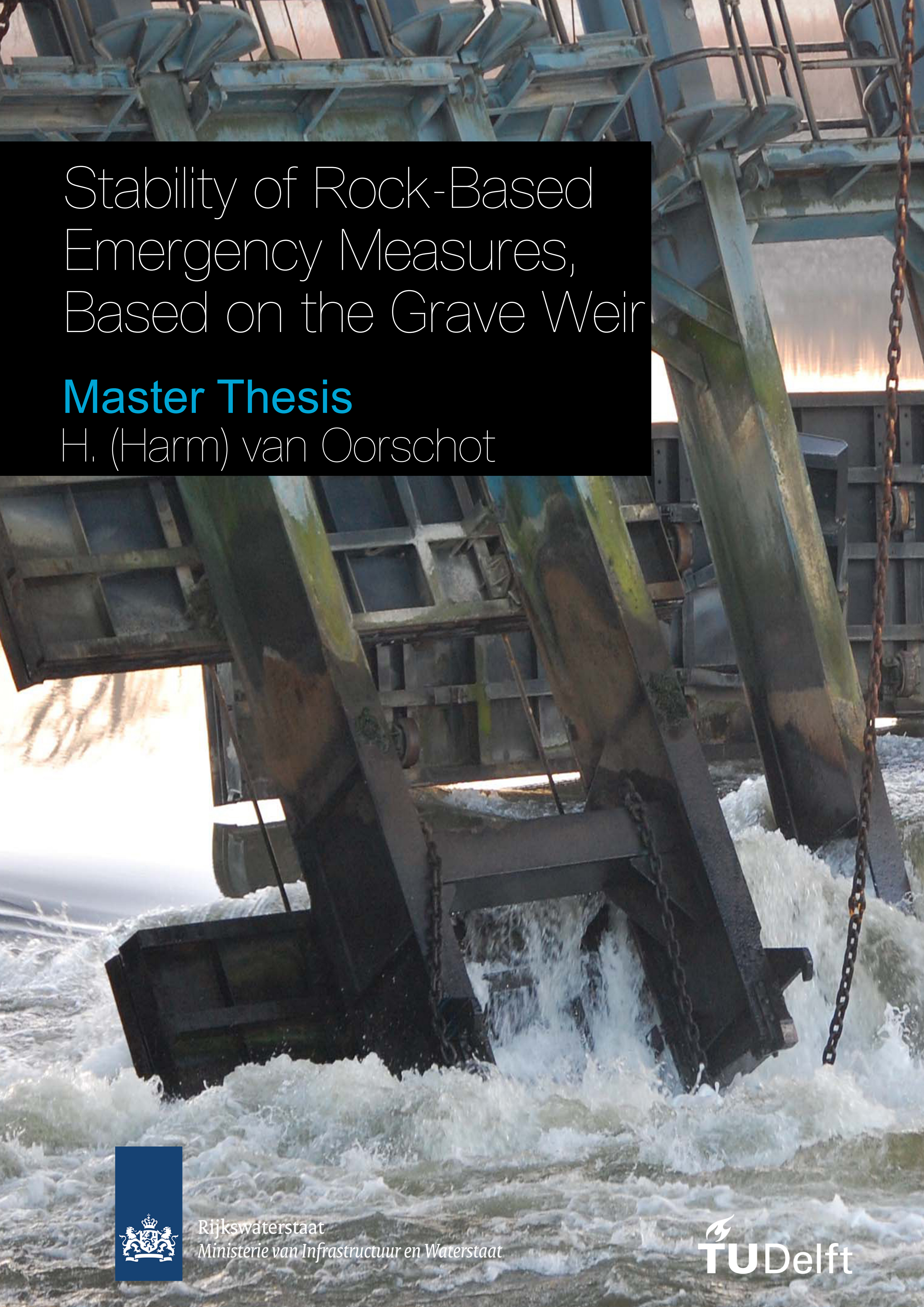

Stability of Rock-Based Emergency Measures, Based on the Grave Weir

Master Thesis

H. (Harm) van Oorschot

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

TU Delft

Stability of rock-based emergency measures based on the Grave Weir calamity

Master Thesis

by

H. (Harm) van Oorschot

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Thesis committee:	Prof. dr. ir. S.N. Jonkman,	TU Delft, Chair of the committee
	Dr. ir. B. Hofland,	TU Delft
	Ir. G. Smith,	TU Delft
	Ir. W.C.D. Kortlever,	Rijkswaterstaat

An electronic version of this thesis is available at http://repository.tudelft.nl/.

Delft University of Technology

Rijkswaterstaat
Ministerie van Verkeer en Waterstaat

Coverphoto: Damage at the Grave Weir after the ship collision. Photo retrieved from http://beeldbank.rws.nl, Rijkswaterstaat

Preface

In front of you lies the result of my Master Thesis, which I have conducted at Rijkswaterstaat. With this Master thesis, I will fulfill my degree of Master of Science in Civil Engineering. After a false start at the Bachelor Civil Engineering at the Delft University in 2009, I decided to study Civil Engineering at the university of applied sciences. After obtaining my HBO diploma I decided to continue my study and went back to the TU Delft for my Master's degree. I have never regretted this choice and I am proud of my final result. Therefore I would like to thank all who have contributed to this Master thesis.

First, I would like to thank Wim Kortlever and Bas Hofland. Thank you for your advice, guidance and support during my Master's theses. It is great to see your expertise and how you can communicate this with so much enthusiasm. I also want to thank Bas Jonkman and Greg Smith. Although we spoke less, I am very grateful for your useful feedback and critical attitude towards my work.

Finally, I would like to thank my family, especially my parents for their support during this thesis, but also for their support during my entire student life. Last but not least, I would like to thank my girlfriend Marloes. Your unconditional support and encouragement helped me through the whole Master thesis project.

H. (Harm) van Oorschot
Delft, August 2018

Abstract

On the 29th of December 2016 a large Rhine ship loaded with 2000 ton benzene sailed through the weir at Grave, located in the river Meuse in the Netherlands. The accident created a large gap in the weir and within 12 hours the upstream water level decreased by a maximum of 3 meters. Due to this decreased water level shipping was limited, houseboats were skewed and there was a risk of instability of the river banks and upstream weirs.

Several alternative measures were considered to close the damaged part of the weir in order to reinstate the upstream water level, and make it possible to repair the weir. Finally it was decided to build a rock-fill dam behind the damaged part of the weir which closed nearly 55% of the weir. Due to this closure, all the discharge had to pass the weir through the remaining 50 meters-wide southern opening. As a result of this upstream water levels were set-up faster than during normal operations. High upstream water levels, relatively high discharges and a low downstream water level caused extreme flow situations with even supercritical flow (hydraulic jump) over the bed protection. At weir Grave the existing bed protection was injected with colloidal concrete and an additional ballasting sill, made of 3-6t carefully placed stones and 4t rock nets was constructed, to prevent additional damage to the bed protection.

In this study the stability of the measures which were used to prevent additional damage to the bed protection are analyzed. This study focusses on the 3-6t carefully placed stones, rock net sill and the bed protection behind it. The 4t rock nets were not able to withstand discharges up to 450m^3/s and flow velocities up to 7.0m/s due to the internal instability of the small rock material inside the nets. The 3-6t stones were able to withstand discharges up to 850m^3/s and flow velocities up to 6.7m/s. Due to the fact that the stones were carefully placed, the stability increased. A stability correction factor (ϕ_{sc}) up to 0.73 can be used instead of 1.5 as prescribed by Pilarczyk for stones on the edge of a bed protection. The 40-200kg bed protection with colloidal concrete has withstood extreme flow velocities up to 7.2m/s whereby only small damages occurred. The 40-200kg quarry stones without colloidal concrete also showed limited damages after the 850m^3/s flood wave and depth averaged flow velocities up to 5.2m/s. The conclusions of the analysis are projected to the other six weirs in the Meuse and to the possible calamities which could occur here.

In order to perform the stability analysis of the bed protection measures at weir Grave, the Meuse and the seven weirs in the Meuse were analyzed. The Meuse is a controlled river in the Netherlands and is kept navigable by a seven weir system. These weirs differ in dimension, head loss and operating system. Based on the characteristics of these weirs one simplified fictive weir is chosen and tested on the consequences of various calamities. Besides, also the long-term maintenance strategy is considered in this study. Both have the similar result that part of the weir is non-operational for a longer period, discharge capacity is limited and all highly variability in occurring discharges is possible.

In this study the consequences to the water management of the fictive weir are considered. To guarantee an upstream water level to a certain target level, panels and slides are removed from a weir for increasing discharge. If part of the weir is not available due to a closure, panels and slides have to be removed earlier than in a normal situation. Therefore, the limit discharge, the discharge for which the weir is completely open, is reached earlier for the different closure situations. If the limit discharge is reached, the upstream water level starts to increase. In this thesis the discharge, according to an upstream water level equal to the flood plain level, is the maximum considered discharge. For further increasing discharge, and water levels, the flood plains start to discharge water and the flow velocities downstream of the weir will no further increase.

The flow velocities for three closure situations and three discharge situations are considered in this study. It turned out that the flow velocities which are calculated in this thesis are always lower than the flow velocities which occurred during the Grave weir calamity. Therefore it is concluded that the measures used during the Grave calamity, are all applicable to the other weirs in the Meuse. But lastly is must be concluded that due to a relative large closure of a weir (>50%), severe flow circumstances like supercritical flow, can occur. In case of a future calamity or long-term closure, it is advised to minimize the closure width as much as possible.

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Nomenclature

Symbol	Definition	Unit
b	Width	[m]
d	Water depth	[m]
d_{min}	Minimal width of flow jet	[m]
d_n	Nominal stone diameter	[m]
D	Characteristic size of the protection element, Dn50 for armourstone	[m]
D_n	Nominal stone diameter	[m]
D_{n50}	Nominal stone diameter	[m]
D_s	Spherical stone diameter	[m]
d_x	Width of flow jet at distance x	[m]
g	Gravitational acceleration	[m/s^2]
H	Upstream water level relative to dam crest	[m]
h	water depth	[m]
h_2	Water level middle of the weir relative to dam crest	[m]
h_3	Downstream water depth relative to dam crest	[m]
h_3^*	Downstream water level relative sill	[m]
$h_{downstream}$	Downstream water level with respect to NAP	[m NAP]
$h_{upstream}$	Upstream water level with respect to NAP	[m NAP]
k_h	Velocity profile factor	[-]
k_{sl}^{-1}	Side slope factor	[-]
k_t	Turbulence factor	[-]
m_f	Discharge coefficient free flow	[-]
$m_{f(Stoney)}$	Discharge coefficient free flow over Stoney slide	[-]
$m_{f(Poiree,m)}$	Discharge coefficient free flow over middle Poiree panels	[-]
$m_{f(Poiree,l)}$	Discharge coefficient free flow over lowest Poiree panels	[-]
m_o	Discharge coefficient open weir	[-]
m_s	Discharge coefficient submerged flow	[-]
$m_{s(Poiree,l)}$	Discharge coefficient submerged flow lowest Poiree panels	[-]
$M_{sack,tot}$	Total mass of sack gabion	[-]
Q	Discharge	[m^3/s]
q_{lim}	Limit discharge	[m^3/s/m]
q_{max}	Maximum discharge	[m^3/s/m]
r	Turbulence intensity	[%]
u_{max}	Maximum flow velocity	[m/s]
u	Flow velocity	[m/s]
u_2	Flow velocity above sill	[m/s]
u_3	Flow velocity (far) downstream of the weir	[m/s]
u_c	Critical flow velocity	[m/s]
u_{cr}	Critical flow velocity	[m/s]
v_{max}	Maximum flow velocity	[m/s]
h_b	Tailwater water level relative to dam crest	[m]

Greek	Definition	Unit
β	Flow coefficient	[-]
γ	Stone stability correction factor	[-]
Δ	Relative buoyant density of stones	[-]
Δh	Head loss	[m]
ΔH	Difference between downstream and upstream water level	[m]
ρ_s	Density quarry stones	[-]
Λ_h	Depth factor	[-]
μ	Contraction coefficient	[-]
ϕ_{sc}	Stability correction factor	[-]
ψ_{cr}	Critical mobility parameter of the protection element	[-]

Abbreviations	Definition
CEMT	Conférence Européeenne des Ministres de Transport
CFD	Computational Fluid Dynamics
FR	Froude number
NAP	Normal Amsterdam Level
RINK	Risk Assessment Hydraulic Structures
	NL: Risico Inventarisatie Natte Kunstwerken
RWS	Rijkswaterstaat
t	Ton, 1000kg

1

Introduction

This chapter describes the origin of this thesis and gives background information about the Grave weir calamity. Thereafter the problem description, scope, research objective and methodology of this thesis are given. Finally the report outline is described.

1.1. Background

In thick fog and darkness on Thursday the 29th of December 2016 the Maria Valentine, a large Rhine Ship loaded with 2000 ton benzene, missed the exit to the ship lock and sailed through the northern opening of the Grave Weir in the Meuse river. This ship collision caused serious damage and created a big gap in the weir (see cover photo). Five beams (In Dutch: jukken) were damaged and within 11 hours the water level between weir Grave and upstream weir Sambeek decreased by 1.75m to a maximum decrease of 3m from 7.95m +NAP to a minimum of 5.10m +NAP. Figure 1.1 shows the decreased water level near to the upstream weir of Grave, weir Sambeek and the increased discharge next to Megen, a measurement station 13 kilometers downstream of weir Grave. (`http://waterinfo.rws.nl`, 2017).

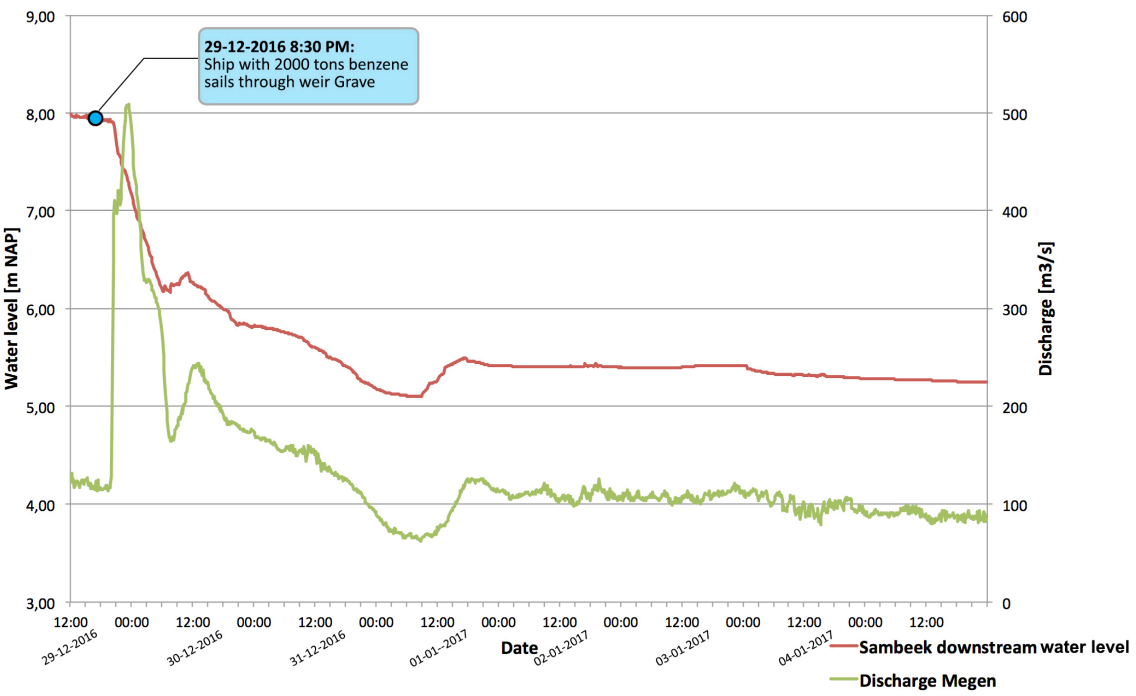


Figure 1.1: Decreased water level and increased discharges arising from the collision

The decreased water level had large consequences: shipping was limited, houseboats were skewed and there was a risk of instability of river banks (Figure 1.2). Furthermore, due to the decreased water level, the stability of the upstream weir Sambeek was jeopardized in the beginning. It was important that the water level between Weir Grave and Weir Sambeek was reinstated as quickly as possible because the obstructed shipping costs load of money.

(a) Damaged weir (b) Skewed houseboat (c) Dried marina

Figure 1.2: Consequences ship collision

1.1.1. Grave weir

Grave weir is located in the river Meuse. The Meuse is a controlled river flowing from France, through Belgium to the Netherlands and drains into the North Sea. The discharge over the year can vary considerably. The average winter and summer discharges of the Meuse are respectively 480 m^3/s and 89 m^3/s. The 1/100 year flood discharge at Borgharen is up to 2900 m^3/s (Bruggeman et al., 2013). During low discharges the Meuse is kept navigable by a seven-weir system and for increasing discharges the weirs are lowered in sections. During extreme high discharges, the Meuse becomes a free flowing river by lowering the weirs completely.

The Grave weir complex, where the ship collision took place, consists of four elements (1-4) shown in Figure 1.3 below. The weir consists of: a southern opening (1), 9 beams and 49.70m wide, and a northern opening (2), 11 beams and 60.75m wide. Each beam consists of three wall panels with which water levels are controlled. Next to the weir two shipping locks (3,4) are located of which one (3) is no longer used. Over the weir and locks the John S. Thompson Bridge is located. The water level difference over the weir, during normal flow conditions, is about 3m (Sikkema, 2010).

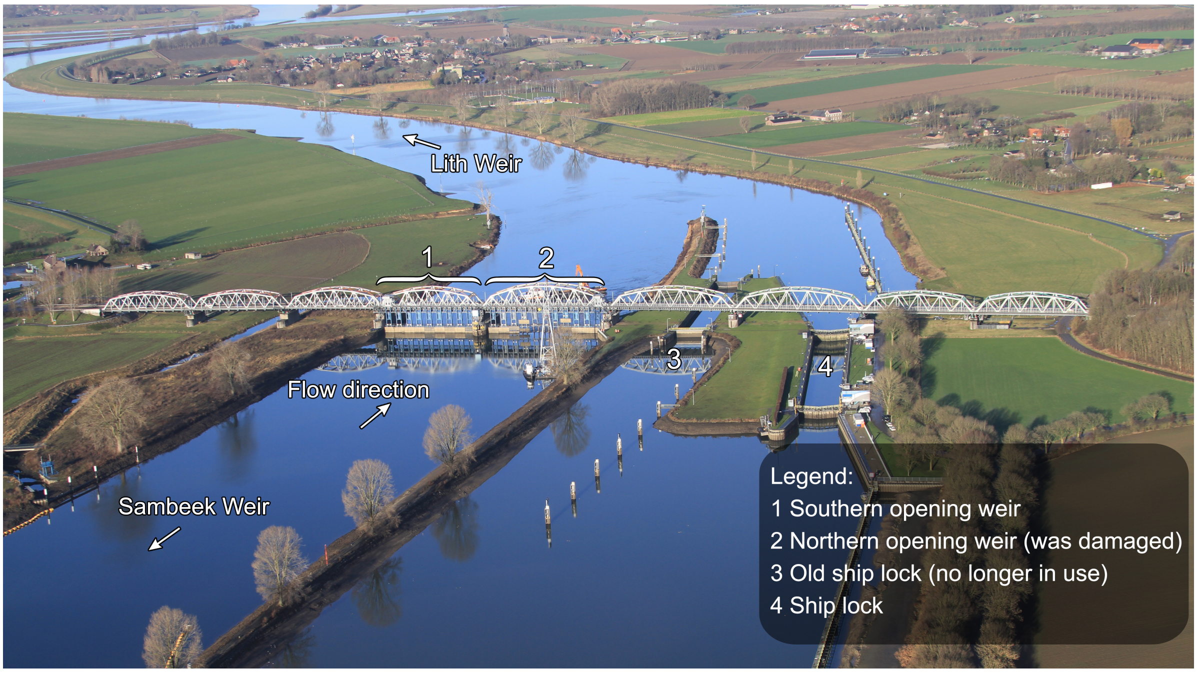


Figure 1.3: Overview Grave weir.

1.1.2. Emergency measures

After the ship collision, the water level between weir Grave and weir Sambeek had to be reinstated and the weir had to be back into operation as quickly as possible. Several alternatives were considered to reinstate the water level upstream of the weir and make navigation possible again. These alternatives also needed to make repair operations possible.

Alternatives

In the first days after the collision many alternatives were suggested. These, very different, ideas came from Rijkswaterstaat, engineering firms and even the public. In the end a total of 12 alternatives were considered by Rijkswaterstaat. Some of these alternatives were:

- Sheet pile wall
- Mobile dyke
- Container wall
- Sinking a barge
- Secondary weir in front of the damaged weir

- Prefab concrete slabs wall
- Rock fill dam downstream

These 12 alternatives were judged in a Multi Criteria Analysis. The most important criteria were: safety, technical feasibility, building time, demobilization within 48 hours (for a possible high discharge flood wave), and room for repair. Based on this Multi Criteria Analysis, a temporary rock-fill dam downstream of the weir was chosen. The biggest advantages of this design with respect to the other alternatives were: low risks, a robust material, building material in stock, and engineering knowledge.

Reinstate water level

The rock fill dam was a solution to recover the water level and to make it possible to repair the damaged gates. Nevertheless, this rock-fill dam also brought about new problems. The dam itself would be stable, but there were uncertainties about the best construction method, stability of the dam during construction, and the hydraulic circumstances in which the dam would have to be built.

The dam was made of dumped loose rock of different gradings. Although design methods exist to design a rock dam in a flowing river, no time was available to make a detailed assessment of the hydraulic design conditions and the stability of the rock gradings. During closure the flow velocities in the closure gap would increase (Figure 1.4a), but it was not proven by a physical model or extensive computational modeling that the chosen stone size and design would be sufficient stable to final close the dam. Basic computations were made in combination with engineering experience. Possibly aided by an extreme low discharge during construction, the closure gap could be closed with readily available material (Figure 1.4b).

(a) Increased flow velocities during construction (b) Dam after construction

Figure 1.4: Construction of rock fill dam

Additional bed protection

By closing the northern opening the full discharge had to pass the weir through the southern opening alone. This increased the loads on the bed protection significantly and during high discharges a hydraulic jump would appear over the existing bed protection and part of the unprotected river bed (de Loor and Weiler, 2017). Figure 1.5 shows the flow conditions through the remaining opening. Therefore, the existing bed protection first needed to be lengthened and parts were strengthened by penetrating it with colloidal concrete. Furthermore a sill, an additional layer of large rock, was made to protect the existing bed protection by an additional ballast on the bed protection between the bridge piers.

Initially this sill was made of 3-6t stones with 4t rock nets behind it. The rock nets turned out not to be stable after discharges up to 450 m^3/s. Therefore the sill was lengthened with 3-6t stones, which seemed more stable. Finally the 3-6t stones have resisted discharges up to 850 m^3/s very well. No extreme discharges occurred anymore and no further damage happened to the weir (Kortlever, 2017a).

After the repair of the weir had been completed in July 2017, the rock fill dam and the ballasting rock bed protection measures were removed again. Making these measures no longer an extra obstacle to future extreme discharges.

Figure 1.5: Extreme flow conditions with hydraulic jump through remaining opening of the weir, retrieved from: https://youtu.be/LvuxY0rYSXE

1.2. Problem description

This chapter describes the problem description and the goal of this thesis. Furthermore the scope of this thesis is defined. Finally the research question, methodology to answer this research question and the report outline are described

1.2.1. Problem description

During a calamity like the Grave Weir ship collision, many measures had to be taken in a very short time. Due to large consequences of the collision, Rijkswaterstaat had to come up with a solution for the decreased water level as soon as possible.

The measures which were used had their individual uncertainties and some measures worked better than others. Rijkswaterstaat wants to learn from the Grave weir accident and therefore this research will provide a better insight in the applicability of rock based emergency measures for calamities at weirs on the river Meuse. The focus of this thesis will be on the increased flow velocities during (a partial) closure of a weir due to a calamity and the consequences due to this closure to the stability of the (additional) bed protection.

1.2.2. Scope

In this paragraph the scope of this thesis is described. The scope describes what is and what is not considered in this thesis and is described point wise below.

- This thesis only focussed on the additional bed protection which was used at the Grave Weir calamity.
- For the applicability of the emergency measures, additional bed protection, is only looked at weirs in the Dutch part of the river Meuse.
- For an additional ballast on the bed protection only the used rock nets and carefully placed stones are considered.
- In this thesis no further research will be done to the erosion of sandy materials as for example the erosion of the bank after the 850 m^3/s discharges.

1.2.3. Research objective

The main purpose of this thesis is to give a better insight in the consequences of a large calamity or long-term (partial) closure of a weir. It will provide information how to act during a future calamity at a weir in the river Meuse. The measures which should be designed are based on the measures used during the Grave Weir calamity. This report focusses on the design of emergency measures, specific on the measures which should be undertaken to prevent damage to the bed protection, and possibly to the weir, due to increased loads on the existing bed protection. Therefore the research question of this thesis reads:

How to prevent additional damage, based on lessons learnt from the Weir Grave calamity, to the bed protection of a weir during a long-term partial closure of a weir in the river Meuse?

This research will provide a theoretical background to the applied measures in Grave and give a better insight for the opportunities and limitations of rock-based emergency measures for a future calamity. .

1.2.4. Methodology

In order to answer the research question five subquestions are formulated. By answering these subquestions the conclusion of the research question can be given. In which way the subquestions will be answered is explained here.

1. *What are the main characteristics of the river Meuse and the weirs in the Meuse?*

   First a description of the river Meuse and the weirs is given. In this part the important hydrodynamic characteristics of the Meuse are described. This description deals with discharges, water levels and bathymetry of the Meuse. Furthermore, the seven weirs in the Meuse are compared to each other. This results in characteristic hydraulic boundary conditions to which the emergency measures have to meet. At the end a normative 'fictive' weir is described which will be further investigated under different load situation.

2. *What is the chance of a calamity?*

   A calamity such as that at the Grave Weir does not occur often. For the design of emergency measures it is important to know how often such calamities occur. For this question a description is given of past calamities or collisions and the probability of a future calamity. Besides calamities, also other possibilities which could ensure long-term closure of a large part of a weir are considered.

3. *What are the consequences of a long-term partial closure of a weir?*

   This subquestion describes the consequences of a long-term closure of a 'fictive' weir due to a calamity or maintenance. Especially flow velocities which could occur behind a weir during variable load situation are described. The increased flow velocities are the bases of the additional measures for the bed protection.

4. *Which measures to protect the bed protection were used after the Grave Weir calamity and what were the results of these measures?* During the Grave calamity different methods were used to protect the existing bed protection. Not all these measures were that successful. In this study the measures used in Grave are analyzed. The analysis for the measures used in Grave, the rock nets and carefully placed stones, will be done in four steps:

   (a) What is the known theory for this measure

   (b) How is this measure used at the Grave Weir

   (c) Analysis of the stability of the measure

   (d) How to improve this measure for a future calamity

   Known theory
   A description of well known stability formulas is given. Furthermore a choice is made which formula is used for a particular situation.

   Measures Grave
   The explanation in what way this measure is used in Grave will be described. Furthermore the advantages, disadvantages and uncertainties of each measure are described.

   Stability of measure
   The stability of each measure is analyzed. The stability of stones, used in different ways, is dependent of forces exerted by flowing water. Therefore it is important, in all the measures, to know what the flow conditions and velocities were during the use of the measure. A second important instrument to determine the stability of a measure is the damage to the specific measure, which occurred during different load situations.

   The stability of the rock nets is determined by a comparison between the known theory, the flow velocities from simplified discharge relations, a CFD (Computational Fluid Dynamics) model made by Deltares and the occurred damage.

   The stability of the carefully placed stones is determined by a comparison of the known theory, flow velocities from discharge relations and a CFD model made by Deltares. This model is used to calculate the local flow velocities, shear stresses, water depths, pressure gradients and flow accelerations. The stability of the additional bed protection will be compared with different stability formulas.

   Improvement measure
   After a comparison of the background theory and experiences from Grave weir a description is given how to use these kind of measures in a better and proper way.

5. *How to use these measures for future calamities or closures of a weir on the river Meuse?* Finally a comparison is made between the measures used after the Grave calamity and how they can be used during a future calamity or long-term closure at a weir on the river Meuse.

1.2.5. Report outline

This thesis starts with a description of the characteristics of the river Meuse. It deals with among others transport over the Meuse, discharges and water levels. Furthermore the seven weirs in the Meuse are described and compared to each other in Chapter 2. Finally a single 'fictive' weir is chosen based on this comparison. This weir is a worst case weir with the most negative characteristics for a future partial closure.

In chapter 3 a description is given about possible calamities at weirs. First a number of past calamities is presented. Then the damages which could occur for a future calamity are discussed. In the end an overview of possible long-term closures of the fictive weir is given. In the next chapter the hydraulic consequences due to these eight partial closures are investigated.

Chapter 4 deals with the hydraulic consequences of a partial closure of the fictive weir. First the consequences according to water management are discussed for the eight possible closure situations. One wants to maintain target levels as long as possible. The water management will change due to a partial closure of the weir. When it is no longer possible to maintain target levels because all the panels and slides are removed, the limit discharge is reached. From this moment the upstream water level starts to increase for a further increasing discharge. The maximum discharge, in this study, is reached if the upstream water level is equal to the flood plains. In this chapter the limit and maximum discharges are determined for the eight closure situations. Thereafter the flow velocities which will occur behind the weir are determined. Instead of calculating for all eight closure situations, three normative situations are calculated in more detail. First the calculation methods and important parameters are described. In the end the maximum flow velocities at a certain distance from the weir are presented. The flow velocities which occur at the various closure situations and discharges are later compared with the flow velocities which occurred after the Grave weir calamity.

Chapter 5 starts with a stability analysis of the emergency measures used after the Grave weir calamity. The critical flow velocities for the various measures are compared to occurred flow velocities at the weir. The critical velocities are determined on the basis of known formulas. The occurred flow velocities are calculated with simplified calculations and with computer models made by Deltares. Based on these differences and the occurred damages a conclusion is drawn about the stability of the applied measures.

In the end the flow velocities which occurred after the Grave weir calamity and the stability of the used measures are compared to the flow velocities which could occur due to a partial closure of the fictive weir. Finally the comparison between these velocities is used to give an advice which measures should be used for future calamity at one of the seven weirs in the Meuse.

2 The Meuse

This chapter describes characteristics of the river Meuse and the weirs in the Meuse. Important characteristics like transport over the Meuse, discharges and water levels are described. Then target levels, operating systems, dimensions, head losses and bed protections of the weirs in the Meuse are compared. On the basis of this comparison a single 'fictive' characteristic weir of the Meuse is described. This fictive weir is a worst case weir for future calamities. Later in this thesis, this weir will be used to investigate the consequences for variable calamities.

2.1. River Meuse

The Meuse is a rainfed river flowing from France, through Belgium to the Netherlands. The river has its source in Poully-en-Bassigny (France). From here the river flows via Verdun, Stenay, and Sedan to Belgium. In Belgium it arrives in Agimont and via Namen flows the river through Liege to the Netherlands. In the Netherlands the Meuse flows from Eijsden to Maastricht, Roermond, Venlo, and 's-Hertogenbosch. After 's-Hertogenbosch, the Meuse splits up in different rivers before ending in the Hollandsch Diep. Between Eijsden and Maasbracht the Meuse forms the frontier between Belgium and the Netherlands. The Meuse has a total length of 935km of which 250km in the Netherlands. An overview picture, retrieved from the Meuse Agreement 1994, is depicted in Appendix A. The bathymetry of the Meuse is characterized by a current-carrying summer bed and a winter bed for high discharges. The width of the summer bed varies between 129 and 149 meters (Bakker et al., 1997).

2.1.1. Navigation

The Meuse is part of the major inland navigation infrastructure, connecting the Rotterdam-Amsterdam-Antwerp port areas to the industrial areas upstream: 's-Hertogenbosch, Venlo, Maastricht, Liege, Namur. The Meuse is canalized in Belgium and the Netherlands by a system of weirs of which seven weirs are located in the Netherlands. These weirs in the Netherlands guarantee a minimal water depth of 3.2 meter for navigation, see Figure 2.1 (Rijkswaterstaat, 2017c). The Meuse is a busy navigation route and Table 2.1 shows the number of ship passings in 2015 of four weirs in the Meuse which are on the navigation route. Between Maastricht and Roermond the Meuse has a strong meandering character, therefore navigation makes use of the Lateraal channel and the Juliana channel. The Meuse route is navigable for ships up to CEMT class Vb (Rijkswaterstaat, 2017c). During (extreme) high discharges it is no longer allowed for ships to use the Meuse due to high flow velocities and the ships probably cause additional loads on dykes.

Table 2.1: Shipping passages in 2015, source: http://binnenvaartcijfers.nl

Weir	Lith	Grave	Sambeek	Belfeld
Passages	18.115	11.138	26.218	20.118

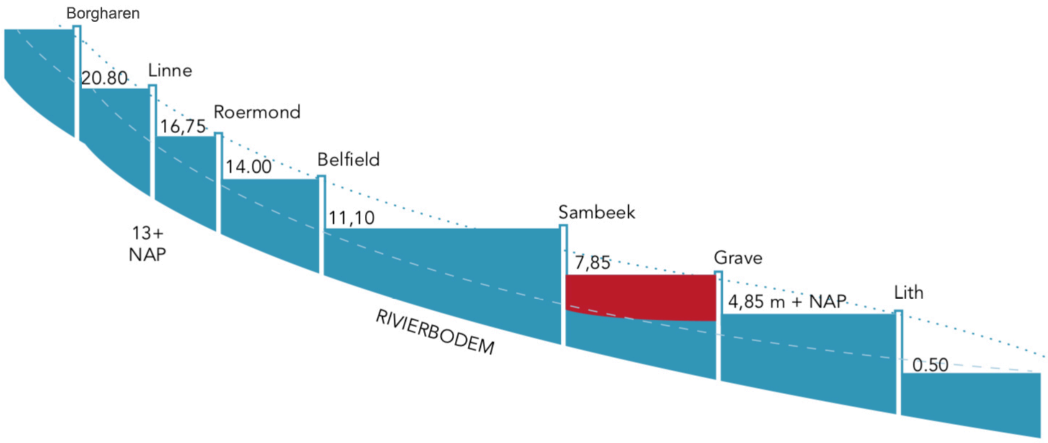


Figure 2.1: Weirs in the Meuse, (Joustra et al., 2018)

2.1.2. Discharges

The Meuse is fed by melting snow and rain from the Ardennes. Therefore discharges during the year are highly variable and the differences between low, average and high discharge are large. The average discharge is about 350m^3/s, the lowest measured discharge 20m^3/s (1976) and the highest measured discharge is about 3000m^3/s (1926 and 1993) (Rijkswaterstaat, 2007). Figure 2.3 shows the averaged discharge of the Meuse for the period 1911 to 2015 measured at Borgharen, just upstream of Maastricht. Borgharen was the former measurement station for discharges of the river Meuse. Furthermore the maximum and minimum discharge ever measured and the discharge of 2015 are shown in this figure. Due to interventions in the Meuse for flood safety, one decided to switch to measurement station St. Pieter Noord. A location just downstream of Maastricht where the Meuse enters the Netherlands. Besides the discharges of recent years, Table 2.2 shows the exceedances of discharges for the period July 2015 till June 2016.

Table 2.2: Discharges measurements 01.07.2015 - 30.06.2016 (Rijkswaterstaat, 2017a)

Discharge at St. Pieter [m^3/s]	80	155	280	530	1030	1280	1500
Number of days/year Q was higher	269	184	107	45	8	4	2

For safety and the design of hydraulic structures, the extreme values of discharge are important. Flood waves in the Meuse usually originate in the Ardennes. Extreme rainfall reaches the Netherlands in a short time due to an elongated river basin and low groundwater storage capacity. From the origin to the Dutch border takes one day and from the border, because the Meuse is flatter in the Netherlands, it takes two days to reach the Hollandsch Diep (Rijkswaterstaat, 2007). The return times for flood waves for the Meuse are shown in Figure 2.2. These discharges are also the discharge at measurement station St. Pieter Noord.

Return period [Years]	2	5	10	20	30	40	50	75	100	250	1250
Discharge [m3/s]	1640	1994	2264	2534	2689	2790	2867	3010	3112	3430	3992

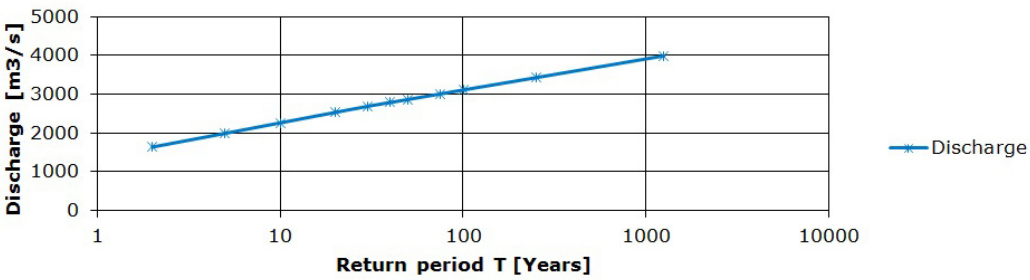


Figure 2.2: Maximum discharges in the Meuse, (Rijkswaterstaat, 2017a)

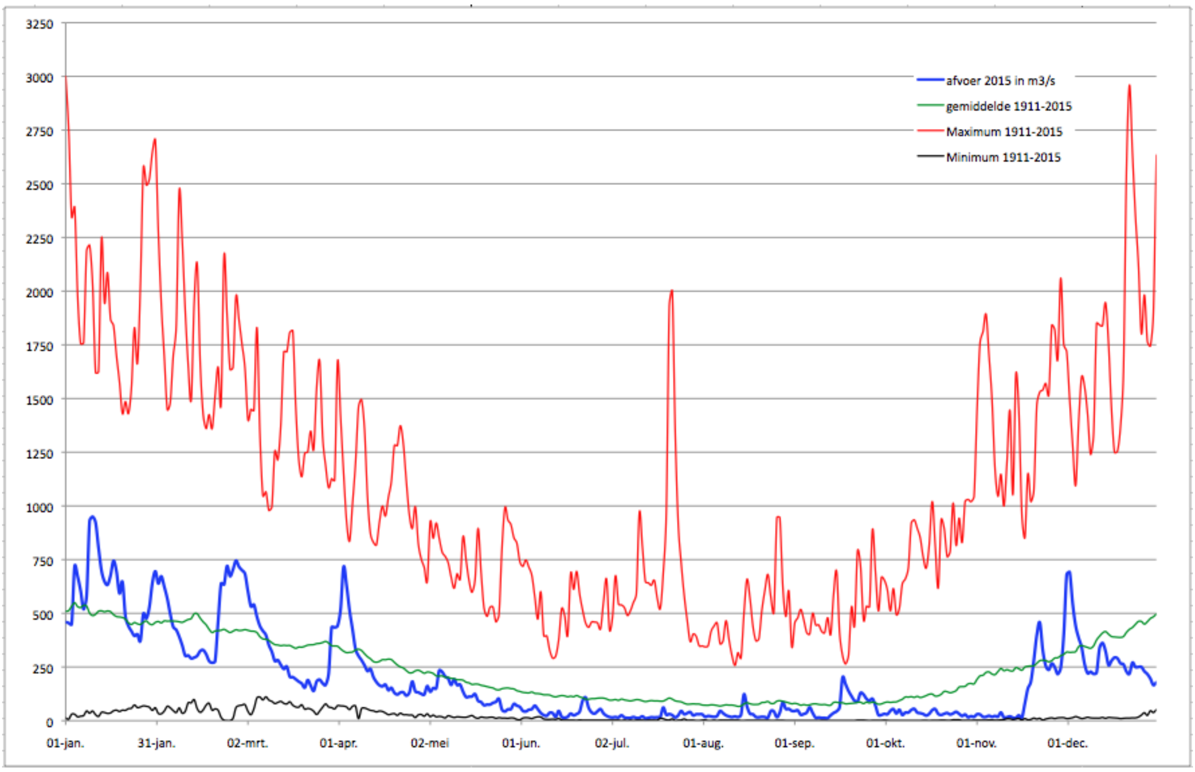


Figure 2.3: Discharge of the Meuse at Borgharen, source: http://waterpeilen.nl

2.1.3. Water levels

To determine the water levels at different location for variable discharges, stage relation curves (Dutch: Betrekkingslijnen) are used. The definition of a stage relation curve is according to TNO (1986): A stage relation curve is a graphical representation indicating which water levels correspond to the different level scales at (quasi) permanent discharges. The stage relation curves used in this Thesis, Rijkswaterstaat (2017a), are based on discharges at measurement station St. Pieter Noord. On the bases of these discharges an estimations of the water levels, corresponding to different discharges, of locations downstream of St. Pieter can be made. The stage relation curve gives an expected value of the maximum water level for a certain discharge. The stage relation curves are based on yearly measurements and interpolated by a WAQUA model. Figure 2.8 shows the stage relation curves for the Meuse for different discharges.

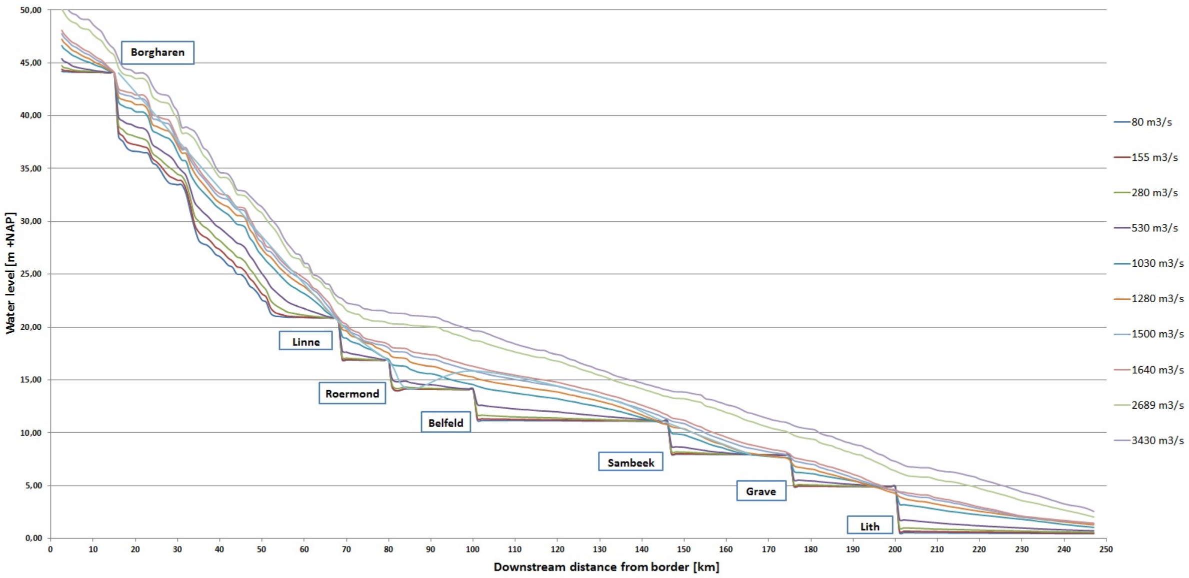


Figure 2.4: Water levels Meuse due to increasing discharges, (Rijkswaterstaat, 2017a)

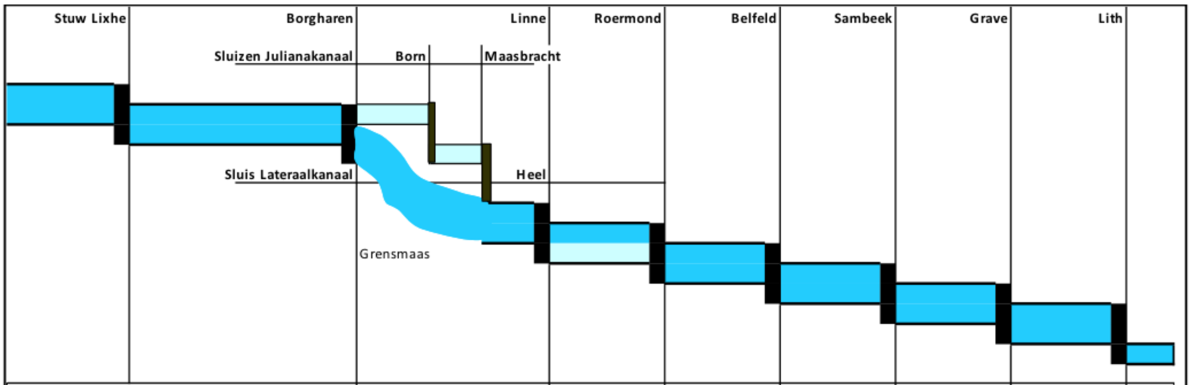
2.2. Weirs

As mentioned in Paragraph 2.1.1, the Dutch part of the Meuse is kept navigable by a seven weirs system. The weirs guarantee a minimal water depth of 3.2 meter and are located in downstream to upstream order near the cities: Lith, Grave, Sambeek, Belfeld, Roermond, Linne, and Borgharen. Figure 2.5 shows the seven weirs. Appendix B gives an individual description of each weir, its regulation system and other characteristics including a schematization of the weir.

Figure 2.5: Overview weirs in the Meuse, photos retrieved from: https://binnenvaartinbeeld.com/nl

2.2.1. Water management Meuse

The target water levels for the different channel sections are shown in Figure 2.6. These water levels are maintained with respect to a certain target point, also shown in Figure 2.6. For some weirs these target points are located further away from a weir and some target levels, and target points, change for an increasing discharge due to the increasing slope of the relation line and to still guarantee a minimum depth for navigation.



Stuurpunt 1 (Q Laag)	Borgharen/julianakanaal	Heel-boven	Roermond-bov	Heel-ben.	Sambeek-bov.	Mook	Lith-bov.
streefpeil m+ NAP	winter 44.05; zomer 44.15	20.85	16.85	14.15	11.10	7.95	4.90
bandbreedte	43.90 - 44.17	20.70 - 20.95	16.80 - 16.90	14.10 /14.20	11.05 - 11.15	7.90 - 8,00	4.88 - 4.92
Stuurpunt 2 (Q hoog)				Belfeld-bov	Well-dorp	Grave-bov.	Megen-dorp
streefpeil m+ NAP				14.05	11.70	7.25	5.40
bandbreedte				14.00 - 14.10	11.65 - 11.75	7.20 - 7.30	5.35 - 5.45
Stuurpunt 3 (Q hoogst)					Sambeek-bov.		
streefpeil m+ NAP					10.85		
bandbreedte					10.80 - 10.90		

Figure 2.6: Target levels channel sections (Kortlever, 2017b)

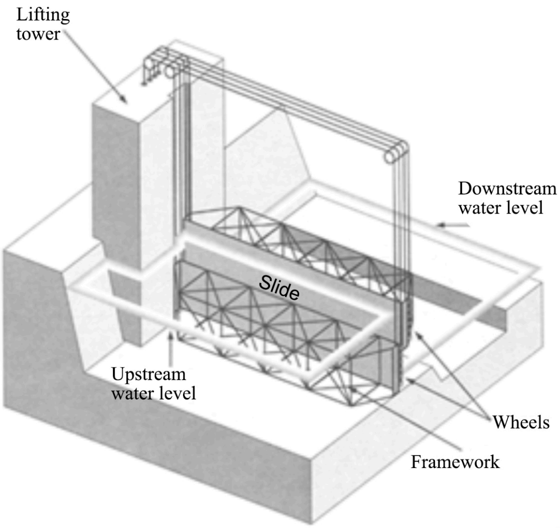
2.2.2. Operating systems

The target levels are maintained through various operating systems in the weirs. These operating systems, the method how they control the water level upstream of a weir for increasing discharge, are not equal for all weirs. This paragraph will describe the various operating systems and in what manner the water levels are controlled. The following information is based on technical reports made for the Risk Assessment Hydraulic Structures (In Dutch: Risico Inventarisatie Natte Kunstwerken, RINK) (Nooij, 2010b), (Sikkema, 2010), (Nooij, 2010d), (van der Ziel, 2010), (Nooij, 2010c), (Mooyaart, 2010) and (Nooij, 2010a).

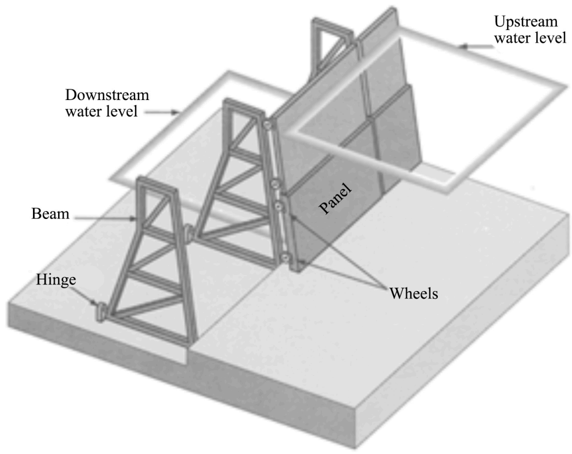
Stoney-Poiree

Weirs Sambeek, Belfeld, Roermond, and Linne are so-called Stoney-Poiree weirs. These weirs consist of two parts, a Stoney part and a Poiree part as shown in figure 2.7. The Stoney part consists of 17 meters wide openings with two superimposed slides (In Dutch: schuiven) in between. Weirs Sambeek, Belfeld, and Roermond have two of these openings with slides, weir Linne has three openings with these Stoney-slides. These 17-meter wide slides are lowered or raised every 10 minutes on the basis of measurements of water levels and expected discharges. For increasing discharges the slides are lowered, so more discharge can pass the weir without an increasing upstream water level. The Stoney part is used for the fine-tuning of the water level. The levels of the Stoney slides are set automatically. The opening of a Stoney consists of two individual slides which are placed above each other. By lowering the top slide, the discharge can be increased, until the slide is located on the sill next to the other slide. To further increase the discharge through the Stoney part, the slides can be lifted above the water level. The Poiree part of the weir is located besides the Stoney part. A Poiree consists of multiple (13 to 17) beams (in Dutch: jukken) with in between these beams three panels above each other. For example, the panels for the Sambeek weir are 4.85m wide and 1.90m high. The Poiree part is used for the coarse regulation of water levels. If the discharge increases too much to control the water level by lowering/raising the Stoney slides, panels are removed from the Poiree part. These panels have to be removed manually which is time consuming. Usually three panels are removed at the same time. For an increasing discharge first panels are removed from the top row, then the middle row, and finally the lowest row. When all the panels are removed, the beams are lowered to the bottom of the weir. When also the slides of the Stoney part are completely raised above water level, a free flow river appears. Ships will navigate through the Poiree part to pass the weir and do not use the ship locks next to the weir anymore.

Weir Grave is a kind of an upside-down Poiree weir and consist of in total 20 beams with three rows of panels. These beams are distributed over two openings. In contrast to the other weirs, the beams of Grave are



(a) Stoney part



(b) Poiree part

Figure 2.7: Schematisation Stoney-Poiree Weir (Schot et al., 1998)

constructed under the overlying bridge. Furthermore, the water levels can only be maintained by removing panels. Also these panels have the by removed (partly) manually. The top and middle row can be removed automatically based on configurations determined by the stewards (In Dutch: stuwmeester). When al the panels are removed, also the beams will be lifted above the water level and ships can pass through the weir.

Slides and valves

Weirs Lith and Borgharen consist of multiple openings (respectively 3 and 4), lifting gates with a flap on top to regulate the water level. Flaps are constructed on top of the slide and can be lowered. When the flaps are maximum lowered, the gate is lifted above water level. These slides and flaps are lowered or raised every 10 minutes also on the basis of measurements of water levels and discharges. By lowering the slide, more discharge will flow over the slide. Raising the slide will induce underflow and also increase the discharge through the weir. For extreme high discharges, the slides are completely raised above the water level. The river becomes a free flowing river and ships pass through the weir. Figure 2.8 shows a schematization of a valve/slide weir.

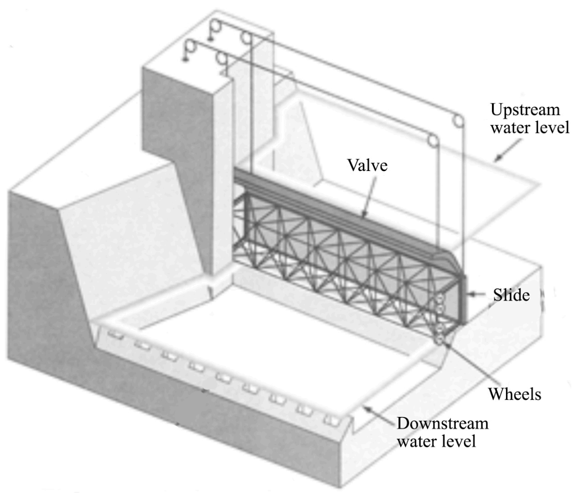


Figure 2.8: Schematization valve-slide weir (Schot et al., 1998)

All the weirs can maintain target level to a so-called limit discharge. From this discharge it is no longer possible to remove panels of lower slides to control the water level. The weir is completely lowered and the Meuse becomes a free flowing river. The limit discharges for the different weirs are shown in Table 2.3. The discharges can differ due to different water level differences over the weir and differences in river width.

Table 2.3: Limit discharges from RINK

Weir	**Limit discharge [m3/s]**
Lith	1097
Grave	1070
Sambeek	1205
Belfeld	800
Roermond	984
Linne	1278
Borgharen	1250

2.2.3. Dimensions

The dimensions of the seven weirs, and the distribution of the openings and regulation systems is shown in Table 2.4. These values are retrieved from the RINK reports for each weir.

Table 2.4: Dimensions

Weir	**Total width** [m]	**Distibution openings** [m]	**Regulation system**
Lith	114	38 - 38 - 38	3 x slide
Grave	110	50 - 60	9 beams & 11 beams
Sambeek	97	17 - 17 - 63	2 x Stoney & 1 x Poiree (13 beams)
Belfeld	97	17 - 17 - 63	2 x Stoney & 1 x Poiree (13 beams)
Roermond	102	17 - 17 - 68	2 x Stoney & 1 x Poiree (17 beams)
Linne	110	17 - 17 - 17 - 60	3 x Stoney & 1 x Poiree (15 beams)
Borgharen	99	23 - 23 - 30 - 23	3 x flap & 1 x slide

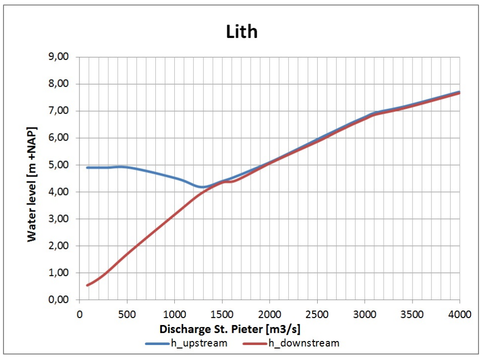
2.2.4. Head loss

The next characteristic which is considered, is the head loss over the weir. The difference between the upstream and downstream water levels over the weir. The head loss (Δh) over the weir changes for an increasing discharge. The water levels over the different weirs, based on Rijkswaterstaat (2017a), are shown in Figure 2.9

According to these figures it is clearly visible that the largest head loss difference over a weir occurs for a minimal discharge. The upstream and downstream water levels for a minimal discharge, Q = 80m^3/s at St. Pieter from Rijkswaterstaat (2017a) are given in Table 2.5. Furthermore the corresponding Δh is given. Besides the maximum head loss, there is a difference in decrease of the head loss. This is caused by the length of the downstream channel section of a specific weir. The water level in a relative long channel section tends to increase faster than for shorter sections. This decrease of head loss, causes a decrease of discharge capacity of a weir, whereby panels or slide have to be lifted or removed earlier.

Table 2.5: Water height differences

Weir	**Downstream level** [NAP+ m]	**Upstream level** [NAP+ m]	**Δh** [m]
Lith	0.20	4.90	4.70
Grave	4.90	7.90	3.00
Sambeek	7.95	11.10	3.15
Belfeld	11.20	14.15	2.95
Roermond	14.15	16.85	2.70
Linne	16.90	20.85	3.95
Borgharen	38.05	44.05	6.00



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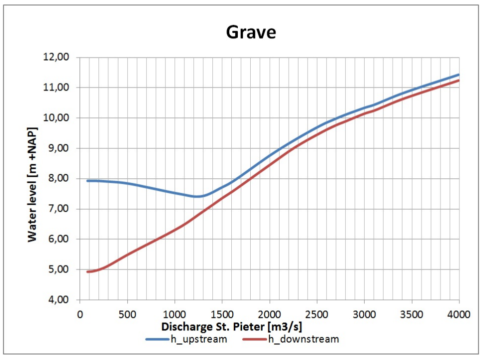

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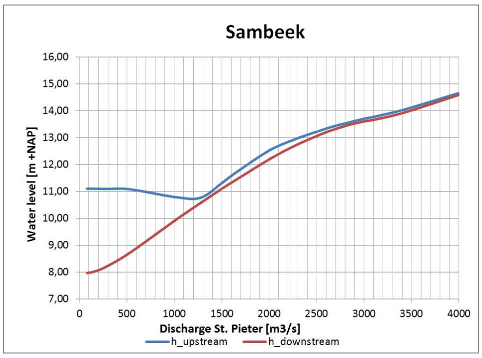

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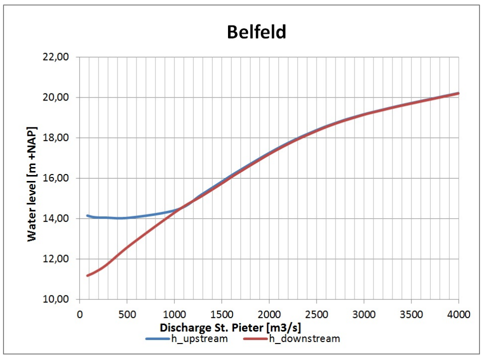

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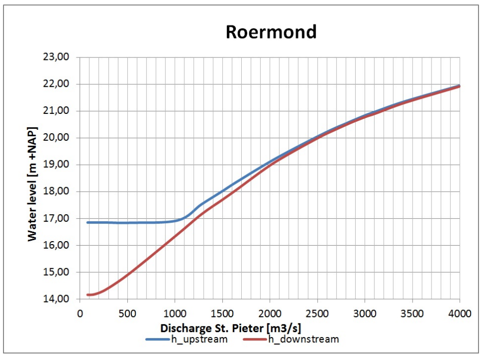

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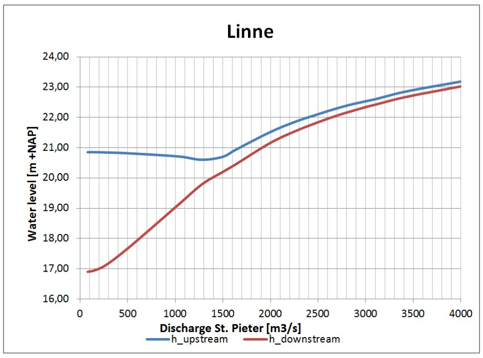

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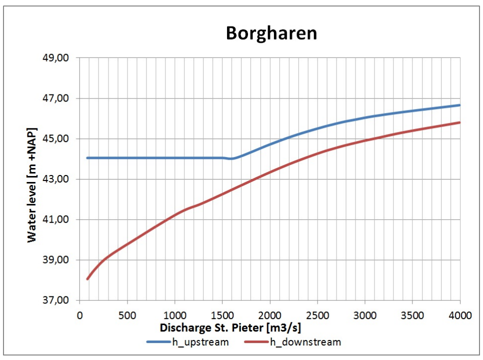


(g)

Figure 2.9: Head losses for increasing discharges

2.2.5. Bed protection

To prevent erosion behind a weir, a bed protection is located behind the weirs. This bed protection differs in material and length for the weirs. The lengths and types of the various bed protections are shown in Figure 2.10. This figure is based on information from RINK reports and Rijkswaterstaat experts knowledge. It should be noticed that the bed protection of weir Roermond seems to be to shortest and less robust. But it is very likely that it is reinforced due to the conclusions of the RINK reports. Furthermore it should be noted that the bed protection behind weir Linne differs behind the Stoney and the Poiree part. For the others Stoney-Poiree weirs, the bed protection is equal over the full width of the weirs.

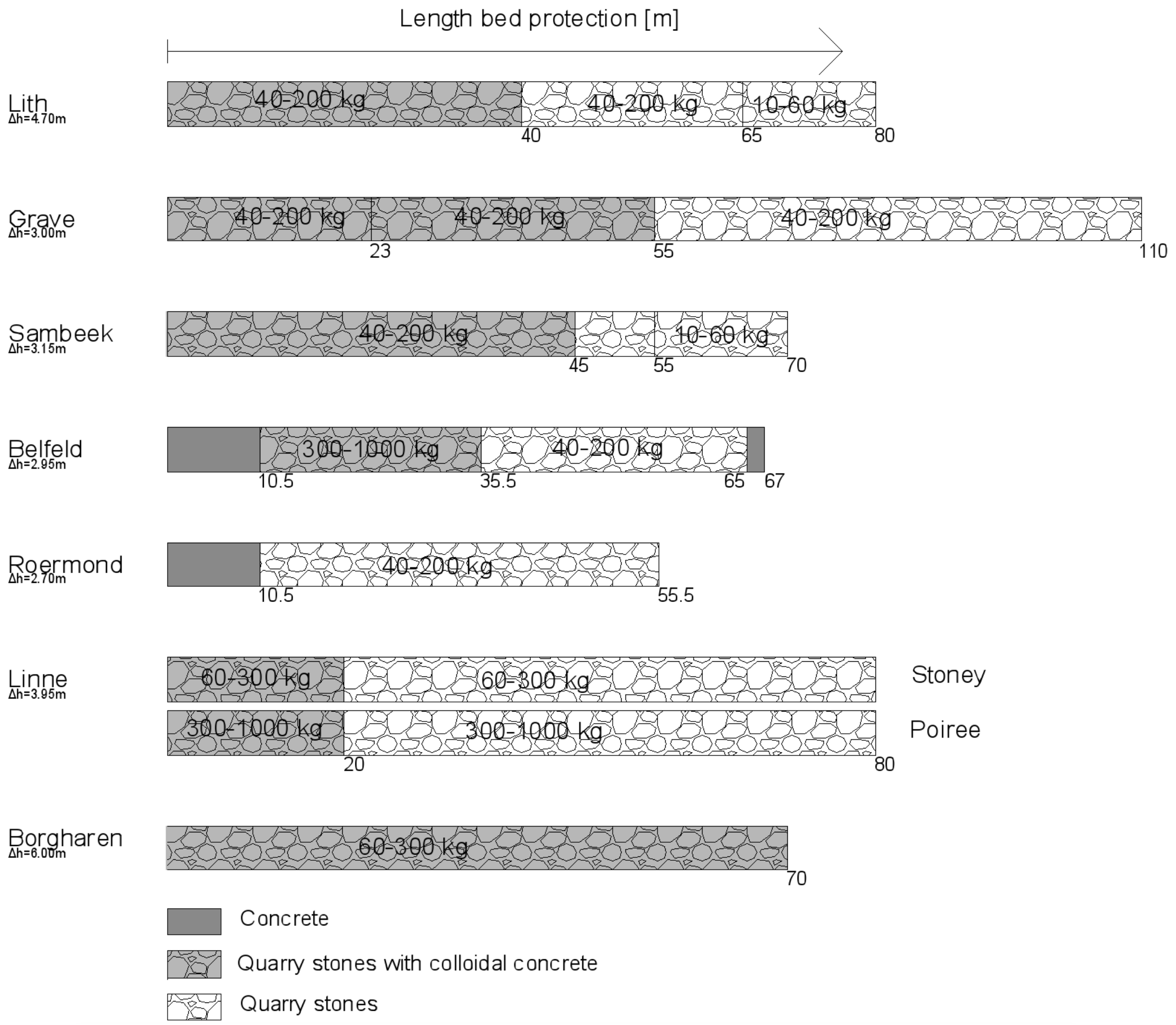


Figure 2.10: Bed protections of the weir in the Meuse

2.2.6. Driel, Amerongen & Hagesteijn

Besides the seven weirs in the Meuse, there are weirs located in the Lek and Nederrijn rivers in the Netherlands. These are the weirs near Driel, Amerongen, and Hagestein. These three, nearly identical weirs, consist of two visors which can be raised or lowered to control the water level. Each weir consists of two 48 meters wide openings. The water level differences over the weir changes for varying discharges. The maximum water level difference over the weirs, retrieved from Rijkswaterstaat (2010), are for weir Driel 2.16m, weir Amerongen 4.36m and weir Hagestein 2.66m. The bed protection is equal for the three weirs and consists of 30 meters length bed protection made of concrete blocks (1.0m x 1.0m x 0.7m) on a filter layer.

2.3. Comparison

In this thesis the choice is made to elaborate a single 'fictive' weir, based on the weirs in the Meuse which represents main characteristics an is a worst case weir with respect to calamities. A first selection is on the type of operation systems. In fact there are two types of weirs in the Meuse: two weirs with several openings with slides/valves and five Stoney-Poiree weirs. The Stoney-Poiree type of weirs are therefore a majority in the Meuse. Furthermore, the Stoney-Poiree weirs are at the end of their lifetime. The next few years, maintenance will be carried out for these weirs which make this thesis also valuable for the closure of part of the weir due to long-term maintenance.

The second criterion is based on the relative closure of a specific weir. Which calamities have the biggest influence on a weir. In other words, for which weir the largest part, with respect to the total width, can be closed due to a calamity or maintenance. Figure 2.11, based on Table 2.4, shows these relative closures for the different weirs. The relative closure is the total closure width, with respect to the total width of a weir. The relative closure is largest and nearly the same for the weirs Sambeek, Belfeld, and Roermond caused by a total closure of the Poiree part. For the other weirs, the consequences of a certain calamity are less or comparable to these three weirs.

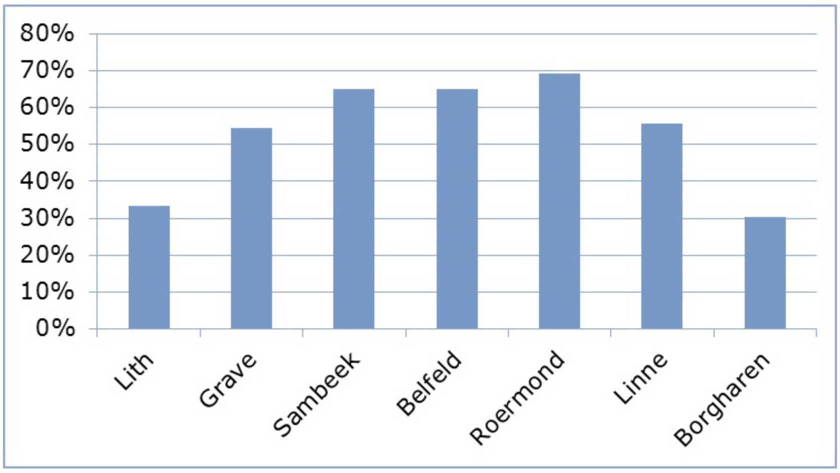


Figure 2.11: Relative closure of weirs according to Table 2.4

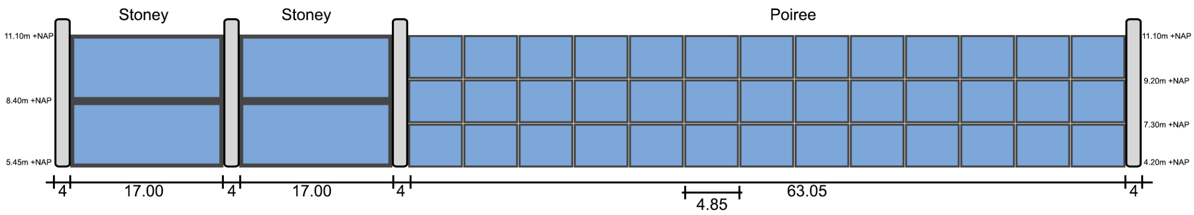
According to Table 2.5 the water level differences over these three residuary weirs are largest for weir Sambeek. Therefore it is assumed that also the attack the bed protection will be most severe for weir Sambeek. To use the most severe attack on the bed protection, the most conservative approach is used. For the other weirs, the circumstances will be less severe and be more safe.

The last criterion to use weir Sambeek as a model for the 'fictive' weir, is the bed protection itself. The bed protection of weir Sambeek is comparable to the bed protection of weir Grave, where the stability of the bed protection in this thesis is based on.

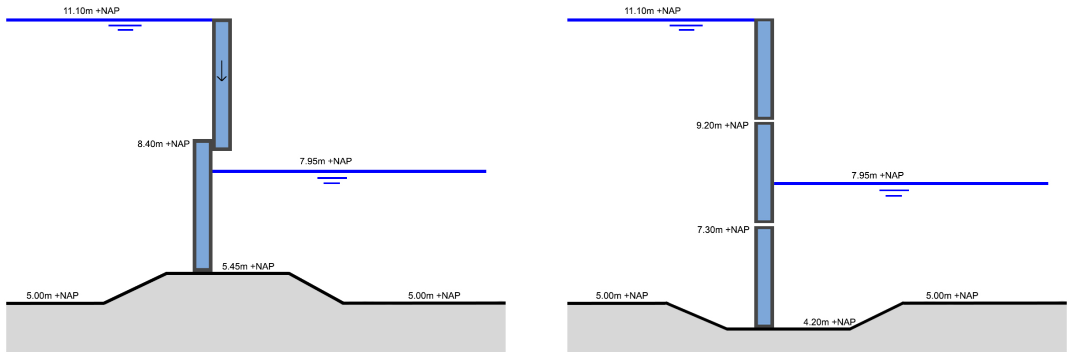
To summarize, the stability of bed protections due to calamities or maintenance in this thesis will be based on dimensions and data for Weir Sambeek. An overview of the important and characteristic values is given in the next paragraph.

2.4. Schematized Weir

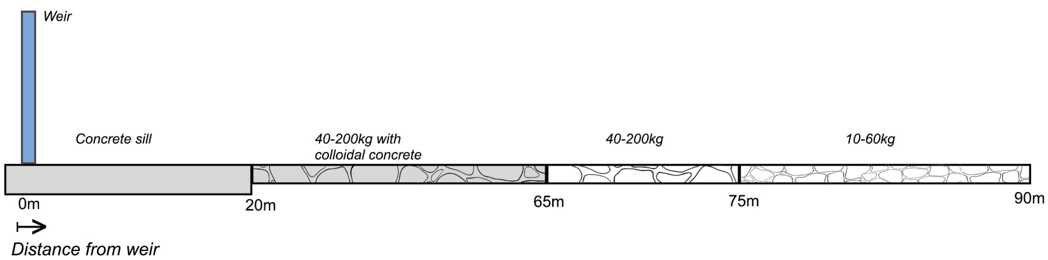
The weir which will be further investigated in this report, is based on weir Sambeek. This is a Stoney-Poiree weir with two 17-meter wide Stoney openings and a 63 meters wide Poiree part. The dimensions and used data of this weir are shown in Table 2.6. Figure 2.12 gives a schematic representation, including important dimensions, of this weir. The bed protections is based on weir Sambeek.



(a) Frontview



(b) Sideview. L: Stoney; R: Poiree



(c) Downstream bed protection

Figure 2.12: Schematization fictive weir

Table 2.6: Characteristics idealized weir

Characteristic	**Value**
Total width weir	113.05 m
Total width openings	97.05 m
Type	Stoney-Poiree weir
Distribution	2x Stoney & 1x Poiree
Target level upstream	11.10m +NAP
Target level downstream	7.95m +NAP
Stoney	
Width	17 m (each)
# slides	2 (per opening)
Level sill	5.45m +NAP
Level top	11.10m +NAP
Level lower slide	8.40m +NAP
Poiree	
Width (total)	63.05 m
# beams	13
Width panel	4.85 m
Level sill	4.20m +NAP
Level lowest row	7.30m +NAP
Level middle row	9.20m +NAP
Level top row	11.10m +NAP
Discharges	
Limit discharge	1150 m^3/s
Level winterbed	11.90m +NAP
Discharge winterbed starts	1400 m3/s

3

Calamities at weirs

This chapter describes possible calamities at a weir in the Meuse. This research will not focus on methods or alternatives to prevent calamities, like ship collisions. But will focus on long-term closure of a part of the weir. Long-term closure which can be caused by a calamity of maintenance. First is looked into past calamities for weirs in the river Meuse. Then the possible damages due to a ship collision are described. On the basis of the various calamities and damages eight closure scenarios are drafted.

3.1. Past calamities

The start of this thesis was the ship collision at weir Grave. An accident of this magnitude and with these consequences, never happened before in the nearly 100 years that the weirs are operational. In the past 15 years, based on public sources like newspapers and Rijkswaterstaat database, there occurred in total four noteworthy accidents with ship collisions on the river Meuse.

December 2016: Ship collision weir Grave
As mentioned in Chapter 1, a ship with 2000 tons benzene missed the exit to the ship lock and sails through weir Grave. Because of the collision 5 beams were completely damaged and the water level upstream of the weir drops 3 meter. Navigation is blocked, house boats are skewed, and companies suffer a lot of financial damage. It took about 3 weeks to recover the water level and 6 months to repair the weir. The total costs for reparation are estimated 20 million Euro's. The total damage for companies which could not navigate over the Meuse is estimated at tens of millions Euros (Source: `https://www.volkskrant.nl/es-b16e2f9e`).

January 2012: Ship anchor snagged weir Belfeld
During high discharge in January 2012 the Poiree part of weir Belfeld was lowered and shipping used this opening. A ship, the Spido II, which became uncontrollable due to motor problems was carried away by the strong current. In an attempt to slow down his ship, the skipper dropped the anchor. This anchor snagged the lowered Poiree part and damaged the weir. Only one beam was damaged. The weir could be raised as usual to the damaged beam, the rest of the weir was raised by a pontoon and a crane. By placing a (dry)dock around the damaged beam and the two adjacent beams, the weir could be repaired while the rest of the Poiree part was operational again. Problems would be much bigger if the complete Poiree could not be raised again (Source: (Schoones, 2012)).

January 2007: Defect slide weir Lith
During calamities and maintenance in January 2007, the slides of the weir were lifted one by one. During repair and maintenance, the slides were open for several hours. Due to the significant water level difference over the weir high flow velocities occurred behind the weir. These extreme high flow velocities considerably damaged the bed protection behind the weir. The bed protection and the slides were repaired again and no further damaged occurred to the weir (Source: (Kortlever, 2014)).

January 2005: Yacht over weir Borgharen
In January 2005 a motor yacht sailed over weir Borgharen. Due to a motor problem this vessel became uncon-

trollable and was pulled over the weir by a strong current. The yacht fell down 7 meters and broke into pieces. Six people, two women and four children survived the fall. Two men did not survive the fall. This accident is remarkable, because weir Borgharen is inaccessible for ships. The channel section behind this weir is not navigable for ships, they make use of the Juliana channel. The damage to the weir was minimal, but also here a vessel came into contact with a weir, with disastrous consequences (Source: https://www.cobouw.nl/).

Besides these large accidents, various ship accidents occur in the inland water in the Netherlands. Between 2006 and 2012 the total number of ship accident for inland waters, according MNV'13 (2013) is shown in Figure 3.1. A distinction is made in magnitude of the accidents. Since 2009 an accident is categorized significant if:

- Victims: dead, missing or severely injured
- Damage to the waterway: when immediately (within 7 days) after the accident measures/repairs are required to either the infrastructure or the object
- Damage to the ship: when the ship is no longer able to navigate on its own or is no longer allowed to
- Damage to cargo: with a minimal loss of 10 tons of cargo or at least one container
- Damage to the environment: in case of spillage of chemicals (packaged or non-packaged) or oil (fuel or cargo)
- Obstruction: complete obstruction of the waterway for the period of at least one hour after the accident

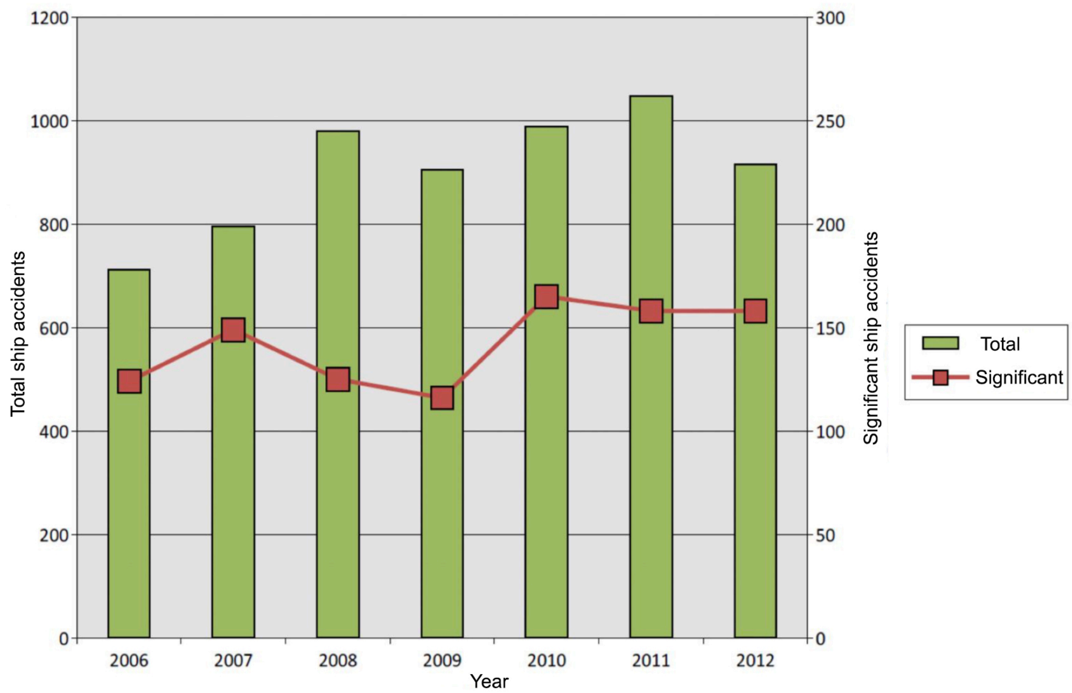


Figure 3.1: Number of registered yearly ship accidents and significant ship accidents, (MNV'13, 2013)

It should be noted that the majority of the accidents occurs at ship locks and in busy areas with a lot of commercial and recreational shipping.

3.2. Damages

Different calamities can occur at the weirs. Some are more severe and cause more damage to a weir then others. Furthermore the time to repair the damage after a calamity and the hydraulic conditions which change due to the calamity are of importance. The chance of a calamity like the Grave weir is very small, but the consequences are enormous. The Grave accident was the first accident, with these large long-term out of operation consequences, for ten weirs in the Netherlands in about 100 years. Therefore the chance for an accident like this is estimated to be 1×10^{-3} per year per weir.

One of the most severe calamities, and basis of this report, is an collision with a large vessel. This causes a large damage for a very long period. Also the reparation of this collision will take a very long time, so the chance of a high discharge wave, according to Table 2.2, in the period of reparation is very likely. The largest vessels on the Meuse are of CEMT Vb class. Characteristics of these vessels are shown in table 3.1.

Table 3.1: Characteristics CEMT Vb class according to Rijkswaterstaat (2017b)

Characteristic	**Value**
Length	172-185 m
Width	11.4 m
Depth	2.4 - 4.5 m
Capacity	3200 - 6000t

A collision to the fictive weir can happen to a Stoney slide or to the Poiree part of a weir. In case of a collision to a slide, it is assumed that the complete slide will fail. To repair the slide it is assumed that the complete opening between the pillars have to be closed. In case of a collision of a CEMT Vb vessel to the Poiree part it is hard to predict what the damage will be. The supports of the beams at a Poiree weir are much stronger than the beams which were hanging under the bridge at the Grave weir. During the Grave weir calamity, the vessel sails relatively easy through the beams and only damaged the beams over the width of the ships which broke down easily. For a Poiree weir, where the beams are solid connected to their foundation it is unknown whether the vessel will sail through the beams and only damages the beams over the width of the vessel or will cause much more damage to surrounding beams. Or possibly a 6000t vessel on full speed will destroy a larger part of the Poiree structure including its foundation. During the ship collision at weir Grave, a ship with also a width of 11.4 meters damaged five 5.45 meters wide beams. These beams were attached to the bridge and broken down relative easy as mentioned before. For a Poiree on a foundation it is assumed in this report that a lot more damage to adjacent beams will happen. Therefore in this thesis it is assumed that a collision with a Poiree will destroy 5 beams completely and on both sides also 2 beam will be damaged. In total the damage will cover a width of 9 beams each 4.85 meter wide, which have to be closed off for a reparation. In the analyses for the consequences also smaller damages, whereby less beams are damages, are taken into account.

Not all possible calamities are further described in detail. It can be stated that a relative large calamity with respect to the rest of the weir, has larger consequences for the weir and its surrounding. To generalize the calamities, not all individual calamities are described but a distinction is made in magnitude of the damage or better, the size of the weir which is not available or has to be closed. Furthermore it is assumed that a calamity is of a significant amount of time, which means at least several weeks to months. A period for which definitely measures have to be taken and in which a great variety in discharges is possible.

As mentioned before, the weirs will also be renovated in the next decades and therefore also (part of) the weir will be closed. In fact these are the same circumstances as closure due to a calamity. To generalize the closure of the weir, due to a calamity or due to maintenance, the next situations for the schematized Stoney-Poiree weir are investigated and assumed that this closure is of relevant time. Furthermore it should be noted that the closure of a number of beams, especially in the centre, with a rock-fill dam, will result almost always in a (much) wider closure. A rock-fill dam needs a slope to reach the necessary height and width of the dam. To decrease this required width, one could build the dam with a vertical wall (made of containers and anchored in the dam for example), to reduce the required width of the dam. The damages in this thesis are assumed to be on the side of the weir. The situations are also shown in Figure 3.2, in which the red colors indicate the (partial) closure of the weir and the blue parts are still used for water level management.

- 1 Stoney closed, increasing discharge (a)
- 2 Stoneys closed, increasing discharge (b)
- 1 row Poiree closed, increasing discharge (c)
- 2 rows Poiree closed, increasing discharge (d)
- Complete Poiree closed, increasing discharge (e)
- 3 beams Poiree closed, increasing discharge (f)
- 6 beams Poiree closed, increasing discharge (g)
- 9 beams Poiree closed, increasing discharge (h)

In the next chapter, the consequences due to these eight closure situations for water management, increased upstream water levels and flow velocities behind the weir are described.

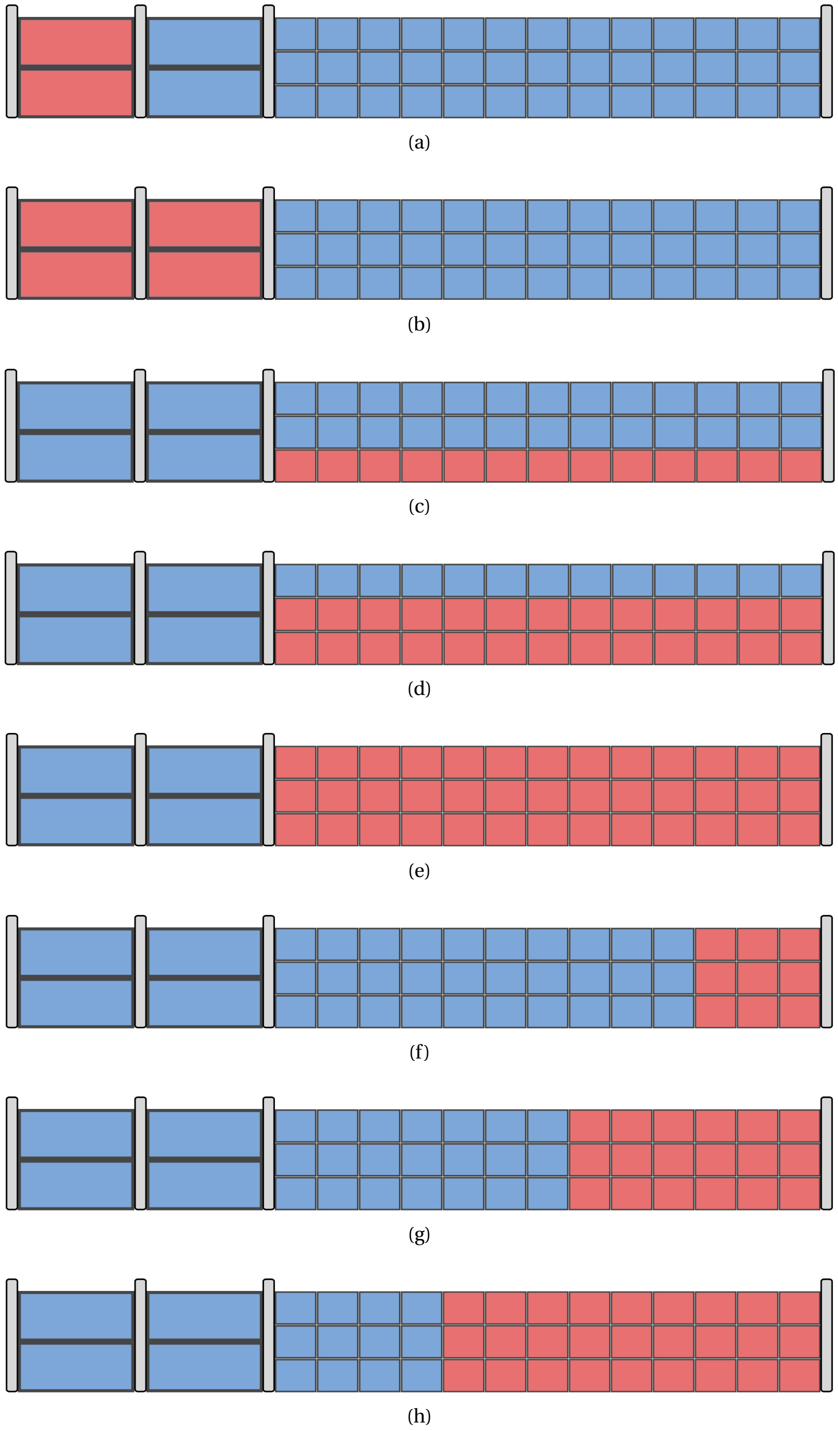


Figure 3.2: Closure situations

4

Hydraulic consequences due to partial closures

This chapter describes the consequences for the various closure situations. First, water management of the weir is discussed. One wants to maintain target levels, by removing slides or panels, as long as possible. The water management will change due to a partial closure of the weir. When it is no longer possible to maintain target levels because all the panels and slides are removed, the limit discharge is reached. From this moment the upstream water level starts to increase for a further increasing discharge. The maximum discharge, in this study, is reached if the upstream water level is equal to the flood plains. In this chapter the limit and maximum discharges are determined for the eight closure situations. Next, for three normative situations, the maximum flow velocities which will occur behind the weir due to those three closures and discharge situations are determined.

4.1. Water management

Not every (partial) closure is an immediate danger to the weir. When part of a weir is closed, still target levels can be maintained by the remaining part of the weir. Usually panels or slides are removed according to a specific occurring discharges. When part of the weir is closed, probably panels or slides have to be removed earlier for an increasing discharge. Whereby the limit discharge is reached earlier, and upstream water levels increases earlier. When no more panels and slides can be removed, the weir becomes a free flow river and the upstream water levels increase for an increasing discharge. Furthermore, earlier with respect to normal water management removing a panel from i.e. the second row can have a negative effect on the flow velocities behind this panel due to a combination in differences in discharge through the opening, a different upstream and a different downstream water level with respect to the default situation. Also the occurring discharge has an effect on the consequences of a calamity. An increasing discharge while part of the weir is closed, will cause higher velocities through the remaining openings. The consequences of a calamity can differ for varying discharges. The consequences for a partly closed weir become worse for an increasing discharge.

4.1.1. Discharge coefficients

The first parameters which have to be determined are the discharge coefficients for different configurations of the weir. The water levels and head losses, according to Rijkswaterstaat (2017a), of Weir Sambeek, on which the fictive weir is based, are shown in Table 4.1 and Figure 2.9(c). These are the water levels during normal operation.

These values are interpolated to make a more detailed calculation of the consequences of a closure. In Appendix C the table is shown with the interpolated values. Figure 4.1 shows the comparison between the upstream and downstream water levels from Rijkswaterstaat (2017a) and the (manually) interpolated upstream and downstream water levels. It can be concluded that the interpolated discharges values are in correspon-

Table 4.1: Waterlevels Weir Sambeek according to discharges Rijkswaterstaat (2017a)

Q_St. Pieter	**h_upstream**	**h_downstream**	**Δh** [m]
80	11.10	7.97	3.13
155	11.10	8.02	3.08
280	11.09	8.20	2.89
530	11.08	8.72	2.36
1030	10.78	9.98	0.80
1280	10.77	10.58	0.19
1500	11.31	11.10	0.21
1640	11.68	11.41	0.27
1994	12.51	12.18	0.33
2264	12.93	12.69	0.24
2534	13.26	13.11	0.15
2689	13.43	13.31	0.12
2790	13.52	13.42	0.10
2867	13.59	13.50	0.09
3010	13.71	13.61	0.10
3112	13.78	13.67	0.11
3430	14.05	13.94	0.11
3992	14.65	14.58	0.07

dance to the discharge values from Rijkswaterstaat (2017a).

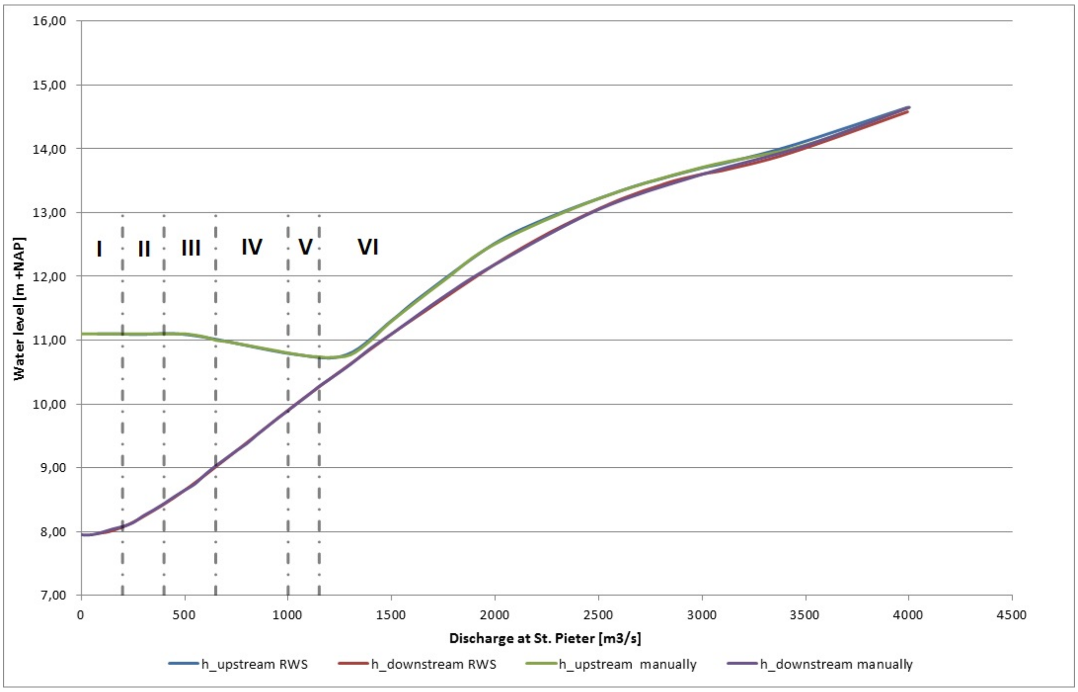


Figure 4.1: Interpolated water levels at Weir Sambeek

According to the water level management, Nooij (2010d) distinguishes six stages in water management:
I : 0 - 200 m^3/s: The Poiree part is on top at a level of 11.10 m +NAP and the discharge is regulated by lowering the Stoney slides. At a discharge of 200m^3/s it is no longer possible to increase the discharge capacity by lowering the slides because the Stoney slides are both on the sill.

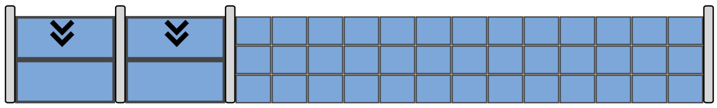
II : 200 - 400m^3/s: The regulate the discharge capacity of the weir the Stoney slides are raised again and panels are removed from the top row of the Poiree part. This is possible up to a discharge of 400m^3/s. At a discharge of 400 m3/s all the panels are removed and the Stoney slides are again on the sill.

III : 400 - 650m^3/s: In the same manner, now the panels from the middle row are removed. Up to a maximum of 650m^3/s, then all the panels from the second row are removed and the Stoney slides are again on the sill.

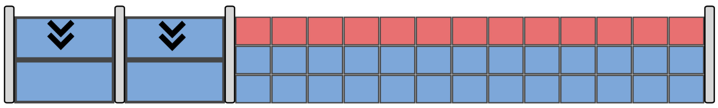
IV : 650 - 1000m^3/s: The Stoney slides are lifted one by one above the water level.

V : 1000 - 1150m^3/s: The lowest row of panels is removed from the Poiree part. This is a very labor intensive job and therefore only done if regulation with the Stoney slides is not possible anymore. At the end of this phase, also the bridge parts, which are located above the panels, are removed. Finally the beams are lowered to the bottom.

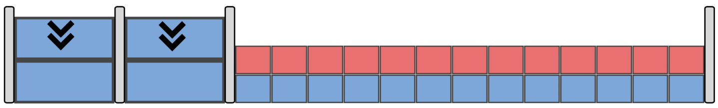
VI : >1150m^3/s: For discharges higher than 1150m^3/s, the Poiree part is completely lowered and the Stoney slides are lifted above water. Therefore the river becomes a free flow river.



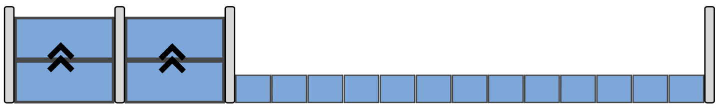
(a) Stage I



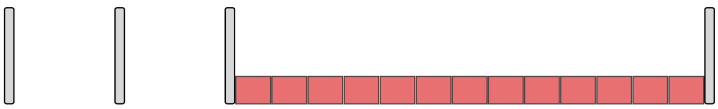
(b) Stage II



(c) Stage III



(d) Stage IV



(e) Stage V

Figure 4.2: Stages water management for increasing discharge

These phases are also shown in Figure 4.1 & 4.2 . The known situations with the positions of the Stoney and Poiree parts are summarized in Table 4.2. The situations are based on the water management with corresponding discharges and water levels. In between these situations it is not exactly clear what the positions of the different Stoney and Poiree parts are. These configurations are made manually on location based on upcoming predictions of discharges and the experience of the steward.

During water management and increasing discharges, different flow regimes occur over the panels and slides. Two flow regimes can be distinguished, namely free flow and submerged flow over the weir. For free flow the downstream water level (h_3) does not influence the upstream water level (H). H and h_3 are always relative

Table 4.2: Flow situations

Discharge	Position Stoneys	Position Poiree [m +NAP]
200 m3/s	Stoneys max down	Poiree 11.10
400 m3/s	Stoneys max down	Poiree 9.20
650 m3/s	Stoneys max down	Poiree 7.30
1000 m3/s	No Stoneys	Poiree 7.30
1150 m3/s	No Stoneys	No Poiree

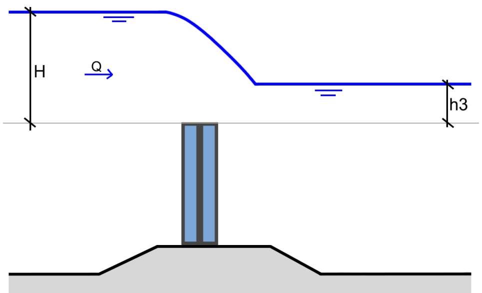
with respect to the top of the weir/sill (Figure 4.3). According to Nortier and de Koning (1996) the formulas for these two flow regimes are.

$$Q = m_f b H^{3/2} \text{ if } h_3 \leq 2/3H \qquad \text{(Free flow)} \tag{4.1}$$

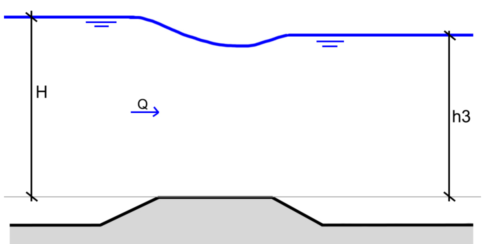
$$Q = m_s b h_3 \sqrt{2g(H-h_3)} \text{ if } h_3 > 2/3H \qquad \text{(Submerged flow)} \tag{4.2}$$

$Q =$	Total discharge	$[m^3/s]$
$b =$	Width of the weir	$[m]$
$H =$	Upstream water level wrt top weir of sill	$[m]$
$h_3 =$	Downstream water level wrt top weir or sill	$[m]$
$m_f =$	Discharge coefficient free flow	$[-]$
$m_s =$	Discharge coefficient submerged flow	$[-]$

In which m is a discharge coefficient for respectively free or submerged flow. In this report a combined discharge coefficient is used, which means that all the (energy) losses are merged into one single coefficient. The value of m_f and m_s can differ for different flow situation. The values for m_s and m_f are determined, on the basis of known situations.



(a) Free flow, h3<2/3H



(b) Submerged flow h3>2/3H

Figure 4.3: Flow regimes

For each flow condition it is determined if the flow over the weir, for a specific discharge, is a free or submerged flow. On the basis of the different known flow situations the discharge coefficient for different stages during water management are determined. The comprehensive calculations of the discharge coefficients can be found in Appendix D. The resulting discharge coefficients for various flow regimes are shown in Table 4.3.

As mentioned, the discharge formula which should be used is dependent on the flow regime. Furthermore the discharge coefficient is thereafter also dependent on the flow regime, and the configuration of the weir. Summarized, the total discharge which flows over the weir is given by the chart given in Figure 4.4.

Table 4.3: Discharge coefficients

Situation	Discharge coefficient
Free flow over Stoney	1.33
Free flow over middle row Poiree	1.21
Free flow over lowest row Poiree	1.03
Submerged flow open weir	0.70
Submerged flow lowest row Poiree	0.68

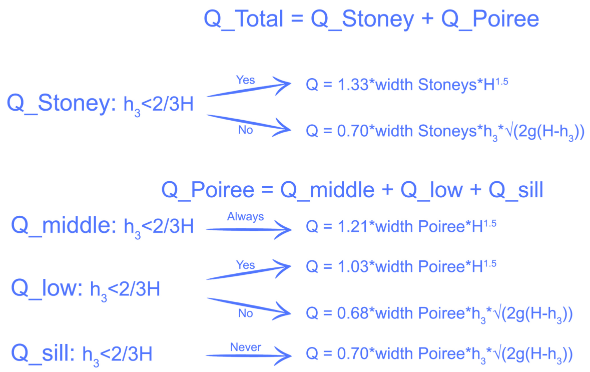
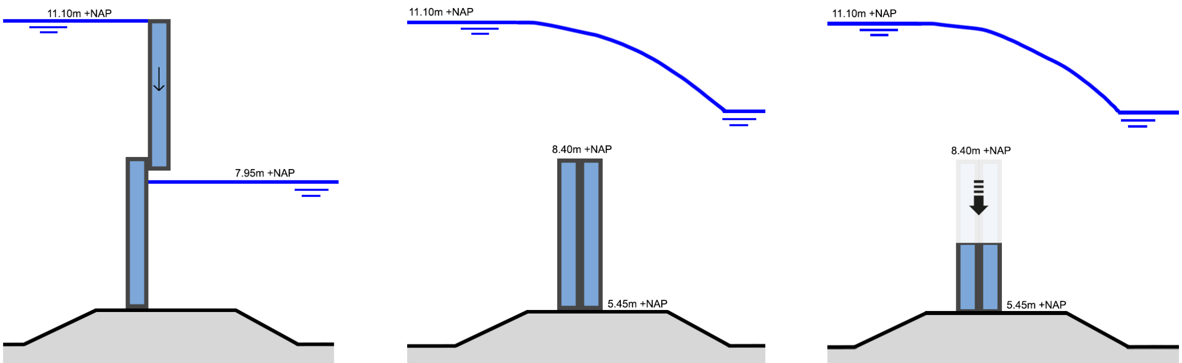


Figure 4.4: Discharge relations for various flow regimes

4.1.2. Schematization

In order to simulate the discharges and watermanagement in a simplified model it is assumed that both Stoney slides are lowered simultaneously. In contrast to reality, when one can operate the slides separately. In the model the discharge capacity is always first regulated by lowering the Stoney slides. As soon as the Stoney slides are located on the sill, with a top height of 8.40m +NAP, one should start to remove panels from the Poiree part. The position of the Stoney slides is determined manually and in reality this is done by the stewards. The discharge capacity over the weir, and therefore holding the upstream water level, is an iterative process whereby one can vary between lowering slides or removing panels. A steward determines in reality if he starts to remove panels, which is usually done when discharge is increasing for a longer time, or lowering slides, which can be done automatically. In this simplified model it is assumed that always first the Stoney slides are lowered to the sill. When they are located on the sill, one starts to remove panels from the Poiree and the slides are placed back to the top so that again the can be lowered in small steps to further increase the discharge capacity. This process repeats itself until only the lowest row of the Poiree part is still present. In reality, for discharges more than 650 m^3/s one starts to lift the Stoney slides one by one above the water level when the lowest row of Poiree panels is still present. In this model lifting slides above water, which creates underflow, is neglected. Instead of lifting above water, it is virtually assumed that the sides will be lowered further then their top height of 8.40m +NAP, as shown in Figure 4.5. Because of this assumption, there is always flow over the slide and no underflow. The slides can maximum be lowered to a level of 5.45m +NAP, to the level of the sill.



(a) Slides top position (b) Slides lowest position (c) Virtually further decreasing

Figure 4.5: Virtually lowering slides

4.1.3. Actual water management

In Appendix E the calculation sheet which is used to model the water management of weir Sambeek is shown. The steps which are calculated in this sheet are:

1. Assume a certain discharge.
2. Determine H and h_3 (according to Figure 4.3).
3. Calculate flow regime ($h_3 < 2/3H$).
4. On the basis of flow regime, level of the slides and number of panels at a certain level, the total discharge for that specific configuration is calculated according to flow chart 4.4.
5. Check if assumed discharges is in correspondence with calculated discharge ($|\Delta Q| < 25$). If necessary, adjust weir configuration.

The positions of the slides and the number of panels which should be removed is adjusted manually, by changing the yellow cells, until the calculated discharge differs less than 25 m^3/s to the occurring discharge. The sum of placed panels is equal to 13, but can differ over the levels. The water management is in accordance with reality till the limit discharge, a completely open weir. For further increasing discharge, the discharge capacity over the weir is no longer correct because the discharge relation differ to formula's 4.1&4.2.

4.1.4. Model

In order to project the water level management for the different closure situations an adjustment is made to the upstream water levels in the model. According to the water management of weir Sambeek, the upstream water level is lowered for discharges higher than 500m^3/s due to a change of target point. In order to generalize this model, and make it applicable for more weirs, this decreasing water level is neglected. In this model it is assumed that the water level remains 11.10m +NAP until the Stoney slides are completely lowered, and all the panels from the Poiree part are removed. From this point, the upstream water level starts to increase for an increasing discharge. The downstream water level are unchanged, because they are dependent on the downstream channel section and target levels. Figure 4.6 shows the comparison between the original water levels and the manually determined water levels, which will be used in the model. The corresponding exact values of the water levels for the various discharges are also shown in Appendix C.

4.1.5. Limit discharges

The first parameter which is determined from the calculation sheets is the limit discharge. The limit discharge, as mentioned before, is the discharge to which it is possible to maintain the upstream water level. Up

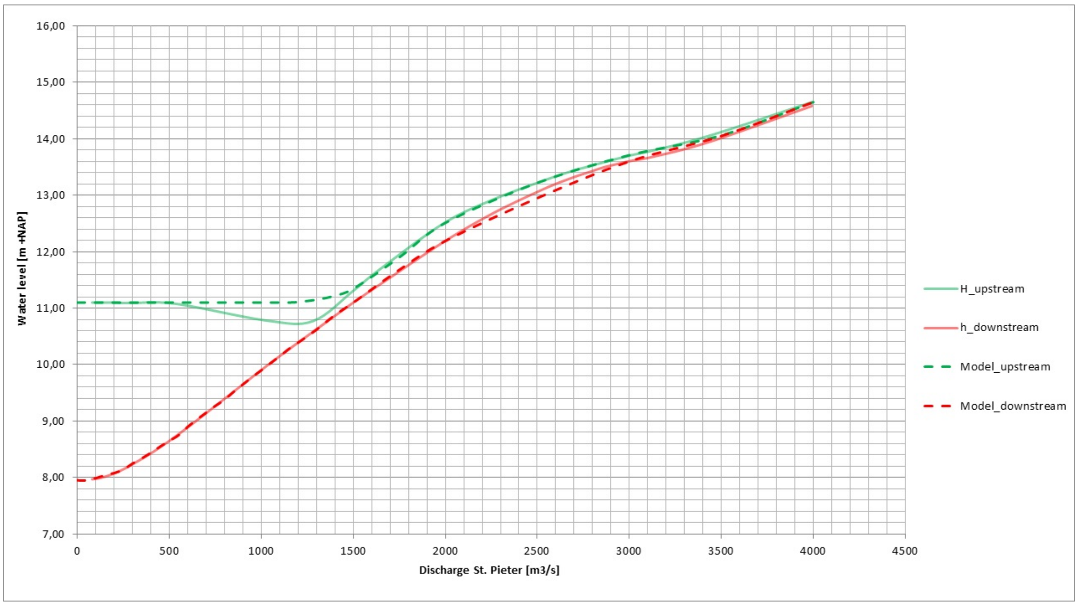


Figure 4.6: Water levels Sambeek from Rijkswaterstaat (2017a) vs. modeled water levels

to this discharge it is possible to remove panels or lower slides. From the limit discharge this is no longer possible and the weir is completely open. In Appendix E the calculation sheets for the different closure situations are shown. According to these calculations the various limit discharges are shown in Table 4.4.

Table 4.4: Limit discharges calamities

Situation	**Limit discharge [m3/s]**	Decrease capacity [%]
Normal operation	1150	0
Model	1300	0
1 Stoney closed	1200	8
2 Stoneys closed	1100	15
1 row Poiree closed	1000	23
2 rows Poiree closed	750	42
Complete Poiree closed	600	54
3 beams closed	1200	8
6 beams closed	1100	15
9 beams closed	850	35

It is visible that the limit discharge of the model is higher than the limit discharge of weir Sambeek. This is due to the fact that the upstream water level is higher and therefore the water level difference over the weir is higher. A higher head loss over the weir causes a larger discharge capacity whereby it is possible to remove panels lor lower slides later than for the Sambeek weir. Furthermore it is clearly visible that for a larger relative closure, the limit discharge is reached earlier. In other words, panels and slides have to be removed faster.

4.1.6. Increased upstream water level

From the moment that the limit discharge is reached and the weir is completely open, the upstream water level will increase for an increasing discharge. According to de Loor and Weiler (2017) the normative discharge is maximum if the upstream water level is equal to the level of the flood plains. For further increasing discharge and water level, the flood plains start discharging water and the flow velocities behind the weir will not further increase or eventually decrease. Therefore, in this thesis, the maximum discharge is reached if the upstream water level is equal to 11.90m +NAP, the level of the flood plains for weir Sambeek (Nooij, 2010d). In the calculation sheets from Appendix E the upstream water level is manually increased until the value of 11.90m +NAP is reached. The discharge coefficient for an open weir is kept constant, the formula for submerged flow is used. The downstream water levels are not changed because these are dependent on the discharge and the downstream channel section which are not affected by a modification at the weir. The maximum discharges for the different closure situations are shown in Table 4.5.

Table 4.5: Maximum discharges before winterbed starts discharging water

Situation	Maximum discharge [m3/s]
Normal operation	1575
Model	1575
1 Stoney closed	1500
2 Stoneys closed	1377
1 row Poiree closed	1317
2 rows Poiree closed	1000
Complete Poiree closed	742
3 beams closed	1482
6 beams closed	1344
9 beams closed	1123

According to this table, it can be concluded that for an increasing partial closure, the maximum discharge is reached earlier with respect to a complete functioning weir. If the maximum discharge is lower it also means that the probability this discharge will occur during reparation will increase. The maximum and limit discharges are input values for the calculation of the expected flow velocities behind the weir. In the next section the flow velocities behind the weir are calculated. The velocities for three normative situations are described in detail.

4.1.7. Flow situation

In the next section the flow velocities behind the weir for various partial closure situations will be calculated. Instead of calculate for all closure situations the flow velocities, three characteristic and normative situations are considered. A calamity in which the lowest and middle row are not available are not further taken into account. These kind of calamities occur mostly due to failure of installations or materials of the weir itself and are assumed to be fixed in a relative short time. The closures which will be further investigated are:

- 1 Stoney closed (Situation (a) from Figure 3.2)
- 6 beams closed (Situation (g) from Figure 3.2)
- Complete Poiree closed (Situation (e) from Figure 3.2)

1 Stoney closed:
The possibility that a single Stoney part of the weir is closed for a longer time is very likely. This can be due to maintenance or a calamity. The probability that both Stoneys are closed at the same time or due to the same calamity is assumed to be negligible and therefore not further taken into account in this Thesis. The probability that the limit ($1200 m^3/s$) and maximum ($1500 m^3/s$) discharge occur during the closure is assumed to be likely according to Table 2.2 and Figure 2.2.

6 beams closed:
Closing 6 beams of the Poiree part means that 29.1m of the weir will be closed. This is approximately 1/3 of the total width of the weir. Furthermore the dimensions of a closure of 6 beams is comparable to the damage which occurred at weir Grave, where 5 beams were damaged. The probability that the limit ($1100 m^3/s$) and maximum($1344 m^3/s$) discharge occur during the closure is approximately equal to the closure of 1 Stoney and assumed to be likely.

Complete Poiree closed:
A complete closed Poiree is assumed to be an extreme situation. If the complete Poiree is closed, nearly 65% of the total width of the weir is closed. This is an extreme situation but comparable to weir Grave, where 55% of the weir was closed by the rock fill dam. The probability that the limit ($600 m^3/s$) and maximum ($742 m^3/s$) discharges occur during closure is very likely.

Besides the limit and maximum discharges, also intermediate discharges can be relevant for flow velocities behind the weir. As described in the previous paragraph, one has to change the default weir configurations when part of the weir is closed. Due to this change slides and panels are removed earlier than during normal management. More discharge, a higher head loss and higher flow velocities will occur behind the remaining opening of the weir. For example, during normal water management, the first Poiree panels from the middle row will be removed for discharges higher than $400m^3/s$ with a water level difference of 2.66m over the weir. When 6 beams are closed, the first panels from the middle row will be removed for discharge higher than $300m^3/s$ according to Appendix E. The water level difference over the weir is in that case 2.85m. Therefore also the flow velocities for half the limit discharge will be considered. The configuration of the weir depends on the situation which is considered. Figure 4.7 shows the situations which are considered in the following flow velocity calculations. The considered discharges are based on Appendix E, where water management for different closure situations was modeled. In the next paragraph the flow velocities for the following situations are calculated.

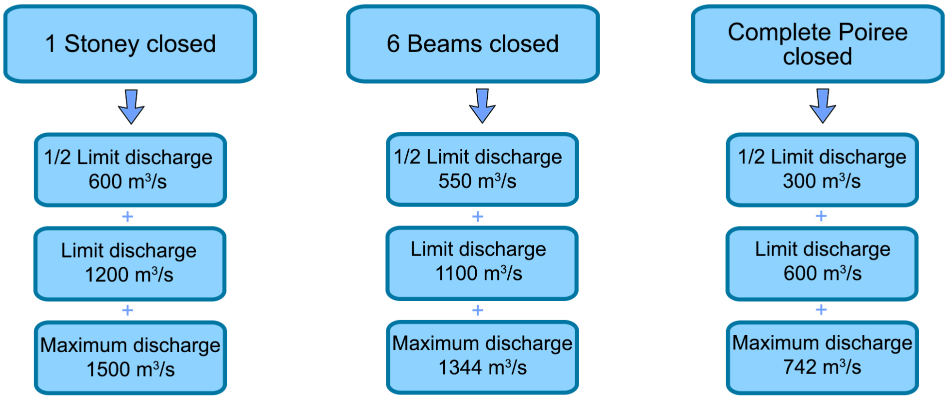


Figure 4.7: Flow velocity situations

4.2. Flow velocities

To determine the occurring flow velocities behind the weir, various calculation methods are used based on the flow situation. The input variables and the calculation methods including the assumptions which are made, are discussed below. The configuration of the weir for the 1/2 limit discharge is determined and in agreement with Appendix E. Furthermore, the discharge and upstream and downstream water levels are also based on Appendix E. First the contraction coefficient for different closure situation is determined.

Contraction coefficient

Due to the partial closure, the flow through the weir will be contracted. In the calculations of the flow velocities, there is a distinction made in the amount of contraction. In this Thesis contraction is categorized in small, considerable and severe. A small contraction coefficient (μ) is used when the flow through an opening is hardly changed. Only due to the pillars, little contraction will occur. If a larger part of the weir is closed, the flow through the remaining opening will be contracted severe. This is comparable to the closure of Grave weir. The contraction coefficient for this situation was around 0.88 based on a flow lines model made by Deltares, shown in Figure 4.8.

In case of a total closure of the Poiree part, the contraction is assumed to be higher. For intermediate cases, the contraction coefficient will be in between. Therefore the three contraction coefficients, as shown in Table 4.6, are used in the calculation. In the calculations it is assumed that the closed part of the weir is on the outer side of the weir. In other words, the flow will be contracted only to one side of the remaining opening of the weir.

Figure 4.9 shows an example of the contraction coefficients used for the situation whereby 1 Stoney gate is closed. Because the contraction of the flow through the Poiree part is negligible and only contraction due to the pillars occurs, a μ value of 0.95 is used for the Poiree part. The contraction through the remaining Stoney opening is more severe and therefore a value of $\mu = 0.90$ is used.

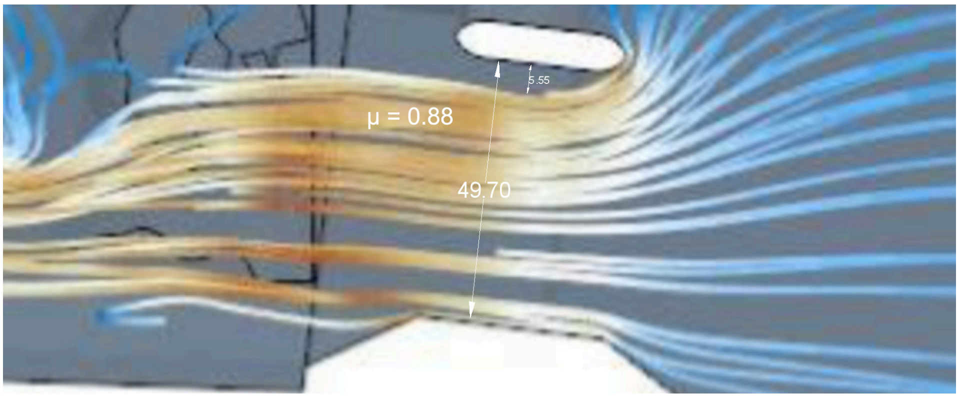


Figure 4.8: Contraction coefficient Grave weir, de Loor and Weiler (2017)

Table 4.6: Contraction coefficients

Flow situation	μ
Small change in flow lines	0.95
Intermediate situation	0.90
Severe contraction	0.85

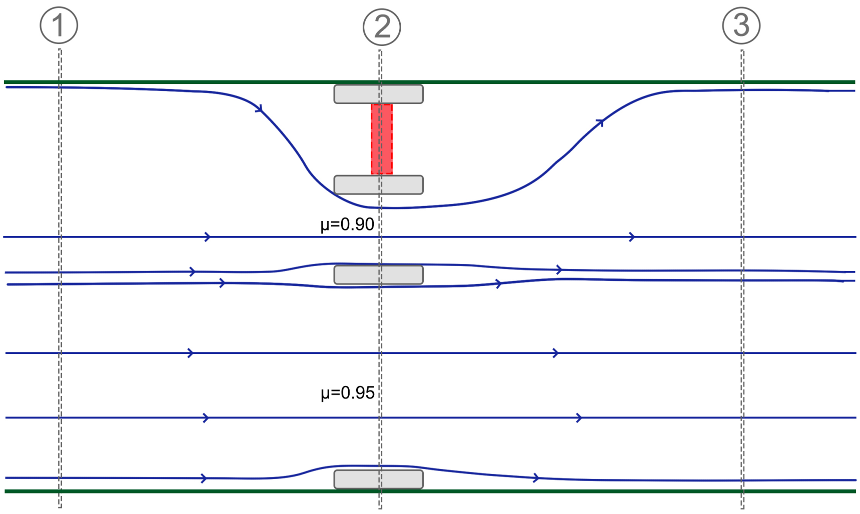


Figure 4.9: Contraction coefficient 1 Stoney closed

Reattachment point

For the 1/2 limit discharge calculation, there are still panels and slides present in the weir. The flow over these panels is a free flow and falls into the downstream water level. The location where the overflowing jet will touch the bottom, and starts to spread, is based on the combination of the reattachment point over a long sill and the reattachment point for a free overflowing jet. In case of an undisturbed free flow over a sharp crested weir, the reattachment point can be calculated due to the horizontal flow velocity on top of the weir and the gravitational acceleration. In case of a long sill, the reattachment point is located 5-7 times the step height behind the sill, Figure 4.10.

The overflowing jet is not a complete free falling jet before it touches the bottom due to a downstream water level behind the weir. This downstream water level will very likely ensure a reattachment point further away from the weir with respect to an entirely free fall jet. The situation considered in this calculation is in between a free overflow and a flow over a long sill. Therefore in this Thesis, for an overflowing jet in combination with a downstream water level where the jet falls, the reattachment point is assumed to be 3 times the weir height.

Spread

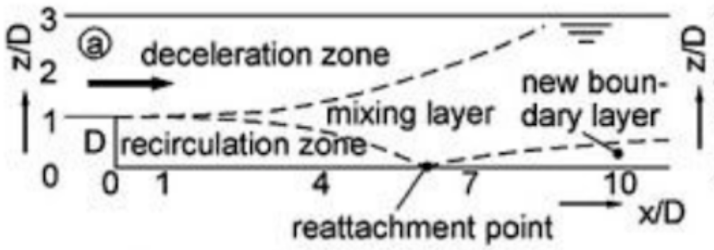


Figure 4.10: Location reattachment point, (G.J. Schiereck, 2012)

At the 1/2 limit discharge the flow over the slides and panels is a free flow. To calculate the flow velocity it is assumed that the overflowing jet is unchanged till it touches the bottom. From the moment the overflowing jet touches the bottom, the reattachment point, the bottom of the jet remains on the bottom and bed protection level. The top of the jet spread at an angle of 1:12 to the water surface (A. Franken, 1995). The depth averaged flow velocity is equal to the discharge divided by the width of the jet and the height of the jet. From the moment the jet height is equal to the water depth, the flow starts to spread also in horizontal direction. An angle of 1:20 is assumed to each side, 1:10 together. In the calculations it is neglected that the jet will already spread in horizontal direction before it reaches the water surface and the jet will also spread in vertical direction before it touches the bottom. Therefore this method is little conservative. The bed level is assumed to be horizontal at a level of 5.00m +NAP according to Nooij (2010d). In reality the level of the bed protection decrease which increases the water depth and therefore decreases the flow velocities above the bed protection. The maximum flow velocity over the weir is based on the head difference by formula 4.3. The minimum height of the overflowing jet, according to this maximum flow velocity is given by formula 4.4.

$$u_{max} = \sqrt{2g\Delta H} \tag{4.3}$$

$$d_{min} = \frac{Q}{\mu b u_{max}} \tag{4.4}$$

The flow velocity at a distance from the weir is finally calculated by:

$$u_x = \frac{Q}{\mu b d_x} \tag{4.5}$$

$$d_x = d_{min} + 1/12x \qquad (\max d_x = h_3)$$

If $d_x = h_3$, horizontal spread is taken into account.

$$\mu b = \mu b + 1/10x$$

In these equations x is defined as the distance from the reattachment point. The determine the flow velocity at a distance from the weir, where a specific type of bed protections starts, the distance of the reattachment point has to be added. The location which are of our interest are on the edges of the various bed protections. Figure 4.11 shows a schematization of the flow velocity calculation, the used parameters and the edges of the various bed protections of the fictive weir.

An example of the determination of the flow velocities at the 1/2 limit discharge behind the weir during the closure of 1 Stoney gate is given below. The input parameters and configuration of the weir are shown in Table 4.7 and Figure 4.12.

The flow velocities behind the weir, due to the closure of 1 Stoney gate at the 1/2 limit discharge, are shown in Figure 4.13. Determinations of the other closure situations can be found in Appendix G.

Open weir
For the situation when the weir is completely open, at the limit and maximum discharge, the flow velocity

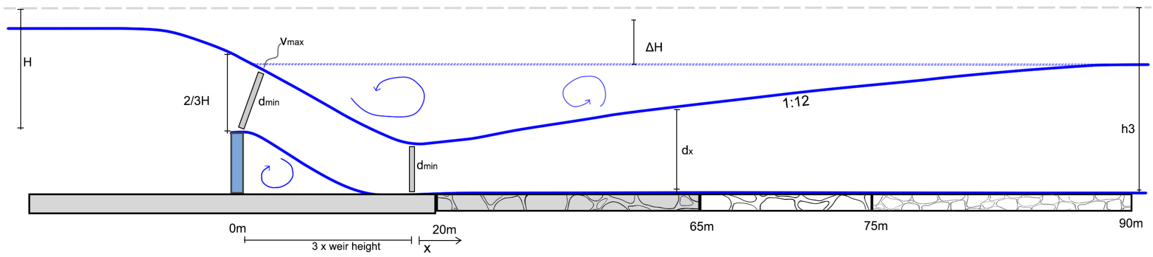
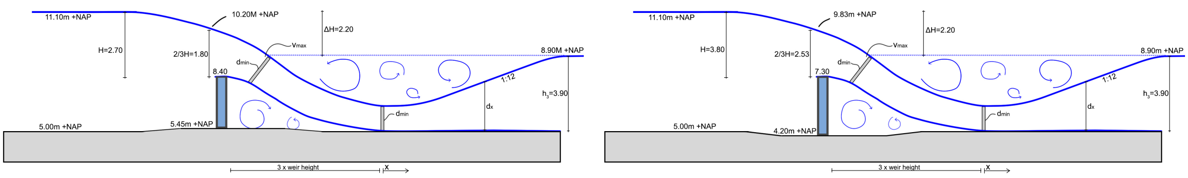


Figure 4.11: Schematization spread overflowing jet

Table 4.7: Parameters 1/2 limit discharge 1 Stoney closed according to Appendix E

Total Q [m3/s]	**Upstream water level [m +NAP]**	**Downstream water level [m +NAP]**	**Width river[m]**	**h3 [m]**	**u3 [m/s]**
581	11.10	8.90	113.05	3.90	1.32
	Flow over Stoney	**Flow over Poiree**			
μb	15.30	59.90	m		
Q	100	481	m^3/s		
Height weir	2.95	3.10	m		
Reattachment point	8.85	9.30	m		



(a) Flow over Stoney part (b) Flow over Poiree part

Figure 4.12: Weir configuration according to Appendix E

is calculated by an energy equation over the weir. This energy equation is based on Bernoulli's and Carnots equation [4.6] and the continuity equation [4.7]. Bernoulli's equation is valid for an accelerating flow between a cross section 1 (upstream of the weir) and a cross section 2 (middle of the weir). Between cross section 2 and cross section 3 (downstream of a weir) the flow is decelerating and energy is lost. This loss of energy is calculated with Carnots equation. The sections are also shown in Figure 4.14.

$$h_2 + \frac{u_2^2}{2g} = h_3^* + \frac{u_3^2}{2g} + \frac{(u_2 - u_3)^2}{2g} \tag{4.6}$$

$$Q = \mu b_2 h_2 u_2 = b_3 h_3 u_3 \tag{4.7}$$

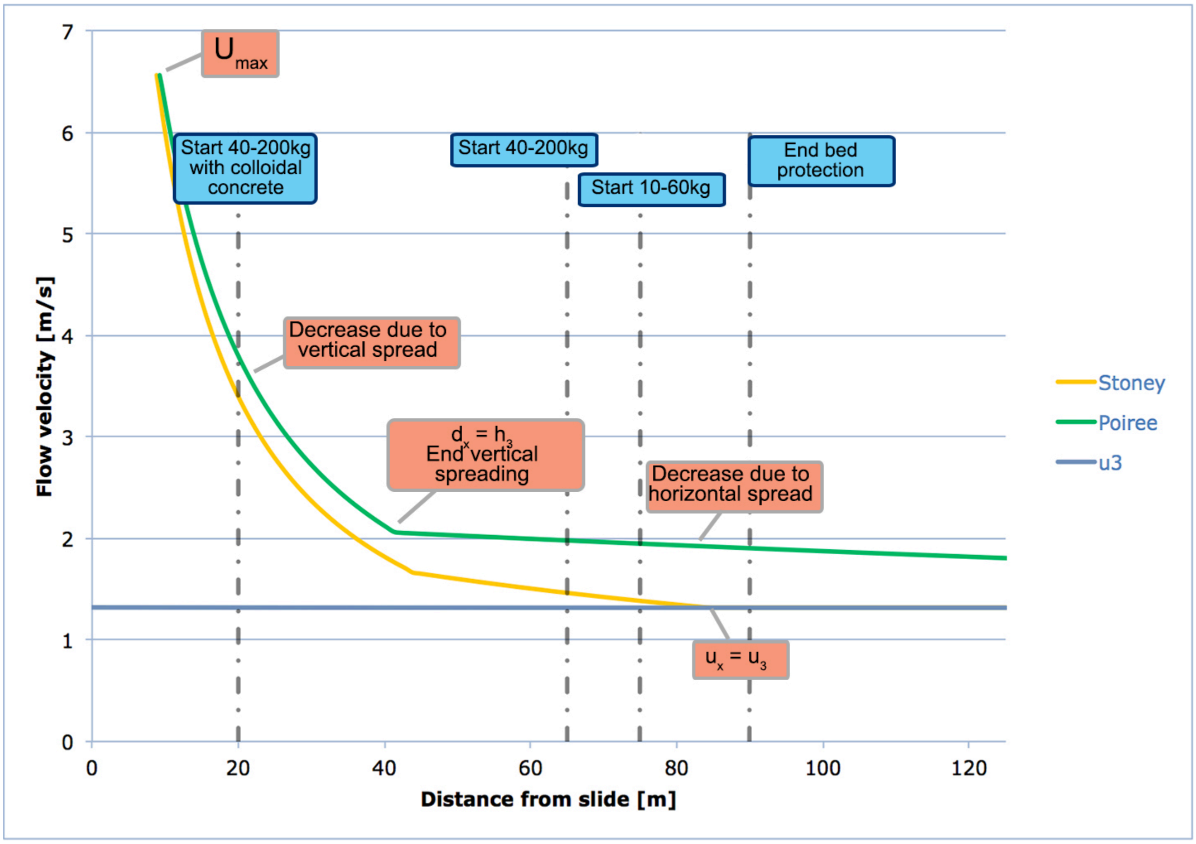


Figure 4.13: Flow velocities behind the weir due to 1 closed Stoney gate

In which:

$h_2 =$	Water depth above sill	$[m]$
$u_2 =$	Depth averaged flow velocity above sill	$[m/s]$
$h_3^* =$	Downstream water level wrt sill	$[m]$
$u_3 =$	Depth averaged flow velocity downstream	$[m/s]$
$Q =$	Discharge	$[m^3/s]$
$\mu =$	Discharge coefficient	$[-]$
$b_2 =$	Total available width weir	$[m]$
$b_3 =$	Total width river	$[m]$
$h_3 =$	Water depth downstream	$[m]$

In these formulae the subscripts 2 and 3 refer to the cross sections. The flow velocity over the bed protection is assumed to be equal to the flow velocity in the middle of the weir, section 2. Again this is a conservative calculation whereby the flow velocity at the location of the bed protection further away from the weir is overestimated. In this calculation there is no distinction made between the flow velocity behind the Stoney and Poiree part. Furthermore, the total width of the weir, which is available to discharge water, is a combination of contraction coefficients of both the Stoney and Poiree parts. The level of the sill of the Poiree part and the Stoney part are different. In the situation for an open weir, an averaged sill height is assumed for the total width of the weir. Therefore the height of the sill becomes:

$$\frac{34 * 5.45 + 63.05 * 4.20}{97.05} = 4.64m + NAP \tag{4.8}$$

The last check for the flow velocity calculation of an open weir is the Froude number. The Froude number is, according to Nortier and de Koning (1996), given by:

$$FR = \frac{u}{\sqrt{gd}} \tag{4.9}$$

For Froude numbers <1 the flow is subcritical. For Froude >1 the flow becomes supercritical and a hydraulic jump will appear.

The schematization of the flow velocity during the closure of 1 Stoney gate at limit discharge is shown below (Figure 4.14). The input parameters are based on Appendix E. According to formulae 4.6 & 4.7, the depth averaged flow velocity above the sill becomes 2.97m/s. This flow velocity will decrease till it is equal to the flow velocity far downstream of the weir (u_3). In this Thesis no further research is done to the decreasing magnitude of the flow behind an open weir. The flow velocity calculated above the sill is taken constant over the entire bed protection. This is a conservative method, because the actual flow velocities will decrease behind the sill due to spreading of the flow in horizontal way due to contraction and in vertical way because the water depth increases due to a decreasing bottom level. The Froude number for this situation is 0.40 which means the flow remains subcritical. The calculations for the maximum discharge and other closure situations can be found in Appendix G.

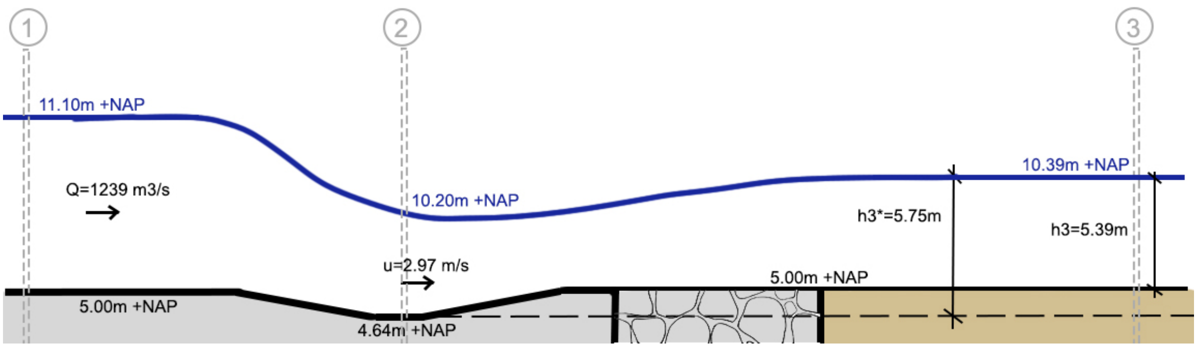


Figure 4.14: Flow velocities limit discharge, 1 Stoney closed

4.3. Overview

An overview of the maximum flow velocities which occur for the different closure and flow situations is shown in the Table 4.8 below.

The highest flow velocities behind the weir occur for a complete closure of the Poiree part. With increasing discharges, the flow velocities increase significantly. The assumption that the flow velocity remain constant over the entire bed protection is a very conservative approach. It can be seen from Table 4.8 that the differences between flow velocity above the weir and the flow velocity far away from the weir (u_3) are large. Especially for the complete closed Poiree part, it is very likely that the flow velocity at a specific distance behind the weir are lower than present in this table.

In these calculations no Froude number is determined for the 1/2 limit discharge. During the 1/2 limit discharge loads, there are still panels and slides present in the weir, and a free flow over these panels occurs. It is likely that the supercritical overflowing jet will result in a hydraulic jump. Because the width of the overflowing jets is relatively small with respect to the downstream water levels, furthermore due to the presence of a sink behind the weir it is assumed that the hydraulic jump will be repressed against the slides. For the open weir situations the flow remain subcritical. Only in case of the maximum discharge with a complete closed Poiree part a supercritical flow, with a Froude number 1.02, behind the weir occurs. Due to this supercritical flow, a hydraulic jump will appear behind the weir and probably above the bed protection, where the water depth increases.

Table 4.8: Overview flow velocities behind weir in m/s

Location	**Start 40-200kg colloidal**	**Start 40-200kg**	**Start 10-60kg**	**End bed protection**	**Downstream u3**	**FR**
Distance from weir [m]	20	65	75	90		
1 Stoney closed						
1/2 q_{lim}	3.42	1.47	1.39	1.32	1.32	-
q_{lim}	2.97	2.97	2.97	2.97	2.03	0.40
q_{max}	3.17	3.17	3.17	3.17	2.16	0.41
6 beams closed						
1/2 q_{lim}	3.17	2.32	2.26	2.17	1.34	-
q_{lim}	3.32	3.32	3.32	3.32	1.88	0.46
q_{max}	3.72	3.72	3.72	3.72	2.07	0.50
Complete Poiree closed						
1/2 q_{lim}	3.96	2.70	2.62	2.52	0.84	-
q_{lim}	5.36	5.36	5.36	5.36	1.38	0.89
q_{max}	6.27	6.27	6.27	6.27	1.54	1.02

The values from Table 4.8 will be compared to the flow velocities which occurred during the Grave weir calamity. In the next chapter, the stability of the bed protections at weir Grave is analyzed. In this analysis is looked into the stability of the various (temporary) measures which were used after the calamity, the flow velocities which occurred at Grave, and the damages which occurred. In the end the flow velocities which occurred at Grave are compared to the flow velocities which could occur during considered closure situations. Finally an advice is given about the measures, based on Grave, which should be used during a (partial) closure situation.

5

Analysis Grave

To protect the present bed protection after the calamity to extreme flow circumstances caused by the closure of nearly 55 % of weir Grave, additional measures had to be taken. Due to the closure highly increased flow velocities sould occur behind the remaining opening of the weir. Furthermore, due to this closure, a high upstream water level and low downstream water level, a hydraulic jump occurred above the present bed protection. This hydraulic jump causes an extreme pressure gradient, which could damage the bed protection and therefore threatens the stability of the weir. In order to protect the bed protection an additional ballasting layer of large rock material was made to prevent erosion of the bed protection and instability of the weir. In this chapter an analysis is made about the stability of the used emergency measures at weir Grave. The critical velocity of a certain measure is compared to the damage and to the flow velocities which occurred. The occurred flow velocities are based on simplified calculations and various computer models made by Deltares.

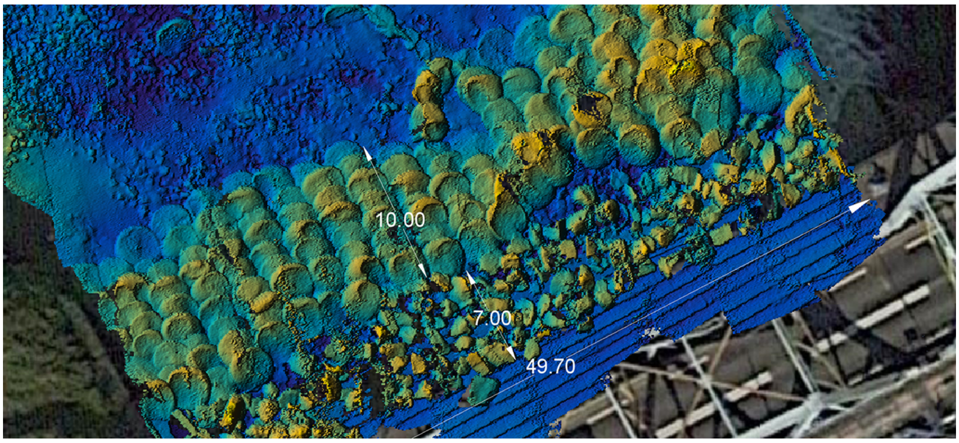
5.1. Rock Nets

Initially the sill consisted of 3-6t carefully placed stones over a length of 7 meters and behind these stones overlapping and coupled 4tons rock nets over a length of 10 meters, as shown in Figure 5.1. This sill started 15 meters behind the weir. It was important that this additional sill was of limited height otherwise the discharge capacity of the remaining opening of the weir would even further decrease. Whereby an even worse flow scenario could occur. The carefully placed stones and the rock nets were placed on the 22th of February 2017. Figure 5.1(a) shows a multibeam image after placing the stones and rock nets. Figure 5.1(b) is a multibeam of 24th of February, and is it clearly visible that some of the rock net moved downstream. Figure 5.1(c) is a multibeam made on 28th of February and nearly all the rock nets moved downstream of their original location. Damages to the 3-6t stones are not visible in Figure 5.1. Despite the large mass of the rock nets, it turned out they where not able to withstand the occurring flow velocities in contrast to the (lighter) carefully placed stones. In the analysis of the stability of the rock nets first the loads, the occurred discharges and flow velocities are considered. Then these loads are compared to various know stability formulas about rock nets. Finally a conclusion is drawn about the stability of the rock nets used after the Grave weir calamity.

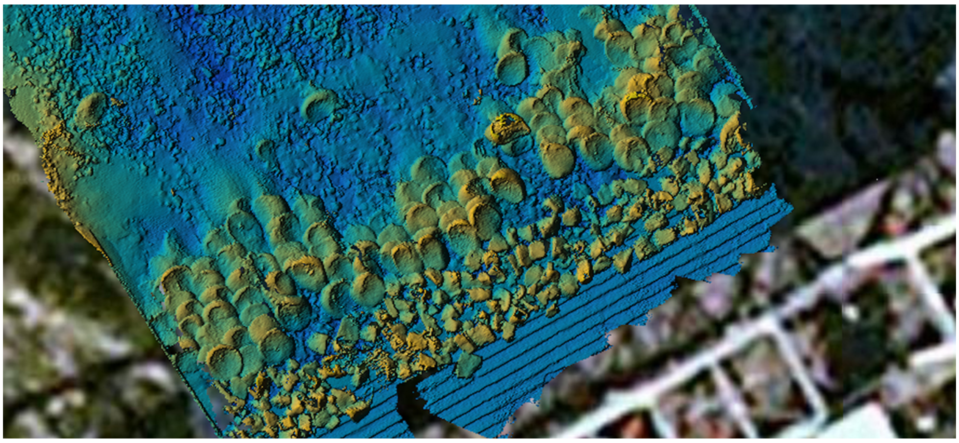
5.1.1. Loads

The carefully placed stones and the rock nets were placed on 22th of February. In the period after placing the stones and rock nets, discharges around 450 m^3/s occurred with some extremes up to 500 m^3/s. Figure 5.2 shows the discharges at Megen in the period 22th to 28th February, the period that the rock nets were placed and moved downstream. Megen is a measurement station 13 kilometers downstream of weir Grave. Furthermore this figure shows the downstream water level at weir Grave for the considered period, the upstream water level is approximately 7.85m +NAP, according to the water management.

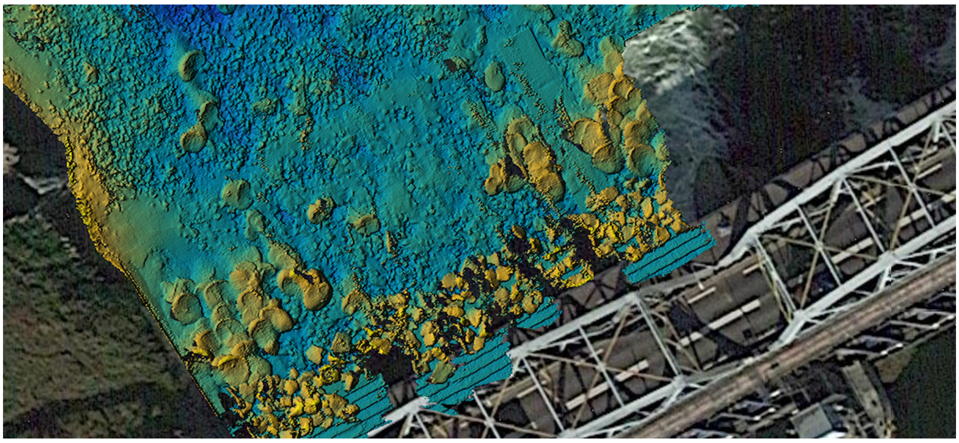
According to de Loor and Weiler (2017), Figure 5.3 gives an estimation of the weir configuration for increasing discharges during the partial closure of weir Grave. From this picture it can be concluded that for a discharge



(a) Multibeam February 22th



(b) Multibeam February 24th



(c) Multibeam February 28th

Figure 5.1: Failure of rock nets, (Multibeam images made by Paans van Oord)

of 450m^3/s, the upper row panels and four panels of the middle row are removed from the southern opening of weir Grave. The lowest row and 5 panels from the middle row are still present. In this Thesis there is no calculation made for the flow velocities behind a weir for intermediate conditions i.e. not all the panels are removed from a specific row. This creates a complex flow regime whereby the discharges differs over the various panels. To estimate the flow velocity over the rock nets at a discharge of 450m^3/s three situations are considered.

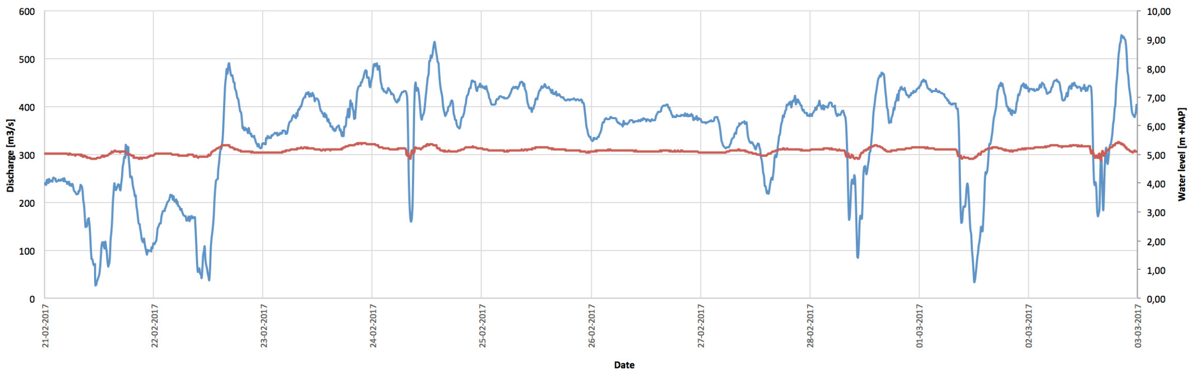


Figure 5.2: Occurring discharges and downstream water levels, http://waterinfo.rws.nl

1. All middle and lowest panels are present (Q = $270m^3/s$)
2. All lowest panels are present (Q = $620m^3/s$)
3. Model made by Deltares where lowest row of panels is present (Q = $575m^3/s$)

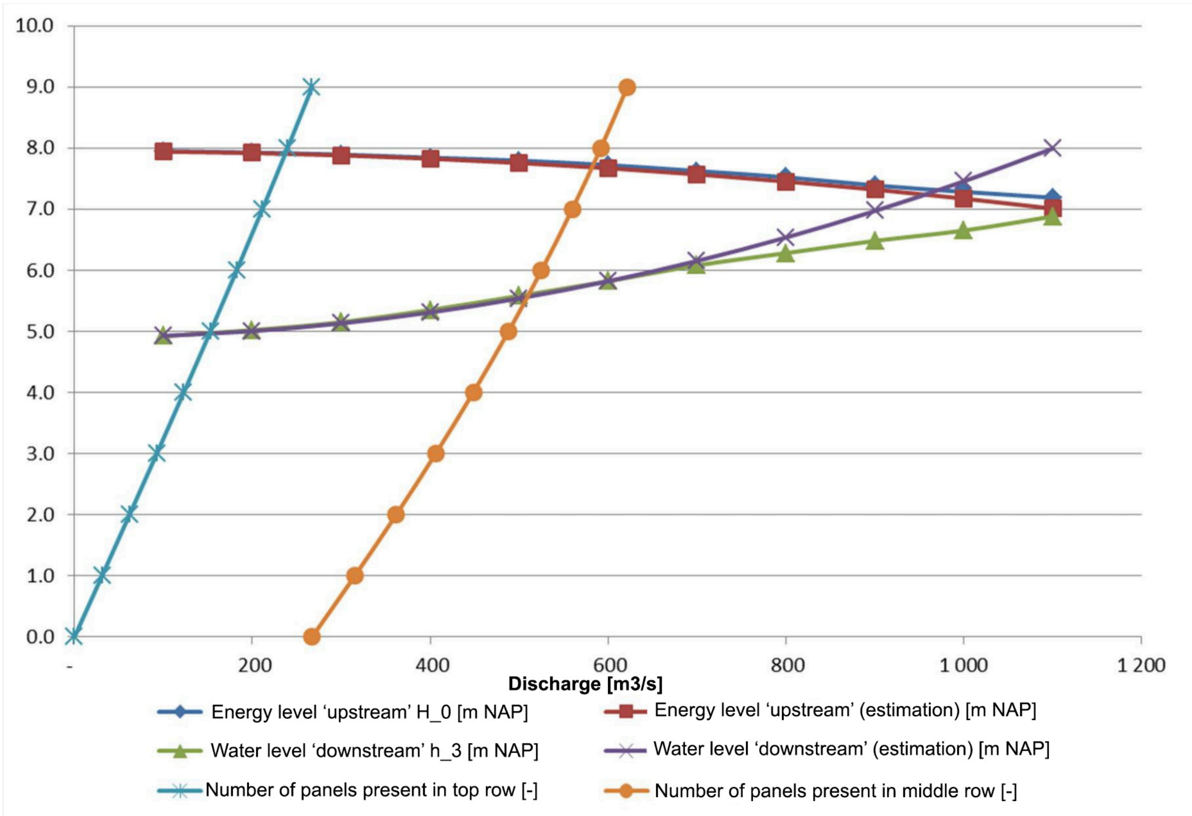


Figure 5.3: Weir configuration during calamity Grave (de Loor and Weiler, 2017)

To determine the flow velocities, which occurred above the rock nets, three calculations are used. A first simplified estimation of the flow velocities is made by a 1D calculation on the same way the flow velocities behind the calamity situations are calculated in paragraph 4.2. Figure 5.4 shows the water levels and corresponding weir configurations. In Figure 5.5 the flow velocities behind the weir due to discharges of $270m^3/s$ and $620m^3/s$ are shown. The black dotted lines are start of the 3-6t stones, start of the rock net and end of the rock nets respectively. The calculation sheets associated to this figure are added in Appendix H.

For the situation at a discharge of $270m^3/s$ there is a relative high downstream water level (5.05m +NAP) with respect to the depth of the jet (0.83m). Therefore it is assumed a repressed hydraulic jump will occur. The

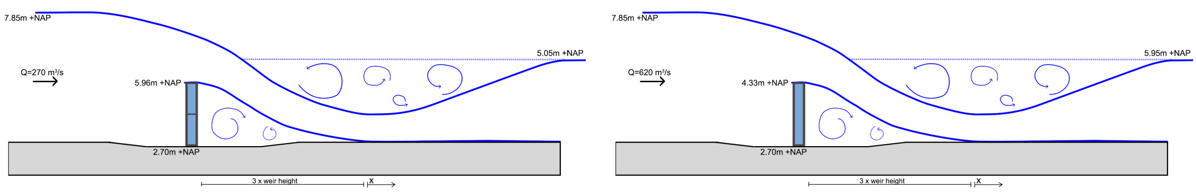


Figure 5.4: Flow situation and weir configuration 270 m3/s and 620 m3/s

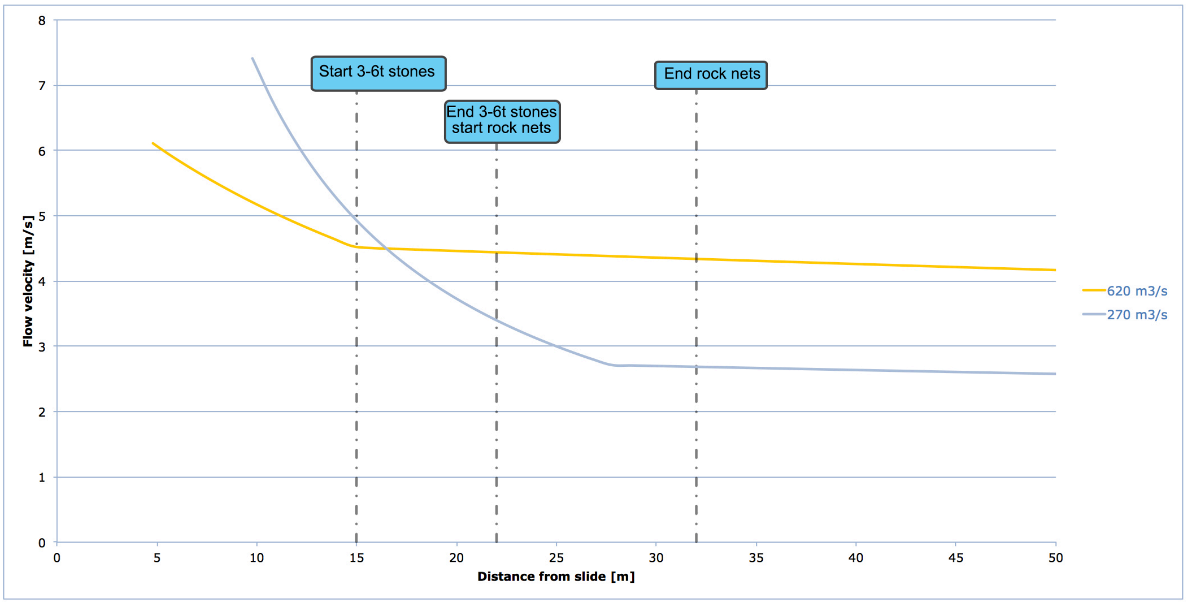


Figure 5.5: First estimation flow velocities behind weir Grave

hydraulic jump will stay close to the weir and the jet will spread into the downstream water level. The flow velocities at the start of the 3-6t stones, start of the rock nets and end of the rock nets are respectively 4.9m/s, 3.4m/s and 2.6m/s.
In case of 620m^3/s discharge, where only the lowest row panels is present, the ratio between depth of the overflowing jet (2.32m) and downstream water level (5.95m +NAP) is much smaller. The maximum flow velocity if the jet would fall into the downstream water level is equal to $\sqrt{2g\Delta H} = 6.11 m/s$ and the minimal water depth is 2.32m. According to this flow velocity and the water depth, the Froude number is equal to 1.26. This means that a supercritical flow with an undular bore occurs. Table 5.1 and Figure 5.6 shows the types of hydraulic jumps for different Froude numbers.

Table 5.1: Classification of hydraulics jumps, (Chow, 1973)

Type jump	**Froude nr.**	**Description**
Strong jump	FR >9	Rough jump, lots of energy dissipation
Steady jump	4.5 <FR <9	Considerably energy losses
Oscillating jump	2.5 <FR <4.5	Unstable oscillating jump. Production of large waves of irregular period
Weak jump	1.7 <FR <2.5	Little energy loss
Undular jump	1.0 <FR <1.7	Free-surface undulations downstream of the jump. Negligible energy losses

Because the flow is supercritical, the discharge is high, and the ratio jet depth to downstream water level is small, it is very likely that the jet will push away the downstream water level and the hydraulic jump will appear further away from the weir. Pushing away the downstream water level allows the jet to develop a higher flow velocity. In the end the maximum flow velocity which occurs at the reattachment point is an equilibrium between the depth of the jet and the flow velocity as illustrated in Figure 5.7. The flow velocity upstream is assumed to be negligible. Because the flow is accelerating, the energy level above the reattachment point is

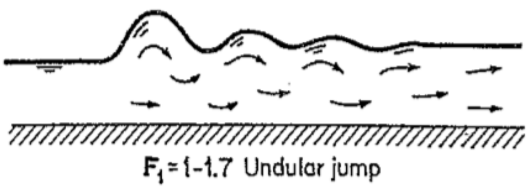


Figure 5.6: Flow characteristics hydraulic jumps, (Chow, 1973)

equal to the energy level of the upstream water level. An equilibrium between flow velocity and jet depth is reached when $\Delta H + d_{min} = h_{upstream}$. The corresponding flow velocity is 8.1 m/s and the jet depth is 1.81 meter as shown in Figure 5.8, with a FR-numer is 1.92.

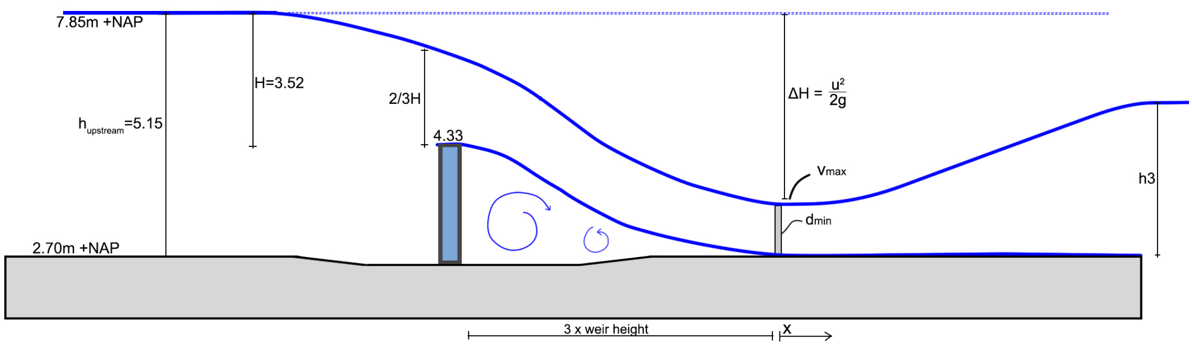


Figure 5.7: Schematization supercritical flow

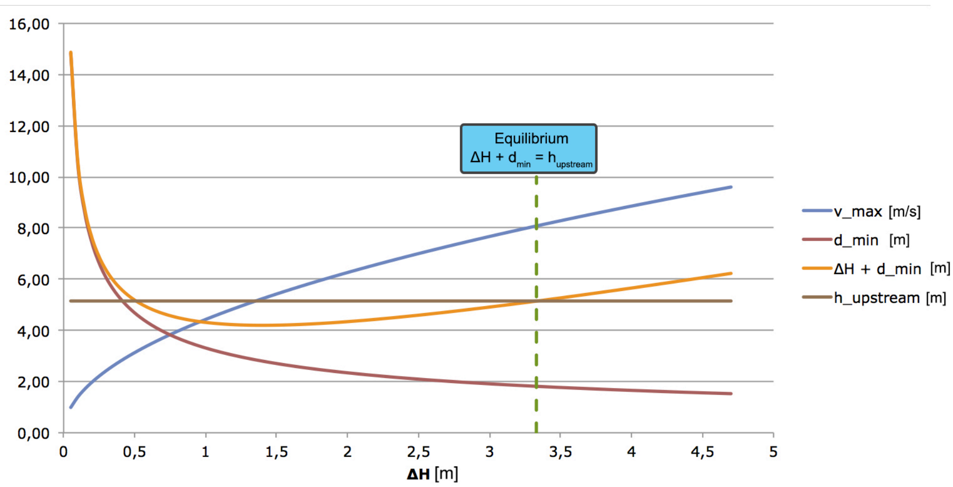
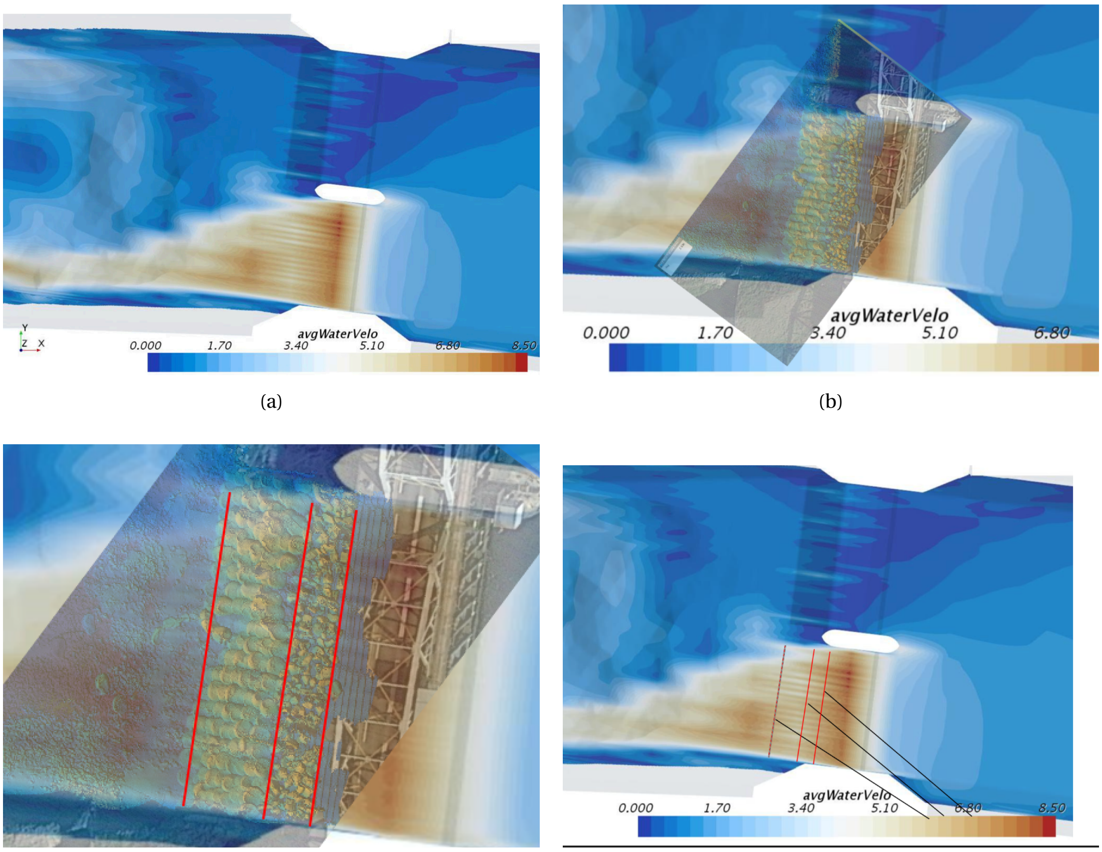


Figure 5.8: Determination flow velocity and jet depth

The flow velocities which occur above the 3-6t stones and rock nets, during a 620m^3/s discharge are assumed to remain 8.1 m/s until the hydraulic jump occurs. The hydraulic jump which occurs, is a weak jump according to Table 5.1. The location of this jump is no further investigated. According to Table 5.1 there is little energy loss under a weak jump. Therefore flow velocity is assumed to be the most dangerous parameter for the stability of the bed protection. The flow velocity is assumed to remain equal above the complete additional bed protection. This is a conservative approach because it is also possible that the weak jump occur earlier and therefore the flow velocities above the bed protection decrease significantly.

The final flow situation in which the flow velocities due to this load situation are calculated, is by a CFD (Computational Fluid Dynamics) model made by Deltares. The determinations of the flow velocities above the additional bed protection is shown in Figure 5.9.



(a) (b) (c) (d)

Figure 5.9: Closure situations

The flow velocities from this model at the start of the 3-6t stones, start of the rock nets and end of the rock nets are respectively approximately 7.0m/s, 6.5m/s and 6.2m/s according to Figure 5.9. It should be noted that this model does not take into account the additional bed protections. Due to these measures, the flow area will further decrease and the flow velocities behind the weir will therefore increase. Figure 5.10 shows the modeled flow characteristics in which the undular hydraulic jump is clearly recognizable. This flow field is in accordance to the calculation of 620m^3/s where the flow velocities, due to the higher discharge, are higher and therefore a stronger hydraulic jump appears.

Due to the three different calculation, the flow velocities at different locations are shown in Table 5.2.

Table 5.2: Flow velocities during loads on the rock nets

	Start 3-6t	**Start rock nets**	**End rock nets**
Q = 270 m3/s	4.9	3.4	2.6
Q = 620 m3/s	8.1	8.1	8.1
Q = 575 m3/s [1]	7.0	6.5	6.2

[1] Higher flow velocities because effect of the additional measures is not taken into account

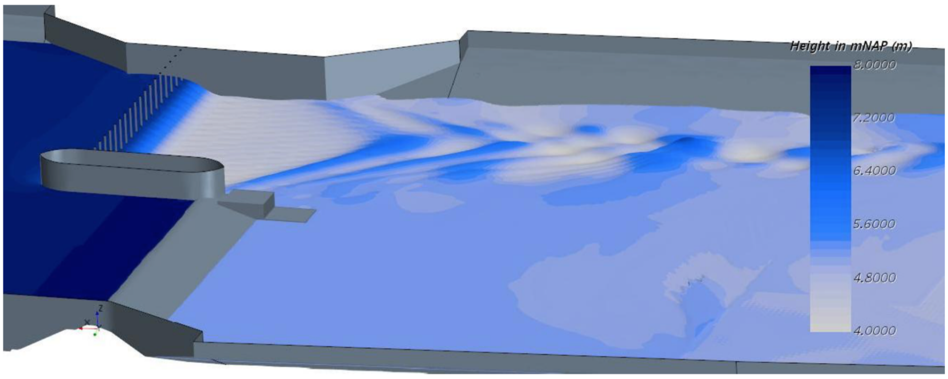


Figure 5.10: Flow field Q = 575 m^3/s, (de Loor and Weiler, 2017)

5.1.2. Strength

The rock nets, used at weir Grave, had a mass of 4 tons, 4000kg (Smith and Slagboom, 2017). For the calculation of the local critical velocity for a bed of sack gabions, Beekx (2006) advised to use Izbash'formula (5.1) with a gabion stability factor (γ) while calculating the nominal diameter of a sack gabion with a mass based approach as in formula 5.2.

$$\Delta d_n = \frac{\beta}{\gamma}\frac{u_c^2}{2g} \tag{5.1}$$

$$d_n = \sqrt[3]{\frac{M_{sack,tot}}{\rho_s}} \Rightarrow d_n = \sqrt[3]{\frac{4000}{2650}} \Rightarrow d_n = 1.15m \tag{5.2}$$

Beekx (2006) proposed to use a γ-factor of 1.26 for sack gabions instead of 1.0 for loose rock. If a mass based approach is used, the relative density (Δ) is calculated by:

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w} \tag{5.3}$$

The relative density of a volume based approach is given by:

$$\Delta = \frac{(1-n)\rho_s - \rho_w}{\rho_w} \tag{5.4}$$

In case of a box gabion, the porosity is important. A box gabion has the same cube size as a cube shaped rock, but with a lower density due to its porosity. A sack gabion has the same relative density as a smaller cube shaped rock. This is illustrated in Figure 5.11. The gabion stability factor in Beekx (2006) formula is based on a mass based approach.

(a) Same size, lower relative density

(b) Same relative density, smaller size

Figure 5.11: Volume (a) vs. mass (b) based approach, (Beekx, 2006)

β in formula 5.1, is a flow coefficient varying from 0.7 for low turbulence to 1.4 for high turbulence (A. Franken, 1995). However the additional bed protection can be considered as rough due to the stone height, the flow is still accelerating over the bed protection and therefore the turbulence is suppressed. For a first calculation of the critical velocity β is approximated of 1.0.

The nominal diameter of a 4t rock net is comparable to the nominal diameter of the 3-6t which is 1.18m according to NEN (2002). Therefore the critical velocity (u_c) of the rock nets is according to Beekx'formula:

$$u_c = 6.93 m/s \tag{5.5}$$

Besides the total mass of the rock nets, also the internal stability of the rock nets is considered. According to Oosthoek (2008) a gabion bed protection is considered stable if there is no movement of individual stones in this gabion. There are no specifications of the exact composition or gradation of these rock net available therefore the determination of internal gradation of the rock net is based on pictures which are made of these rock nets. The nominal diameter of a stone is about 0.84 times the sieve diameter (CETMEF, 2007).

$$D_n \cong 0.84 D_s \tag{5.6}$$

Figure 5.12(a) shows the rock nets after placing. Based on this image, the dimensions of the rock nets are estimated. The width of five sack gabions is determined based on a measurement from the multibeam: 2.64 + 2.95 + 2.79 + 2.74 + 2.85 –> average width = 2.80m. Figure 5.12(b) shows one of the used rock nets lying on the quay. The size of individual stones is also based on this picture. It should be noted that only the larger stones are measured. It is clearly visible that there are also a lot of smaller stones present in this rock net. A calculation based on only the larger stones is therefore probably overestimating the stability of the individual stones. Table 5.3 shows the determination of the averaged stone diameter. Based on these values the composition of the rock nets is probably a 90/250mm gradation with a $d_n = 0.128 m$ (G.J. Schiereck, 2012).

Table 5.3: Determination stone diameter

Measurement	$D_s [m]$	D_n [m]
	0.19	0.16
	0.22	0.18
	0.19	0.16
	0.28	0.24
	0.24	0.20
Mean	**0.22**	**0.19**

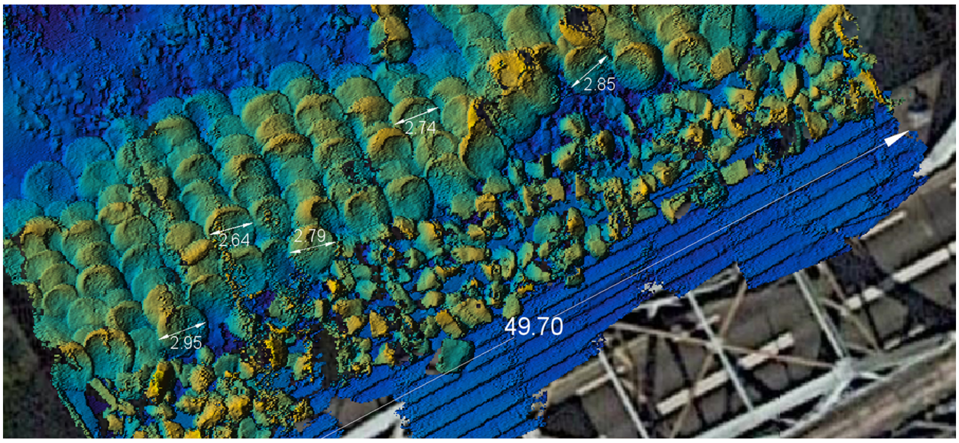
Using the same approach for the individual stones as for rock nets, with γ = 1.0 (G.J. Schiereck, 2012), the critical velocity of an individual stone is:

$$u_c = 2.04 m/s \tag{5.7}$$

The critical velocity of the individual stones is much lower than for the mass based approach for the complete net. Beekx formula was based on rock nets with relative large stones with respect to the total mass of the nets and therefore probably not valid for the rock nets used at weir Grave.

5.1.3. Stability rock nets

The occurring flow velocities, calculated with different methods, are for the 270 m^3/s and 575 m^3/s calculations lower than the critical velocity calculated with Beekx'formula and according to this formula the rock nets should be stable. The 620m^3/s shows higher flow velocities, but it should be noted that the discharge in this calculation is also 38% higher than the occurred discharge. As Oostbeek mentioned, the intern stability of a gabion determines the total stability of it. The critical velocity for the intern individual stones is far exceeded. Furthermore, Oosthoek (2008) stated that the retaining grid of a gabion results in the effect that the particles inside a compartment function as a group. A gabion revetment protection can therefore be constructed out of smaller stones. Mostly this type of gabions consists of a grid with a high stiffness. According to pictures of the rock nets, it can be concluded that the stones are hold together by some kind of a flexible



(a) Width estimation rock net

(b) Width estimation individual stones

Figure 5.12: Determination gradation material rock nets

net, with a very low stiffness instead of a stiff grid. Furthermore, Beekx'used in his research sack gabion with a composition of stones which was comparable to the total weight of the sack gabion. The ratio between individual stones and the total weight of the rock nets was not proportional. Therefore is it is very likely that the movement of the rock net started due to the relative small stones compared to the total weight of the rock net. This internal instability of the small stones caused probably a rolling movement of the nets making them ending downstream of the weir. Last, according to Beekx (2006) a gabion, sack gabion in this case, start to move more abruptly and with more gabions at the time. If one gabion fails, mostly other gabions fail as well because they stabilize each other.

5.2. Carefully placed stones

According to the multibeam scans, it turned out that the rock nets were not stable as discussed in the previous paragraph. The 3-6t carefully placed stones proved to be stable for discharges up to 500m^3/s at least. Therefore it was decided by Rijkswaterstaat to extend the 3-6t sill with extra 3-6t carefully placed stones. After extending the sill, a flood wave occurred at the river Meuse. Discharges up to 900m^3/s were supposed to be maximum limit discharge (de Loor and Weiler, 2017). For higher discharges the flood plains started to discharge water, which decreased, or at least not further increased, the flow velocities behind the weir. After this flood wave, new multibeam images were made. Figure 5.13 shows the 3-6t sill after the extension and after the flood wave. As can be seen in this figure, stones are not completely placed over the whole width and not in a straight line. Furthermore there is a dark colored area where it was impossible to execute the multibeam due to high flow velocities, turbulence and too severe circumstances to do accurate measurements. Unfortunately there is no information available about the state of the bed protection between the extension and the flood wave. The stones are placed one by one and are placed precisely next to each other on a single layer. In contrast to a traditional dumping method where the stones fall in an irregular multi layered pattern. According to Figure 5.13 a couple of stones (circled in red), were moved downstream of their original location. The sill did not fail completely and not many stones are located more downstream due to the flow. Therefore it is assumed that the centre of the sill, especially the edge of the sill, was on the limit of stability. On the most northern side, next to the rock-fill dam, no damages occurred and therefore this part of the sill is assumed to be stable. In the black area, where no information is available, nothing can be said about the stability of the southern part of the sill. In the next paragraphs the differences in loads between various locations around the sill are considered to draw a conclusion about the stability of the carefully placed stones.

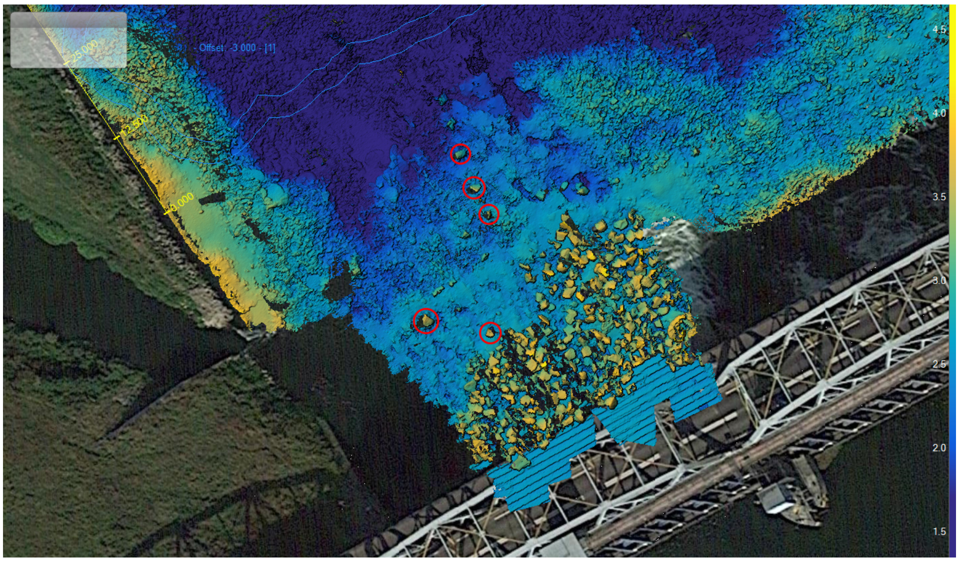


Figure 5.13: Multibeam after 850m^3/s with moved stones made by Paans and Van Oord

5.2.1. Loads

The carefully placed stones, as shown in Figure 5.13, have been loaded with discharge up to 850 m^3/s. Figure 5.14 shows the discharges which occurred during this flood wave in the period between placing the stones (March 9th) and the multibeam (March 15th).

In accordance with these discharges, Deltares made a Star-CCM+ CFD model, including the additional bed protections, of this situation. Input of the model was an upstream water level of 8.30m +NAP and a downstream water level of 6.00m +NAP resulting in a discharge of 890m^3/s through the weir. With a sill level of 2.70m +NAP (Sikkema, 2010), the flow through the weir is a free flow instead of a submerged flow according to $h_3 < 2/3H$. The bathymetry is similar to the soundings of Figure 5.13. The bottom is modelled as a closed layer with the roughness based on the 3-6t stones, which are located there. The dark area, where measurements were impossible, is filled with an equivalent roughness material as adjacent to it.

At different locations various results are generated with the CFD model. The locations, which are used in this thesis to determine the stability of the carefully placed stones, are shown in Figure 5.15. In stream wise direction these 6 output locations are at specific locations with respect to the bed protection (Table 5.4). For each row, perpendicular to the flow, 9 locations at different distances away from the centre pillar are considered, each at a distance of 5 meters from each other.

The depth averaged flow velocities in streamwise direction, according to O'Mahoney (2018), are shown in Figure 5.16. The distances 5, 10, 15 etc. refer to the distance of that specific point to the centre pillar, as

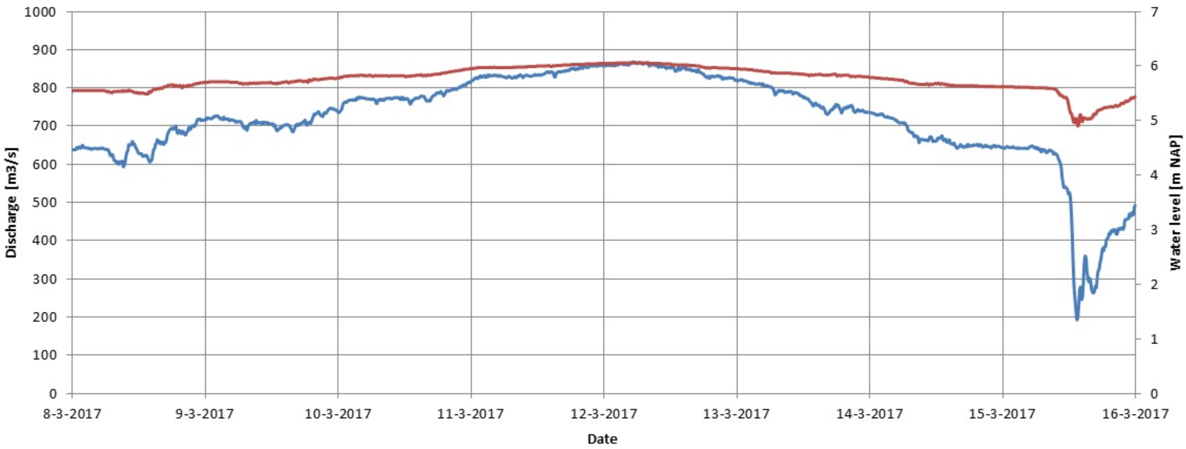


Figure 5.14: Occurring discharges during flood wave, http://waterinfo.rws.nl

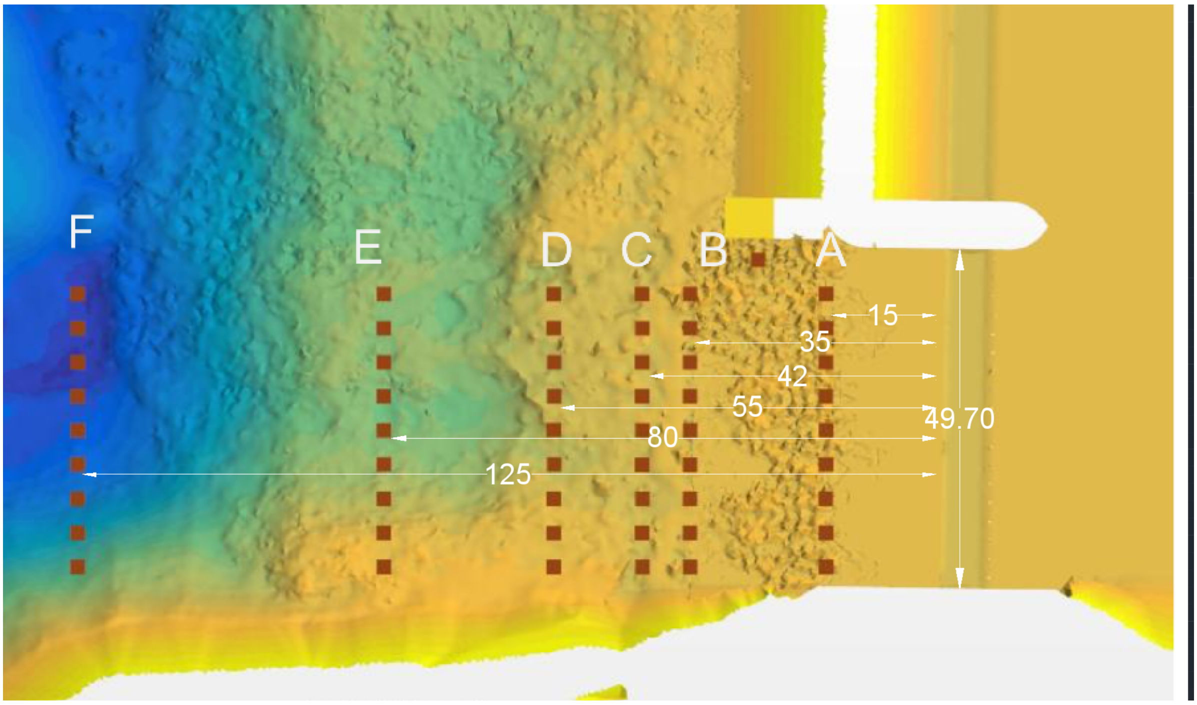


Figure 5.15: Output locations of CFD model, (O'Mahoney, 2018)

Table 5.4: Output location CFD model

Row	Description	Distance from weir [m]
A	Above the 3-6t carefully placed stones	15
B	End 3-6t stones and start 40-200kg colloidal concrete	35
C	Above 40-200kg with colloidal concrete	42
D	End of 40-200kg with colloidal concrete	55
E	Above 40-200kg quarry stones	80
F	Above scour hole behind bed protection	125

shown in Figure 5.15.

Figure 5.16 shows the flow velocities in streamwise direction above the various (additional) bed protections. According this figure, the maximum flow velocity at the end of the 3-6t rock sill is about 7 m/s but varies between the 4.6m/s and 7.1 m/s. It is also clearly visible that the flow is accelerating above the additional 3-6t

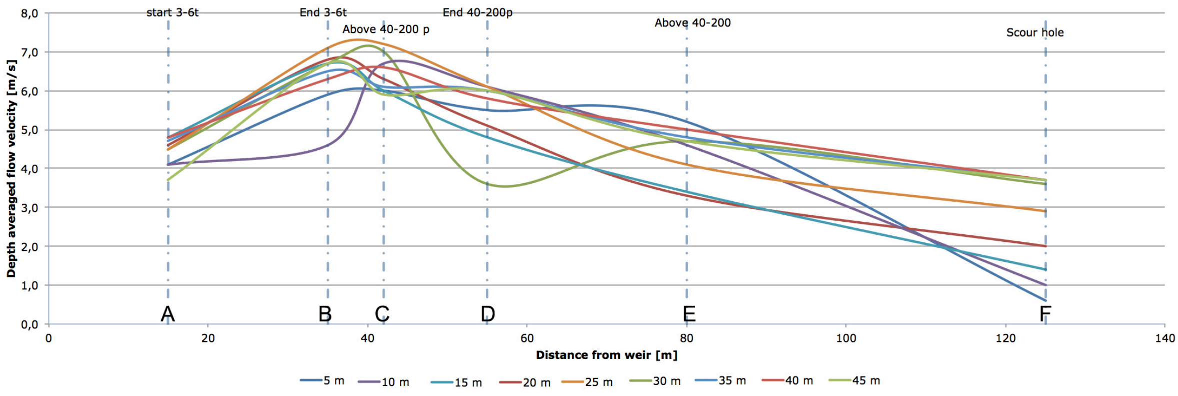


Figure 5.16: Averaged flow velocities in streamwise direction

carefully placed stones bed protection.

A second outcome of the CFD model is the turbulence intensity. The turbulence intensity is an important characteristic for the loads on a bed protection. However it was not possible to produce realistic values with the CFD model among other things by the complexity of the bottom profile and highly variability in velocity fluctuations (O'Mahoney, 2018). Figure 5.17 shows for example the output of the turbulence intensity at row B.

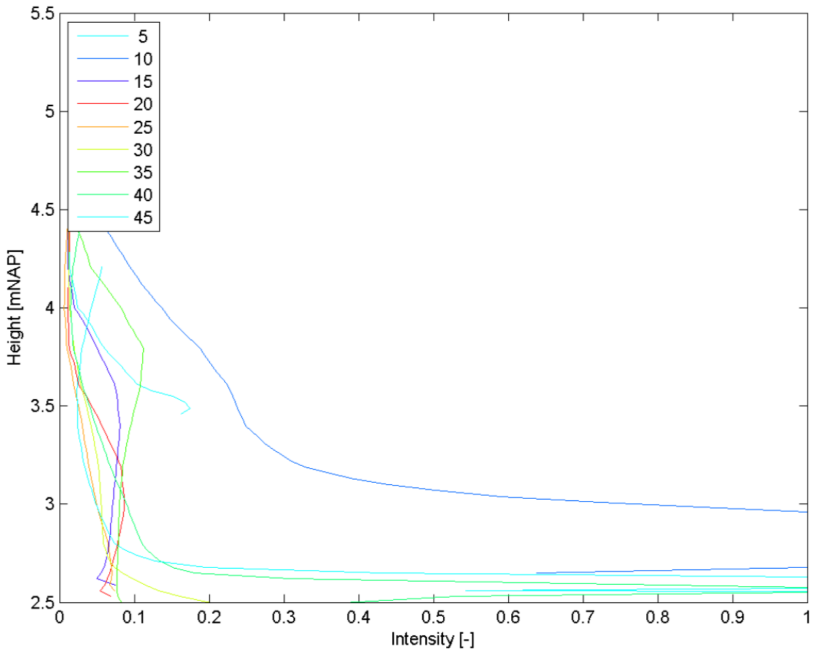


Figure 5.17: Vertical profiles of turbulence intensity at row B, (O'Mahoney, 2018)

Due to the complexity of these vertical profiles, O'Mahoney (2018) advices to use the values from Table 5.5 for the turbulent intensity at the different measurement locations. These turbulence intensities are averaged over the complete width of a row. From this turbulence intensity the turbulence factor is calculated according to CETMEF (2007):

$$k_t = \frac{1+3r}{1.3} \tag{5.8}$$

Table 5.5: Turbulent intensities according to O'Mahoney (2018)

Location	Turbulent intensity (r) [%]	k_t
A	10	1.0
B	20	1.2
C	20	1.2
D	15	1.1
E	30	1.4
F	30	1.4

5.2.2. Theory

To calculate the stability of the 3-6t stones, Pilarckzyks (1995) formula (5.9) is used. This formula is an unified relationship between the required armourstone size for stability and the hydraulic and structural parameters. The formula combines various design formulae and special factors and coefficients are added to the Izbash and Shields formula (CETMEF, 2007). This formula reads:

$$D = \frac{\phi_{sc}}{\Delta} \frac{0.035}{\psi_{cr}} k_h k_{sl}^{-1} k_t^2 \frac{u_c^2}{2g} \tag{5.9}$$

In which:

D	= Characteristic size of the protection element, Dn50 for armourstone
ϕ_{sc}	= Stability correction factor
Δ	= Relative density stones
ψ_{cr}	= Critical mobility parameter of the protection element
k_h	= Velocity profile factor
k_{sl}^{-1}	= Side slope factor
k_t	= Turbulence factor
u_c	= Critical flowvelocity

Now the parameters and the estimated or assumed values which will be used during the stability calculation will be explained further. The characteristic values for various parameters according to CETMEF (2007) are shown in Figure 5.18.

Stability correction factor ϕ_{sc}
The first point of interest point in this stability calculation is the edge of the sill, where the stones started to move first. These outer stones are not supported by other stones and therefore most vulnerable for instability. A value of ϕ_{sc} = 1.5 is used for the stability of exposed edges of the additional bed protection. For the stones which are located more in the middle of the bed protection, a value of ϕ_{sc} = 0.75 (continuous bed protection) is advised. This factor possibly also could further decrease due to the placement method of the carefully placed stones. The stones are placed tightly against each other which creates some kind of an interlocked system instead of a irregular armourstone.

Critical mobility parameter ψ_{cr}
A critical mobility parameter of 0.035 is advised for rip-rap and armourstone. This value increases for stones which are placed in gabions or mattresses. The fact that the stones are hold together due to there construction method is already taken into account in the Stability correction factor and therefore neglected here.

Velocity profile factor k_h
The velocity profile factor is a measure for the development of the logarithmic velocity profile. According to Figure 5.19, the flow tends to have a logarithmic velocity profile above the 3-6t carefully placed stones. In case of a shallow rough flow (h/D<5), a k_h value of 1.0 is prescribed. The d_{n50} of 3-6t stones is 1.18m and the water depth is considerably less than 6 meters. Therefore a k_h value of 1.0 is used in the stability calculations.

Characteristic size, D	• armourstone and rip-rap: $D = D_{n50} \cong 0.84D_{50}$ (m) • box gabions and gabion mattresses: D = thickness of element (m) **NOTE:** The armourstone size is also determined by the need to have at least two layers of armourstone inside the gabion.
Relative buoyant density, Δ **Mobility parameter, ψ_{cr}**	• rip-rap and armourstone: $\Delta = \rho_r/\rho_w - 1$ • box gabions and gabion mattresses: $\Delta = (1 - n_v)(\rho_r/\rho_w - 1)$ where n_v = layer porosity $\cong$ 0.4 (-), ρ_r = apparent mass density of rock (kg/m³) and ρ_w = mass density of water (kg/m³) • rip-rap and armourstone: $\psi_{cr} = 0.035$ • box gabions and gabion mattresses: $\psi_{cr} = 0.070$ • rock fill in gabions: $\psi_{cr} < 0.100$
Stability factor, ϕ_{sc}	• exposed edges of gabions/stone mattresses: $\phi_{sc} = 1.0$ • exposed edges of rip-rap and armourstone: $\phi_{sc} = 1.5$ • continuous rock protection: $\phi_{sc} = 0.75$ • interlocked blocks and cabled blockmats: $\phi_{sc} = 0.5$
Turbulence factor, k_t	• normal turbulence level: $k_t^2 = 1.0$ • non-uniform flow, increased turbulence in outer bends: $k_t^2 = 1.5$ • non-uniform flow, sharp outer bends: $k_t^2 = 2.0$ • non-uniform flow, special cases: $k_t^2 > 2$
Velocity profile factor, k_h	• **fully developed logarithmic velocity profile:** $k_h = 2/\left(\log^2(1+12h/k_s)\right)$ where h = water depth (m) and k_s = roughness height (m); k_s = 1 to $3D_{n50}$ for rip-rap and armourstone; for shallow rough flow ($h/D < 5$), $k_h \cong 1$ can be applied • **not fully developed velocity profile:** $k_h = (1+h/D)^{-0.2}$
Side slope factor, k_{sl}	The side slope factor is defined as the product of two terms: a side slope term, k_d, and a longitudinal slope term, k_l: $k_{sl} = k_d\, k_l$ where $k_d = (1 - (\sin^2\alpha / \sin^2\phi))^{0.5}$ and $k_l = \sin(\phi - \beta)/(\sin\phi)$; α is the side slope angle (°), ϕ is the angle of repose of the armourstone (°) and β is the slope angle in the longitudinal direction (°).

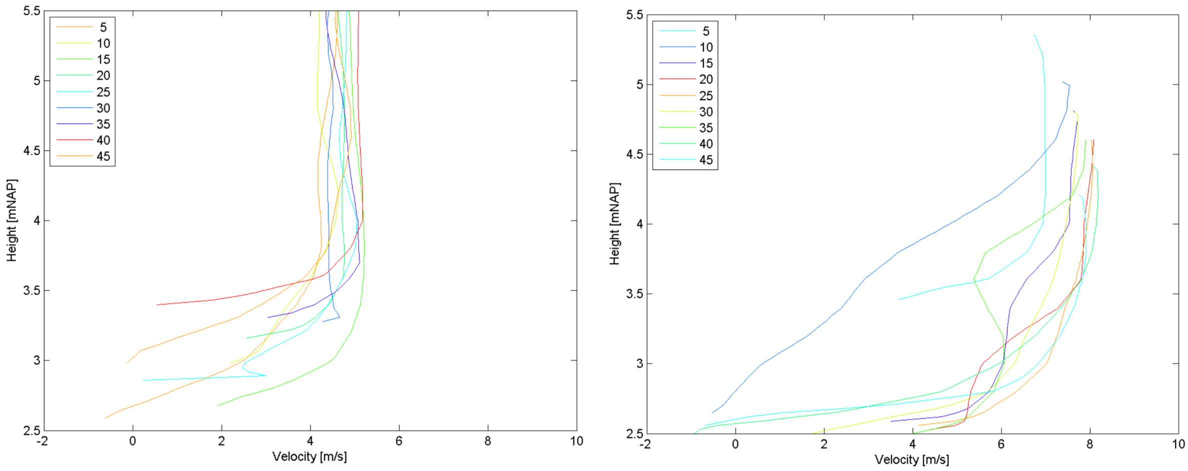
Figure 5.18: Design guidance for parameters in the Pilarczyk design formula, (CETMEF, 2007)

Side slope factor k_{sl}
In this calculation the bottom and bed protection is assumed to be horizontal. Therefore the side slope factor is assumed to be 1.0.

Turbulence factor k_t
The flow over the over the 3-6t stones is an accelerating flow. Due to the acceleration the turbulence is suppressed. In case the flow would accelerate over a smooth sill, the turbulence factor, k_t^2 should be 1.0. But instead of a smooth bed, the 3-6t stoney form a 1-meter high, rough and partial permeable sill. The flow through the stones will be highly turbulent. Therefore it can be stated that the flow on local level is very turbulent, close to and between the stones. But at a global level, the flow is accelerating and turbulence is suppressed. The turbulence factors from Table 5.5 will be used.

5.2.3. Strength

In order to check the stability of the 3-6t carefully placed stones, the flow in streamwise direction is considered. The streamlines on 35,40 and 45 meter are not taken into account, because the bottom is interpolated in



(a) Vertical velocity profile row A (b) Vertical velocity profile row B

Figure 5.19: Vertical velocity profiles above 3-6t carefully placed stones, (O'Mahoney, 2018)

the model and it is unclear if here were stones present or damage occurred. To calculate the stability of the 3-6t stones three characteristic streamlines are considered. Streamline at 5 meter where the 3-6t were definitely stable because they are still present at measurement location B. Streamline at 30 meter from the middle pillar. Here are definitely no stones anymore. And streamline at 15 meters. According to Figure 5.13, it seems that here a few stones moved more downstream. For these three locations the required (minimal) stone diameters for the known parameters are calculated according to formula 5.9. In the calculations Δ=1.65, k_h=1.0 and k_{sl}=1.0 are equal for all situations. The variable parameters with the corresponding required stone diameters, are shown in Table 5.6.

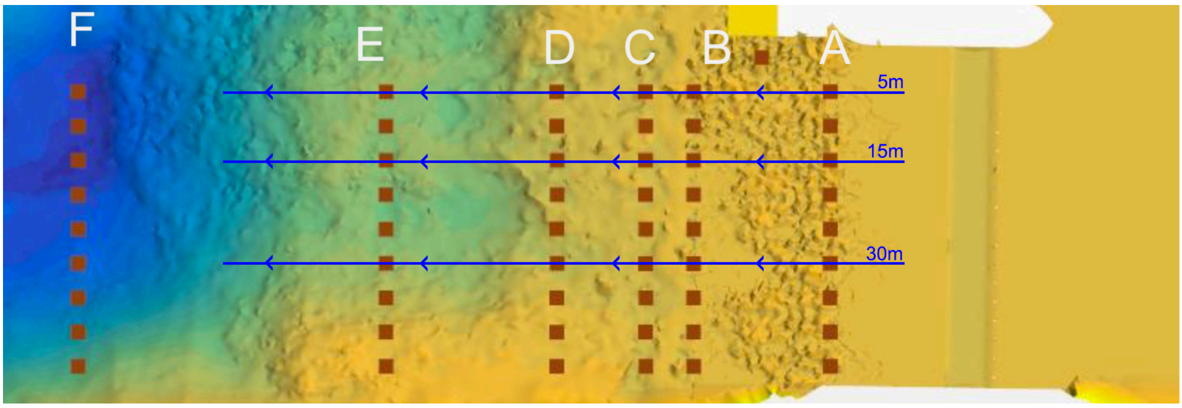


Figure 5.20: Considered streamlines for stability check

Table 5.6: Required stone diameters

	5 meter		**15 meter**		**30 meter**	
	Row A	Row B	Row A	Row B	Row A	Row B
u [m/s]	4.1	5.9	4.8	6.7	4.5	6.7
ϕ_{sc} [-]	0.75	1.5	0.75	1.5	0.75	1.5
k_t [-]	1.0	1.2	1.0	1.2	1.0	1.2
D_{req} [m]	0.39	**2.44**	0.53	**3.14**	0.47	**3.14**

Stability carefully placed stones

The calculated required stone diameters in the middle of the bed protection (Row A) are much lower than the applied diameter of the 3-6t stones. From Table 5.6 it can be concluded that the stability of the carefully placed stones in the middle of the bed protection is sufficient. No damages has been observed, so in line with calculations. The required stone diameter for the edges of the additional bed protection (in bold) is much larger than the applied stone diameter. However, the applied stones, with a diameter of 1.18m seemed to be stable for the occurred conditions. In this Thesis is assumed that the stability correction factor is too conservative for the applied situation. The stability correction factor for exposed edges of an armourstone was used ($\phi_{sc} = 1.5$). The stones are placed tightly and exact next to each other, which is comparable to interlocked blocks ($\phi_{sc} = 0.5$). It is suggested to apply a different stability correction factor for the additional sill. The stability correction factor is based on the difference in stability of the streamlines. For the streamline 5 meters from the pillar, the edge of the 3-6t bed protection was definitely stable. For the streamlines 15 and 30 meters from the pillar, the edge of the protection was on the limit of stability, or definitely not stable. The stability correction factor is calculated by formula 5.10.

$$\phi_{sc} = D * \Delta * \frac{1}{k_t^2} * \frac{2g}{u^2} \tag{5.10}$$

ϕ_{sc} $= 0.73$ 5 meter streamline (stable)

ϕ_{sc} $= 0.57$ 15 and 30 meter streamlines (unstable)

The stability of the bed protection increases due to the fact that the stones are placed in a regular way, next to each other. Therefore one can use a lower stability correction factor than the suggested factor of 1.5 in CETMEF (2007). The value which should be used to design an additional bed protection with large, carefully placed stones, may use a stability correction factor up to $\phi_{sc} = 0.73$. To this value, the edges are definitely stable. If a higher stability correction factor is used, the required stone diameter will increase and therefore the height of the additional sill wil increase. For values lower than 0.73, it is not sure if the edges of the additional sill are still stable. For $\phi_{sc} < 0.57$ the edges of the sill are definitely not stable.

5.3. Other Measures

Besides the additional sill, which was made in first instance of stones and rock nets and later supplemented with large rock, also the stability of the origin bed protection is considered. Due to the expected extra loads to the bed protection at weir Grave, the existing bed protection was reinforced. The original 40-200kg quarry stones with colloidal concrete bed protection was extended over a length of 32 meters. Downstream of this bed protection over a length of 55 meters 40-200kg quarry stones were placed. The final bed protection is shown in Figure 5.21. The stability of these measures is determined on the basis of a comparison between the occurred flow velocities from the CFD model, the critical velocities and the occurred damages.

5.3.1. Loads

The loads considered in this calculation are also from the CFD model made by Deltares with a discharge of 890m^3/s. As mentioned before, this was approximately the maximum load which could occur. Based on O'Mahoney (2018) the loads to the 40-200kg quarry stones with colloidal concrete at row C (above the bed protection), Row D (End of the 40-200kg quarry stones with colloidal concrete) and Row E (above 40-200kg quarry stones) are considered. The depth averaged flow velocities according to O'Mahoney (2018) are shown in Table 5.7.

Table 5.7: Flow velocities location C

Location [m]	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**		**Mean**	**Max.**
Row C [m/s]	6.0	6.7	6.0	6.3	7.2	7.0	6.1	6.6	5.9		6.4	7.2
Row D [m/s]	5.5	6.1	4.8	5.1	6.1	3.6	6.0	5.8	6.0		5.4	6.1
Row E [m/s]	5.2	4.6	3.4	3.3	4.1	4.7	4.8	5.0	4.7		4.4	5.2

The turbulence intensities for these locations are shown in Table 5.5.

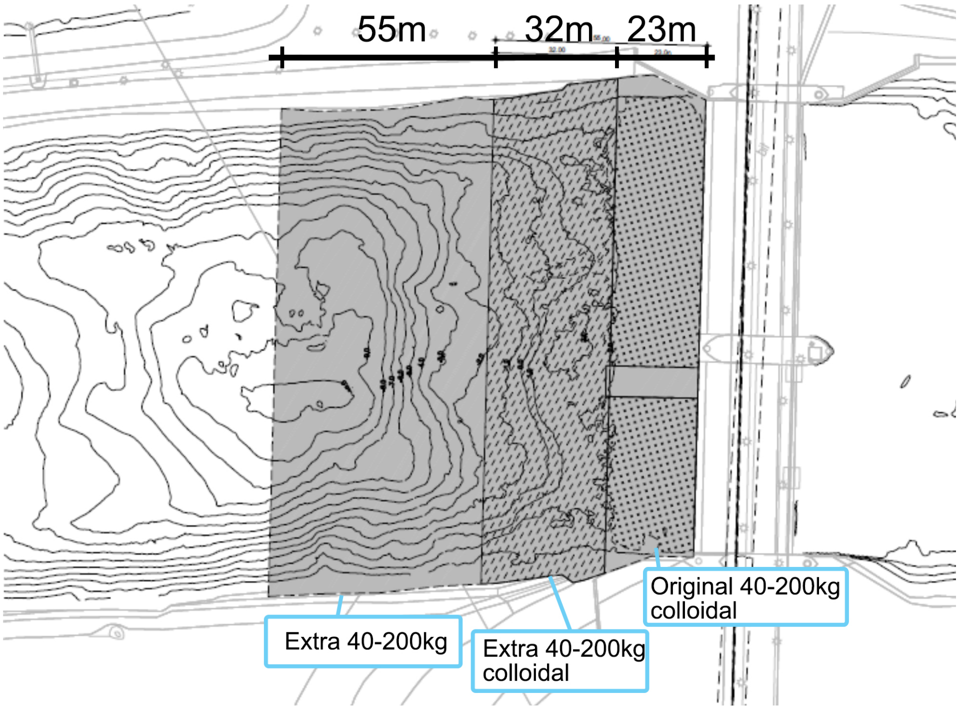


Figure 5.21: Bed protection weir Grave, (Kortlever, 2017b)

5.3.2. Strength

The strength of a bed protection with colloidal concrete (Row C) depends on the thickness of the layer and the amount of concrete which is used. Figure 5.22 shows the permissible flow velocities for different amounts of concrete according to Römisch (2000). The porosity of the 40-200kg bed protection is 40%, which was

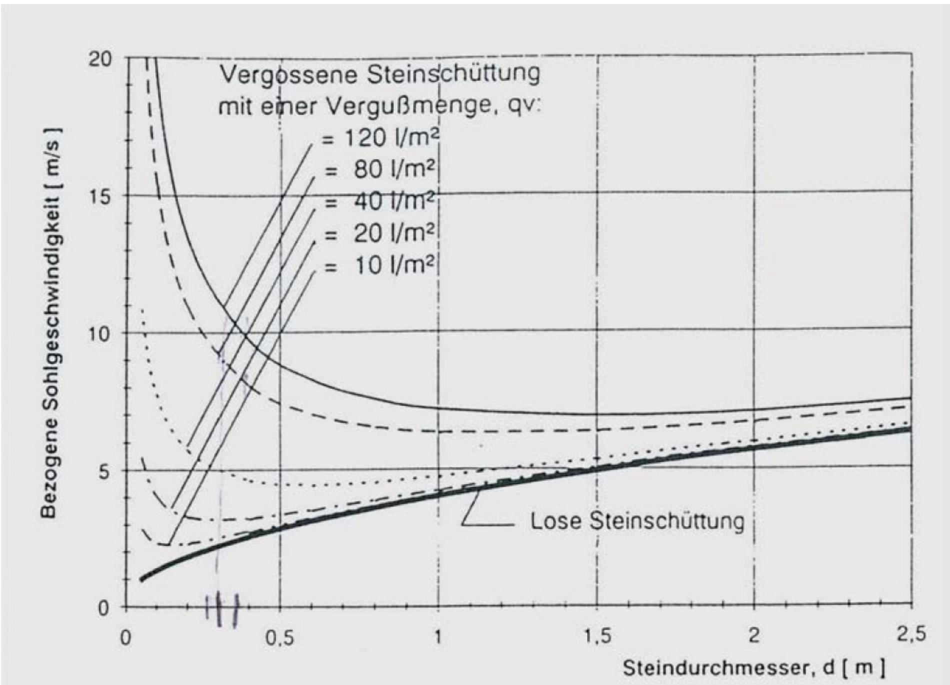
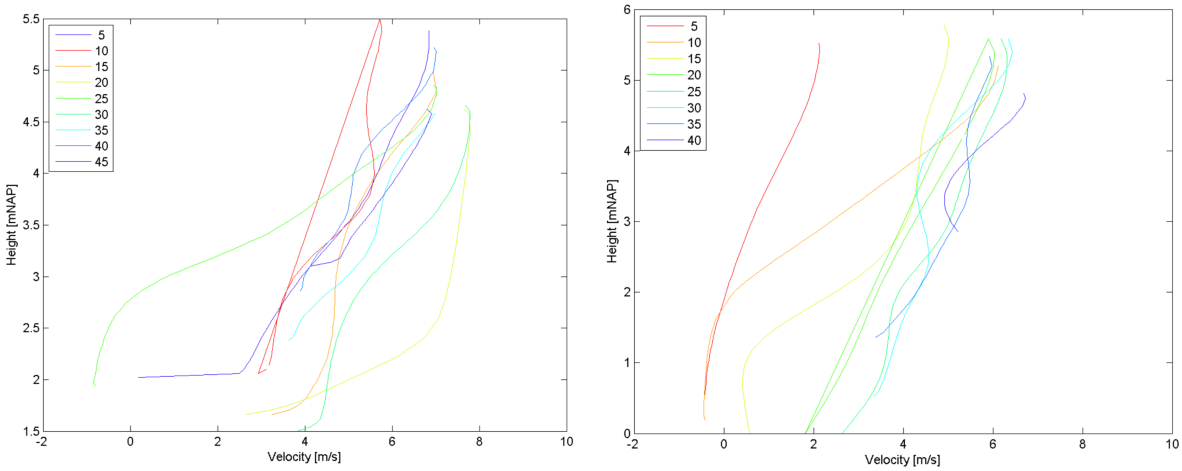


Figure 5.22: Critical flow velocities colloidal concrete bed protections, (Römisch, 2000)

filled with 60 % concrete and an assumed layer thickness of 50cm results in $120 l/m^2$. According to Römisch

(2000), the bed protection could resist flow velocities up to 9m/s. MBW (2004) stated that bed protections with colloidal concrete, with a layer thickness of at least 0.40, can resist flow velocities up to 7.7m/s.

The strength of the 40-200kg quarry stones is determined with Pilarczyks formula (5.9). In these calculations Δ=1.65, ϕ_{sc}=0.75 (continuous bed protection), ψ_{cr}=0.035 and k_{sl}=1.0 are equal for all situations. The d_{n50} of 40-200kg quarry stones is equal to 0.34m (G.J. Schiereck, 2012). In contrast to the stability calculation of the 3-6t stones, the vertical velocity profile is no longer logarithmic according to Figure 5.23. Furthermore, the approximation for shallow rough flow, as used for the 3-6t stones, is no longer valid.



(a) Vertical velocity profile Row D (b) Vertical velocity profile Row E

Figure 5.23: Vertical velocity profiles, (O'Mahoney, 2018)

According to these figures the water depth for Row D and E are approximately 3.5m and 5.7m. According to CETMEF (2007) and Figure 5.18 the velocity profile factor for not fully developed velocity profile is:

$$k_h = (1 + \frac{h}{D})^{-0.2} \tag{5.11}$$

Which results in:

$$\begin{aligned} &\text{Row D}: \quad && h = 3.5m \quad && \Rightarrow \quad && k_h = 0.62 \\ &\text{Row E}: \quad && h = 5.7m \quad && \Rightarrow \quad && k_h = 0.56 \end{aligned}$$

The parameters and critical velocities according to Pilarczyks formula for row D and E are shown in Table 5.8.

Table 5.8: Input parameters critical velocities

	Row D	**Row E**
D [m]	0.34	0.34
k_h [m]	0.62	0.56
k_t [-]	1.1	1.4
u_{cr} [m/s]	**4.4**	**3.7**

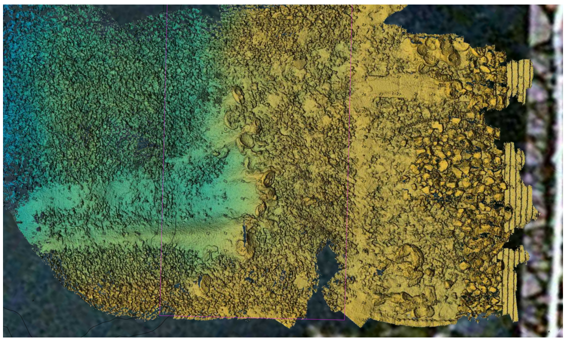
Behind the 40-200kg quarry stones a layer of 10-60kg quarry stones is located (d_{n50}= 0.21m (G.J. Schiereck, 2012)). An estimation of the critical velocity of these bed protection by Pilarczyk (ϕ_{sc}=0.75, k_h=1.0, k_{sl}=1.0 and k_t=1.0) is u_{cr}=3.0m/s. An overview of the critical velocities calculated above the various bed protections and the maximum and mean occurred flow velocities according to O'Mahoney (2018) are shown in Table 5.9 below.

Table 5.9: Flow velocities location C

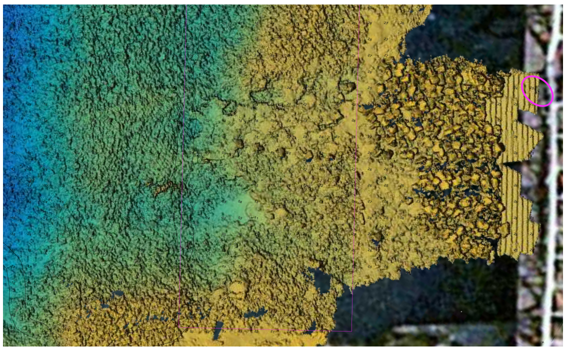
	Above 40-200kg colloidal	Start 40-200kg	Above 40-200kg
u_{cr} Pilarczyk [m/s]	-	4.4	3.7
u_{cr} Römisch [m/s]	9.0	-	-
u_{cr} MTB [m/s]	7.7	-	-
CFD			
u_{mean} [m/s]	6.4	5.4	4.4
u_{max} [m/s]	7.2	6.1	5.2

5.3.3. Stability other measures

The flow velocities which occurred, based on the CFD model, above the 40-200kg quarry stones with colloidal concrete bed protection are lower than the critical velocities based on Römisch (2000) and MBW (2004). Therefore minimal damage is supposed to this part of the bed protection, which is in accordance with the multibeam images which are made before and after the flood wave (Figure 5.24). With Pilarczyks formula calculated critical velocities for the 40-200kg quarry stones are lower than the occurred flow velocities. Therefore damage is expected to the bed protection. Figure 5.24 shows some damage to the 40-200kg quarry stones bed protection. It can be seen, that only at the end of the 40-200kg with colloidal concrete and the beginning of the 40-200kg quarry stones some damage occurred. Based on the (large) difference between the occurred flow velocities and the calculated critical velocities, more damage could be expected. Probably the damage to the bed protection is not that severe due to the increasing water depth, which decreases the flow velocity significantly. It is possible that the velocity outcomes of the model are higher than in reality occurred. Because there were no in field measurements performed it is hard to verify the model.



(a) Multibeam by Paans van Oord March 6th



(b) Multibeam by Paans van Oord March 15th

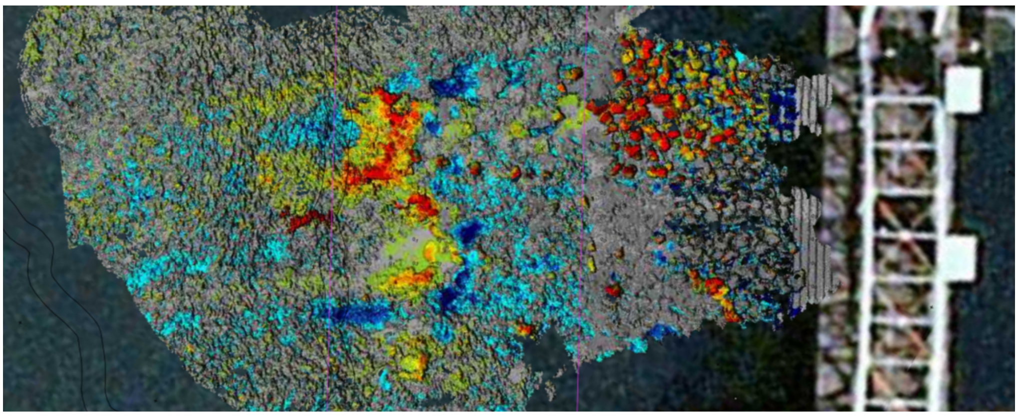


Figure 5.24: Differences between multibeams of 6 and 15 March by Paans van Oord

5.4. Overall stability conclusion

Due to the relative small internal gradation, the rock nets used in Grave, were not able to withstand the occurring discharges and flow velocities. If the rock nets were made of larger rocks, comparably to the rock nets investigated in Beekx (2006) study, they could withstand higher flow velocities and probably be an useful solution for a temporary additional bed protection. What the preferable dimensions and gradation of a rock net are and which flow velocities they can withstand is no further investigated in this study. The single layer carefully placed stones seemed to be a good solution to protect the existing bed protection. Due to the construction method, placing the stones tightly next to each other, the stability of the 3-6t stones increased. The measure proved to be definitely stable for flow velocities up to 5.9m/s according to the Deltares CFD model. While designing an additional bed protection of carefully placed stones with Pilarczyks formula, one can use a lower stability correction factor. CETMEF (2007) prescribes a stability correction factor (ϕ_{sc}) of 1.5 for the edges of a bed protection, based on the Grave measure, a correction factor up to 0.73 can be used. For lower correction factors, the stability of the carefully placed stones is no longer guaranteed.

The 40-200kg quarry stones with colloidal concrete were loaded with the highest flow velocities according to O'Mahoney (2018), up to 7.2m/s. Despite Römisch (2000) and MBW (2004) suggested a higher critical velocity, some damages occurred to this part of the bed protection. Something probably caused by locally higher flow velocities or also possible, due to a lower construction quality. Generally, 40-200kg quarry stones with colloidal concrete seemed to be a robust solution to protect a bed protection to high flow velocities.

The flow velocities according to the CFD model were higher than the calculated critical velocities for the 40-200kg quarry stones. Given the (low) damages to this part of the bed protection, the values from the CFD model seem on the high side. At the start of the bed protection, where most damages were visible, the difference between the calculated and modeled flow velocities are highest. 40-200kg quarry stones are an useful bed protection if the occurring flow velocities are decreased significantly.

6

Discussion

In this chapter the limitations and most important assumptions for this study are summarized and discussed. The discussion is divided into three sections: choice weir, flow velocity calculations and analysis Grave weir.

6.1. Choice weir

In the beginning of this study the choice was made to use a single fictive weir to investigate the consequences of a certain calamity. The choice of this fictive weir was based on a minimal amount of input parameters. It has to be mentioned that for each of the weirs in the Meuse, the specific conditions are different and the boundary conditions for the occurring flow velocities can vary a lot. However the fictive weir is based on the most severe situation, one should keep in mind that flow situations and loads can be very different for another weir. The second limitation of the choice of a single weir is the simplification in weir management. In reality the water management is a very complex relation between expected discharges and removing panels or lowering slides. In this study the interaction between varying discharges and the water management is neglected. Only for a few specific discharges the configuration of the weir is known, and the calculations are based on these simplified configurations. Probably higher flow velocities can occur when the levels of the panels differs.

6.2. Flow velocity calculations

As mentioned before, only a few (standard) configuration of the weir were used in the flow velocity calculations. In reality there are numerous possible configurations of the slides and panels. The configuration which are considered in the flow velocity calculations are all specific situations in which a complete row is removed. In reality there will be also intermediate situations where panels on different levels are present. The discharge coefficients will change for changing weir configurations. Also the flow due to these intermediate configuration can vary a lot. When, for example, the first panels from a (next) row are removed, the flow velocities will increase significantly through these panels. This effect is not taken into account in the flow velocity calculations and should eventually be investigated further.
A second simplification in the flow velocity calculation is the fact that underflow is neglected. Instead of further lowering the Stoney slides, which is assumed in this report, the slides will be lifted above the water level. When the slides are lifted above the water level, underflow occurs which can cause significant loads to the (additional) bed protection. Here again the flow velocities behind the weir can be very dependent on the specific weir configuration.

To calculate the flow velocities which occurred during different calamity/maintenance situations, first the water management was modeled. In this model the simplification of a constant upstream water level was used and therefore the limit discharge increased with respect to the real situation. Due to this increased limit discharge of the model also the limit discharge for the different closure situations increased and occurs later. In reality the probability that the limit discharge occurs is higher. As soon as the limit discharge is reached, the weir is completely open, the upstream water level starts to increase and higher flow velocities occur. If the limit discharge is lower and reached sooner, the downstream water level is probably lower and the flow situations may be more severe. In this study a negligible upstream flow velocity is assumed. When the limit discharge is reached, the upstream water level increases and assumed to stay horizontal with zero velocity. In reality the river is flowing under a gradient. The stage relation curve, gradient, of the river will increase for an increasing discharge. An increasing gradient means also an increasing flow velocity of the river. Due to the higher flow velocity a lower water level corresponds to a specific discharge. Therefore in this study lower discharges are used for specific upstream water levels.

Not every weir configuration is taken into account, but also not all discharges over the weir are taken into account for the calculations of the flow velocity. For three flow situations the flow velocities behind the weir are considered. Probably situation could occur with more severe circumstances. Again the variance in weir configuration can contribute to a more severe flow situation. For the discharges which are considered, simplifications and assumptions are used in the calculations.
In case of the 1/2 limit discharge, the determination of the exact path of the jet, no information was available and the calculations are based on several assumptions and schematizations. The first assumption was the location of the reattachment point. This is a assumption and should be further investigated to determine the exact location where the jet will reached the bottom. Also the spread of the jet in the water column is neglected in this calculations, which was a conservative approach. Furthermore it is hard to predict what kind of flow regime will occur behind the slides.

In case of the limit and maximum discharge a simplified energy equation over the weir was used to calculate the flow velocities behind the weir. In this approach it is assumed that the velocity above the weir is equal to the flow velocity above the bed protection. This is a conservative approach due to increasing water depth and flow width which decreases the flow velocities above the bed protection.

6.3. Analysis Grave

The analyzes of the stability of the measures used after the Grave weir calamity are mainly based on models made by Deltares. The first limitation is the reliability of these models. It turned out that the flow characteristic are very irregular for a complex bathymetry. Therefore averaged values for the flow velocity and turbulence intensity are used in this study which may differ greatly from extreme values. The use and reliability of these complex models are still up to discussion. Besides the complex models, also the greatly simplified manual calculation is used to determine the flow velocities behind the weir. The simplified calculation have the same limitations as mentioned for the calculation of the flow velocities during different closure situations. Due to a large simplification probably lots of detailed information is lost.

Due to the fact that there was no multibeam made just after placing the 3-6t stones and the multibeam of the 3-6t stones is not complete, the exact damages are hard to determine. In this study it is concluded that the 3-6t stones were on the brink of stability. Also the fact that the 3-6t stones were not placed in a straight line, makes it hard to distinguish the limit of stability.

The final point of discussion is the difference between calculated critical velocities, modeled velocities and the occurred damage to the bed protection, especially above the 40-200kg quarry stones bed protection. The critical velocity calculations showed a lower critical flow velocity than the occurred velocities according to the CFD model. This difference can be explained due to uncertainties in the model or different estimations in the stability formulas. CFD modeling on this type of complex flow situations is hard due to the computer force which is needed to completely solve the flow field. The reliability of this model is also hard to determine due to the fact that the model is not verified for this flow situation. On the other hand, the stability formula which is used, is usually based on fairly normal flow conditions while in this case, the flow was extremely complex by among other contraction, supercritical flow, additional sill, a decreasing level of the bed protection and return flow.

7

Conclusion

In this chapter the final conclusions of this study are given and in the end the answer to the research question is provided. The research question was:

How to prevent additional damage, based on lessons learnt from the Grave Weir calamity, to the bed protection of a weir during a long-term partial closure of a weir in the river Meuse?

During the Grave weir calamity several measures have been used to prevent (additional) damage to the bed protection and the weir. Due to the ship collision 5 beams collapsed and nearly 55% of the total weir was closed by a rock fill dam to repair the weir. During this long-term closure variable discharge and severe flow conditions occurred behind the remaining opening of the weir. Due to the relative large closure, the flow through the remaining opening became supercritical for discharges upward of 450m^3/s and an undular hydraulic jump appeared behind the weir. The existing bed protection was reinforced by extending the 40-200kg quarry stones with colloidal concrete and the 40-200kg quarry stones bed protection. In order to protect the existing bed protection an additional ballasting layer of large rock material was made to prevent erosion of the bed protection and instability of the weir. The additional sill was made of 3-6t carefully placed stones over a length of 7 meters and behind it overlapping and coupled 4 tons rock nets over a length of 10 meters. Due to the relative small internal gradation and the large flexibility of the nets, these rock nets were not able to withstand discharges up to 450m^3/s which caused flow velocities up to 7.0m/s.

The 3-6t carefully placed stones proved to be stable for discharges up to 450m^3/s and therefore the additional sill was extended with 3-6t stones for upcoming more severe circumstances. The bed protection was loaded to maximum loads during a flood wave with discharges up to 850m^3/s in the weeks after the calamity. During this flood wave, the stones in the middle of the bed protection were stable and no damage occurred here. The edge of the additional sill was on the brick of stability. Instead of prescribed ϕ_{sc} = 1.5, it is allowed to apply a lower stability correction factor to a minimum of ϕ_{sc} = 0.73 for carefully placed stones on the edge of a sill. Up to this value, the 3-6t carefully placed stones on the edge are stable for flow velocities up to 5.9m/s and in the centre of the sill up to 7.1m/s in acceleration supercritical flow.
The 40-200kg quarry stones with pattern penetrated colloidal concrete bed protection proved to be stable for flow velocities up to 7.2m/s and only small damages occurred to this bed protection. The 40-200kg quarry stones seemed to be more stable than expected. Critical velocities calculated with Pilarczyks formula showed lower values than the occurred velocities calculated with the CFD model. This increase of critical velocity is probably due to uncertainties in the CFD model, which is not verified in this study or due to conservative estimations in the stability formula.

Table 7.1 shows the calculated critical velocities for the measures used in Grave and the maximum occurred velocities above the various bed protections at weir Grave. These values are compared to maximum expected flow velocities above the various bed protections for three investigated closure situations of a fictive weir considered in this study. The values 'above 40-200kg quarry stones with colloidal concrete' and 'above 40-200kg quarry stones' are interpolated from the determined values at the start and end of a specific bed protections. The flow velocities for limit and maximum discharges are calculated by an energy equation between the cen-

Table 7.1: Overview calculated and occurred flow velocities [m/s]

	Start 40-200kg colloidal	**Above 40-200kg colloidal**[1]	**Start 40-200kg**	**Above 40-200kg**[1]	**Start 10-60kg**
Grave weir					
Northern opening closed					
q_{max} (850m^3/s)	7.1	7.2	**6.1**	**5.2**	-
Fictive weir					
1 Stoney closed					
1/2 q_{lim} (600m^3/s)	3.42	2.45	1.47	1.40	1.32
q_{lim} (1200m^3/s)	2.97	2.97	2.97	2.97	2.97
q_{max} (1500m^3/s)	3.17	3.17	3.17	3.17	**3.17**
6 beams closed					
1/2 q_{lim} (550m^3/s)	3.17	2.75	2.32	2.29	2.26
q_{lim} (1100m^3/s)	3.32	3.32	3.32	3.32	**3.32**
q_{max} (1344m^3/s)	3.72	3.72	3.72	**3.72**	**3.72**
Complete Poiree closed					
1/2 q_{lim} (300m^3/s)	3.96	3.33	2.70	2.66	2.62
q_{lim} (600m^3/s)	5.36	5.36	**5.36**	**5.36**	**5.36**
q_{max} (742m^3/s)	6.27	6.27	**6.27**	**6.27**	**6.27**
u_{crit} [2]	7.7	7.7	4.4	3.7	3.0

tre of the weir and a sufficient distance from the weir. Because no information was available about the spread of the flow directly behind the weir, the flow velocities calculated in the centre of the weir are taken equal over the complete bed protection.

The bold velocities are higher than the critical velocities and damage can be expected. From this table it can be concluded that the stability of the 40-200kg quarry stones with colloidal concrete bed protection is stable for all closure and discharge situations. Due to the closure of 1 Stoney, the stability of the present bed protection is almost sufficient for the investigated discharges. Only the stability of the 10-60kg quarry stones is exceeded. For the closure of 6 beams of the Poiree part, the stability of the 40-200kg quarry stones in the centre and the 10-60kg quarry stones of the bed protection is not sufficient. However, the flow velocities at weir Grave shown that the 40-200kg quarry stones can probably withstand a higher flow velocity than calculated. In case of a complete closure of the Poiree part, the stability of 40-200kg and 10-60kg quarry stones bed protections are definitely not sufficient. The flow velocities which occur during the limit and maximum discharge exceed the critical flow velocity by far.

In order to guarantee no damage to the 40-200kg quarry stones during a closure of 6 beams and a total closure of the complete Poiree, it is advised to reinforce this part of the bed protection with colloidal concrete. The critical velocity of a colloidal concrete bed protection is not exceeded by the occurring flow velocities during the closure situations. In case of a complete closure of the Poiree part, where also supercritical flow could occur for the maximum discharge, it is advised to use an additional 3-6t bed protection. This measure has proven to be stable to maximum conditions at weir Grave. Conditions which are more severe than investigated for other closure situations.

[1] Interpolated values between start and end of specific bed protection
[2] According to MTB and Pilarczyks formula

Emergency measures

Based on the measures which should be taken during different closure situations at the fictive weir a final advice is given for measures which should be taken at the weirs in the Meuse. The proposed measures are just indications, for the exact determination of variable dimensions and measures, further specific research of each individual object is advised.

Weir Lith
Weir Lith consist of three equal openings, whereby the maximum closure is 33% of the total width of the weir. Furthermore the head loss over weir Lith is smaller than for the fictive weir. These factor causes less severe circumstances with resect to the fictive weir. The asphalt penetrated bed protection of weir Lith is shorter than both the fictive weir and weir Grave, therefore it advisable to do further research to the needed length of reinforced bed protection. Finally, the water regulation system of weir Lith differs from the considered fictive weir. This can have large consequences for the water management and occurring flow velocities during a long-term closure.

Weir Grave
Weir Grave has been tested to the maximum loads and it is concluded that the measures which were used during the Grave weir calamity all withstand these loads. The bed protection was sufficiently reinforced and the additional bed protection, the 3-6t stones, withstood the occurring loads. These extreme loads occurred due to the extreme partial closure of the weir. For a future calamity it is advised to, if possible, minimize the closure, this would significantly decrease the severe flow velocities and flow regimes which occurred at weir Grave.

Weir Sambeek
Weir Sambeek was on the basis of the fictive weir. The differences between the fictive weir and weir Sambeek are negligible. Therefore the same advice is given for weir Sambeek as for the fictive weir.

Weir Belfeld
Weir Belfeld is comparable to weir Sambeek. The weirs are a copy of each other and the dimensions are similar. The colloidal concrete bed protection of weir Belfeld is shorter, but against that, the maximum head loss is also smaller for weir Belfeld. It is advised to extend the colloidal concrete bed protection in case of a total closure of the Poiree part of the weir. In case of the other calamity situations, additional research is advised.

Weir Roermond
Weir Roermond is comparable to the fictive weir, however the Poiree part is slightly larger. The most severe flow circumstances and flow velocities occur when the complete Poiree part is closed. This situation causes the largest relative closure and therefore probably the highest flow velocities behind the weir. On the other hand, the head loss of weir Roermond is smaller than the head loss of the fictive weir and therefore the flow velocities behind the weir will of will not decrease. Nevertheless, the bed protections is not reinforce with colloidal concrete, which decrease the stability significantly. In case of a calamity it is advised to reinforce the bed protections, the exact amount of reinforcement has to be researched in more detail.

Weir Linne
Weir Linne is comparable to the fictive weir. Instead of two Stoney slides, weir Linne consists of three Stoney slides, which decreases the maximum closure. Therefore the occurring flow velocities behind the weir will be less compared to the fictive weir. It should be noted that the head loss difference is higher and the bed protection is less robust, compared to the fictive weir. Therefore possible more severe flow circumstances and damages could occur.

Weir Borgharen
Weir Borgharen has the smallest relative closure of all weirs. In case of a closure of a single opening, no too severe flow velocities will occur with respect to normal flow conditions. Furthermore the bed protection of weir Borgharen is long and very robust. In case of a calamity at weir Borgharen probably no additional measures for the bed protections are needed.

Driel, Amerongen & Hagesteijn
In case of a closure situation at one of the three weirs at Driel, Amerongen or Hagesteijn, always 50% of the weir is closed. Given the large head loss and relatively short bed protection, additional measures to the

bed protection are definitely necessary. The concrete bed protection will be strong enough but should be extended due to higher flow velocities behind this protection.

During the Grave weir calamity extreme flow circumstances and flow velocities occurred. The extreme conditions were caused by the largely partial closure of the weir. This study showed that the increase of flow velocities which occur behind a weir due to smaller closures (1 Stoney, 6 beams) are relatively small and no extreme flow conditions occur. In case of the complete closure of the Poiree part, also these extreme flow velocities tend to occur. Therefore the final conclusion of this report is try to minimize the relative closure (<50%, or preferably <1/3) of a weir during a calamity or maintenance to limit flow velocities. When the closure is not to large with respect to the total width, the consequences are relatively small and no large additional measures have to be taken to protect the bed protection.

8 Recommendations

This final chapter describes the recommendation based on this study. In this study a first insight is given in the consequences of different partial closures of a weir in the river Meuse. In this study large simplification, schematizations and assumptions are used. In order to give a better advice about the consequences of different partial closures additional research should be done to give a more detailed image of the consequences of a closure. The recommendations are categorized in general, schematization and modeling recommendations.

General recommendations

- In this study, a single fictive weir was considered to calculate the consequences of a partial closure. If one want to give an advice for a specific weir in the river Meuse, one should apply the same calculations with the exact dimensions and characteristic of this weir.
- In order to design preventive measures for a future calamity, one should execute more research to the probability of calamity like the Grave weir calamity. This research showed that multiple accidents happened at weir in the Meuse the past decades and possible it could be prevented with additional preventive measures. In this study is not looked into these kind of measures.
- It is concluded in this study that it is advisable to minimize the relative closure of a weir. The method to close a weir during a calamity or maintenance are not further investigated in this research. There are opportunities to come up with inventional solutions which minimize the relative closure but on the other hand, guarantee enough space to repair or renovate a large part of a weir.
- During the Grave weir calamity different damages occured and some uncertainties of the design are not taken into account in this study. The first uncertainty was the possibility of closure of the rock-fill dam. Due to the low discharge at the time it was constructed, it was possible to close the dam. The exact processes and limitations of the design have to be further investigated for a probably future application of this emergency measure. Also the damage which occurred to riverside behind the weir is not taken into account in this study.
- In this study only the stability of rock based emergency measures for the bed protection are considered. The choice of rock during the Grave weir calamity was based on availability of material and the time needed to construct. For a future calamity, when there is more preparation time, also other measures or materials could be used to (if necessary) protect the bed protection. For example, during maintenance of the visors of weirs Driel, Amerongen and Hagesteijn, large steel (reusable) plates are used a a temporary bed protection.

Schematizations

- During the determination of the flow velocities behind the weir, only a limited number of discharges and weir configurations is considered. It is advised in a detailed study to tae into account intermediate flow situations. As mentioned in the report, a more severe flow situation can occur when the first panels from a new row are removed.
- In the flow velocity calculations, large simplifications are made for an overflowing jet. To give a better insight in the processes which occur when a jet flows over a weir and falls into a downstream water level additional research should be done. Especially when the discharge is high and probably supercritical

flow occurs, the consequences are hard to predict.
- For an open weir, the flow velocities are determined by an energy equation over the weir. The flow velocities above the weir are continued over the bed protection. In reality the flow velocities will decrease due to spread in horizontal and vertical direction. A more detailed calculation of the flow velocities behind the weir can contribute to a better design of possible emergency measures.

Stability fomulas

- From the stability calculation it was concluded that the carefully placed stones had an additional strength with respect to usually dumped loose rock. In this study stability correction factor is based only on a single case with a single discharge. To give a better insight in this additional strength one should execute more research to this construction method of placing stones. It is recommended to do more research with for example experimental tests.
- The stability of the bed protections with colloidal concrete is a rough estimation based on limited knowledge. At the moment various tests are done to give a better insight in the stability of bed protections with colloidal concrete. On the basis of these tests additional measures to the bed protection are not necessary due to the strength of the colloidal concrete itself.

Modeling

- In this study, the stability of the Grave weir measures was based on the output of a single CFD model. The use of detailed CFD models is the future. Nevertheless, the models which are used nowadays have there limitations. Furthermore the models which are used have to be calibrated and verified with measured data. It remains uncertain if the output of a model is comparable to reality when it is not verified.
- The occurred flow velocities calculated by the CFD model were higher than the critical velocities for the 40-200kg quarry stone bed protection. It is not completely clear what caused this difference. It is advisable to do additional research to phenomenon and what caused this extra strength of the bed protection.

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A

Flow area Meuse

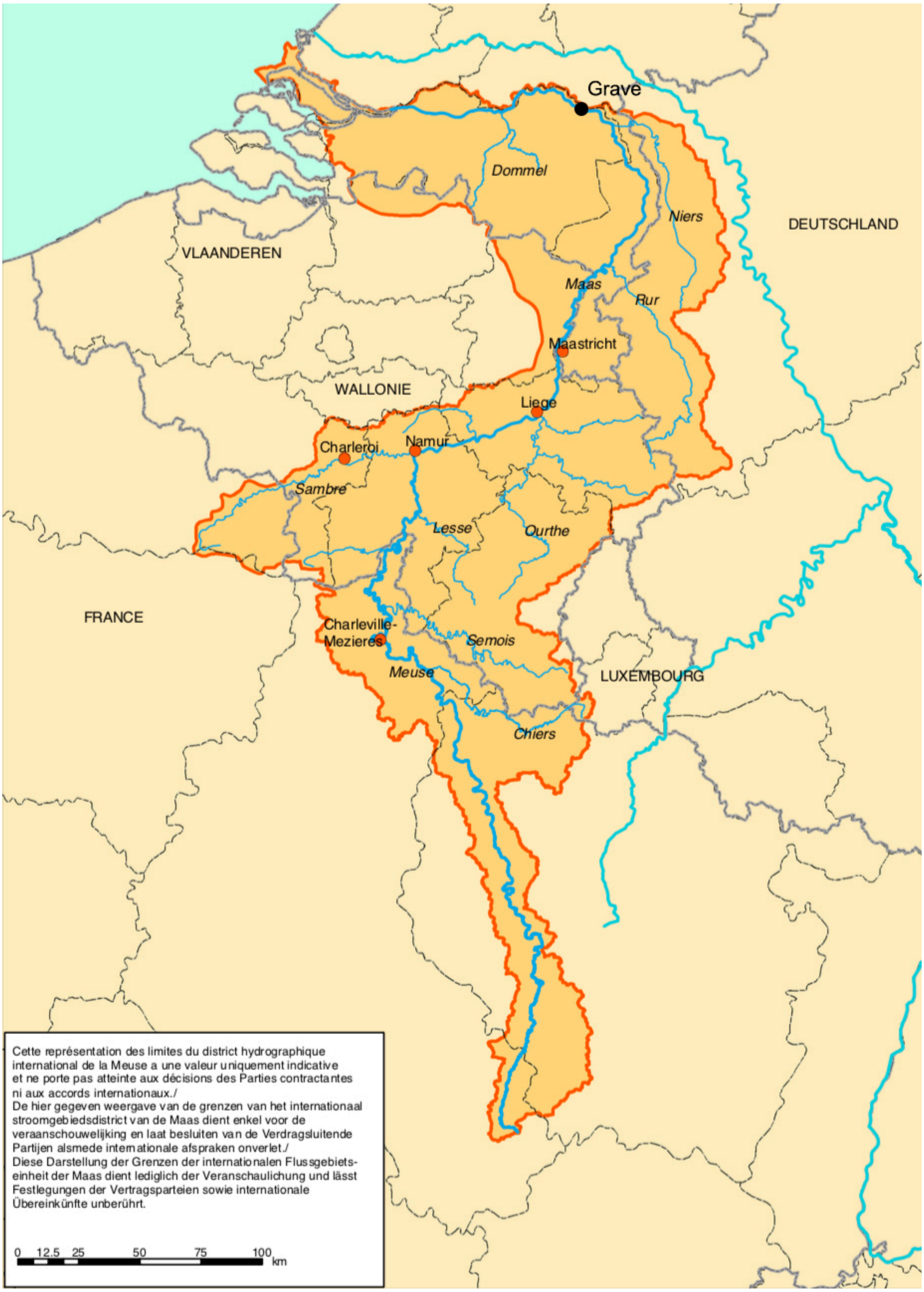

Figure A.1: Catchment area Meuse

B

Weirs in the Meuse

This appendix gives an individual description of the seven weirs in the Meuse.

Lith

The first weir in the Meuse in upstream direction is weir Lith. Weir Lith is build between 1934 and 1936 and consists of 3 opening of each 38 m wide and has therefore a total flow opening of 114 meter. The water level is regulated by three slides which are lifted up to regulate the water level. The water height difference over the weir is 4.36 m with a downstream target level of 0.54 m +NAP and an upstream target level of 4.90 m +NAP. The sill of the weir is located on 2.50 m -NAP. Figure B.1 shows a picture and a schematization of weir Lith.

The 85 meters long bed protection behind the sill of wier Lith consists of first 40 meters 40-200 kg quarry stones poured with asphalt. Then 25 meters of standard 40-200 kg quarry stones, followed by 15 meters of 10-60 kg quarry stones.

Figure B.1: Weir Lith

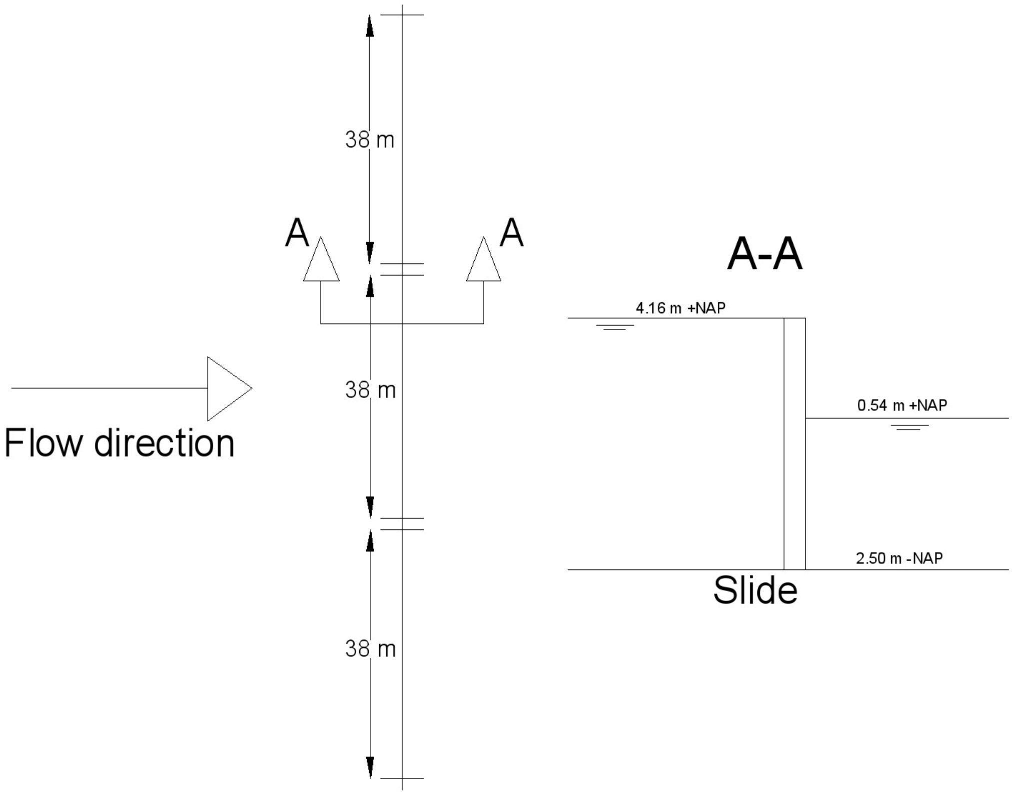

Figure B.2: Weir Lith schematization

Grave

Weir Grave is the second weir and the construction was finished in 1929. Weir Grave consists of two openings of respectively 60 and 50 meters and a total flow opening of 110 meters. These openings consists of respectively 11 and 9 beams. In between these beams three panels are located which can be removed individually to control the water level upstream. The water levels over weir Grave are 4.93 +NAP downstream and 7.93 m +NAP upstream of the weir. This gives a maximum water height difference over the weir of 3 m. The height of the sill is located at 2.70 m +NAP.

Figure B.3: Weir Grave

The bed protection before the ship collision was in total 85 meters long and consisted of 40-200 kg quarry stones of which the first 20 meter is strengthened with colloidal concrete. After the ship collision and the repair work of the weir, the bed protection with colloidal concrete is extend to 55 meters. And behind that 55 m 40-200 kg quarry stones. The total length of the bed protection is now 110 meters.

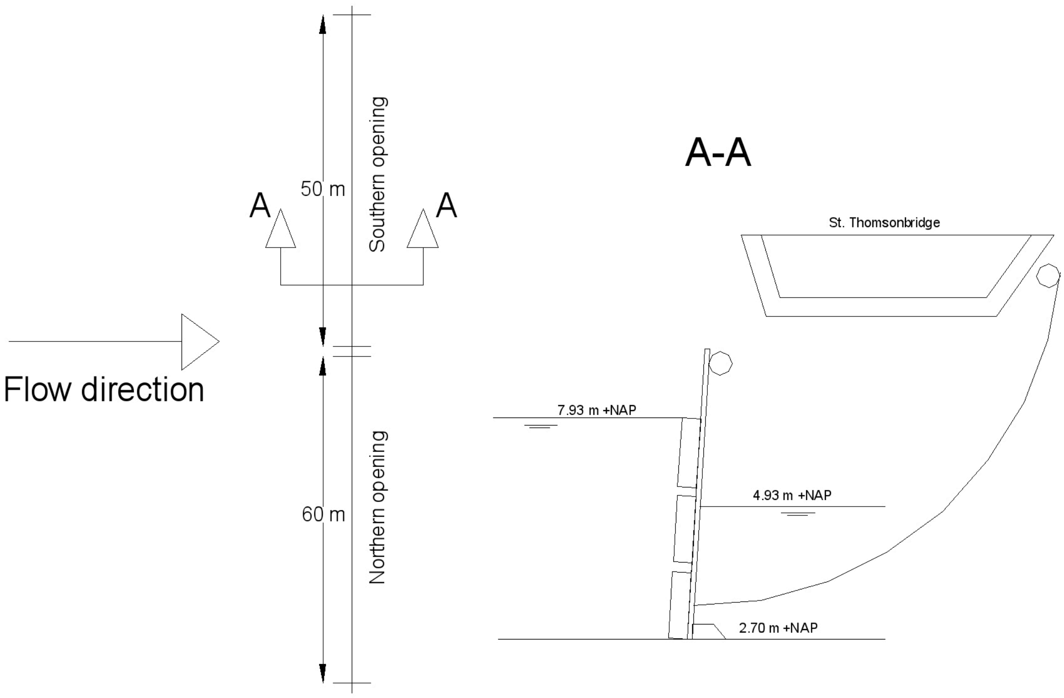

Figure B.4: Weir Grave schematization

Sambeek

Weir Sambeek, build in 1926 and 97 m flow opening wide in total, consists of two parts. A Stoney part, for the fine tuning of water levels, and a Poiree part, for coarse regulation of the water level. The stoney part consists of two openings of 17 meters each. In this openings two slides are constructed which can be raise or lowered and thereby control the water levels. The Poiree part, 63 meters wide, consists of 13 partitions, with each three panels, which can be removed individually. The water level downstream of the weir is 7.97 m +NAP and upstream of the weir 11.10 m +NAP. The water height difference over the weir therefore, during low discharges, becomes 3.13 m. The sill of the Stoney part is located at 5.45 m +NAP and the sill of the Poiree part at 8.05 m +NAP.

Figure B.5: Weir Sambeek

Behind the sill are concrete blocks located. These blocks (1.50 x 1.00 x 0.95 m) are serrated behind the Stoney part and the blocks (1.50 x 1.00 x 0.80 m) are plane behind the Poiree part. Contiguous to these blocks there is a bed protection of 55 meters 40-200 kg quarry stones, of which the first 6 meter is penetrated with colloidal concrete. At the end of the bed protection is another 15 meters of 10-60 kg grading present.

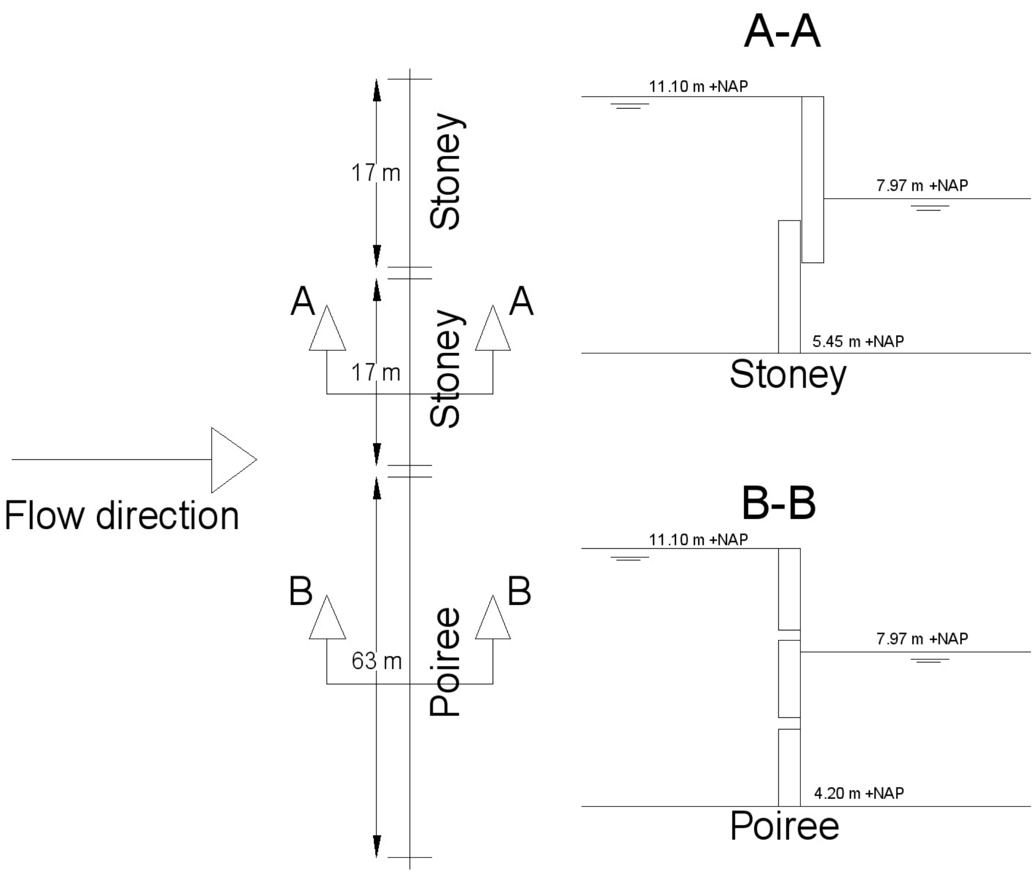

Figure B.6: Weir Sambeek schematization

Belfeld

Weir Belfeld is almost a copy of weir Sambeek and consists also of two 17-meters wide Stoney parts and a 63 meters wide Poiree part. The Poiree part also consists of 13 partitions with each 3 panels.The water height difference over the weir is 3.25 m, from 14.10 m +NAP upstream to 10.85 m +NAP downstream of the weir. The sill of the Stoney part is located at 8.35 m +NAP and the sill of the Poiree part at 8.05 m +NAP.

Figure B.7: Weir Belfeld

Behind the sill is also a bed protecting of 8.5 m concrete blocks. Between these blocks and the quarry stones bed protection is double sheet pile with 2 meters concrete in between. In total a concrete structure of 10.5 m is located behind the sill. Behind this concrete structure is in total 55 meters of bed protection of which the first 25 meters 300-1000 kg and the last 30 meters 40-200 kg grading. This structure also ends with a concrete caisson at the end of the bed protection.

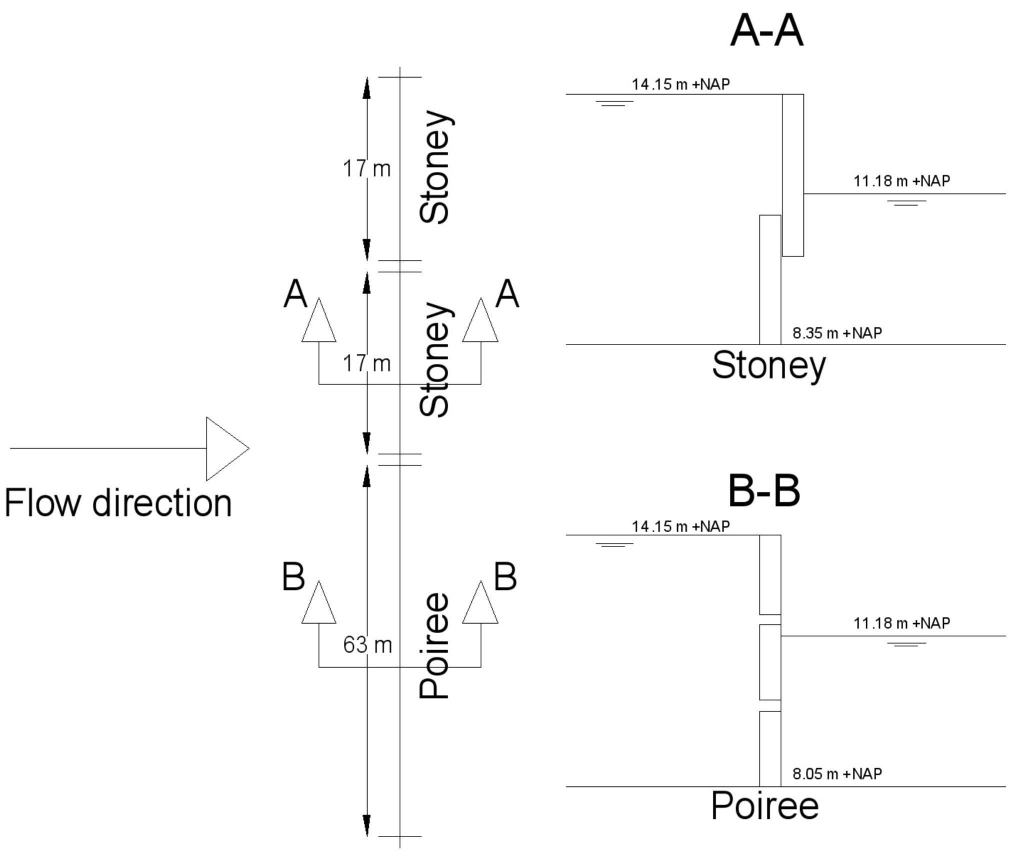

Figure B.8: Weir Belfeld schematization

Roermond

Weir Roermond consists of two 17 meters wide Stoney parts and a Poiree part of 68 meters wide. The Poiree part consists of 17 partitions with each 3 panels. The upstream target level is 16.85 m +NAP, the downstream target level is 14.16 m +NAP. Which results in a difference of 2.69 m. The sill of the Stoney and Poiree part are on 11.80 m +NAP and 11.60 m +NAP respectively.

Behind the sill is the samen construction present as at weir Belfeld. 8.5 m serrated concrete blocks and a 2 m wide concrete block in between sheet piles. Behind this concrete construction a 45 meter long 40-200 kg quarry stones bed protection is present.

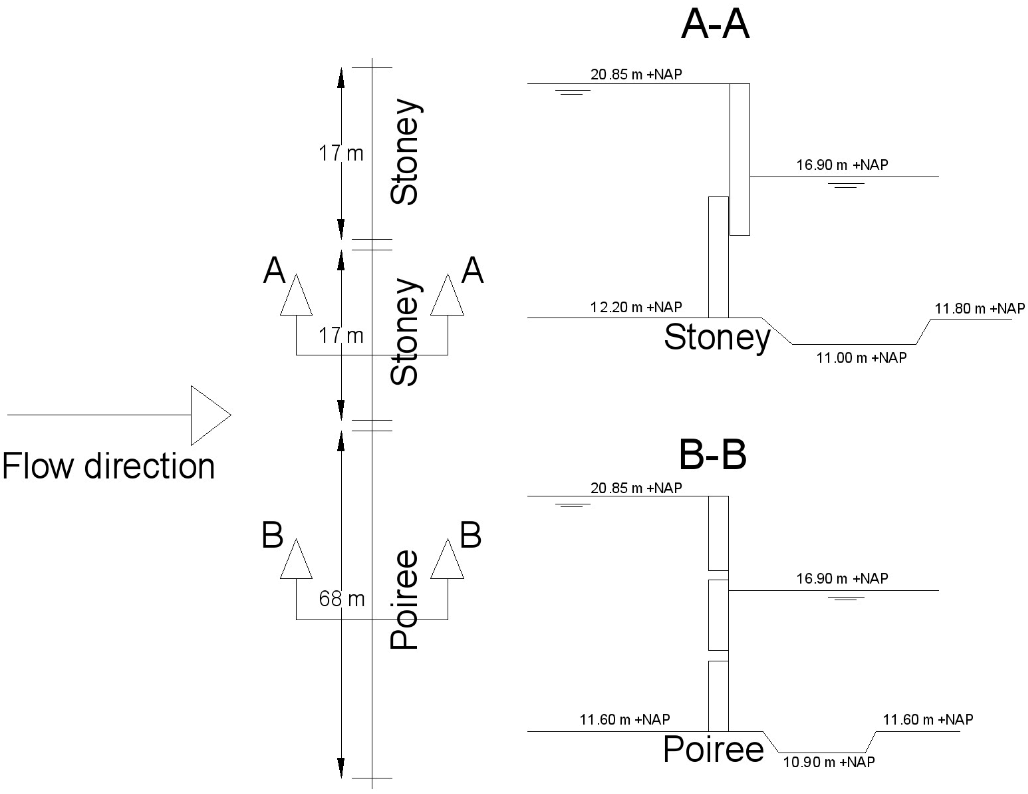

Figure B.10: Weir Roermond schematization

Linne

Weir Linne, into operation in 1926, consists of three 17 meters wide Stoney parts and a 60 meters wide Poiree part. The Poiree part is made of 15 partitions with each three panels. The head loss over the weir is 3.95 m, from 20.85 m +NAP to 16.90 m +NAP. The sill of the Stoney part is located at 16.95 m +NAP and the Poiree part at 15.95 m +NAP. A hydroelectric power plant is located next to the weir. The full discharge, up to 500 m^3/s, flows through this power plant. For higher discharges the power is switched off and the weir is used.

Behind the sill, similar construction as at weir Roermond and Belfeld is present. The bed protection behind the concrete structure is 80 meters long. Behind the Stoney part it is made of 60-300 kg stones and 300-1000 kg stones are used behind the Poiree. The first 20 meters of this protection a strengthened with colloidal concrete.

Figure B.11: Weir Linne

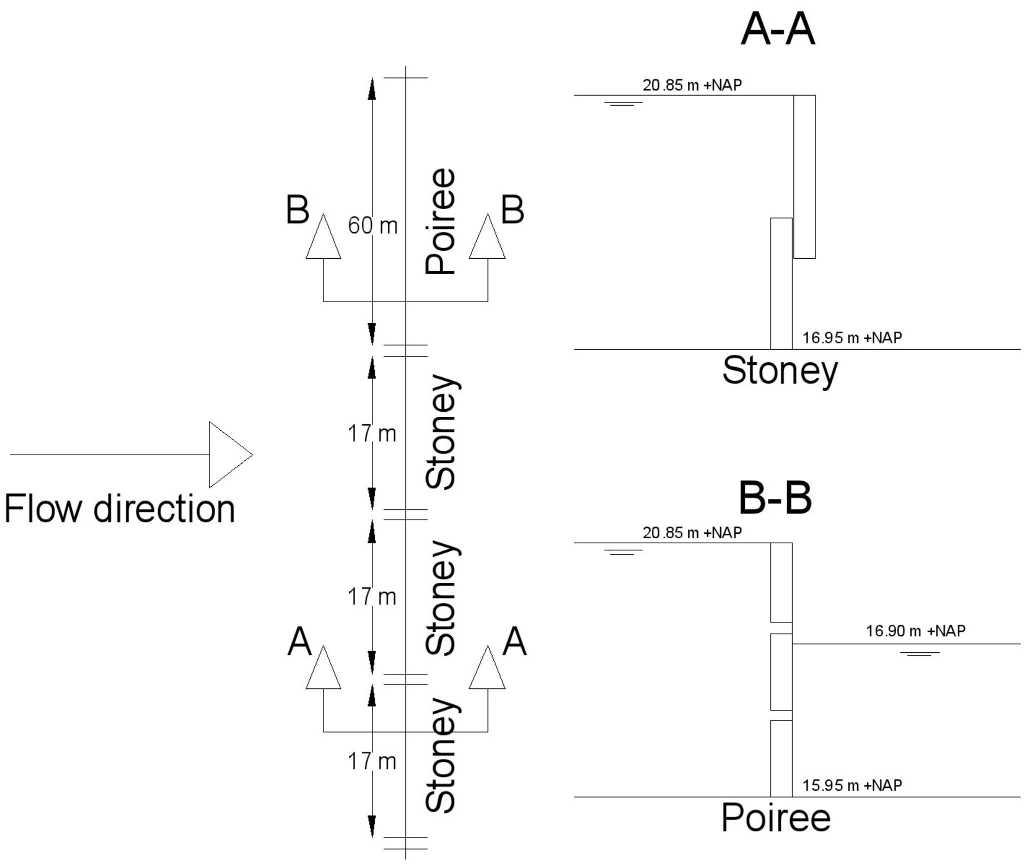

Figure B.12: Weir Linne schematization

Borgharen

The last weir in the Dutch part of the Meuse is weir Borgharen, built in 1926. The weir consists of four openings. Three opening of each 23 meters wide in which the water level is controlled by a flap. And one opening with a slide of 30 meters wide. The upstream water level is 44.05 m +NAP and the downstream level is 38.06 m +NAP. The water height difference is 5.99 m, for low discharges. The sill of the three flap opening is at 39.60 m +NAP and for the slide opening at 38.50 m +NAP.

The bed protection is made of 40 meters 300-1000 kg quarry stones. Only behind the most western opening, the bed protection is made of 40-200 kg stones.

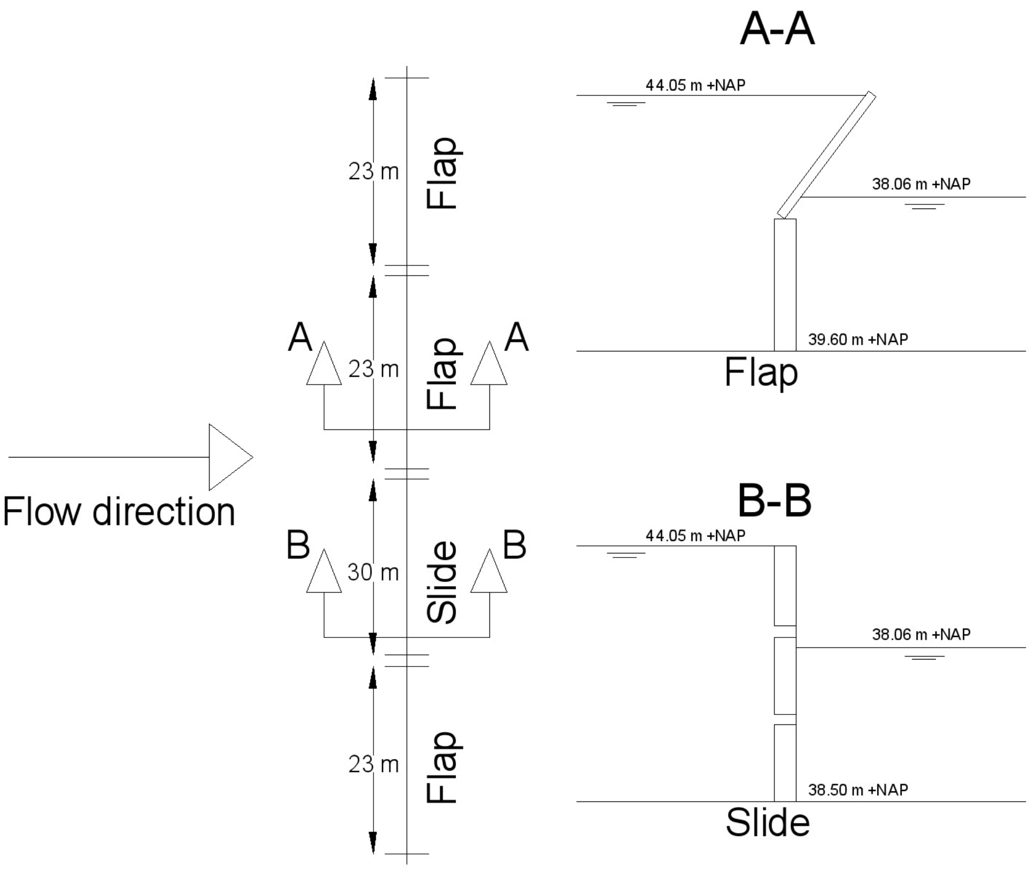

Figure B.14: Weir Borgharen schematization

C

Water levels

Table C.1: Actual water levels

Q	**H_Upstream**	**h_downstream**	**Δh** [m]		**Q**	**H_Upstream**	**h_downstream**	**Δh** [m]
0	11.10	7.95	3.15		850	10.89	9.52	1.58
50	11.10	7.95	3.15		900	10.86	9.65	1.45
100	11.10	7.99	3.11		950	10.83	9.78	1.32
150	11.10	8.04	3.06		1000	10.80	9.90	1.20
200	11.10	8.08	3.02		1100	10.75	10.15	0.95
250	11.10	8.14	2.96		1150	10.74	10.28	0.82
300	11.10	8.25	2.85		1200	10.73	10.39	0.74
350	11.10	8.34	2.76		1300	10.77	10.62	0.55
400	11.10	8.44	2.66		1400	11.00	10.88	0.34
450	11.10	8.55	2.55		1500	11.30	11.10	0.25
500	11.10	8.65	2.45		1750	11.93	11.68	0.22
550	11.08	8.75	2.35		2000	12.51	12.19	0.32
600	11.05	8.90	2.20		2500	13.22	13.05	0.27
650	11.00	9.03	2.07		3000	13.71	13.60	0.11
700	10.98	9.15	1.95		3500	14.06	14.05	0.01
750	10.95	9.27	1.83		4000	14.65	14.65	0.00
800	10.92	9.38	1.72					

Table C.2: Modelled water levels

Q	**H_Upstream**	**h_downstream**	**Δh** [m]		**Q**	**H_Upstream**	**h_downstream**	**Δh** [m]
0	11.10	7.95	3.15		850	11.10	9.52	1.58
50	11.10	7.95	3.15		900	11.10	9.65	1.45
100	11.10	7.99	3.11		950	11.10	9.78	1.32
150	11.10	8.04	3.06		1000	11.10	9.90	1.20
200	11.10	8.08	3.02		1100	11.10	10.15	0.95
250	11.10	8.14	2.96		1150	11.10	10.28	0.82
300	11.10	8.25	2.85		1200	11.10	10.39	0.72
350	11.10	8.34	2.76		1300	11.15	10.62	0.53
400	11.10	8.44	2.66		1400	11.22	10.88	0.34
450	11.10	8.55	2.55		1500	11.35	11.10	0.25
500	11.10	8.65	2.45		1750	11.90	11.68	0.22
550	11.10	8.75	2.35		2000	12.51	12.19	0.32
600	11.10	8.90	2.20		2500	13.22	13.05	0.27
650	11.10	9.03	2.07		3000	13.71	13.60	0.11
700	11.10	9.15	1.95		3500	14.06	14.05	0.01
750	11.10	9.27	1.83		4000	14.65	14.65	0.00
800	11.10	9.38	1.72					

D
Discharge coefficients

Discharge coefficient Stoney

From a discharge higher than 200 m^3/s it is no longer possible to regulate the water level with the Stoney slides and it is assumed that the slides are both on the sill with the top at a height of 8.40m +NAP. Therefore the discharge coefficient for both Stoneys becomes:

Table D.1: Characteristics Q = 200 m^3/s

Q	H_upstream	H_downstream	Sill height Stoney	H	h3	Sill height Poiree	H	h3
200 m^3/s	11.10	8.08	8.40	2.70	-0.37 <2/3H (free flow)	11.10	0 (no flow)	-3.12 (free flow)

$$Q = m_{f(Stoney)} * b * H^{3/2}$$

$$\begin{aligned} Q &= 200 m^3/s \\ b &= 34 m && \text{(Width two Stoneys)} \\ H &= 2.70 m \end{aligned}$$

$$200 = m_{f(Stoney)} * 34 * 2.70^{3/2}$$

$$m_{f(Stoney)} = 1.33$$

The discharge coefficient over the Stoney slides is therefore $m_{f(Stoney)} = 1.33$.

Discharge coefficient middle row Poiree

From a discharge up to 400 m^3/s, the first row panels is removed and the fine-tuning is done by lowering the Stoney slides. At a discharge of 400 m^3/s it is no longer possible to control the water level by the Stoney slides and all the panels are removed from the top row of the Poiree part. It is assumed that the Stoney slides are again located on the sill and the complete top row of panels is removed from the Poiree at a discharge of 400 m3/s. According to the upstream and downstream water levels is it clear that there is still a free flow discharge.

Table D.2: Characteristics Q = 400 m^3/s

Q	H_upstream	H_downstream	Sill height Stoney	H	h3	Sill height Poiree	H	h3
400 m^3/s	11.10	8.44	8.40	2.70	0.04 <2/3H (free flow)	9.20	1.90	-0.76 (free flow)

$$Q = m_{f(Stoney)} * b_s * H_s^{3/2} + m_{f(Poiree,m)} * b_p * H_p^{3/2}$$

$$Q = 400m^3/s$$
$$b_s = 34m \quad \text{(Width two Stoneys)}$$
$$b_p = 63m \quad \text{(Width Poiree)}$$
$$H_s = 2.70m$$
$$H_p = 1.90m$$

$$400 = 1.33 * 34 * 2.70^{3/2} + m_{f(Poiree,m)} * 63 * 1.90^{3/2}$$

$$m_{f(Poiree,m)} = 1.21$$

The discharge coefficient for free flow over the middle row of the Poiree part therefore is $m_{f(Poiree,m)} = 1.21$.

Discharge coefficient lowest row Poiree

From a discharge up to 650 m^3/s, the first row panels is removed and the fine-tuning is done by lowering the Stoney slides. At a discharge of 650 mm^3/s it is no longer possible to control the water level by the Stoney slides and all the panels are removed from the top row of the Poiree part. It is assumed that the Stoney slides are again located on the sill and the complete top row of panels is removed from the Poiree at a discharge of 650 m3/s. According to the upstream and downstream water levels is it clear that there is still a free flow discharge.

Table D.3: Characteristics Q = 650 m^3/s

Q	**H_upstream**	**H_downstream**	**Sill height Stoney**	**H**	**h3**	**Sill height Poiree**	**H**	**h3**
650 mm^3/s	11.00	9.03	8.40	2.60	0.63 <2/3H (free flow)	7.30	3.70	1.73 (free flow)

$$Q = m_{f(Stoney)} * b_s * H_s^{3/2} + m_{f(Poiree,l)} * b_p * H_p^{3/2}$$

$$Q = 650m^3/s$$
$$b_s = 34m \quad \text{(Width two Stoneys)}$$
$$b_p = 63m \quad \text{(Width Poiree)}$$
$$H_s = 2.60m$$
$$H_p = 3.70m$$

$$650 = 1.33 * 34 * 2.60^{3/2} + m_{f(Poiree,l)} * 63 * 3.70^{3/2}$$

$$m_{f(Poiree)} = 1.03$$

The discharge coefficient for free flow over the lowest row of the Poiree part therefore is $m_{f(Poiree,l)} = 1.03$.

Discharge coefficient open weir

From a discharge of 1150 m^3/s, the weir is completely open. The Stoney slides are above water and the Poiree part is completely lowered. The flow over the weir is now a submerged flow, therefore m is a discharge coefficient for the complete width of the weir.

Table D.4: Characteristics Q = 1150 m^3/s

Q	H_upstream	H_downstream	Sill height Stoney	H	h3	Sill height Poiree	H	h3
1150 m^3/s	10.74	10.28	5.45	5.29	4.83 (submerged flow)	4.30	6.54	6.08 (submerged flow)

$$Q = m_{s(Stoney)} * b_s * h_{3,s}\sqrt{2g(H_s - h_{3,s})} + m_{s(Poiree,l)} * b_p * h_{3,p}\sqrt{2g(H_p - h_{3,p})}$$

$$\begin{aligned}
Q &= 1150m^3/s \\
b_s &= 34m \\
b_p &= 63m \\
H_s &= 6.29m \\
h_{3,s} &= 4.83m \\
H_p &= 6.54m \\
h_{3,s} &= 6.08m
\end{aligned}$$

It is assumed that the discharge coefficient for a complete open weir is the same for the Stoney and Poiree part and therefore called m_o for an open weir.

$$1150 = m_o * 34 * 4.83\sqrt{2 * 9.81(6.29 - 4.83)} + m_o * 63 * 6.08\sqrt{2 * 9.81(6.54 - 6.08)}$$

The discharge coefficient for an open weir therefore is $m_o = 0.70$.

Transition free to submerged flow

The last discharge coefficient which has to be determined is for a submerged flow over the lowest row of Poiree panels. At a certain point, the flow over these panels changes from free to submerged flow. Change from free flow to submerged flow over the lowest row of panels occurs between 900 m^3/s and 950 m^3/s discharge. Due to this change in flow regime a different discharge formula is used, with a different discharge coefficient, but there will be no sudden change in discharge over the Poiree. This is a gradual transition. To calculate this coefficient the positions of the Stoneys, the flow regime and the discharge coefficients of the Stoneys is not changed over this increased discharge. The discharge over the Stoney is calculated first, for the given water levels, and the remaining, or extra, discharge will flow over the lowest row of Poiree panels. In this way the corresponding discharge coefficient for a submerged flow over the lowest row panels is calculated. Both Stoneys are above water and only the lowest row of panels is still present in the Poiree part. The corresponding water levels are shown in Table D.5 & D.6.

$$Q_{total} = Q_{Stoney} + Q_{Poiree}$$

$$Q_{total} = m_o * b_s * h_{3,s}\sqrt{2g(H_s - h_{3,s})} + m_{s(Poiree,l)} * b_p * h_{3,p}\sqrt{2g(H_p - h_{3,p})}$$

Table D.5: Flow over Stoney part

Q	H_upstream	H_downstream	Sill height Stoney	H	h3	m
900 m^3/s	10.86	9.65	5.45	5.41 (submerged)	4.20	0.70
950 m^3/s	10.83	9.78	5.45	5.38 (submerged)	4.33	0.70

Table D.6: Flow over Poiree part

Q	H_upstream	H_downstream	Heigth Poiree	H	h3	m
900 m^3/s	10.86	9.65	7.30	3.56 (free)	2.35	0.70
950 m^3/s	10.83	9.78	7.30	3.53 (submerged)	2.48	...

$$
\begin{aligned}
Q &= 950 m^3/s \\
b_s &= 34 m \\
b_p &= 63 m \\
H_s &= 5.38 m \\
h_{3,s} &= 4.33 m \\
H_p &= 3.53 m \\
h_{3,p} &= 2.48 m \\
m_o &= 0.70
\end{aligned}
$$

$$950 = 0.70 * 34 * 4.33\sqrt{2 * 9.81(5.38 - 4.33)} + m_{s(Poiree,l)} * 63 * 2.48\sqrt{2 * 9.81(3.53 - 2.48)}$$

$$m_{s(Poiree,l)} = 0.68$$

E

Limit discharges

Situation: Example

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Flow stages

Check: h3<2/3H

Number of panels on a specific level. Sum must be total 13 panels in Poiree part

Discharge determined by discharge relations as described in Figure 4.4

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Flow stage	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	Poiree 9,20	Poiree 7,30	Poiree 4,20	Poiree Total	Middle panels H	Middle panels h3	Middle panels Free flow?	Lowest panels H	Lowest panels h3	Lowest panels Free flow?	Sill H	Sill h3	Sill Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**		11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**		10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	I	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**		9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**		8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**230**		9,00	9,00	2,10	-0,86	ja	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	11,10	8,25	2,85	**291**	II	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	11,10	8,34	2,76	**337**		9,00	9,00	2,10	-0,66	ja	0	13	0	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	11,10	8,44	2,66	**400**		8,40	8,40	2,70	0,04	ja	0	13	0	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	11,10	8,55	2,55	**443**		9,50	9,50	1,60	-0,95	ja	0	6	7	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	46	46	92	259	0
500	11,10	8,65	2,45	**508**		9,50	9,50	1,60	-0,85	ja	0	3	10	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	46	46	46	370	0
550	11,08	8,75	2,33	**548**	III	9,00	9,00	2,08	-0,25	ja	0	3	10	0	13	1,88	-0,45	ja	3,78	1,45	ja	6,88	4,55	ja	68	68	45	367	0
600	11,05	8,90	2,15	**604**		9,00	9,00	2,05	-0,10	ja	0	0	13	0	13	1,85	-0,30	ja	3,75	1,60	ja	6,85	4,70	nee	66	66	0	472	0
650	11,00	9,03	1,97	**652**		8,40	8,40	2,60	0,63	ja	0	0	13	0	13	1,80	-0,17	ja	3,70	1,73	ja	6,80	4,83	nee	95	95	0	462	0
700	10,98	9,15	1,83	**691**		8,00	8,00	2,98	1,15	ja	0	0	13	0	13	1,78	-0,05	ja	3,68	1,85	ja	6,78	4,95	nee	116	116	0	458	0
750	10,95	9,27	1,68	**743**		7,50	7,50	3,45	1,77	ja	0	0	13	0	13	1,75	0,07	ja	3,65	1,97	ja	6,75	5,07	nee	145	145	0	453	0
800	10,92	9,38	1,54	**798**		7,00	7,00	3,92	2,38	ja	0	0	13	0	13	1,72	0,18	ja	3,62	2,08	ja	6,72	5,18	nee	175	175	0	447	0
850	10,89	9,52	1,37	**851**	IV	6,20	6,20	4,69	3,32	nee	0	0	13	0	13	1,69	0,32	ja	3,59	2,22	ja	6,69	5,32	nee	205	205	0	442	0
900	10,86	9,65	1,21	**906**		5,60	5,60	5,26	4,05	nee	0	0	13	0	13	1,66	0,45	ja	3,56	2,35	ja	6,66	5,45	nee	235	235	0	436	0
950	10,83	9,78	1,05	**950**		5,45	5,45	5,38	4,33	nee	0	0	13	0	13	1,63	0,58	ja	3,53	2,48	nee	6,63	5,58	nee	234	234	0	483	0
1000	10,80	9,90	0,90	**1004**		5,45	5,45	5,35	4,45	nee	0	0	11	2	13	1,60	0,70	ja	3,50	2,60	nee	6,60	5,70	nee	223	223	0	396	163
1100	10,75	10,15	0,60	**1100**	V	5,45	5,45	5,30	4,70	nee	0	0	5	8	13	1,55	0,95	ja	3,45	2,85	nee	6,55	5,95	nee	192	192	0	161	554
1150	10,74	10,28	0,46	**1151**		5,45	5,45	5,29	4,83	nee	0	0	0	13	13	1,54	1,08	nee	3,44	2,98	nee	6,54	6,08	nee	173	173	0	0	806
1200	10,73	10,39	0,34	**1009**		5,45	5,45	5,28	4,94	nee	0	0	0	13	13	1,53	1,19	nee	3,43	3,09	nee	6,53	6,19	nee	152	152	0	0	706
1300	10,77	10,62	0,15	**697**		5,45	5,45	5,32	5,17	nee	0	0	0	13	13	1,57	1,42	nee	3,47	3,32	nee	6,57	6,42	nee	106	106	0	0	486
1400	[illegible]	[illegible]	[illegible]	**651**		5,45	5,45	5,55	5,43	nee	0	0	0	13	13	1,80	1,68	nee	3,70	3,58	nee	6,80	6,68	nee	99	99	0	0	452
1500	[illegible]	[illegible]	[illegible]	**[illegible]**		5,45	5,45	5,85	5,65	nee	0	0	0	13	13	2,10	1,90	nee	4,00	3,80	nee	7,10	6,90	nee	133	133	0	0	603
1750	[illegible]	[illegible]	[illegible]	**[illegible]**	VI	5,45	5,45	6,48	6,23	nee	0	0	0	13	13	2,73	2,48	nee	4,63	4,38	nee	7,73	7,48	nee	164	164	0	0	731
2000	[illegible]	[illegible]	[illegible]	**[illegible]**		5,45	5,45	7,06	6,74	nee	0	0	0	13	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	884
2500	[illegible]	[illegible]	[illegible]	**[illegible]**		5,45	5,45	7,77	7,60	nee	0	0	0	13	13	4,02	3,85	nee	5,92	5,75	nee	9,02	8,85	nee	165	165	0	0	713
3000	[illegible]	[illegible]	[illegible]	**[illegible]**		5,45	5,45	8,26	8,15	nee	0	0	0	13	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	609
3500	14,06	14,05	0,01	**283**		5,45	5,45	8,61	8,60	nee	0	0	0	13	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	193
4000	14,65	14,65	0,00	**0**		5,45	5,45	9,20	9,20	nee	0	0	0	13	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Limit discharge. No longer possible to regulate the water level. Q Total differs from Q St Pieter.

Situation: Normal management

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja	0	13	0	0	13
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja	0	13	0	0	13
450	11,10	8,55	2,55	**443**	9,50	9,50	1,60	-0,95	ja	0	6	7	0	13
500	11,10	8,65	2,45	**508**	9,50	9,50	1,60	-0,85	ja	0	3	10	0	13
550	11,08	8,75	2,33	**548**	9,00	9,00	2,08	-0,25	ja	0	3	10	0	13
600	11,05	8,90	2,15	**604**	9,00	9,00	2,05	-0,10	ja	0	0	13	0	13
650	11,00	9,03	1,97	**652**	8,40	8,40	2,60	0,63	ja	0	0	13	0	13
700	10,98	9,15	1,83	**691**	8,00	8,00	2,98	1,15	ja	0	0	13	0	13
750	10,95	9,27	1,68	**743**	7,50	7,50	3,45	1,77	ja	0	0	13	0	13
800	10,92	9,38	1,54	**798**	7,00	7,00	3,92	2,38	ja	0	0	13	0	13
850	10,89	9,52	1,37	**851**	6,20	6,20	4,69	3,32	nee	0	0	13	0	13
900	10,86	9,65	1,21	**906**	5,60	5,60	5,26	4,05	nee	0	0	13	0	13
950	10,83	9,78	1,05	**950**	5,45	5,45	5,38	4,33	nee	0	0	13	0	13
1000	10,80	9,90	0,90	**1004**	5,45	5,45	5,35	4,45	nee	0	0	11	2	13
1100	10,75	10,15	0,60	**1100**	5,45	5,45	5,30	4,70	nee	0	0	5	8	13
1150	10,74	10,28	0,46	**1151**	5,45	5,45	5,29	4,83	nee	0	0	0	13	13
1200	10,73	10,39	0,34	**1009**	5,45	5,45	5,28	4,94	nee	0	0	0	13	13
1300	10,77	10,62	0,15	**697**	5,45	5,45	5,32	5,17	nee	0	0	0	13	13
1400	11,00	10,88	0,12	**651**	5,45	5,45	5,55	5,43	nee	0	0	0	13	13
1500	11,30	11,10	0,20	**870**	5,45	5,45	5,85	5,65	nee	0	0	0	13	13
1750	11,93	11,68	0,25	**1060**	5,45	5,45	6,48	6,23	nee	0	0	0	13	13
2000	12,51	12,19	0,32	**1286**	5,45	5,45	7,06	6,74	nee	0	0	0	13	13
2500	13,22	13,05	0,17	**1044**	5,45	5,45	7,77	7,60	nee	0	0	0	13	13
3000	13,71	13,60	0,11	**894**	5,45	5,45	8,26	8,15	nee	0	0	0	13	13
3500	14,06	14,05	0,01	**283**	5,45	5,45	8,61	8,60	nee	0	0	0	13	13
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	0	0	0	13	13

Q St. Pieter	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	46	46	92	259	0
500	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	46	46	46	370	0
550	1,88	-0,45	ja	3,78	1,45	ja	6,88	4,55	ja	68	68	45	367	0
600	1,85	-0,30	ja	3,75	1,60	ja	6,85	4,70	nee	66	66	0	472	0
650	1,80	-0,17	ja	3,70	1,73	ja	6,80	4,83	nee	95	95	0	462	0
700	1,78	-0,05	ja	3,68	1,85	ja	6,78	4,95	nee	116	116	0	458	0
750	1,75	0,07	ja	3,65	1,97	ja	6,75	5,07	nee	145	145	0	453	0
800	1,72	0,18	ja	3,62	2,08	ja	6,72	5,18	nee	175	175	0	447	0
850	1,69	0,32	ja	3,59	2,22	ja	6,69	5,32	nee	205	205	0	442	0
900	1,66	0,45	ja	3,56	2,35	ja	6,66	5,45	nee	235	235	0	436	0
950	1,63	0,58	ja	3,53	2,48	nee	6,63	5,58	nee	234	234	0	483	0
1000	1,60	0,70	ja	3,50	2,60	nee	6,60	5,70	nee	223	223	0	396	163
1100	1,55	0,95	ja	3,45	2,85	nee	6,55	5,95	nee	192	192	0	161	554
1150	1,54	1,08	nee	3,44	2,98	nee	6,54	6,08	nee	173	173	0	0	806
1200	1,53	1,19	nee	3,43	3,09	nee	6,53	6,19	nee	152	152	0	0	706
1300	1,57	1,42	nee	3,47	3,32	nee	6,57	6,42	nee	106	106	0	0	486
1400	1,80	1,68	nee	3,70	3,58	nee	6,80	6,68	nee	99	99	0	0	452
1500	2,10	1,90	nee	4,00	3,80	nee	7,10	6,90	nee	133	133	0	0	603
1750	2,73	2,48	nee	4,63	4,38	nee	7,73	7,48	nee	164	164	0	0	731
2000	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	884
2500	4,02	3,85	nee	5,92	5,75	nee	9,02	8,85	nee	165	165	0	0	713
3000	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	609
3500	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	193
4000	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: Model normal management

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q	h	h		Q	Stoney_1	Stoney_2				Poiree					Middle panels			Lowest panels			Sill			Q	Q	Q	Q	Q
St. Pieter	**Upstream**	**Downstream**	**ΔH**	**Total**	Level	Level	H	h3	Free flow?	11,10	9,20	7,30	4,20	Total	H	h3	Free flow?	H	h3	Free flow?	H	h3	Free flow?	**Stoney 1**	**Stoney 2**	**middle**	**low**	**sill**
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja	0	13	0	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja	0	13	0	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	11,10	8,55	2,55	**443**	9,50	9,50	1,60	-0,95	ja	0	6	7	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	46	46	92	259	0
500	11,10	8,65	2,45	**508**	9,50	9,50	1,60	-0,85	ja	0	3	10	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	46	46	46	370	0
550	11,10	8,75	2,35	**554**	9,00	9,00	2,10	-0,25	ja	0	3	10	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	69	69	46	370	0
600	11,10	8,90	2,20	**575**	9,00	9,00	2,10	-0,10	ja	0	2	11	0	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	69	69	31	407	0
650	11,10	9,03	2,07	**638**	8,40	8,40	2,70	0,63	ja	0	2	11	0	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	100	100	31	407	0
700	11,10	9,15	1,95	**712**	7,60	7,60	3,50	1,55	ja	0	3	10	0	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	148	148	46	370	0
750	11,10	9,27	1,83	**734**	7,60	7,60	3,50	1,67	ja	0	2	11	0	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	148	148	31	407	0
800	11,10	9,38	1,72	**790**	7,50	7,50	3,60	1,88	ja	0	0	13	0	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	154	154	0	481	0
850	11,10	9,52	1,58	**829**	7,20	7,20	3,90	2,32	ja	0	0	13	0	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	174	174	0	481	0
900	11,10	9,65	1,45	**884**	6,80	6,80	4,30	2,85	ja	0	0	13	0	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	202	202	0	481	0
950	11,10	9,78	1,32	**939**	6,00	6,00	5,10	3,78	nee	0	0	13	0	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	229	229	0	481	0
1000	11,10	9,90	1,20	**1014**	5,80	5,80	5,30	4,10	nee	0	0	13	0	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	237	237	0	541	0
1100	11,10	10,15	0,95	**1104**	5,45	5,45	5,65	4,70	nee	0	0	11	2	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	0	446	174
1150	11,10	10,28	0,82	**1147**	5,45	5,45	5,65	4,83	nee	0	0	9	4	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	0	355	331
1200	11,11	10,39	0,72	**1225**	5,45	5,45	5,66	4,94	nee	0	0	6	7	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	0	230	553
1300	11,15	10,62	0,53	**1310**	5,45	5,45	5,70	5,17	nee	0	0	0	13	13	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	914
1400	11,22	10,88	0,34	**1095**	5,45	5,45	5,77	5,43	nee	0	0	0	13	13	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	0	0	761
1500	11,35	11,10	0,25	**962**	5,45	5,45	5,90	5,65	nee	0	0	0	13	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	0	668
1750	11,90	11,68	0,22	**994**	5,45	5,45	6,45	6,23	nee	0	0	0	13	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	686
2000	12,51	12,19	0,32	**1286**	5,45	5,45	7,06	6,74	nee	0	0	0	13	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	884
2500	13,22	12,95	0,27	**1300**	5,45	5,45	7,77	7,50	nee	0	0	0	13	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	889
3000	13,71	13,60	0,11	**894**	5,45	5,45	8,26	8,15	nee	0	0	0	13	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	609
3500	14,06	14,05	0,01	**283**	5,45	5,45	8,61	8,60	nee	0	0	0	13	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	193
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	0	0	0	13	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 1 Stoney closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP

m_Stoney free	1,33	-
m_Stoney sub.	0,70	-
m_Poiree_middle free	1,21	-
m_Poiree_low free	1,03	-
m_Poiree_low sub	0,68	-
m_Poiree_sill	0,70	-

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13
50	11,10	7,95	3,15	**26**	11,10	10,00	1,10	-2,05	ja	13	0	0	0	13
100	11,10	7,99	3,11	**100**	11,10	8,40	2,70	-0,41	ja	13	0	0	0	13
150	11,10	8,04	3,06	**146**	11,10	8,40	2,70	-0,36	ja	10	3	0	0	13
200	11,10	8,08	3,02	**208**	11,10	8,40	2,70	-0,32	ja	6	7	0	0	13
250	11,10	8,14	2,96	**269**	11,10	9,00	2,10	-0,86	ja	0	13	0	0	13
300	11,10	8,25	2,85	**300**	11,10	8,40	2,70	-0,15	ja	0	13	0	0	13
350	11,10	8,34	2,76	**365**	11,10	8,40	2,70	-0,06	ja	0	10	3	0	13
400	11,10	8,44	2,66	**387**	11,10	8,40	2,70	0,04	ja	0	9	4	0	13
450	11,10	8,55	2,55	**452**	11,10	8,40	2,70	0,15	ja	0	6	7	0	13
500	11,10	8,65	2,45	**516**	11,10	8,40	2,70	0,25	ja	0	3	10	0	13
550	11,10	8,75	2,35	**560**	11,10	8,40	2,70	0,35	ja	0	1	12	0	13
600	11,10	8,90	2,20	**581**	11,10	8,40	2,70	0,50	ja	0	0	13	0	13
650	11,10	9,03	2,07	**642**	11,10	10,00	1,10	-0,97	ja	0	0	11	2	13
700	11,10	9,15	1,95	**710**	11,10	8,50	2,60	0,65	ja	0	0	11	2	13
750	11,10	9,27	1,83	**774**	11,10	8,50	2,60	0,77	ja	0	0	10	3	13
800	11,10	9,38	1,72	**777**	11,10	8,40	2,70	0,98	ja	0	0	10	3	13
850	11,10	9,52	1,58	**836**	11,10	8,40	2,70	1,12	ja	0	0	9	4	13
900	11,10	9,65	1,45	**890**	11,10	8,40	2,70	1,25	ja	0	0	8	5	13
950	11,10	9,78	1,32	**938**	11,10	8,40	2,70	1,38	ja	0	0	7	6	13
1000	11,10	9,90	1,20	**1007**	11,10	8,40	2,70	1,50	ja	0	0	6	7	13
1100	11,10	10,15	0,95	**1094**	11,10	8,40	2,70	1,75	ja	0	0	3	10	13
1150	11,10	10,28	0,82	**1166**	11,10	8,40	2,70	1,88	nee	0	0	0	13	13
1200	11,10	10,39	0,71	**1239**	11,10	5,45	5,65	4,94	nee	0	0	0	13	13
1300	11,15	10,62	0,53	**1112**	11,10	5,45	5,70	5,17	nee	0	0	0	13	13
1400	11,22	10,88	0,34	**929**	11,10	5,45	5,77	5,43	nee	0	0	0	13	13
1500	11,35	11,10	0,25	**818**	11,10	5,45	5,90	5,65	nee	0	0	0	13	13
1750	11,90	11,68	0,22	**854**	11,10	5,45	6,45	6,23	nee	0	0	0	13	13
2000	12,51	12,19	0,32	**1117**	11,10	5,45	7,06	6,74	nee	0	0	0	13	13
2500	13,22	12,95	0,27	**1145**	11,10	5,45	7,77	7,50	nee	0	0	0	13	13
3000	13,71	13,60	0,11	**796**	11,10	5,45	8,26	8,15	nee	0	0	0	13	13
3500	14,06	14,05	0,01	**253**	11,10	5,45	8,61	8,60	nee	0	0	0	13	13
4000	14,65	14,65	0,00	**0**	11,10	5,45	9,20	9,20	nee	0	0	0	13	13

Q St. Pieter	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	26	0	0	0
100	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	0	100	0	0	0
150	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	0	100	46	0	0
200	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	0	100	108	0	0
250	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	0	69	200	0	0
300	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	0	100	200	0	0
350	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	0	100	154	111	0
400	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	0	100	138	148	0
450	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	0	100	92	259	0
500	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	0	100	46	370	0
550	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	0	100	15	444	0
600	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	0	100	0	481	0
650	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	0	26	0	407	209
700	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	0	95	0	407	208
750	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	0	95	0	370	309
800	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	0	100	0	370	306
850	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	0	100	0	333	402
900	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	0	100	0	296	493
950	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	0	100	0	259	578
1000	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	0	100	0	250	657
1100	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	0	100	0	122	872
1150	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	0	90	0	0	1076
1200	1,90	1,19	ja	3,80	3,09	nee	6,90	6,19	nee	0	219	0	0	1020
1300	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	0	198	0	0	914
1400	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	1	167	0	0	761
1500	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	3	147	0	0	668
1750	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	14	154	0	0	686
2000	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	33	201	0	0	884
2500	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	51	205	0	0	889
3000	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	44	142	0	0	609
3500	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	16	45	0	0	193
4000	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 2 Stoneys closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**46**	11,10	11,10	0,00	-3,15	ja	10	3	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	46	0	0
100	11,10	7,99	3,11	**92**	11,10	11,10	0,00	-3,11	ja	7	6	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	0	0	92	0	0
150	11,10	8,04	3,06	**154**	11,10	11,10	0,00	-3,06	ja	3	10	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	0	0	154	0	0
200	11,10	8,08	3,02	**200**	11,10	11,10	0,00	-3,02	ja	0	13	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	0	0	200	0	0
250	11,10	8,14	2,96	**265**	11,10	11,10	0,00	-2,96	ja	0	10	3	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	0	0	154	111	0
300	11,10	8,25	2,85	**308**	11,10	11,10	0,00	-2,85	ja	0	8	5	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	0	0	123	185	0
350	11,10	8,34	2,76	**351**	11,10	11,10	0,00	-2,76	ja	0	6	7	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	0	0	92	259	0
400	11,10	8,44	2,66	**416**	11,10	11,10	0,00	-2,66	ja	0	3	10	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	0	0	46	370	0
450	11,10	8,55	2,55	**459**	11,10	11,10	0,00	-2,55	ja	0	1	12	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	0	0	15	444	0
500	11,10	8,65	2,45	**481**	11,10	11,10	0,00	-2,45	ja	0	0	13	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	0	0	0	481	0
550	11,10	8,75	2,35	**530**	11,10	11,10	0,00	-2,35	ja	0	0	11	2	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	0	0	0	407	123
600	11,10	8,90	2,20	**617**	11,10	11,10	0,00	-2,20	ja	0	0	11	2	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	0	0	0	407	210
650	11,10	9,03	2,07	**650**	11,10	11,10	0,00	-2,07	ja	0	0	11	3	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	0	0	0	389	261
700	11,10	9,15	1,95	**682**	11,10	11,10	0,00	-1,95	ja	0	0	10	3	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	0	0	0	370	312
750	11,10	9,27	1,83	**746**	11,10	11,10	0,00	-1,83	ja	0	0	9	4	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	0	0	0	333	413
800	11,10	9,38	1,72	**807**	11,10	11,10	0,00	-1,72	ja	0	0	8	5	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	0	0	0	296	511
850	11,10	9,52	1,58	**862**	11,10	11,10	0,00	-1,58	ja	0	0	7	6	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	0	0	0	259	603
900	11,10	9,65	1,45	**913**	11,10	11,10	0,00	-1,45	ja	0	0	6	7	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	0	0	0	222	691
950	11,10	9,78	1,32	**956**	11,10	11,10	0,00	-1,32	ja	0	0	5	8	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	0	0	0	185	771
1000	11,10	9,90	1,20	**1012**	11,10	11,10	0,00	-1,20	ja	0	0	4	9	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	0	0	0	166	845
1100	11,10	10,15	0,95	**1134**	11,10	11,10	0,00	-0,95	ja	0	0	0	13	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	0	0	0	0	1134
1150	11,10	10,28	0,82	**1076**	11,10	11,10	0,00	-0,82	ja	0	0	0	13	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	0	0	0	0	1076
1200	11,11	10,39	0,72	**1027**	11,10	11,10	0,01	-0,71	ja	0	0	0	13	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	0	0	0	0	1027
1300	11,15	10,62	0,53	**914**	11,10	11,10	0,05	-0,48	ja	0	0	0	13	13	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	0	0	0	0	914
1400	11,22	10,88	0,34	**763**	11,10	11,10	0,12	-0,22	ja	0	0	0	13	13	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	1	1	0	0	761
1500	11,35	11,10	0,25	**673**	11,10	11,10	0,25	0,00	ja	0	0	0	13	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	3	3	0	0	668
1750	11,90	11,68	0,22	**715**	11,10	11,10	0,80	0,58	nee	0	0	0	13	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	14	14	0	0	686
2000	12,51	12,19	0,32	**949**	11,10	11,10	1,41	1,09	nee	0	0	0	13	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	33	33	0	0	884
2500	13,22	12,95	0,27	**990**	11,10	11,10	2,12	1,85	nee	0	0	0	13	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	51	51	0	0	889
3000	13,71	13,60	0,11	**697**	11,10	11,10	2,61	2,50	nee	0	0	0	13	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	44	44	0	0	609
3500	14,06	14,05	0,01	**224**	11,10	11,10	2,96	2,95	nee	0	0	0	13	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	16	16	0	0	193
4000	14,65	14,65	0,00	**0**	11,10	11,10	3,55	3,55	nee	0	0	0	13	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 1 row closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja	0	13	0	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja	0	13	0	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	11,10	8,55	2,55	**443**	9,50	9,50	1,60	-0,95	ja	0	6	7	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	46	46	92	259	0
500	11,10	8,65	2,45	**508**	9,50	9,50	1,60	-0,85	ja	0	3	10	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	46	46	46	370	0
550	11,10	8,75	2,35	**554**	9,00	9,00	2,10	-0,25	ja	0	3	10	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	69	69	46	370	0
600	11,10	8,90	2,20	**619**	9,00	9,00	2,10	-0,10	ja	0	0	13	0	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	69	69	0	481	0
650	11,10	9,03	2,07	**660**	8,60	8,60	2,50	0,43	ja	0	0	13	0	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	89	89	0	481	0
700	11,10	9,15	1,95	**682**	8,40	8,40	2,70	0,75	ja	0	0	13	0	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	100	100	0	481	0
750	11,10	9,27	1,83	**728**	8,00	8,00	3,10	1,27	ja	0	0	13	0	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	123	123	0	481	0
800	11,10	9,38	1,72	**790**	7,50	7,50	3,60	1,88	ja	0	0	13	0	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	154	154	0	481	0
850	11,10	9,52	1,58	**856**	7,00	7,00	4,10	2,52	ja	0	0	13	0	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	188	188	0	481	0
900	11,10	9,65	1,45	**881**	6,50	6,50	4,60	3,15	nee	0	0	13	0	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	200	200	0	481	0
950	11,10	9,78	1,32	**939**	6,00	6,00	5,10	3,78	nee	0	0	13	0	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	229	229	0	481	0
1000	11,10	9,90	1,20	**1014**	5,80	5,80	5,30	4,10	nee	0	0	13	0	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	237	237	0	541	0
1100	11,10	10,15	0,95	**1010**	5,45	5,45	5,65	4,70	nee	0	0	13	0	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	0	528	0
1150	11,10	10,28	0,82	**974**	5,45	5,45	5,65	4,83	nee	0	0	13	0	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	0	512	0
1200	11,11	10,39	0,72	**940**	5,45	5,45	5,66	4,94	nee	0	0	13	0	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	0	498	0
1300	11,15	10,62	0,53	**856**	5,45	5,45	5,70	5,17	nee	0	0	13	0	13	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	459	0
1400	11,22	10,88	0,34	**730**	5,45	5,45	5,77	5,43	nee	0	0	13	0	13	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	0	396	0
1500	11,35	11,10	0,25	**652**	5,45	5,45	5,90	5,65	nee	0	0	13	0	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	357	0
1750	11,90	11,68	0,22	**698**	5,45	5,45	6,45	6,23	nee	0	0	13	0	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	390	0
2000	12,51	12,19	0,32	**927**	5,45	5,45	7,06	6,74	nee	0	0	13	0	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	525	0
2500	13,22	12,95	0,27	**968**	5,45	5,45	7,77	7,50	nee	0	0	13	0	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	558	0
3000	13,71	13,60	0,11	**682**	5,45	5,45	8,26	8,15	nee	0	0	13	0	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	397	0
3500	14,06	14,05	0,01	**219**	5,45	5,45	8,61	8,60	nee	0	0	13	0	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	128	0
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	0	0	13	0	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 2 rows closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja	0	13	0	0	13
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja	0	13	0	0	13
450	11,10	8,55	2,55	**447**	8,00	8,00	3,10	0,55	ja	0	13	0	0	13
500	11,10	8,65	2,45	**509**	7,50	7,50	3,60	1,15	ja	0	13	0	0	13
550	11,10	8,75	2,35	**562**	7,10	7,10	4,00	1,65	ja	0	13	0	0	13
600	11,10	8,90	2,20	**603**	6,80	6,80	4,30	2,10	ja	0	13	0	0	13
650	11,10	9,03	2,07	**646**	6,50	6,50	4,60	2,53	ja	0	13	0	0	13
700	11,10	9,15	1,95	**721**	6,00	6,00	5,10	3,15	ja	0	13	0	0	13
750	11,10	9,27	1,83	**745**	5,45	5,45	5,65	3,82	nee	0	13	0	0	13
800	11,10	9,38	1,72	**743**	5,45	5,45	5,65	3,93	nee	0	13	0	0	13
850	11,10	9,52	1,58	**739**	5,45	5,45	5,65	4,07	nee	0	13	0	0	13
900	11,10	9,65	1,45	**733**	5,45	5,45	5,65	4,20	nee	0	13	0	0	13
950	11,10	9,78	1,32	**724**	5,45	5,45	5,65	4,33	nee	0	13	0	0	13
1000	11,10	9,90	1,20	**714**	5,45	5,45	5,65	4,45	nee	0	13	0	0	13
1100	11,10	10,15	0,95	**683**	5,45	5,45	5,65	4,70	nee	0	13	0	0	13
1150	11,10	10,28	0,82	**661**	5,45	5,45	5,65	4,83	nee	0	13	0	0	13
1200	11,11	10,39	0,72	**643**	5,45	5,45	5,66	4,94	nee	0	13	0	0	13
1300	11,15	10,62	0,53	**746**	5,45	5,45	5,70	5,17	nee	0	13	0	0	13
1400	11,22	10,88	0,34	**665**	5,45	5,45	5,77	5,43	nee	0	13	0	0	13
1500	11,35	11,10	0,25	**613**	5,45	5,45	5,90	5,65	nee	0	13	0	0	13
1750	11,90	11,68	0,22	**701**	5,45	5,45	6,45	6,23	nee	0	13	0	0	13
2000	12,51	12,19	0,32	**974**	5,45	5,45	7,06	6,74	nee	0	13	0	0	13
2500	13,22	12,95	0,27	**1069**	5,45	5,45	7,77	7,50	nee	0	13	0	0	13
3000	13,71	13,60	0,11	**778**	5,45	5,45	8,26	8,15	nee	0	13	0	0	13
3500	14,06	14,05	0,01	**255**	5,45	5,45	8,61	8,60	nee	0	13	0	0	13
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	0	13	0	0	13

Q St. Pieter	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	123	123	200	0	0
500	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	154	154	200	0	0
550	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	181	181	200	0	0
600	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	202	202	200	0	0
650	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	223	223	200	0	0
700	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	260	260	200	0	0
750	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	272	272	200	0	0
800	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	272	272	200	0	0
850	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	270	270	200	0	0
900	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	267	267	200	0	0
950	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	262	262	200	0	0
1000	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	257	257	200	0	0
1100	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	200	0	0
1150	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	200	0	0
1200	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	201	0	0
1300	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	349	0	0
1400	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	331	0	0
1500	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	318	0	0
1750	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	393	0	0
2000	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	572	0	0
2500	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	658	0	0
3000	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	493	0	0
3500	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	164	0	0
4000	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: Complete Poiree closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**247**	8,00	8,00	3,10	0,14	ja	13	0	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	123	123	0	0	0
300	11,10	8,25	2,85	**309**	7,50	7,50	3,60	0,75	ja	13	0	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	154	154	0	0	0
350	11,10	8,34	2,76	**335**	7,30	7,30	3,80	1,04	ja	13	0	0	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	167	167	0	0	0
400	11,10	8,44	2,66	**375**	7,00	7,00	4,10	1,44	ja	13	0	0	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	188	188	0	0	0
450	11,10	8,55	2,55	**446**	6,50	6,50	4,60	2,05	ja	13	0	0	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	223	223	0	0	0
500	11,10	8,65	2,45	**521**	6,00	6,00	5,10	2,65	ja	13	0	0	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	260	260	0	0	0
550	11,10	8,75	2,35	**567**	5,70	5,70	5,40	3,05	ja	13	0	0	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	284	284	0	0	0
600	11,10	8,90	2,20	**607**	5,45	5,45	5,65	3,45	ja	13	0	0	0	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	304	304	0	0	0
650	11,10	9,03	2,07	**607**	5,45	5,45	5,65	3,58	ja	13	0	0	0	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	304	304	0	0	0
700	11,10	9,15	1,95	**607**	5,45	5,45	5,65	3,70	ja	13	0	0	0	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	304	304	0	0	0
750	11,10	9,27	1,83	**545**	5,45	5,45	5,65	3,82	nee	13	0	0	0	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	272	272	0	0	0
800	11,10	9,38	1,72	**543**	5,45	5,45	5,65	3,93	nee	13	0	0	0	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	272	272	0	0	0
850	11,10	9,52	1,58	**539**	5,45	5,45	5,65	4,07	nee	13	0	0	0	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	270	270	0	0	0
900	11,10	9,65	1,45	**533**	5,45	5,45	5,65	4,20	nee	13	0	0	0	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	267	267	0	0	0
950	11,10	9,78	1,32	**524**	5,45	5,45	5,65	4,33	nee	13	0	0	0	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	262	262	0	0	0
1000	11,10	9,90	1,20	**514**	5,45	5,45	5,65	4,45	nee	13	0	0	0	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	257	257	0	0	0
1100	11,10	10,15	0,95	**483**	5,45	5,45	5,65	4,70	nee	13	0	0	0	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	0	0	0
1150	11,10	10,28	0,82	**461**	5,45	5,45	5,65	4,83	nee	13	0	0	0	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	0	0	0
1200	11,11	10,39	0,72	**442**	5,45	5,45	5,66	4,94	nee	13	0	0	0	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	0	0	0
1300	11,15	10,62	0,53	**397**	5,45	5,45	5,70	5,17	nee	13	0	0	0	13	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	0
1400	11,22	10,88	0,34	**334**	5,45	5,45	5,77	5,43	nee	13	0	0	0	13	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	0	0	0
1500	11,35	11,10	0,25	**295**	5,45	5,45	5,90	5,65	nee	13	0	0	0	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	0	0
1750	11,90	11,68	0,22	**308**	5,45	5,45	6,45	6,23	nee	13	0	0	0	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	0
2000	12,51	12,19	0,32	**402**	5,45	5,45	7,06	6,74	nee	13	0	0	0	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	0
2500	13,22	12,95	0,27	**411**	5,45	5,45	7,77	7,50	nee	13	0	0	0	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	0
3000	13,71	13,60	0,11	**285**	5,45	5,45	8,26	8,15	nee	13	0	0	0	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	0
3500	14,06	14,05	0,01	**91**	5,45	5,45	8,61	8,60	nee	13	0	0	0	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	0
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	13	0	0	0	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 3 beams closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q	h	h		Q	Stoney_1	Stoney_2				Poiree					Middle panels			Lowest panels			Sill			Q	Q	Q	Q	Q
St. Pieter	Upstream	Downstream	ΔH	Total	Level	Level	H	h3	Free flow?	11,10	9,20	7,30	4,20	Total	H	h3	Free flow?	H	h3	Free flow?	H	h3	Free flow?	Stoney 1	Stoney 2	middle	low	sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	11,10	8,34	2,76	**354**	8,40	8,40	2,70	-0,06	ja	3	10	0	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	100	100	154	0	0
400	11,10	8,44	2,66	**419**	8,40	8,40	2,70	0,04	ja	3	7	3	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	108	111	0
450	11,10	8,55	2,55	**462**	8,40	8,40	2,70	0,15	ja	3	5	5	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	100	100	77	185	0
500	11,10	8,65	2,45	**490**	8,40	8,40	2,70	0,25	ja	3	2	7	0	12	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	100	100	31	259	0
550	11,10	8,75	2,35	**549**	8,40	8,40	2,70	0,35	ja	3	1	9	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	100	100	15	333	0
600	11,10	8,90	2,20	**606**	8,70	8,70	2,40	0,20	ja	3	0	9	1	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	84	84	0	333	105
650	11,10	9,03	2,07	**638**	8,40	8,40	2,70	0,63	ja	3	0	9	1	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	100	100	0	333	105
700	11,10	9,15	1,95	**705**	8,40	8,40	2,70	0,75	ja	3	0	8	2	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	100	100	0	296	208
750	11,10	9,27	1,83	**769**	8,40	8,40	2,70	0,87	ja	3	0	7	3	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	100	100	0	259	309
800	11,10	9,38	1,72	**799**	8,40	8,40	2,70	0,98	ja	3	0	7	4	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	100	100	0	241	358
850	11,10	9,52	1,58	**857**	8,40	8,40	2,70	1,12	ja	3	0	6	5	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	100	100	0	204	453
900	11,10	9,65	1,45	**879**	8,40	8,40	2,70	1,25	ja	3	0	5	5	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	100	100	0	185	493
950	11,10	9,78	1,32	**927**	8,40	8,40	2,70	1,38	ja	3	0	4	6	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	100	100	0	148	578
1000	11,10	9,90	1,20	**983**	8,40	8,40	2,70	1,50	ja	3	0	3	7	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	100	100	0	125	657
1100	11,10	10,15	0,95	**1093**	8,00	8,00	3,10	2,15	nee	3	0	0	10	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	110	110	0	0	872
1150	11,10	10,28	0,82	**1141**	7,00	7,00	4,10	3,28	nee	3	0	0	10	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	157	157	0	0	828
1200	11,11	10,39	0,72	**1209**	5,70	5,70	5,41	4,69	nee	3	0	0	10	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	210	210	0	0	790
1300	11,15	10,62	0,53	**1100**	5,45	5,45	5,70	5,17	nee	3	0	0	10	13	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	703
1400	11,22	10,88	0,34	**920**	5,45	5,45	5,77	5,43	nee	3	0	0	10	13	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	0	0	586
1500	11,35	11,10	0,25	**808**	5,45	5,45	5,90	5,65	nee	3	0	0	10	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	0	514
1750	11,90	11,68	0,22	**836**	5,45	5,45	6,45	6,23	nee	3	0	0	10	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	528
2000	12,51	12,19	0,32	**1082**	5,45	5,45	7,06	6,74	nee	3	0	0	10	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	680
2500	13,22	12,95	0,27	**1095**	5,45	5,45	7,77	7,50	nee	3	0	0	10	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	684
3000	13,71	13,60	0,11	**754**	5,45	5,45	8,26	8,15	nee	3	0	0	10	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	469
3500	14,06	14,05	0,01	**239**	5,45	5,45	8,61	8,60	nee	3	0	0	10	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	148
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	3	0	0	10	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 6 beams closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13
300	11,10	8,25	2,85	**308**	8,40	8,40	2,70	-0,15	ja	6	7	0	0	13
350	11,10	8,34	2,76	**373**	8,40	8,40	2,70	-0,06	ja	6	4	3	0	13
400	11,10	8,44	2,66	**416**	8,40	8,40	2,70	0,04	ja	6	2	5	0	13
450	11,10	8,55	2,55	**460**	8,40	8,40	2,70	0,15	ja	6	0	7	0	13
500	11,10	8,65	2,45	**506**	8,00	8,00	3,10	0,65	ja	6	0	7	0	13
550	11,10	8,75	2,35	**568**	7,50	7,50	3,60	1,25	ja	6	0	7	0	13
600	11,10	8,90	2,20	**607**	7,20	7,20	3,90	1,70	ja	6	0	7	0	13
650	11,10	9,03	2,07	**634**	7,00	7,00	4,10	2,03	ja	6	0	7	0	13
700	11,10	9,15	1,95	**701**	7,00	7,00	4,10	2,15	ja	6	0	6	1	13
750	11,10	9,27	1,83	**771**	6,50	6,50	4,60	2,77	ja	6	0	6	1	13
800	11,10	9,38	1,72	**800**	6,30	6,30	4,80	3,08	ja	6	0	6	1	13
850	11,10	9,52	1,58	**845**	6,30	6,30	4,80	3,22	nee	6	0	5	3	13
900	11,10	9,65	1,45	**900**	6,30	6,30	4,80	3,35	nee	6	0	4	4	13
950	11,10	9,78	1,32	**930**	6,20	6,20	4,90	3,58	nee	6	0	3	4	13
1000	11,10	9,90	1,20	**980**	6,20	6,20	4,90	3,70	nee	6	0	2	5	13
1100	11,10	10,15	0,95	**1093**	5,45	5,45	5,65	4,70	nee	6	0	0	7	13
1150	11,10	10,28	0,82	**1041**	5,45	5,45	5,65	4,83	nee	6	0	0	7	13
1200	11,11	10,39	0,72	**995**	5,45	5,45	5,66	4,94	nee	6	0	0	7	13
1300	11,15	10,62	0,53	**889**	5,45	5,45	5,70	5,17	nee	6	0	0	7	13
1400	11,22	10,88	0,34	**744**	5,45	5,45	5,77	5,43	nee	6	0	0	7	13
1500	11,35	11,10	0,25	**654**	5,45	5,45	5,90	5,65	nee	6	0	0	7	13
1750	11,90	11,68	0,22	**677**	5,45	5,45	6,45	6,23	nee	6	0	0	7	13
2000	12,51	12,19	0,32	**878**	5,45	5,45	7,06	6,74	nee	6	0	0	7	13
2500	13,22	12,95	0,27	**889**	5,45	5,45	7,77	7,50	nee	6	0	0	7	13
3000	13,71	13,60	0,11	**613**	5,45	5,45	8,26	8,15	nee	6	0	0	7	13
3500	14,06	14,05	0,01	**194**	5,45	5,45	8,61	8,60	nee	6	0	0	7	13
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	6	0	0	7	13

Q St. Pieter	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	100	100	108	0	0
350	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	100	100	61	111	0
400	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	31	185	0
450	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	100	100	0	259	0
500	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	123	123	0	259	0
550	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	154	154	0	259	0
600	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	174	174	0	259	0
650	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	188	188	0	259	0
700	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	188	188	0	222	104
750	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	223	223	0	222	103
800	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	238	238	0	222	102
850	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	213	213	0	167	251
900	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	213	213	0	130	345
950	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	217	217	0	111	386
1000	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	214	214	0	83	469
1100	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	0	0	610
1150	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	0	0	580
1200	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	0	0	553
1300	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	492
1400	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	0	0	410
1500	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	0	360
1750	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	369
2000	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	476
2500	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	479
3000	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	328
3500	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	104
4000	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 9 beams closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**262**	8,40	8,40	2,70	-0,26	ja	9	4	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	100	100	61	0	0
300	11,10	8,25	2,85	**305**	8,40	8,40	2,70	-0,15	ja	9	2	2	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	100	100	31	74	0
350	11,10	8,34	2,76	**349**	8,40	8,40	2,70	-0,06	ja	9	0	4	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	100	100	0	148	0
400	11,10	8,44	2,66	**398**	8,40	8,40	2,70	0,04	ja	9	0	2	2	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	0	74	123
450	11,10	8,55	2,55	**444**	8,00	8,00	3,10	0,55	ja	9	0	2	2	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	123	123	0	74	123
500	11,10	8,65	2,45	**506**	7,50	7,50	3,60	1,15	ja	9	0	2	2	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	154	154	0	74	123
550	11,10	8,75	2,35	**532**	7,30	7,30	3,80	1,45	ja	9	0	2	2	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	167	167	0	74	123
600	11,10	8,90	2,20	**619**	7,30	7,30	3,80	1,60	ja	9	0	2	2	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	167	167	0	74	210
650	11,10	9,03	2,07	**658**	7,00	7,00	4,10	2,03	ja	9	0	2	2	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	188	188	0	74	209
700	11,10	9,15	1,95	**699**	6,70	6,70	4,40	2,45	ja	9	0	2	2	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	209	209	0	74	208
750	11,10	9,27	1,83	**764**	6,70	6,70	4,40	2,57	ja	9	0	1	3	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	209	209	0	37	309
800	11,10	9,38	1,72	**790**	6,50	6,50	4,60	2,88	ja	9	0	1	3	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	223	223	0	37	306
850	11,10	9,52	1,58	**869**	6,00	6,00	5,10	3,52	nee	9	0	0	4	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	233	233	0	0	402
900	11,10	9,65	1,45	**928**	5,45	5,45	5,65	4,20	nee	9	0	0	4	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	267	267	0	0	395
950	11,10	9,78	1,32	**910**	5,45	5,45	5,65	4,33	nee	9	0	0	4	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	262	262	0	0	386
1000	11,10	9,90	1,20	**889**	5,45	5,45	5,65	4,45	nee	9	0	0	4	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	257	257	0	0	376
1100	11,10	10,15	0,95	**832**	5,45	5,45	5,65	4,70	nee	9	0	0	4	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	0	0	349
1150	11,10	10,28	0,82	**792**	5,45	5,45	5,65	4,83	nee	9	0	0	4	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	0	0	331
1200	11,11	10,39	0,72	**758**	5,45	5,45	5,66	4,94	nee	9	0	0	4	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	0	0	316
1300	11,15	10,62	0,53	**678**	5,45	5,45	5,70	5,17	nee	9	0	0	4	13	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	281
1400	11,22	10,88	0,34	**568**	5,45	5,45	5,77	5,43	nee	9	0	0	4	13	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	0	0	234
1500	11,35	11,10	0,25	**500**	5,45	5,45	5,90	5,65	nee	9	0	0	4	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	0	205
1750	11,90	11,68	0,22	**519**	5,45	5,45	6,45	6,23	nee	9	0	0	4	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	211
2000	12,51	12,19	0,32	**674**	5,45	5,45	7,06	6,74	nee	9	0	0	4	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	272
2500	13,22	12,95	0,27	**684**	5,45	5,45	7,77	7,50	nee	9	0	0	4	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	273
3000	13,71	13,60	0,11	**472**	5,45	5,45	8,26	8,15	nee	9	0	0	4	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	188
3500	14,06	14,05	0,01	**150**	5,45	5,45	8,61	8,60	nee	9	0	0	4	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	59
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	9	0	0	4	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

F
Maximum discharges

Situation: Example

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja
450	11,10	8,55	2,55	**443**	9,50	9,50	1,60	-0,95	ja
500	11,10	8,65	2,45	**508**	9,50	9,50	1,60	-0,85	ja
550	11,08	8,75	2,33	**548**	9,00	9,00	2,08	-0,25	ja
600	11,05	8,90	2,15	**604**	9,00	9,00	2,05	-0,10	ja
650	11,00	9,03	1,97	**652**	8,40	8,40	2,60	0,63	ja
700	10,98	9,15	1,83	**691**	8,00	8,00	2,98	1,15	ja
750	10,95				7,50	7,50	3,45	1,77	ja
800	10,92				7,00	7,00	3,92	2,38	ja
850	10,89				6,20	6,20	4,69	3,32	nee
900	10,86				5,60	5,60	5,26	4,05	nee
950	10,83				5,45	5,45	5,38	4,33	nee
1000	10,80				5,45	5,45	5,35	4,45	nee
1100	10,75	10,15	0,60	**1100**	5,45	5,45	5,30	4,70	nee
1150	10,74	10,28	0,46	**1151**	5,45	5,45	5,29	4,83	nee
1200	10,88	10,39	0,49	**1212**	5,45	5,45	5,43	4,94	nee
1300	11,15	10,62	0,53	**1310**	5,45	5,45	5,70	5,17	nee
1400	11,43	10,88	0,55	**1393**	5,45	5,45	5,98	5,43	nee
1500	11,70	11,10	0,60	**1506**	5,45	5,45	6,25	5,65	nee
1575	11,90	11,28	0,62	**1574**	5,45	5,45	6,45	5,83	nee
1750	12,36	11,68	0,68	**1747**	5,45	5,45	6,91	6,23	nee
2000	12,51	12,			5,45	5,45	7,06	6,74	nee
2500	13,22	13,			5,45	5,45	7,77	7,60	nee
3000	13,71	13,			5,45	5,45	8,26	8,15	nee
3500	14,06	14,			5,45	5,45	8,61	8,60	nee
4000	14,65	14,			5,45	5,45	9,20	9,20	nee

Manually start to increase upstream water level. Till Q total = Q St Pieter.

Maximum at 11.90m +NAP. Interpolation if needed.

Q St. Pieter	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?
0	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja
50	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja
100	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja
150	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja
200	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja
250	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja
300	3	10	0	0	13	1,90	-0,95	ja	3,80	0,95	ja
350	0	13	0	0	13	1,90	-0,86	ja	3,80	1,04	ja
400	0	13	0	0	13	1,90	-0,76	ja	3,80	1,14	ja
450	0	6	7	0	13	1,90	-0,65	ja	3,80	1,25	ja
500	0	3	10	0	13	1,90	-0,55	ja	3,80	1,35	ja
550	0	3	10	0	13	1,88	-0,45	ja	3,78	1,45	ja
600	0	0	13	0	13	1,85	-0,30	ja	3,75	1,60	ja
650	0	0	13	0	13	1,80	-0,17	ja	3,70	1,73	ja
700	0	0	13	0	13	1,78	-0,05	ja	3,68	1,85	ja
750	0	0	13	0	13	1,75	0,07	ja	3,65	1,97	ja
800	0	0	13	0	13	1,72	0,18	ja	3,62	2,08	ja
850	0	0	13	0	13	1,69	0,32	ja	3,59	2,22	ja
900	0	0	13	0	13	1,66	0,45	ja	3,56	2,35	ja
950	0	0	13	0	13	1,63	0,58	ja	3,53	2,48	nee
1000	0	0	11	2	13	1,60	0,70	ja	3,50	2,60	nee
1100	0	0	5	8	13	1,55	0,95	ja	3,45	2,85	nee
1150	0	0	0	13	13	1,54	1,08	nee	3,44	2,98	nee
1200	0	0	0	13	13	1,68	1,19	nee	3,58	3,09	nee
1300	0	0	0	13	13	1,95	1,42	nee	3,85	3,32	nee
1400	0	0	0	13	13	2,23	1,68	nee	4,13	3,58	nee
1500	0	0	0	13	13	2,50	1,90	nee	4,40	3,80	nee
1575	0	0	0	13	13	2,70	2,08	nee	4,60	3,98	nee
1750	0	0	0	13	13	3,16	2,48	nee	5,06	4,38	nee
2000	0	0	0	13	13	3,31	2,99	nee	5,21	4,89	nee
2500	0	0	0	13	13	4,02	3,85	nee	5,92	5,75	nee
3000	0	0	0	13	13	4,51	4,40	nee	6,41	6,30	nee
3500	0	0	0	13	13	4,86	4,85	nee	6,76	6,75	nee
4000	0	0	0	13	13	5,45	5,45	nee	7,35	7,35	nee

Q St. Pieter	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	6,90	3,75	ja	0	0	0	0	0
50	6,90	3,75	ja	26	26	0	0	0
100	6,90	3,79	ja	46	46	0	0	0
150	6,90	3,84	ja	69	69	0	0	0
200	6,90	3,88	ja	100	100	0	0	0
250	6,90	3,94	ja	69	69	92	0	0
300	6,90	4,05	ja	69	69	154	0	0
350	6,90	4,14	ja	69	69	200	0	0
400	6,90	4,24	ja	100	100	200	0	0
450	6,90	4,35	ja	46	46	92	259	0
500	6,90	4,45	ja	46	46	46	370	0
550	6,88	4,55	ja	68	68	45	367	0
600	6,85	4,70	nee	66	66	0	472	0
650	6,80	4,83	nee	95	95	0	462	0
700	6,78	4,95	nee	116	116	0	458	0
750	6,75	5,07	nee	145	145	0	453	0
800	6,72	5,18	nee	175	175	0	447	0
850	6,69	5,32	nee	205	205	0	442	0
900	6,66	5,45	nee	235	235	0	436	0
950	6,63	5,58	nee	234	234	0	483	0
1000	6,60	5,70	nee	223	223	0	396	163
1100	6,55	5,95	nee	192	192	0	161	554
1150	6,54	6,08	nee	173	173	0	0	806
1200	6,68	6,19	nee	182	182	0	0	847
1300	6,95	6,42	nee	198	198	0	0	914
1400	7,23	6,68	nee	212	212	0	0	968
1500	7,50	6,90	nee	231	231	0	0	1045
1575	7,70	7,08	nee	242	242	0	0	1090
1750	8,16	7,48	nee	271	271	0	0	1206
2000	8,31	7,99	nee	201	201	0	0	884
2500	9,02	8,85	nee	165	165	0	0	713
3000	9,51	9,40	nee	142	142	0	0	609
3500	9,86	9,85	nee	45	45	0	0	193
4000	10,45	10,45	nee	0	0	0	0	0

Situation: Normal management

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP

m_Stoney free	1,33	-
m_Stoney sub.	0,70	-
m_Poiree_middle free	1,21	-
m_Poiree_low free	1,03	-
m_Poiree_low sub	0,68	-
m_Poiree_sill	0,70	-

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja	0	13	0	0	13
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja	0	13	0	0	13
450	11,10	8,55	2,55	**443**	9,50	9,50	1,60	-0,95	ja	0	6	7	0	13
500	11,10	8,65	2,45	**508**	9,50	9,50	1,60	-0,85	ja	0	3	10	0	13
550	11,08	8,75	2,33	**548**	9,00	9,00	2,08	-0,25	ja	0	3	10	0	13
600	11,05	8,90	2,15	**604**	9,00	9,00	2,05	-0,10	ja	0	0	13	0	13
650	11,00	9,03	1,97	**652**	8,40	8,40	2,60	0,63	ja	0	0	13	0	13
700	10,98	9,15	1,83	**691**	8,00	8,00	2,98	1,15	ja	0	0	13	0	13
750	10,95	9,27	1,68	**743**	7,50	7,50	3,45	1,77	ja	0	0	13	0	13
800	10,92	9,38	1,54	**798**	7,00	7,00	3,92	2,38	ja	0	0	13	0	13
850	10,89	9,52	1,37	**851**	6,20	6,20	4,69	3,32	nee	0	0	13	0	13
900	10,86	9,65	1,21	**906**	5,60	5,60	5,26	4,05	nee	0	0	13	0	13
950	10,83	9,78	1,05	**950**	5,45	5,45	5,38	4,33	nee	0	0	13	0	13
1000	10,80	9,90	0,90	**1004**	5,45	5,45	5,35	4,45	nee	0	0	11	2	13
1100	10,75	10,15	0,60	**1100**	5,45	5,45	5,30	4,70	nee	0	0	5	8	13
1150	10,74	10,28	0,46	**1151**	5,45	5,45	5,29	4,83	nee	0	0	0	13	13
1200	10,88	10,39	0,49	**1212**	5,45	5,45	5,43	4,94	nee	0	0	0	13	13
1300	11,15	10,62	0,53	**1310**	5,45	5,45	5,70	5,17	nee	0	0	0	13	13
1400	11,43	10,88	0,55	**1393**	5,45	5,45	5,98	5,43	nee	0	0	0	13	13
1500	11,70	11,10	0,60	**1506**	5,45	5,45	6,25	5,65	nee	0	0	0	13	13
1575	11,90	11,28	0,62	**1574**	5,45	5,45	6,45	5,83	nee	0	0	0	13	13
1750	12,36	11,68	0,68	**1747**	5,45	5,45	6,91	6,23	nee	0	0	0	13	13
2000	12,51	12,19	0,32	**1286**	5,45	5,45	7,06	6,74	nee	0	0	0	13	13
2500	13,22	13,05	0,17	**1044**	5,45	5,45	7,77	7,60	nee	0	0	0	13	13
3000	13,71	13,60	0,11	**894**	5,45	5,45	8,26	8,15	nee	0	0	0	13	13
3500	14,06	14,05	0,01	**283**	5,45	5,45	8,61	8,60	nee	0	0	0	13	13
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	0	0	0	13	13

Q St. Pieter	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	46	46	92	259	0
500	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	46	46	46	370	0
550	1,88	-0,45	ja	3,78	1,45	ja	6,88	4,55	ja	68	68	45	367	0
600	1,85	-0,30	ja	3,75	1,60	ja	6,85	4,70	nee	66	66	0	472	0
650	1,80	-0,17	ja	3,70	1,73	ja	6,80	4,83	nee	95	95	0	462	0
700	1,78	-0,05	ja	3,68	1,85	ja	6,78	4,95	nee	116	116	0	458	0
750	1,75	0,07	ja	3,65	1,97	ja	6,75	5,07	nee	145	145	0	453	0
800	1,72	0,18	ja	3,62	2,08	ja	6,72	5,18	nee	175	175	0	447	0
850	1,69	0,32	ja	3,59	2,22	ja	6,69	5,32	nee	205	205	0	442	0
900	1,66	0,45	ja	3,56	2,35	ja	6,66	5,45	nee	235	235	0	436	0
950	1,63	0,58	ja	3,53	2,48	nee	6,63	5,58	nee	234	234	0	483	0
1000	1,60	0,70	ja	3,50	2,60	nee	6,60	5,70	nee	223	223	0	396	163
1100	1,55	0,95	ja	3,45	2,85	nee	6,55	5,95	nee	192	192	0	161	554
1150	1,54	1,08	nee	3,44	2,98	nee	6,54	6,08	nee	173	173	0	0	806
1200	1,68	1,19	nee	3,58	3,09	nee	6,68	6,19	nee	182	182	0	0	847
1300	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	914
1400	2,23	1,68	nee	4,13	3,58	nee	7,23	6,68	nee	212	212	0	0	968
1500	2,50	1,90	nee	4,40	3,80	nee	7,50	6,90	nee	231	231	0	0	1045
1575	2,70	2,08	nee	4,60	3,98	nee	7,70	7,08	nee	242	242	0	0	1090
1750	3,16	2,48	nee	5,06	4,38	nee	8,16	7,48	nee	271	271	0	0	1206
2000	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	884
2500	4,02	3,85	nee	5,92	5,75	nee	9,02	8,85	nee	165	165	0	0	713
3000	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	609
3500	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	193
4000	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: Model normal management

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q	h	h		Q	Stoney_1	Stoney_2				Poiree					Middle panels			Lowest panels			Sill			Q	Q	Q	Q	Q
St. Pieter	Upstream	Downstream	ΔH	Total	Level	Level	H	h3	Free flow?	11,10	9,20	7,30	4,20	Total	H	h3	Free flow?	H	h3	Free flow?	H	h3	Free flow?	Stoney 1	Stoney 2	middle	low	sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja	0	13	0	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja	0	13	0	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	11,10	8,55	2,55	**443**	9,50	9,50	1,60	-0,95	ja	0	6	7	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	46	46	92	259	0
500	11,10	8,65	2,45	**508**	9,50	9,50	1,60	-0,85	ja	0	3	10	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	46	46	46	370	0
550	11,10	8,75	2,35	**554**	9,00	9,00	2,10	-0,25	ja	0	3	10	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	69	69	46	370	0
600	11,10	8,90	2,20	**575**	9,00	9,00	2,10	-0,10	ja	0	2	11	0	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	69	69	31	407	0
650	11,10	9,03	2,07	**638**	8,40	8,40	2,70	0,63	ja	0	2	11	0	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	100	100	31	407	0
700	11,10	9,15	1,95	**712**	7,60	7,60	3,50	1,55	ja	0	3	10	0	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	148	148	46	370	0
750	11,10	9,27	1,83	**734**	7,60	7,60	3,50	1,67	ja	0	2	11	0	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	148	148	31	407	0
800	11,10	9,38	1,72	**790**	7,50	7,50	3,60	1,88	ja	0	0	13	0	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	154	154	0	481	0
850	11,10	9,52	1,58	**829**	7,20	7,20	3,90	2,32	ja	0	0	13	0	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	174	174	0	481	0
900	11,10	9,65	1,45	**884**	6,80	6,80	4,30	2,85	ja	0	0	13	0	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	202	202	0	481	0
950	11,10	9,78	1,32	**939**	6,00	6,00	5,10	3,78	nee	0	0	13	0	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	229	229	0	481	0
1000	11,10	9,90	1,20	**1014**	5,80	5,80	5,30	4,10	nee	0	0	13	0	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	237	237	0	541	0
1100	11,10	10,15	0,95	**1104**	5,45	5,45	5,65	4,70	nee	0	0	11	2	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	0	446	174
1150	11,10	10,28	0,82	**1147**	5,45	5,45	5,65	4,83	nee	0	0	9	4	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	0	355	331
1200	11,11	10,39	0,72	**1225**	5,45	5,45	5,66	4,94	nee	0	0	6	7	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	0	230	553
1300	11,15	10,62	0,53	**1310**	5,45	5,45	5,70	5,17	nee	0	0	0	13	13	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	914
1400	11,44	10,88	0,56	**1406**	5,45	5,45	5,99	5,43	nee	0	0	0	13	13	2,24	1,68	nee	4,14	3,58	nee	7,24	6,68	nee	214	214	0	0	977
1500	11,70	11,10	0,60	**1506**	5,45	5,45	6,25	5,65	nee	0	0	0	13	13	2,50	1,90	nee	4,40	3,80	nee	7,50	6,90	nee	231	231	0	0	1045
1575	11,90	11,28	0,62	**1574**	5,45	5,45	6,45	5,83	nee	0	0	0	13	13	2,70	2,08	nee	4,60	3,98	nee	7,70	7,08	nee	242	242	0	0	1090
1750	12,36	11,68	0,68	**1747**	5,45	5,45	6,91	6,23	nee	0	0	0	13	13	3,16	2,48	nee	5,06	4,38	nee	8,16	7,48	nee	271	271	0	0	1206
2000	12,51	12,19	0,32	**1286**	5,45	5,45	7,06	6,74	nee	0	0	0	13	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	884
2500	13,22	12,95	0,27	**1300**	5,45	5,45	7,77	7,50	nee	0	0	0	13	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	889
3000	13,71	13,60	0,11	**894**	5,45	5,45	8,26	8,15	nee	0	0	0	13	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	609
3500	14,06	14,05	0,01	**283**	5,45	5,45	8,61	8,60	nee	0	0	0	13	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	193
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	0	0	0	13	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 1 Stoney closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP

m_Stoney free	1,33	-
m_Stoney sub.	0,70	-
m_Poiree_middle free	1,21	-
m_Poiree_low free	1,03	-
m_Poiree_low sub	0,68	-
m_Poiree_sill	0,70	-

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**26**	11,10	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	26	0	0	0
100	11,10	7,99	3,11	**100**	11,10	8,40	2,70	-0,41	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	0	100	0	0	0
150	11,10	8,04	3,06	**146**	11,10	8,40	2,70	-0,36	ja	10	3	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	0	100	46	0	0
200	11,10	8,08	3,02	**208**	11,10	8,40	2,70	-0,32	ja	6	7	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	0	100	108	0	0
250	11,10	8,14	2,96	**269**	11,10	9,00	2,10	-0,86	ja	0	13	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	0	69	200	0	0
300	11,10	8,25	2,85	**300**	11,10	8,40	2,70	-0,15	ja	0	13	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	0	100	200	0	0
350	11,10	8,34	2,76	**365**	11,10	8,40	2,70	-0,06	ja	0	10	3	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	0	100	154	111	0
400	11,10	8,44	2,66	**387**	11,10	8,40	2,70	0,04	ja	0	9	4	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	0	100	138	148	0
450	11,10	8,55	2,55	**452**	11,10	8,40	2,70	0,15	ja	0	6	7	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	0	100	92	259	0
500	11,10	8,65	2,45	**516**	11,10	8,40	2,70	0,25	ja	0	3	10	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	0	100	46	370	0
550	11,10	8,75	2,35	**560**	11,10	8,40	2,70	0,35	ja	0	1	12	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	0	100	15	444	0
600	11,10	8,90	2,20	**581**	11,10	8,40	2,70	0,50	ja	0	0	13	0	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	0	100	0	481	0
650	11,10	9,03	2,07	**642**	11,10	10,00	1,10	-0,97	ja	0	0	11	2	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	0	26	0	407	209
700	11,10	9,15	1,95	**710**	11,10	8,50	2,60	0,65	ja	0	0	11	2	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	0	95	0	407	208
750	11,10	9,27	1,83	**774**	11,10	8,50	2,60	0,77	ja	0	0	10	3	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	0	95	0	370	309
800	11,10	9,38	1,72	**777**	11,10	8,40	2,70	0,98	ja	0	0	10	3	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	0	100	0	370	306
850	11,10	9,52	1,58	**836**	11,10	8,40	2,70	1,12	ja	0	0	9	4	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	0	100	0	333	402
900	11,10	9,65	1,45	**890**	11,10	8,40	2,70	1,25	ja	0	0	8	5	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	0	100	0	296	493
950	11,10	9,78	1,32	**938**	11,10	8,40	2,70	1,38	ja	0	0	7	6	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	0	100	0	259	578
1000	11,10	9,90	1,20	**1007**	11,10	8,40	2,70	1,50	ja	0	0	6	7	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	0	100	0	250	657
1100	11,10	10,15	0,95	**1094**	11,10	8,40	2,70	1,75	ja	0	0	3	10	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	0	100	0	122	872
1150	11,10	10,28	0,82	**1166**	11,10	8,40	2,70	1,88	nee	0	0	0	13	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	0	90	0	0	1076
1200	11,11	10,39	0,72	**1223**	11,10	6,00	5,11	4,39	nee	0	0	0	13	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	0	196	0	0	1027
1300	11,35	10,62	0,73	**1308**	11,10	5,45	5,90	5,17	nee	0	0	0	13	13	2,15	1,42	ja	4,05	3,32	nee	7,15	6,42	nee	3	233	0	0	1072
1400	11,65	10,88	0,77	**1406**	11,10	5,45	6,20	5,43	nee	0	0	0	13	13	2,45	1,68	nee	4,35	3,58	nee	7,45	6,68	nee	9	251	0	0	1146
1500	11,90	11,10	0,80	**1489**	11,10	5,45	6,45	5,65	nee	0	0	0	13	13	2,70	1,90	nee	4,60	3,80	nee	7,70	6,90	nee	16	266	0	0	1206
1750	12,00	11,68	0,32	**1032**	11,10	5,45	6,55	6,23	nee	0	0	0	13	13	2,80	2,48	nee	4,70	4,38	nee	7,80	7,48	nee	19	186	0	0	827
2000	12,51	12,19	0,32	**1117**	11,10	5,45	7,06	6,74	nee	0	0	0	13	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	33	201	0	0	884
2500	13,22	12,95	0,27	**1145**	11,10	5,45	7,77	7,50	nee	0	0	0	13	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	51	205	0	0	889
3000	13,71	13,60	0,11	**796**	11,10	5,45	8,26	8,15	nee	0	0	0	13	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	44	142	0	0	609
3500	14,06	14,05	0,01	**253**	11,10	5,45	8,61	8,60	nee	0	0	0	13	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	16	45	0	0	193
4000	14,65	14,65	0,00	**0**	11,10	5,45	9,20	9,20	nee	0	0	0	13	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 2 Stoneys closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13
50	11,10	7,95	3,15	**46**	11,10	11,10	0,00	-3,15	ja	10	3	0	0	13
100	11,10	7,99	3,11	**92**	11,10	11,10	0,00	-3,11	ja	7	6	0	0	13
150	11,10	8,04	3,06	**154**	11,10	11,10	0,00	-3,06	ja	3	10	0	0	13
200	11,10	8,08	3,02	**200**	11,10	11,10	0,00	-3,02	ja	0	13	0	0	13
250	11,10	8,14	2,96	**265**	11,10	11,10	0,00	-2,96	ja	0	10	3	0	13
300	11,10	8,25	2,85	**308**	11,10	11,10	0,00	-2,85	ja	0	8	5	0	13
350	11,10	8,34	2,76	**351**	11,10	11,10	0,00	-2,76	ja	0	6	7	0	13
400	11,10	8,44	2,66	**416**	11,10	11,10	0,00	-2,66	ja	0	3	10	0	13
450	11,10	8,55	2,55	**459**	11,10	11,10	0,00	-2,55	ja	0	1	12	0	13
500	11,10	8,65	2,45	**481**	11,10	11,10	0,00	-2,45	ja	0	0	13	0	13
550	11,10	8,75	2,35	**530**	11,10	11,10	0,00	-2,35	ja	0	0	11	2	13
600	11,10	8,90	2,20	**617**	11,10	11,10	0,00	-2,20	ja	0	0	11	2	13
650	11,10	9,03	2,07	**650**	11,10	11,10	0,00	-2,07	ja	0	0	11	3	13
700	11,10	9,15	1,95	**682**	11,10	11,10	0,00	-1,95	ja	0	0	10	3	13
750	11,10	9,27	1,83	**746**	11,10	11,10	0,00	-1,83	ja	0	0	9	4	13
800	11,10	9,38	1,72	**807**	11,10	11,10	0,00	-1,72	ja	0	0	8	5	13
850	11,10	9,52	1,58	**862**	11,10	11,10	0,00	-1,58	ja	0	0	7	6	13
900	11,10	9,65	1,45	**913**	11,10	11,10	0,00	-1,45	ja	0	0	6	7	13
950	11,10	9,78	1,32	**956**	11,10	11,10	0,00	-1,32	ja	0	0	5	8	13
1000	11,10	9,90	1,20	**1012**	11,10	11,10	0,00	-1,20	ja	0	0	4	9	13
1100	11,10	10,15	0,95	**1090**	11,10	11,10	0,00	-0,95	ja	0	0	0	13	13
1150	11,22	10,28	0,94	**1154**	11,10	11,10	0,12	-0,82	ja	0	0	0	13	13
1200	11,36	10,39	0,97	**1198**	11,10	11,10	0,26	-0,71	ja	0	0	0	13	13
1300	11,66	10,62	1,04	**1299**	11,10	11,10	0,56	-0,48	ja	0	0	0	13	13
1377	11,90	10,82	1,08	**1377**	11,10	11,10	0,80	-0,28	ja	0	0	0	13	13
1400	11,97	10,88	1,09	**1400**	11,10	11,10	0,87	-0,22	ja	0	0	0	13	13
1500	11,35	11,10	0,25	**673**	11,10	11,10	0,25	0,00	ja	0	0	0	13	13
1750	11,90	11,68	0,22	**715**	11,10	11,10	0,80	0,58	nee	0	0	0	13	13
2000	12,51	12,19	0,32	**949**	11,10	11,10	1,41	1,09	nee	0	0	0	13	13
2500	13,22	12,95	0,27	**990**	11,10	11,10	2,12	1,85	nee	0	0	0	13	13
3000	13,71	13,60	0,11	**697**	11,10	11,10	2,61	2,50	nee	0	0	0	13	13
3500	14,06	14,05	0,01	**224**	11,10	11,10	2,96	2,95	nee	0	0	0	13	13
4000	14,65	14,65	0,00	**0**	11,10	11,10	3,55	3,55	nee	0	0	0	13	13

Q St. Pieter	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	46	0	0
100	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	0	0	92	0	0
150	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	0	0	154	0	0
200	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	0	0	200	0	0
250	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	0	0	154	111	0
300	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	0	0	123	185	0
350	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	0	0	92	259	0
400	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	0	0	46	370	0
450	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	0	0	15	444	0
500	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	0	0	0	481	0
550	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	0	0	0	407	123
600	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	0	0	0	407	210
650	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	0	0	0	389	261
700	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	0	0	0	370	312
750	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	0	0	0	333	413
800	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	0	0	0	296	511
850	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	0	0	0	259	603
900	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	0	0	0	222	691
950	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	0	0	0	185	771
1000	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	0	0	0	166	845
1100	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	0	0	0	0	1090
1150	2,02	1,08	ja	3,92	2,98	nee	7,02	6,08	nee	1	1	0	0	1152
1200	2,16	1,19	ja	4,06	3,09	nee	7,16	6,19	nee	3	3	0	0	1192
1300	2,46	1,42	ja	4,36	3,32	nee	7,46	6,42	nee	9	9	0	0	1280
1377	2,70	1,62	ja	4,60	3,52	nee	7,70	6,62	nee	16	16	0	0	1345
1400	2,77	1,68	ja	4,67	3,58	nee	7,77	6,68	nee	18	18	0	0	1363
1500	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	3	3	0	0	668
1750	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	14	14	0	0	686
2000	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	33	33	0	0	884
2500	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	51	51	0	0	889
3000	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	44	44	0	0	609
3500	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	16	16	0	0	193
4000	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 1 row closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q	h	h		Q	Stoney_1	Stoney_2				Poiree					Middle panels			Lowest panels			Sill			Q	Q	Q	Q	Q
St. Pieter	Upstream	Downstream	ΔH	Total	Level	Level	H	h3	Free flow?	11,10	9,20	7,30	4,20	Total	H	h3	Free flow?	H	h3	Free flow?	H	h3	Free flow?	Stoney 1	Stoney 2	middle	low	sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja	0	13	0	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja	0	13	0	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	11,10	8,55	2,55	**443**	9,50	9,50	1,60	-0,95	ja	0	6	7	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	46	46	92	259	0
500	11,10	8,65	2,45	**508**	9,50	9,50	1,60	-0,85	ja	0	3	10	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	46	46	46	370	0
550	11,10	8,75	2,35	**554**	9,00	9,00	2,10	-0,25	ja	0	3	10	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	69	69	46	370	0
600	11,10	8,90	2,20	**619**	9,00	9,00	2,10	-0,10	ja	0	0	13	0	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	69	69	0	481	0
650	11,10	9,03	2,07	**660**	8,60	8,60	2,50	0,43	ja	0	0	13	0	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	89	89	0	481	0
700	11,10	9,15	1,95	**682**	8,40	8,40	2,70	0,75	ja	0	0	13	0	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	100	100	0	481	0
750	11,10	9,27	1,83	**728**	8,00	8,00	3,10	1,27	ja	0	0	13	0	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	123	123	0	481	0
800	11,10	9,38	1,72	**790**	7,50	7,50	3,60	1,88	ja	0	0	13	0	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	154	154	0	481	0
850	11,10	9,52	1,58	**856**	7,00	7,00	4,10	2,52	ja	0	0	13	0	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	188	188	0	481	0
900	11,10	9,65	1,45	**881**	6,50	6,50	4,60	3,15	nee	0	0	13	0	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	200	200	0	481	0
950	11,10	9,78	1,32	**939**	6,00	6,00	5,10	3,78	nee	0	0	13	0	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	229	229	0	481	0
1000	11,10	9,90	1,20	**1014**	5,80	5,80	5,30	4,10	nee	0	0	13	0	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	237	237	0	541	0
1100	11,27	10,15	1,12	**1097**	5,45	5,45	5,82	4,70	nee	0	0	13	0	13	2,07	0,95	ja	3,97	2,85	nee	7,07	5,95	nee	262	262	0	573	0
1150	11,42	10,28	1,14	**1148**	5,45	5,45	5,97	4,83	nee	0	0	13	0	13	2,22	1,08	ja	4,12	2,98	nee	7,22	6,08	nee	272	272	0	604	0
1200	11,57	10,39	1,18	**1203**	5,45	5,45	6,12	4,94	nee	0	0	13	0	13	2,37	1,19	ja	4,27	3,09	nee	7,37	6,19	nee	283	283	0	637	0
1300	11,85	10,62	1,23	**1304**	5,45	5,45	6,40	5,17	nee	0	0	13	0	13	2,65	1,42	ja	4,55	3,32	nee	7,65	6,42	nee	302	302	0	699	0
1317	11,90	10,66	1,24	**1322**	5,45	5,45	6,45	5,21	nee	0	0	13	0	13	2,70	1,46	ja	4,60	3,36	nee	7,70	6,46	nee	306	306	0	711	0
1400	12,15	10,88	1,27	**1411**	5,45	5,45	6,70	5,43	nee	0	0	13	0	13	2,95	1,68	ja	4,85	3,58	nee	7,95	6,68	nee	323	323	0	766	0
1500	11,35	11,10	0,25	**652**	5,45	5,45	5,90	5,65	nee	0	0	13	0	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	357	0
1750	11,90	11,68	0,22	**698**	5,45	5,45	6,45	6,23	nee	0	0	13	0	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	390	0
2000	12,51	12,19	0,32	**927**	5,45	5,45	7,06	6,74	nee	0	0	13	0	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	525	0
2500	13,22	12,95	0,27	**968**	5,45	5,45	7,77	7,50	nee	0	0	13	0	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	558	0
3000	13,71	13,60	0,11	**682**	5,45	5,45	8,26	8,15	nee	0	0	13	0	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	397	0
3500	14,06	14,05	0,01	**219**	5,45	5,45	8,61	8,60	nee	0	0	13	0	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	128	0
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	0	0	13	0	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 2 rows closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13
350	11,10	8,34	2,76	**337**	9,00	9,00	2,10	-0,66	ja	0	13	0	0	13
400	11,10	8,44	2,66	**400**	8,40	8,40	2,70	0,04	ja	0	13	0	0	13
450	11,10	8,55	2,55	**447**	8,00	8,00	3,10	0,55	ja	0	13	0	0	13
500	11,10	8,65	2,45	**509**	7,50	7,50	3,60	1,15	ja	0	13	0	0	13
550	11,10	8,75	2,35	**562**	7,10	7,10	4,00	1,65	ja	0	13	0	0	13
600	11,10	8,90	2,20	**603**	6,80	6,80	4,30	2,10	ja	0	13	0	0	13
650	11,10	9,03	2,07	**646**	6,50	6,50	4,60	2,53	ja	0	13	0	0	13
700	11,10	9,15	1,95	**721**	6,00	6,00	5,10	3,15	ja	0	13	0	0	13
750	11,10	9,27	1,83	**745**	5,45	5,45	5,65	3,82	nee	0	13	0	0	13
800	11,27	9,38	1,89	**797**	5,45	5,45	5,82	3,93	nee	0	13	0	0	13
850	11,45	9,52	1,93	**854**	5,45	5,45	6,00	4,07	nee	0	13	0	0	13
900	11,59	9,65	1,94	**899**	5,45	5,45	6,14	4,20	nee	0	13	0	0	13
950	11,75	9,78	1,97	**951**	5,45	5,45	6,30	4,33	nee	0	13	0	0	13
983	11,85	9,86	1,99	**985**	5,45	5,45	6,40	4,41	nee	0	13	0	0	13
1000	11,90	9,90	2,00	**1002**	5,45	5,45	6,45	4,45	nee	0	13	0	0	13
1100	11,10	10,15	0,95	**683**	5,45	5,45	5,65	4,70	nee	0	13	0	0	13
1150	11,10	10,28	0,82	**661**	5,45	5,45	5,65	4,83	nee	0	13	0	0	13
1200	11,11	10,39	0,72	**643**	5,45	5,45	5,66	4,94	nee	0	13	0	0	13
1300	11,15	10,62	0,53	**746**	5,45	5,45	5,70	5,17	nee	0	13	0	0	13
1400	11,22	10,88	0,34	**665**	5,45	5,45	5,77	5,43	nee	0	13	0	0	13
1500	11,35	11,10	0,25	**613**	5,45	5,45	5,90	5,65	nee	0	13	0	0	13
1750	11,90	11,68	0,22	**701**	5,45	5,45	6,45	6,23	nee	0	13	0	0	13
2000	12,51	12,19	0,32	**974**	5,45	5,45	7,06	6,74	nee	0	13	0	0	13
2500	13,22	12,95	0,27	**1069**	5,45	5,45	7,77	7,50	nee	0	13	0	0	13
3000	13,71	13,60	0,11	**778**	5,45	5,45	8,26	8,15	nee	0	13	0	0	13
3500	14,06	14,05	0,01	**255**	5,45	5,45	8,61	8,60	nee	0	13	0	0	13
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	0	13	0	0	13

Q St. Pieter	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	69	69	200	0	0
400	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	200	0	0
450	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	123	123	200	0	0
500	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	154	154	200	0	0
550	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	181	181	200	0	0
600	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	202	202	200	0	0
650	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	223	223	200	0	0
700	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	260	260	200	0	0
750	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	272	272	200	0	0
800	2,07	0,18	ja	3,97	2,08	ja	7,07	5,18	nee	285	285	227	0	0
850	2,25	0,32	ja	4,15	2,22	ja	7,25	5,32	nee	298	298	257	0	0
900	2,39	0,45	ja	4,29	2,35	ja	7,39	5,45	nee	308	308	282	0	0
950	2,55	0,58	ja	4,45	2,48	ja	7,55	5,58	nee	320	320	311	0	0
983	2,65	0,66	ja	4,55	2,56	ja	7,65	5,66	nee	328	328	329	0	0
1000	2,70	0,70	ja	4,60	2,60	ja	7,70	5,70	nee	332	332	338	0	0
1100	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	200	0	0
1150	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	200	0	0
1200	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	201	0	0
1300	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	349	0	0
1400	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	331	0	0
1500	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	318	0	0
1750	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	393	0	0
2000	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	572	0	0
2500	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	658	0	0
3000	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	493	0	0
3500	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	164	0	0
4000	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: Complete Poiree closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13
250	11,10	8,14	2,96	**247**	8,00	8,00	3,10	0,14	ja	13	0	0	0	13
300	11,10	8,25	2,85	**309**	7,50	7,50	3,60	0,75	ja	13	0	0	0	13
350	11,10	8,34	2,76	**335**	7,30	7,30	3,80	1,04	ja	13	0	0	0	13
400	11,10	8,44	2,66	**375**	7,00	7,00	4,10	1,44	ja	13	0	0	0	13
450	11,10	8,55	2,55	**446**	6,50	6,50	4,60	2,05	ja	13	0	0	0	13
500	11,10	8,65	2,45	**521**	6,00	6,00	5,10	2,65	ja	13	0	0	0	13
550	11,10	8,75	2,35	**567**	5,70	5,70	5,40	3,05	ja	13	0	0	0	13
600	11,10	8,90	2,20	**607**	5,45	5,45	5,65	3,45	ja	13	0	0	0	13
650	11,36	9,03	2,33	**650**	5,45	5,45	5,91	3,58	ja	13	0	0	0	13
700	11,65	9,15	2,50	**698**	5,45	5,45	6,20	3,70	ja	13	0	0	0	13
742	11,90	9,25	2,65	**741**	5,45	5,45	6,45	3,80	ja	13	0	0	0	13
750	11,95	9,27	2,68	**749**	5,45	5,45	6,50	3,82	ja	13	0	0	0	13
800	11,85	9,38	2,47	**732**	5,45	5,45	6,40	3,93	ja	13	0	0	0	13
850	11,10	9,52	1,58	**539**	5,45	5,45	5,65	4,07	nee	13	0	0	0	13
900	11,10	9,65	1,45	**533**	5,45	5,45	5,65	4,20	nee	13	0	0	0	13
950	11,10	9,78	1,32	**524**	5,45	5,45	5,65	4,33	nee	13	0	0	0	13
1000	11,10	9,90	1,20	**514**	5,45	5,45	5,65	4,45	nee	13	0	0	0	13
1100	11,10	10,15	0,95	**483**	5,45	5,45	5,65	4,70	nee	13	0	0	0	13
1150	11,10	10,28	0,82	**461**	5,45	5,45	5,65	4,83	nee	13	0	0	0	13
1200	11,11	10,39	0,72	**442**	5,45	5,45	5,66	4,94	nee	13	0	0	0	13
1300	11,15	10,62	0,53	**397**	5,45	5,45	5,70	5,17	nee	13	0	0	0	13
1400	11,22	10,88	0,34	**334**	5,45	5,45	5,77	5,43	nee	13	0	0	0	13
1500	11,35	11,10	0,25	**295**	5,45	5,45	5,90	5,65	nee	13	0	0	0	13
1750	11,90	11,68	0,22	**308**	5,45	5,45	6,45	6,23	nee	13	0	0	0	13
2000	12,51	12,19	0,32	**402**	5,45	5,45	7,06	6,74	nee	13	0	0	0	13
2500	13,22	12,95	0,27	**411**	5,45	5,45	7,77	7,50	nee	13	0	0	0	13
3000	13,71	13,60	0,11	**285**	5,45	5,45	8,26	8,15	nee	13	0	0	0	13
3500	14,06	14,05	0,01	**91**	5,45	5,45	8,61	8,60	nee	13	0	0	0	13
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	13	0	0	0	13

Q St. Pieter	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	123	123	0	0	0
300	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	154	154	0	0	0
350	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	167	167	0	0	0
400	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	188	188	0	0	0
450	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	223	223	0	0	0
500	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	260	260	0	0	0
550	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	284	284	0	0	0
600	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	304	304	0	0	0
650	2,16	-0,17	ja	4,06	1,73	ja	7,16	4,83	nee	325	325	0	0	0
700	2,45	-0,05	ja	4,35	1,85	ja	7,45	4,95	ja	349	349	0	0	0
742	2,70	0,05	ja	4,60	1,95	ja	7,70	5,05	ja	370	370	0	0	0
750	2,75	0,07	ja	4,65	1,97	ja	7,75	5,07	ja	375	375	0	0	0
800	2,65	0,18	ja	4,55	2,08	ja	7,65	5,18	nee	366	366	0	0	0
850	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	270	270	0	0	0
900	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	267	267	0	0	0
950	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	262	262	0	0	0
1000	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	257	257	0	0	0
1100	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	0	0	0
1150	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	231	231	0	0	0
1200	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	0	0	0
1300	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	0
1400	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	0	0	0
1500	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	0	0
1750	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	0
2000	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	0
2500	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	0
3000	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	0
3500	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	0
4000	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 3 beams closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	11,10	8,25	2,85	**291**	9,00	9,00	2,10	-0,75	ja	3	10	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	69	69	154	0	0
350	11,10	8,34	2,76	**354**	8,40	8,40	2,70	-0,06	ja	3	10	0	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	100	100	154	0	0
400	11,10	8,44	2,66	**419**	8,40	8,40	2,70	0,04	ja	3	7	3	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	108	111	0
450	11,10	8,55	2,55	**462**	8,40	8,40	2,70	0,15	ja	3	5	5	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	100	100	77	185	0
500	11,10	8,65	2,45	**490**	8,40	8,40	2,70	0,25	ja	3	2	7	0	12	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	100	100	31	259	0
550	11,10	8,75	2,35	**549**	8,40	8,40	2,70	0,35	ja	3	1	9	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	100	100	15	333	0
600	11,10	8,90	2,20	**606**	8,70	8,70	2,40	0,20	ja	3	0	9	1	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	84	84	0	333	105
650	11,10	9,03	2,07	**638**	8,40	8,40	2,70	0,63	ja	3	0	9	1	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	100	100	0	333	105
700	11,10	9,15	1,95	**705**	8,40	8,40	2,70	0,75	ja	3	0	8	2	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	100	100	0	296	208
750	11,10	9,27	1,83	**769**	8,40	8,40	2,70	0,87	ja	3	0	7	3	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	100	100	0	259	309
800	11,10	9,38	1,72	**799**	8,40	8,40	2,70	0,98	ja	3	0	7	4	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	100	100	0	241	358
850	11,10	9,52	1,58	**857**	8,40	8,40	2,70	1,12	ja	3	0	6	5	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	100	100	0	204	453
900	11,10	9,65	1,45	**879**	8,40	8,40	2,70	1,25	ja	3	0	5	5	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	100	100	0	185	493
950	11,10	9,78	1,32	**927**	8,40	8,40	2,70	1,38	ja	3	0	4	6	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	100	100	0	148	578
1000	11,10	9,90	1,20	**983**	8,40	8,40	2,70	1,50	ja	3	0	3	7	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	100	100	0	125	657
1100	11,10	10,15	0,95	**1093**	8,00	8,00	3,10	2,15	nee	3	0	0	10	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	110	110	0	0	872
1150	11,10	10,28	0,82	**1141**	7,00	7,00	4,10	3,28	nee	3	0	0	10	13	1,90	1,08	ja	3,80	2,98	nee	6,90	6,08	nee	157	157	0	0	828
1200	11,11	10,39	0,72	**1209**	5,70	5,70	5,41	4,69	nee	3	0	0	10	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	210	210	0	0	790
1300	11,36	10,62	0,74	**1299**	5,45	5,45	5,91	5,17	nee	3	0	0	10	13	2,16	1,42	ja	4,06	3,32	nee	7,16	6,42	nee	234	234	0	0	831
1400	11,67	10,88	0,79	**1402**	5,45	5,45	6,22	5,43	nee	3	0	0	10	13	2,47	1,68	nee	4,37	3,58	nee	7,47	6,68	nee	254	254	0	0	893
1482	11,90	11,06	0,84	**1488**	5,45	5,45	6,45	5,61	nee	3	0	0	10	13	2,70	1,86	nee	4,60	3,76	nee	7,70	6,86	nee	271	271	0	0	945
1500	11,95	11,10	0,85	**1506**	5,45	5,45	6,50	5,65	nee	3	0	0	10	13	2,75	1,90	nee	4,65	3,80	nee	7,75	6,90	nee	275	275	0	0	957
1750	11,90	11,68	0,22	**836**	5,45	5,45	6,45	6,23	nee	3	0	0	10	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	528
2000	12,51	12,19	0,32	**1082**	5,45	5,45	7,06	6,74	nee	3	0	0	10	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	680
2500	13,22	12,95	0,27	**1095**	5,45	5,45	7,77	7,50	nee	3	0	0	10	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	684
3000	13,71	13,60	0,11	**754**	5,45	5,45	8,26	8,15	nee	3	0	0	10	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	469
3500	14,06	14,05	0,01	**239**	5,45	5,45	8,61	8,60	nee	3	0	0	10	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	148
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	3	0	0	10	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 6 beams closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**230**	9,00	9,00	2,10	-0,86	ja	7	6	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	69	69	92	0	0
300	11,10	8,25	2,85	**308**	8,40	8,40	2,70	-0,15	ja	6	7	0	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	100	100	108	0	0
350	11,10	8,34	2,76	**373**	8,40	8,40	2,70	-0,06	ja	6	4	3	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	100	100	61	111	0
400	11,10	8,44	2,66	**416**	8,40	8,40	2,70	0,04	ja	6	2	5	0	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	31	185	0
450	11,10	8,55	2,55	**460**	8,40	8,40	2,70	0,15	ja	6	0	7	0	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	100	100	0	259	0
500	11,10	8,65	2,45	**506**	8,00	8,00	3,10	0,65	ja	6	0	7	0	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	123	123	0	259	0
550	11,10	8,75	2,35	**568**	7,50	7,50	3,60	1,25	ja	6	0	7	0	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	154	154	0	259	0
600	11,10	8,90	2,20	**607**	7,20	7,20	3,90	1,70	ja	6	0	7	0	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	174	174	0	259	0
650	11,10	9,03	2,07	**634**	7,00	7,00	4,10	2,03	ja	6	0	7	0	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	188	188	0	259	0
700	11,10	9,15	1,95	**701**	7,00	7,00	4,10	2,15	ja	6	0	6	1	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	188	188	0	222	104
750	11,10	9,27	1,83	**771**	6,50	6,50	4,60	2,77	ja	6	0	6	1	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	223	223	0	222	103
800	11,10	9,38	1,72	**800**	6,30	6,30	4,80	3,08	ja	6	0	6	1	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	238	238	0	222	102
850	11,10	9,52	1,58	**845**	6,30	6,30	4,80	3,22	nee	6	0	5	3	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	213	213	0	167	251
900	11,10	9,65	1,45	**900**	6,30	6,30	4,80	3,35	nee	6	0	4	4	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	213	213	0	130	345
950	11,10	9,78	1,32	**930**	6,20	6,20	4,90	3,58	nee	6	0	3	4	13	1,90	0,58	ja	3,80	2,48	ja	6,90	5,58	nee	217	217	0	111	386
1000	11,10	9,90	1,20	**980**	6,20	6,20	4,90	3,70	nee	6	0	2	5	13	1,90	0,70	ja	3,80	2,60	nee	6,90	5,70	nee	214	214	0	83	469
1100	11,10	10,15	0,95	**1093**	5,45	5,45	5,65	4,70	nee	6	0	0	7	13	1,90	0,95	ja	3,80	2,85	nee	6,90	5,95	nee	241	241	0	0	610
1150	11,28	10,28	1,00	**1149**	5,45	5,45	5,83	4,83	nee	6	0	0	7	13	2,08	1,08	ja	3,98	2,98	nee	7,08	6,08	nee	255	255	0	0	640
1200	11,44	10,39	1,05	**1201**	5,45	5,45	5,99	4,94	nee	6	0	0	7	13	2,24	1,19	ja	4,14	3,09	nee	7,24	6,19	nee	267	267	0	0	668
1300	11,75	10,62	1,13	**1298**	5,45	5,45	6,30	5,17	nee	6	0	0	7	13	2,55	1,42	ja	4,45	3,32	nee	7,55	6,42	nee	290	290	0	0	718
1344	11,90	10,73	1,17	**1346**	5,45	5,45	6,45	5,28	nee	6	0	0	7	13	2,70	1,53	ja	4,60	3,43	nee	7,70	6,53	nee	301	301	0	0	744
1400	12,09	10,88	1,21	**1403**	5,45	5,45	6,64	5,43	nee	6	0	0	7	13	2,89	1,68	ja	4,79	3,58	nee	7,89	6,68	nee	315	315	0	0	773
1500	11,35	11,10	0,25	**654**	5,45	5,45	5,90	5,65	nee	6	0	0	7	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	0	360
1750	11,90	11,68	0,22	**677**	5,45	5,45	6,45	6,23	nee	6	0	0	7	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	369
2000	12,51	12,19	0,32	**878**	5,45	5,45	7,06	6,74	nee	6	0	0	7	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	476
2500	13,22	12,95	0,27	**889**	5,45	5,45	7,77	7,50	nee	6	0	0	7	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	479
3000	13,71	13,60	0,11	**613**	5,45	5,45	8,26	8,15	nee	6	0	0	7	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	328
3500	14,06	14,05	0,01	**194**	5,45	5,45	8,61	8,60	nee	6	0	0	7	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	104
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	6	0	0	7	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

Situation: 9 beams closed

Width Stoney	17	m	Level Stoneys	11,10 to 8,40 and 8,40 to 5,45m +NAP
Width Poiree	63	m		
Width panel	4,85	m	Levels Poiree	11,10 m +NAP
				9,20 m +NAP
Sill Stoney	5,45	m +NAP		7,30 m +NAP
Sill Poiree	4,20	m +NAP		4,20 m +NAP
m_Stoney free	1,33	-		
m_Stoney sub.	0,70	-		
m_Poiree_middle free	1,21	-		
m_Poiree_low free	1,03	-		
m_Poiree_low sub	0,68	-		
m_Poiree_sill	0,70	-		

Q St. Pieter	h Upstream	h Downstream	ΔH	Q Total	Stoney_1 Level	Stoney_2 Level	H	h3	Free flow?	Poiree 11,10	9,20	7,30	4,20	Total	Middle panels H	h3	Free flow?	Lowest panels H	h3	Free flow?	Sill H	h3	Free flow?	Q Stoney 1	Q Stoney 2	Q middle	Q low	Q sill
0	11,10	7,95	3,15	**0**	11,10	11,10	0,00	-3,15	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	0	0	0	0	0
50	11,10	7,95	3,15	**52**	10,00	10,00	1,10	-2,05	ja	13	0	0	0	13	1,90	-1,25	ja	3,80	0,65	ja	6,90	3,75	ja	26	26	0	0	0
100	11,10	7,99	3,11	**92**	9,50	9,50	1,60	-1,51	ja	13	0	0	0	13	1,90	-1,21	ja	3,80	0,69	ja	6,90	3,79	ja	46	46	0	0	0
150	11,10	8,04	3,06	**138**	9,00	9,00	2,10	-0,96	ja	13	0	0	0	13	1,90	-1,16	ja	3,80	0,74	ja	6,90	3,84	ja	69	69	0	0	0
200	11,10	8,08	3,02	**201**	8,40	8,40	2,70	-0,32	ja	13	0	0	0	13	1,90	-1,12	ja	3,80	0,78	ja	6,90	3,88	ja	100	100	0	0	0
250	11,10	8,14	2,96	**262**	8,40	8,40	2,70	-0,26	ja	9	4	0	0	13	1,90	-1,06	ja	3,80	0,84	ja	6,90	3,94	ja	100	100	61	0	0
300	11,10	8,25	2,85	**305**	8,40	8,40	2,70	-0,15	ja	9	2	2	0	13	1,90	-0,95	ja	3,80	0,95	ja	6,90	4,05	ja	100	100	31	74	0
350	11,10	8,34	2,76	**349**	8,40	8,40	2,70	-0,06	ja	9	0	4	0	13	1,90	-0,86	ja	3,80	1,04	ja	6,90	4,14	ja	100	100	0	148	0
400	11,10	8,44	2,66	**398**	8,40	8,40	2,70	0,04	ja	9	0	2	2	13	1,90	-0,76	ja	3,80	1,14	ja	6,90	4,24	ja	100	100	0	74	123
450	11,10	8,55	2,55	**444**	8,00	8,00	3,10	0,55	ja	9	0	2	2	13	1,90	-0,65	ja	3,80	1,25	ja	6,90	4,35	ja	123	123	0	74	123
500	11,10	8,65	2,45	**506**	7,50	7,50	3,60	1,15	ja	9	0	2	2	13	1,90	-0,55	ja	3,80	1,35	ja	6,90	4,45	ja	154	154	0	74	123
550	11,10	8,75	2,35	**532**	7,30	7,30	3,80	1,45	ja	9	0	2	2	13	1,90	-0,45	ja	3,80	1,45	ja	6,90	4,55	ja	167	167	0	74	123
600	11,10	8,90	2,20	**619**	7,30	7,30	3,80	1,60	ja	9	0	2	2	13	1,90	-0,30	ja	3,80	1,60	ja	6,90	4,70	nee	167	167	0	74	210
650	11,10	9,03	2,07	**658**	7,00	7,00	4,10	2,03	ja	9	0	2	2	13	1,90	-0,17	ja	3,80	1,73	ja	6,90	4,83	nee	188	188	0	74	209
700	11,10	9,15	1,95	**699**	6,70	6,70	4,40	2,45	ja	9	0	2	2	13	1,90	-0,05	ja	3,80	1,85	ja	6,90	4,95	nee	209	209	0	74	208
750	11,10	9,27	1,83	**764**	6,70	6,70	4,40	2,57	ja	9	0	1	3	13	1,90	0,07	ja	3,80	1,97	ja	6,90	5,07	nee	209	209	0	37	309
800	11,10	9,38	1,72	**790**	6,50	6,50	4,60	2,88	ja	9	0	1	3	13	1,90	0,18	ja	3,80	2,08	ja	6,90	5,18	nee	223	223	0	37	306
850	11,10	9,52	1,58	**869**	6,00	6,00	5,10	3,52	nee	9	0	0	4	13	1,90	0,32	ja	3,80	2,22	ja	6,90	5,32	nee	233	233	0	0	402
900	11,10	9,65	1,45	**915**	5,55	5,55	5,55	4,10	nee	9	0	0	4	13	1,90	0,45	ja	3,80	2,35	ja	6,90	5,45	nee	260	260	0	0	395
950	11,22	9,78	1,44	**951**	5,45	5,45	5,77	4,33	nee	9	0	0	4	13	2,02	0,58	ja	3,92	2,48	ja	7,02	5,58	nee	274	274	0	0	403
1000	11,42	9,90	1,52	**1001**	5,45	5,45	5,97	4,45	nee	9	0	0	4	13	2,22	0,70	ja	4,12	2,60	ja	7,22	5,70	nee	289	289	0	0	423
1100	11,81	10,15	1,66	**1100**	5,45	5,45	6,36	4,70	nee	9	0	0	4	13	2,61	0,95	ja	4,51	2,85	ja	7,61	5,95	nee	319	319	0	0	461
1123	11,90	10,21	1,69	**1122**	5,45	5,45	6,45	4,76	nee	9	0	0	4	13	2,70	1,01	ja	4,60	2,91	ja	7,70	6,01	nee	326	326	0	0	470
1150	12,01	10,28	1,73	**1151**	5,45	5,45	6,56	4,83	nee	9	0	0	4	13	2,81	1,08	ja	4,71	2,98	ja	7,81	6,08	nee	335	335	0	0	481
1200	11,11	10,39	0,72	**758**	5,45	5,45	5,66	4,94	nee	9	0	0	4	13	1,91	1,19	ja	3,81	3,09	nee	6,91	6,19	nee	221	221	0	0	316
1300	11,15	10,62	0,53	**678**	5,45	5,45	5,70	5,17	nee	9	0	0	4	13	1,95	1,42	nee	3,85	3,32	nee	6,95	6,42	nee	198	198	0	0	281
1400	11,22	10,88	0,34	**568**	5,45	5,45	5,77	5,43	nee	9	0	0	4	13	2,02	1,68	nee	3,92	3,58	nee	7,02	6,68	nee	167	167	0	0	234
1500	11,35	11,10	0,25	**500**	5,45	5,45	5,90	5,65	nee	9	0	0	4	13	2,15	1,90	nee	4,05	3,80	nee	7,15	6,90	nee	147	147	0	0	205
1750	11,90	11,68	0,22	**519**	5,45	5,45	6,45	6,23	nee	9	0	0	4	13	2,70	2,48	nee	4,60	4,38	nee	7,70	7,48	nee	154	154	0	0	211
2000	12,51	12,19	0,32	**674**	5,45	5,45	7,06	6,74	nee	9	0	0	4	13	3,31	2,99	nee	5,21	4,89	nee	8,31	7,99	nee	201	201	0	0	272
2500	13,22	12,95	0,27	**684**	5,45	5,45	7,77	7,50	nee	9	0	0	4	13	4,02	3,75	nee	5,92	5,65	nee	9,02	8,75	nee	205	205	0	0	273
3000	13,71	13,60	0,11	**472**	5,45	5,45	8,26	8,15	nee	9	0	0	4	13	4,51	4,40	nee	6,41	6,30	nee	9,51	9,40	nee	142	142	0	0	188
3500	14,06	14,05	0,01	**150**	5,45	5,45	8,61	8,60	nee	9	0	0	4	13	4,86	4,85	nee	6,76	6,75	nee	9,86	9,85	nee	45	45	0	0	59
4000	14,65	14,65	0,00	**0**	5,45	5,45	9,20	9,20	nee	9	0	0	4	13	5,45	5,45	nee	7,35	7,35	nee	10,45	10,45	nee	0	0	0	0	0

G

Calculation flow velocities fictive weir

G.0.1. 1 Stoney closed

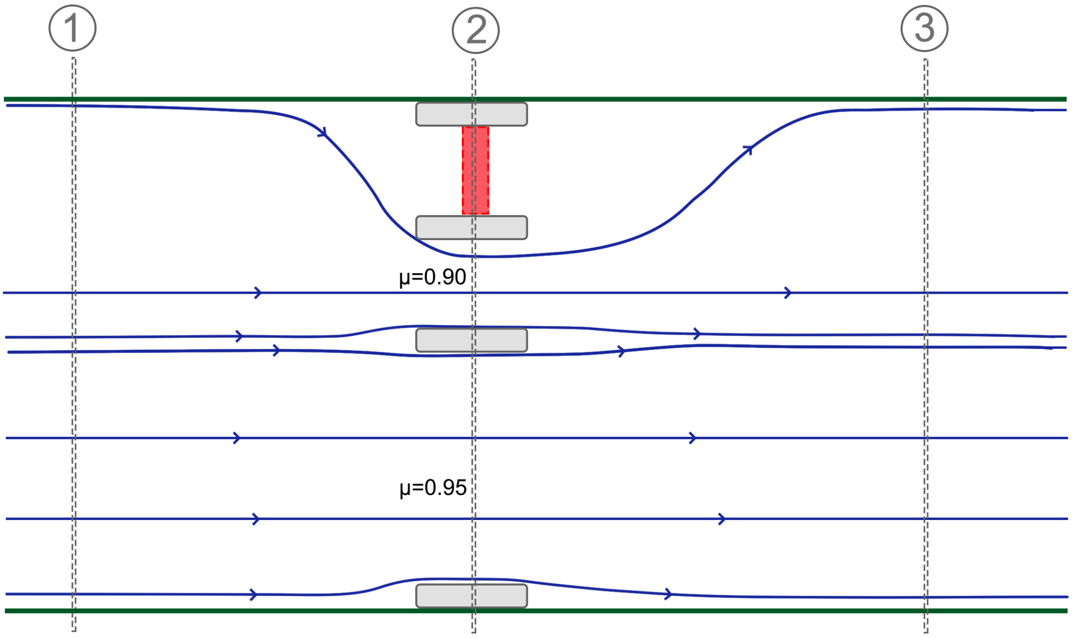

Figure G.1: Top view 1 Stoney closed

Because the contraction of the flow through the Poiree part is negligible and only contraction due to the pillars occurs, a μ value of 0.95 is used for the Poiree part. The contraction through the remaining Stoney opening is more severe and therefore a value of $\mu = 0.90$ is used. The values which are used in the following calculations are retrieved from Appendix E. Therefore the exact discharge can differ slightly from the approximated discharge. Furthermore the distribution of discharge over the Stoney and Poiree part and the corresponding levels of the Stoney slides and Poiree panels is retrieved form Appendix E.
The discharges which are considered are

Table G.1: Considered discharges 1 Stoney closed

Situation	App. Q [m3/s]	Exact Q [m3/s]	Upstream water level [m +NAP]	Downstream water level [m +NAP]	Delta H [m]	Flow regime
1/2 limit discharge	600	581	11.10	8.90	2.20	Free flow
Limit discharge	1200	1239	11.10	10.39	0.71	Submerged flow
Maximum discharge	1500	1489	11.90	11.10	0.80	submerged flow

1/2 limit discharge

Parameters:
1/2 limit discharge: Q = 581 m^3/s
Water level upstream = 11.10m +NAP
Water level downstream = 8.90m +NAP
Width river = b_3 = 113.05m
$u_3 = 1.32 m/s$

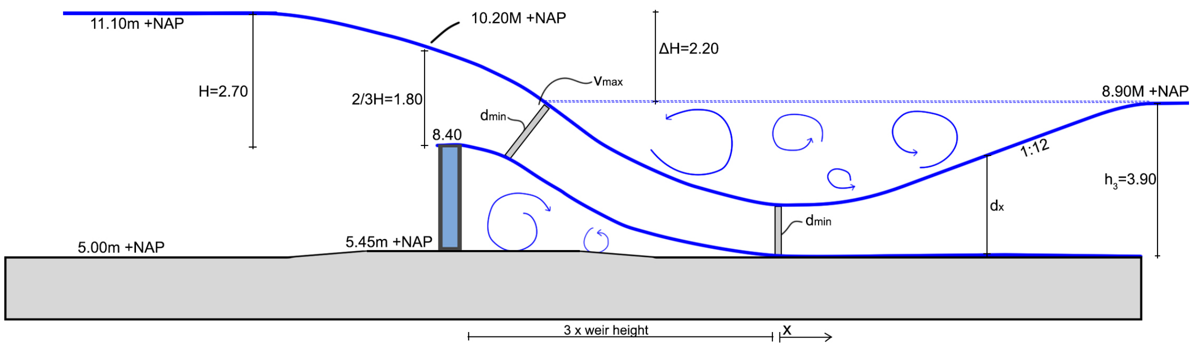

Figure G.2: Flow situation Stoney, 1 Stoney closed

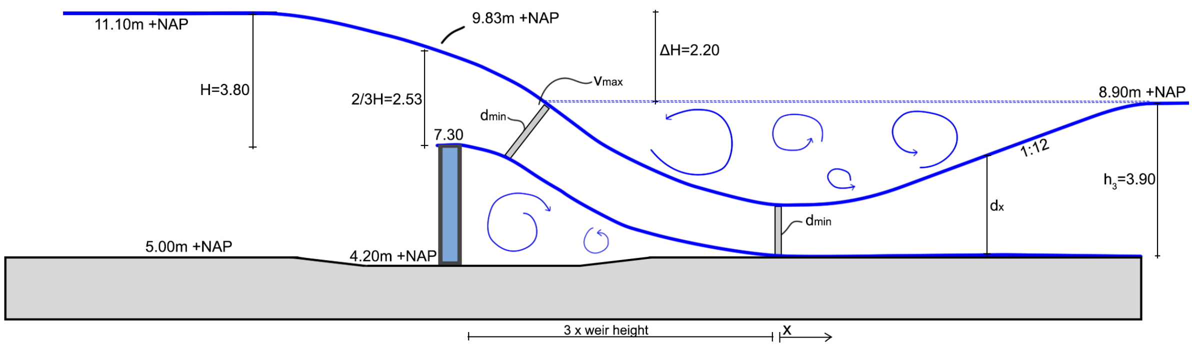

Figure G.3: Flow situation Poiree, 1 Stoney closed

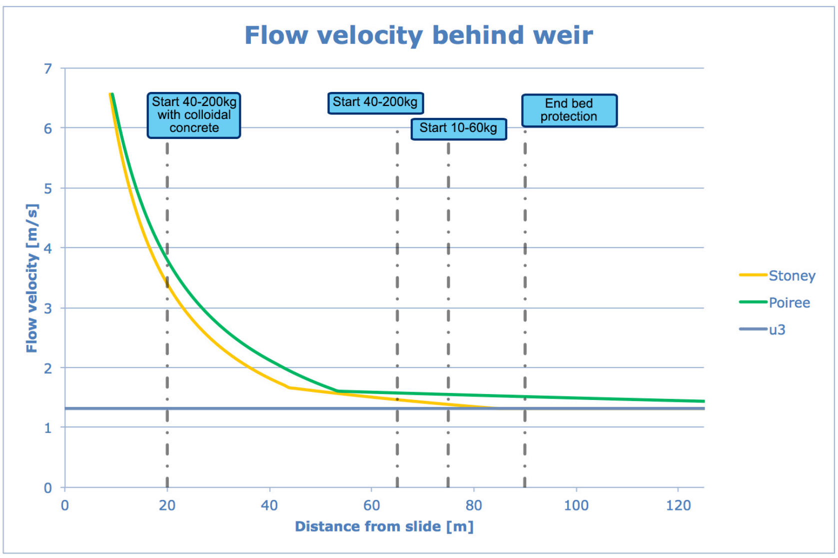

Figure G.4: Flow velocities Stoney and Poiree, 1 Stoney closed

Flow over Stoney		
μ*b	15,3	m
Q	100	m3/s
h_upstream	11,10	m
h_downstream	8,90	m
Delta_H	2,20	m
u_max	6,57	m/s
d_min	0,99	m
Level Stoney	8,40	m +NAP
Heigth weir	2,95	m
Reattachment	8,85	m
h_3	3,90	m
Max spreiding	2,91	m
x_max	34,86	m
Vert. Spread 1:	12	-
Hor. Spread 1:	10	-

Flow over Poiree		
μ*b	59,90	m
Q	481	m3/s
h_upstream	11,10	m
h_downstream	8,90	m
Delta_H	2,20	m
u_max	6,57	m/s
d_min	1,22	m
Level Poiree	7,30	m +NAP
Heigth weir	3,10	m
Reattachment	9,30	m
h_3	4,9	m
Max spreiding	3,68	m
x_max	44,13	m

Stoney

x	d_x	u	X_from weir	Vert. spread	Hor. sprea	b
0	0,99	6,57	8,85	0,99	0,00	15,30
5	1,41	4,63	13,85	1,41	0,00	15,30
10	1,83	3,58	18,85	1,83	0,00	15,30
15	2,24	2,91	23,85	2,24	0,00	15,30
20	2,66	2,46	28,85	2,66	0,00	15,30
25	3,08	2,12	33,85	3,08	0,00	15,30
30	3,49	1,87	38,85	3,49	0,00	15,30
40	3,90	1,61	48,85	4,33	0,60	15,90
50	3,90	1,52	58,85	5,16	1,60	16,90
60	3,90	1,43	68,85	5,99	2,60	17,90
70	3,90	1,36	78,85	6,83	3,60	18,90
80	3,90	1,32	88,85	7,66	4,60	19,90
90	3,90	1,32	98,85	8,49	5,60	20,90
100	3,90	1,32	108,85	9,33	6,60	21,90
125	3,90	1,32	133,85	11,41	9,10	24,40

Poiree

x	d_x	u	X_from weir	Vert. spread	Hor. sprea	b
0	1,22	6,57	9,30	1,22	0,00	59,90
5	1,64	4,90	14,30	1,64	0,00	59,90
10	2,06	3,91	19,30	2,06	0,00	59,90
15	2,47	3,25	24,30	2,47	0,00	59,90
20	2,89	2,78	29,30	2,89	0,00	59,90
25	3,31	2,43	34,30	3,31	0,00	59,90
30	3,72	2,16	39,30	3,72	0,00	59,90
40	4,56	1,74	49,30	4,56	0,80	60,70
50	4,90	1,59	59,30	5,39	1,80	61,70
60	4,90	1,57	69,30	6,22	2,80	62,70
70	4,90	1,54	79,30	7,06	3,80	63,70
80	4,90	1,52	89,30	7,89	4,80	64,70
90	4,90	1,49	99,30	8,72	5,80	65,70
100	4,90	1,47	109,30	9,56	6,80	66,70
125	4,90	1,42	134,30	11,64	9,30	69,20

Figure G.5: Input parameters 1 Stoney closed

Limit discharge

Parameters:
Limit discharge: Q = 1239 m^3/s
Water level upstream = 11.10m +NAP
Water level downstream = 10.39m +NAP
Width river = b_3 = 113.05m
Flow width weir = μb_2 = 0.90*17 + 0.95*63.05 = 75.20m

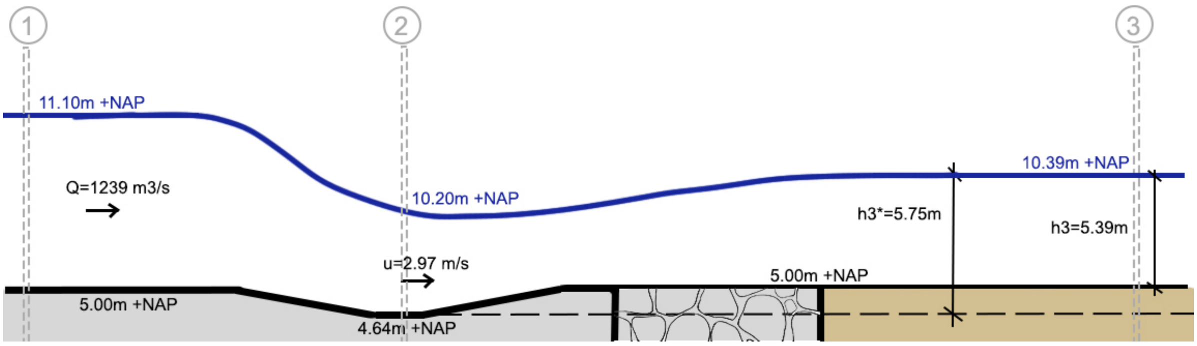

Figure G.6: Schematization energy equation q_{lim}, 1 Stoney closed

$$h_2 + \frac{u_2^2}{2g} = h_3^* + \frac{u_3^2}{2g} + \frac{(u_2 - u_3)^2}{2g} \tag{G.1}$$

$$Q = \mu b_2 h_2 u_2 = b_3 h_3 u_3 \tag{G.2}$$

h_3 = 10.39-5.00 = 5.39m
$h_3^* = h_3 + 0.36 = 5.75$m
$u_3 = \frac{Q}{b_3 h_3} = \frac{1239}{113.05*5.39} = 2.03 m/s$

G.2: $1239 = 75.20 h_2 u_2 \Rightarrow h_2 = \frac{16.48}{u_2}$
G.1: $\frac{16.48}{u_2} + \frac{u_2^2}{2g} = 5.75 + \frac{2.03^2}{2g} + \frac{(u_2-2.03)^2}{2g}$

u_2 = **2.97 m/s**
h_2 = 5.56m
h_2 = 5.56 + 4.64 = 10.20m +NAP

$FR = \frac{u}{\sqrt{gd}} = \frac{2.97}{\sqrt{9.81*5.56}} \Rightarrow = 0.40$ <1, subcritical flow

Maximum discharge

Parameters:
Limit discharge: Q = 1489 m^3/s
Water level upstream = 11.90m +NAP
Water level downstream = 11.10m +NAP
Width river = b_3 = 113.05m
Flow width weir = μb_2 = 0.90*17 + 0.95*63.05 = 75.20m

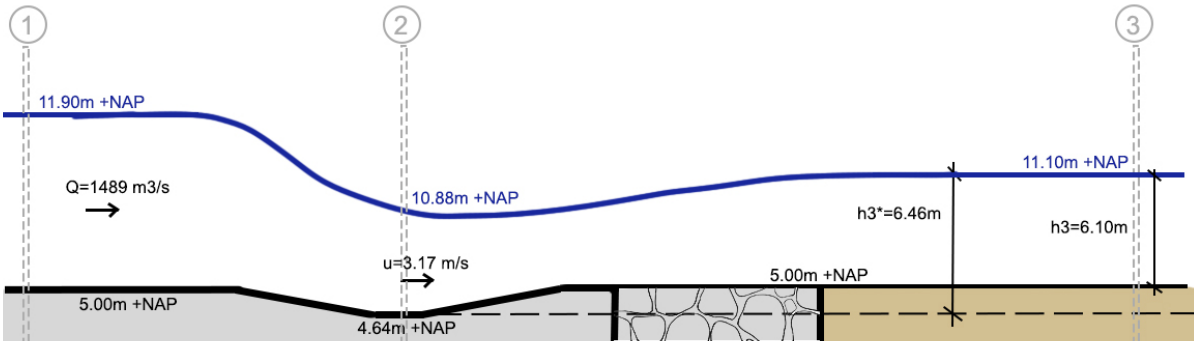

Figure G.7: Schematization energy equation q_{max}, 1 Stoney closed

$$h_2 + \frac{u_2^2}{2g} = h_3^* + \frac{u_3^2}{2g} + \frac{(u_2 - u_3)^2}{2g} \tag{G.3}$$

$$Q = \mu b_2 h_2 u_2 = b_3 h_3 u_3 \tag{G.4}$$

h_3 = 11.10-5.00 = 6.10m
h_3^* = $h_3 + 0.36$ =6.46m
$u_3 = \frac{Q}{b_3 h_3} = \frac{1489}{113.05*6.10} = 2.16 m/s$

G.4: $1489 = 75.20 h_2 u_2 \Rightarrow h_2 = \frac{19.80}{u_2}$
G.3: $\frac{19.80}{u_2} + \frac{u_2^2}{2g} = 6.46 + \frac{2.16^2}{2g} + \frac{(u_2-2.16)^2}{2g}$

u_2 = **3.17 m/s**
h_2 = 6.24m
h_2 = 6.24 + 4.64 = 10.88m +NAP

$FR = \frac{u}{\sqrt{gd}} = \frac{3.17}{\sqrt{9.81*6.24}} \Rightarrow = 0.41$ <1, subcritical flow

G.0.2. 6 beams closed

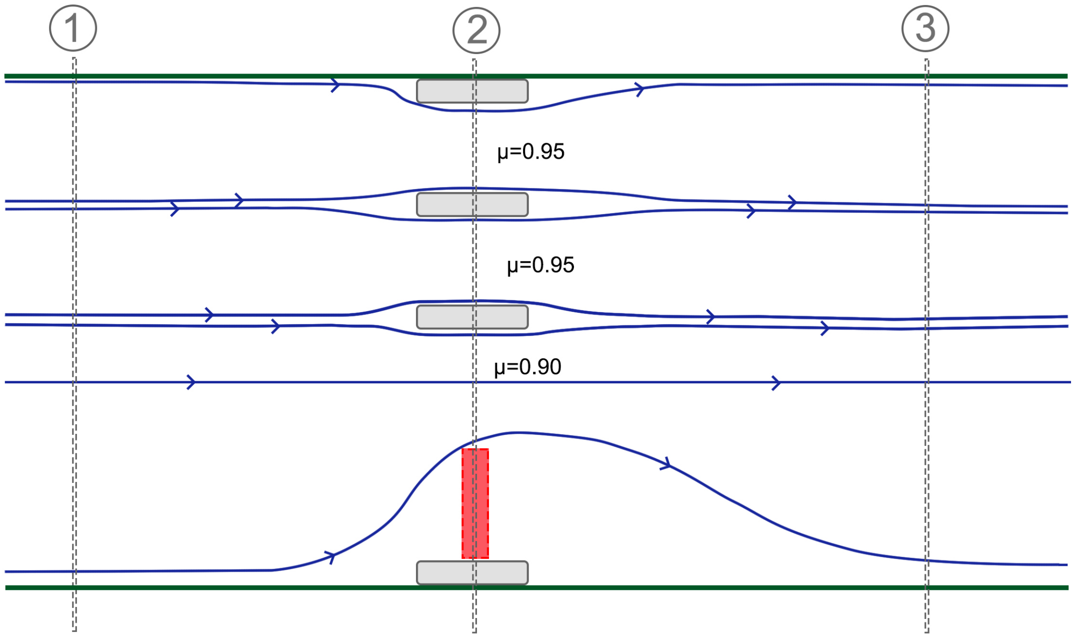

Figure G.8: Top view 6 beams closed

Because the contraction of the flow through the Stoney parts is negligible and only contraction due to the pillars occurs, a μ value of 0.95 is used for the Stoney slides. The contraction through the remaining Poiree opening is more severe and therefore a value of $\mu = 0.90$ is used. The values which are used in the following calculations are retrieved from Appendix E. Therefore the exact discharge can differ slightly from the approximated discharge. Furthermore the distribution of discharge over the Stoney and Poiree part and the corresponding levels of the Stoney slides and Poiree panels is retrieved form Appendix E.
The discharges which are considered are

Table G.2: Considered discharges 6 beams closed

Situation	App. Q [m3/s]	Exact Q [m3/s]	Upstream water level [m +NAP]	Downstream water level [m +NAP]	Delta H [m]	Flow regime
1/2 limit discharge	550	567	11.10	8.75	2.35	Free flow
Limit discharge	1100	1093	11.10	10.15	0.95	Submerged flow
Maximum discharge	1344	1346	11.90	10.73	1.17	submerged flow

1/2 limit discharge

Parameters:
1/2 limit discharge: Q = 567 m^3/s
Water level upstream = 11.10m +NAP
Water level downstream = 8.75m +NAP
Width river = b_3 = 113.05m
$u_3 = 1.34 m/s$

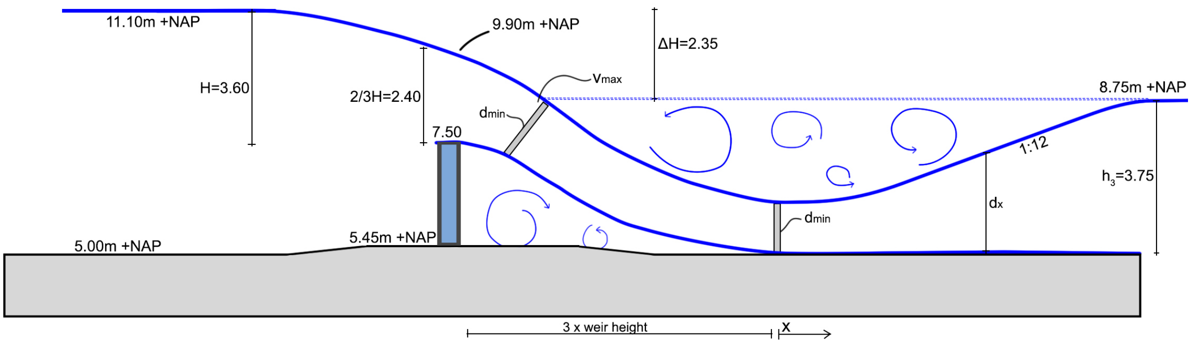

Figure G.9: Flow situation Stoney, 6 beams closed

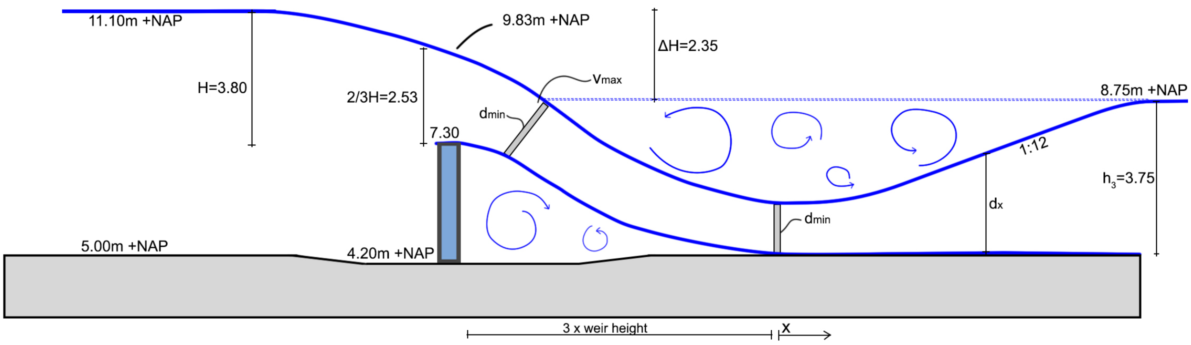

Figure G.10: Flow situation Poiree, 6 beams closed

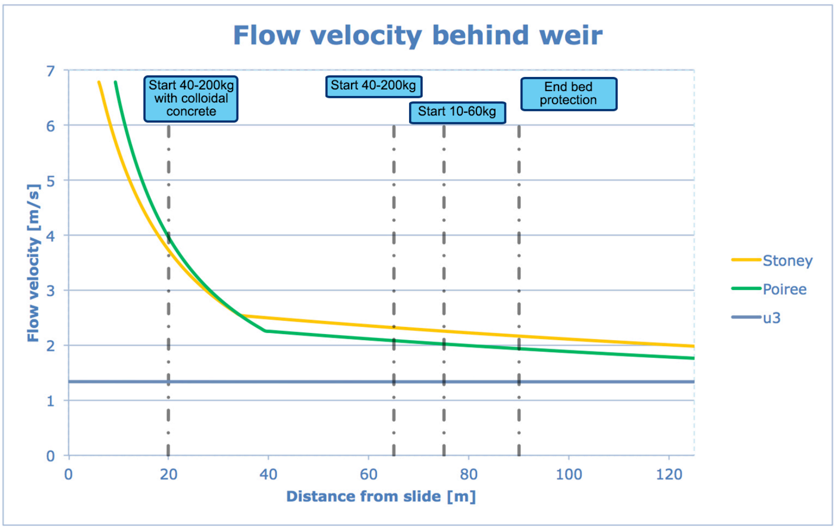

Figure G.11: Flow velocities Stoney and Poiree, 6 beams closed

Flow over Stoney

μ*b	32,30	m
Q	308	m3/s
h_upstream	11,10	m
h_downstrean	8,75	m
Delta_H	2,35	m
u_max	6,79	m/s
d_min	1,40	m
Level Stoney	7,50	m +NAP
Heigth weir	2,05	m
Reattachment	6,15	m
h_3	3,75	m
Max spreiding	2,35	m
x_max	28,15	m
Vert. Spread 1	12	-
Hor. Spread 1:	10	-

Flow over Poiree

μ*b	30,56	m
Q	259	m3/s
h_upstream	11,10	m
h_downstream	8,75	m
Delta_H	2,35	m
u_max	6,79	m/s
d_min	1,25	m
Level Poiree	7,30	m +NAP
Heigth weir	3,10	m
Reattachment	9,30	m
h_3	3,75	m
Max spreiding	2,50	m
x_max	30,02	m

Stoney

x	d_x	u	X_from weir	Vert. spread	Hor. spread	b
0	1,40	6,79	6,15	1,40	0,00	32,30
5	1,82	5,24	11,15	1,82	0,00	32,30
10	2,24	4,26	16,15	2,24	0,00	32,30
15	2,65	3,59	21,15	2,65	0,00	32,30
20	3,07	3,11	26,15	3,07	0,00	32,30
25	3,49	2,73	31,15	3,49	0,00	32,30
30	3,75	2,53	36,15	3,90	0,20	32,50
40	3,75	2,45	46,15	4,74	1,20	33,50
50	3,75	2,38	56,15	5,57	2,20	34,50
60	3,75	2,31	66,15	6,40	3,20	35,50
70	3,75	2,25	76,15	7,24	4,20	36,50
80	3,75	2,19	86,15	8,07	5,20	37,50
90	3,75	2,13	96,15	8,90	6,20	38,50
100	3,75	2,08	106,15	9,74	7,20	39,50
125	3,75	1,96	131,15	11,82	9,70	42,00

Poiree

x	d_x	u	X_from weir	Vert. spread	Hor. spread	b
0	1,25	6,79	9,30	1,25	0,00	30,56
5	1,67	5,09	14,30	1,67	0,00	30,56
10	2,08	4,07	19,30	2,08	0,00	30,56
15	2,50	3,39	24,30	2,50	0,00	30,56
20	2,92	2,91	29,30	2,92	0,00	30,56
25	3,33	2,54	34,30	3,33	0,00	30,56
30	3,75	2,26	39,30	3,75	0,00	30,56
40	3,75	2,19	49,30	4,58	1,00	31,56
50	3,75	2,12	59,30	5,42	2,00	32,56
60	3,75	2,06	69,30	6,25	3,00	33,56
70	3,75	2,00	79,30	7,08	4,00	34,56
80	3,75	1,94	89,30	7,92	5,00	35,56
90	3,75	1,89	99,30	8,75	6,00	36,56
100	3,75	1,84	109,30	9,58	7,00	37,56
125	3,75	1,72	134,30	11,67	9,50	40,06

Figure G.12: Input parameters 6 beams closed

Limit discharge

Parameters:
Limit discharge: Q = 1093 m^3/s
Water level upstream = 11.10m +NAP
Water level downstream = 10.15m +NAP
Width river = b_3 = 113.05m
Flow width weir = μb_2 = 0.95*17 + 0.95*17 + 0.90*(7*4.85) = 62.86m

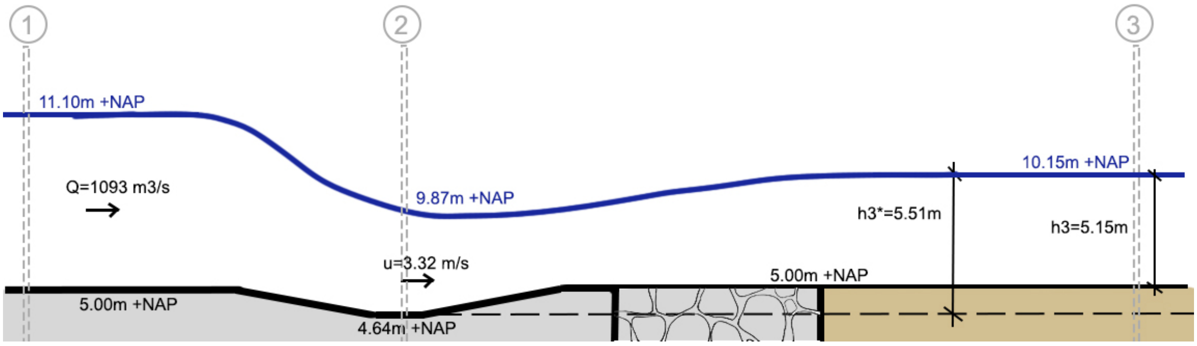

Figure G.13: Schematization energy equation q_{lim}, 6 beams closed

$$h_2 + \frac{u_2^2}{2g} = h_3^* + \frac{u_3^2}{2g} + \frac{(u_2 - u_3)^2}{2g} \tag{G.5}$$

$$Q = \mu b_2 h_2 u_2 = b_3 h_3 u_3 \tag{G.6}$$

h_3 = 10.15-5.00 = 5.15m
$h_3^* = h_3 + 0.36 = 5.51$m
$u_3 = \frac{Q}{b_3 h_3} = \frac{1093}{113.05*5.15} = 1.88 m/s$

G.6: $1093 = 62.86 h_2 u_2 \Rightarrow h_2 = \frac{17.39}{u_2}$
G.5: $\frac{17.39}{u_2} + \frac{u_2^2}{2g} = 5.51 + \frac{1.88^2}{2g} + \frac{(u_2 - 1.88)^2}{2g}$

u_2 = **3.32 m/s**
h_2 = 5.23m
h_2 = 5.23 + 4.64 = 9.87m +NAP

$FR = \frac{u}{\sqrt{gd}} = \frac{3.32}{\sqrt{9.81*5.23}} \Rightarrow = 0.46$ <1, subcritical flow

Maximum discharge

Parameters:
Limit discharge: Q = 1344 m^3/s
Water level upstream = 11.90m +NAP
Water level downstream = 10.73m +NAP
Width river = b_3 = 113.05m
Flow width weir = μb_2 = 0.95*17 + 0.95*17 + 0.90*(7*4.85) = 62.86m

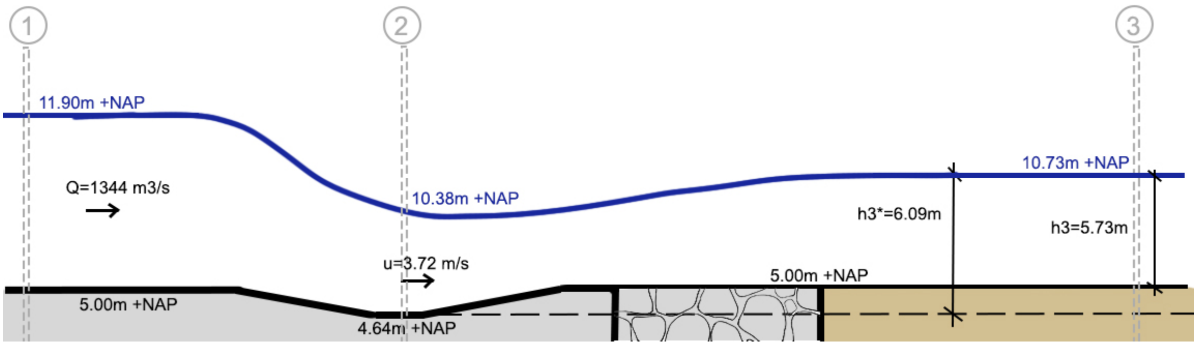

Figure G.14: Schematization energy equation q_{max}, 6 beams closed

$$h_2 + \frac{u_2^2}{2g} = h_3^* + \frac{u_3^2}{2g} + \frac{(u_2 - u_3)^2}{2g} \tag{G.7}$$

$$Q = \mu b_2 h_2 u_2 = b_3 h_3 u_3 \tag{G.8}$$

h_3 = 10.73-5.00 = 5.73m
$h_3^* = h_3 + 0.36 = 6.09$m
$u_3 = \frac{Q}{b_3 h_3} = \frac{1344}{113.05*5.73} = 2.07 m/s$

G.8: $1344 = 62.86 h_2 u_2 \Rightarrow h_2 = \frac{21.38}{u_2}$
G.7: $\frac{21.38}{u_2^2} + \frac{u_2}{2g} = 6.09 + \frac{2.07^2}{2g} + \frac{(u_2 - 2.07)^2}{2g}$

u_2 = **3.72 m/s**
h_2 = 5.74m
h_2 = 5.74 + 4.64 = 10.38m +NAP

$FR = \frac{u}{\sqrt{gd}} = \frac{3.72}{\sqrt{9.81*5.74}} \Rightarrow = 0.50$ <1, subcritical flow

G.0.3. Complete Poiree closed

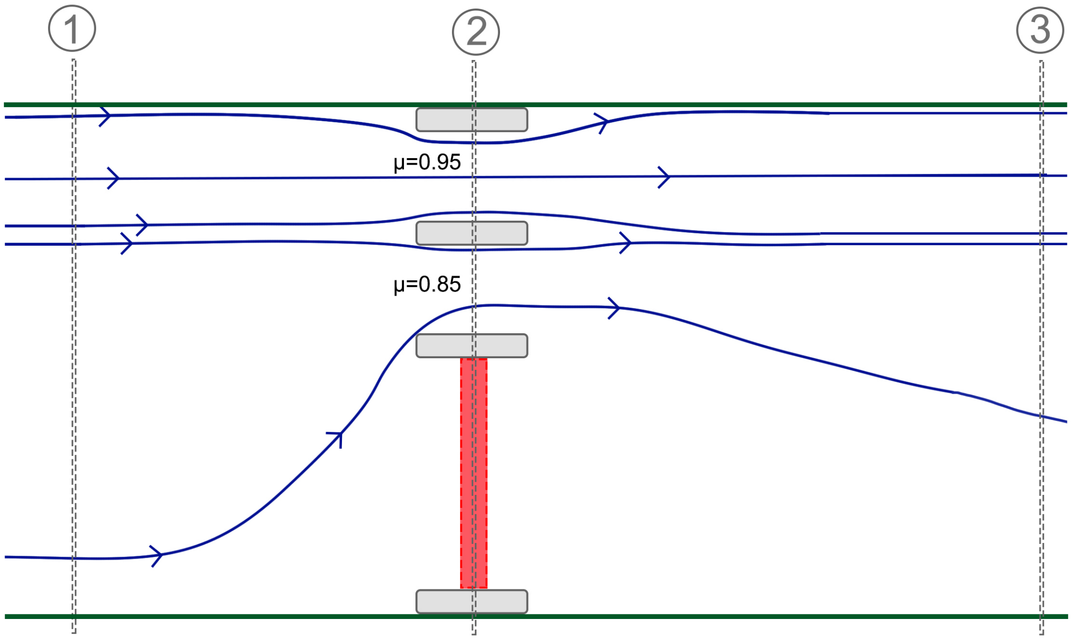

Figure G.15: Top view complete Poiree closed

Because the contraction of the flow through the Northern Stoney part is negligible and only contraction due to the pillars occurs, a μ value of 0.95 is used for the Northern Stoney opening. The middle pillar prevent that the flow through this opening a influenced by the contacted flow. The contraction through the remaining Stoney opening is severe and therefore a value of $\mu = 0.85$ is used. The contraction through this opening is most severe of all calamity situations which are considered. The values which are used in the following calculations are retrieved from Appendix E. Therefore the exact discharge can differ slightly from the approximated discharge. Furthermore the distribution of discharge over the Stoney and Poiree part and the corresponding levels of the Stoney slides and Poiree panels is retrieved form Appendix E.
The discharges which are considered are

Table G.3: Considered discharges complete Poiree closed

Situation	**App. Q [m3/s]**	**Exact Q [m3/s]**	**Upstream water level [m +NAP]**	**Downstream water level [m +NAP]**	**Delta H [m]**	**Flow regime**
1/2 limit discharge	300	581	11.10	8.25	2.85	Free flow
Limit discharge	600	607	11.10	8.90	2.20	Free flow
Maximum discharge	742	742	11.90	9.25	2.65	Free flow

1/2 limit discharge

Parameters:
1/2 limit discharge: Q = 309 m^3/s
Water level upstream = 11.10m +NAP
Water level downstream = 8.25m +NAP
Width river = b_3 = 113.05m
$u_3 = 0.84 m/s$

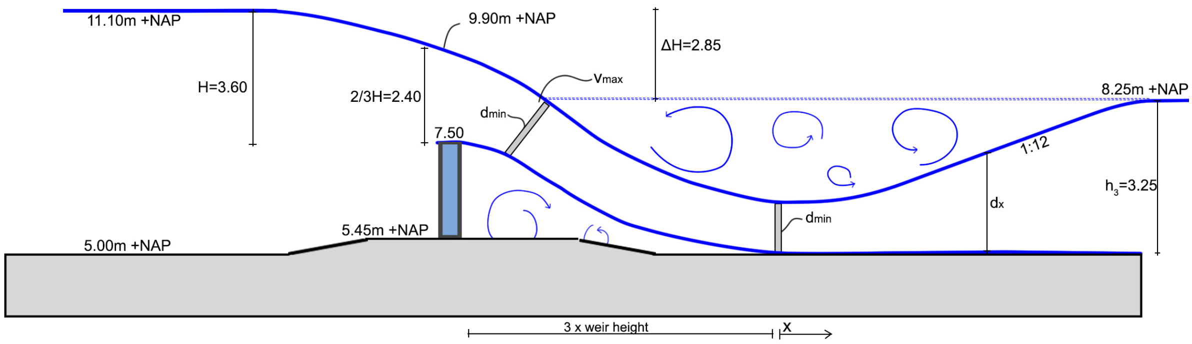

Figure G.16: Flow situation Stoney, complete Poiree closed

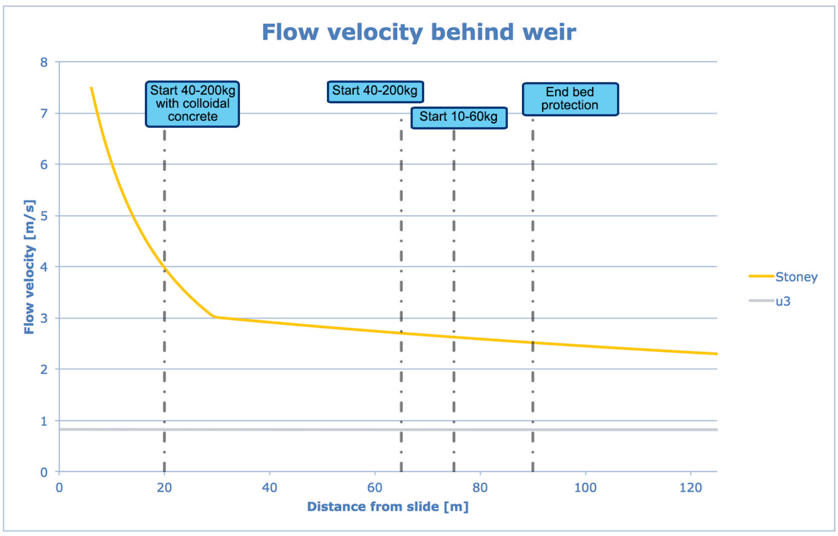

Figure G.17: Flow velocities Stoney and Poiree, complete Poiree closed

The Froude number according to this situation is equal to $FR = \frac{7.48}{\sqrt{9.81*1.31}} = 2.08$. Therefore the flow is supercritical. Because the jet is small with respect to the downstream water level and the discharge is relatively low, it is assumed that the hydraulic jump will occurs against the weir.

Flow over Stoney

μ*b	30,6	m
Q	300	m3/s
h_upstream	11,10	m
h_downstream	8,25	m
Delta_H	2,85	m
u_max	7,48	m/s
d_min	1,31	m
Level Stoney	7,50	m +NAP
Heigth weir	2,05	m
Reattachment	6,15	m
h_3	3,25	m
Max spreiding	1,94	m
x_max	23,27	m
Vert. Spread 1:	12	-
Hor. Spread 1:	10	-

Stoney

x	d_x	u	X_from weir	Vert. spre	Hor. sprea	b
0	1,31	7,48	6,15	1,31	0,00	30,60
5	1,73	5,67	11,15	1,73	0,00	30,60
10	2,14	4,57	16,15	2,14	0,00	30,60
15	2,56	3,83	21,15	2,56	0,00	30,60
20	2,98	3,29	26,15	2,98	0,00	30,60
25	3,25	3,00	31,15	3,39	0,20	30,80
30	3,25	2,95	36,15	3,81	0,70	31,30
40	3,25	2,86	46,15	4,64	1,70	32,30
50	3,25	2,77	56,15	5,48	2,70	33,30
60	3,25	2,69	66,15	6,31	3,70	34,30
70	3,25	2,61	76,15	7,14	4,70	35,30
80	3,25	2,54	86,15	7,98	5,70	36,30
90	3,25	2,47	96,15	8,81	6,70	37,30
100	3,25	2,41	106,15	9,64	7,70	38,30
125	3,25	2,26	131,15	11,73	10,20	40,80

Figure G.18: Input parameters complete Poiree closed

Limit discharge

Parameters:
Limit discharge: Q = 607 m^3/s
Water level upstream = 11.10m +NAP
Water level downstream = 8.90m +NAP
Width river = b_3 = 113.05m
Flow width weir = μb_2 = 0.95*17 + 0.85*17 = 30.60m

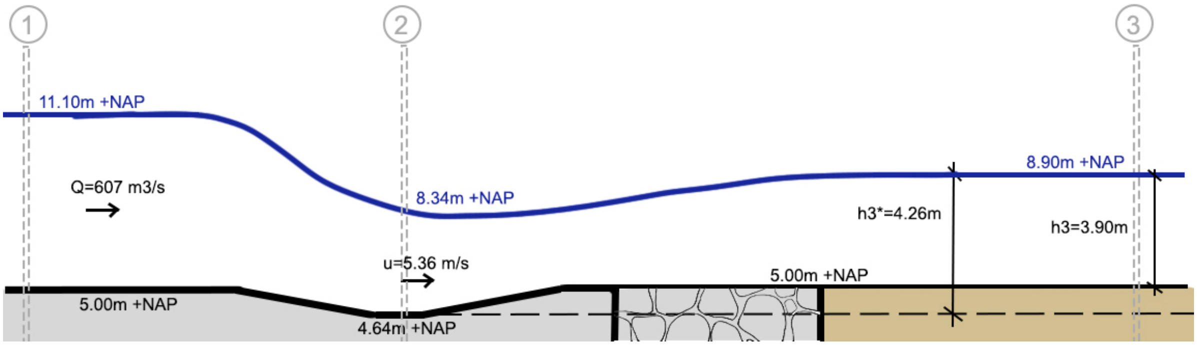

Figure G.19: Schematization energy equation q_{lim}, complete Poiree closed

$$h_2 + \frac{u_2^2}{2g} = h_3^* + \frac{u_3^2}{2g} + \frac{(u_2 - u_3)^2}{2g} \tag{G.9}$$

$$Q = \mu b_2 h_2 u_2 = b_3 h_3 u_3 \tag{G.10}$$

h_3 = 8.90-5.00 = 3.90m
$h_3^* = h_3 + 0.36 = 4.26$m
$u_3 = \frac{Q}{b_3 h_3} = \frac{607}{113.05 * 3.90} = 1.38 m/s$

G.10: $607 = 30.60 h_2 u_2 \Rightarrow h_2 = \frac{19.84}{u_2}$
G.9: $\frac{19.84}{u_2} + \frac{u_2^2}{2g} = 4.26 + \frac{1.38^2}{2g} + \frac{(u_2 - 1.38)^2}{2g}$

u_2 = **5.36 m/s**
h_2 = 3.70m
h_2 = 3.70 + 4.64 = 8.34m +NAP

$FR = \frac{u}{\sqrt{gd}} = \frac{5.36}{\sqrt{9.81 * 3.70}} \Rightarrow = 0.89$ <1, subcritical flow

Maximum discharge

Parameters:
Limit discharge: Q = 742 m^3/s
Water level upstream = 11.90m +NAP
Water level downstream = 9.25m +NAP
Width river = b_3 = 113.05m
Flow width weir = μb_2 = 0.95*17 + 0.85*17 = 30.60m

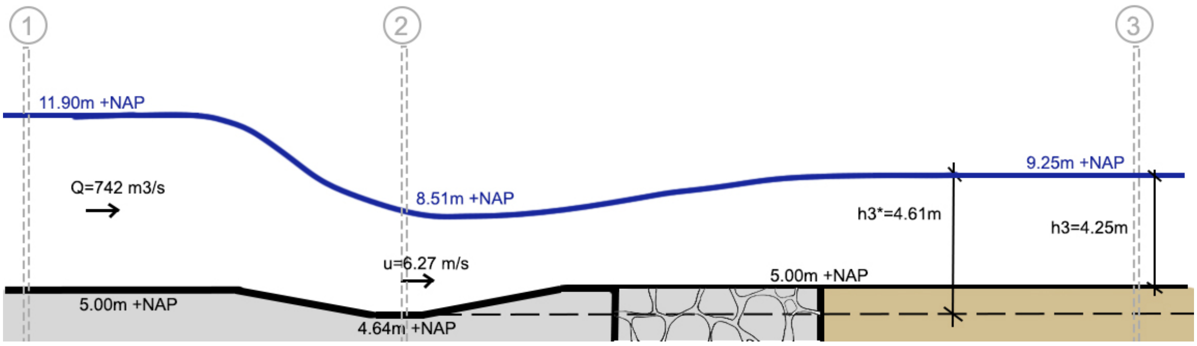

Figure G.20: Schematization energy equation q_{max}, complete Poiree closed

$$h_2 + \frac{u_2^2}{2g} = h_3^* + \frac{u_3^2}{2g} + \frac{(u_2 - u_3)^2}{2g} \tag{G.11}$$

$$Q = \mu b_2 h_2 u_2 = b_3 h_3 u_3 \tag{G.12}$$

h_3 = 9.25-5.00 = 4.25
$h_3^* = h_3 + 0.36 = 4.61$m
$u_3 = \frac{Q}{b_3 h_3} = \frac{742}{113.05*4.25} = 1.54 m/s$

G.12: $742 = 30.60 h_2 u_2 \Rightarrow h_2 = \frac{24.25}{u_2}$
G.11: $\frac{24.25}{u_2} + \frac{u_2^2}{2g} = 4.61 + \frac{1.54^2}{2g} + \frac{(u_2-1.54)^2}{2g}$

u_2 = **6.27 m/s**
h_2 = 3.87m
h_2 = 3.87 + 4.64 = 8.51m +NAP

$FR = \frac{u}{\sqrt{gd}} = \frac{6.27}{\sqrt{9.81*3.87}} \Rightarrow = 1.02$ >1, supercritical flow

H

Calculation flow velocities Grave weir

H.0.1. Flow velocities Rock nets

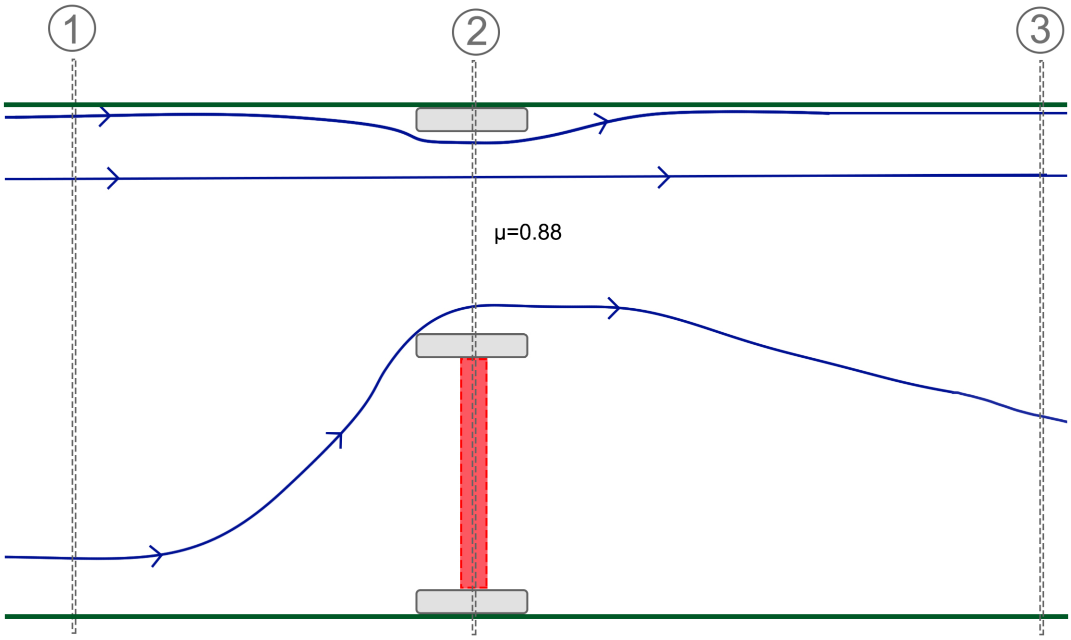

Figure H.1: Top view Grave Northern opening closed

The flow through the remaing opening of the Grave weir is shown in the figure above. The contraction coefficient $\mu = 0.88$ based in Figure 4.8. On the next pages the calculations for a discharge of 270 m^3/s and 620 m^3/s are shown. The weir configurations are based on de Loor and Weiler (2017).

Discharge 270 m^3/s

Parameters:
Discharge: $Q = 270\ m^3/s$
Water level upstream = 7.85m +NAP
Water level downstream = 5.05m +NAP

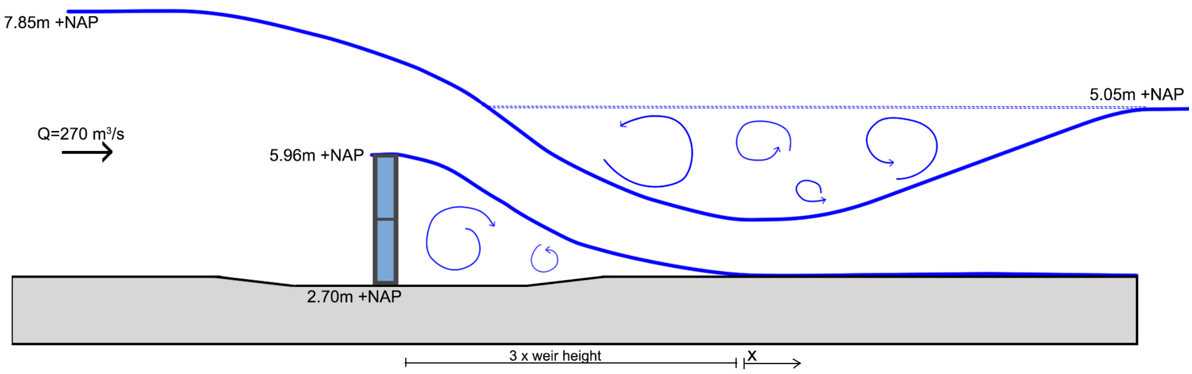

Figure H.2: Flow situation Grave middle and lowest row panels present

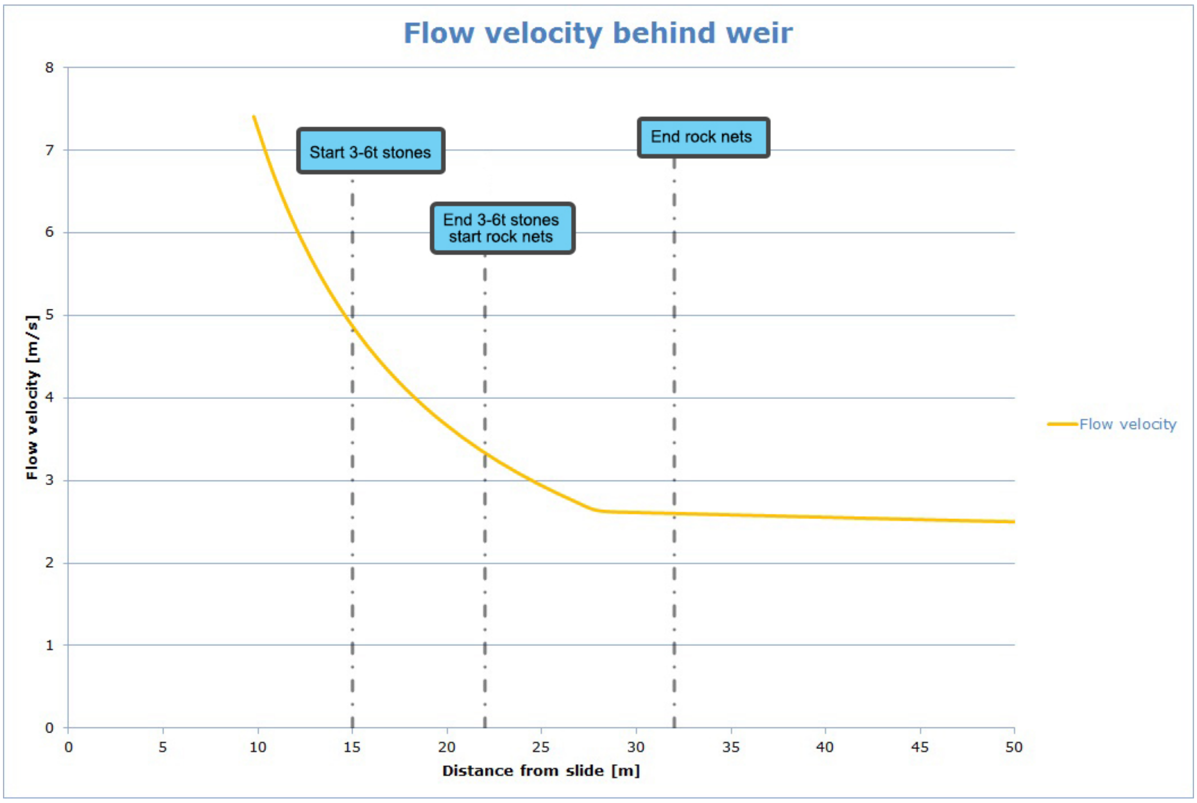

Figure H.3: Flow velocities Grave middle and lowest row panels present

Situation:	Lowest and middle row present	
Flow over Stoney		
μ	0,88	-
μb	43,74	m
Q	270	m3/s
h_upstream	7,85	m
h_downstream	5,05	m
Delta_H	2,80	m
u_max	7,41	m/s
d_min	0,83	m
Heigth weir	3,26	m
Reattachment	9,78	m
h_3	2,35	m
Max spreiding	1,52	m
x_max	18,21	m
Vert. Spread 1:	12	-
Hor. Spread 1:	10	-

x	d_x	u	X_from weir	Vert. spread	-lor. Spread	b
0	0,81	7,41	9,78	0,81	0,00	44,73
5	1,23	4,90	14,78	1,23	0,00	44,73
10	1,65	3,66	19,78	1,65	0,00	44,73
15	2,06	2,92	24,78	2,06	0,00	44,73
20	2,35	2,56	29,78	2,48	0,10	44,93
25	2,35	2,53	34,78	2,90	0,10	45,43
30	2,35	2,50	39,78	3,31	0,10	45,93
35	2,35	2,47	44,78	3,73	0,10	46,43
40	2,35	2,45	49,78	4,15	0,10	46,93

Figure H.4: Input parameters Grave middle and lowest row panels present

Discharge 620 m^3/s

Parameters:
Discharge: $Q = 270\ m^3/s$
Water level upstream = 7.85m +NAP
Water level downstream = 5.95m +NAP

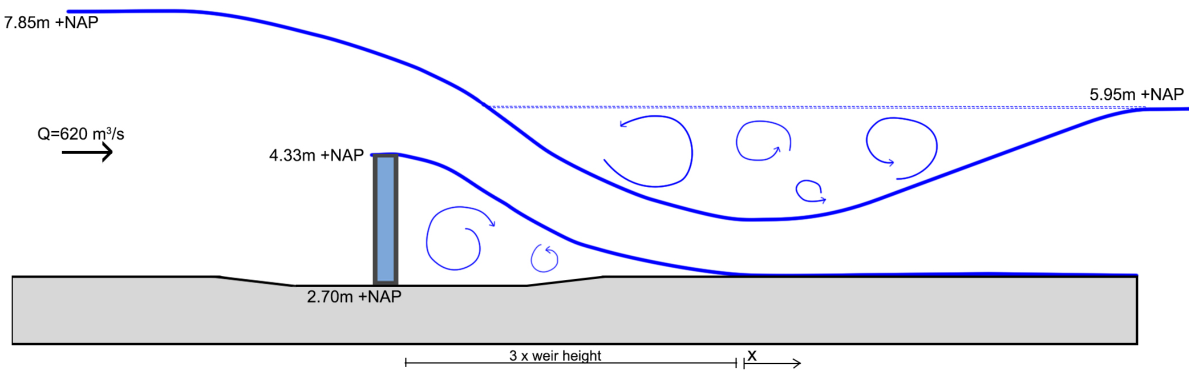

Figure H.5: Flow situation Grave lowest row panels present

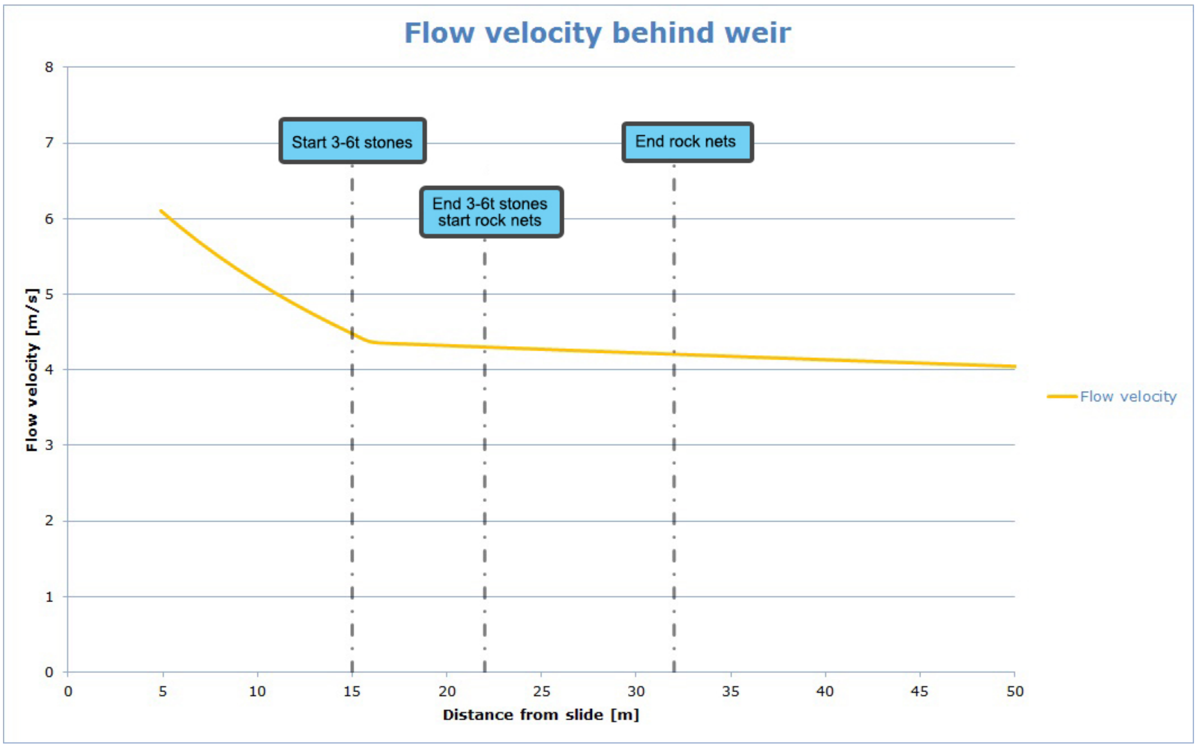

Figure H.6: Flow velocities Grave lowest row panels present

Situation:	**Lowest row present**	
Flow over Stoney		
μ	0,88	-
μb	43,74	m
Q	620	m3/s
h_upstream	7,85	m
h_downstream	5,95	m
Delta_H	1,90	m
u_max	6,11	m/s
d_min	2,32	m
Heigth weir	1,63	m
Reattachment	4,89	m
h_3	3,25	m
Max spreiding	0,93	m
x_max	11,14	m
Vert. Spread 1:	12	-
Hor. Spread 1:	10	-

x	**d_x**	**u**	**X_from weir**	**Vert. spread**	**Hor. Spread**	**b**
0	2,40	6,11	4,80	2,40	0,00	42,25
5	2,82	5,20	9,80	2,82	0,00	42,25
10	3,24	4,53	14,80	3,24	0,00	42,25
15	3,25	4,46	19,80	3,65	0,10	42,75
20	3,25	4,41	24,80	4,07	0,10	43,25
25	3,25	4,36	29,80	4,49	0,10	43,75
30	3,25	4,31	34,80	4,90	0,10	44,25
35	3,25	4,26	39,80	5,32	0,10	44,75
40	3,25	4,22	44,80	5,74	0,10	45,25

Figure H.7: Input parameters Grave lowest row panels present

Velocity profiles CFD

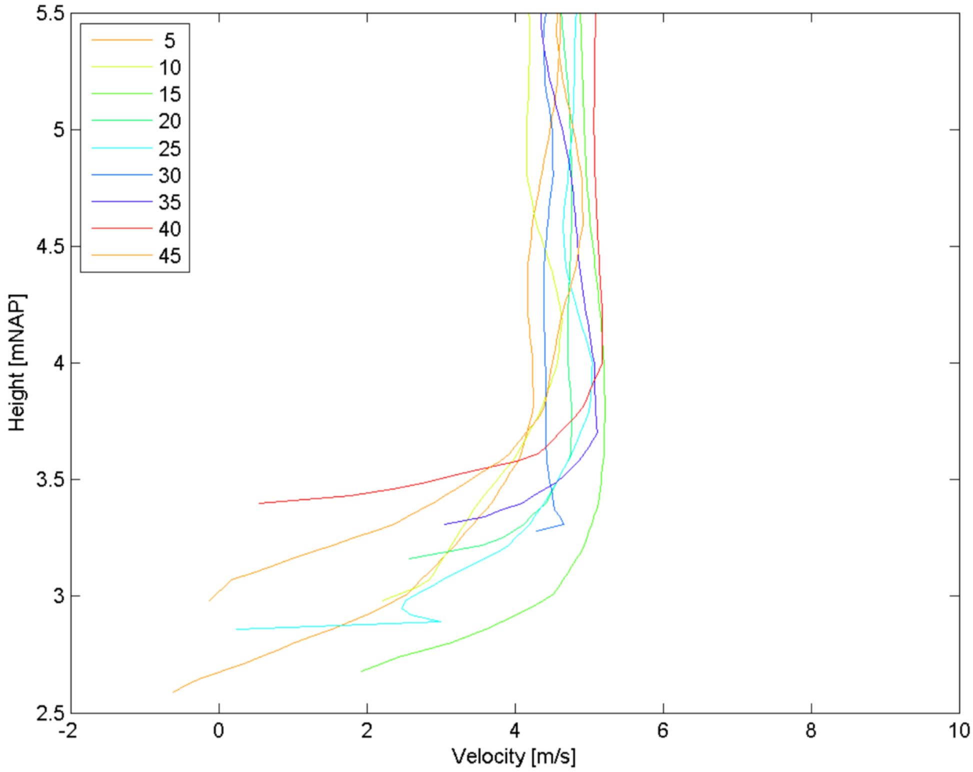

Figure I.1: Vertical velocity profile row A

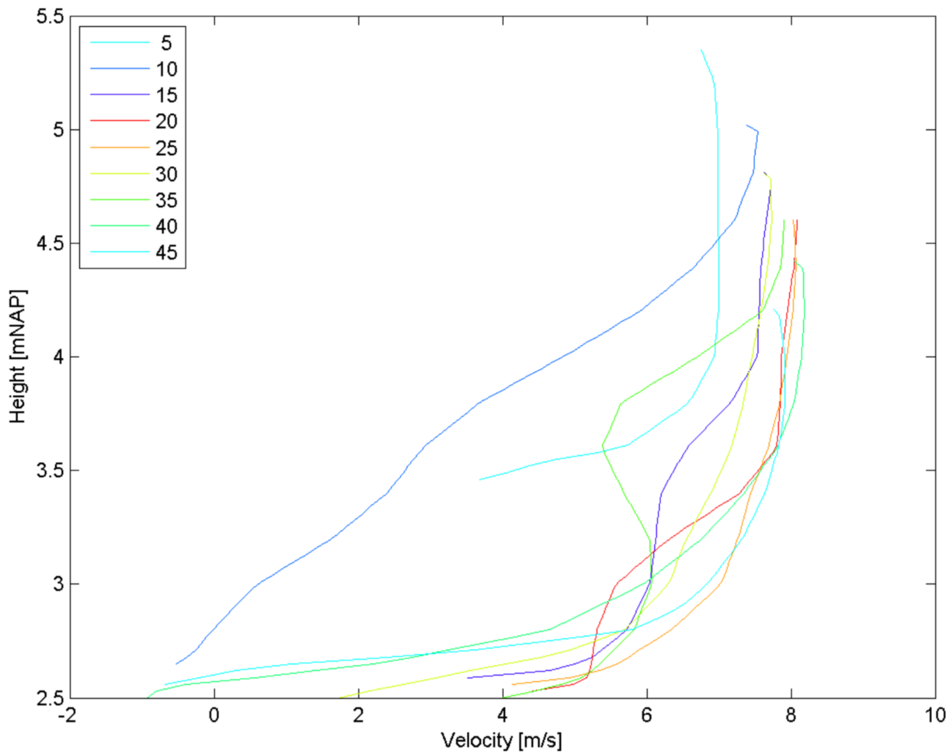

Figure I.2: Vertical velocity profile row B

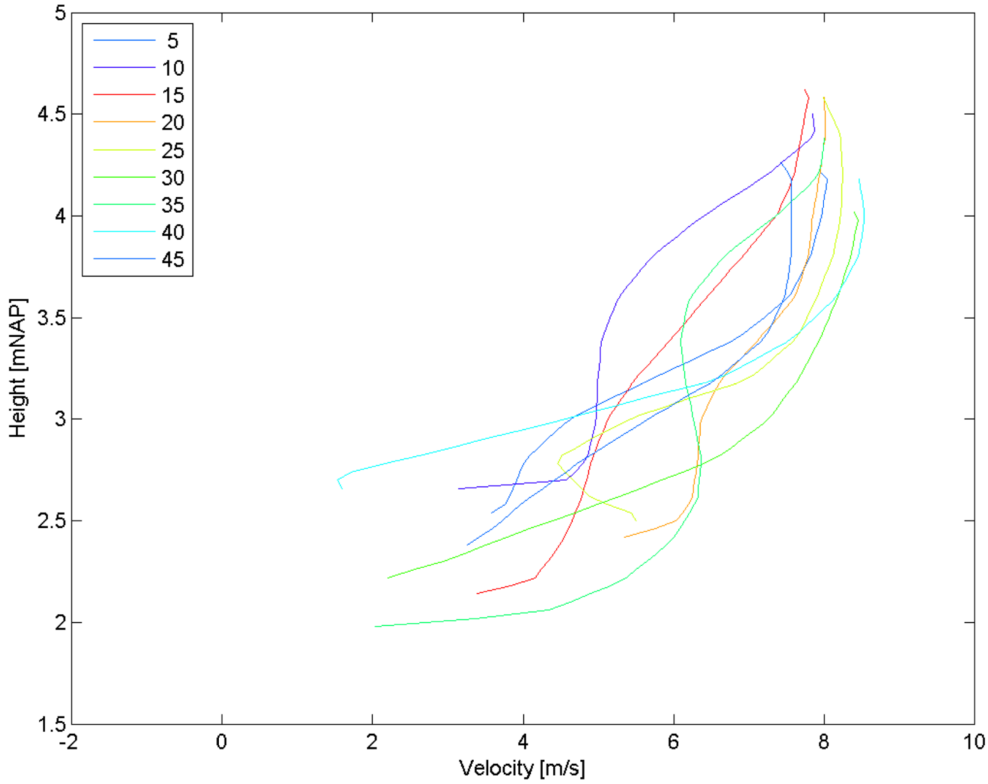

Figure I.3: Vertical velocity profile row C

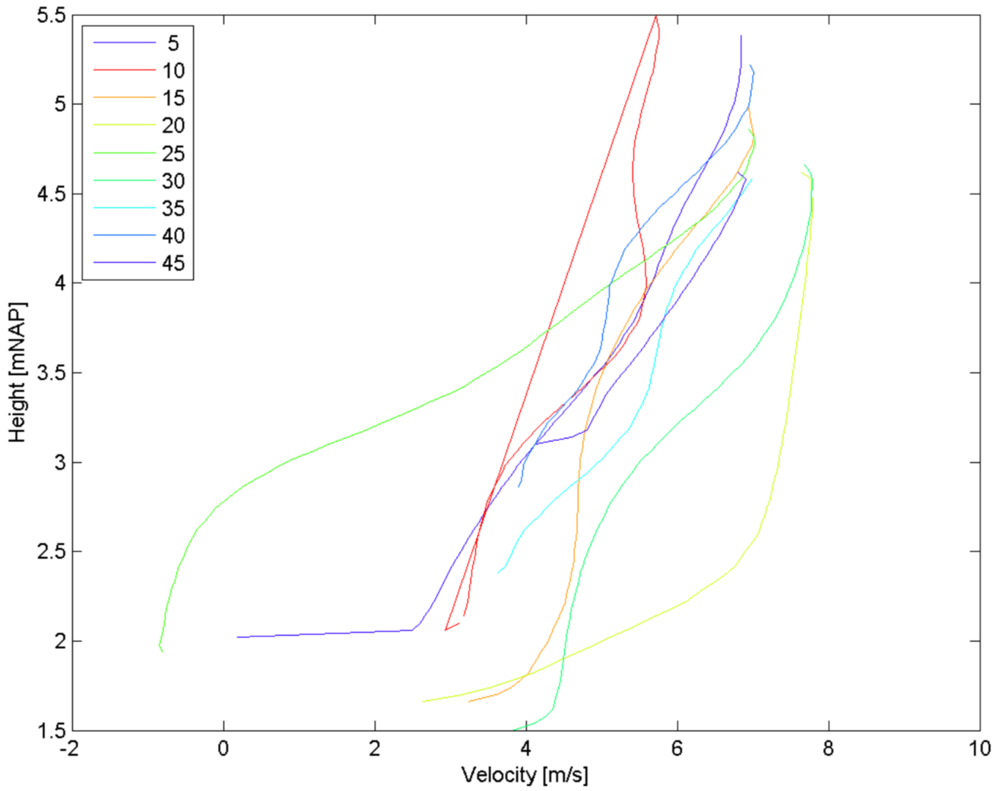

Figure I.4: Vertical velocity profile row D

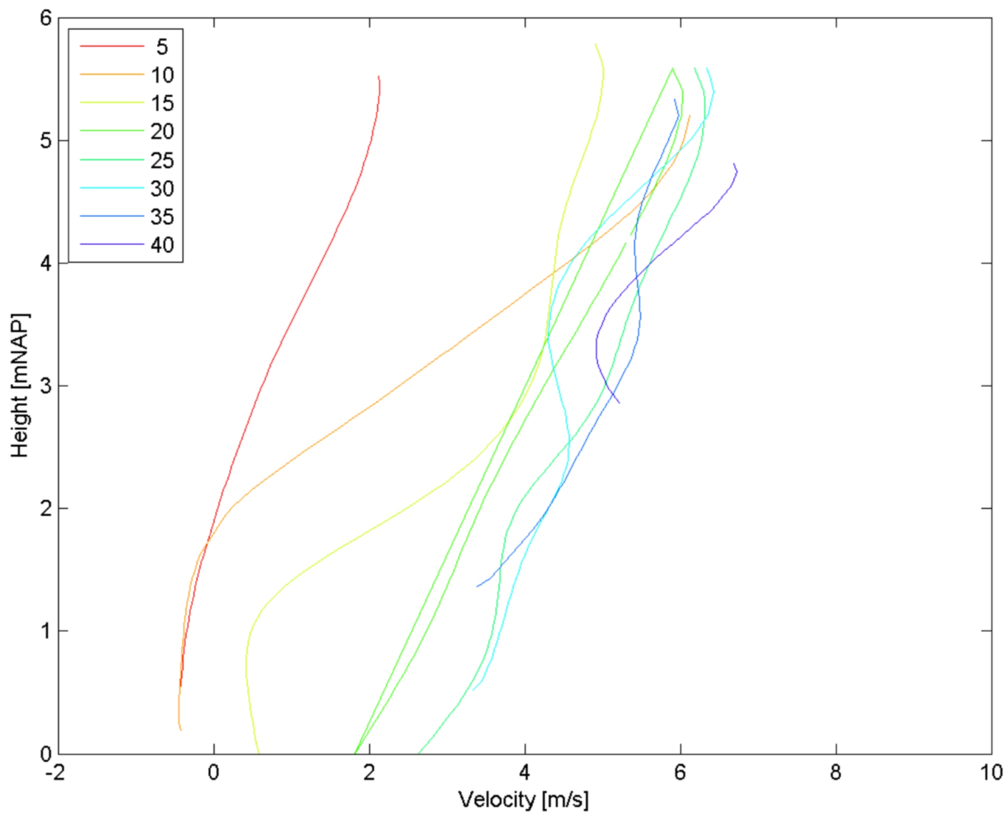

Figure I.5: Vertical velocity profile row E