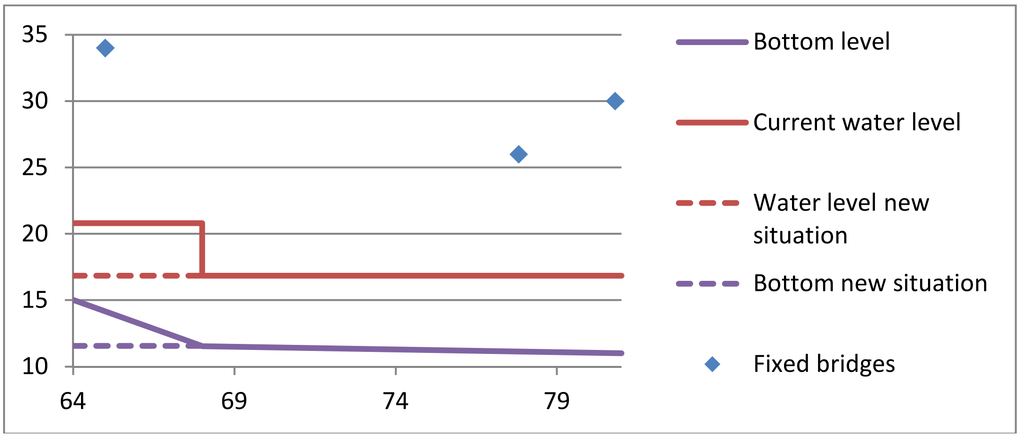
Because the water level in the former canal section of Linne is not raised or lowered will the bridges over the Border Meuse be sufficient for the new situation.



Graph 52 - Border Meuse: option 1 bridges

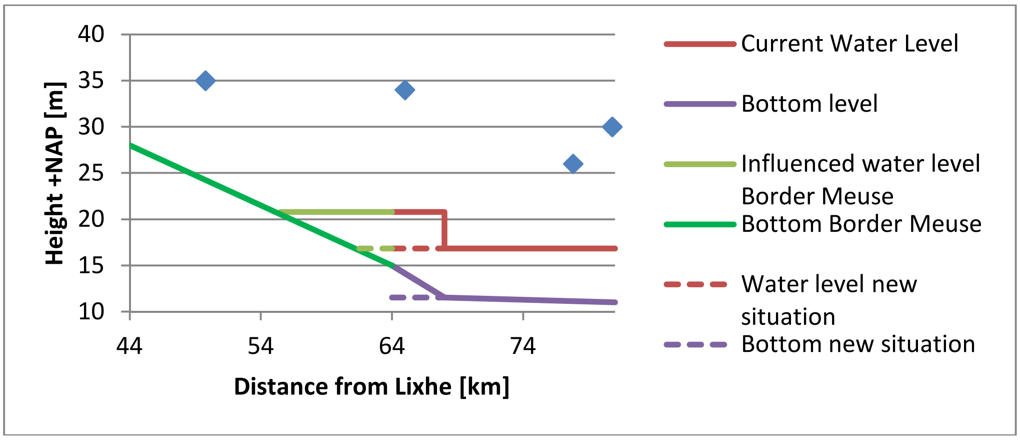
4.2.2 Option 2

In the second option is the water level in the former canal section of Linne lowered. So the vertical clearance under the bridge in this canal section increases. Because the water level in the former canal section of Roermond is kept at the same level as the current situation will the two bridges over this canal section also meet the requirement of the vertical clearance. The situation is represented in Graph 53.



Graph 53 - Canal section Linne: option 2 bridge

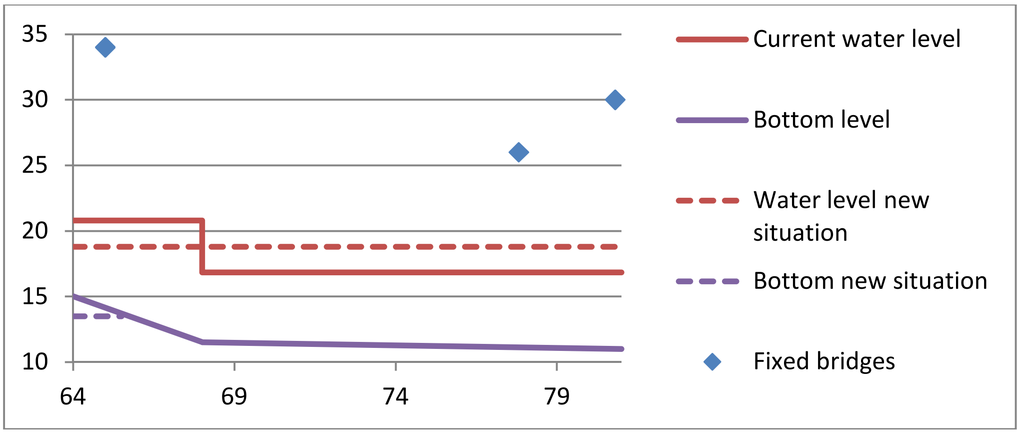
Because only the water level in the former canal section of Linne is lowered will all the bridges over the Border Meuse meet there requirements of the vertical clearance. The situation is represented in Graph 54.



Graph 54 - Border Meuse: option 2 bridges

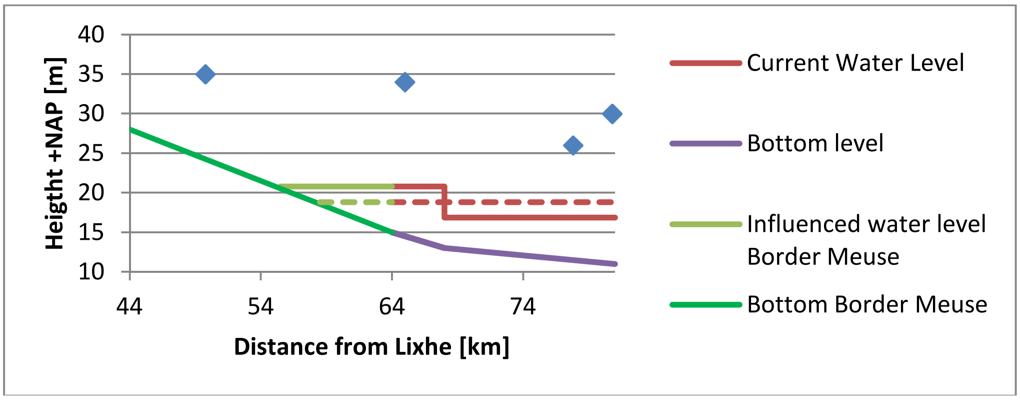
4.2.3 Option 3

In the third option will the bridge over the former canal section Linne and the second bridge over the former canal section Roermond meet the requirements for the vertical clearance, this can be seen in Graph 55. The first bridge over the former canal section Roermond will just meet the requirement of vertical clearance. A clearance between 7 and 9.1 m is required while the vertical clearance in this situation is 7.2 m, so this bridge has not to be adapted to the maintain the route to the harbor of Roermond.



Graph 55 - Canal section Linne: option 3 bridge

Because the water level in the former canal section Linne is lowered will the bridges over the Border Meuse automatically meet the requirements for the vertical clearance.

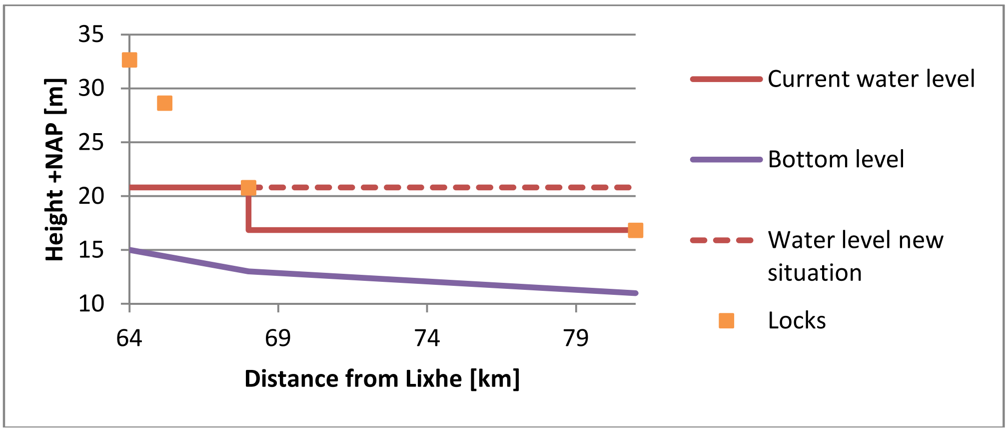


Graph 56 - Border Meuse: option 3 bridges

4.3 Locks

4.3.1 Option 1

In the new canal section are five locks located near Maasbracht, Panheel, Heel, Linne and Roermond, in Graph 57 are four locks represented but the locks of Heel and Linne are located next to each other. Because the weir of Linne will be removed is also the lock of Linne unnecessary so can be removed. As can be seen in the graph can in this option the three upstream locks act as in the current situation. Only the downstream lock, the lock of Roermond will in the new situation be too low. By increasing the water level in the former canal section of Roermond from 16.85 m +NAP to 20.80 m +NAP will the height not be sufficient. A new lock has to be constructed besides the new weir of Roermond.

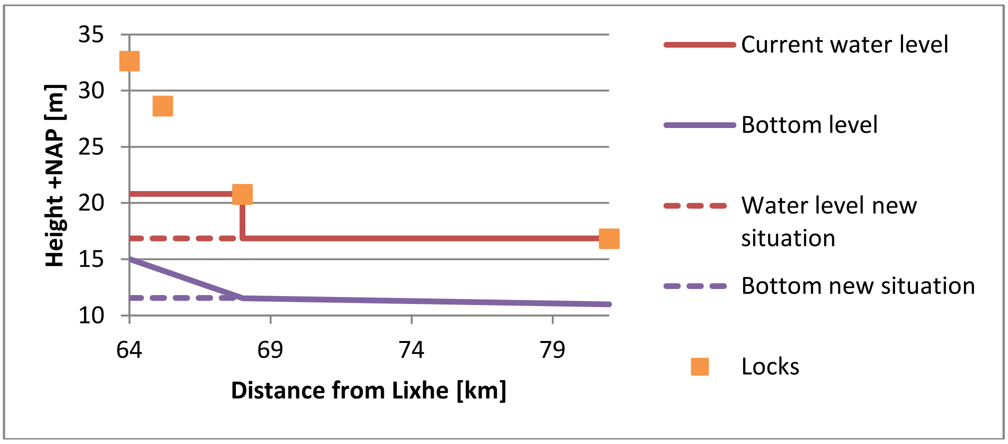


Graph 57 - Canal section Linne: option 1 locks

4.3.2 Option 2

In the second option is the water level in the former canal section of Linne be lowered. Due to this lowering will the water level difference over the two upstream lock larger than in the current situation. It has to be checked whether the locks of Born and Panheel can resist the larger water pressure on the gates. The locks itself are high enough so have only to be checked on the water pressure on the gates.

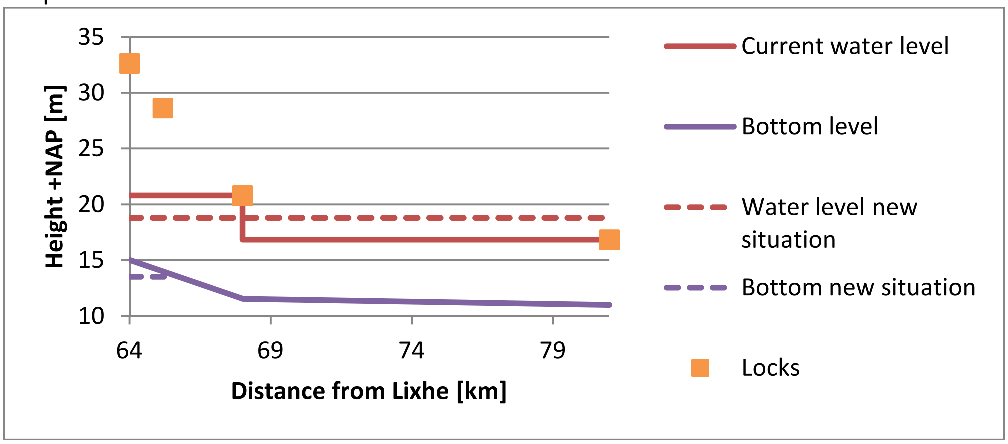
The lock of Heel will in the new situation be too high and also the water level difference will be smaller. The lock provides a connection between the former canal section of Linne and the Lateral Canal which water level is controlled by the canal section of Belfeld (14.10 m +NAP). Due to the lowering of the water level from 20.80 m +NAP to 16.85 m +NAP decreases the water level difference between up and downstream of lock Heel from 6.7 m to 2.75 m. The lock of Roermond can act as in the current situation because the water level in the former canal section Roermond is not changed.



Graph 58 - Canal section Linne: option 2 locks

4.3.3 Option 3

In the third option is the water level in the former canal section Linne be lowered, this resulted in an increase of the water level difference of the locks of Born and Panheel. It has to be investigated if these locks have to be adapted or that they are strong enough to resist the increasing water level difference. The water level lowering in the canal section Linne is beneficial for the lock of Heel because the water level with the Lateral canal becomes smaller. The lock of Roermond has to be adapted to the new situation because the lock of Roermond is this situation to low as can be seen in Graph 59.



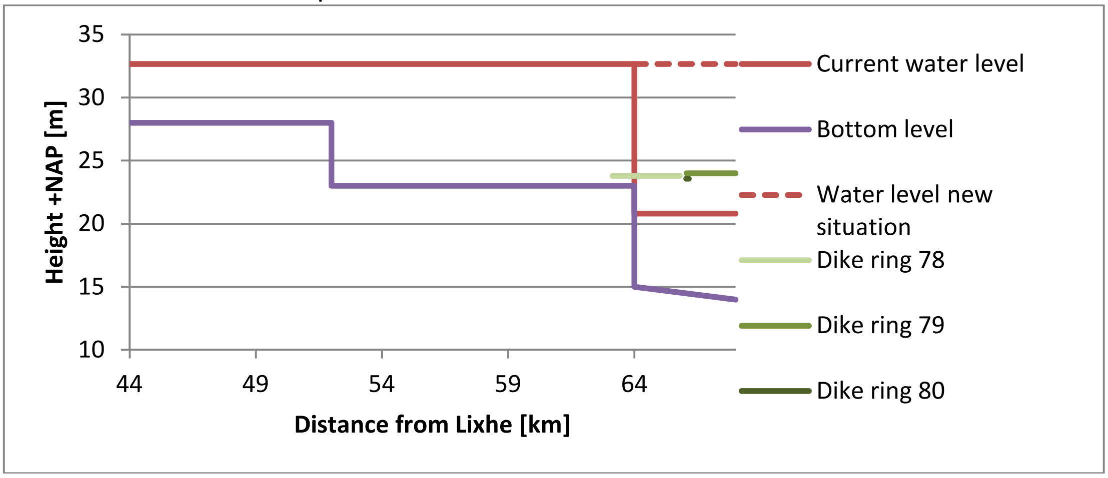
Graph 59 - Canal section Linne: option 3 locks

4.4 Flood protection

The dike ring areas along the new canal section are located along the former canal section of Linne. Dike ring 78 has to protect Heel, dike ring 79 has to protect Wessem and Thorn and dike ring 80 has to protect the Clauscentrale, a power plant nearby Maasbracht. Along the Juliana Canal is no flood protection present because the canal has only a navigable function and no discharging function. The Border Meuse has this discharging function which resulted in flood protection along the Border Meuse. In the considered part of the Border Meuse are the dike ring areas 78, 81 and 82 located. Dike ring area 81 has to protect Stevensweerd and Ohé en Laak and dike ring 82 has to protect Aasterberg.

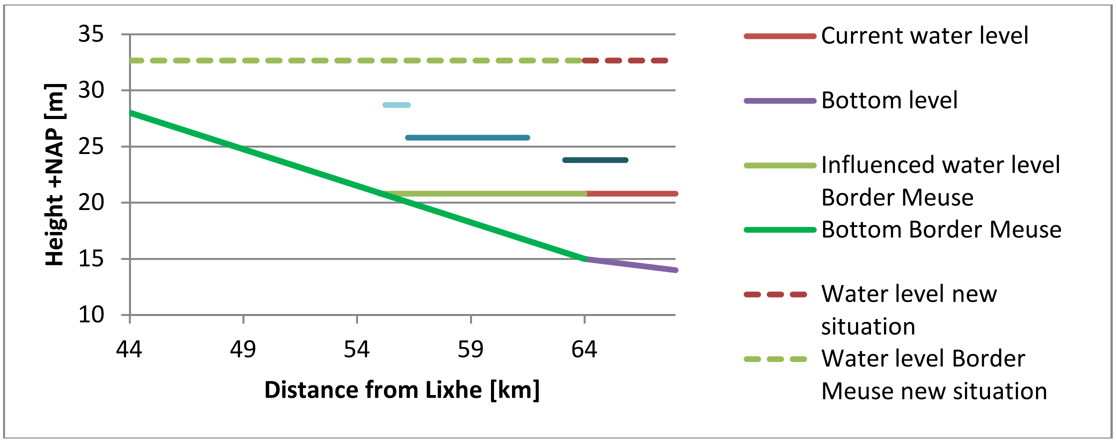
4.4.1 Option 1

In the first option will all the flood protections along the former canal section Linne be under the water level. To adapt the current flood protection to the new situation has the flood protection be raised by nearly 10 m. This flood protection is not only necessary during floods but also as permanent protection for the raised water level in the new canal section. This flood protection are no dikes but walls which are sometimes located in the middle of the village centers. By raising the flood protection should large wall arise in village centers or back yards of citizens. It is questionable if this is in the best interest of the villages along the Meuse. The situation is represented in Graph 60. The Juliana Canal has not to be adapted in this situation.



Graph 60 - Canal section Linne: option 1 flood protection

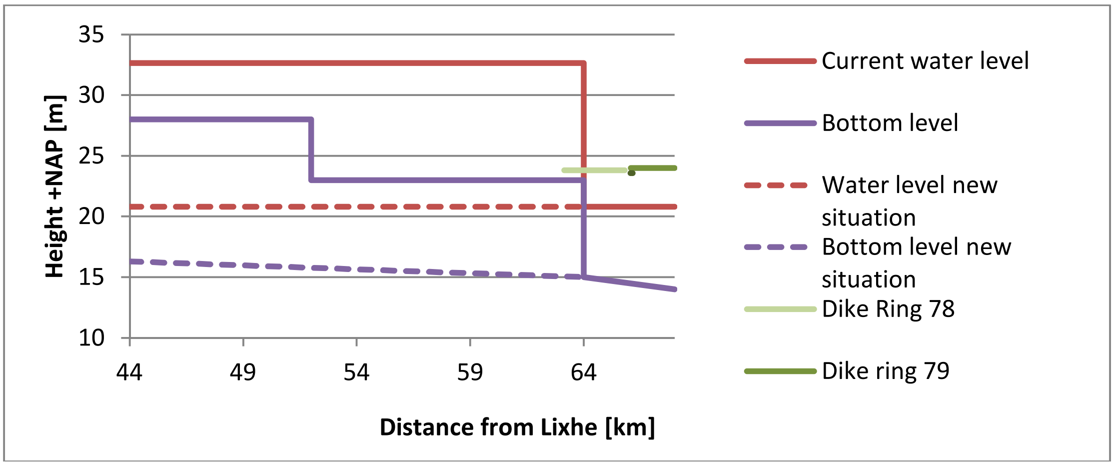
By raising the water level will also the water level in the downstream part of the Border Meuse rise. As can be seen in Graph 61 will all the dike rings be under water in this new situation. All the dike ring areas have to be raised with at least 10 m to maintain a sufficient flood protection along the Border Meuse.



Graph 61 - Border Meuse: option 1 flood protection

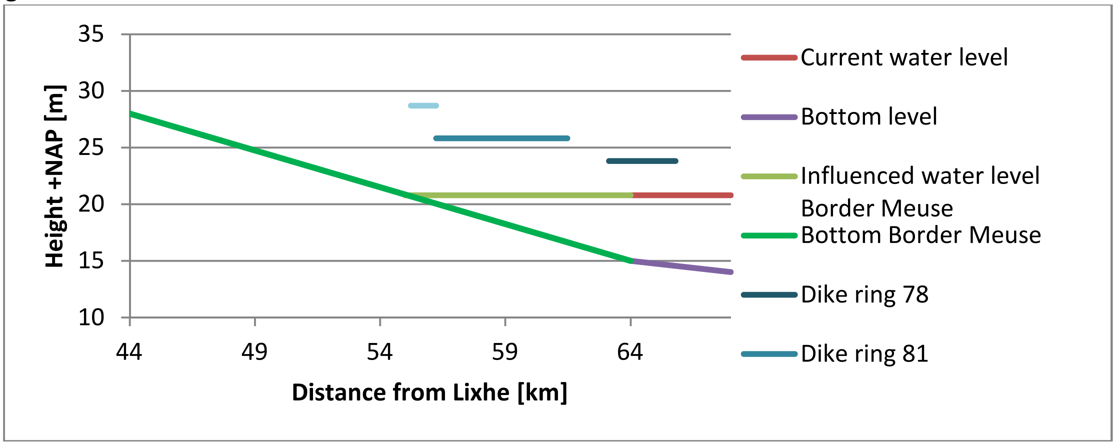
4.4.2 Option 2

In the second option will the water level in the former canal section of Linne not be raised as can be seen in Graph 62. This is beneficial for the flood protection because it means that the current flood protection is high enough so has not to be raised. The new water level means a reduction of the water level in the Julian canal. It has to be ensured that the walls of the canal will be stable in the new situation. It has to be investigated if and how this should be done.



Graph 62 - Canal section Linne: option 2 flood protection

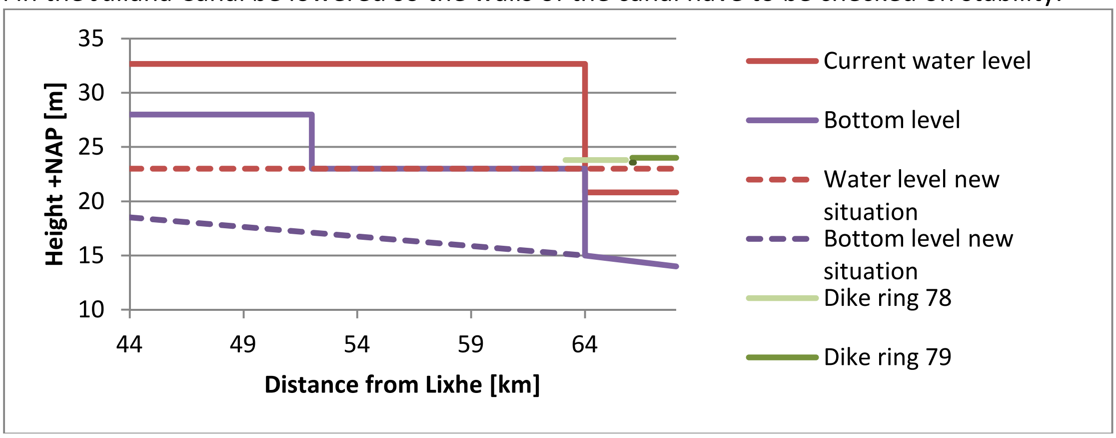
The maintenance of the water level in the former canal section Linnen is beneficial for the flood protection along the Border Meuse. As can be seen in Graph 63 are the dike ring areas high enough for the new situation. So for this option has no adaption to be made for the current dike ring areas along the Border Meuse.



Graph 63 - Border Meuse: option 2 flood protection

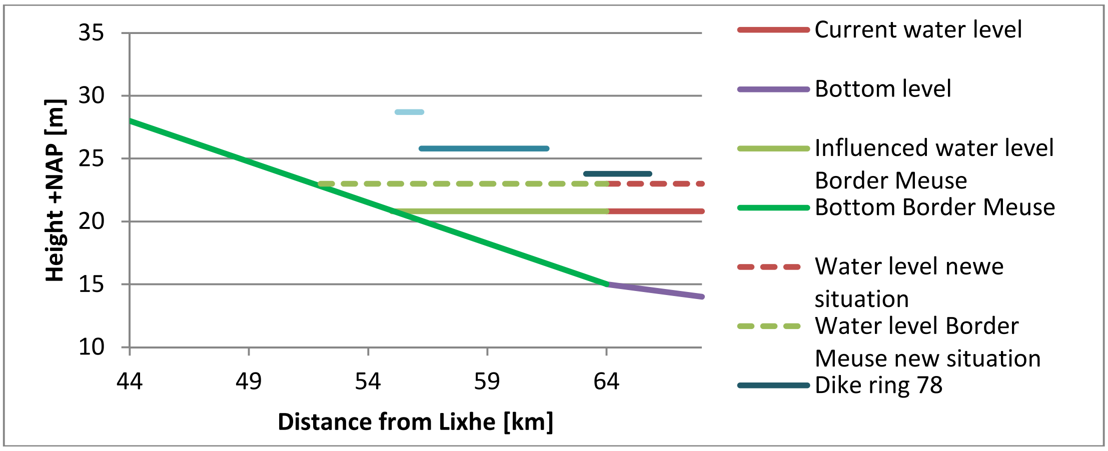
4.4.3 Option 3

In the third option will the flood protection of the former canal section Linne be just above water level as is represented in Graph 64. However, when the water level will rise during high discharges will the water level probably higher than the current flood protection. In this situation should the high water protection be raised but not as rigorous as in option 1. Just as in option 1 will the water level in the Juliana Canal be lowered so the walls of the canal have to be checked on stability.



Graph 64 - Canal section Linne: option 3 flood protection

The small raise in water level in the former canal section of Linne ensured that the flood protection along the Border Meuse. However the water level will be nearly as high as dike ring 78 and also the over height of dike ring 81 becomes smaller. Probably dike ring 78 will be to low and should be raised, it has to be investigate if dike ring 81 have to be raised. Dike ring area 82 will probably be high enough because when discharge become higher will water level rise but with a maximum of about 2 m.

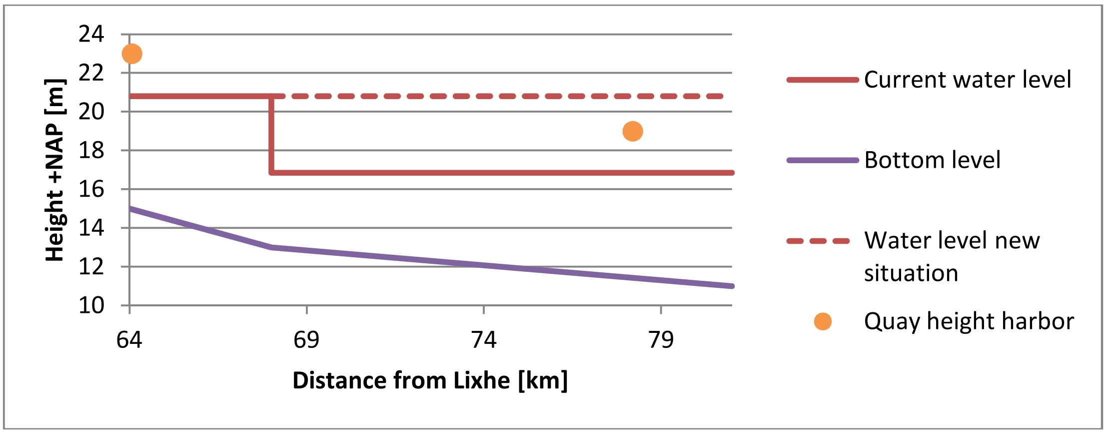


Graph 65 - Border Meuse: option 3 flood protection

4.5 Harbors

4.5.1 Option 1

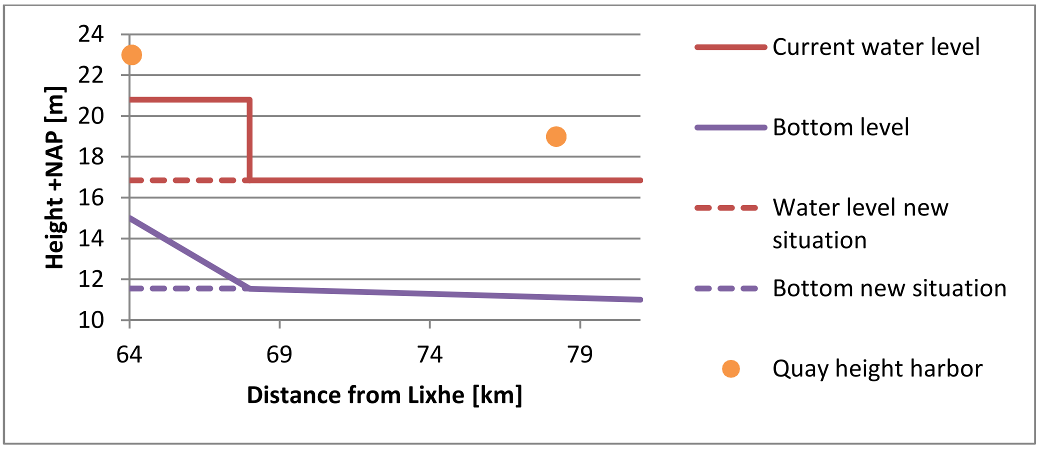
In the new canal section are two harbors located, the upstream harbor is located near Wessem and Maasbracht and the second harbor is located at Roermond. In the first option is the water level in the former canal section Roermond raised with nearly 4 m. The result is that the water level in this former canal section becomes higher than the quay walls of the Harbor of Roermond. To keep this harbor operational should the quay walls be heightened from 19 m +NAP to 23 m +NAP. Because the water level in the former canal section Linne is kept at the same level can the harbor of Wessem/Maasbracht act as in the current situation.



Graph 66 - Canal section Linne: option 1 harbors

4.5.2 Option 2

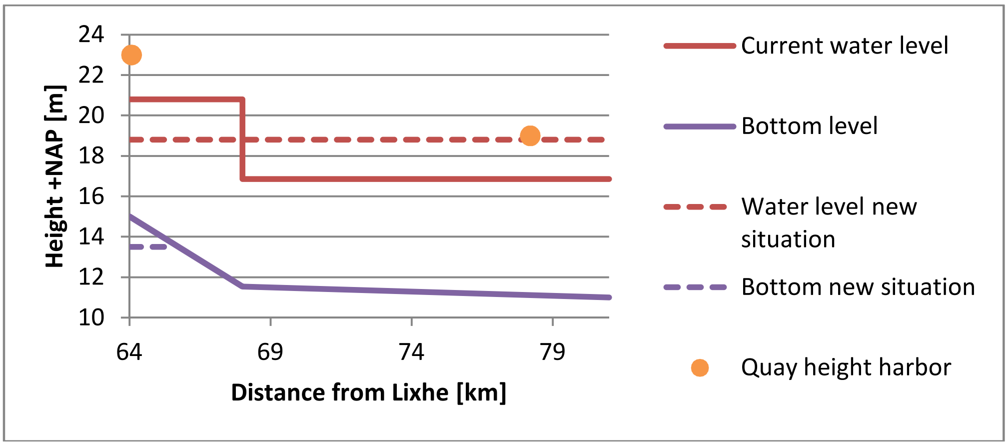
The second option is not beneficial for the harbor of Wessem/Maasbracht. By lowering the water level in the former canal section Linne will the quay walls of the harbor nearly 4 m to high. To keep the harbor operational should the quay walls be lowered with nearly 4 m from 23 m +NAP to 19 m +NAP. The harbor of Roemond can in the new situatin act in the same way because the water level in the former canal section in Roermond is kept the same as the current situation. The situation is represented in Graph 67.



Graph 67 - Canal section Linne: option 2 harbors

4.5.3 Option 3

The third option is not beneficial for the harbor of Wessem/Maasbracht as well the harbor of Roermond. The quay walls of the harbor of Wessem/Maastricht will be too high in the new situation, the quays have to be lowered from 23 m +NAP to about 21 m +NAP. By the increase of the water level in the former canal section of Roermond will the harbor of Roermond just be above water level. However by a slight water level rise during high discharges will the quays become under water level so to avoid this problem should these quays be heightened.



Graph 68 - Canal section Linne: option 3 harbors

5 Weir Roermond

The canal section of Roermond has two locks, the locks are located Linne and Roermond. The lock of Linne is the connection between the canal sections of Linne and Roermond and the lock of Roermond is the connection between the canal section of Roermond and Belfeld. In the new considered canals section are two more locks located near Heel and Belfeld. The lock of Heel provides access entrance to the Lateral canal so actually the canal section of Belfeld, the current water level in this section is 14.10 m +NAP. The lock of Belfeld is the connection between the canal sections of Belfeld and Sambeek, the current water level in the canal section of Sambeek is set at 10.85 m +NAP. It has to be noticed that the canal section of Roemond is not part of the main navigational route, Ships use the Lateral Canal parallel to this canal section and enter the canal section Belfeld at 88 km from Lixhe.

Three possible solutions are discussed when the weir of Roermond is removed. In the first situation will the water level in the new canal section taken the same as the former canal section of

Roermond. The water level in the former canal section of Roemond will stay at 16.85 m +NAP. The water level of the former canal section of Belfeld will be raised by 2.75 m from 14.10 m +NAP to 16.85 m +NAP.

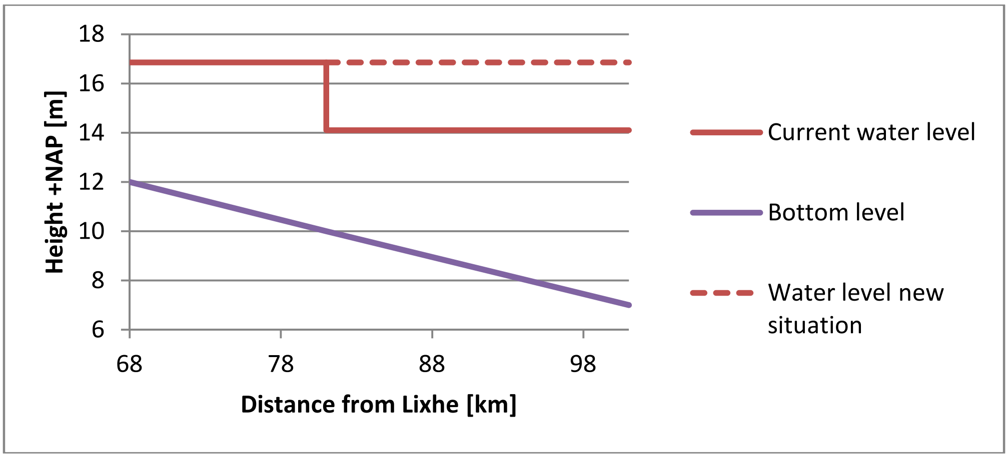
In the second situation will the water level in the new canal section be taken the same as in the former canal section of Belfeld. The water level in the former canal section of Roermond will be lowered by 2.75 m from 16.85 m +NAP to 14.10 m +NAP. The water level in the former canal section Belfeld will be the same as in the current situatin.

In the third option will the water level be taken as the mean value of the water levels in the former canal sections of Roermond and Belfeld, the water level will be taken at 15.5 m +NAP. The water level in the former canal section of Roermond will be lowered by 1.35 m from 16.85 m +NAP to 15.50 m +NAP. The water level in the former canal section of Belfeld will be raised by 1.40 m from 14.10 m +NAP to 15.50 m +NAP.

5.1 Navigation

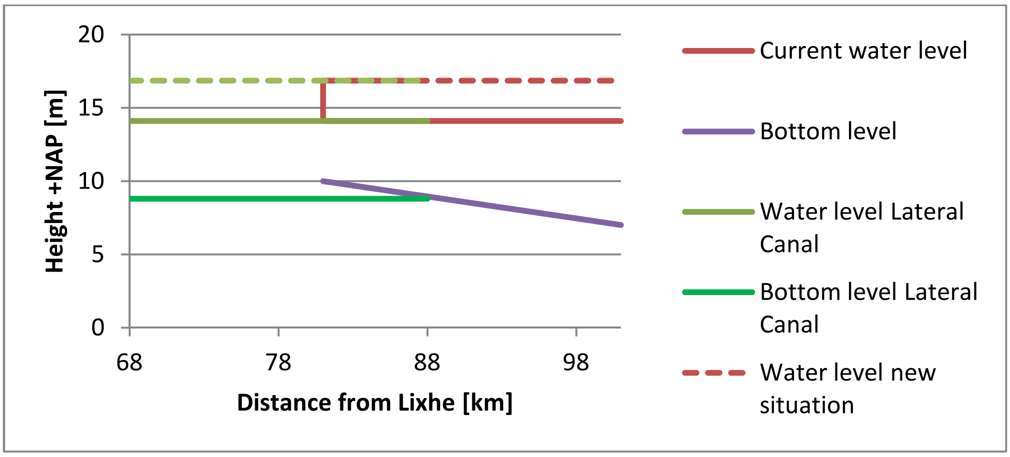
5.1.1 Option 1

The first option is beneficial for navigation in the new canal section. The water depth will in the whole of the new canal section be sufficient. The water level downstream of the weir of Linne is 4.85 m which is smaller than the current required 5.3 m. However the main navigation route is not going through canal section Roermond, most transport is done by smaller vessels so 5.3 m depth is not a hard requirement for this section. Also in the canal section Belfeld downstream near the weir of Roermond is the water depth not sufficient for Vb class vessels. However most vessels enter the canal section by the Lateral Canal that enters the canal section at 88 km from Lixhe. At this point is the Meuse deep enough for class Vb vessels. The situation is represented in Graph 69.



Graph 69 - Canal section Roermond: option 1 navigation

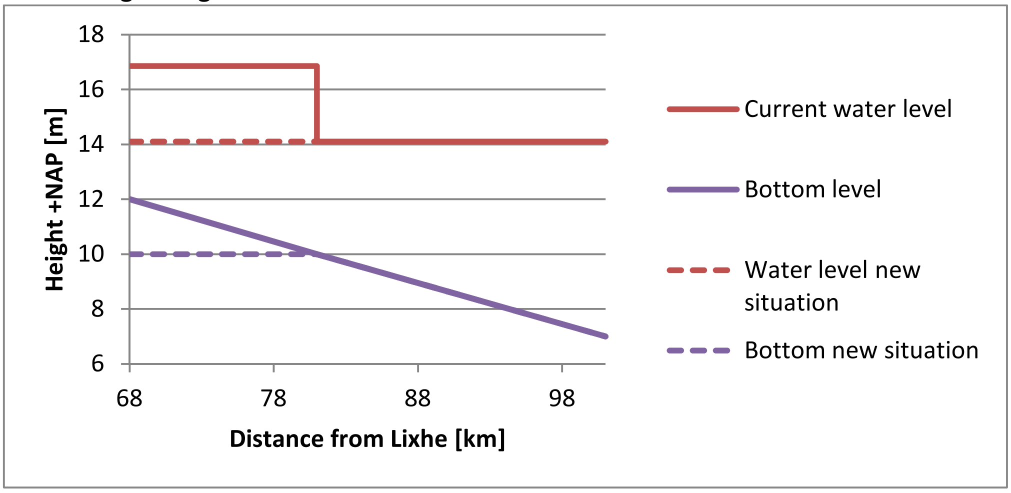
The change of the water level has not only influence on the former canal sections of Roermond and Belfeld but also on the water level on the Lateral Canal. Because the water level in the Lateral Canal is maintained by the weir of Belfeld, has a water level change in this canal section also influence on the water level of the Lateral Canal. In the first option will not only the water level in the former canal section Belfeld rise but also the water level in the Lateral canal. For navigation is this beneficial because the draught in the Lateral canal is raised by 2.75 m from 14.10 m +NAP to 16.85 m +NAP as can be seen in Graph 70.



Graph 70 - Lateraalkanaal: option 1 navigation

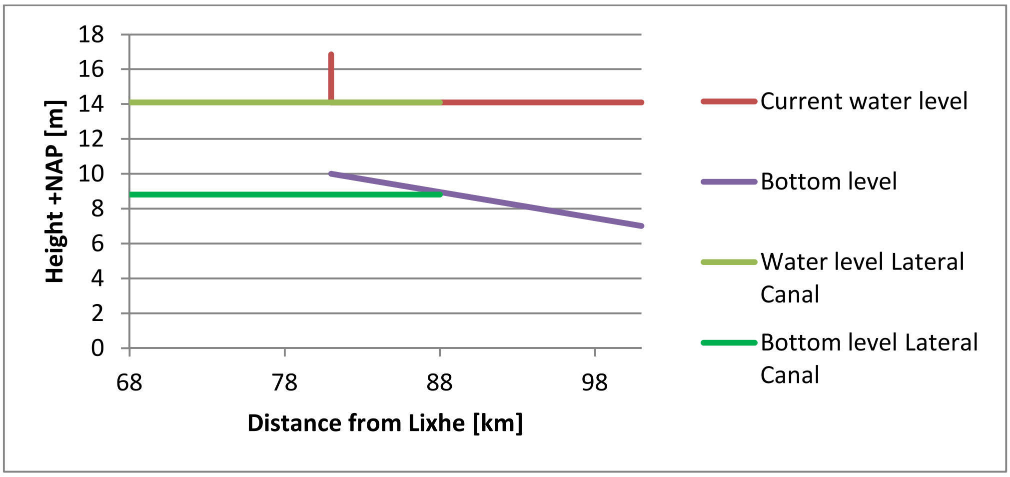
5.1.2 Option 2

In the second option will the water level in the former canal section of Roermond lowered with 2.75 m from 16.85 m +NAP to 14.10 m +NAP. To obtain sufficient draught in the canal section Roermond has the bottom to be lowered to 10 m + NAP. The situation is depicted in Graph 71. The water level in the former canal section Belfeld will stay the same as in the current situation so in this canal section will nothing change.



Graph 71 - Canal section Roermond: option 2 navigation

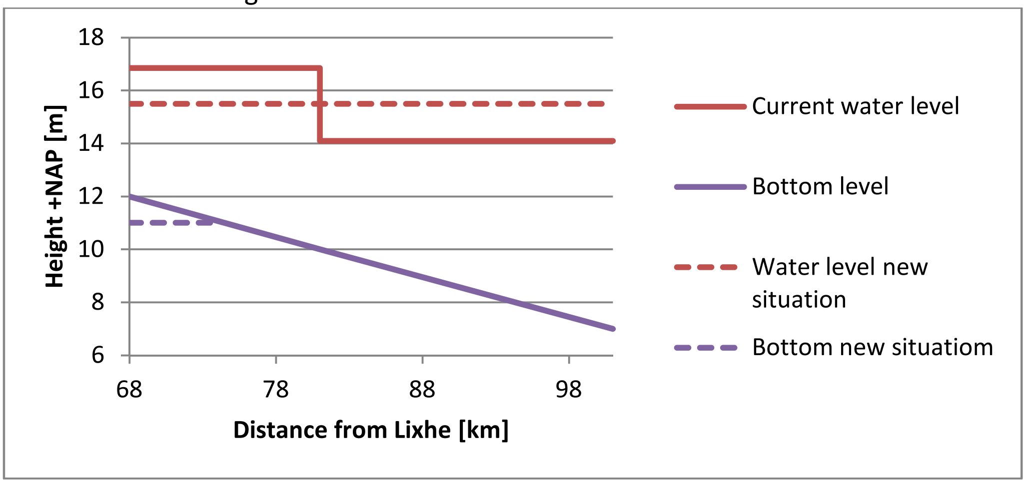
Because the water level in the former canal section of Belfeld will stay the same as in the current situation, the result is that also the water level in the Lateral canal will stay the same. So the current main navigational route will not change in the new situation because the main navigational route is not going through the former canal section of Roermond.



Graph 72 - Lateraalkanaal: option 2 navigation

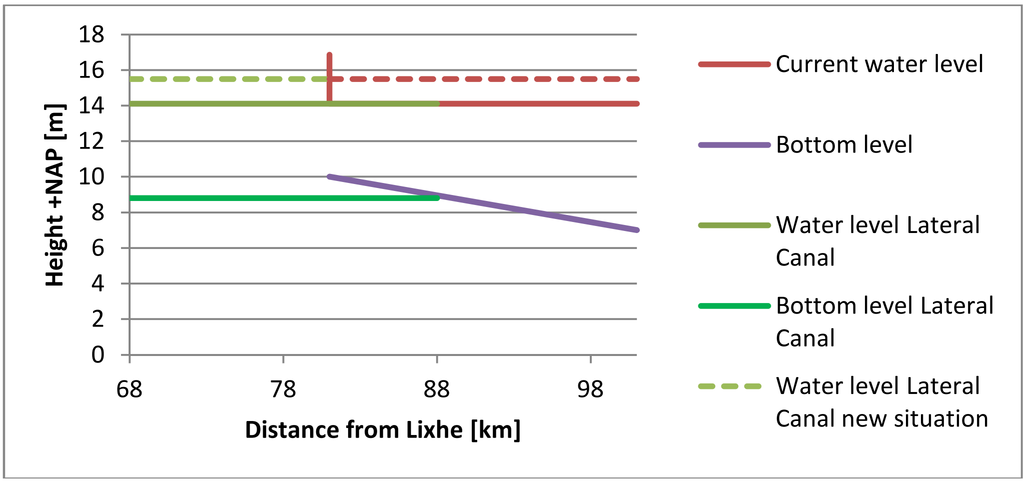
5.1.3 Option 3

In the third option will the water level in the former canal section of Roermond be lowered from 16.85 m +NAP to 15.5 m +NAP, a lowering of 1.35 m compared to the current situation. To maintain navigational route to the harbor of Roermond should the river bottom be lowered to at least 11 m +NAP to obtain the sufficient draught. The water level in the former canal section of Belfeld is raised from 14.10 m +NAP to 15.50 m +NAP. The raise of the water level is beneficial for the purpose of navigation because the draught is increased.



Graph 73 - Canal section Roermond: option 3 navigation

Due to the water level raise in the canal section Belfeld will the water level in the Lateral Canal also rise. The water level rise is beneficial for the navigation on the Lateral Canal as can be seen in Graph 74.

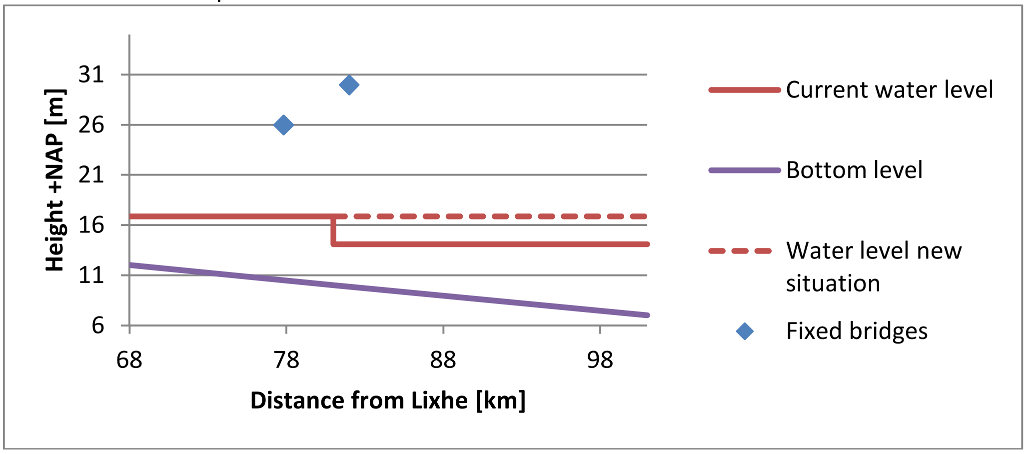


Graph 74 - Lateraalkanaal: option 3 navigation

5.2 Bridges

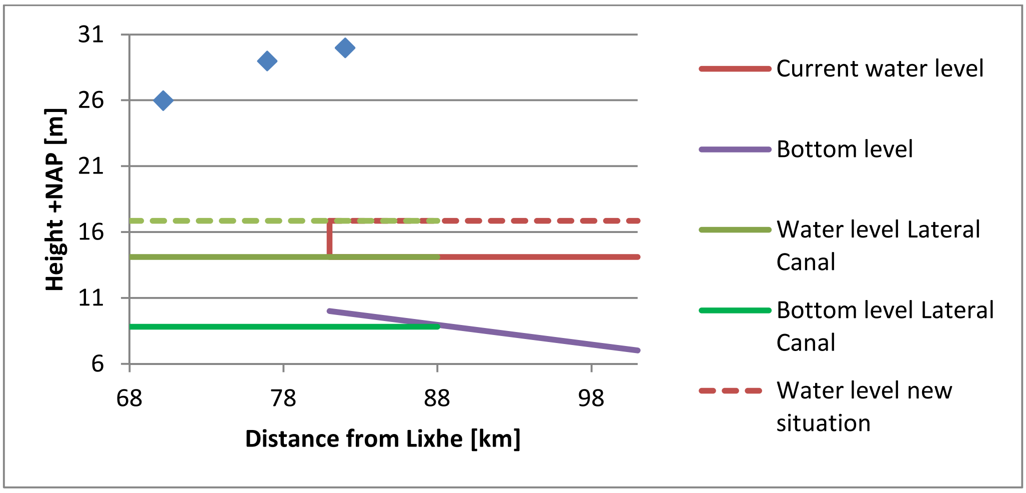
5.2.1 Option 1

Over the new considered canal section are two bridges located. The upstream bridge is the bridge in road N280 near Roermond and this located in the former canal section Roermond. The second bridge is the railway bridge near Buggenum and is located in the canal section of Belfeld. The vertical clearance of the upstream bridge is 9.15 m, because the water level in the former canal section Roermond is not raised will the vertical clearance also in the new situation satisfy.
The vertical clearance of the downstream bridge is in the current situation 15.90 m. By the increase of the water level in the former canal section Belfeld will this vertical clearance reduce to 13.15 m. This is larger than the required 7 to 9.10 m for Vb class vessels. So for this option have no bridges over the Meuse to be adapted.



Graph 75 - Canal section Roermond: option 1 bridges

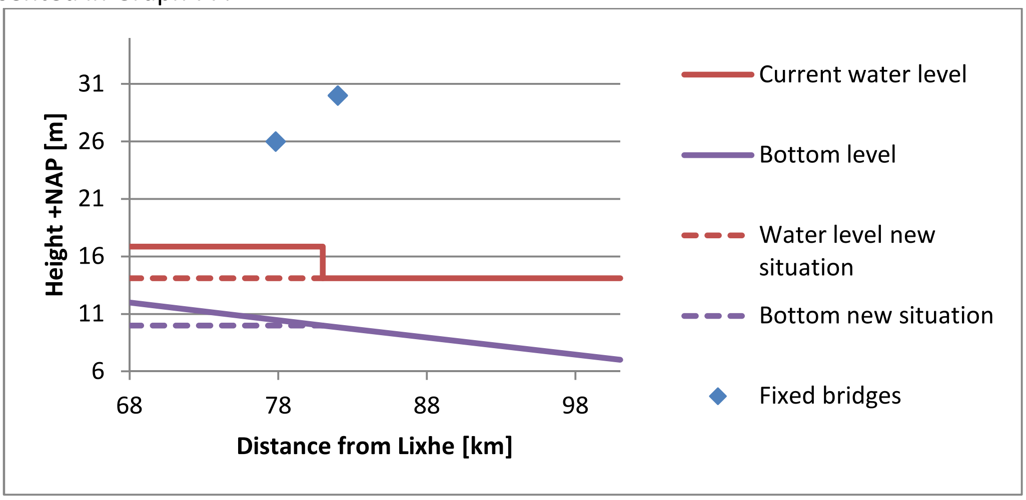
Compared to the Meuse itself are over the navigational route three bridges places instead of two. This extra bridge is located near the lock of Heel and is located over the Lateral Canal. The vertical clearance is in the current situation is 11.90 m, by the rise of the water level in the former canal section Belfeld to 16.85 m +NAP will the vertical clearance of the bridge become 9.15 m. This is sufficient for the required vessel class on the Meuse. The middle bridge in Graph 51 is the same bridges as the left bridge in Graph 75. However it is the same bridge does the bridge differ in height, the part over the Lateral Canal is higher than the part over the Meuse itself. By raising the water level in the former canal section Belfeld will the vertical clearance of middle bridge be sufficient in the new situation. The last bridge will satisfy in the new situation as is shown above.



Graph 76 - Lateraalkanaal: option 1 bridges

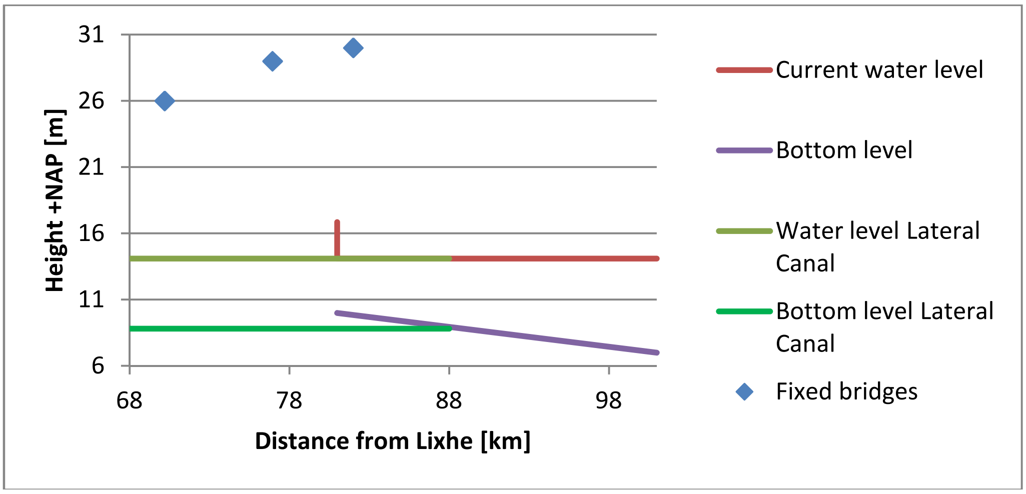
5.2.2 Option 2

The second option is beneficial for the bridges in the new considered canal section. By lowering the water level in the former canal section Roermond will the vertical clearance of the bridges over this section also increase. Because the vertical clearance of the bridges satisfy in the current situation so also in the new situation. The railway bridge over the former canal section Belfeld will also satisfy in the new situation because the water level in this section will kept in at the same level. The situation is represented in Graph 77.



Graph 77 - Canal section Roermond: option 2 bridges

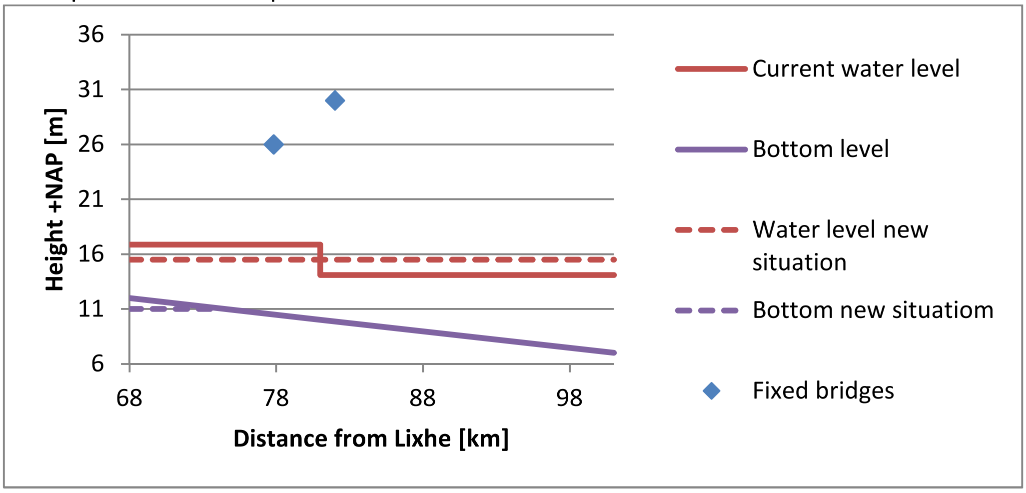
For the bridges over the Lateral Canal will satisfy in the new situation because the water level in the former canal section of Belfeld is kept the same in the new situation.



Graph 78 - Lateraalkanaal: option 2 bridges

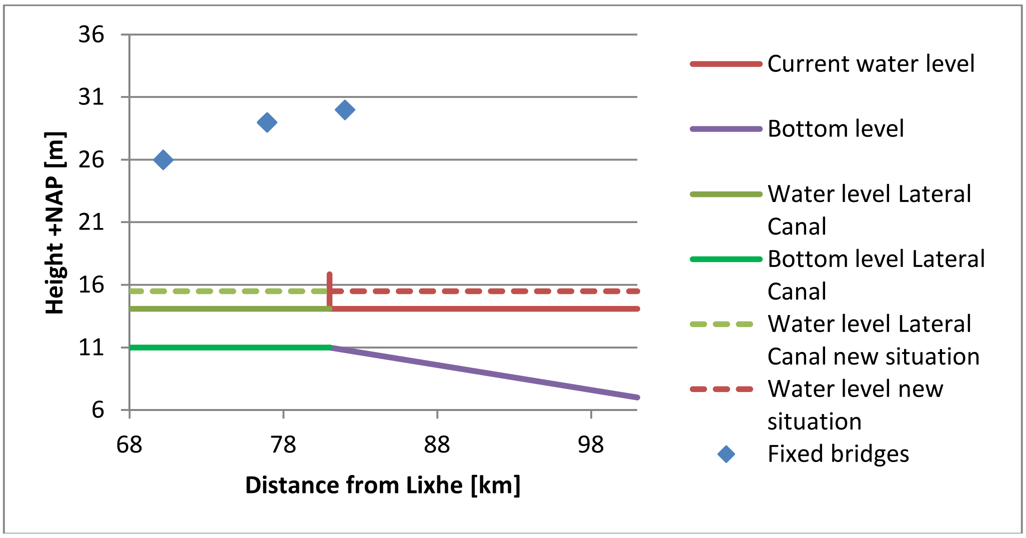
5.2.3 Option 3

In the third option will the water level in the former canal section Roermond be lowered and in the former canal section Belfeld be raised. Lowering of the water level of the canal section Roermond is beneficial for the vertical clearance of this bridge. The vertical clearance is raised from 9.15 m in the old situation to 10.5 m in the new situation. By the rise of the water level in the former canal section Belfeld will the vertical clearance of the railroad bridge of Buggenum be smaller. The vertical clearance in the current situation is 15.90 m, after rising of the water level will the vertical clearance be 14.50 m. This vertical clearance is large enough for the required vessel class on the Meuse. The situation is represented in Graph 79.



Graph 79 - Canal section Roermond: option 3 bridges

The rise of the water level in the former canal section Belfeld will have no large negative effect on the vertical clearance of the bridges over the Lateral canal. The clearance will be smaller in the new situation however larger than 9.10 m as can be seen in Graph 80. No adoptions have to be made on the brides in this situation.

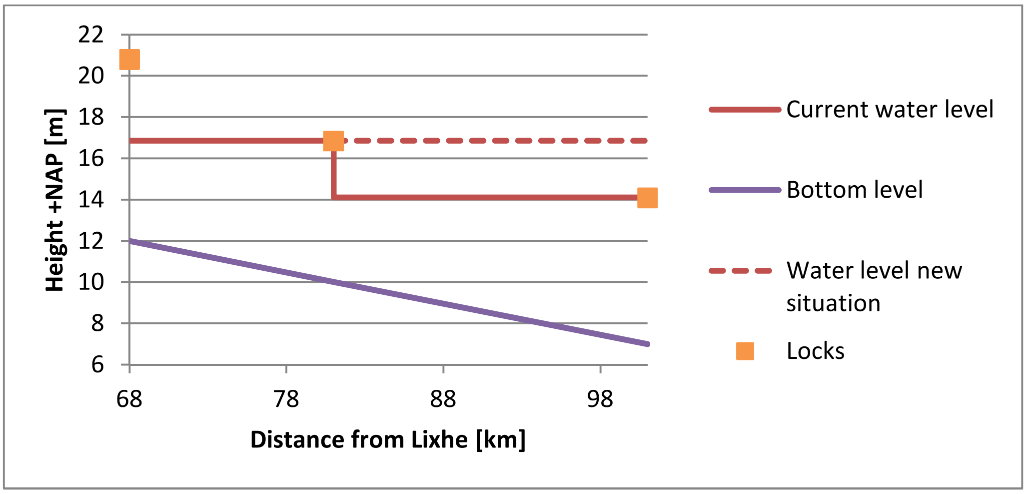


Graph 80 - Lateraalkanaal: option 3 bridges

5.3 Locks

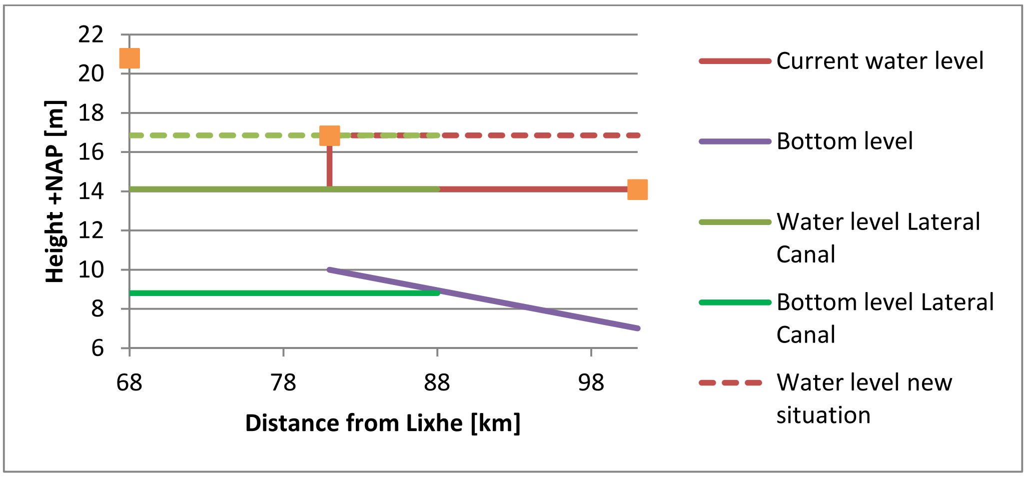
5.3.1 Option 1

In the new considered canal section are four locks located, the locks are located near Heel, Linne, Roermond and Belfeld. By the rise of the water level in the former canal section Belfeld will the lock of Linne act in the same way as in the current situation. Because the water level in the former canal section Roermond is not changed have these locks not to be adapted to the new situation. The lock of Belfeld does not satisfy in the new situation because the lock is not high enough. The lock has for this option be raised to at least 16.85 m +NAP, so the lock of Belfeld has to be raised with at least 2.75 m. For the lock of Roermond does the water level change make no sense because the water levels on both sides of the lock will be at the same level.



Graph 81 - Canal section Roermond: option 1 locks

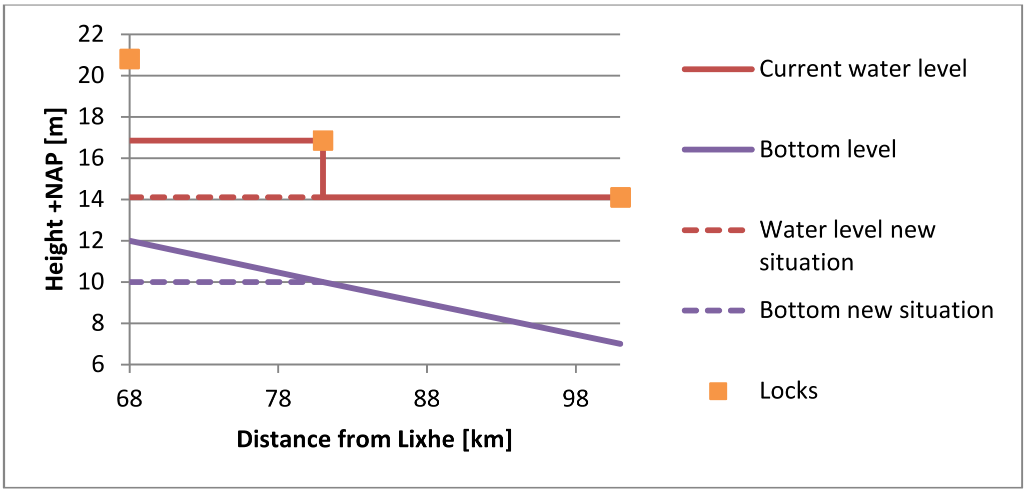
The rise of the water level in the former canal section Belfeld has a positive effect on the lock of Heel. Due to the rise of water level in the Lateral canal will the fall of the lock become smaller so vessels it will take lesser time for vessels to pass the lock. Also the forces on the lock gates will be smaller due to the smaller difference in water level on both sides of the lock. For the locks of Belfeld and Roermond holds the same as is described above, the situation is represented in Graph 82.



Graph 82 - Lateraalkanaal: option 1 locks

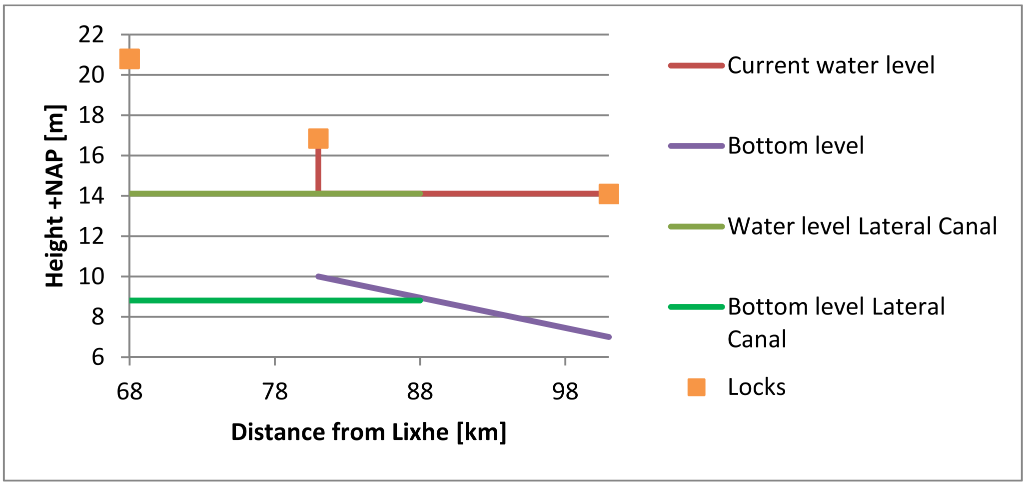
5.3.2 Option 2

The second option is beneficial for the lock of Belfeld. In this situation has the lock of Belfeld not to be adapted to the new situation because the water level in the former canal section of Belfeld has not been changed. This new situation is less beneficial for the lock of Linne due to the lowering of the water level in the former canal section Roermond. Due to this lowering will the water difference on both sides of the lock be larger which results larger locking times and larger forces on the gates. It has to be investigated if the lock and especially the gates are strong enough to resist this larger forces. The lock of Roermond (middle lock in Graph 83) is not necessary any more in this option because the water level on both sides of the lock will be the same.



Graph 83 - Canal section Roermond: option 2 locks

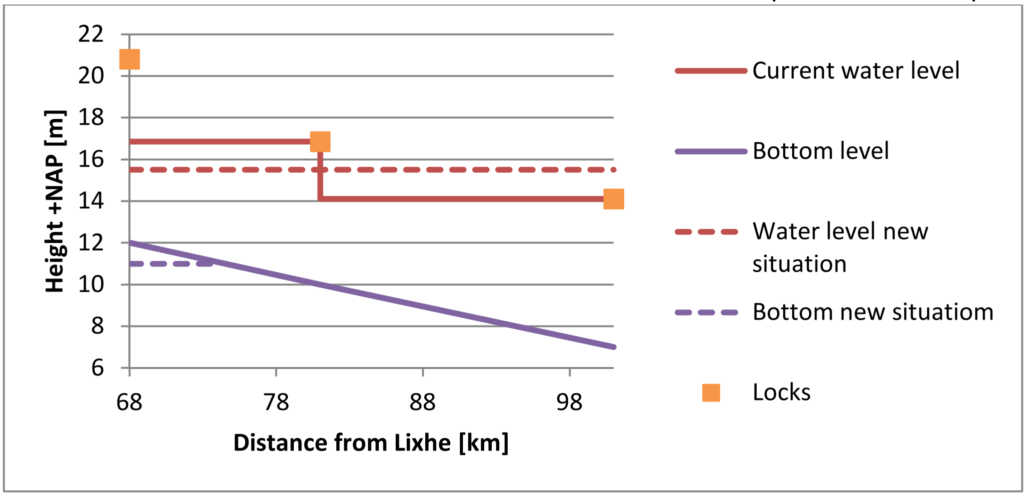
Because the water level in the former canal section Belfeld is not changed will in not be necessary for the lock of Heel (left lock in Graph 84) to be adapted. This situation can be seen in Graph 84.



Graph 84 - Lateraalkanaal: option 2 locks

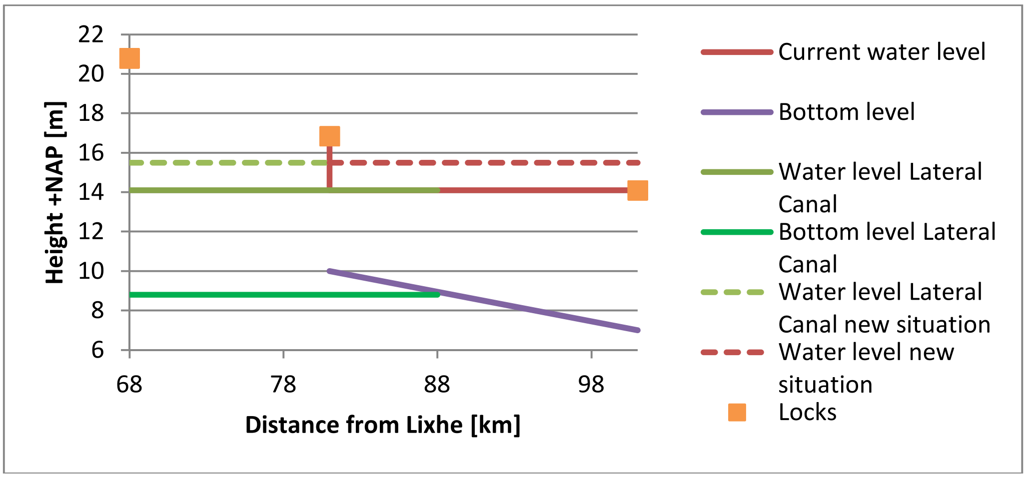
5.3.3 Option 3

In the third option is not beneficial for the locks in the new canal section. Due to the decrease of the water level in the former canal section of Roermond will the water level difference between both sides of lock Linne increase. This results in larger locking times and larger forces on the gates, it has to be investigated if the lock is robust enough for this new situation. Due to the rise of the water level in the former canal section Belfeld will the same situation arise as for the lock of Linne. Larger locking ties will occur and the resulting force on the gates will increase due to the larger water difference on both sides of the lock. The lock of Roermond will not be used anymore because the water level on both sides of the lock will be the same. This situation is represented in Graph 85.



Graph 85 - Canal section Roermond: option 3 locks

In case of the lock of Heel is this situation beneficial because the water level in the former canal section of Belfeld is raised so also the water level in the Lateral Canal. This results in a smaller water level difference between both sides of lock Heel. Locking times will be smaller in this situation and the hydraulic forces on the lock gates will be smaller than in the current situation. This situation is represented in Graph 86.

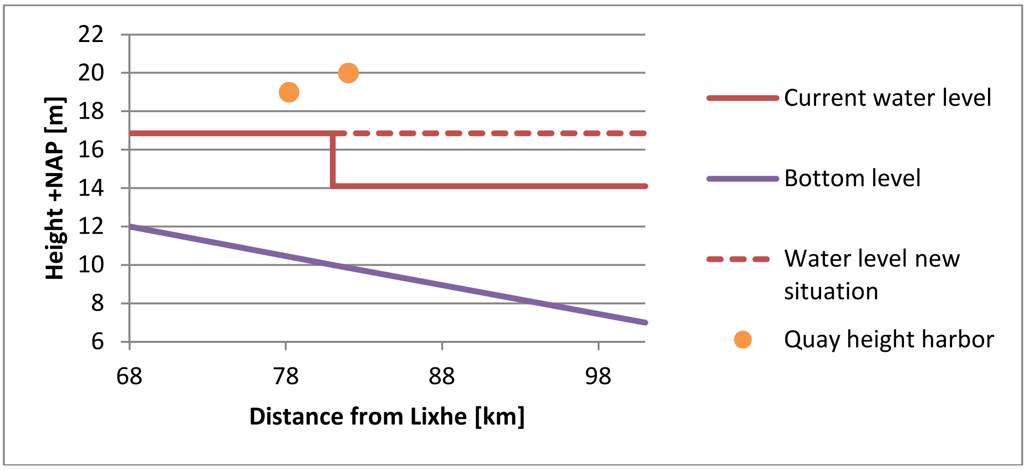


Graph 86 - Lateraalkanaal: option 3 locks

5.4 Harbors

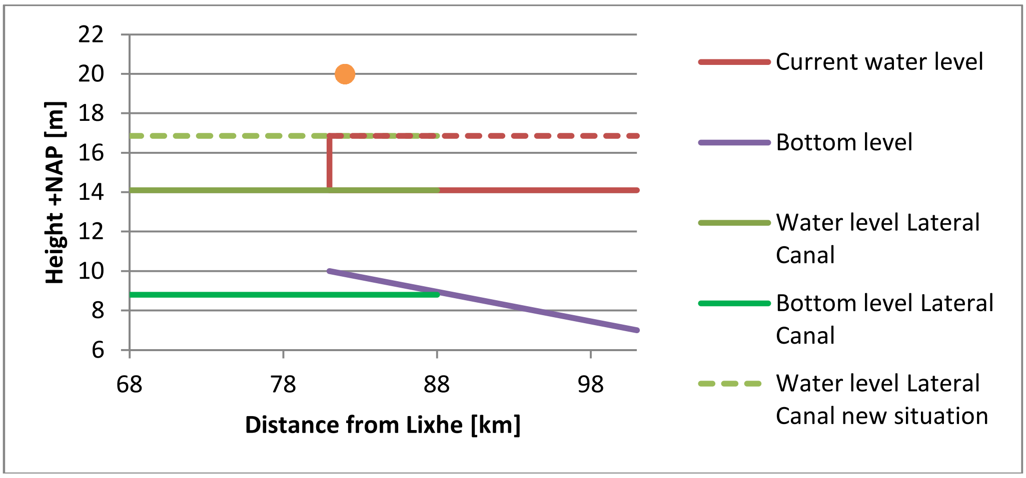
5.4.1 Option 1

In the new considered canal section are two harbors located, the upstream harbor in Graph 87 is the lock of Roermond and the downstream lock is the harbor of Buggenum. The rise of the water level in the water level in the former canal section Belfeld is not of large influence on the harbors along the new canal section. As can be seen in Graph 87 are the quays of both harbors far above water level of the new situation.



Graph 87 - Canal section Roermond: option 1 harbors

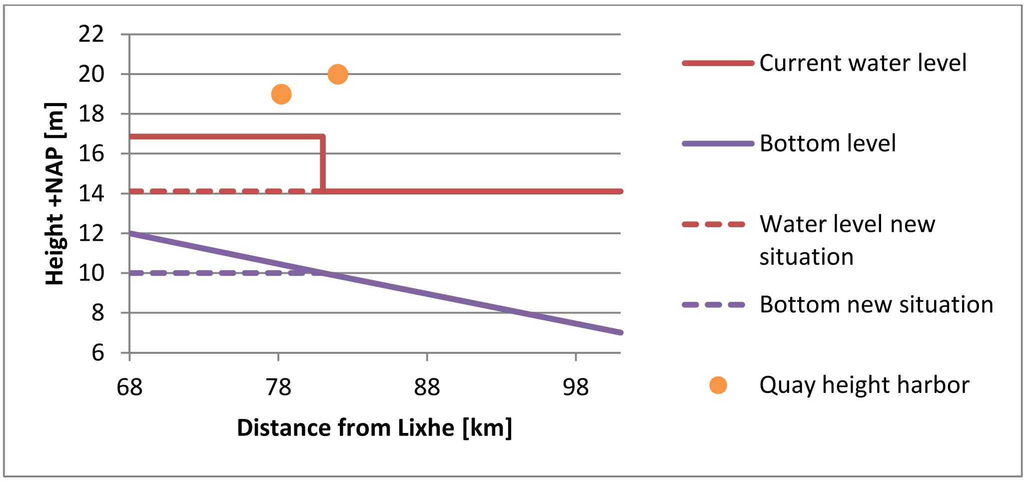
Because the rise of the water level of canal section Belfeld will not harm the harbors along this canal section is the rise of water level in the Lateral Canal of no importance for the harbors. The water level of the Lateral Canal has no influence on the harbors in the new canal section. This can be seen in Graph 88.



Graph 88 - Lateraalkanaal: option 1 harbors

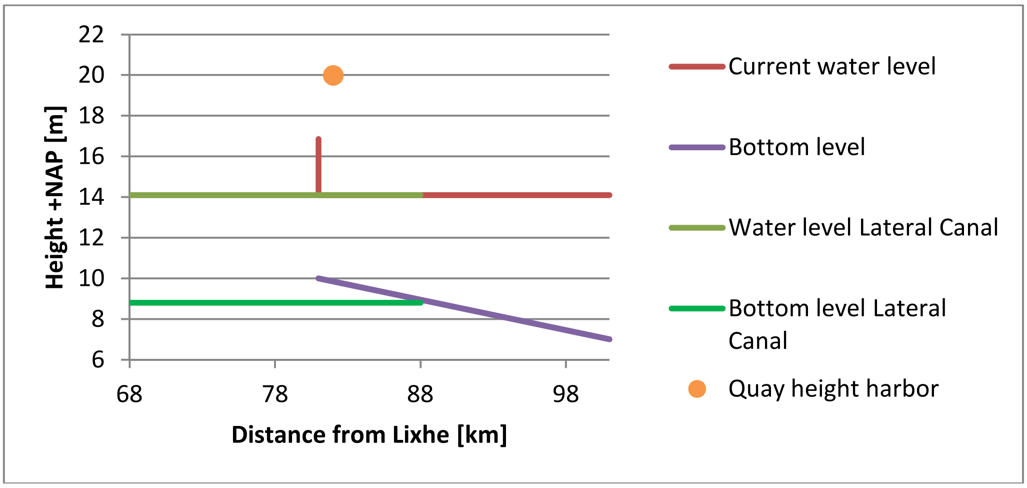
5.4.2 Option 2

The lowering of the water level in the former canal section Roermond does cause no flooding of the harbor of Roermond. However due to the fall of water level will the quay walls be more above the water level, it has to be investigated if the quay walls will not collapse due the larger resulting force on the wall. For the harbor of Buggenum will nothing change in this situation because the water level will not change in the former canal section of Belfeld.



Graph 89 - Canal section Roermond: option 2 harbors

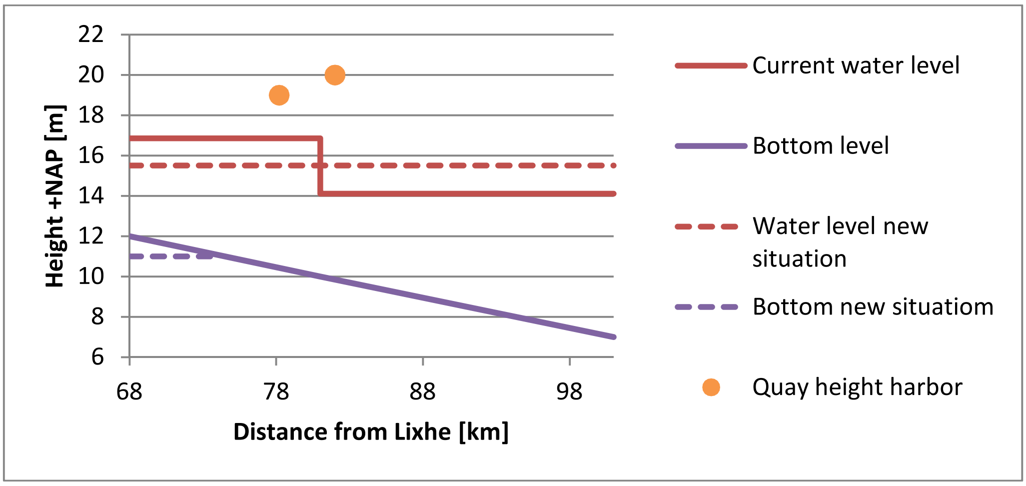
Because the water level of the Lateral Canal has no influence on the harbors will the situation in Graph 90 make no difference for the harbors in the canal section.



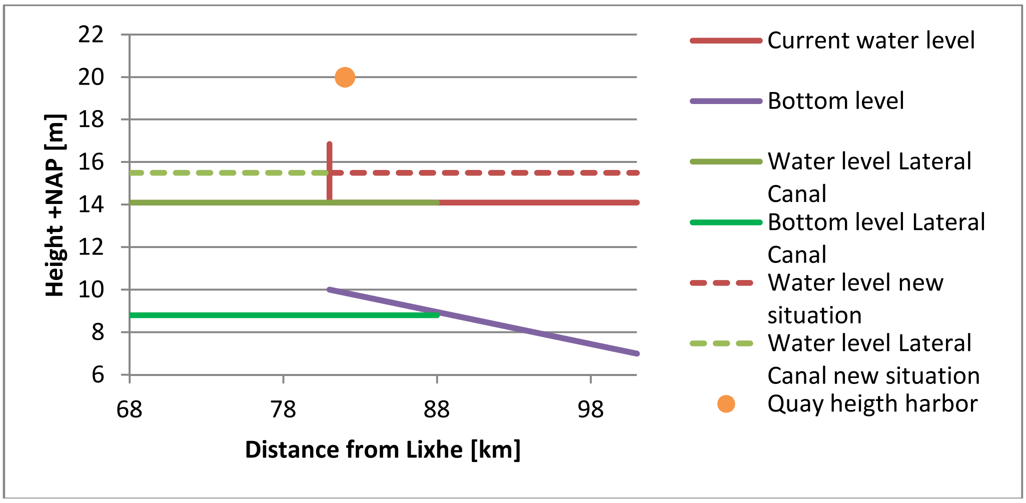
Graph 90 - Lateraalkanaal: option 2 harbors

5.4.3 Option 3

The first and second option will have no damaging effect on the harbors in the new created canal section. The water level of the third situation will not flood the harbors however has to be investigated if the quay walls of the harbor of Roermond can deal with the water level fall. The raise of the water level in the canal section Belfeld has a positive effect on the harbor of Buggenum. The situations are represented in Graph 91 and Graph 92.



Graph 91 - Canal section Roermond: option 3 harbors



Graph 92 - Lateraalkanaal: option 3 harbors

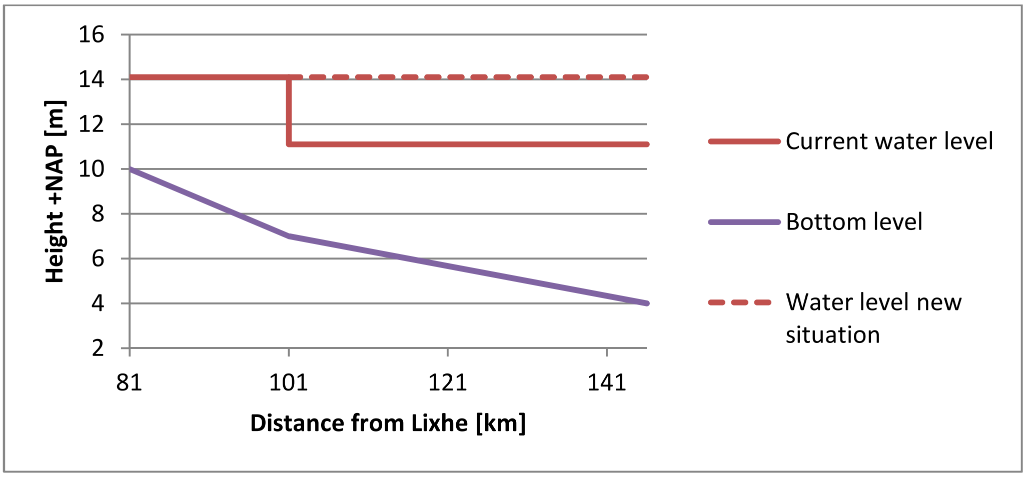
6 Weir Belfeld

Three possible options are considered after the removal of the weir of Belfeld. In the first option will the water level of the of the new canal section be at 14.10 m +NAP. This is the same height as the water level of the former canal section of Belfeld. The water level in the former canal section of Sambeek has to be raised with 3 m from 11.10 m +NAP to 14.10 m +NAP.
In the second option will the water level of the new canal section be at 11.10 m +NAP. The water level in the new canal section will be equalized with the water level with the former canal section Sambeek. The water level in the former canal section of Belfeld has to be lowered by 3 m to obtain the required water level.
In the third option will the water level be at 12.6 m +NAP, this is the mean between the water levels in the former canal sections of Belfeld and Sambeek. To obtain this new water level should the water level of the former canal section Belfeld be lowered with 1.5 m. The water level of the former canal section Sambeek has to be raised with 1.5 m.

6.1 Navigation

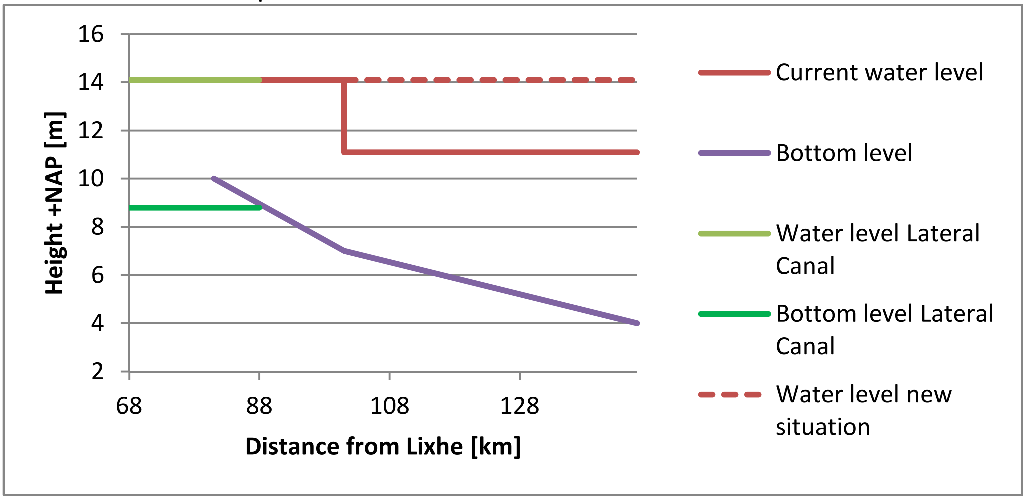
6.1.1 Option 1

The first option is beneficial for the navigation in the new canal section. Due to the rise of the water level in the former canal section Sambeek will the lock of Belfeld become useless because the water levels on both sides of the lock will be the same. By raising the water level in the former canal section Sambeek will a larger dept be created so vessels with a larger draught can use this part of the Meuse. The situation is represented in Graph 93.



Graph 93 - Canal section Belfeld: option 1 navigation

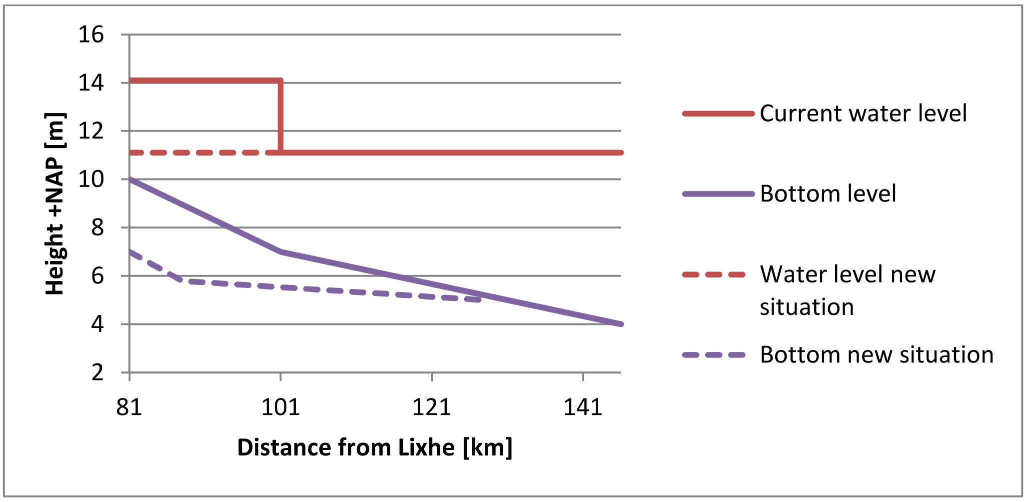
The rise of the water level of the new canal section to 14.10 m +NAP will not change the situation on the Lateral Canal. So for the situation on the Lateral Canal and canal section of Belfeld will change nothing as can be seen in Graph 94.



Graph 94 - Lateraalkanaal: option 1 navigation

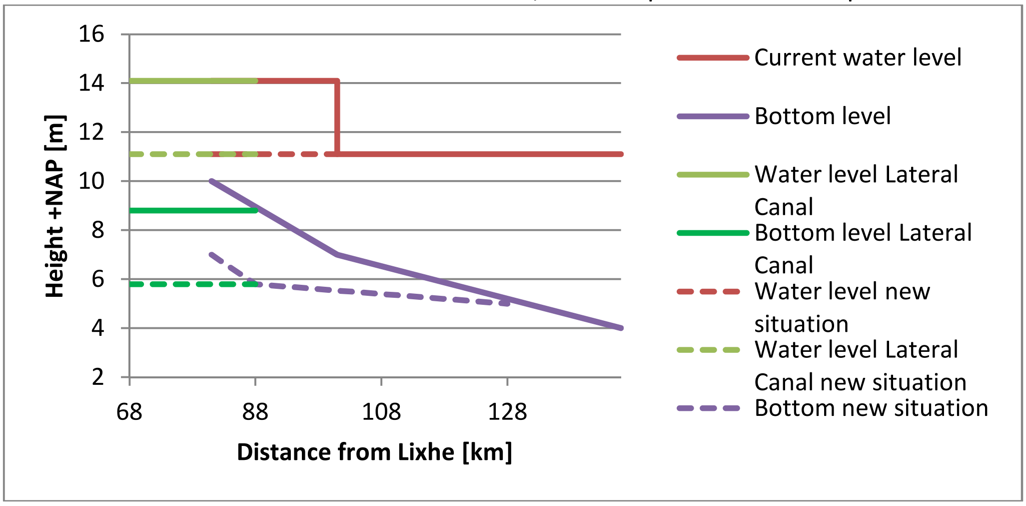
6.1.2 Option 2

The second option is less beneficial for navigation on the Meuse. In this option will the water level in the new canal section be at 11.10 m +NAP, the same water level as the former canal section Sambeek. To obtain enough navigational depth should the bottom of the former canal section Belfeld be lowered over the whole section. At the beginning of the section has the bottom to be lowered from 10 m +NAP to 5.8 m +NAP to obtain a smooth connection with the Lateral Canal. After the connection with the Lateral Canal will the slope become smaller from 5.8 m +NAP to 5 m +NAP. It is not chosen to obtain a flat bottom because the canal section has also a discharging function. It is chosen to lower not the whole canal section to 5.8 m +NAP as at the end of the canal section because a total flat bottom is not beneficial for the discharge capacity of the canal section. The situation is represented in Graph 95.



Graph 95 - Canal section Belfeld: option 2 navigation

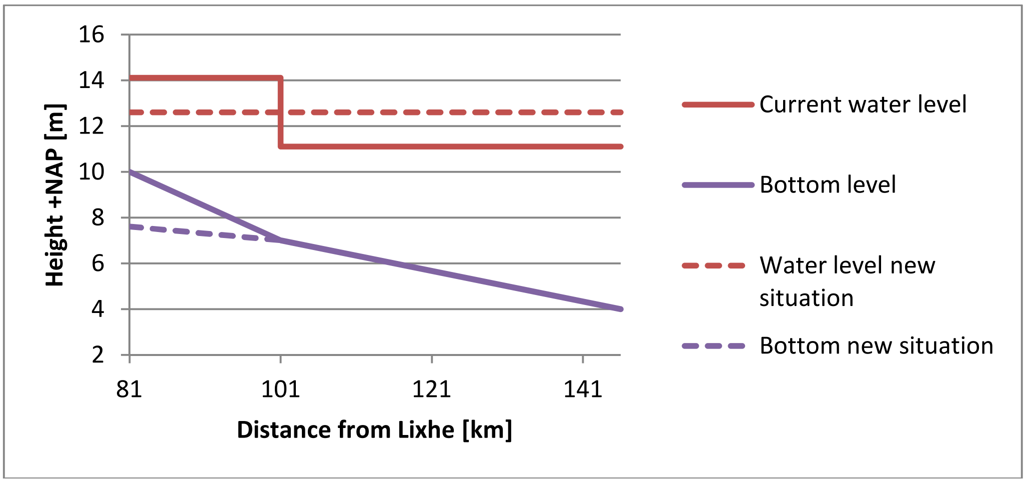
By lowering the water level in of the former canal section Belfeld will also the water level in the Lateral canal be lowered. By the lowering the water level to 11.10 m +NAP will in the depth in the Lateral Canal be come 10 cm. To obtain enough navigational depth has the bottom of the Lateral canal to be lowered from 8.8 m +NAP to 5.8 m +NAP, this is represented in Graph 96.



Graph 96 - Lateraalkanaal: option 2 navigation

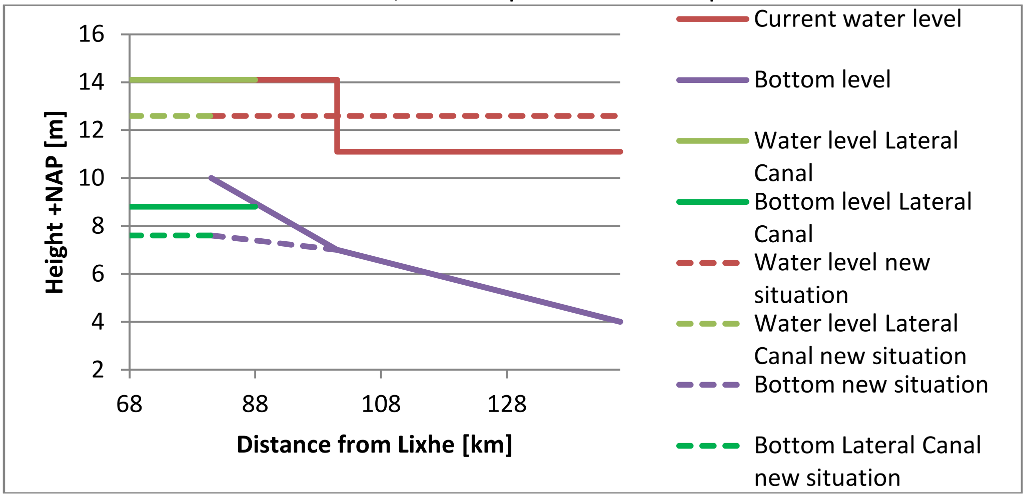
6.1.3 Option 3

In the third option is beneficial for navigation in the former canal section Sambeek. Due to the water level rise in this former canal section from 11.10 m +NAP to 12.60 m +NAP will the dept be increased, so vessels with a larger draught will be able to use this part of the Meuse. The water level fall in the former canal section of Belfeld is less beneficial for navigation. The water level lowering from 14.10 m +NAP to 12.60 m +NAP decreases the navigational depth in this former canal section. To maintain navigation in this canal section has the river bottom partly be lowered. At the beginning of the canal section has the bottom to be lowered from 10 m +NAP to 7.3 m +NAP. After this point will the bottom have a slope of about 0.07 ‰ until 7 m +NAP at the end of the former canal section Belfeld. The situation is represented in Graph 97.



Graph 97 - Canal section Belfeld: option 3 navigation

Due to the lowering in the former canal section Belfeld will the dept in the Lateral canal also become too shallow. To maintain the navigable activities on the canal has the bottom of the canal to be lowered from 8.8 m +NAP to 7.3 m +NAP, this is represented in Graph 98.

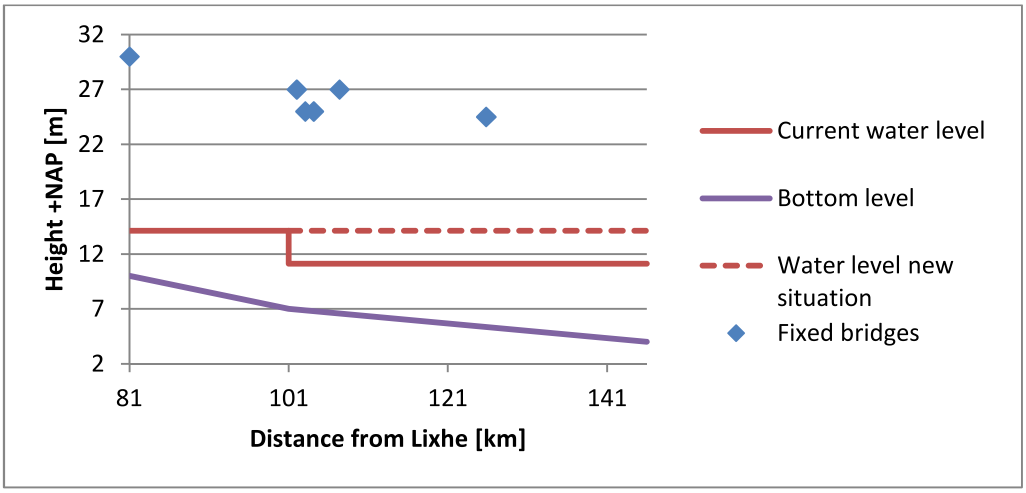


Graph 98 - Lateraalkanaal: option 3 navigation

6.2 Bridges

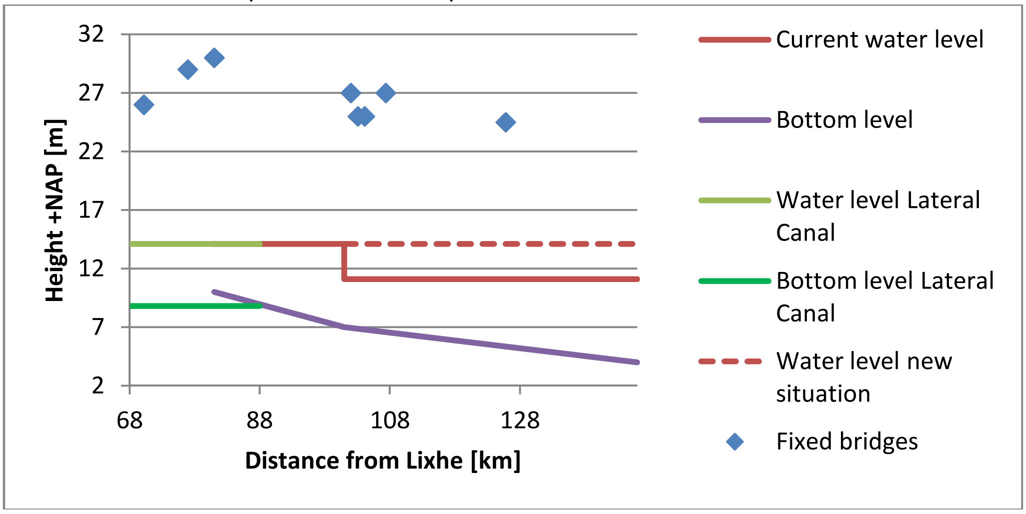
6.2.1 Option 1

The first option is not beneficial for the bridges in the former canal section Sambeek. Because the water level in this section will be raised by 3 m to 14.10 m +NAP will the vertical clearance of the bridges in this section also be 3 m shorter. The lowest bridge in this former canal section is the Koninginnenbrug in Venlo. With a height of 24.5 m +NAP will the vertical clearance of this bridge also in the new situation be larger than the required 7 to 9.1 m. The other bridges in this section are higher than the Koninginnenbrug so the vertical clearance of these bridges will automatically be large enough. The water level in the former canal section of Belfeld will stay at the current level so the vertical clearance of these bridges will automatically satisfy.



Graph 99 - Canal section Belfeld: option 1 bridges

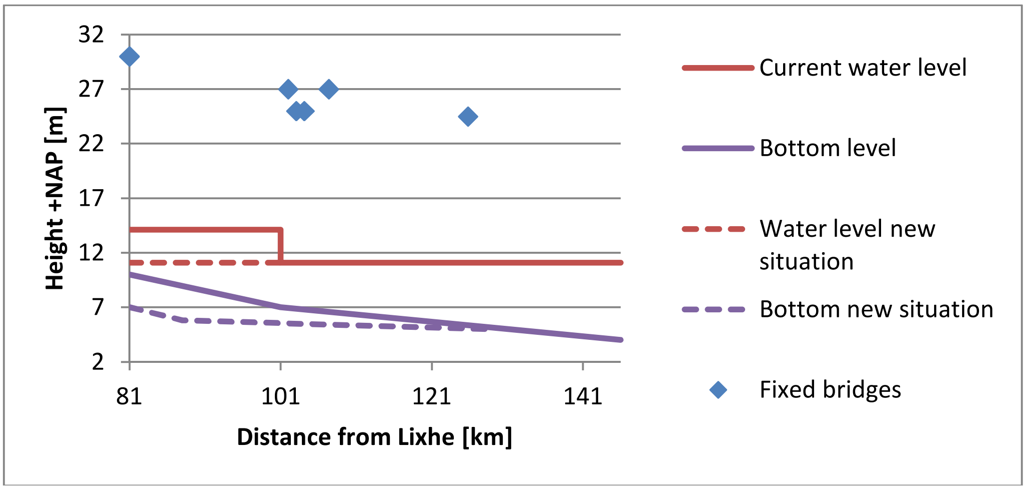
Because the water level in the former canal section of Belfeld will be the same as in the current situation, will also the water level in the Lateral canal stay at the same level as the current situation. So the bridges over the Lateral Canal will automatically satisfy the requirement of 7 to 9.1 m vertical clearance. The situation is represented in Graph 99.



Graph 100 - Lateraalkanaal: option 1 bridges

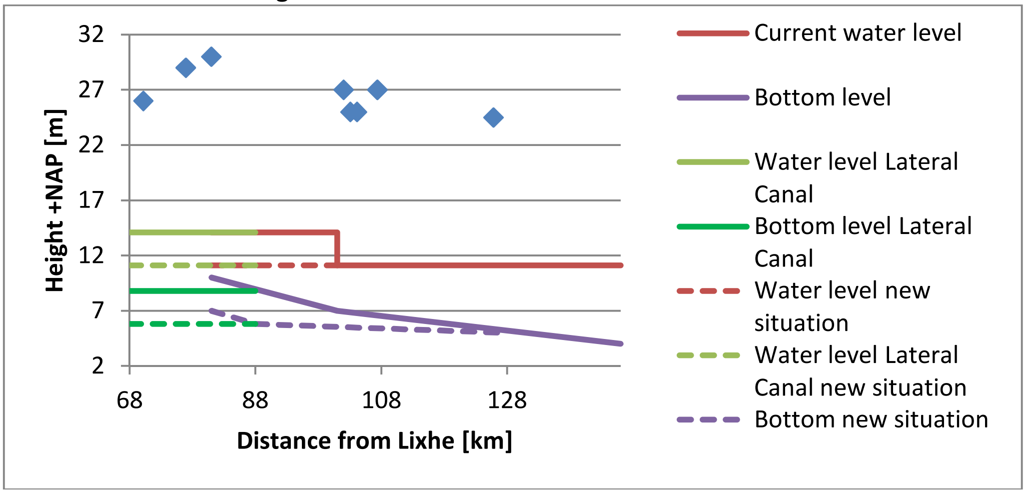
6.2.2 Option 2

The second option will be beneficial for bridges over the new canal section. Due to the lowering of the water level in the former canal section Belfeld by 3 m to 11.10 m +NAP will the vertical clearance of the bridges in the former canal section Belfeld become 3 m larger. The water level in the former canal section Sambeek will in the new situation be at the same level as in the current situation. For vertical clearance of the bridges in this canal section will noting change in the new situation as can be seen in Graph 101.



Graph 101 - Canal section Belfeld: option 2 bridges

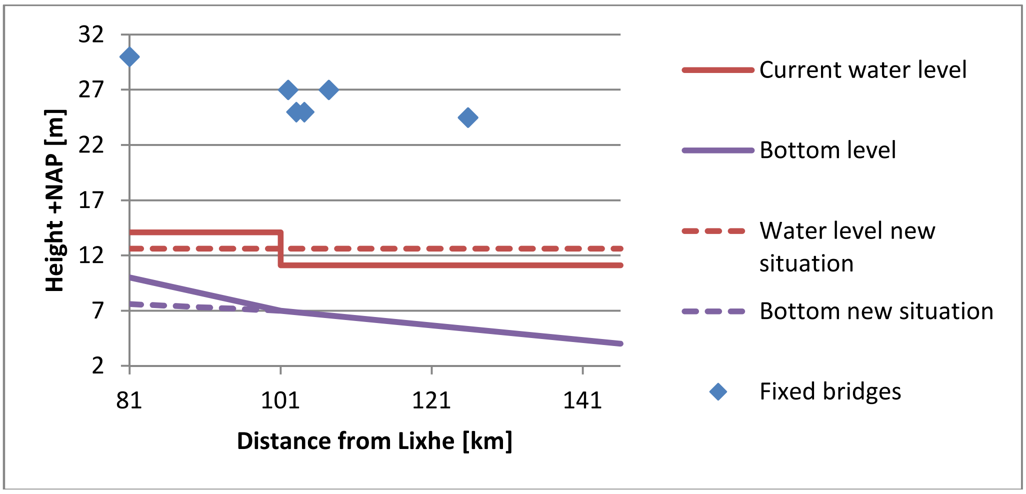
The lowering of the water level in the former canal section of Belfeld is also beneficial for the vertical clearance of the bridges over the Lateral Canal. Due to the lowering of the water level by 3 m will the vertical clearance of these bridges be increased with 3 m.



Graph 102 - Lateraalkanaal: option 2 bridges

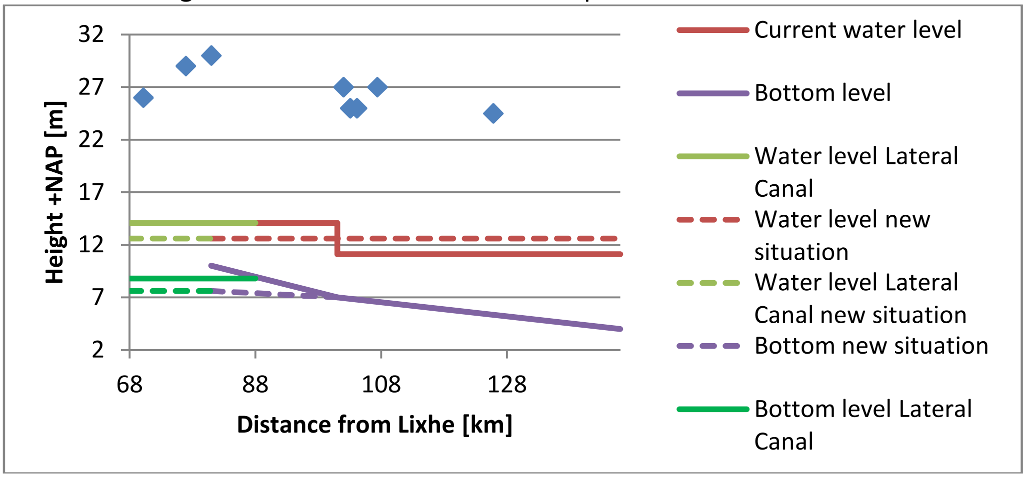
6.2.3 Option 3

The third option is partly beneficial and partly less beneficial for the vertical clearance for the bridges in the new canal section. The situation is beneficial for the former canal section Belfeld because in this section will the water level be lowered with 1.5 m, so the vertical clearance of the bridges over this section will increase with 1.5 m. The water level of the former canal section Sambeek will be raised by 1.5 m so the vertical clearance of the bridges over this canal section will be decreased with 1.5 m. However also with the rise of the water level with 1.5 m will the vertical clearance of the bridges be sufficient. The situation is represented in Graph 103.



Graph 103 - Canal section Belfeld: option 3 bridges

The lowering of water level of the former canal section of Belfeld has a positive effect on the vertical clearance of bridges over the Lateral Canal. Due to the fall of the water level will the vertical clearance of these bridges increase as can be seen in Graph 104.

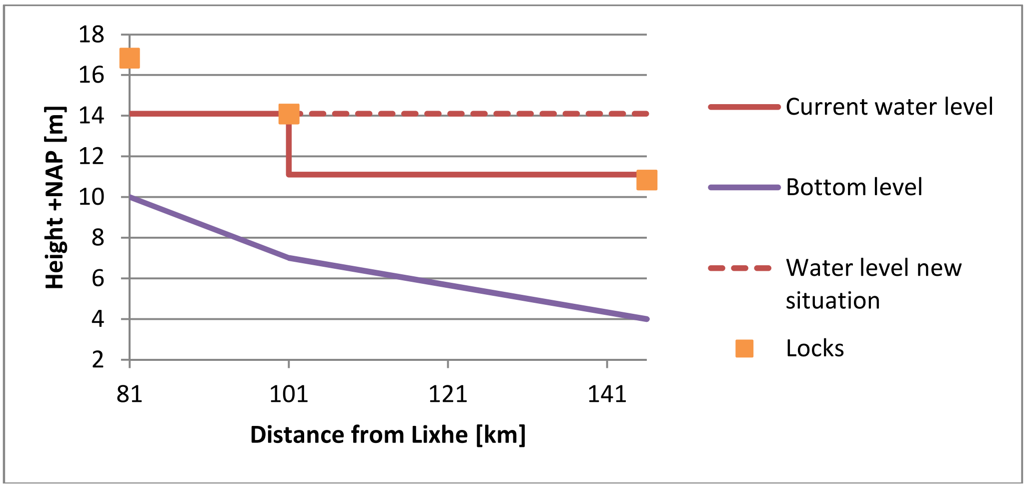


Graph 104 - Lateraalkanaal: option 3 bridges

6.3 Locks

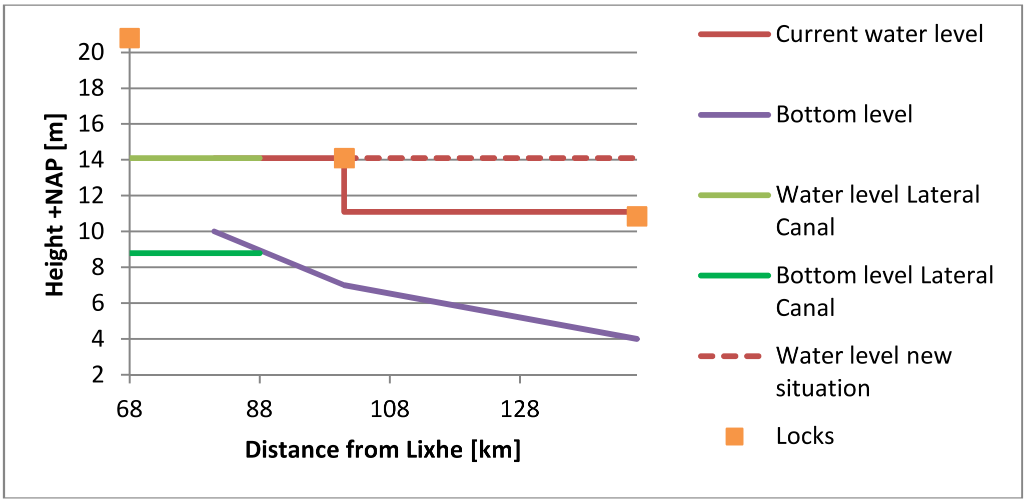
6.3.1 Option 1

The considered canal section from Roermond until Sambeek. has three lock, this are from upstream to downstream lock Roermond, lock Belfeld and lock Sambeek. The rise of the water level in the former canal section Sambeek has a negative effect on the lock of Sambeek. Due to the higher water level will the lock not be high enough so has to be adapted to the new situation. The new situation has no effect on the lock of Roermond because the water level in the former canal section Belfeld will stay the same as in the current situation. The lock can act in the same way as in the current situation. The change of water levels has no effect on the lock of Belfeld because the water levels on both sides of the lock will be exactly the same so the lock has in the new situation no function. The situation is represented in Graph 105.



Graph 105 - Canal section Belfeld: option 1 locks

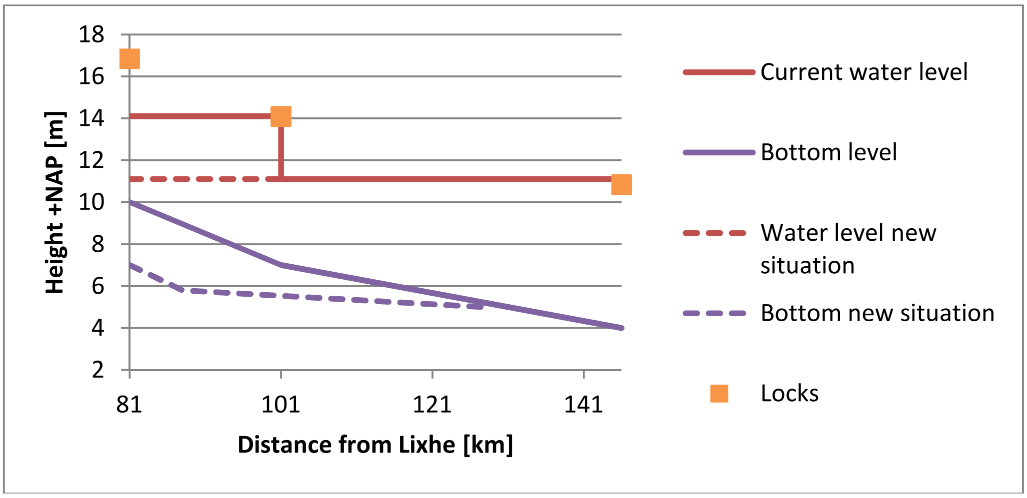
Because the water level of the Lateral Canal is in the new situation maintained by the weir of Sambeek should also be investigated what the water level changes mean for lock Heel. In the first option has the new situation no effect on the performance of lock heel because the downstream water levels does not change compared to the current situation. The situation is represented in Graph 106.



Graph 106 - Lateraalkanaal: option 1 locks

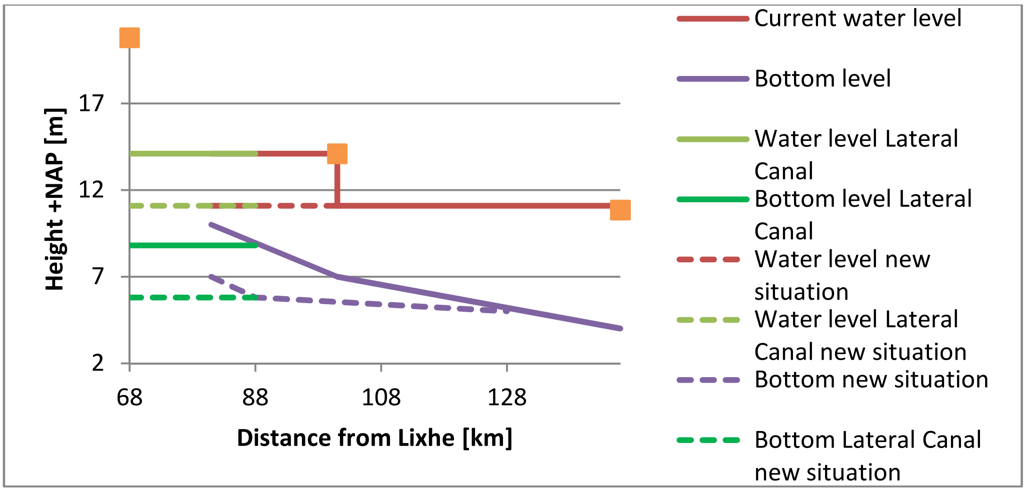
6.3.2 Option 2

The second option is beneficial for the lock Sambeek because the water level in the former canal section Sambeek is not changed has this lock not to be adapted. Due to the lowering of the water level in the former canal section Belfeld is this option less beneficial for the lock of Roermond. The lowering of the water level will increase the locking time and the resulting force on the lock gates. It has to be investigated if the lock has to be adapted to this increasing resulting load or that the gates and lock heads are strong enough. The lock of Belfeld will be far too high in the new situation however the water levels on both sides of the lock will be the same so the lock become useless in the new situation, this canal be seen in Graph 107.



Graph 107 - Canal section Belfeld: option 2 locks

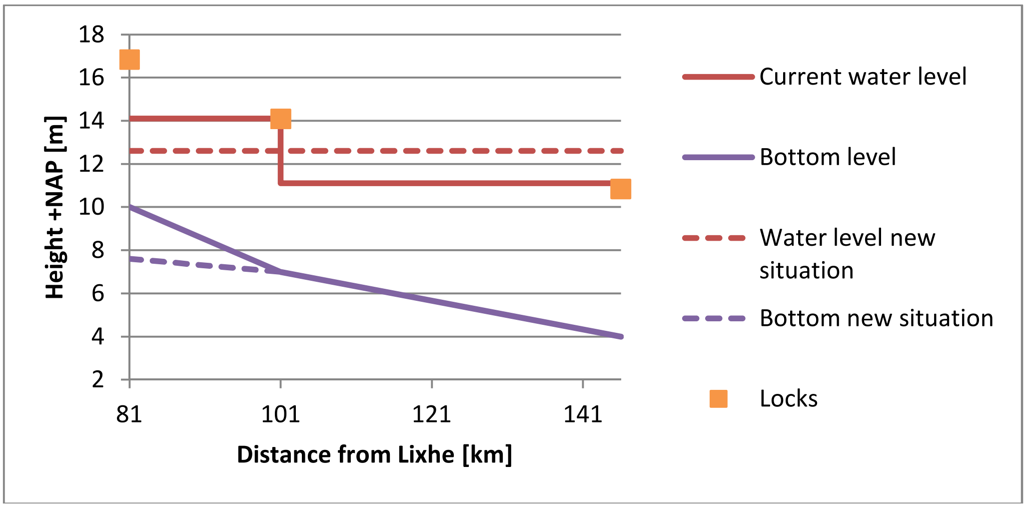
The new situation is for lock Heel just as for lock Roermond less beneficial. Due to the water level lowering in the former canal section will the locking time increase and the resulting force on the lock increase. It should be investigated if the gates and the lock heads will be strong enough for the new situation.



Graph 108 - Lateraalkanaal: option 2 locks

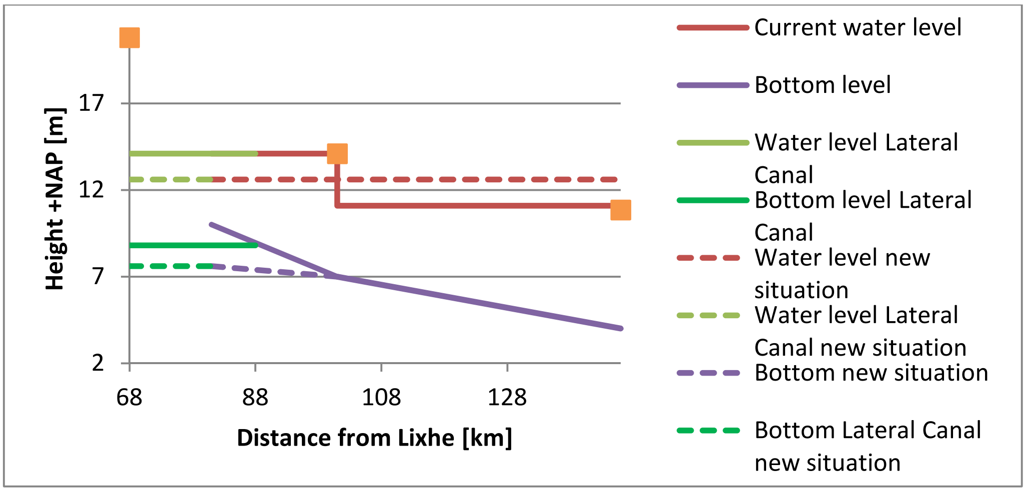
6.3.3 Option 3

The third option is the most less beneficial situation for the locks in the new canal section. By lowering the water level in the former canal section Sambeek has the lock of Sambeek be adapted to the new hydraulic loads due to the larger water height upstream. Also the locking time of the new lock should be larger than of the current one. The lowering the water level of the former canal section Belfeld will result in larger locking times and increasing resulting hydraulic loads. It has to be investigated if the lock of Roermond is strong enough for this situation. The situation is represented in Graph 109.



Graph 109 - Canal section Belfeld: option 3 locks

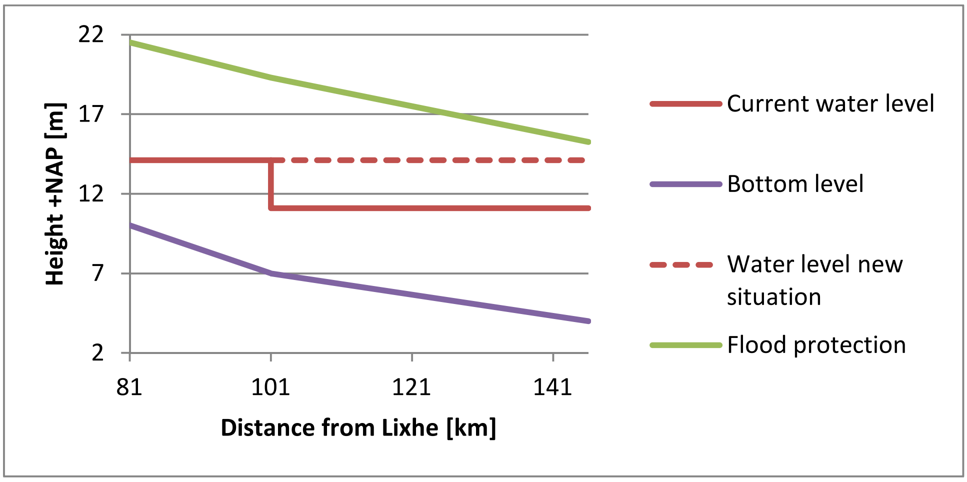
The lowering of the water level has not only a negative effect on the lock of Roermond but also on the lock of Heel. The above described problems described for the lock of Roermond are exactly the same for lock Heel. The situation is represented in Graph 110.



Graph 110 - Lateraalkanaal: option 3 locks

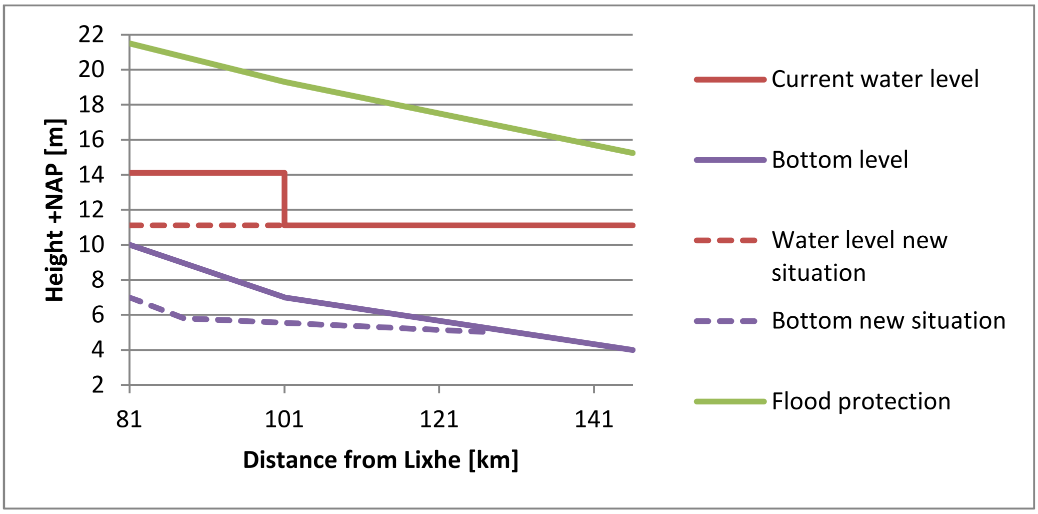
6.4 Flood protection

6.4.1 Option 1



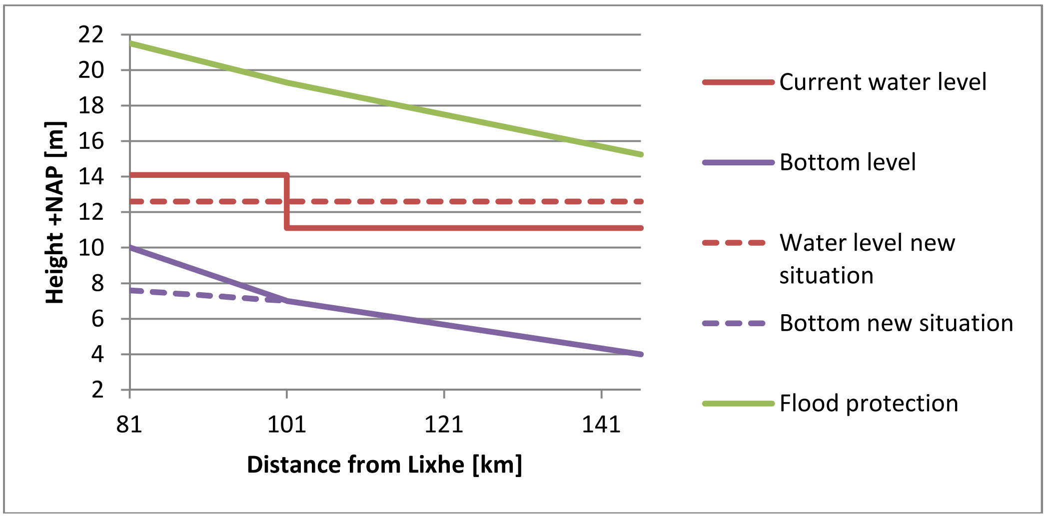
Graph 111 - Canal section Belfeld: option 1 flood protection

6.4.2 Option 2



Graph 112 - Canal section Belfeld: option 2 flood protection

6.4.3 Option 3

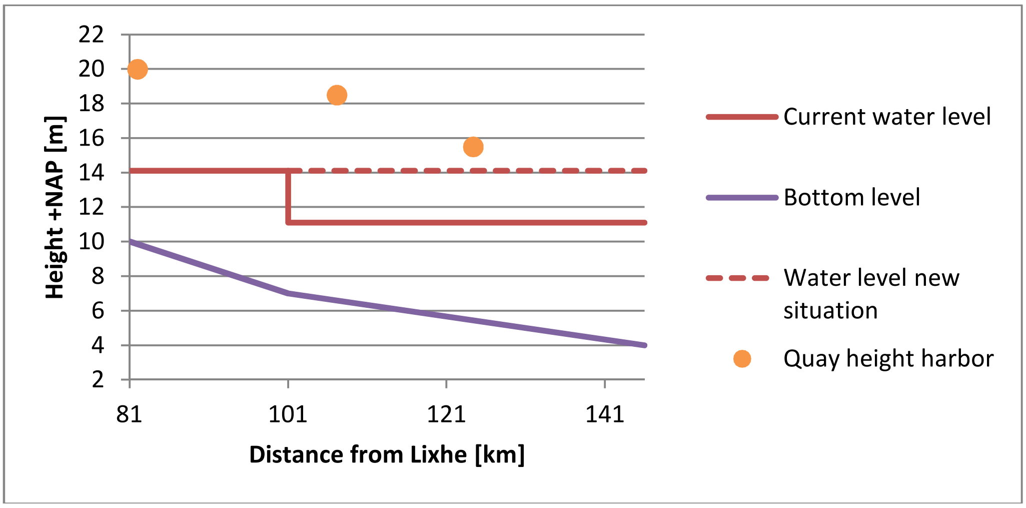


Graph 113 - Canal section Belfeld: option 3 flood protection

6.5 Harbors

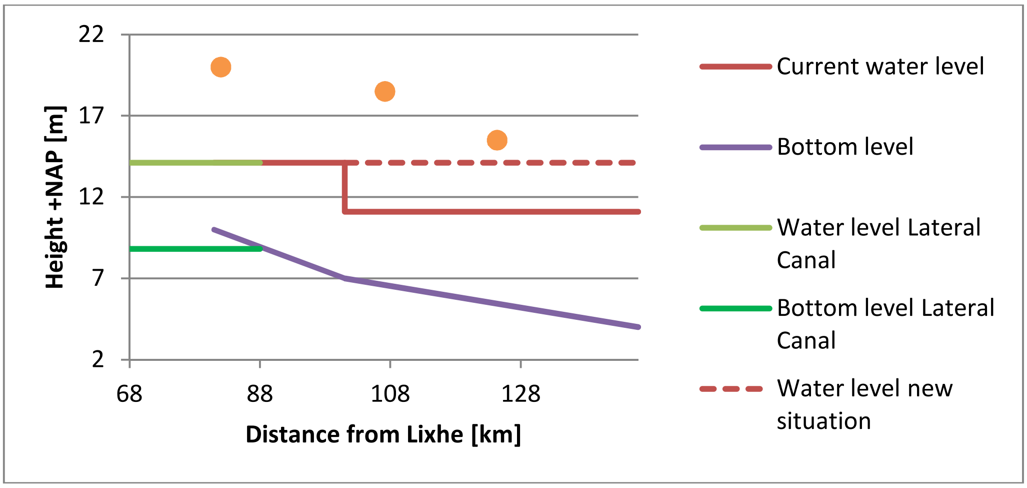
6.5.1 Option 1

In the new considered canal section are three harbors located. From upstream to downstream are the harbors are located near Buggenum, Venlo and Wanssum. By raising the water level in the former canal section Sambeek will the quays of the harbors of Buggenum and Wanssum be above water level. However the quays of the harbor of Wannsum should probably heightened to transfer vessel loadings on and off vessels in the new situation. The quays of the harbor of Venlo will apparently be high enough. The harbor of Buggenum will act in the same way as in the current situation because the water level in the former canal section Belfeld is not raised. The situation is represented in Graph 114.



Graph 114 - Canal section Belfeld: option 1 harbors

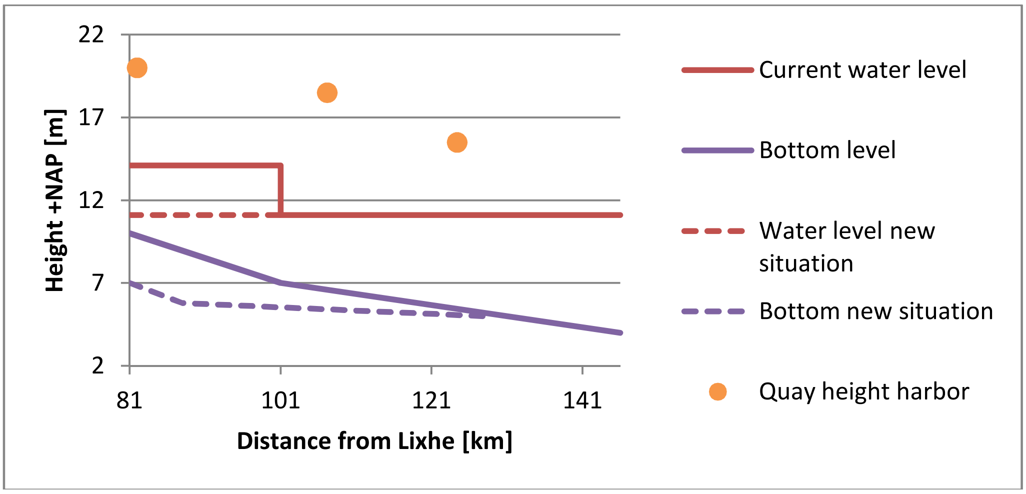
Along the Lateral Canal are no harbors situated so water level changes of the canal have no effect on the operability of harbors. The situation is represented in Graph 115.



Graph 115 - Canal section Belfeld: option 1 harbors

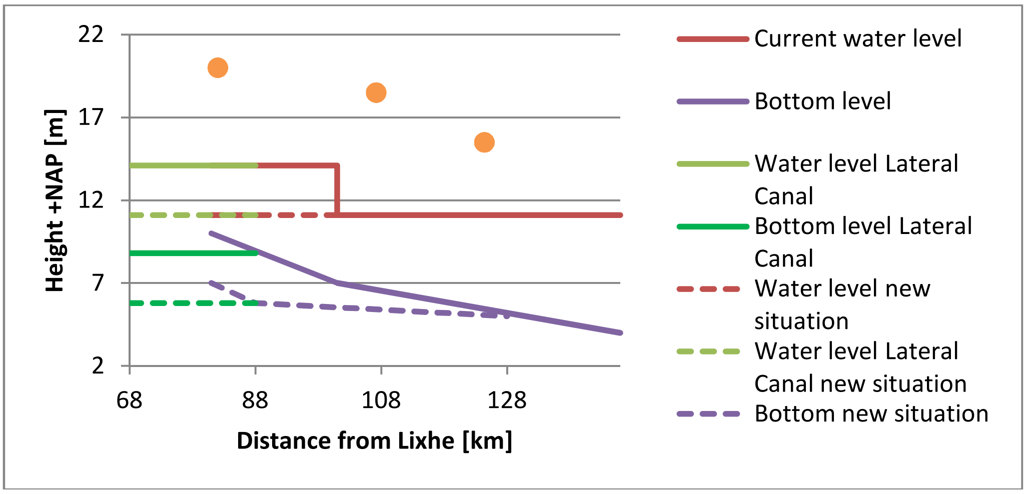
6.5.2 Option 2

In the second option is beneficial for the harbors of Venlo and Wanssum. Because the water level in the former canal section Sambeek is not heightened will these harbors in the new situation act as in the current situation. The lowering of the water level in the former canal section Belfeld will probably cause problems for the harbor of Buggenum. The quays will become too high for the new water level. The harbor should possibly be adapted to this new situation, the situation is represented in Graph 116.



Graph 116 - Canal section Belfeld: option 2 harbors

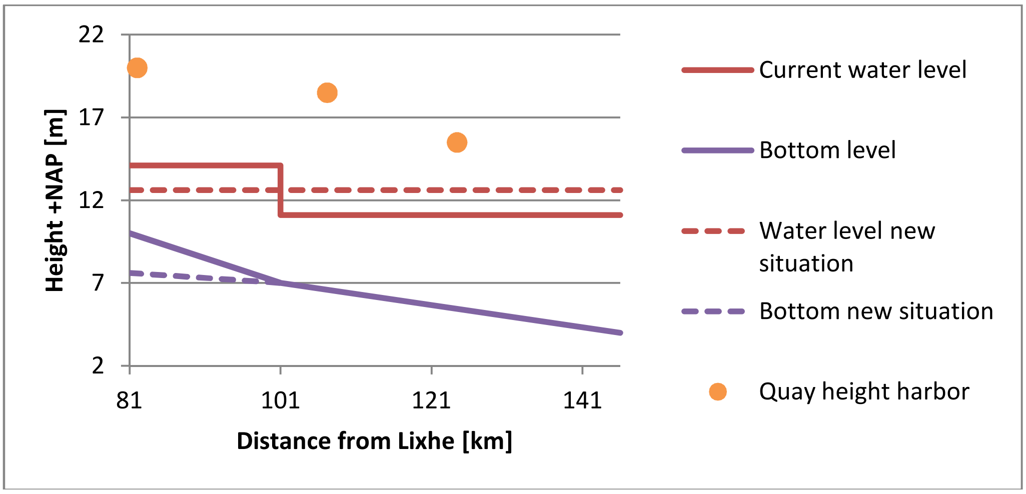
Along the Lateral Canal are no harbors situated so water level changes of the canal have no effect on the operability of harbors. The situation is represented in Graph 117.



Graph 117 - Canal section Belfeld: option 2 harbors

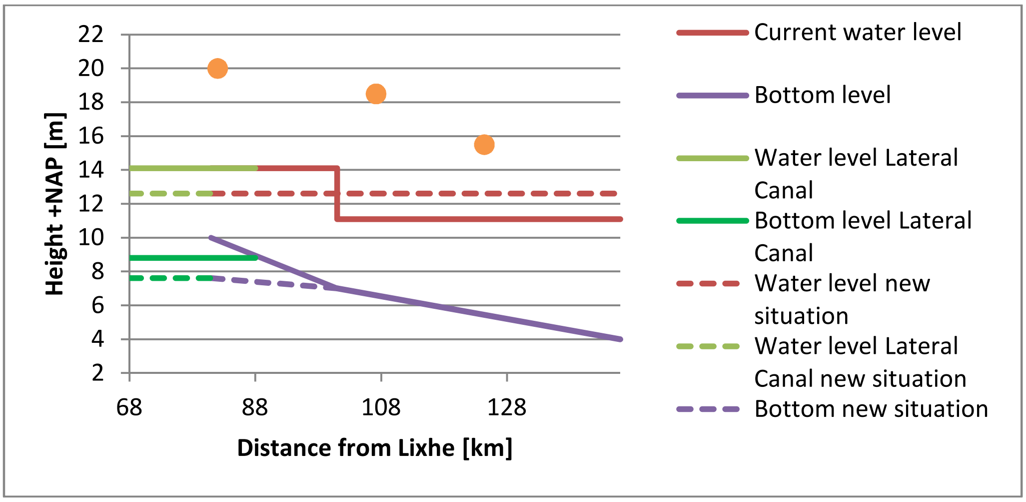
6.5.3 Option 3

By lowering the water level of the former canal section Belfeld will the quay height of the quays of the harbor of Buggenum become further above the water level. It has to be investigated if the quays walls are able to resist the forces in the new situation. However will the difference between quay and water level not be that high as in option 3. The rise of the water level in the former canal section Sambeek will cause a decrease of the difference between the harbor quays of Venlo and Wanssum and the water level of the canal section. However will in this situation the quays probably high enough for the handling of vessels. The situation is represented in Graph 118.



Graph 118 - Canal section Belfeld: option 3 harbors

Along the Lateral Canal are no harbors situated so water level changes of the canal have no effect on the operability of harbors. The situation is represented in Graph 119.



Graph 119 - Canal section Belfeld: option 3 harbors

7 Canal section Sambeek

Three possible options are considered after the removal of the weir of Sambeek. By the first options will the water level of the new considered canal section be at 11.10 m +NAP. This is the same height as the former canal section of Sambeek, this means that the water level in the former canal section of Grave will be raised by 3 m from 8.10 m +NAP to 11.10 m +NAP.

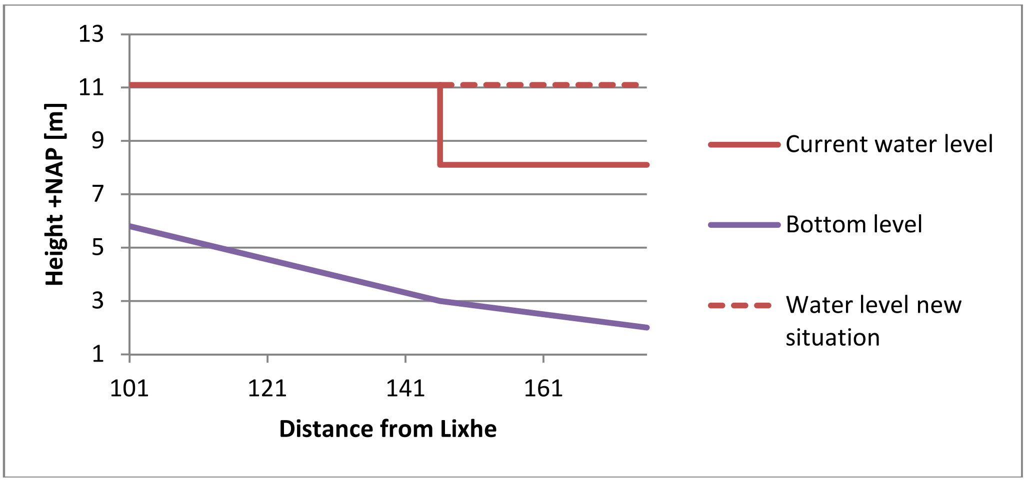
In the second option will the water level in the new canal section be set at 8.10 m +NAP. The water level in the new canal section will be at the same level as the water level of the former canal section of Grave. The water level in the former canal section of Sambeek will drop by 3 m from 11.10 m + NAP to 8.10 m +NAP.

In the third option will the water level in the new canal section be set at 9.6 m +NAP, this is the mean between the water levels of the former canal sections of Sambeek and Grave. The water level of the former canal section of Sambeek will drop by 1.5 m and the water level of the former canal section Grave will be raised by 1.5 m +NAP.

7.1 Navigation

7.1.1 Option 1

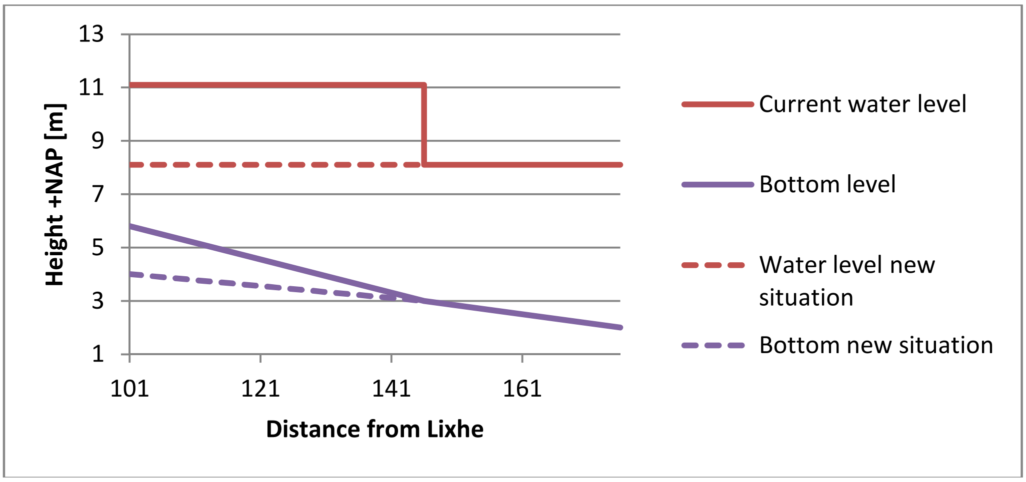
The first option is beneficial for navigation in the new canal section. The smallest water level in the canal section is on the upstream side, in the former canal section Sambeek. The water depth near the weir of Belfeld is at least 5.3 m which is sufficient for the current vessel class on the Meuse. The water level in the former canal section of Grave is raised by 3 m to 11.10 m + NAP, in the current situation is the water depth in this canal section sufficient so automatically also in the new situation. The first option is represented in Graph 120.



Graph 120 - Canal section Sambeek: option 1 navigation

7.1.2 Option 2

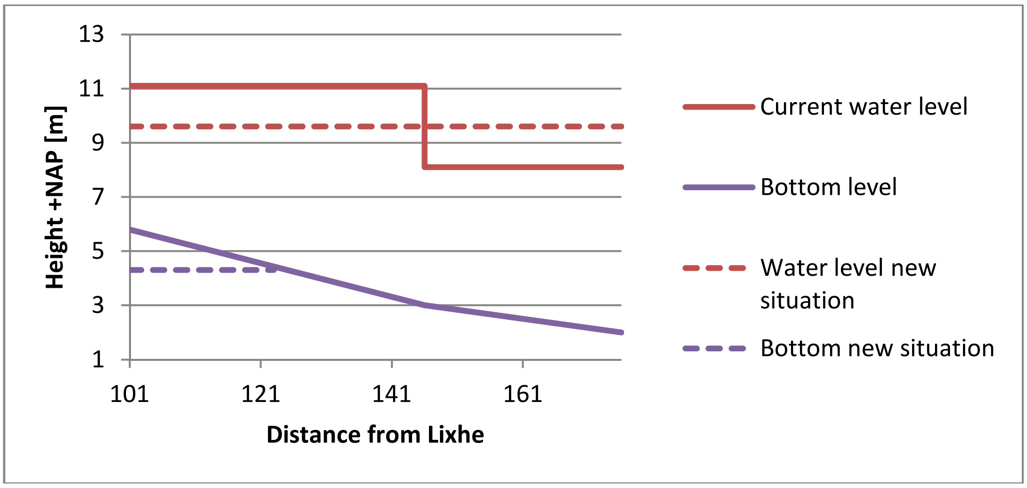
The second option is less beneficial for navigation of the new canal section. Due to the fall of the water level in the former canal section of Sambeek will the water depth become too small for navigation. To create sufficient water depth has the river bottom to be lowered from 7 m +NAP to 4 m +NAP at the beginning of the canal section to 3 m +NAP near the weir of Sambeek. The lowering of the river bottom has consequences for the upstream weir and lock of Belfeld. The situation in the former canal section Grave does not change from the current situation, the water level stays at 8.10 m +NAP. The water depth in this canal section is sufficient in the current situation for the required vessel class, so also in the new situation. The situation is represented in Graph 121.



Graph 121 - Canal section Sambeek: option 2 navigation

7.1.3 Option 3

The third option is partly beneficial for navigation. Due to the fall of the water level in the former canal section Sambeek by 1.5 m will not the whole section fulfill the requirement for sufficient water depth. To obtain sufficient water depth should the river be lowered between kilometer 101 and 123 to 4.3 m +NAP. The rise of the water level in the former canal section Grave wit 1.5 m to 9.6 m +NAP is beneficial for navigation because the water depth increases so also the possibilities for larger vessels in this former canal section.

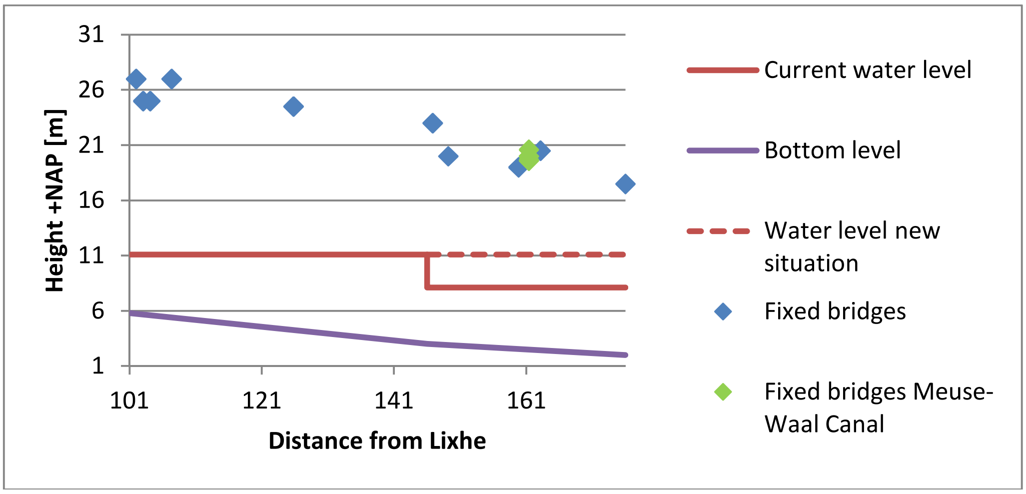


Graph 122 - Canal section Sambeek: option 3 navigation

7.2 Bridges

7.2.1 Option 1

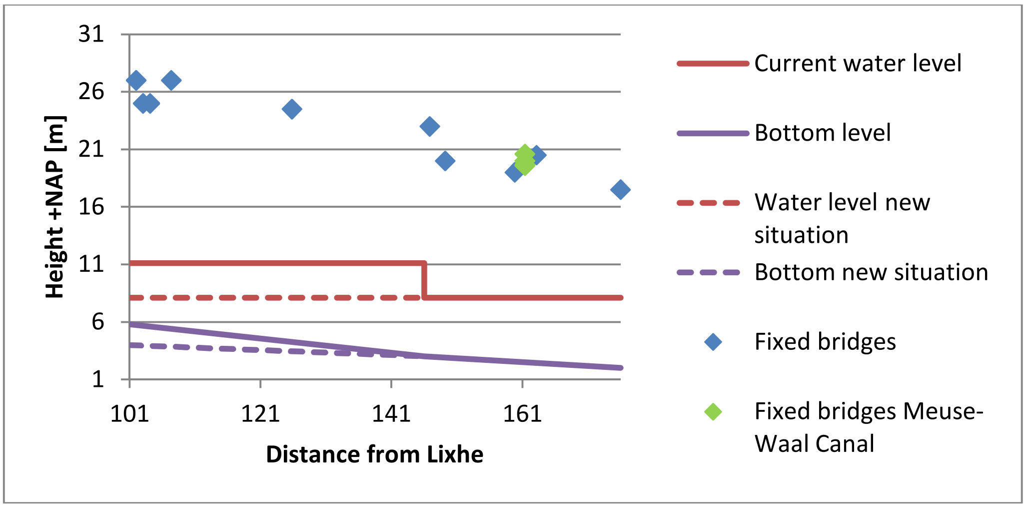
The first option is not beneficial for the vertical clearance of the bridges of the new canal section. The vertical clearance of the bridges under the former canal section Belfeld is sufficient because the water level in this canal section is not changed. In the current situation are the vertical clearances of these bridges sufficient so automatically also in the new situation. By the rise of the water level in the former canal section Grave will decrease the vertical clearance of the bridges over this canal section. One bridge does not fulfill the required vertical clearance of 7 to 9.1 m, this is the John S. Thomsongbrug near Grave. Because the water level in the Meuse-Waal Canal is during normal conditions maintained by the water level in the former canal section of Grave, are the vertical clearances of the bridges over this canal also influenced by the water level change. All 7 brides will meet the requirement of vertical clearance. The situation is represented in Graph 123.



Graph 123 - Canal section Sambeek: option 1 bridges

7.2.2 Option 2

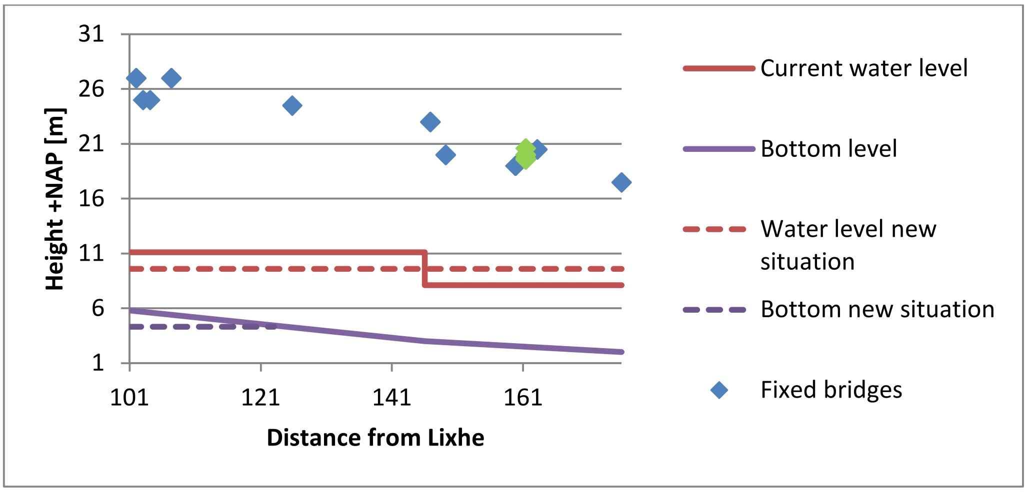
In the second option is beneficial for the vertical clearance of bridges. The water level in the former can section of Grave is not changed so the bridges in this part will fulfill the requirement for vertical clearance. The water level in the former canal section Sambeek will be dropped in the new situation, this results in an increase of the vertical clearance under the bridges in this part of the new canal section.



Graph 124 - Canal section Sambeek: option 2 bridges

7.2.3 Option 3

The third option is partly beneficial for the vertical clearance under the bridges. The water level in the former canal section Sambeek is dropped which results in a increase of the vertical clearance of the bridges over this former canal section. The water level in the former canal section Grave is raised by 1.5 m, this results in a decrease of the vertical clearance in this section and the Meuse-Waal Canal. All the bridges over the Meuse will meet the requirement of vertical clearance, the bridges over the Meuse-Waal Canal will also meet the requirement in the new situation.



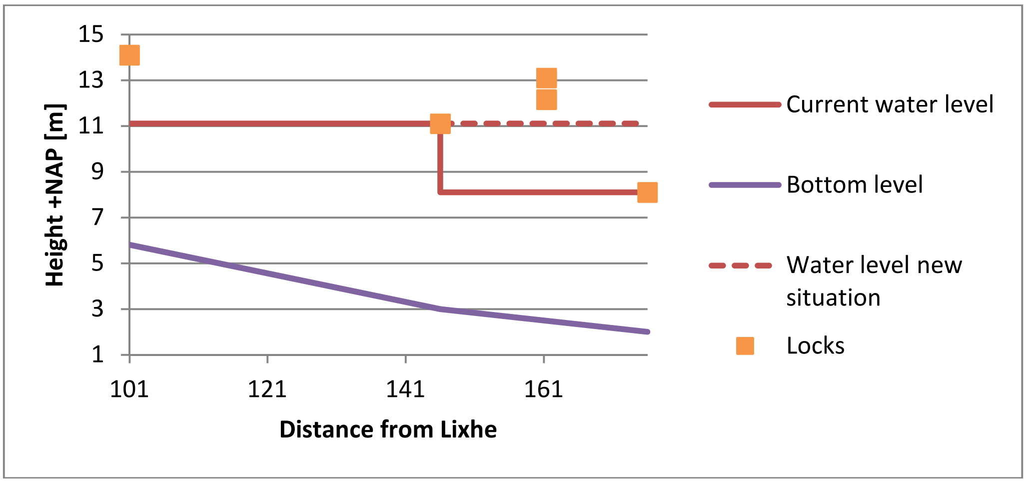
Graph 125 - Canal section Sambeek: option 3 bridges

7.3 Locks

7.3.1 Option 1

In the Meuse-Waal Canal are two locks located near Heumen and Weurt. Lock near Heumen is a guard lock and the lock near Weurt a normal navigation lock, both locks are part of the primary flood defense. The guard lock of Heumen is closed a high water levels on the Meuse. Until a water level of 12.15 m +NAP acts the guard lock as part of the high water defense of dike ring area 41. The lock of Weurt consist of two locks, the eastern lock is the smalles lock and is used as governing lock. On the north side is the lock of Weurt subjected to the water level of the Waal and on the south side to the water level of the Meuse. The gates on the north side have a height of 15.10 m +NAP and the gates on the south side a height of 13.10 m +NAP.

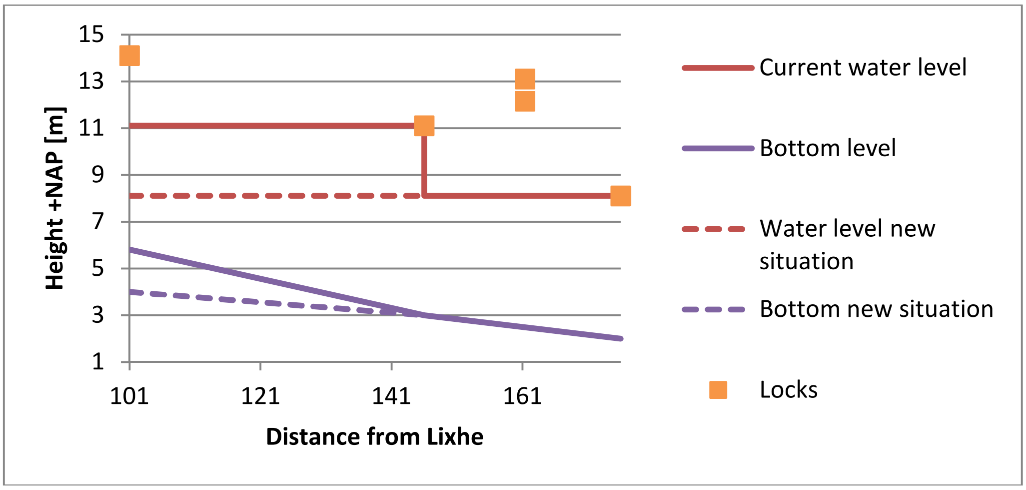
The first option is not beneficial for the locks in the new canal section. Because most locks are located in the former canal section Grave will these locks become under the proposed water level. In the Meuse will the lock of Grave become under water level. The locks of Weurt and Heumen are high enough and would be able to resist the higher water pressures on the gates because they are able to resist water levels up to 12.15 m + NAP. The lock of Belfeld is able to fulfill its function as in the current situation. The situation is represented in Graph 126.



Graph 126 - Canal section Sambeek: option 1 locks

7.3.2 Option 2

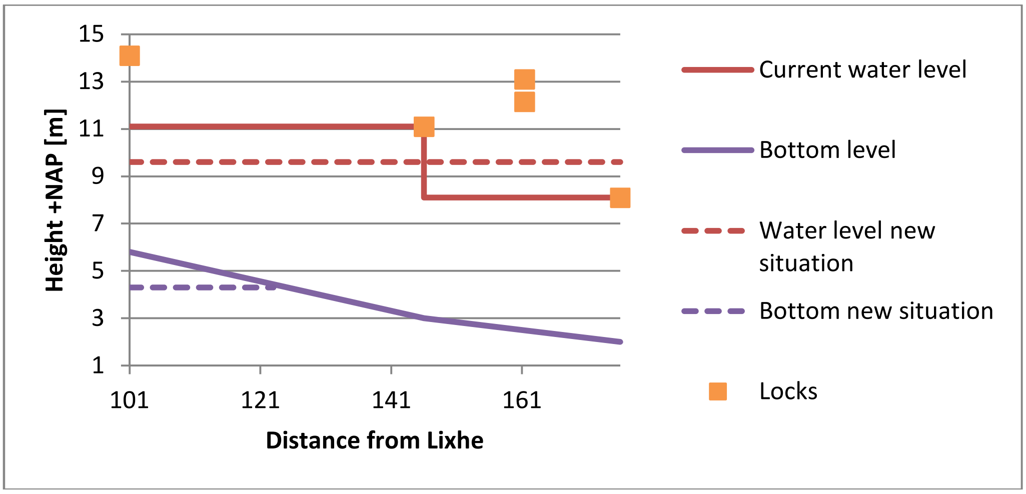
The second option is beneficial for the locks in the former canal section Grave because the water level of the new canal section is proposed at 8.10 m +NAP. The locks of Weurt and Grave can act as in the current situation. Due to the water level lowering in former canal section Sambeek will the hydraulic loads on the lock Belfeld increase. It has to be investigated is the lock is strong enough. However due to the necessarily bottom lowering on the downstream side of the lock will the bottom of the lock become insufficient. The situation is represented in Graph 127.



Graph 127 - Canal section Sambeek: option 2 locks

7.3.3 Option 3

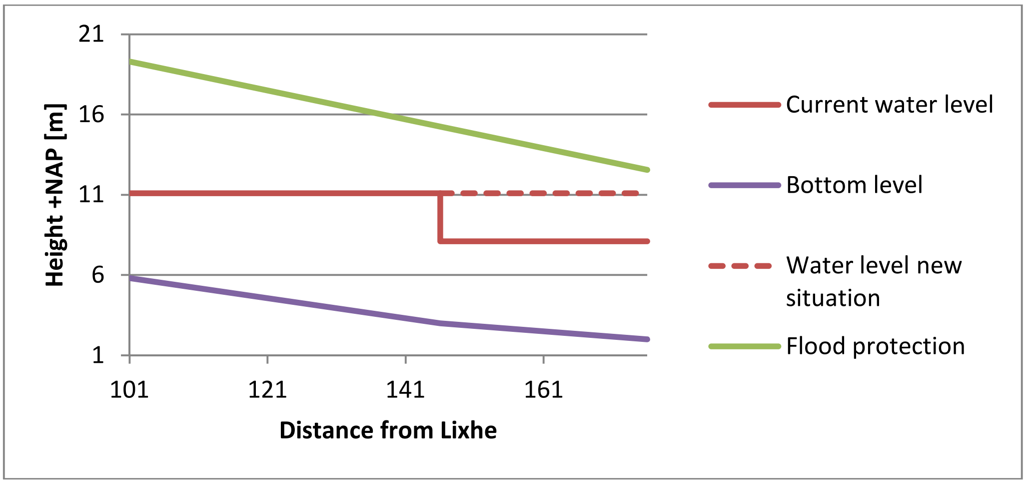
The third option is the less beneficial for the locks in the new canal section. The water level lowering of the former canal section Sambeek has effect on the lock of Belfeld. It has to be investigated if the gates and the lock are strong enough to resist the increasing water head. Also the stability of the lock has to be investigated because of the lowering of the river bottom near the lock. The lock of Grave become under the new proposed water level so has to be adapted of renewed to the new water level. The situation is represented in Graph 128.



Graph 128 - Canal section Sambeek: option 3 locks

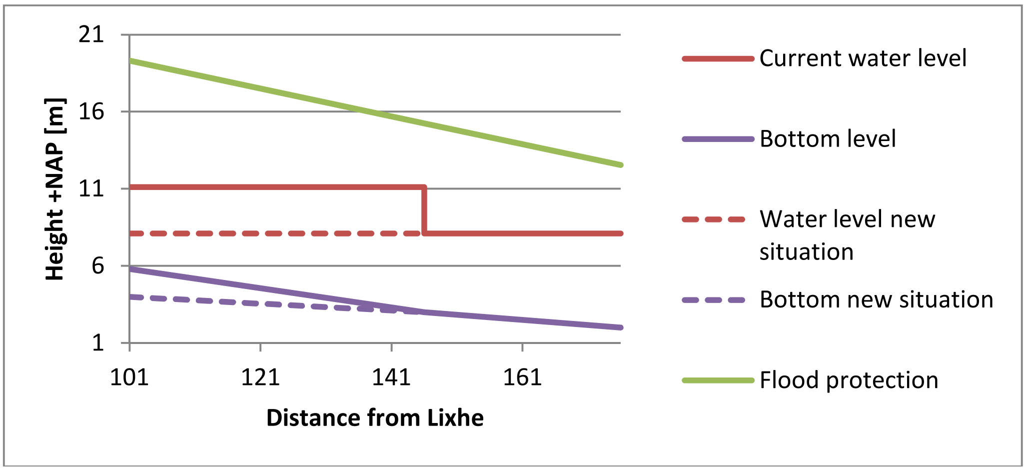
7.4 Flood protection

7.4.1 Option 1



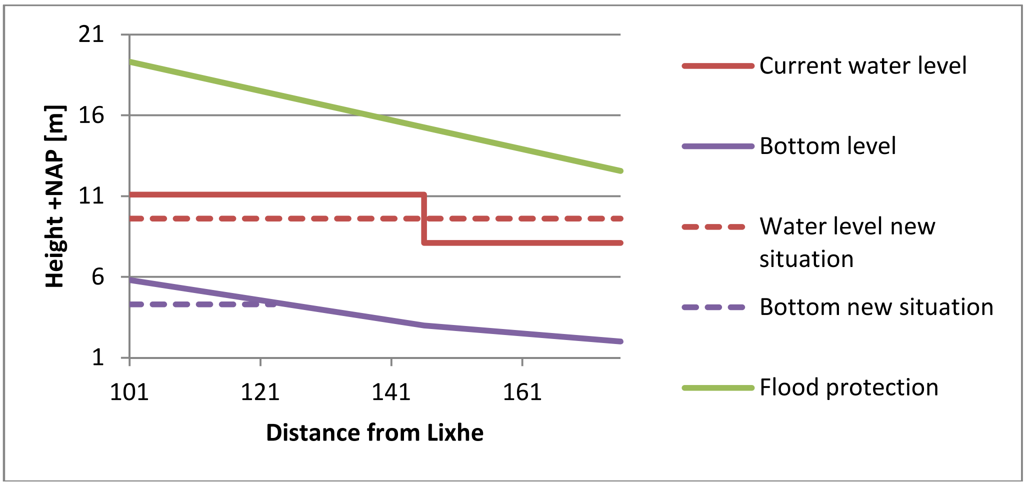
Graph 129 - Canal section Sambeek: option 1 flood protection

7.4.2 Option 2



Graph 130 - Canal section Sambeek: option 2 flood protection

7.4.3 Option 3

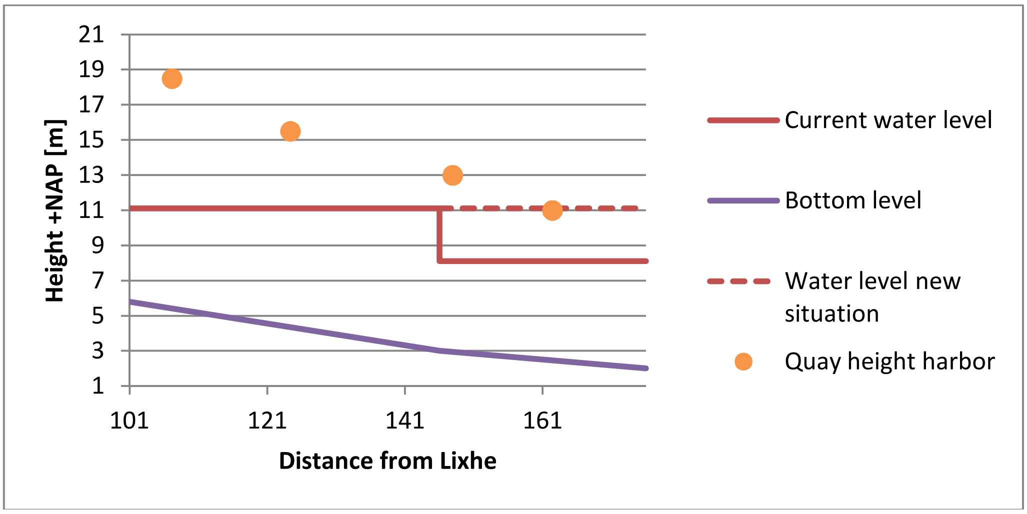


Graph 131 - Canal section Sambeek: option 3 flood protection

7.5 Harbors

7.5.1 Option 1

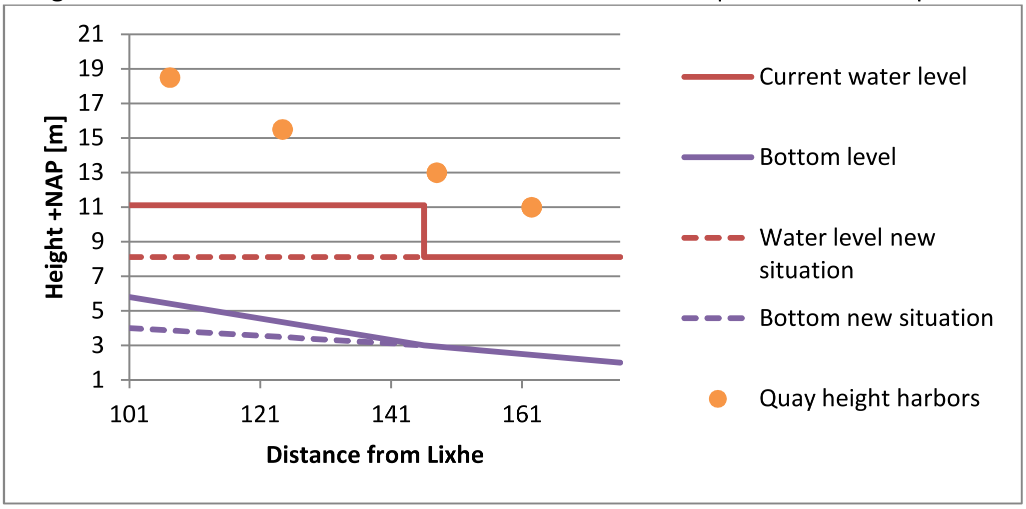
In the first option will the most downstream harbor, the harbor of Cuijk be flooded due to the new water level. To maintain the operability of the harbor should the quay walls be raised. The other harbors in this new canal section are above water level. The two upstream harbors, the harbors of Venlo and Wanssum can act as in the current situation because the water level along these harbors does not change from the current situation. It has to be investigated if the quays of the third harbor, the harbor of Gennep are high enough to the water level raise in the former canal section Grave.



Graph 132 - Canal section Sambeek: option 1 harbors

7.5.2 Option 2

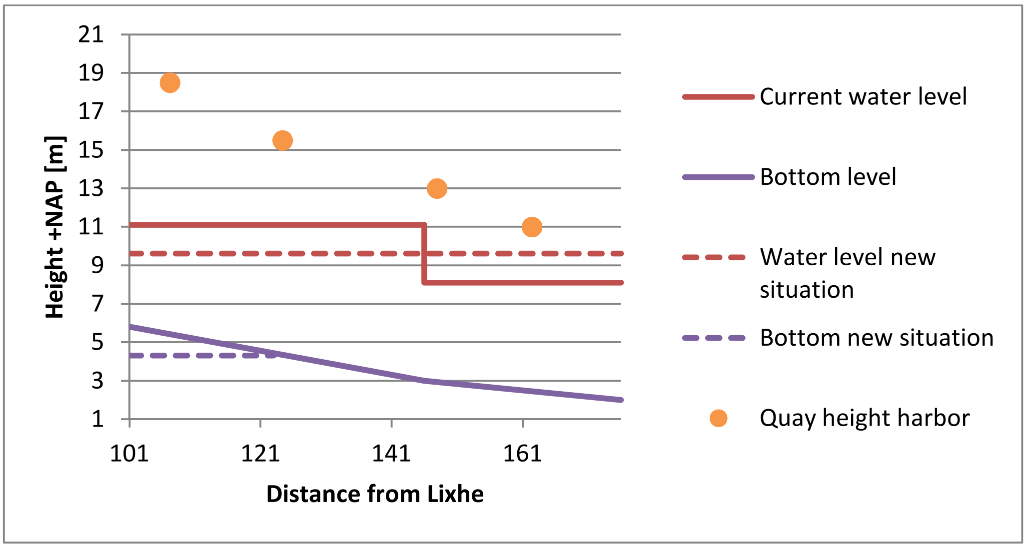
In the second option will no harbor become under the new proposed water level. This option is most beneficial for the harbors in the former canal section Grave because the water level along these harbors does not change from the current situation. The water level drop in the former canal section Sambeek has effect on the harbors along this section. It has to be investigated if the quay walls are strong enough to resist the new load distribution. The situation is represented in Graph 133.



Graph 133 - Canal section Sambeek: option 2 harbors

7.5.3 Option 3

The third option is most beneficial for the harbors in the former canal section of Grave however it has to be investigated is the distance between the water level and the quays does not become to small. The water level drop in the former canal section Sambeek has effect on the stability of the quay walls of the harbors of Venlo and Wanssum, it has to be investigated if the quay walls of these harbors are stable enough in the new situation.



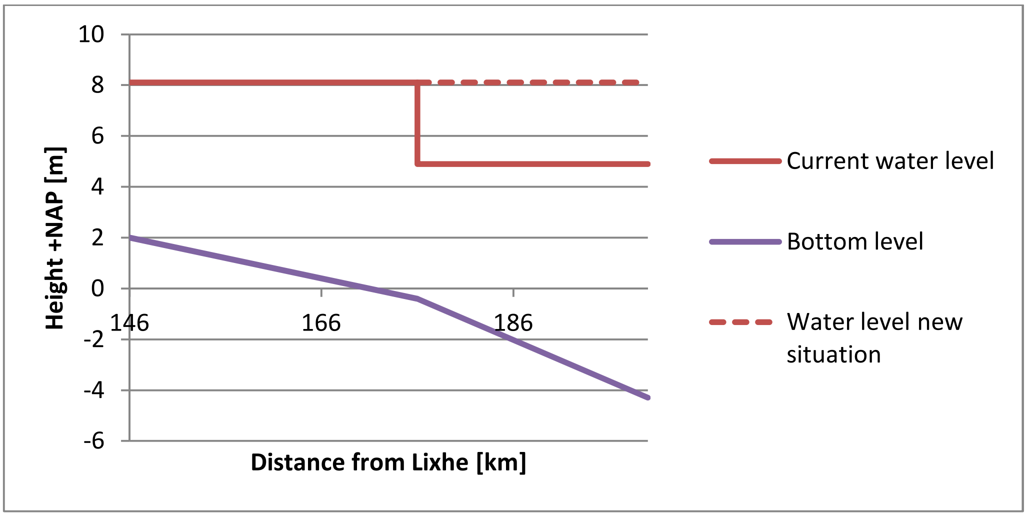
Graph 134 - Canal section Sambeek: option 3 harbors

8 Canal section Grave

8.1 Situation

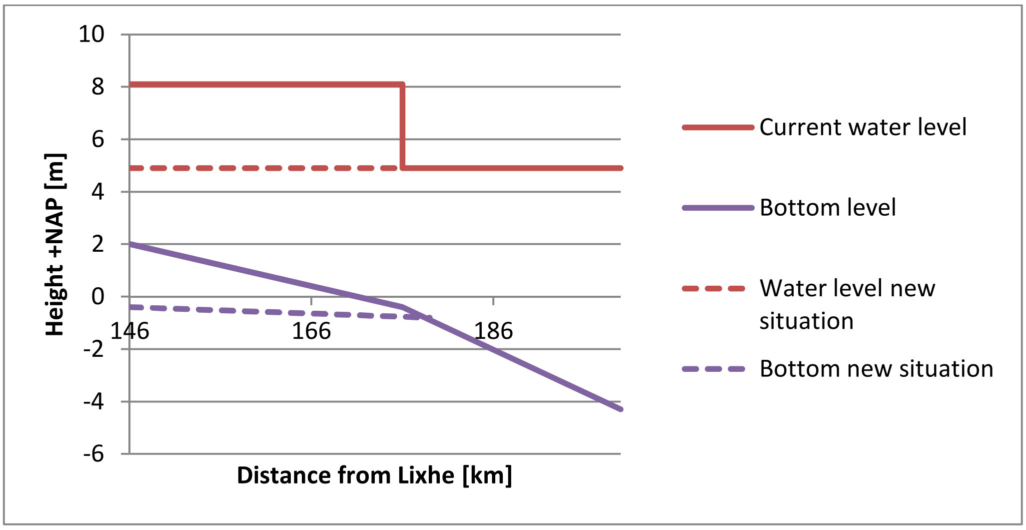
8.2 Navigation

8.2.1 Option 1



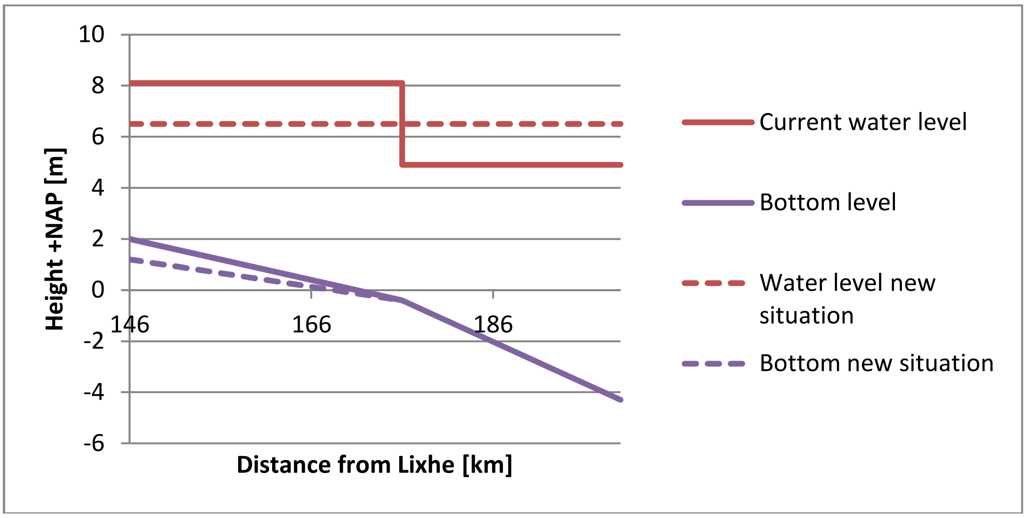
Graph 135 - Canal section Grave: option 1 navigation

8.2.2 Option 2



Graph 136 - Canal section Grave: option 2 navigation

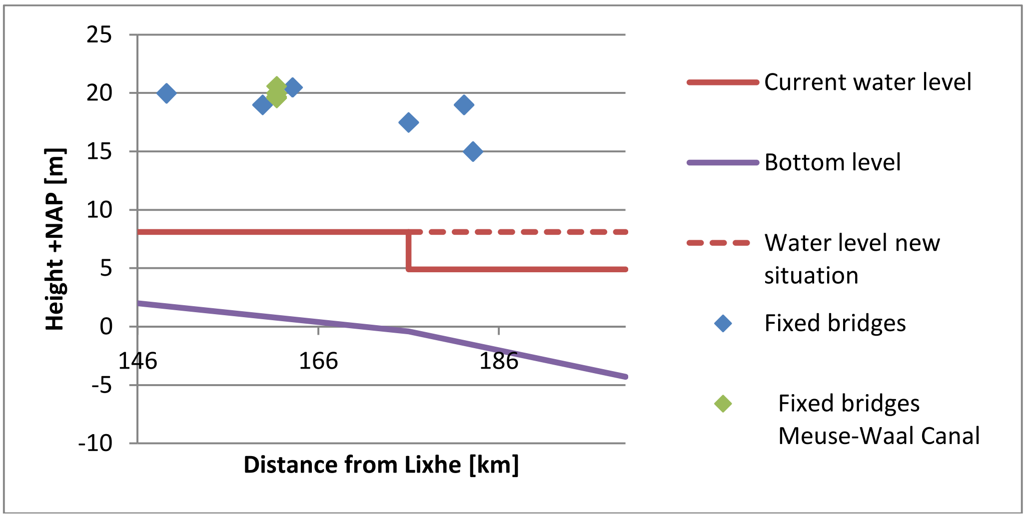
8.2.3 Option 3



Graph 137 - Canal section Grave: option 3 navigation

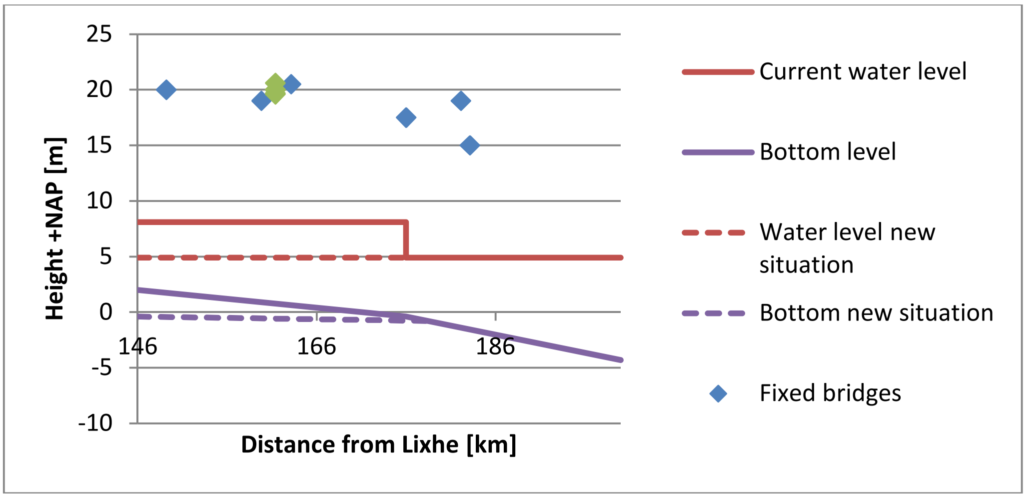
8.3 Bridges

8.3.1 Option 1



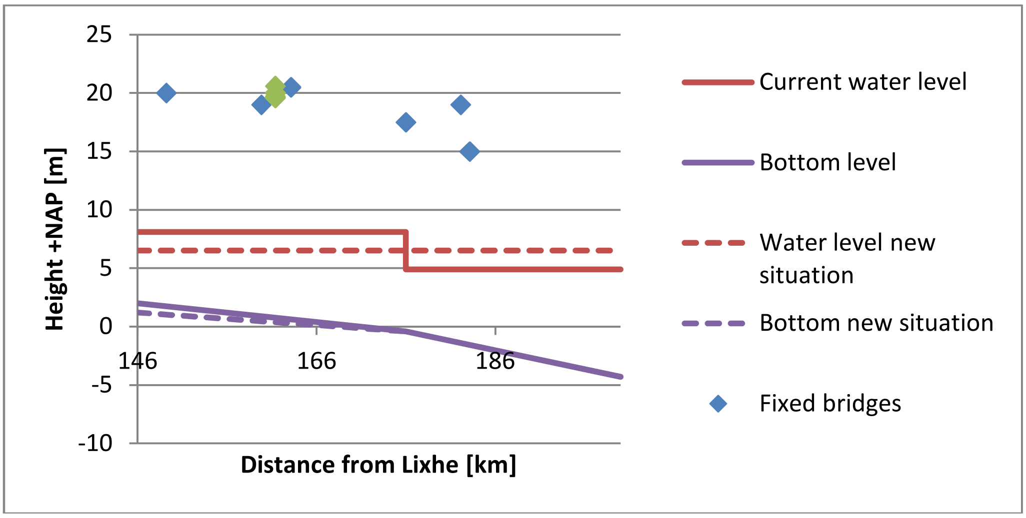
Graph 138 - Canal section Grave: option 1 bridges

8.3.2 Option 2



Graph 139 - Canal section Grave: option 2 bridges

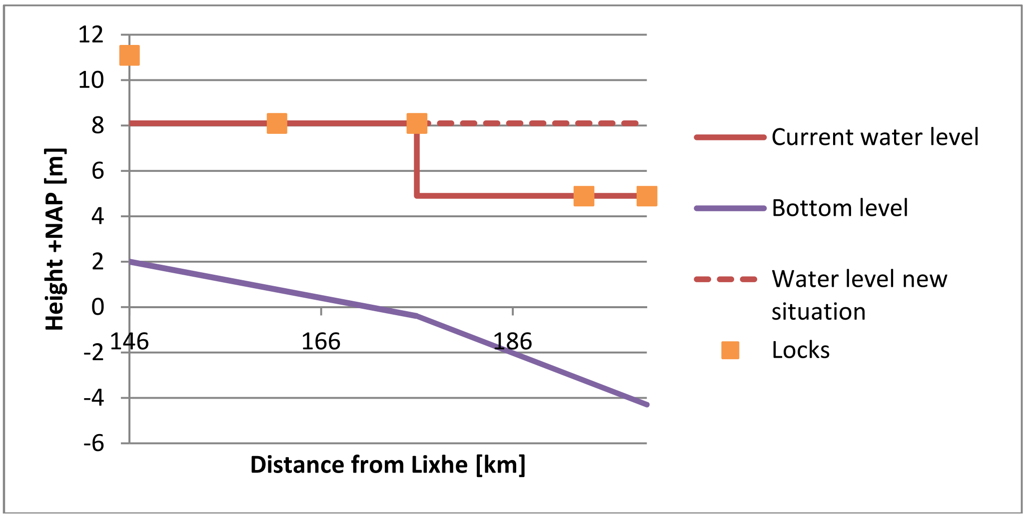
8.3.3 Option 3



Graph 140 - Canal section Grave: option 3 bridges

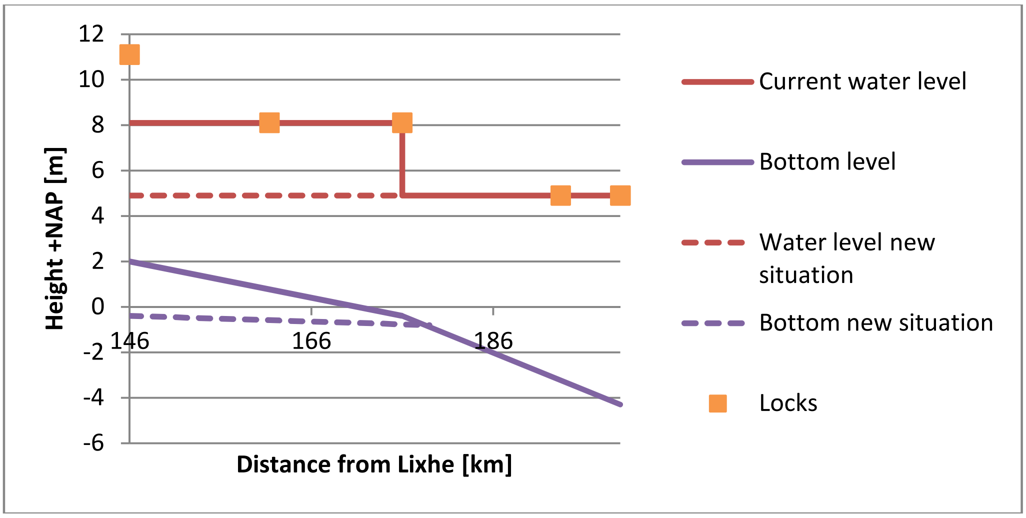
8.4 Locks

8.4.1 Option 1



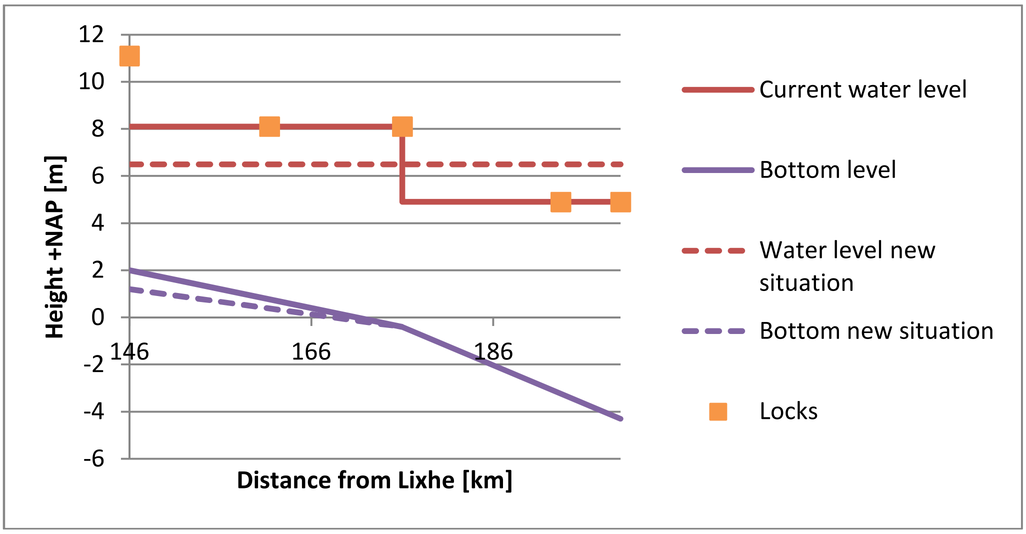
Graph 141 - Canal section Grave: option 1 locks

8.4.2 Option 2



Graph 142 - Canal section Grave: option 2 locks

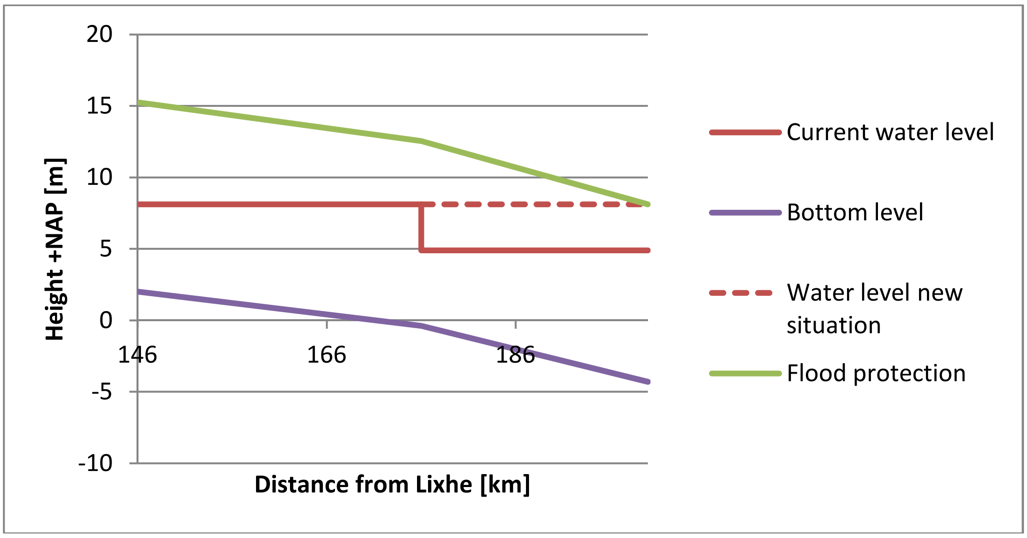
8.4.3 Option 3



Graph 143 - Canal section Grave: option 3 locks

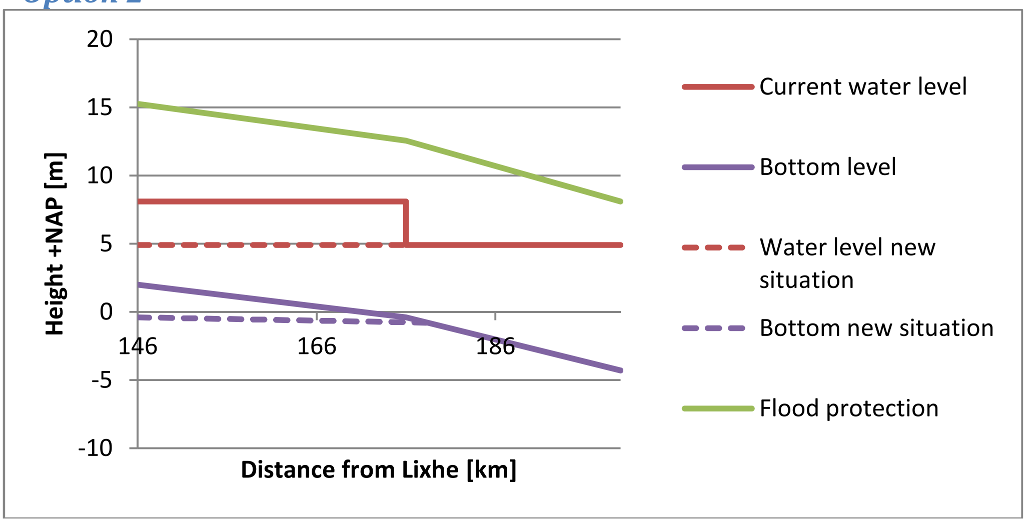
8.5 Flood protection

8.5.1 Option 1



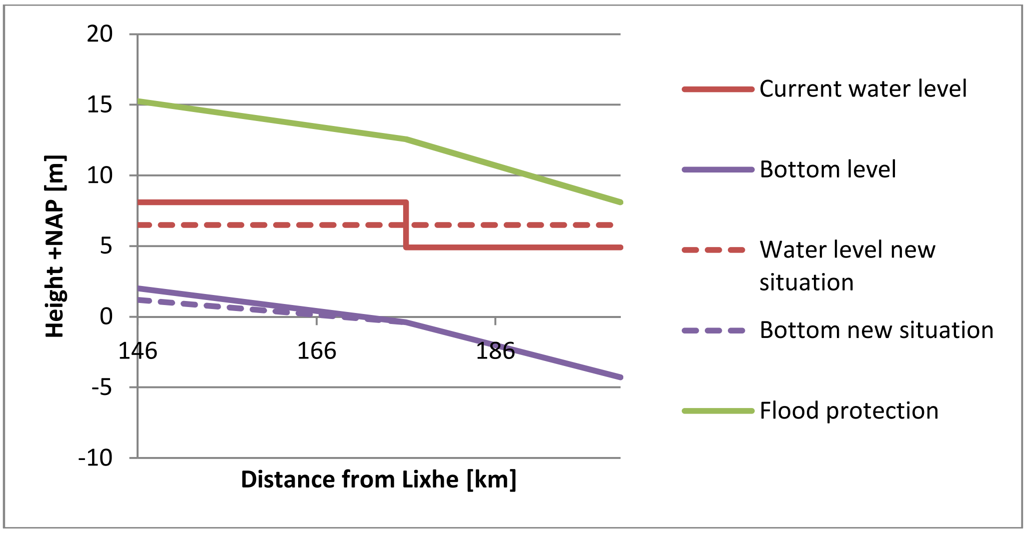
Graph 144 - Canal section Grave: option 1 flood protection

8.5.1.1 *Option 2*



Graph 145 - Canal section Grave: option 2 flood protection

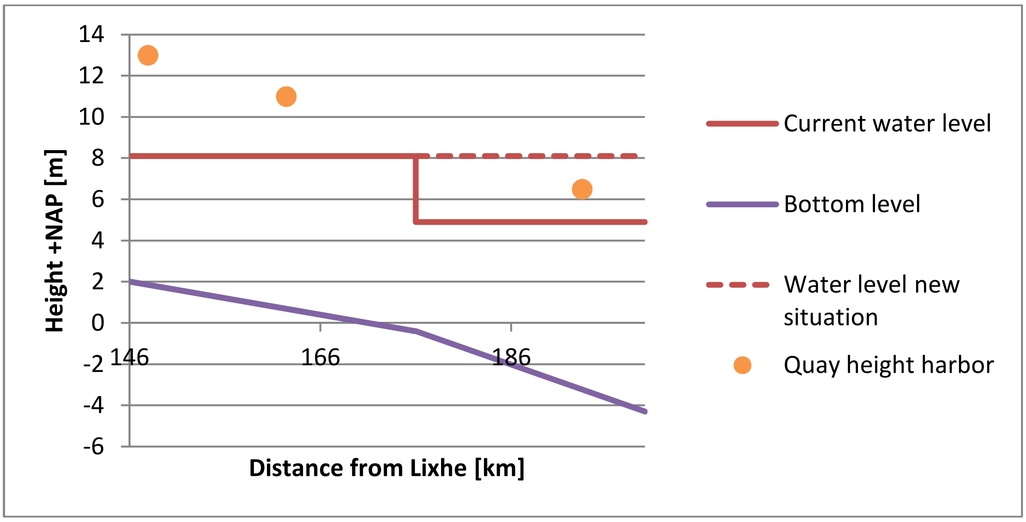
8.5.2 Option 3



Graph 146 - Canal section Grave: option 3 flood protection

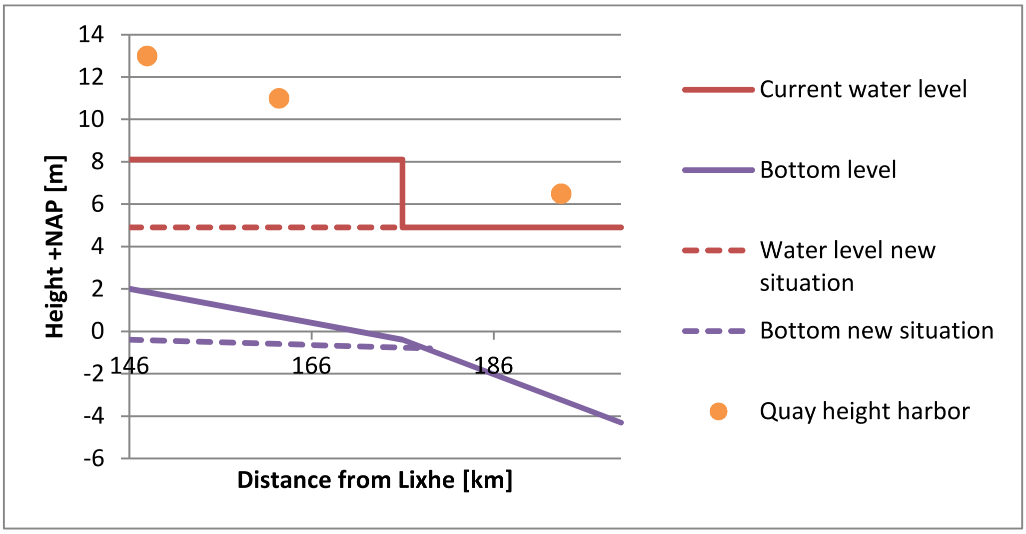
8.6 Harbors

8.6.1 Option 1



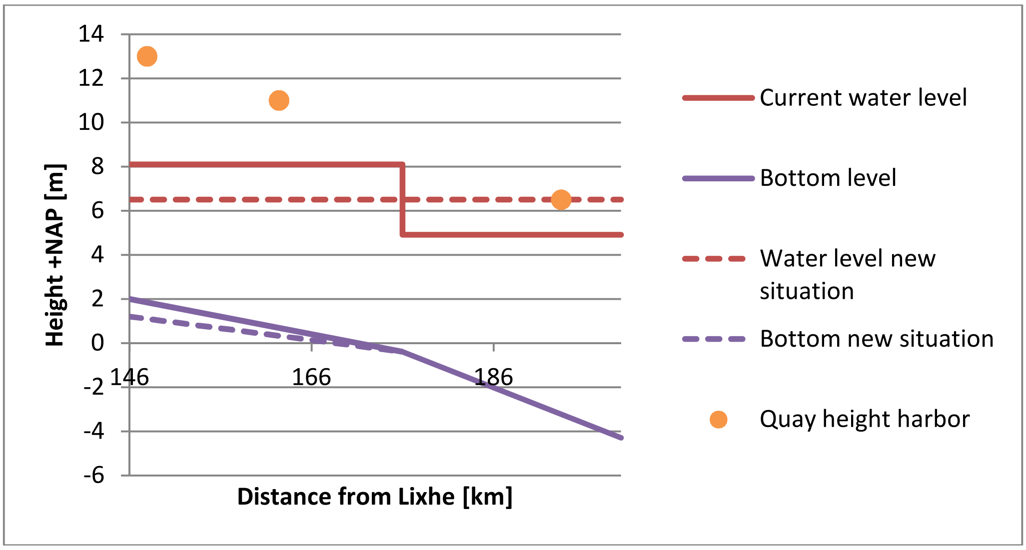
Graph 147 - Canal section Grave: option 1 harbors

8.6.2 Option 2



Graph 148 - Canal section Grave: option 2 harbors

8.6.3 Option 3



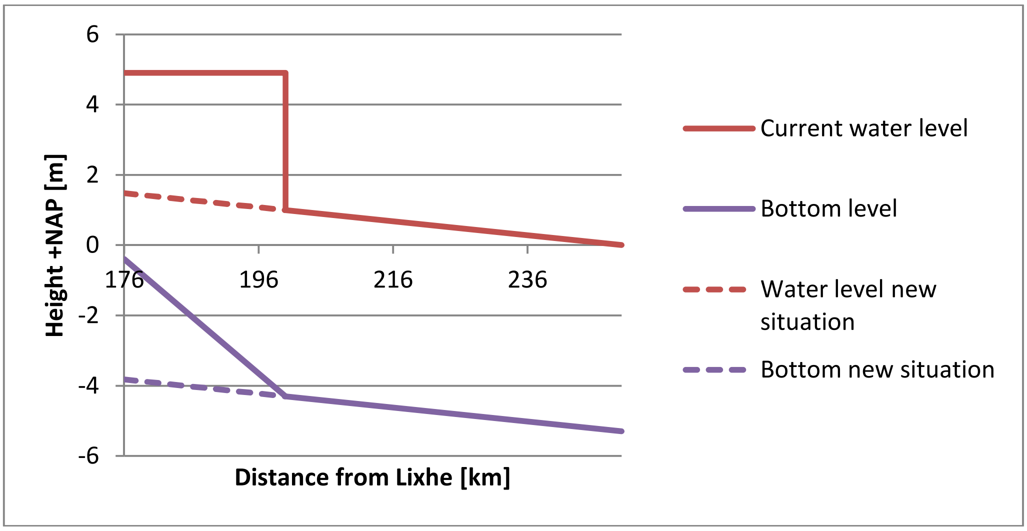
Graph 149 - Canal section Grave: option 3 harbors

9 Canal section Lith

9.1 Situation

9.2 Navigation

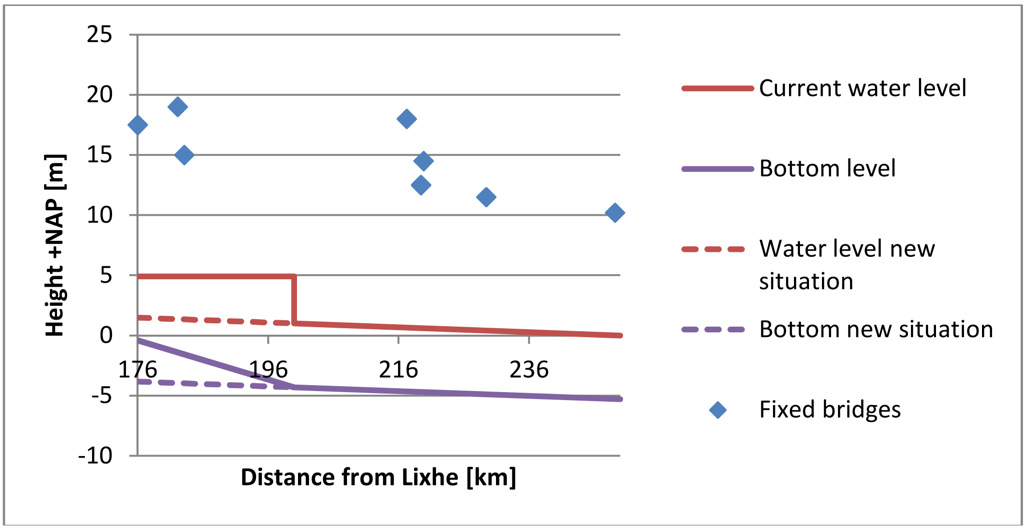
9.2.1 Option 2



Graph 150 - Canal section Lith: option 2 navigation

9.3 Bridges

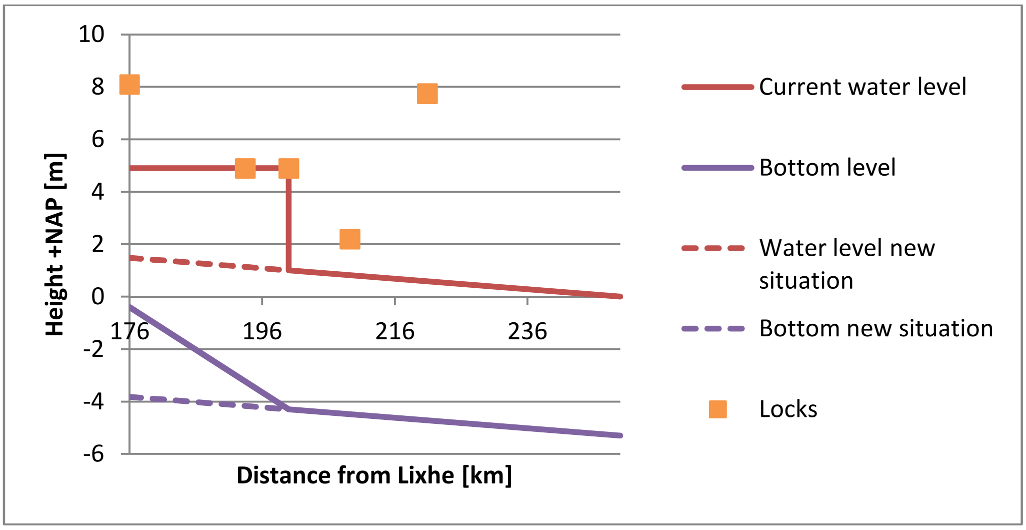
9.3.1 Option 2



Graph 151 - Canal section Lith: option 2 bridges

9.4 Locks

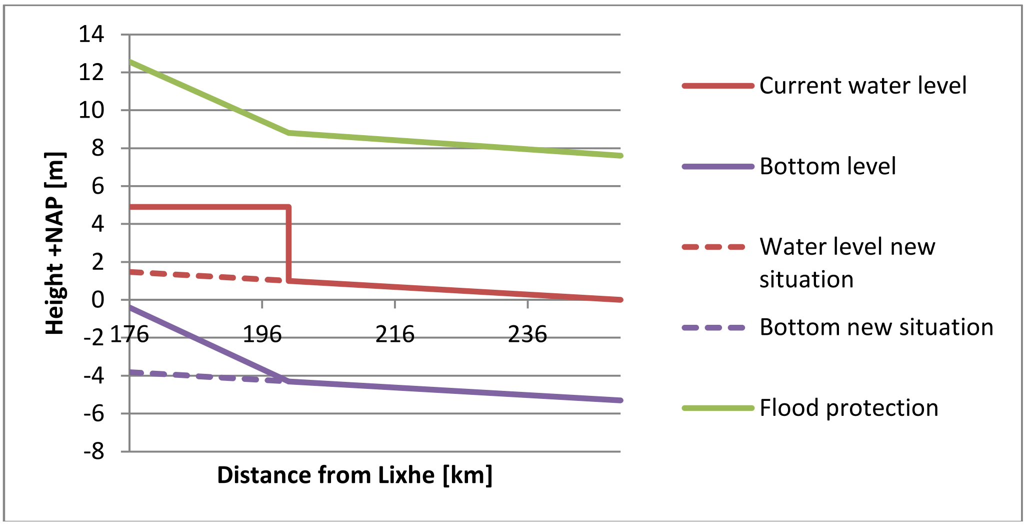
9.4.1 Option 2



Graph 152 - Canal section Lith: option 2 locks

9.5 Flood protection

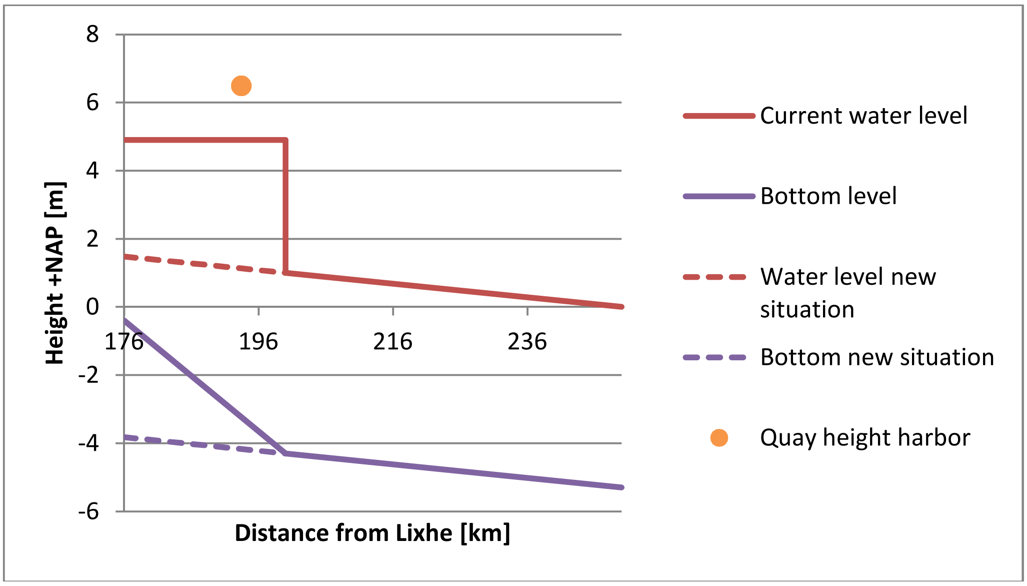
9.5.1 Option 2



Graph 153 - Canal section Lith: option 2 flood protection

9.6 Harbors

9.6.1 Option 2



Graph 154 - Canal section Lith: option 2 harbors

Appendix G - Canal section Linne

1 Mass balance

The canal section is modeled as a closed barrel which contains two pipelines, a supply pipe and a drain pipe. The supply pipe provides an inflow of a certain amount of water per unit of time and the drain pipe provides an outflow of a certain amount of water per unit time. Using a mass balance provides insight in the velocity of the water level change in the area for different discharges.

The model starts with choosing a fixed area G between the considered boundaries. The mass balance obtains this fixed considered area. At the location of the supply pipe does the water flow enter the canal section and at the location of the drain pipe enters the water flow the section. The amount of water that is entering and leaving the area per unit of time is called the mass flow S.

For a short time interval Δt is an amount of mass S_{in}Δt flown into area G and an amount of mass S_{out}Δt out of the area. It is assumed that water in this model is homogeneous and incompressible, this results in water with a constant mass density. The increase of the water volume, so also the water level, in the area is thereby only influenced by the inflow and outflow. The mass balance is described by the change of the water level Δh in time interval Δt together with surface area O (the area of a horizontal cross section of the barrel). The increase of the mass in area G can be described as ρOΔh. The mass balance for the area G becomes:

$$S_{in}\Delta t - S_{out}\Delta t = \rho O \Delta h$$

For fluids like water that can be assumed to be incompressible is the flow SΔt described as discharge Q. The discharge is an fluid volume that flows per unit time trough a certain surface. The relation with the mass flow of area G becomes S = ρQ. The mass balance can be rewritten to:

$$(Q_{in} - Q_{out})\rho\Delta t = \rho O\Delta h \qquad \text{or} \qquad (Q_{in} - Q_{out})\Delta t = O\Delta h$$

If Δt → 0 becomes the mass balance:

$$Q_{in} - Q_{out} = O\frac{dh}{dt} \qquad \text{or} \qquad \Delta Q = O\frac{dh}{dt}$$

In this equation is the velocity of the water level change be represented as dh/dt. This velocity is equal to the mean up or downward directed velocity component of the water particles in area G.

1.1 Mass balance canal section Linne

The mass balance is used to described the water level change of the canal section Linne. The fixed area contains the canal section of Linne behind the defined boundaries. The boundaries of the canal section Linne are:

- Border Meuse from Maaseik
- Weir of Linne
- Hydroelectric power plant Linne
- Lock Linne
- Lock Heel
- Lock Panheel
- Lock Maasbracht

The part of the Meuse that is located behind the boundaries, the entrances to side canals and the harbors contains an area of about 3.5 km^2. The area between these boundaries does not only contain a part of the Meuse and entrances to side canals but also several lakes. The lakes that are directly connected to the Meuse are part of the surface O of fixed area G. The directly connected lakes increase the surface of area so a damping effect on the velocity of the water level change. Besides the directly connected lakes are several unconnected lakes located in the area of canal section Linne.

Graph 155 - Maasplassen in canal section Linne

Lake	Connected with the Meuse	Not connected with the Meuse
	km^2	
Herenlaak	0,823	
Schroevendaalseplas	0,328	
Maasplas Kinrooi (groot)	2,746	
Maasplas Kinrooi (klein)	0,539	
Huyskensplas/De Kist	0,404	
Maasplas Stevensweert	1,582	
De Grote Hegge	1,582	
Molengreend	0,354	
De Slaag	0,214	
Polderveld	0,464	
Tesken	0,174	
Sint-Antoniusplas	0,108	
Dilkensplas		0,160
Teggerse Plas		0,052
Boschmolenplas		1,011
De Lange Vlieter		1,240
Total	9,318	2,463

The inflow and outflow is in the model represented as the in and outflow water in and out the canal section by the Meuse. The model is represented in Figure 56. The figure represents the mass balance of the water in the canal section. A certain Meuse discharge Q_{in} is entering the area and a certain discharge Q_{out} is leaving the area. The discharge entering the area is equal to the discharge of the Border Meuse nearby Maaseik. The discharge leaving the area is equal to the sum of the discharge over the hydroelectricity plant of Linne and the weir of Linne.

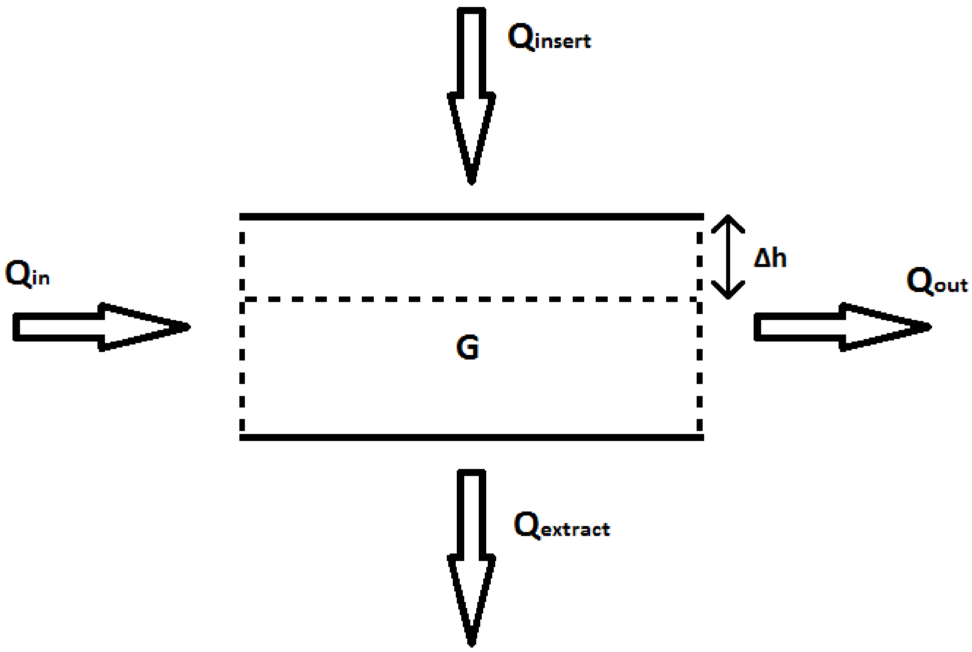


Figure 56 - Mass ballance canal section Linne

Besides the in and outflow is water inserted and extracted from the canal section. With inserted water Q_{insert} is meant water that is not added to the canal section by the Meuse. With extracted water $Q_{extract}$ is meant water that is not leaving the canal section by the Meuse. Examples of inserted or extracted water are leakages of locks. The amount for inserted and extracted water is mainly for low discharges important. When during a long time more water is necessary than enters the area can arise a shortage of water in the canal section. This is an undesirable situation. The inserted and extracted discharges do change the mass balance, the new mass balance becomes:

$$Q_{in} + Q_{insert} - Q_{out} - Q_{extract} = O\frac{dh}{dt} \qquad \text{or} \qquad \Delta Q = O\frac{dh}{dt}$$

1.2 Variants

To analyze what is the effect of the lakes in the area of the canal section are three different variants considered. The variant differ in water storage capacity. According to the analysis of the three variants can be considered in what way the new weir of Linne has to behave when the current situation is changed. The three considered situations are:

- *Variant 1: Current situation*
  The area of the current situation contain the part of the Meuse located behind the considered boundaries and the lakes directly connected to the Meuse.
- *Variant 2: No lakes*
  The area in the second variant contains only the part of the Meuse located behind the considered boundaries. The connections with open connected lakes are closed, this means a decrease of the storage capacity.
- *Variant 3: All lakes*
  In the third variant is the storage capacity of the canal section increased. The unconnected lakes are connected with the Meuse. The storage capacity becomes the Meuse located behind the considered boundaries, the lakes directly connected and the former unconnected lakes.

The three variants are checked for four scenarios represented in Appendix D. The variants are analyzed for the extreme high and extreme low discharges. The extreme high discharges are analyzed to investigate the required reaction times of the weir. The low discharges are analyzed to investigate the accuracy of the discharge over the weir.

1.3 High discharges

The high discharges are of the four scenarios are used in the model. It has to be imagined that the discharges are the reference discharges, the real discharges are normally be lower. Due to this reason is chosen for the following discharges:

Table 33 - Future (maximum) discharges

	Year	Q [m^3/s]
Highest measured discharge	-	3000
Current design discharge	-	3800
Scenario's 'Druk' & 'Rust'	2050	4000
Scenario's 'Druk' & 'Rust'	2100	4200
Scenario's 'Stroom' & 'Warm'	2050	4200
Scenario's 'Stroom' & 'Warm'	2100	4600

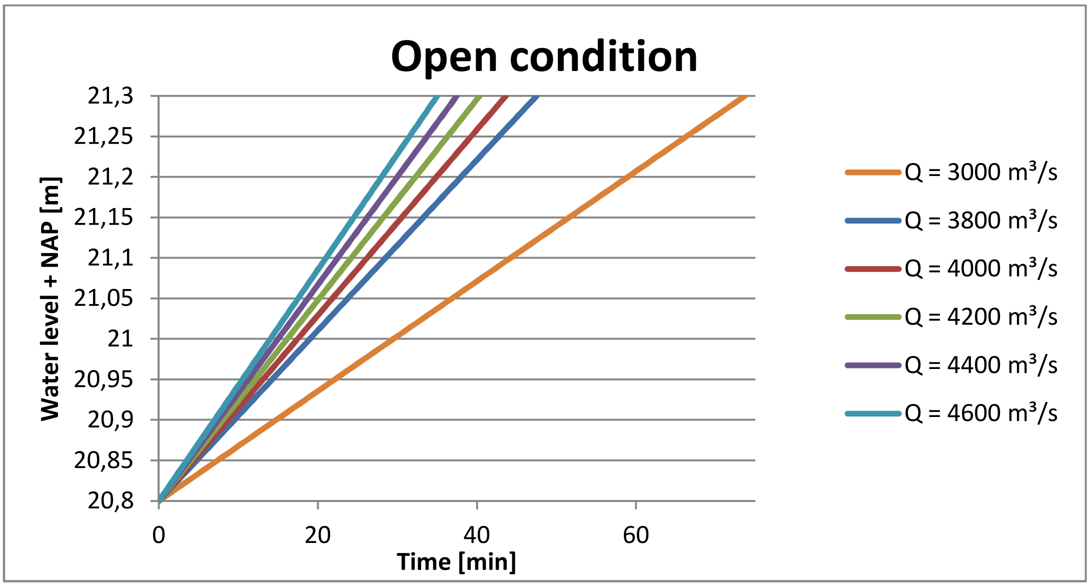
With the year is meant the year it is expected that the certain design discharge will be governing for the discharge of the Meuse. The scenario's 'Druk' and 'Rust' have the same design discharges, the same holds for the scenario's 'Stroom' and 'Warm'.

1.4 High discharge variants

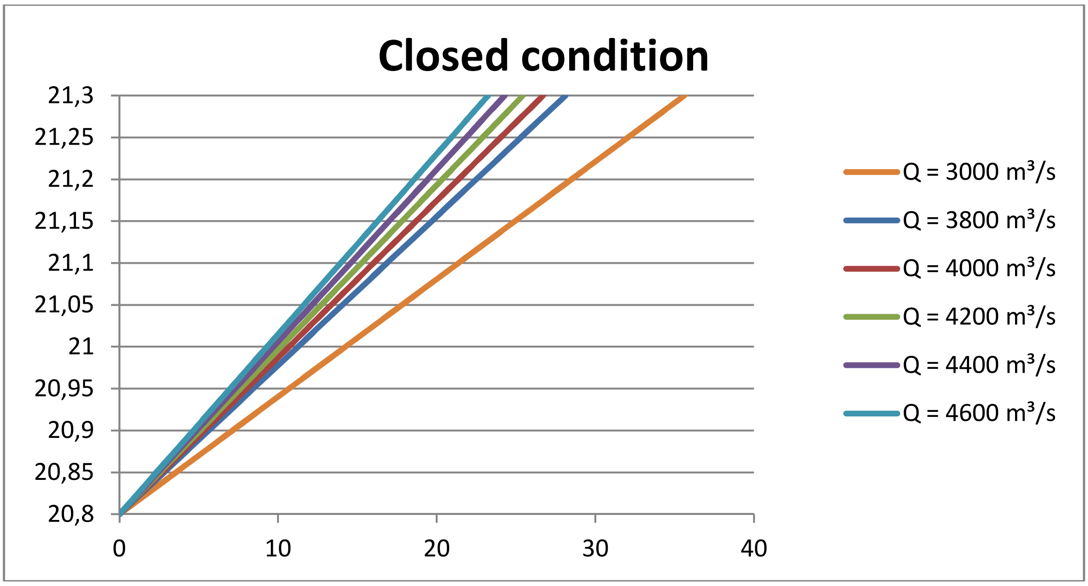
For every variants are three graphs represented. The graphs represent the water level in the canal section during a certain time interval as result of a certain dischargeThe water level until 21.30 m +NAP is represented in the graphs because above this water level is the spillway of Linne activated, several flooding areas are activated and water will flow around the weir. . The water levels are plotted with respect to the time that is required to obtain a water level of 21.30 m +NAP. The three graphs represent:

- *Opened condition*
  The first graph represents the water level change in the canal section when the weir of Linne is totally opened.
- *Closed condition*
  The second graph represent the water level change in the canal section when the weir of Linne is completely closed.
- *Time difference*
  The third graph represent the time difference of the water level rise between the opened and closed condition. For small time differences is a quick responding weir required.

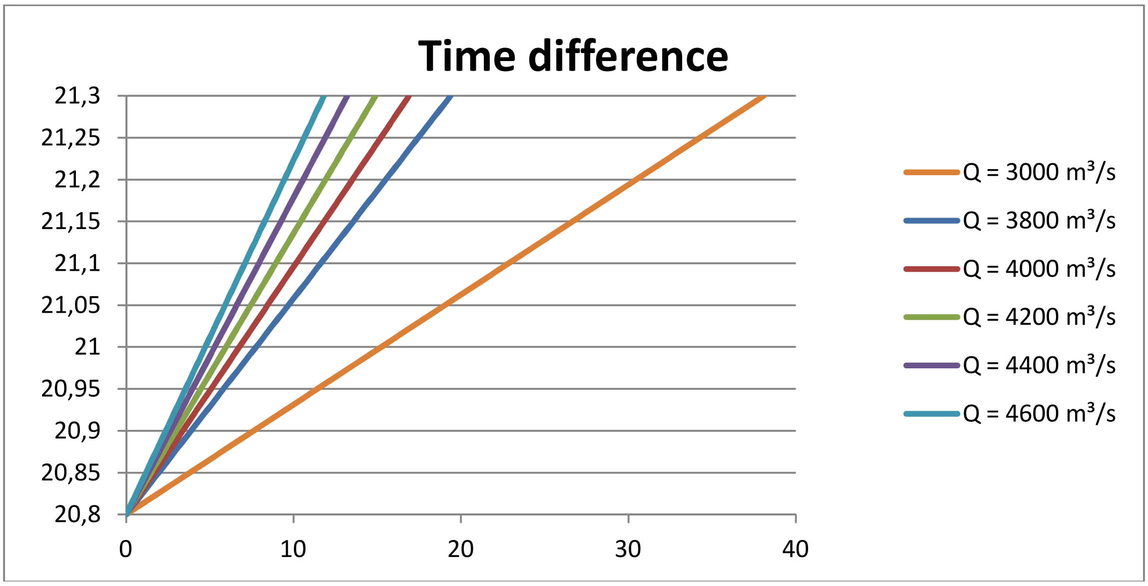
1.4.1 Variant 1



Graph 156 - High discharge: opened condition (variant 1)

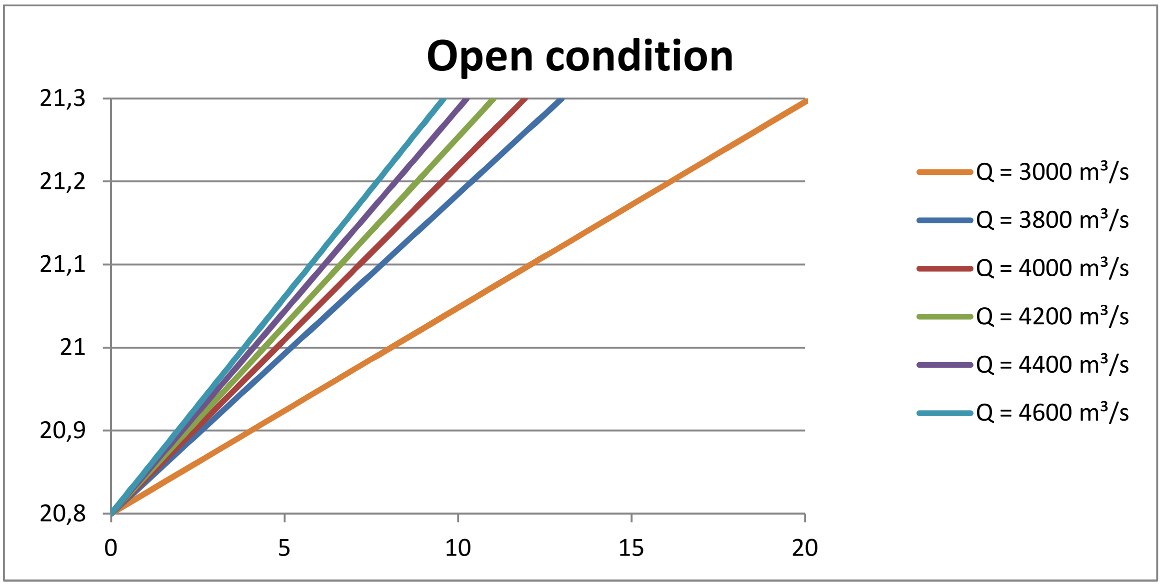


Graph 157 - High discharge: closed condition (variant 1)



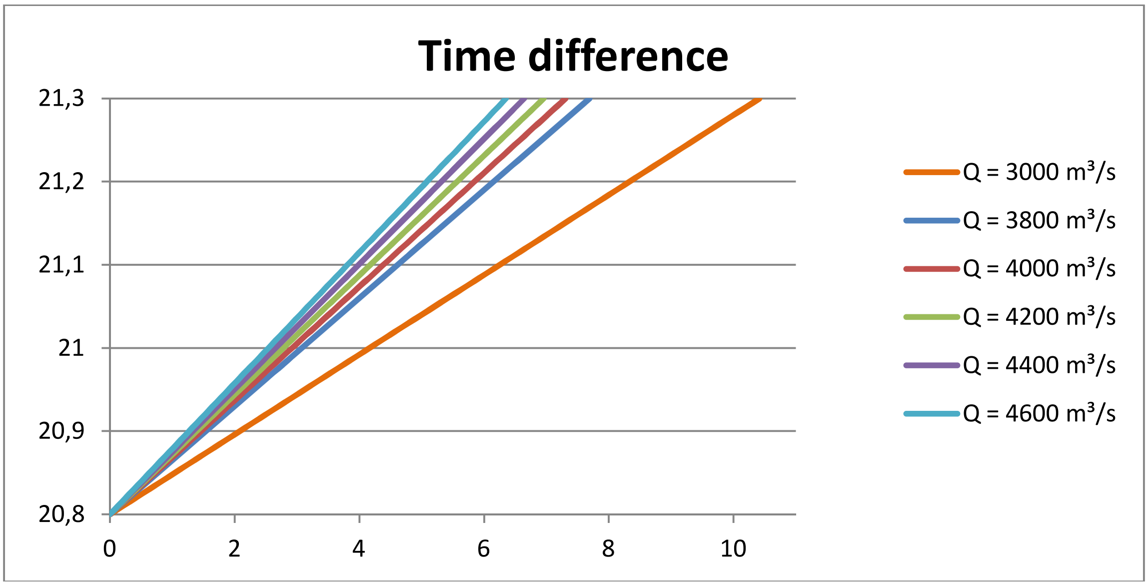
Graph 158 - High discharge: time difference between opened and closed condition (variant 1)

1.4.2 Variant 2



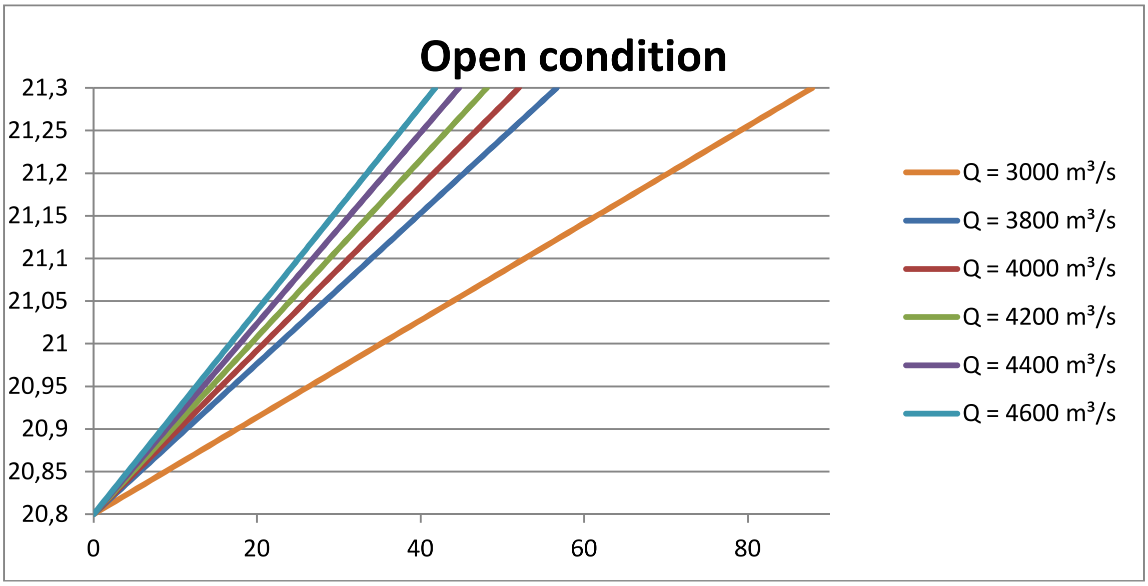
Graph 159 - High discharge: opened condition (variant 2)

Graph 160 - High discharge: closed condition (variant 2)

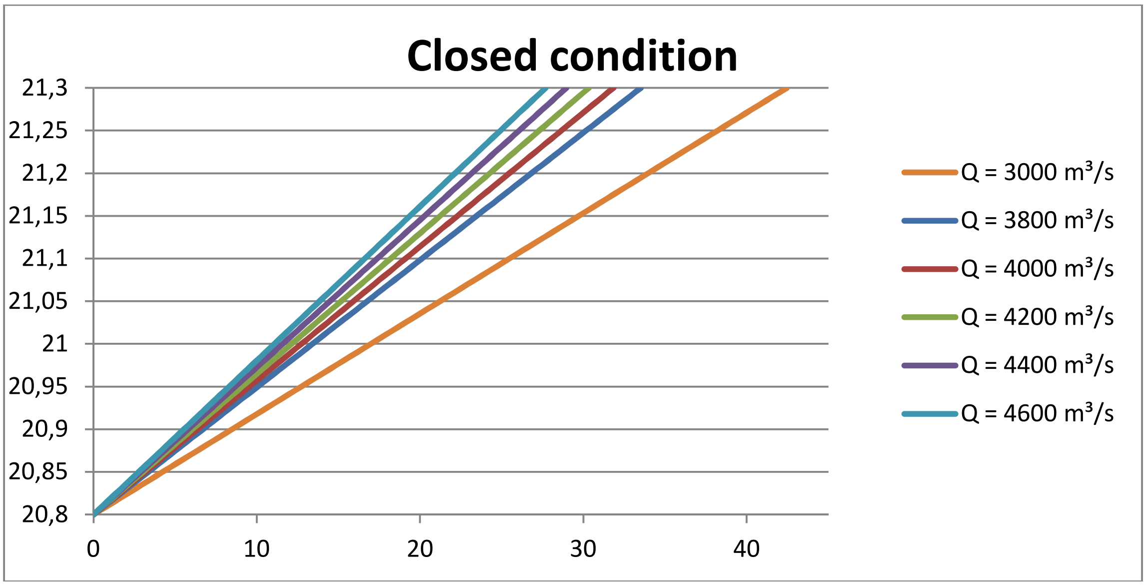


Graph 161 - High discharge: time difference between opened and closed condition (variant 2)

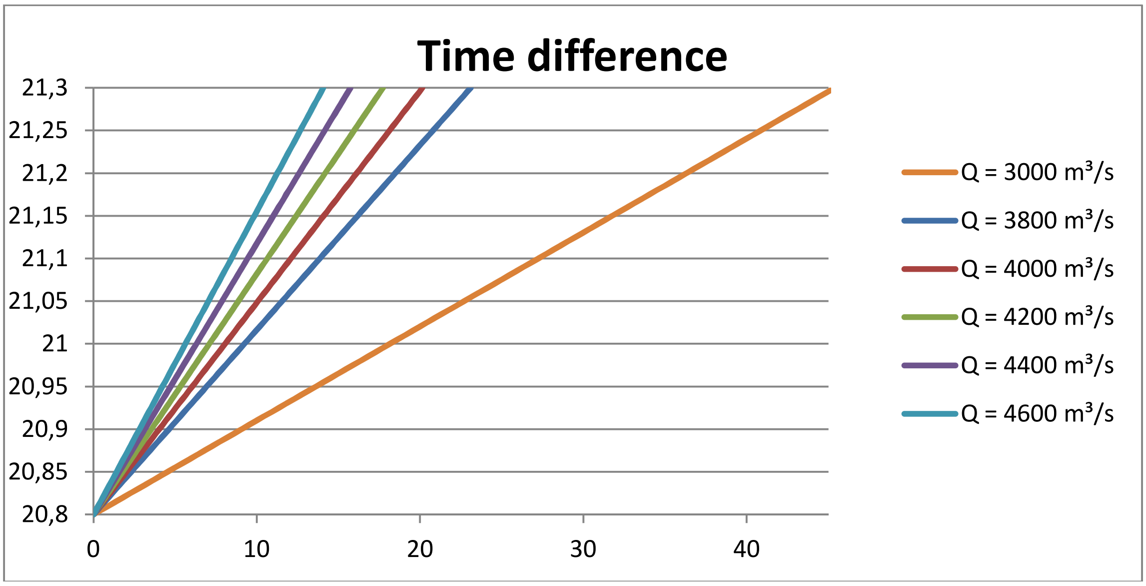
1.4.3 Variant 3



Graph 162 - High discharge: opened condition (variant 3)



Graph 163 - High discharge: closed condition (variant 3)



Graph 164 - High discharge: time difference between opened and closed condition (variant 3)

1.4.4 Comparison of variants

- The velocity of the water level rise in the third variant is the most beneficial because the velocity is lower than in the other variants, this corresponds with the equations is section 1.1.
- The velocity in the first variant is higher than in the third variant, however the storage capacity of the third variant is not substantial larger than the capacity of the first variant. This results in a velocity comparable to the velocity of the third variant.
- The water level rises the fastest in the second variant. The reason is the low storage capacity of the variant.
- For increasing discharges becomes the difference between a perfect responding and a not responding weir smaller. The damping effect of the lakes has less influence on high discharges.

1.5 Low discharge

When discharges of the Meuse become very low can a shortage of water arise. During a water shortage is not enough water available to fulfill all the functions. The effect of a water shortage on the water level changes during extreme low discharges are investigated. A water shortage arises when the discharge of the Meuse near at the Dutch - Belgian border becomes smaller than 36 m^3/s. This discharge is necessary to meet the following requirements (Breukel, Silva, van Vuuren, Botterweg, & Venema, De Maas - Verleden, heden en toekomst, 1992):

- *Discharge to the Zuid-Willemsvaart*
  According to the Tractate of 1863 is a minimal discharge of at least 10 m^3/s from the Meuse to the Zuid-Willemsvaart required. In practice is normally 16 m^3/s going to the Zuid-Willemsvaart. The water is necessary to feed the Kemische Kanalen in Belgium.
- *Discharge to the Border Meuse*
  A discharge to the Border Meuse of at least 10 m^3/s is required. The discharge is required for water refreshment and to maintain the ecological aspects of the Border Meuse.
- *Julianakanaal*
  To maintain the water levels of the canal sections in the Julianakanaal is 16 m^3/s discharges to the canal.

The inflow Q_{in} of the canal section is represented by the discharge of the Border Meuse and the outflow Q_{out} is until 500 m^3/s only generated by the hydroelectric power plant of Linne. The Q_{insert} and $Q_{extract}$ in Figure 56 are represented in the model as:

- Discharge of the Juliankanaal/leakage of lock Maasbracht
- Leakage of lock Heel
- Leakage of lock Linne
- Leakage of lock Panheel
- Pumping station Panheel (to feed the Kanaal Wessem-Nederweert)
- Fish ladder of Linne
- Water extracted by the Clauscentrale.

During extreme low discharges when not enough water is available is the water distribution adapted, near Borhgaren is no water discharged to the Julianakanaal. To maintain the water levels of the canal sections in the Julianakanaal is water from canal section Linne pumped into the Julianakanaal. In Table 34are the in and outflow discharges for the canal section Linne represented. The discharges used in the model for low discharges are represented in Table 35.

Table 34 - Outflow discharges during minimum Meuse discharges

	Q = 26 m^3/s		Q = 18-10 m^3/s		Q = 6 m^3/s	
	In	Out	In	Out	In	Out
	m^3/s					
Julianakanaal	7	9	7-0	9	7	9
Grensmaas	15		10		6	
Lock Heel		4		4		4
Lock Linne		3		3		3
Lock Panheel/Pumping station Panheel	1	4	1	4	1	4
Fish ladder		2		2		2
Hydro power plant						
Clauscentrale		1		1		1
Shortage of water	0		-5		-9	

Table 35 - Future (minimum) discharges

	Year	Q [m^3/s]
Current extreme low discharge	-	18
Scenario's 'Druk' & 'Rust'	2050	18
Scenario's 'Druk' & 'Rust'	2100	18
Scenario's 'Stroom' & 'Warm'	2050	10
Scenario's 'Stroom' & 'Warm'	2100	6

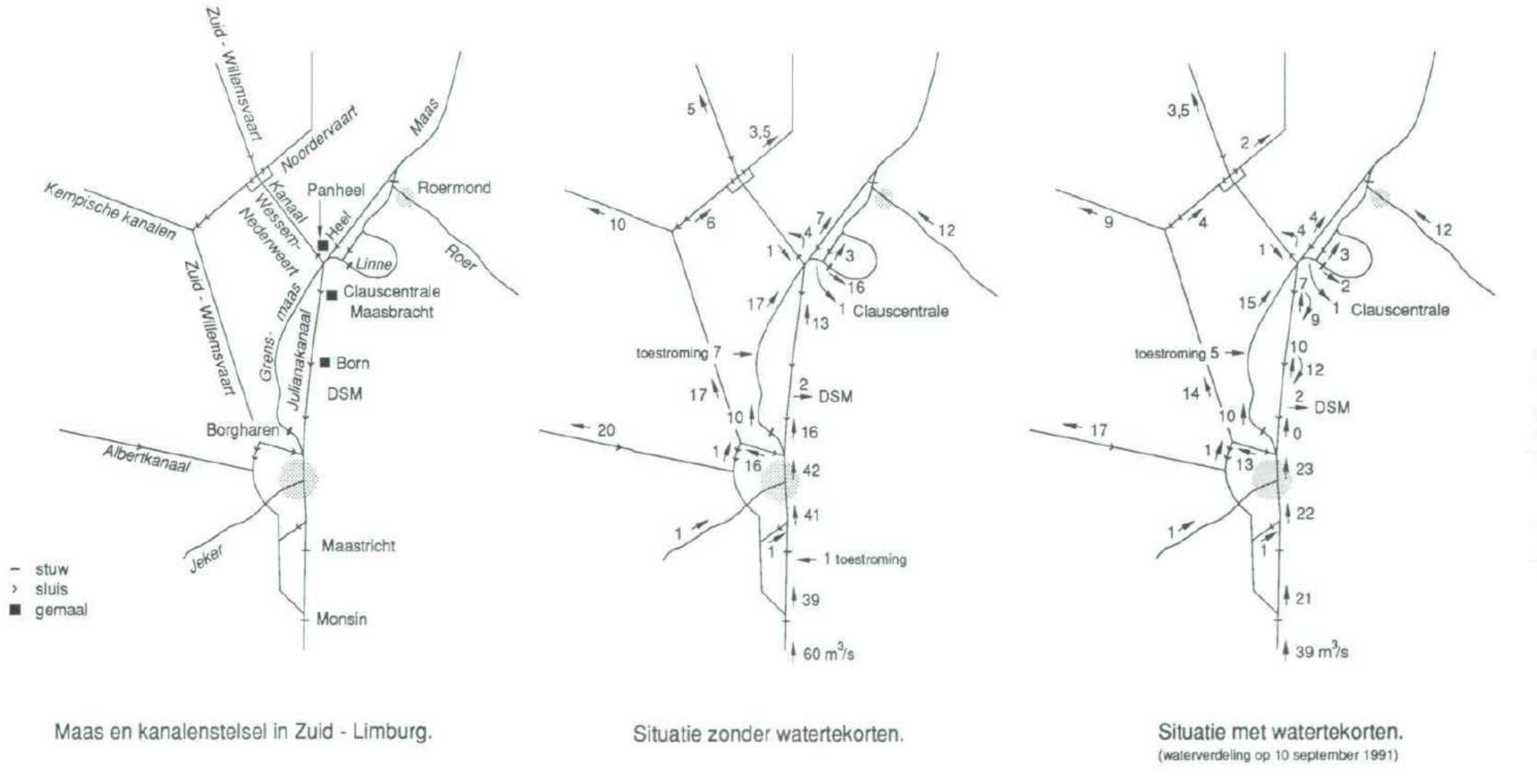


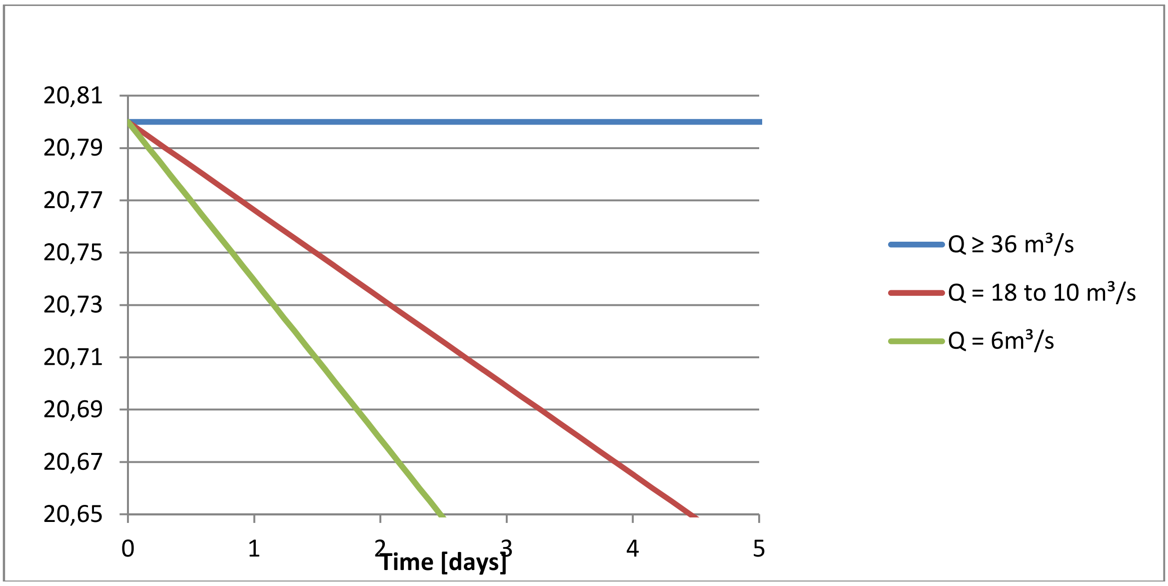
Figure 57 - Discharge distribution; left: situation without discharge shortage; right: situation with low discharge (Breukel, Silva, van Vuuren, Botterweg, & Venema, De Maas - Verleden, heden en toekomst, 1992)

1.6 Low discharge variants

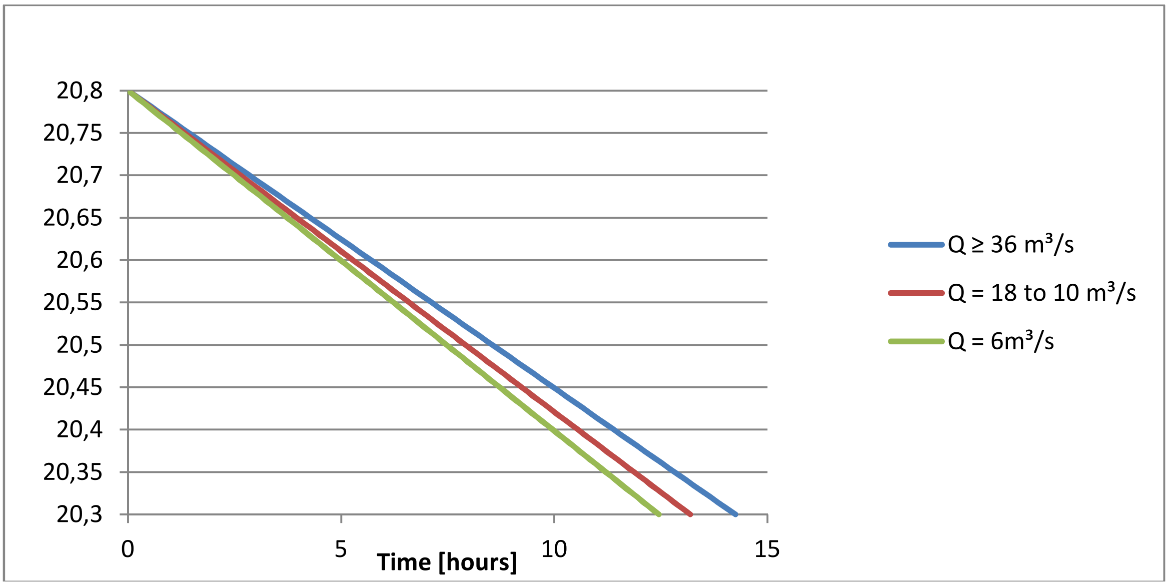
The water level change during low discharges are just like for the high discharges represented in graphs. Three discharges are represented because by all discharged above 26 m^3/s at Borgharen can all functions of the Meuse be fulfilled. The water level until 20.65 m +NAP is represented, at this water level in no navigation on the Meuse possible (Rijkswaterstaat, Hoogwater op Rijn en Maas, 2007). This low water level is only measured in the summer of 1976. Compared to the high discharges are the time intervals represented in days instead of minutes.

Two graphs are represented, the first graph represents the model according to the values represented in Table 34. The second graph represents also the value of Table 35 inclusive the activation of one of the turbines the hydroelectric power plant. The maximum discharge of the plant is 500 m^3/s and the plant contains 4 turbines. It is assumed that 1 turbine is fully operated, this means a discharge of 125 m^3/s out of the canal section. The second graph is represented to investigate what the effect is of the hydroelectric power plant on the water level change during low discharges.

1.6.1 Variant 1

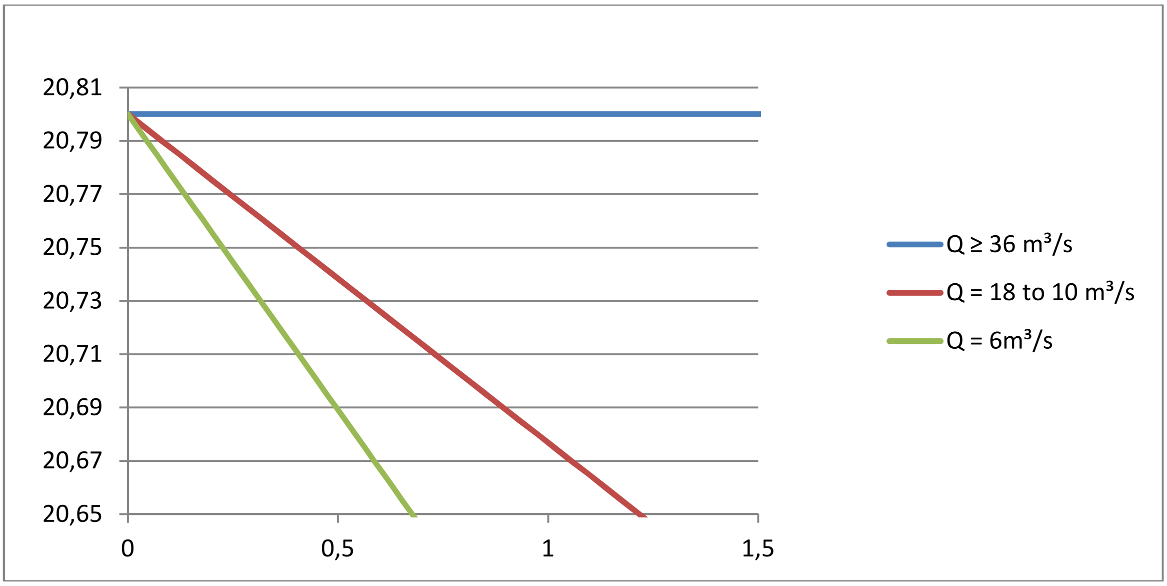


Graph 165 -Low discharge (variant 1)

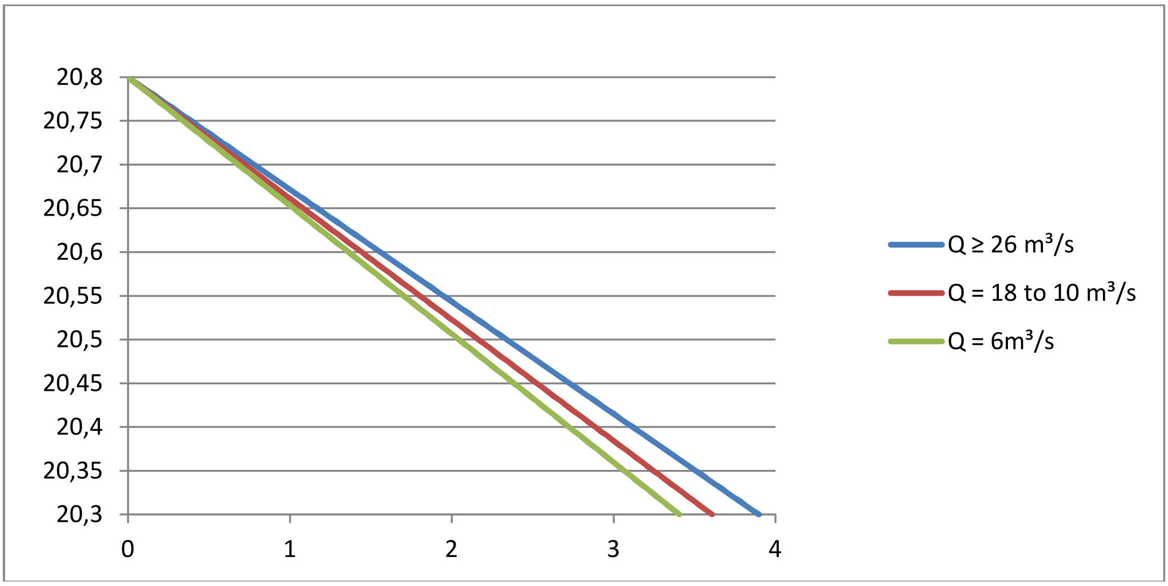


Graph 166 - Low discharge, hydropowerplant operable (variant 1)

1.6.2 Variant 2

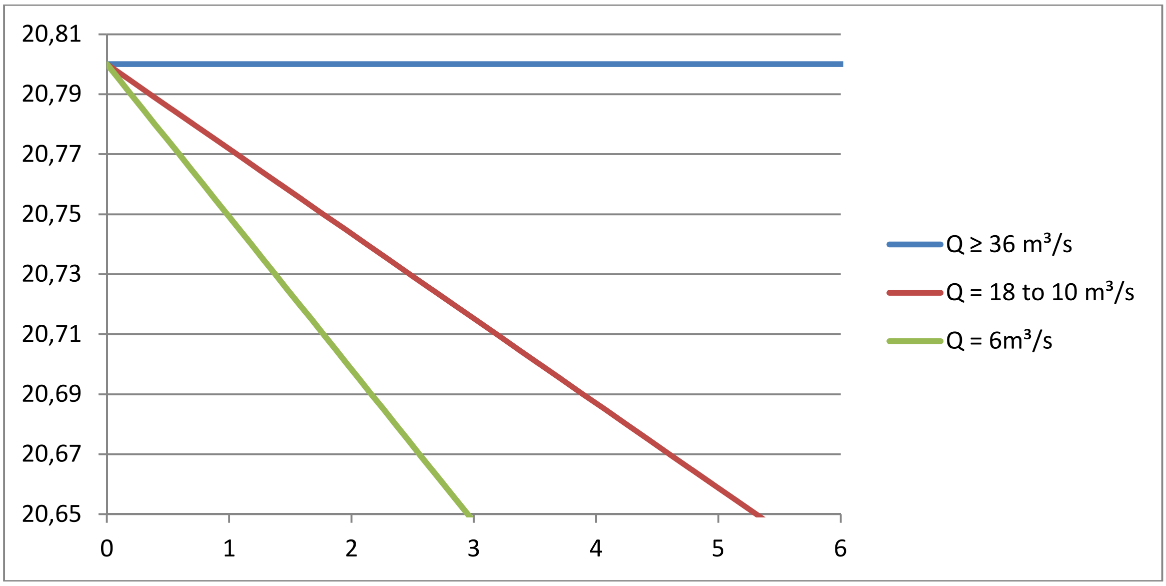


Graph 167 - Low discharge (variant 2)

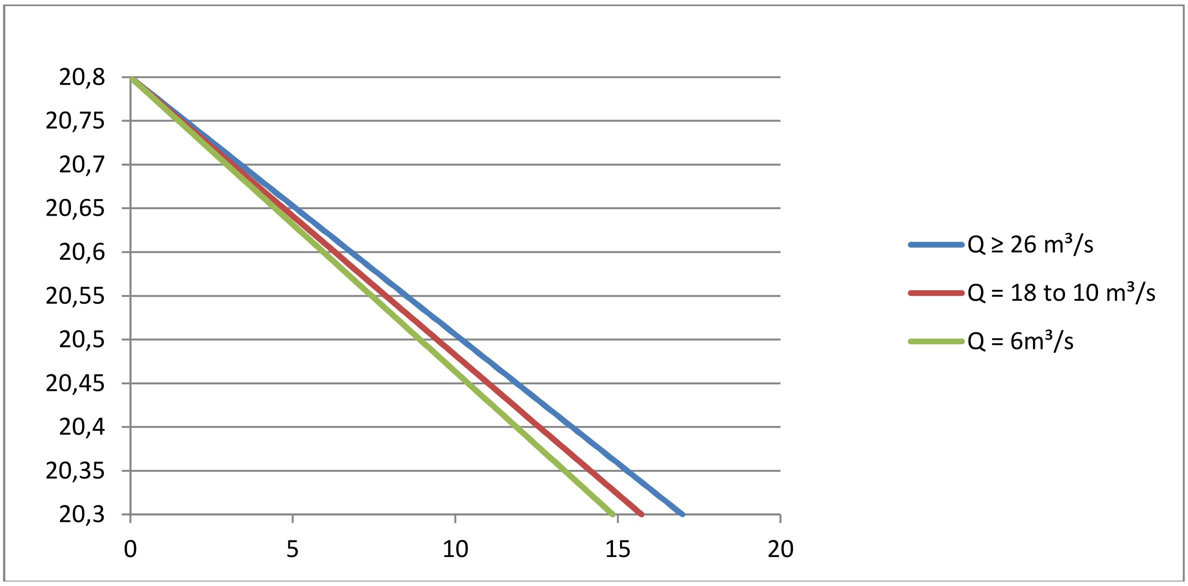


Graph 168 - Low discharge, hydropowerplant operable (variant 2)

1.6.3 Variant 3



Graph 169 - Low discharge (variant 3)



Graph 170 - Low discharge, hydropowerplant operable (variant 3)

1.6.4 Comparison of variants

Exclusive hydroelectric power plant

- The velocity of the water level rise in the third variant is the most beneficial because the velocity is lower than in the other variants, this corresponds with the equations in section 1.1. The velocity in the first variant is higher than in the third variant, however the storage capacity of the third variant is not substantial larger than the capacity of the first variant. This results in a velocity comparable to the velocity of the third variant.
- The water level drops the fastest in the second variant, the reason is the low storage capacity of the variant.
- The water level of 20.65 m +NAP is reached much faster for all variants in comparison with the situation of a closed hydroelectric station.

Inclusive hydroelectric power plant

- The velocity of the water level rise in the third variant is the most beneficial because the velocity is lower than in the other variants, this corresponds with equations in section 1.1.
- The velocity in the first variant is higher than in the third variant, however the storage capacity of the third variant is not substantial larger than the capacity of the first variant. This results in a velocity comparable to the velocity of the third variant.
- The water level drops the fastest in the second variant, the reason is the low storage capacity of the variant.
- The water level of 20.65 m +NAP is reached much faster for all variants in comparison with the situation of a closed hydroelectric station.

1.7 Multi criteria analysis

1.7.1 Weight factors

To determine the importance of several factors in the MCA analysis is the weight of the factors determined. The factors are represented in Table 36.

Table 36 -Weight factors

	Safety	Navigation	Discharge	Adaptability	Industry	Gravel extraction	Recreation	Total	Weight factor
Safety		1	1	1	1	1	1	6	0.29
Navigation	0		0	1	1	1	1	4	0.19
Discharge	0	1		1	1	1	1	5	0.24
Adaptability	0	0	0		1	1	1	3	0.15
Industry	0	0	0	0		1	0	1	0.05
Gravel excavations	0	0	0	0	0		0	0	0
Recreation	0	0	0	0	1	1		2	0.10
								21	1

1.7.1.1 *Safety*
With the factor safety is meant the safety against quick raise of water levels. Along the Meuse are several living areas, recreational areas and industries. When the water level in the canal section becomes higher will areas along the Meuse be flooded. Municipalities or individual persons can be surprised by a quick rise of the water level. Also economical damage to industrial or personal possessions should be avoided. By a slower rise of water level is more time available to anticipate on the water level rise.

1.7.1.2 *Navigation*
Navigation is an important task of the canal section because it is the main reason that weir Linne is constructed. It is during high discharges for a long time possible to navigate through the canal section. When water levels and flow velocities become too high becomes navigation impossible. During low discharges can sufficient navigational depth become problematic. Is important that navigation on the Meuse is maintained as long as possible during high and low discharges. It is important because the economical losses should be kept as low as possible.

1.7.1.3 *Discharge*
It is important that during high discharges the water can pass the canal section as quickly as possible. Obstacles in the canal section can delay the discharge of water which is not beneficial for a quick discharge.

1.7.1.4 *Adaptability*
The adaptability of the variant is important to anticipate on changing conditions. Four different scenarios are distinguished based on the KNMI'14 climate change scenarios. However which of the future scenarios will become reality is not known. The it is beneficial for the variants if the variant has the possibility of adaption to a new situation.

1.7.1.5 *Industry*
Industry uses water from the canal section. In most situations is the water used as cooling water. Sufficient water is required, especially during dry periods. During extreme low discharges are industries not always allowed to use water from the Meuse. Some industries have a water storage to have sufficient water during a certain time. However not all industries have such facilities, during dry periods should these factories have to decrease the production. Decreasing production has influence on the profits of the industries.

1.7.1.6 *Gravel excavations*
Gravel extraction was for several decades an important activity in the canal sections of Linne and Roermond. Due to the gravel excavations have the Maasplassen been arisen. In the current the canal section is only near Maaseik is gravel excavated. However, by changing the storage capacity of the canal section can excavation of sand and gravel be an option. The gravel can be sold which is beneficial for the costs of the project.

1.7.1.7 *Recreation*
The lakes along the Meuse have a important recreational function. Marinas are located in the lakes and the lakes are used for all kinds of water sports. Disconnection of the lakes is not beneficial for the recreational opportunities of the region because the Maasplassen is the most important water sports area of southern Netherlands. The recreational purposes of the lakes attracts lots of tourists from the Netherlands and Belgium.

1.7.2 Rating of variants
To compare the variants is per aspect a mark granted to the variants. For every aspect are the marks 1, 2 and 3 assigned. The variant that satisfies the specific aspect the most is granted with the mark 3, the second best variant is granted with 2 points and the worst variant is marked with 1 point. In the end are the scores multiplied with the weight factors of Table 36. In the last line of Table 36 are the scores per variant represented.

Because gravel excavations is according to Table 36 of little importance is this aspect not taken into account in the rating of the variants.

Table 37 - MCA table

Aspects	Weight factor	Variant 1	Variant 2	Variant 3
Safety	0.29	2	1	3
Navigation	0.19	2	1	3
Discharge	0.24	2	3	1
Adaptability	0.15	3	2	1
Industry	0.05	2	1	3
Recreation	0.10	3	1	2
Score excl. factor		14	9	13
Score incl. factor		2.29	1.65	2.18

1.7.2.1 *Safety*
The third variant has scored the highest mark for the aspect safety. The variant has the largest storage capacity of the three variants. The large storage capacity results in the slowest water level rise so inhabitants of the area have more time to react on the upcoming high water. The first variant is granted with 2 points because the storage capacity of the in the first variant is smaller than in the third variant. The result is a quicker water level rise than the third variant. The second variant has the smallest storage capacity so is marked with 1 point.

1.7.2.2 *Navigation*
The third variant has also on the aspect navigation marked with the highest score. The highest score is granted due to the large storage capacity of the third variant. Due to the large storage capacity will the water level for the third variant decrease the slowest. The slow decrease of water level results in more navigable days in the canal section. The first variant is granted with 2 points because in this variant is the water level decrease faster than in the third variant but slower than for the second variant. The water level in the second variant decreases the fastest of all three variants. The result is

that for the second variant navigation becomes quicker impossible compared to the other two variants.

1.7.2.3 *Discharge*

The second variant has been rated with 3 points for the aspect discharge. The second variant has the smallest storage capacity so the water that is entering the canal section is very quickly be discharged because no water is stored in the canal section. However this is only beneficial for average discharges, on the other hand are average discharge more common than extreme discharges. The first variant has been rated with 2 points because the storage capacity is larger than the second variant. A substantial amount of water is stored in the lakes along the Meuse, so not all water is directly discharged out of the canal section. The third variant is granted with the lowest score because this option has the largest storage capacity so the slowest discharge.

1.7.2.4 *Adaptability*

The first variant has obtained the highest score for the aspect of adaptability. The reason is that the storage capacity of the first variant can be decreased and be increased. The advantage of the variant is that the variant can be simply adapted to one of the four climate scenarios (Appendix D). The second scenario has been granted with 2 points. The advantage of this scenario is the possibility to a large increase the of storage capacity, however it is difficult to decrease the storage capacity. The third capacity has gets 1 point. For this variant holds the same as for variant 1 but in variant 2 it is impossible to increase the storage capacity.

1.7.2.5 *Industry*

Variant 3 is the most beneficial for the aspect industry. Due to the large storage capacity in the third is during low Meuse discharges more water present in the canal section for the purpose of industry. During low discharges can industry longer fully operable than in the two other variants because more water is available. The first variant has got two points because the storage capacity of this variant is smaller than of the third variant, so during low discharges can industry be for a shorter time be fully operable. The second option has got the lowest mark because the water storage capacity of this variant is relatively low compared to the other options. Industry can only for a short time use Meuse water during low discharges.

1.7.2.6 *Recreation*

The second option is the most beneficial for the aspect recreation. The current recreational facilities are maintained. This option can also beneficial for marina holders in the area because competition does not increase. The third option is granted with 2 points More lakes are connected with the Meuse so an increase of water recreation along the Meuse becomes possible. However, more recreation facilities means more competition for current marina holders. The second option is rated with 1 point because most of the marinas become unreachable.

1.7.3 Costs

The costs of the variants are not determined in detail. Only the required measurements that are mentioned to obtain insight of what aspects contribute to the costs.

- *Variant 1: Current situation*

- *Variant 2: No lakes*
    - Connections with lakes have to be closed
    - Flood protection has to be adapted
    - Loss of jobs in the recreational sector

- *Variant 3: All lakes*
    - Connections between Meuse and lakes should to be made

- Flood protections have to be adapted

1.7.4 Conclusion

The design choice is made based on the MCA score and the possible costs per variant.

- *Variant 1: Current situation*
  - It is considered as the most preferable solution. The variant has the best performance compared the two other variants. Furthermore are the costs of this option lower than for the other variants. The combination of the high score according to the MCA analysis and the low cost prefer this variant above the other variants.
- *Variant 2: No lakes*
  - It is considered as the worst preferable solution. The safety and navigable disadvantages due to the quick reaction of water levels on the discharge are not required.
- *Variant 3: All lakes*
  - It is considered as a possible solution. The high scores on safety and navigation are preferable. The low scores on discharge and adaptability are not desirable. Also the costs of variant 3 are not beneficial for the variant.

G	=	Optional fixed area	km^2
S	=	Mass flow	kg/s
Δt	=	Time interval	s
Δh	=	Water level change	m
O	=	Area of a horizontal cross section of the canal section	km^2
Q	=	Discharge	m^3/s
Q_{in}	=	Discharge entering canal section Linne	m^3/s

Appendix H Analysis of the weir Linne

1 Weir Linne

The Meuse corridor was analyzed according to RINK, however not all results are public. The results for the weirs of Sambeek and Lith are available. The weir of Sambeek is most comparable with weir Linne, both weirs consist of a Poirée and Stoney part. Weir Lith consists of three large discharge openings with wheel gates.

1.1 Parts of the weir

Before the state of the weirs are analyzed as short summary of a simple weir layout is given. The summary is represented to give a better view about the analyzed parts of the weirs of Sambeek and Lith.

1.1.1 Principle of weir design

Different types of weirs exist, however all weirs can be divided into three main components. The main components of the weir are (de Gijt & van de Toorn, 2012):

- *Fixed structure*
  The fixed structure of a movable weir forms a single or multiple U-shaped framework and bearings for movable parts. The fixed part consists of:
  - Two abutments
  - Floor slab/foundation
  - Sill beam
  - Pillars in the middle
  - Shallow foundation
  - Cut off screens
- *Superstructure (incl. movable parts)*
  By movable parts is meant all moving parts of the weir. The movable parts of a weir consist of:
  - Closing element
  - Mechanical operating mechanism
  - Electrical steering system.
- *Bottom protection*
  The bottom protection prevent scour in and in the vicinity of the weir. A bottom protection can consist of filter layers, natural stones, concrete blocks, mattresses or stone asphalt. For highly attacked places with high flow velocities, sometimes only monolithic concrete constructions are able to reach the requirements, for example a sterling basin.

1.2 RINK (Risico Inventaris Natte Kunstwerken)

Rijkswaterstaat manages a large number of hydraulic structures. Most structures have a lifetime of 100 years. Of the structures was 1/3 build before 1940. Rijkswaterstaat has started the RINK project to obtain a total view of the maintenance condition of hydraulic structures in relation to new risks arising from changing conditions. New risks are originated from:

- Changing conditions and design principles
- Maintainability
- Usage and operability
- Law and regulation.

The basis for RINK is the analysis of hydraulic structures according the RAMS systematic. The analysis has based on reliability (R), availability (A), maintainability (M) and safety (S). The main methods to obtain the four aspects are (Figure 58):

- On-site inspections
- Constructive and technical analyses
- Risk- and reliability analyses

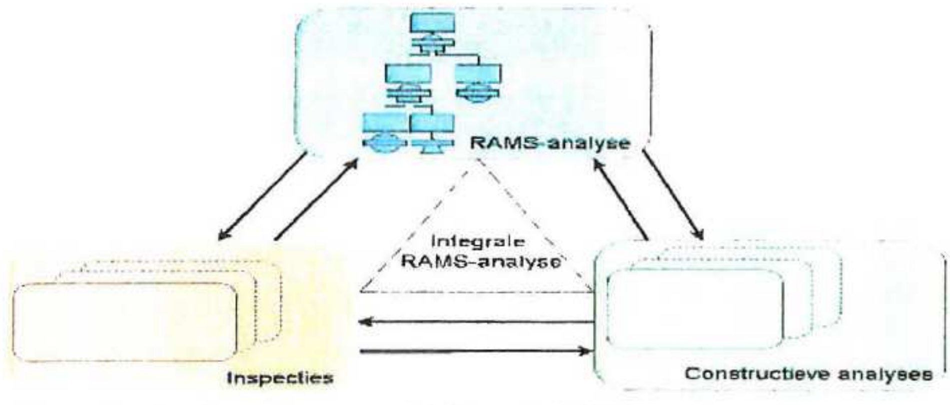


Figure 58 - Pilars of the RAMS analysis (de Wilde, Kiljan, & Janssen, 2010)

Not only the single object but all objects inside the corridor are important in the RAMS analysis. For this purpose is for RINK a corridor performance model is developed. The model is a helpful tool to formulate cost-effective measure scenarios in relation to the required performance level of objects inside the corridor.

The main purposes of RINK are:

- Obtaining a overall view of the maintenance state of the hydraulic structures in relation to the new risks and determining the remaining lifetime of the structures. The maintenance state and remaining lifetime are important for the right replacement strategy.
- Determine the performance (RAMS) of the hydraulic structures based on the on network level developed measuring method (SLA). On the occasion of the results are suggestions and priorities of measurements ranked to obtain a better and more cost-efficient maintenance model.
- To ensure that the RINK systematic become a fixed principle for Rijkswaterstaat whereby periodical inspections are important.

1.3 Weir Sambeek and Lith

1.3.1 Changing conditions and design principles

The design conditions and principles form the past are different from the conditions and principles of today. Due to changing principles it is possible that the construction, designed according to old design rules, does not meet the today's requirements.

1.3.1.1 *Effects of changing hydraulic loads:*

- Influence of larger loads on parts of the weirs as result of increasing water levels. Water levels have been changed since the original design for navigational purposes.
- Influence of changes in weir management for navigational purposes. The results are: increased wear of essential parts, influence of larger (combined) loads on the strength and stability of gates, valves and bottom protection. Changes in weir management also increased the probability of human failure as result of a more frequent manual control instead of automatic control.

1.3.1.2 *Effects of new design principles*
Recalculation of critical parts of the construction resulted in objects that not satisfy the design loads according to the new design principles. The probability of failure of the insufficient part is relative small. However the consequences of failure are large with respect to repair time (unavailability) and costs. The insufficient parts are:

- Foundation of the Poirée part of weir Sambeek
- Valves and levers of weir Lith

1.3.2 Maintainability

1.3.2.1 *Effects of the outsourcing of maintenance*
The consequence of outsourcing of maintenance to the market resulted in high focus on corrective instead of preventive maintenance. In particular the first years when the market and Rijkswaterstaa had to gained experience. The focus on corrective instead of preventive maintenance could have had effect on the deterioration of construction parts.

1.3.3 Availability and reliability
For the weir Sambeek as well for the weir Lith holds that the availability of the function is to lot according to the performance requirement (SLA/PIN) of 99.5%. The availability of the weir is in between 98 and 99%. The events that contribute the most to the unavailability and unreliability of the weirs are for both weirs:

- Weir Sambeek
  - Failure of driving and lifting installations of the Stoney Part
  - Failure of the civil constructions and foundation of the Poirée part
  - Failure of the operation-, controlling and hoisting installation of the Poirée part
- Weir Lith
  - Failure of the operation- and controlling system
  - Failure of hinges between valve and gate and lever
  - Failure of lifting chains and the stuck of wheels as consequence of too quick lifting of the gates
  - Failure of the electrical installation as result of lightning strike of the hoisting towers

1.3.4 Law and regulations

1.3.4.1 *Effect of changed laws and regulations*
It is concluded that safety measures in context of ARBO-regulations, low voltage-, EMC- and machine guidelines are not or partly implemented. Especially the unsafe ARBO situation at the manual proceedings that are necessary to handle the Poirée part of weir Sambeek. The maintenance status and object knowledge are often not formalized. Most of the times is also technical information missing or incomplete. As long as maintenance is done by a fixed maintenance organization this need not be a problem. However for a change in maintenance contractor dangerous and undesirable situation could occur as has happened for the weir of Lith.

1.3.5 Costs
The approach for the cost of RINK is based the maintenance model represented in Figure 59. On the vertical axis are the reliability/risk levels of function losses represented. On the horizontal axis is the lifetime of the construction represented. The curves represent the condition of the construction parts. The numbers on the right side of the figure represent the different safety levels, the levels represent:

- Level 1: Loss of function
- Level 2: Intervention level to avoid loss of functions
- Level 3: Quality level of the original design

- Level 4: Quality level of the construction adapted to the "new risk"

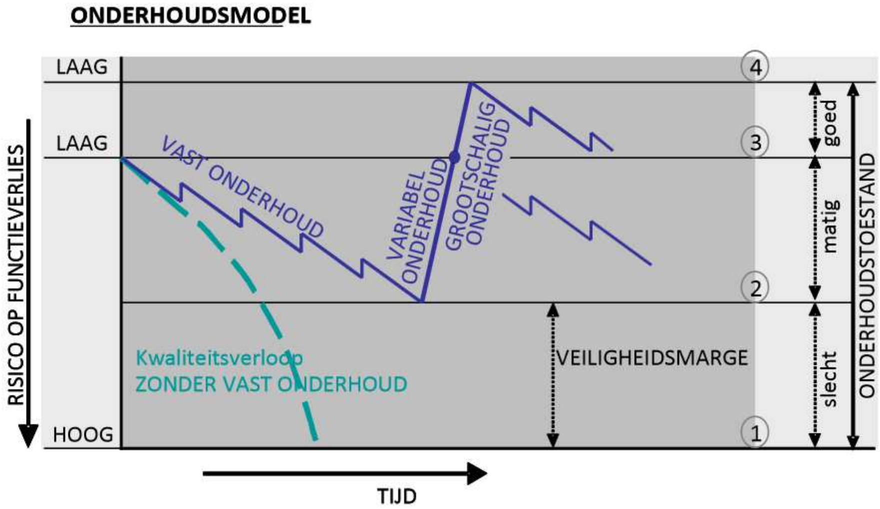


Figure 59 - Maintenace model (source: Rijkswaterstaat)

Per object are the costs of the management and maintenance scenarios determined for safety level 3 and 4. The costs are the sum of fixed and variable costs for a period of 20 years (2010 - 2030).

Table 38 - Cost estimation

Weir	Costs level 3	Costs level 4	Replacement	Remark
	M€			
Sambeek	7.6	70 - 100(1)	185 - 270	(1)costs of lifetime extended maintenance; 100 million when towers have to replaced.
Lith	26	50 - 65(1)	255 - 354	(1)costs of lifetime extended maintenance

1.3.6 Conclusion

- *Weir Sambeek*
  It is in fist instance advised to maintain and keep the weir operable for a period of 20 years. Based on the state of the weir after the 20 years will be decided what to do. Two possible situations are distinguished:
  - Maintaining the current weir for a certain time (safety level 3)
  - Replacing the movement installation of the Stoney part and replacing the whole Poirée part (safety level 4).
- *Weir Lith*
  It is advised to maintain the weir for the period until 2030, in 2025 will be decided what the strategy for longer terms should be. Three possible situations are distinguished:
  - Maintaining the current weir for a certain time (safety level 2 to 3)
  - Maintaining the current weir for a certain time + solve structural problems (safety level 3)
  - Replacing the gates and movement installation (safety level 4)

1.4 Weir Linne

In this part is analyzed if the total weir of Linne has to be renewed or that parts of the weir can be reused. The analysis is mainly focused on the fixed structure and the movable parts of the weir. Because a summary of the RINK report of weir Linne is not available at the time are the main aspects of weir Sambeek used. The weir of Linne is comparable with the weir of Sambeek, the similarity of both weirs are:

- Construction period
- End of lifetime
- Fall height
- Construction type, both contain a stone and Poirée part.

Based on the main aspects (not details) of the weir of Sambeek and found information of weir Linne is tried as good as possible to make a analysis of the state of weir Linne.

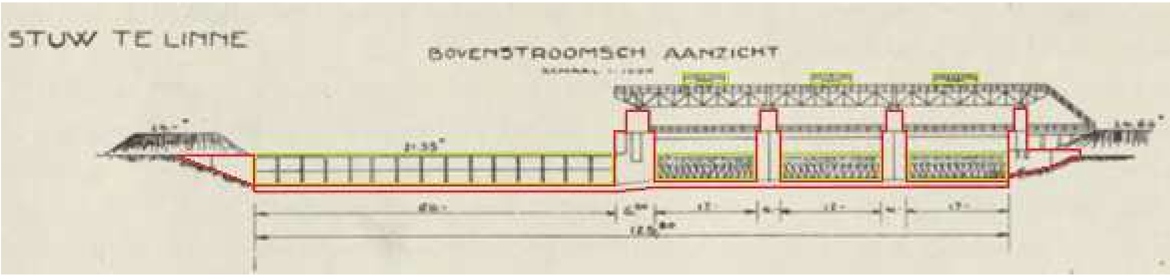


Table 39 - Weir Linne; red: concrete structure; yellow: gates

1.4.1.1 *Fixed structure*

The fixed structure of the weir of Linne consists of four discharge openings. Three openings with a width of 17 m and one opening of 60 m width. The fixed construction is made from concrete. The concrete constructions is made between 1918 and 1921. No clear design rules were present in these times. The result was a strong over-dimensioned construction. The available concrete in these times was of good quality what results in a robust fixed construction.

The concrete construction of the weir was in a bad state according to investigations in 1993. The construction was subjected concrete degradation, large cracks and corrosion of the reinforcement were the result. Mainly the state of the pillars of the Stoney part were in bad condition. Vegetation in the cracks increased the velocity of the degradation process (Rijkswaterstaat, Achtergebleven onderhoud natte infrastructuur rijk, 1993). In 1997 and 2007 were large reconstruction works done to the concrete construction. Due to the strong over-dimensioning of the weir and with sufficient maintenance could the weir probably also after 2035 fulfill its function.

1.4.1.2 *Movable parts*

- *Stoney part*

The foundation of the Stoney part does meet the requirements according to the SLS (service limit state) and ULS (ultimate limit state). The steel gates itself are able to fulfill its function. The lift installation is the main problem of the Stoney part. The unavailability of the weir is closely related to failure of the lift installation. With a sufficient maintenance plan and yearly inspections it should be possible to decrease the unavailability of the lifting installation.

- *Poirée part*

The foundation of the Poirée part does meet the requirements according to the SLS however not the requirements for the ULS. In the possible suggested future scenarios is a complete replacement of the Poirée part a essential part. Operation and management of the Poirée part is not safe in accordance with the ARBO (arbeidsomstandighedenwet) legislations. Two to three people have to have place or remove the partitions by hand with the aid of a small crane. The people should do the operation on top of the Poirée part during high discharges. For example, no railing is present on the Poirée pat otherwise the crane is not able to move over the top of the Poirée part. An impression of the situation is given in Figure 60. Up to now this situation is tolerated however it is expected that this situation will change in the future.

Figure 60 - Unsafe situation during operation of the Poirée part of weir Linne (source: youtube)

1.5 Conclusion

It is decided not to advise at the moment to replace the total weir of Linne at the moment. It is advised to monitor the weir until the period 2030 - 2035. Based on the robustness of the fixed construction . Besides it function is the weir an important high valuable architectural object and a landmark in middle Limburg. The architectural aspect is determined by the importance of the history of building technology, the esthetical qualities and the innovative use of materials. For example the weir is of importance due to the early and bare concrete construction in hydraulic engineering. The weir has also an important cultural and historical value and is determined by the technological development of hydraulic engineering in the Netherlands.

The part of the weir that is most problematic and advised to replace are the gates of the Poirée part. The operability of the weir part is old fashioned and unsafe. Old fashioned because the weir part should be places or removed by hand while central control is more beneficial. For the weirs with the Poirée parts always two to three people should be standby to handle the weir. These people should be quickly on the weir location because water levels of the Meuse can rise very quickly and some time is necessary to remove the Poirée part. In the current situation are the locks and Stoney parts of weirs of the Meuse centrally controlled form the central control station in Maasbracht. Only the Poirée parts of the weirs of Linne, Roermond, Belfeld and Sambeek are manually operated.

A second important aspect are the unsafe work conditions on the Poirée weir. The unsafe work conditions are not meeting the requirements of the ARBO legislation. The unsafe conditions are tolerated in the current situation. Because it is expected that in the future the unsafe conditions will not be tolerated. It is questionable if the construction is enough valuable to adapt to the ARBO legislation because the undesirable operational conditions are not changed.

A new gate type should be centrally controlled and meet the requirements according to the ARBO legislation.

Appendix I: Determination gate type

1 Gate type determination

In this appendix is the type of closing element for the current Poirée part investigated. The different types of closing elements are represented in Appendix A. The selection is done in three steps. In the first step are the main properties of a closing element investigated and is the importance of the certain properties determined. Closing elements that not met the required properties are dropped out of the selection. In the second step are the remaining closing elements compared to important performance aspects like maintainability, material usage and safety. The three most preferable closing elements are taken to the third step. The third step contains the MCA analysis and is the final type of closing element determined. The closing elements that are considered are:

- Sector gate
- Inflatable construction
- Flap gate
- Radial gate
- Roller gates
- Poirée segments
- Visor gate
- Lifting gates (Sliding gates, Wheel gates or Stoney gates

1.1 Step 1 - Basic properties of a closing element

The superstructure of the weir is formed by movable closing elements. To obtain a right selection of the closing element first the properties of a closing element are discussed. The closing element has three main properties that has to be considerate, the properties are:

- Retaining water
  The aspects that are important for the retaining water functions are:
  - The direction of the load transport
    - upward
    - downward
    - sideward
  - Behavior of the closing element
    - stiff
    - flexible
- Movability
  The main aspects of movability are:
  - Direction
    - translation in y-direction or z-direction
    - rotation around the x-axis, y-axis or z-axis
    - combination
- Number of elements
  - Single element
  - Multiple elements in y-direction
  - Multiple elements in z-direction
- Managing of water discharge
  - Overflow
    - Water level regulation
    - Discharge of floating material
  - Underflow

- Discharge regulation
- Sediment transport

The first inventory of the closing element is made by means of the four mentioned properties. In Table 40 are the most preferable properties represented. For every aspect the most perferable property and the importance of the property appointed.

Table 40 - Properties of the gate type

Retaining water	Preferable	Importance	Remark
• Direction load transport	downward / sideward*	middle	*Upward is possible however lifting towers should be placed
• Behavior of closing element	stiff	low	
Movability			
• Direction	translation in y-direction / rotation around the y-axis	middle	
Number of elements	single element*	high	*More elements are possible however extra columns are necessary.
Managing of water discharge	Overflow*	high	*An underflow can be obtained by lifting the lower Stoney gate.

All of the selected closing elements meet the preferable properties for the new closing element. All the elements are going to the second step. According to

1.2 Step 2 - Performance aspects of a closing element

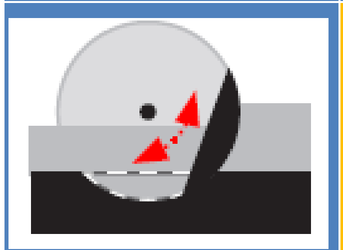
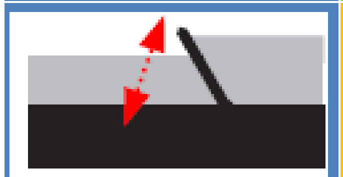
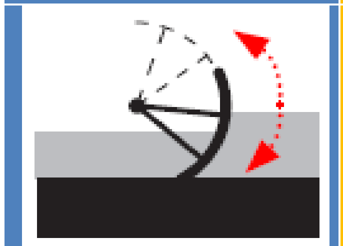
The performance aspects are important in the choice of a suitable closing element. The general properties of the selected closing elements (van der Ziel & Dijk, 2009) are tested to the requirements for the new closing element. The aspects are represented in Table 41. If the closing element meets the requirements for the weir of Linne is the aspect green marked. If adoptions to the closing element or weir constructions are needed, the aspect is orange marked (for example an extra column if the required width could not be obtained). If the aspect does not meet the requirements, the aspect is marked red. The three most preferable The performance aspects that are used to compare the closing elements are:

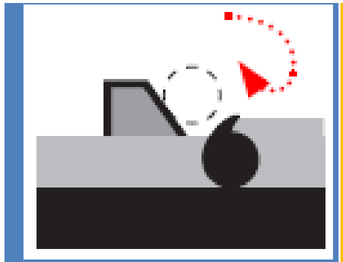
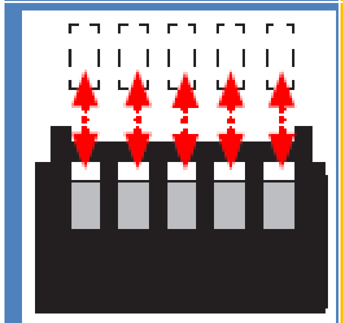
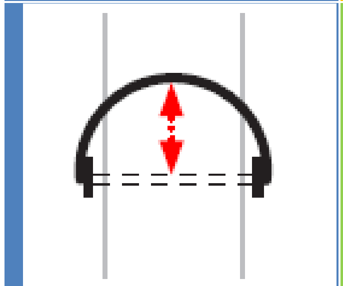
- Maximum width
- Maximum height
- Maximum retaining height
- Modular expandable
- Controlling of the water level
- Material usage
- Probability of failure
- Maintenance

An inflatable construction as represented in Table 42 seems a preferable option. However, it is not possible to use this kind of inflatable construction as river weir. The inflatable construction is mainly used as barrier. An inflatable construction in combined with flap gate is on the other hand a suitable as river weir. In Table 41 are the property values and tested to the requirements for the closing element of weir Linne.

The three most preferable closing elements according to Table 41 and Table 42 are:

- Radial gate
- Lifting gate
- Inflatable flap gate

Gate type	Maximum width	Maximum height	Maximum retaining height	Modular expandable	2 Sides retaining	Controlled water level	Navigational obstruction	Material usage	Probability of failure	Maintainance	visibility
	m			yes / possibly / no			high / middle / low				
 Sector gate	15 - 40	8	2	yes	possibly	no	low	high	high	high	middle
 Inflatable gate	20 - 120	10	6	yes	yes	no	low	low	middle	low	middle
 Flap gate	2 - 6 (singe flap)	8	2	yes	no	possibly	low	middle	middle	high	middle
 Radial gate	20 - 40	8	6	yes	no	yes	high	middle	low	middle	high

 Roller gate	10 - 50	5	2	yes	no	yes	high	high	middle	high	high
 Poirée segments	1 - 4 (without jokes)	6	4	yes	yes	yes	middle	high	middle	high	high
 Visor gate (horizontal axis)	15 - 65	10	4	yes	possibly	yes	middle	low	low	middle	high

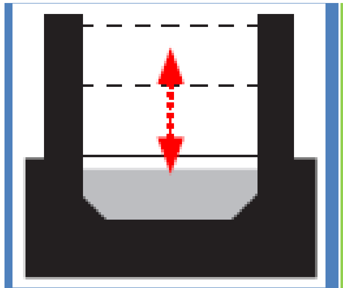
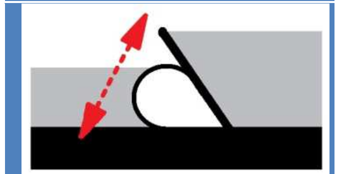
 Lifting gate	10 - 60	12	4	yes	yes	yes	middle	high	middle	middle	high

Table 41 - Performance aspects of the weir gate

Table 42 - Inflatable flap gate

Gate type	Maximum width	Maximum height	Maximum retaining height	Modular expanable	2 Sides retaining	Controlled water level	Navigational obstruction	Material usage	Probability of failure	Maintainance	visibility
	m			yes / possibly / no			high / middle / low				
 Inflatable flap gate	20 - 120	8	6	yes	no	yes (not accurate)	low	middle	middle	high	middle

1.3 Step 3 - Multi criteria analysis

MCA analysis is made for the three remaining gates. The aspects that are taken into account are:

- *Safety*
  The construction should be safe, the probability of failure should be low. Failure of the weir results in an obstruction for navigational traffic.
- *Adaptability*
  The height construction should be adaptable. If in the future larger vessels are required on the Meuse should the construction be adaptable to obtain a higher water level in the canal section.
- *Maintenance*
  Less maintenance has a positive effect on the choice of gate type. The maintenance aspect focuses on the construction instead of the materials. For example, maintenance becomes more difficult when important parts of the construction are under water.
- *Construction time*
  Construction time is an important aspect. The gate (or parts of the gate) should be placed between two high discharge periods. Periods of high discharges are between December and February.

Table 43 - Weight factors

	Safety	Adaptability	Maintenance	Construction time	Discharge regulation	Total	Weight factor
Safety		1	1	1	1	4	0.4
Adaptability	0		0	1	0	1	0.1
Maintenace	0	1		1	1	3	0.3
Construction time	0	0	0		1	1	0.1
Discharge regulation	0	1	0	0		1	0.1
						10	1.0

Table 44 - MCA table

Aspects	Weight factor	Radial gate	Lifting gate	Inflatable flap gate
Safety	0.4	2	1	3
Adaptability	0.1	1	2	3
Maintenace	0.3	2	3	1
Construction time	0.1	2	1	3
Discharge regulation	0.1	1	3	2
Score excl. factor		8	10	12
Score incl. factor		1.8	1.9	2.3

Appendix J: Weir dimenions

1 Weir dimensions

In this appendix is analyzed if the width of the current weir is sufficient for the required discharge over the weir. The required discharge over the weir must at least be 1200 m^3/s. It is important to investigate if the discharge capacity of the current weir construction is sufficient. If the discharge capacity does not meet the requirements is a total new construction or large adoptions necessary. For a sufficient capacity is also the possibility of renovation of the current construction an option.

In the analysis are the widths of the Stoney discharge openings kept constant and the width of the Poirée part is made variable. If adoptions are necessary is the best option to adapt the Poirée part because the Poirée part is the most problematic part of the weir.

1.1 Discharge type

The type of discharge is an important property of a weir. Weirs are divided into two discharge types namely:

- *Overflow*

The overflowing type discharges water over the crest of the closing element. The overflowing type is used for water level regulation and discharge of floating material. Two types of overflow discharges are known namely:

  - Tail controlled weir flow (imperfect weir)
  - Structure controlled weir flow (perfect weir)

The flow types are represented in Figure 61. At the structure controlled weir flow is the upstream water level independent from the downstream water level. At the tail controlled weir flow is the water level upstream of the weir controlled by the water level downstream.

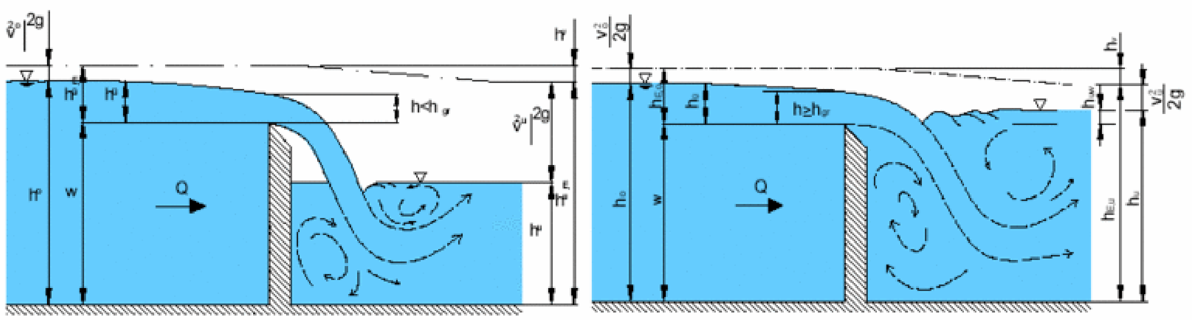


Figure 61 - Overflow discharge; Left: perfect weir ; Right: imperfect weir (source: Flood manager E learning)

- *Underflow*

The underflowing type discharges water underneath the closing element. The under flowing types is used for the purposes of discharge regulation and sediment transport. Two types of underflow discharges are known namely:

  - Submerged weir flow
  - Free weir flow

The submerged weir flow is comparable to the tail controlled weir flow, the water level upstream of the weir is influenced by the downstream water level. The free weir flow is comparable with the structure controlled weir flow, the upstream water level is independent from the donwstream water. level

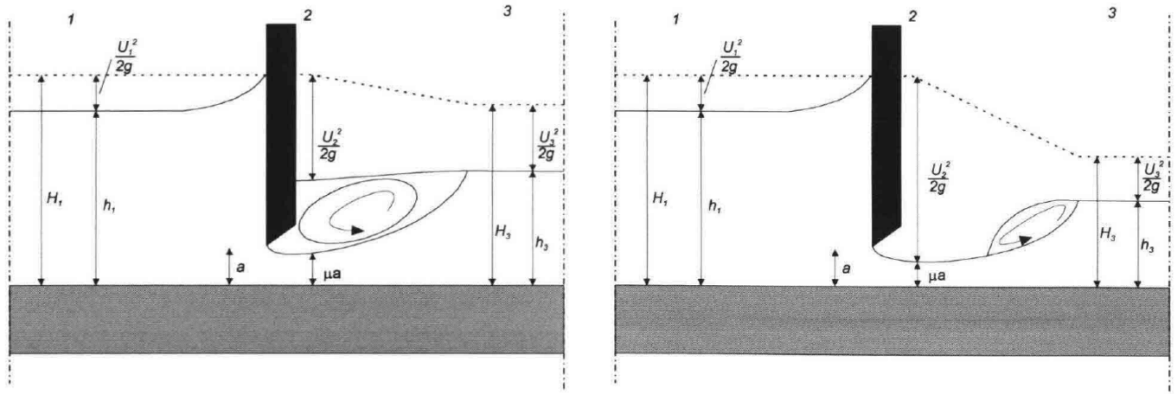


Figure 62 - Underflow discharge; Left: submerged weir flow; Right: free weir flow (source: Inleiding waterbouw, TU Delft)

The most important function of the weir of Linne is controlling the water level. Because the Stoney gates are able to create an underflow for sediment transport or discharge regulation is chosen to execute the former Poirée part as an overflow weir. The two types of overflow patterns are modeled to obtain insight about the required width of the weir.

1.2 Central aspects

1.2.1 Water level

The water level on the upstream side of the weir is varying for changing discharges. The water level rise due to increasing discharge is simple modeled as a linear increasing. The values of water level according the "Betrekkingslijnen 1991.0" are used (Rijkswaterstaat). Because the water levels upstream of the weir of Linne are not available are the water levels upstream of lock Heel used.

1.2.1.1 *Upstream water level*

Description	Symbol	Value	Unity
Upstream water level +NAP (for Q = 230 m^3/s)	$h_{up,230}$	20.80	m
Upstream water level +NAP (for Q = 1200 m^3/s)	$h_{up,1200}$	21.00	m
Upstream water level +NAP (for Q = 1450 m^3/s)	$h_{up,1450}$	21.30	m
Progress upstream water level	h_{up}	Variable	m
Downstream water level +NAP (for Q = 230 m^3/s)	$h_{down,230}$	16.85	m
Downstream water level +NAP (for Q = 1200 m^3/s)	$h_{down,1200}$	18.60	m
Downstream water level +NAP (for Q = 1450 m^3/s)	$h_{down,1450}$	19.05	m
Progress downstream water level	h_{down}	Variable	m

The middle equation represents the water level change upstream of the weir for discharges between 230 and 1200 m^3/s. This range contains the total opening or closing operation of the weir. (for discharges higher than 1200 m^3/s is the current weir fully opened). The lower equation represents discharges larger than 1200 m^3/s.

$$h_{up,1} = 20.8$$

$$h_{up,2} = h_{up,230} + \left(\frac{h_{up,1200} - h_{up,230}}{1200 - 230}\right) * (Q - 230)$$

$$h_{up,3} = h_{up,230} + \left(\frac{h_{up,1200} - h_{up,230}}{1200 - 230}\right) * (1200 - 230) + \left(\frac{h_{up,1450} - h_{up,1200}}{1200 - 230}\right) * (Q - 1200)$$

In the model is the used upstream water level represented as h_{up} and is:.

$$h_{up} = \begin{cases} h_{up,1}, & 0 \le Q \le 230 \\ h_{up,2}, & 230 \le Q \le 1200 \\ h_{up,3}, & Q > 1200 \end{cases}$$

1.2.2 Gate width

Table 45 - Width of the weir parts

Description	Symbol	Value	Unity
Width Stoney gates	B_{Stoney}	3 x 17	m
Width Poirée part	$B_{Poirée}$	Variable	m
Discharge width	B	Variable	m

The gate width is influenced by the discharge over the weir. At discharges lower than 500 m^3/s is water not discharges by the weir but by the hydroelectric station. For discharges to 800 m^3/s is 500 m^3/s discharges by the hydroelectric station and the rest by the Stoney part. Discharges higher than 800 m^3/s are discharged by the Stoney and the Poirée part, the hydroelectric station is closed. The varying widths are represented in the quation below. The width of the Poirée weir is taken variable in the model to check if the width is sufficient or should be larger/smaller.

$$B = \begin{cases} B_{Stoney} & 500 \le Q \le 800 \\ B_{Stoney} + B_{Poirée} & Q > 800 \end{cases}$$

It has to be noticed that in reality in the range $500 \le Q \le 800$ partition from the Poirée part are removed. However to simplify the model is chosen to model the opening of the Poirée part after the closure of the hydroelectric station.

1.2.3 Discharge coefficient

Table 46 - Values to determine the discharge coefficient

Description	Symbol	Value	Unity
Coefficient (relation between effective width of the discharge opening and river width)	C	Variable	-
Crest height of the weir gates	h_{cr}	Variable	m
Gravitational constant	g	9.81	m/s^2
Discharge coefficient (perfect weir)	m_{pw}	variable	-
Discharge coefficient (imperfect weir)	m_{iw}	variable	-

A simple formulation of a discharge coefficient for sharp crested weirs presented in the expressions below.

$$m = 0.611 + C * \frac{(h_{up} - h_{cr})}{(h_{cr} - h_{bottom})}$$

The discharge coefficient varies with the ratio H/W and has a value of 0.611 when W is large. The factor C (=f(B_e/B)) is the relation between the width of the effective discharge opening and the width of the river in front of the weir. For unknown situations is usually a factor C = 0.08 used. In 1979 is by means of a calibration the discharge coefficient for the weir of Linne determined. For the removal of several partitions is the discharge coefficient is determined. For a closed weir holds that the discharge coefficient m = 0.611 (up to Q = 800 m^3/s) and for a total opened weir m = 0.685 (at 1200 m^3/s = totally opened weir).

The coefficients of perfect and imperfect weirs are different. An expression that relates both coefficients to each other is obtained by Nortier. The expression is presented below.

$$m_{pw} = \frac{2}{3} * \sqrt{\frac{2}{3} * g} * m_{pi}$$

1.2.4 Imperfect weir (onvolkomen overlaat)

Table 47 - Table 47 - Values to determine the imperfect weir flow pattern

Description	Symbol	Value	Unity
Flow velocity imperfect weir	u_{iw}	Variable	m/s
Wet cross section of the weir	A	Variable	m/s
Crest height of the weir gates	h_{cr}	Variable	m
Discharge	Q	variable	m/s^3
Width of the Meuse upstream of the weir	B_{Meuse}	140	m
Bottom gradient	i_b	0.0005	‰
Chezy coefficient (based on Manning coefficient for gravel n_{gravel} = 0.029)	C	45.17	$m^{1/2}/s$

The flow velocity for an imperfect weir is presented by the first equation below and the cross wet section is presented by the second equation.

$$u_{iw} = \sqrt{2 * g * \left(h_{up} - h_{down}\right)}$$

$$A = B * (h_{down} - h_{cr})$$

The discharge over a weir is obtained by combining the two equations above and introducing the discharge coefficient. The equation of the imperfect weir is presented below.

$$Q = m_{iw} * (h_{down} - h_{cr}) * B * \sqrt{2 * g * \left(h_{up} - h_{down}\right)}$$

The parameter to be solved is the height of the crest h_{cr} for a changing discharge of the Meuse. The expression for the crest height of an imperfect weir is obtained by rewriting the equation above. The result is expressed in the equation below.

$$h_{cr} = h_{down} - \left(\frac{Q}{m_{iw} * B * \sqrt{2 * g * (h_{up} - h_{down})}}\right)$$

The downstream water level is represented by equation:

$$h_{down} = \left(\frac{Q^2}{B_{Meuse}^2 * C^2 * i_b}\right)^{1/3}$$

1.2.5 Perfect weir (volkomen overlaat)

Table 48 - Values to determine the perfect weir flow pattern

Description	Symbol	Value	Unity
Flow velocity perfect weir	u_{pw}	Variable	m/s
Wet cross section of the weir	A	Variable	m/s
Crest height of the weir gates	h_{cr}	Variable	m
Gravitational constant	g	9.81	m/s^2

The flow velocity for a perfect weir is given by the first equation below and the expression for the cross sectional area is represented in second equation.

$$u_{pw} = \sqrt{2 * g * (h_{up} - h_{cr})}$$

$$A = B * (h_{up} - h_{cr})$$

The discharge of the perfect weir is obtained by combining the two equations above and introducing a discharge coefficient. The expression for the discharge is represented in the equation below.

$$Q = m_{pw} * (h_{up} - h_{cr}) * B * \sqrt{2 * g * (h_{up} - h_{cr})}$$

By introducing the discharge coefficient presented in section 1..2.3 in the equation above is a discharge expression for a perfect weir created containing an discharge coefficient of an imperfect weir. The expression is presented in the equation below.

$$Q = m_{iw} * \frac{2}{3} * (h_{up} - h_{cr}) * B * \sqrt{\frac{2}{3} * g * (h_{up} - h_{cr})}$$

The parameter to be solved is the height of the crest h_{cr} for a changing discharge of the Meuse. The expression for the crest height of an imperfect weir is obtained by rewriting the equation above. The result is expressed in below.

$$h_{cr} = h_{up} - \left(\frac{Q}{m_{iw} * B * \frac{2}{3} * \sqrt{\frac{2}{3} * g}} \right)^{2/3}$$

1.2.6 Opened

$$H_{up} = H_{cr}$$

$$H = h + \frac{u^2}{2 * g}$$

$$Q = Q_{up} = Q_{cr}$$

$$Q_{up} = B_{up} * h_{up} * u_{up}$$

$$Q_2 = B * h_{cr} * u_{cr}$$

$$h_{up} + \frac{u_{up}^2}{2 * g} = h_{cr} + \frac{u_{cr}^2}{2 * g}$$

$$h_1 + \frac{Q^2}{B_{up}^2 * h_{up}^2 * 2 * g} = \frac{Q}{B * u_{cr}} + \frac{u_{cr}^2}{2 * g}$$

Transition between a perfect and imperfect weir

There exist a transition point between the perfect and imperfect weir situation. At closed situation dominates the perfect weir situation. A perfect weir situation becomes an imperfect weir situation when the downstream water level influences the flow over the weir or in other words the upstream water level. The transition point is represented by the equation below.

$$h_{down} = \frac{1}{3} * (2 * h_{up} - h_{cr})$$

It has to be investigated whether the discharge equations and the crest height equations for a perfect and imperfect weir flow are differentiable. The equations are differentiable when the graphs intersect at the same angle so that a continuous transition from perfect to imperfect weir is created. Two models are used to investigate the differentiability of the functions for discharge and crest height.

1.2.6.1 *Verification of discharge equation*

The upstream water level (set at 3.95 m above crest level) and the crest height (set at 0 m above crest level) are set as constants for the models. The downstream water levels differ from 0 to 3.95 m measured from the crest level. The graph of the perfect weir is represented as a straight line because the downstream water level does not influence the upstream water level. In Figure 63 represents three situations, namely discharge over:

- only the Stoney part
- only over the Poirée part
- Stoney and Poirée part

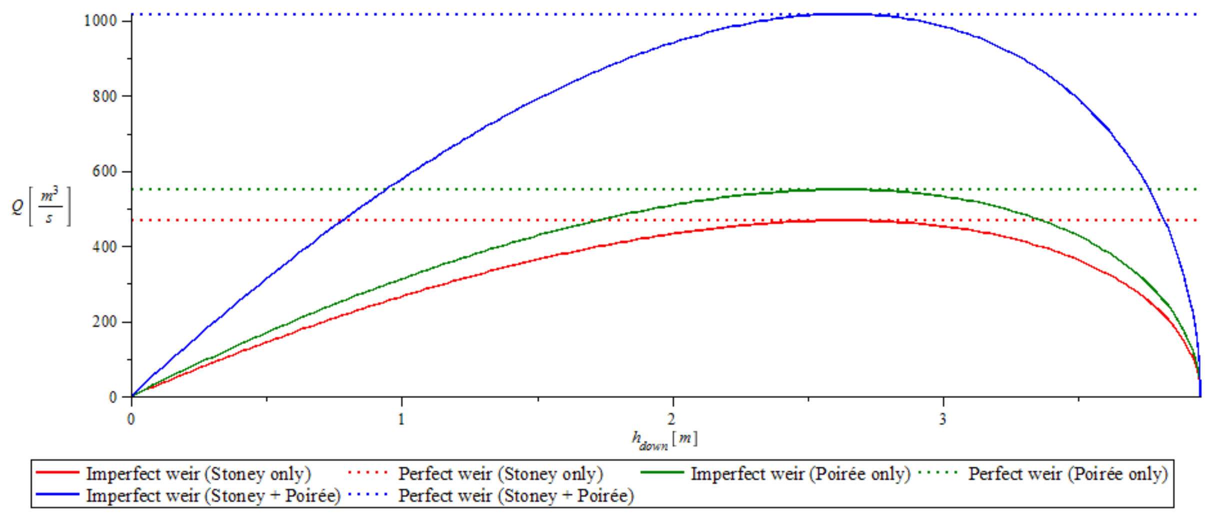


Figure 63 - Verrification of the discharge equations

It can be seen that for every situation the lines for imperfect and perfect weir intersect under the same angle. It can also be seen that for a downstream water level of 2.63 m exist a transition point for the transition from perfect to imperfect weir. The intersection point corresponds with a certain discharge. The corresponding discharges are:

- Only the Stoney part: 468 m^3/s
- Only the Poirée part: 550 m^3/s
- Stoney + Poirée part: 1018 m^3/s

The discharge of the opened Stoney and Poirée part corresponds with the weir management in the current situation. In the current situation should the Poirée part be completely opened for a discharge of more than 1200 m^3/s.

1.2.6.2 *Verification of crest height equation*

The upstream water level (set at 3.95 m above crest level) and the discharge are set as constants for the models. The downstream water levels differ from 0 to 3.95 m measured from the crest level. The discharges are set at:

- Only the Stoney part: 200 m^3/s
- Stoney + Poirée part: 1200 m^3/s

The result is presented in Figure 64. The lines of the perfect weir are represented as a straight lines because the downstream water level does not influence the upstream water level. It can be seen that also for the crest height equations the angles are equal in the transition point.

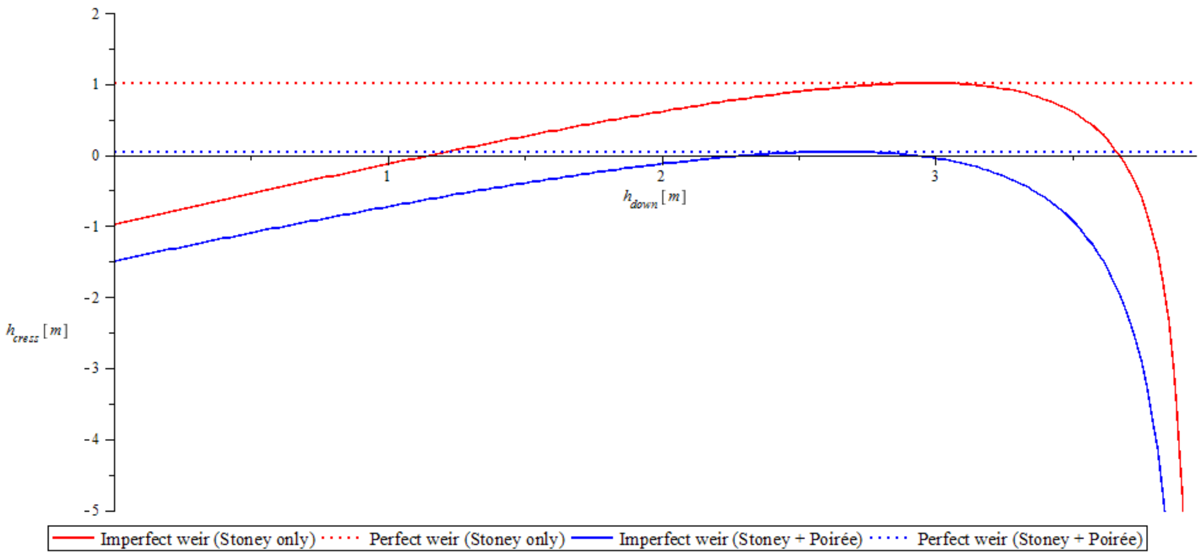


Figure 64 - Verification of the crest height

It has to be mentioned that the crest height of the combined Stoney Poirée part is the theoretical crest height. The real crest height has a stepped configuration due to the partition of the Poirée part. The theoretical crest height should be interpreted as average crest height of the Stoney and the Poirée part.

1.3 Result of the hydraulic model of a the current weir (with overflow)

Table 49 - Values to determine the flow pattern over the weir

Description	Symbol	Value	Unity
Gravitational constant	g	9.81	m/s^2
Upstream water level (Q = 1200 m^3/s)	h_{up}	21.00	m
Width of the Meuse upstream of the weir	B_{Meuse}	140	m
Bottom gradient	i_b	0.0005	‰
Chezy coefficient (based on Manning coefficient for gravel n_{gravel} = 0.029)	C	45.17	$m^{1/2}/s$
Weir width	B	111	m

The theoretical crest levels for a perfect an imperfect weir flow pattern as function of the discharge for a 111 m wide weir (51 m of the Stoney part and 60 m of the Poirée part) are presented in Figure 65. The water level for 1200 m^3/s is at 21.00 m +NAP and the crest height of the weir is at 15.95 m +NAP. For discharges lower than 500 m^3/s is the water discharges by the hydroelectric station. Because the discharge by the station influences the downstream water level as well, is the hydroelectric station not separately represented in the model. The flow pattern for the current weir changes from perfect to imperfect for discharges higher than 858 m^3/s.

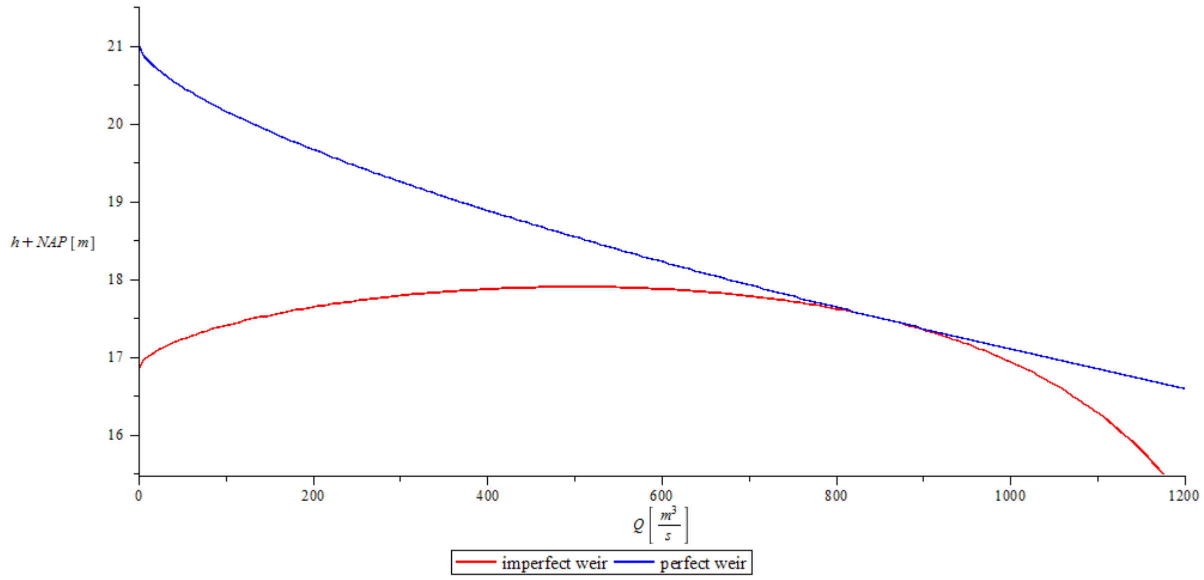


Figure 65 Crest height a perfect and imperfect weir

In Figure 66 is the theoretical position of the weir crest represented, the graph is a combination of the imperfect and perfect flow pattern from Figure 65. The capacity of the weir decreases quick after the transition discharge of 858m^3/s. The quick decrease of capacity is the result of a lower discharge capacity of a imperfect weir flow and the decreasing of water head over the weir caused by changing water levels up- and downstream of the weir. The result is a rising water level upstream of the weir. This corresponds with increasing water levels in canal section Linne during high discharges. The position of the crest of the gate is in theory lower than in reality with respect to the bed level for discharges before opening.

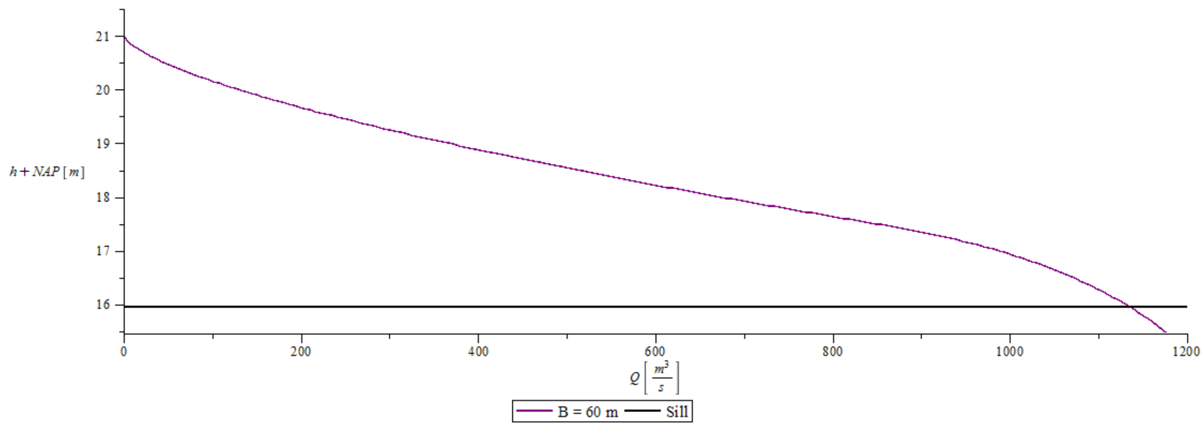


Figure 66 - Crest height of the weir

It is remarkable that according to Figure 66 the weir is opened but the required at discharge of 1200 m^3/s cannot be obtained. This can be explained by analyzing the downstream boundary, the water level of canal section Roermond. The downstream water level rise is modeled for a waterway with a constant width. However, canal section Roermond contains just like canal section Linne several lakes. These lakes have a damping effect on the water level of canal section Roermond. The real water level rise will become smaller than the modeled water level. The downstream water level is modeled according to the equation below. For a larger storage capacity of the water level will the water level rise become smaller and results in a higher transition point between perfect and imperfect.

$$h_{down} = \left(\frac{Q^2}{B_{Meuse}^2 * C^2 * i_b}\right)^{1/3}$$

1.4 Discharge capacity new situation

The flow characteristics for other widths of the Poirée are determined in order to investigate the effects of changing widths of the Poirée part. The characteristics are represented inFigure 67, also the sill of the weir is represented in the graph. Widths from 10 to 80 m are used in steps of 10 m. The discharge capacity is usually between 0.7 and 1.4. For a new weir a discharge coefficient of 0.8 is used instead of 0.685 for the current weir (including Poirée part).

In Figure 67 can be seen that for larger widths the discharge capacity increases. However the larger the width, the smaller the increase of capacity. It can also be seen that the width of the Poirée part can be decreased to 50 m. A weir of 101 m is able to discharge 1200 m^3/s. The advantage is that a extra pillar on the Poirée part could be possible. This could be necessary if the new gate type is not able to span more than 50 m. A disadvantage is the quicker raise of water level in canal section Linne during high discharges.

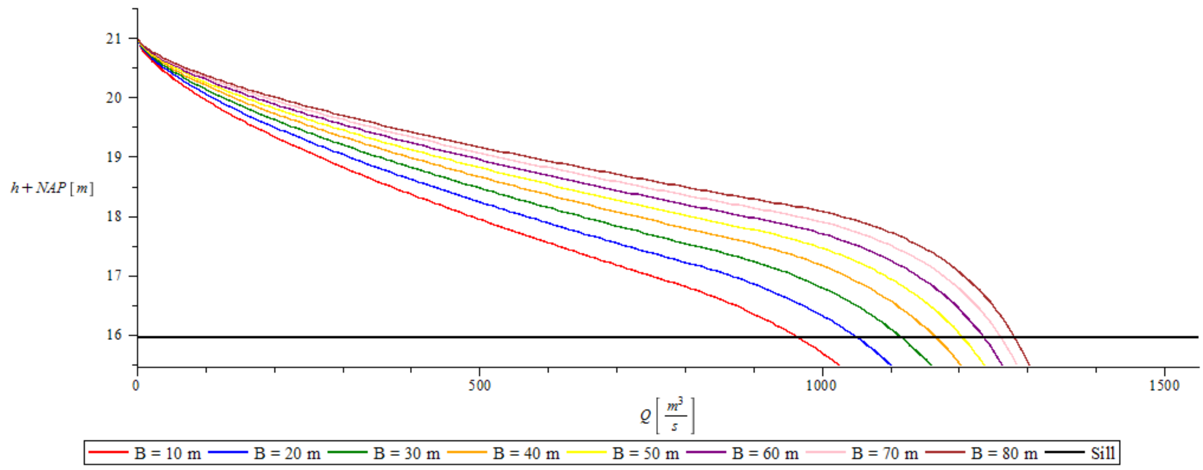


Figure 67 - Crest height for different weir widths

For higher discharges in the future a larger discharge capacity could be required. Several options are possible. A possible solution could be raising the water level in canal section Linne, a larger water head over the weir means a higher discharge capacity. Other possibilities are: a larger weir width, larger downstream storage capacity or a larger bottom gradient downstream.

The water level on the upstream side (canal section Linne) is raised from 21.00 m +NAP (1200 m^3/s) to 21.30 m + NAP (height of the spillway). The result is represented in Figure 68. It can be seen that the raise of the upstream water level has a substantial effect on the discharge capacity. By raising the upstream water level by 0.5 m is the discharge capacity raised by more than 100 m^3/s. The discharge could aslo be increased by a larger width of the weir, larger storing capacity downstream and larger bottom gradient downstream.

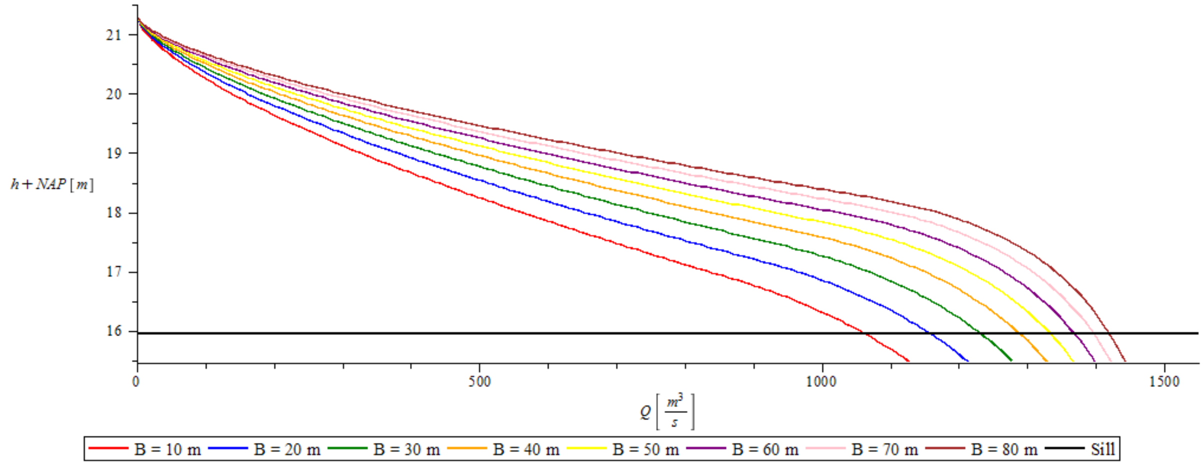


Figure 68 - Crest height for different weir widths (changed upstream water level)

H = 21.3

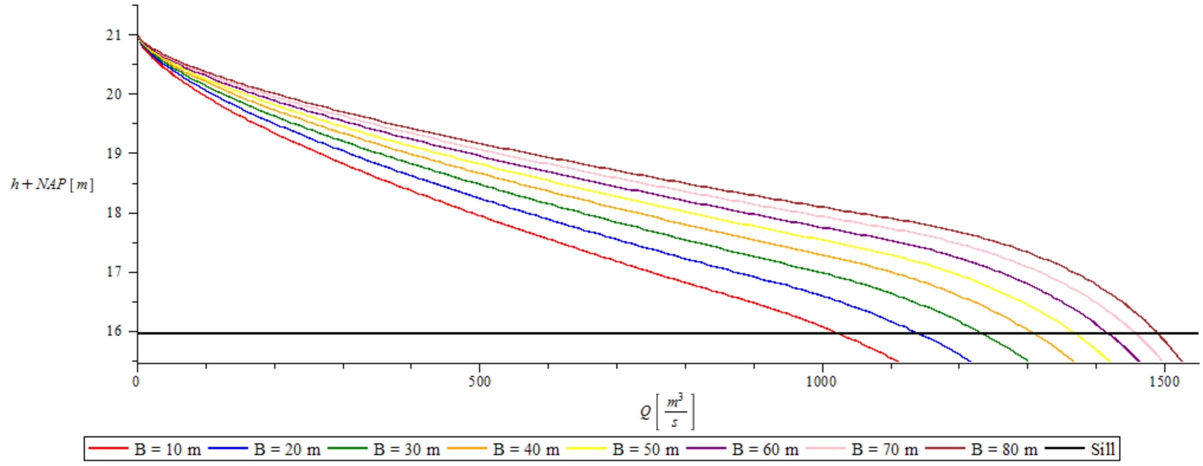


Figure 69 - Crest height for different weir widths (changed width of the Meuse)

B=170

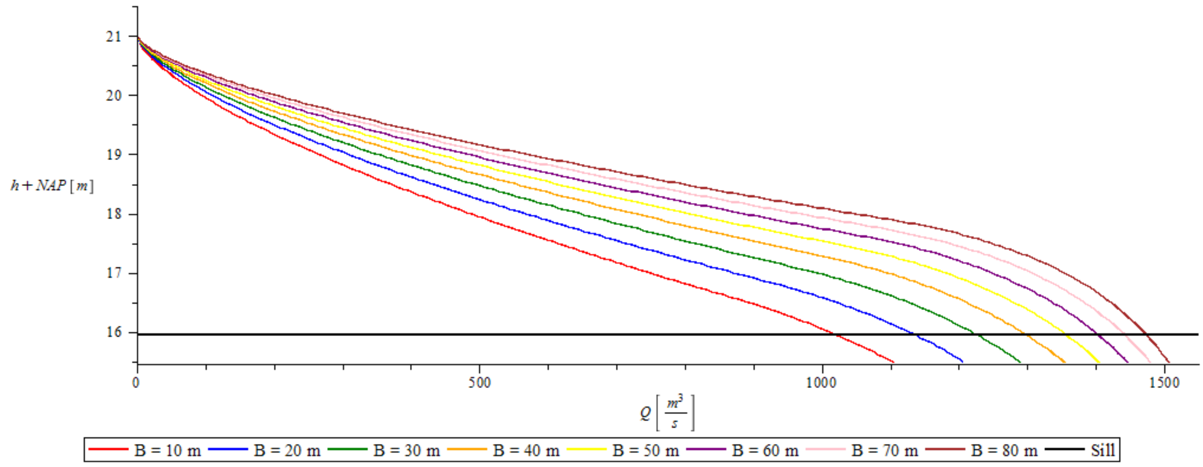


Figure 70 - Crest height for different weir widths (changed bottom gradient downstream)

i = 1e-3

1.5 Flow velocities

Changes of the width of the Poirée part have effect on the flow velocity behind the weir. Increasing flow velocities have effect on the stability of the bottom protection downstream of the weir. The bottom protection is able to withstand velocities of 2.5 to 3 m/s (Wijbenga, Viera da Silva, & Termes, 2010). Larger flow velocities result in damage to the bottom protection and consequently in instability of the weir construction. The flow velocities of different widths are presented in Figure 71. It can be concluded based on the graph that the with Poirée part should be 50 m or more. Smaller widths result in too high flow velocities.

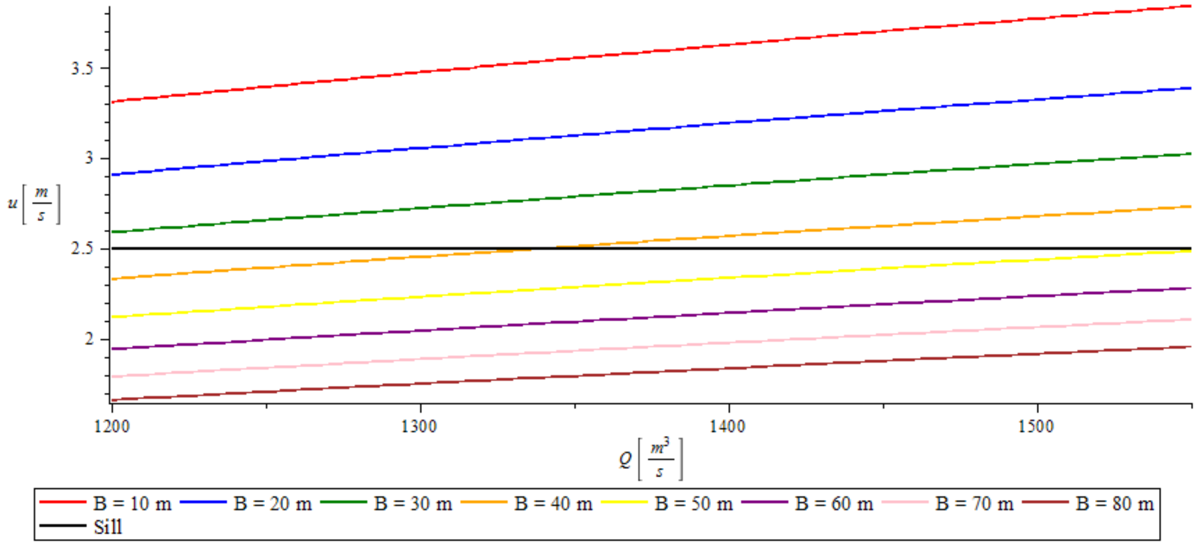


Figure 71 - Flow velocities behind the weir for differen weir widths

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