Deltares

Rapid assessment study on the Geul river basin:

Screening of flood reduction measures

With contributions from:

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This document provides a summary of the rapid assessment study on the Geul river basin. In this study, an international team of researchers assessed the hydrological response of the basin to heavy rainfall during the summer 2021 event, the associated floodings and their consequences in order to find measures that are potentially suitable for the prevention of future floods impacts.

We focused on the following main research question:

> *What can we learn from the July 2021 floods in the Geul river catchments about its hydrological response to heavy rainfall, the associated floodings and their consequences in order to find measures that are potentially suitable to prevent impacts of future floods?*

The answers to this main question will be supported by answering the following sub-questions:

> *a) How do the physical characteristics of the Geul river basin determine its response to heavy rainfall?*
>
> *b) How were the flooded areas at the July 2021 flood event distributed and what where the impacts of the flooding?*
>
> *c) What types of measures are potentially suitable and effective at short and long term to mitigate the (most severe) consequences?*

We made extensively use of three recently published reports from Klein (2022), Natuurmonumenten en Bureah Stroming (2022) and Deltares (2022) about this flood event in the Geul basin. We extended this knowledge base with an assessment based on a set of computer-based flood simulations, covering the entire transboundary basin of the Geul river. Further, insights and experiences, such as those from experimental basins, from different universities in neighboring countries are included, as well.

In this rapid assessment we have a strong focus on describing basin characteristics where we concentrate on the differences and similarities between the main Belgian and Dutch basin parts. We assess their contributions to the flood peak discharges observed in Valkenburg and target the evaluation of the flood hazard reduction only on the city of Valkenburg. During the peak flood in July 2021 also other settlements more upstream and downstream of Valkenburg have been affected. It is not certain that measures effective or ineffective for reducing peak flows for Valkenburg are likewise effective or ineffective for other settlements in the basin. These effects will be further investigated in an ongoing broad system-wide analysis from Deltares.

This document starts with conclusions and recommendations, followed by more supporting information and analyses. A separate appendix document provides background material contributed by the different institutes for this rapid assessment study. This should be considered as technical background information with overviews on specific analyses and modelling activities. In several sections within this summary we refer to this appendix document.

What do we learn from the analysis?

The size of any single measure or combination of measures, no matter whether these are nature-, engineering- or spatial planning-based, that could effectively and fully prevent the impact of ***the summer 2021 event*** will be very extensive. And thus, expensive and/or complicated to implement.

Main conclusions

Physical basin characteristics explaining the hydrological response to heavy rainfall

1. Differences in the contribution from sub-basins to the peak discharge at Valkenburg during the flooding event of July 2021 can be attributed to both the rainfall distribution and differences in sub-basin response[1]. Both factors play a role in the observed, relatively large contribution to the flood from the Belgian upstream part of the basin.
2. The differences in geology have played a role in the response of the sub-basins. A comparison between the total rainfall and runoff volumes during the event shows that in the area where rock formations with small soil storage capacities prevail, the response is more flashy (more rapidly larger volumes of rainfall come to discharge) than in areas consisting of formations with larger soil storage capacities.
3. Areas with steeper slopes typically produce more surface runoff as less water can infiltrate into the soil. In our assessment we did however not find a clear signal that differences in slopes were as important in the contribution to the flood volume, than rainfall distribution, land use and geology.
4. Differences in land use played a role in the contribution from sub-basins, but land use differences between larger sub-basins are relatively small. For larger areas the main difference is between arable land in Belgium (8%) and The Netherlands (28%). We assess that these differences had a smaller effect on observed discharge differences than the rainfall distribution and the differences in geology.

Flood-affected areas with adverse flood consequences

5. The largest flood damage and affected households are measured in the Netherlands. In Belgium only incidental media reports on floodings and damages within the Geul basin were found. The difference in damage can be attributed to the smaller flood-affected area in Belgium and the fewer buildings located in the flood prone area, than in the Netherlands.

Potentially suitable and effective measures to mitigate the (most severe) consequences

6. A broad package of measures is needed to reduce flood hazards and risk in the Geul river basin. In this study, we focused on large-scale land use change and river system interventions. Considering this flood event, land use changes in the basin and in river valleys, as well as urban rainwater diversion might have reduced peak flows for Valkenburg. However, the scale needed for these single measures to be effective is large. Other considered measures, such as increasing runoff water storage at the foothills in Belgium up to a same volume as currently implemented in The Netherlands (around 7 Million m^3) would reduce the peak discharge by in the order of up to 8%. Re-meandering of the main river only has limited effect. In theory, more water storage in the valley can be achieved by forestation of the floodplains and/or creating a large reservoir in the river valley at for example Schin op Geul in the Netherlands, and thus locally allowing greater inundation depth. The reducing effect on peak discharges downstream is however strongly

[1] expressed as basin runoff coefficient

dependent on the correct operation of such a reservoir. Besides that, there is already a large storage volume in the river valley, so increasing that volume is a relatively small increment, with subsequent relatively small effect (estimated up to in the order of 16% discharge reduction at Valkenburg).

7. Measures implemented in the Geul floodplain in the Netherlands seem most effective to reduce the flood peak discharge at Valkenburg in this extreme rainfall event. It should be noted that these measures locally will lead to higher water levels.
8. A preliminary quantitative assessment for a sequence of suitable and selected number of measures is provided below. This figure illustrates the potential to reduce or prevent flood damage in Valkenburg by reducing the flood peak (observed in 2021) from 130 m^3/s to a maximum of about 60 m^3/s. In our assessment we assumed that a fraction of 10 to 20% of the maximum possible land use transformation may be plausible to be implemented. We also assumed that, the modelled effects of measures can be simply added together. Our assessment shows that combining all measures would potentially lead to a reduction of the discharge at Valkenburg in the order of up to 30%. None of the measures are suitable for the short-term, as the implementation period for these measures is typically very long to be in full effect (est. > 10 years up to more 30 years for nature-based and spatial planning etc.).
9. On the other hand, large-scale application of these 'source control' measures have strong co-benefits for drought control, nature management and will probably be more effective in less extreme flood conditions.

The potential cumulative peak discharge reduction at Valkenburg is summarized in the figure 8 below. The measures are ordered from measures to be taken upstream to downstream. The values should be considered indicative and based on the models and knowledge of the river basin available at this moment. Sensitivity analyses on model input parameters, preferably based on empirical evidence, could provide an uncertainty range and should be part of further research.

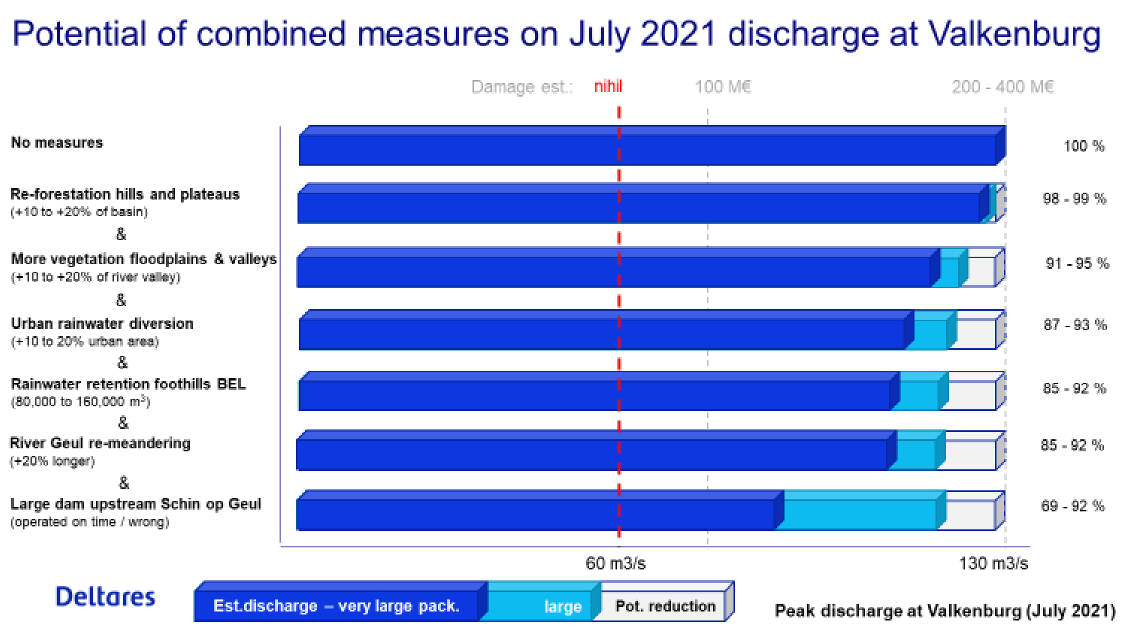

Figure C1. Potential to a cumulative decrease on peak discharge at Valkenburg and associated flood damages; dark blue = extreme large package of measures; light blue = large package of measures

Recommendations

1. On the short term, it will be difficult, maybe even impossible, to implement measures that reduce the flow peak in such way that impact would be prevented or enable a save passing of the flow peak (observed in 2021) through Valkenburg. **In order to be better prepared and/or improve the response or recovery in case this would happen again, we recommend to also explore measures that seem easier, faster to implement.** These are (a.o.) local flood protection, and flood proofing, improving early warning, recovery (build back better) and strengthening of localized awareness. The latter for example by placing information signs throughout the basin on the flood hazards of the Geul, provide information to citizens on how to protect their properties and investigate the potential and implementation of dry- or wet-proofing of buildings and temporary flood defences in the flood prone areas.

2. This assessment showed that considered nature-based solutions potentially can reduce flood peaks, but may be insufficient to fully prevent damage from this 2021 event. As a matter of fact, the Geul river basin stored a lot of the rainwater in this event. Preventing damage from other, more common flood events may very well be achieved through nature-based measures. **Since this type of measures have ample co-benefits, we recommend to facilitate and support nature-based projects - yet with proper monitoring so that we increase our understanding of these measures - that will increase the soil storage and infiltration capacity, as well as slow down water flow in the floodplains, throughout the international basin.**

3. Considering the large dimensions of measures needed to prevent damage of such extreme events and the associated costs and efforts required to implement these we advocate for initiatives to increase empirical knowledge about basin response. Studies solely based on numerical models cannot provide this. Therefore, **we recommend to support the setup of an international collaboration on a living-lab with high quality monitoring on this river basin, in order to assemble empirical evidence on (geo-)hydrological characteristics for a longer period and to be used for better flood early warning.** Further, to better monitor and understand the impact of (nature-based) solutions in normal and extreme conditions in larger basins. The Geul basin is a good candidate for such a large scale experimental basin with optimal monitoring since it crosses three countries and has already several natural storage projects are underway.

4. This assessment did not further investigate potential effectiveness of more local interventions and water management infrastructure upgrades (e.g. bridge design at bottlenecks in Schin op Geul and Valkenburg, climate-robust storage basins, bypass or tunnel in Valkenburg) in the Netherlands. **We recommend to study to implement such interventions as they may be locally very effective and relatively (more) easy to implement in the coming years.** That such "end-of-pipe" solutions are potentially less sustainable and do not provide the co-benefits as nature based solutions do, is a factor to be taken into account as well.

5. This assessment focused on reducing the flood damage at Valkenburg. The consequences, adverse or beneficial of these measures upstream were not part of the analysis. Some measures in the valleys, may lead locally to considerable higher flood levels and thus to an increase of the flood hazard in the upstream area. **We recommend the governments to develop and implement a transboundary Geul basin management plan, based on (risk-based) system-wide insights and in close consultation with the involved stakeholders. In its evaluation, its effectiveness for other flood events, drought, climate adaptation and transformations planned in the agricultural area should be included.**

Synthesis: Rapid assessment study on the Geul basin – floods and adverse consequences

This rapid assessment study aimed at answering the following questions:

- How do the physical characteristics of the Geul river basin determine its response to heavy rainfall?
- How were the flooded areas at the July 2021 flood event distributed and what were the impacts of the flooding?
- What types of measures are potentially suitable and effective at short and long-term to mitigate the (most severe) consequences?

Our assessment started to investigate the hydrological response of the basin to the rainfall event of July 2021. We investigated the flooded areas and the impact of the flooding, where we focused on the differences between the basin area located Belgium and The Netherlands. Using this information we made an assessment for the maximum potential of basin-wide measures to prevent the flood damage in the city of Valkenburg, as one of the most severe affected areas during the floods.

In figure 1, below, an overview map of the Geul river basin is provided, including discharge stations and identified sub-basins. Valkenburg is located in the middle of the most downstream sub-basin identified. In the following sections we try to provide information supporting our conclusions.

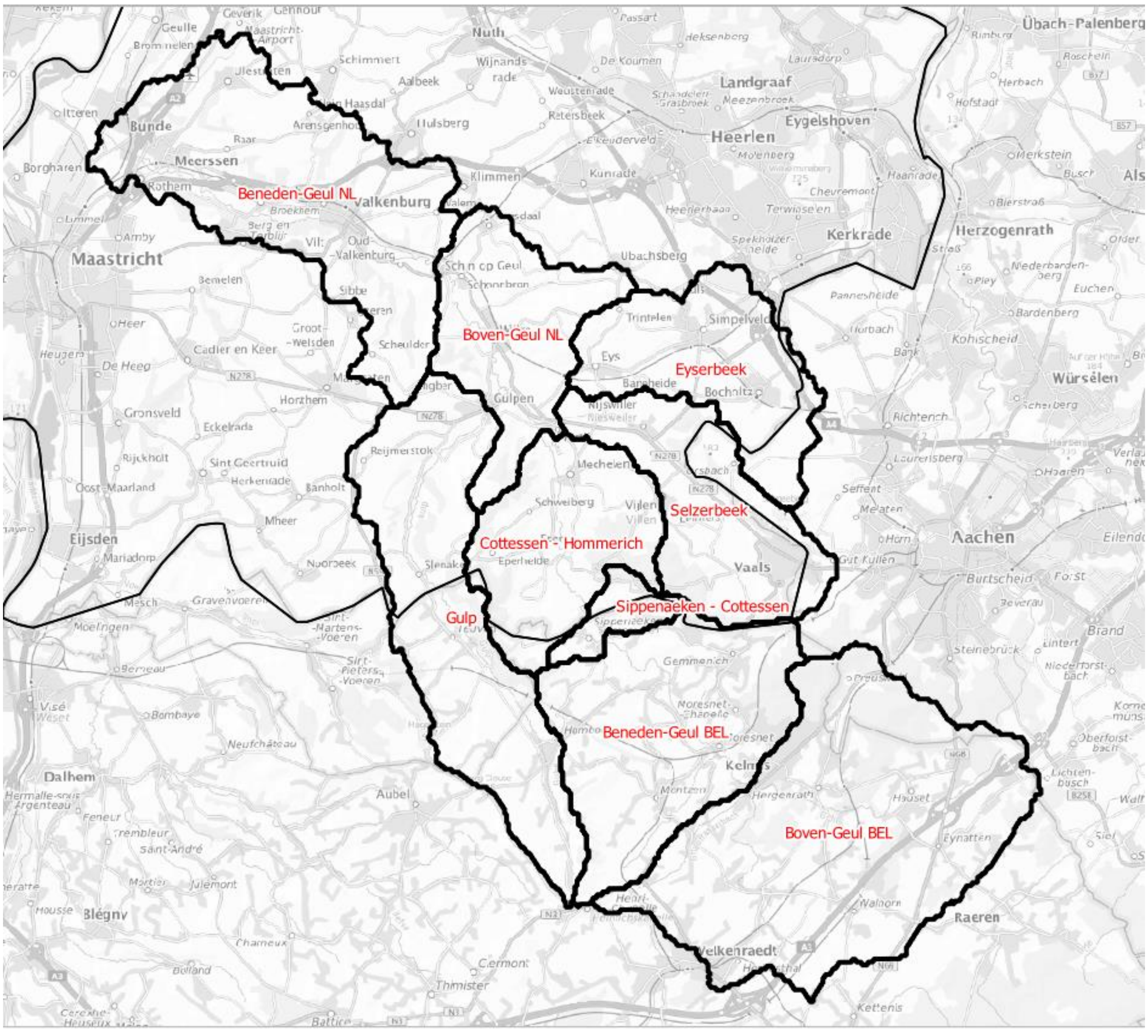

Figure 1: Overview map of Geul river basin with sub-basins

How do the physical characteristics of the Geul river basin determine its response to heavy rainfall?

(1) Differences in the contribution from sub-basins to the peak discharge at Valkenburg during the flooding event of July 2021 can be attributed to both the rainfall distribution and differences in sub-basin response[2]. Both factors play a role in the observed, relatively large contribution to the flood from the Belgian upstream part of the basin.

Different areas contributed disproportionally to the total runoff in July 2021 (see table 1). During the event in July 2021, between 13-07-2021 and 21-07-2021, the Geul basin upstream of gauging station Cottessen and the Gulp basin upstream of Slenaken, contributed ~60% of the cumulative discharge at Schin op Geul, while the basin size upstream these stations is around half of the total basin area. The tributaries Selzerbeek, Eyserbeek and Gulp together contributed only 23% to the discharge, while their area covers more than 30%. Results from separate detailed analyses done by Moustakas and Willems, as described in appendix 7, does further confirm the indication that the upstream part of the Geul basin (upstream of Sippenaeken and Kelmis) responds faster to rainfall, compared to the entire catchment (in this case upstream of Meerssen).

Table 1. Sub-basin sizes, rainfall and discharge characteristics for the area upstream of Schin op Geul (as simulated by our hydrological model – see appendix 4)

Sub-basin	Area (ha)	Area (%)	Precipitation (mm)	Discharge[1] (%)	Run-off coefficient
Boven Geul Wallonië	7,495	26 %	180	41 %	0.45
Beneden Geul Wallonië	4,639	16 %	150	14 %	0.41
Boven Gulp België	2,541	9%	130	5 %	0.21
Total België	14,675	51 %	160	60 %	
Boven Geul Nederland[2]	6,019	21%	150	23%	0.40
Beneden Gulp Nederland	2,098	7%	130	5%	0.21
Selzerbeek	2,936	10%	130	6%	0.18
Eyserbeek[3]	2,845	10%	130	7%	0.23
Total Nederland	13,898	48 %	130	40%	
Total upstream of Schin	28,573	100 %		100 %	

[1] as a contribution to discharge at Schin op Geul

[2] this Boven Geul sub-basin is split in trajectories: Sippenaeken Cottessen (area 9%), Cottessen – Hommerich (area 46%) and Hommerich – Schin op Geul (area 45%)

[3] Eyserbeek springs in Germany and where its contributing area is about 3% of Geul basin area total

Differences in estimations of rainfall-runoff coefficients

To calculate absolute and relative contributions of sub-basins to rainfall and discharge totals, ideally they should make use of measured data. The density of the discharge and water level monitoring network does not allow to determine the exact contribution to the response of one single characteristic from observations. During the extreme floods, much of the measurement equipment malfunctioned. The only two monitoring stations that provided a continuous discharge series are located close to Kelmis in Belgium and Sippenaeken, near the Belgian-Dutch border. We consider at least one of these recordings suspicious, since the difference between the peak flows recorded at both stations is small, although the contributing area for Sippenaeken is almost 30% larger than the upstream area at Kelmis. Therefore, our assessment is based on the simulations

[2] expressed as basin runoff coefficient

with the WFLOW-SOBEK models, common hydrological theory, the reported field observations during heavy rainfall events and observations from research catchments in Luxemburg.

We used the ratio between the runoff simulated and the rainfall volume, the runoff coefficient during the event, as a metric for the differences in river basin response. In basins that show a small runoff coefficient, relatively little rainfall comes rapidly to discharge and most of the rainfall is temporarily stored in the soil or in the floodplain.

Between reports differences in ratios appear. These typically can be attributed to differences in model data, focus on different periods (peak or cumulative for one week) and evaluations for different gauging stations. In general, the assessments come to the same general conclusion: more rainfall and faster runoff in particularly the most upstream part of the Geul basin.

Rainfall

The differences can be attributed to both the rainfall distribution and to the different response of sub-basins to (heavy) rainfall. Particularly the head water area in Belgium, *Boven Geul BEL* (see figure 1 for its location), received a lot more rainfall 180mm than the three tributaries Gulp, Selzerbeek and Eyserbeek (130mm). The Belgian part of the basin received larger rainfall volumes than in the Netherlands. The area upstream Cottessen received 160mm where the area downstream the border received approximately 130 mm.

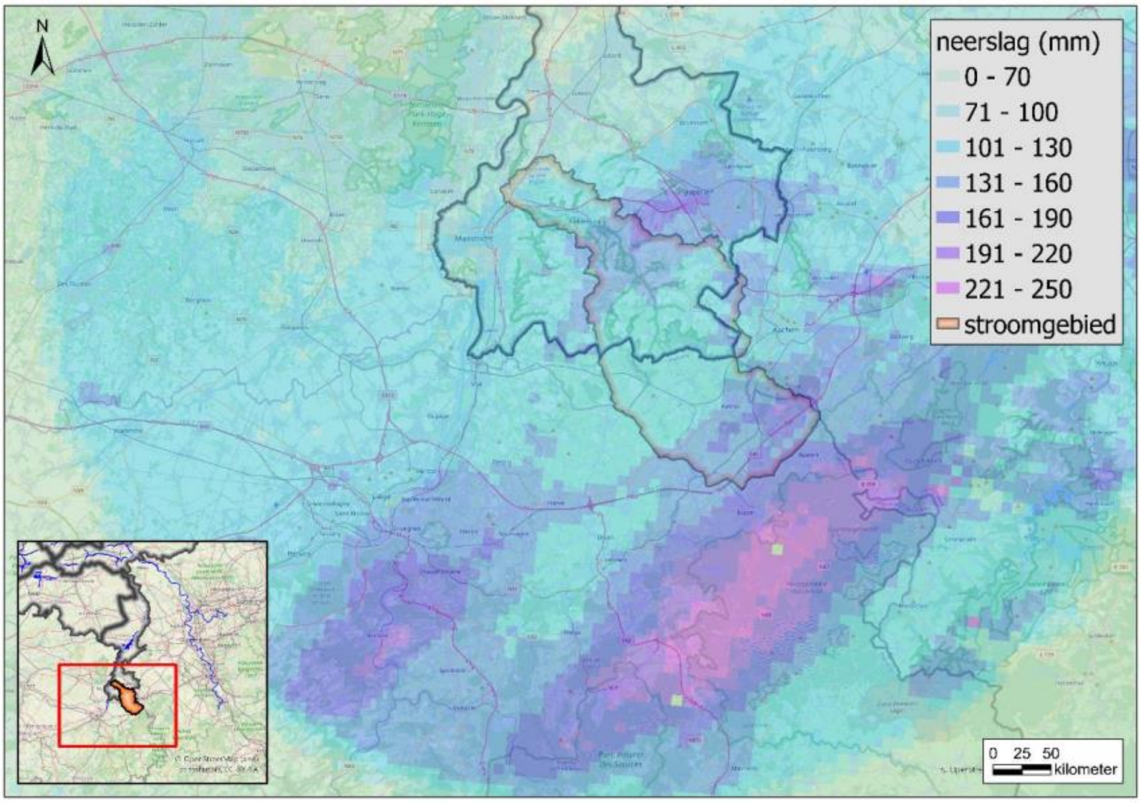

Figure 2: Rainfall estimates of precipitation distribution: 13 July 10:00 to 15 July 10:00 (based on Deltares, 2022)

Characteristics that contribute to *hydrologic* basin response to heavy rainfall - how much time does it take before the rainfall reaches the brooks and rivers - are relief, slopes, geology and land use practices. The *hydraulic* response - how fast does the flood wave travel through the river network - is mainly determined by the slope of the length profile, the width of floodplains and its vegetation, as well as the occurrence of water management infrastructure in the flood plains and riverbed; such as bridges, culverts and weirs.

Geology

> *(2) The differences in geology have played a role in the response of the basins. A comparison between the total rainfall and runoff volumes during the event shows that in the area where rock formations with small soil storage capacities prevail, the response is more flashy (more rapidly larger volumes of rainfall come to discharge) than in areas consisting of rock formations with larger soil storage capacities.*

The different geology in Belgium leads to a more rapid response in the basin area in Belgium than in the area in The Netherlands. Evidence for this partially comes from an observed denser drainage pattern in Belgium than in the Netherlands, indicating that in normal conditions more water flows across the surface to the brooks. In figure 3 a general geological map of the basin is provided. In Belgium the bedrock comprises shale, sand stone and limestone formations. The permeability and porosity of the sand stone and shale formations is low, meaning that only little water can percolate into and through the underlying rock formations. Due to cracks and joints the limestone formations may store some more water, although the storage is still limited compared to unconsolidated sediment. Moreover, the same cracks and joints cause water to flow rapidly through this formation, leading to a rapid ground water and runoff response. Generally, the weathered top layer and soil covering the bedrock in Belgium is thin, leaving also little space for storing water. In the Netherlands thicker layers of unconsolidated sediments, loess and sands are covering the bedrock. These have larger porosity and permeability providing relatively more storage capacity for rainfall leading to a slower response for the runoff.

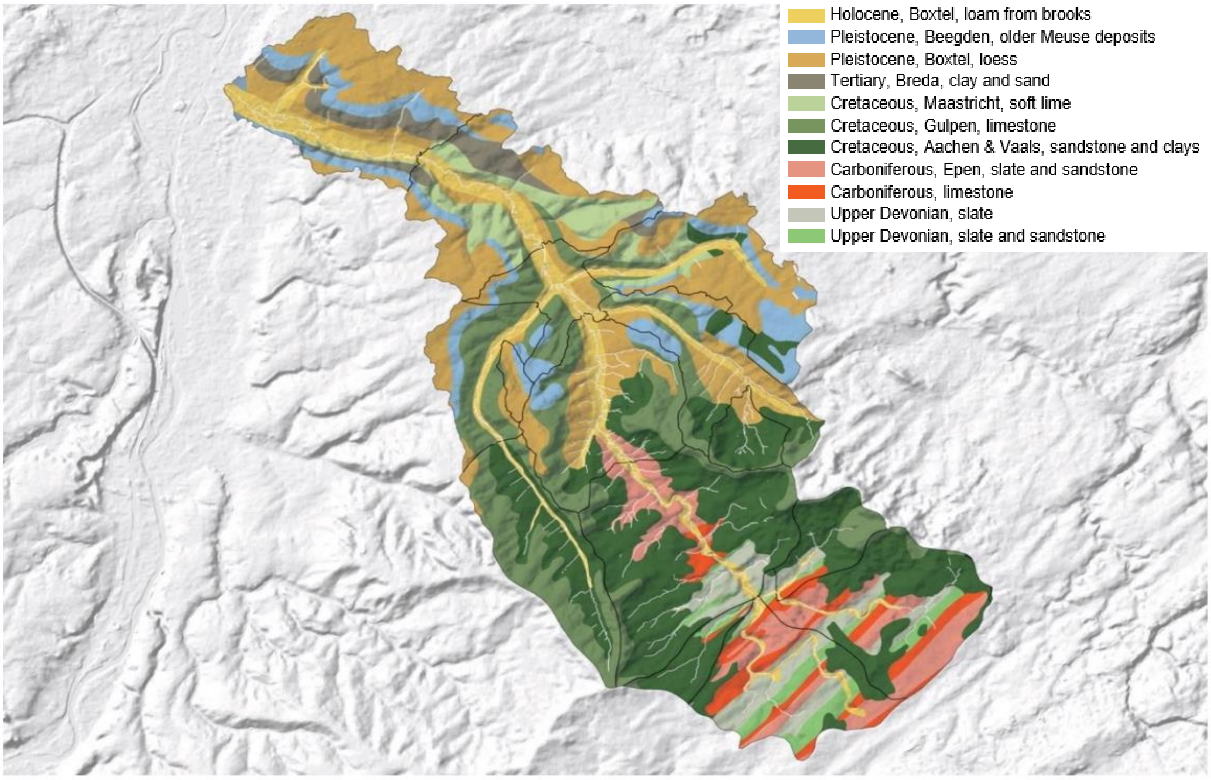

Figure 3: Geological map of the Geul river basin, including information on formations and indicative soil material (from Natuurmonumenten en Bureau Stroming, 2022)

Studies from a nested research catchment set-up in Luxemburg, covering a wide range of clean and mixed physiographic settings (i.e., topography, geology, land use) have shown that fundamental hydrological functions of water collection, storage and release are mainly controlled by bedrock geology (Pfister et al., 2017). Additional work on extreme rainfall events and their translation into (flash-)floods have confirmed the prominent role of geology (Douinot et al., 2022).

<u>*Slopes*</u>

> *(3) Areas with steeper slopes typically produce more surface runoff as less water can infiltrate into the soil. In our assessment we did however not find a clear signal that differences in slopes were as important in the contribution to the flood volume, than rainfall distribution, land use and geology.*

Short and gentle sloping areas (less than 6%) prevail in the head water section in Belgium and in the far downstream section in The Netherlands (Figure 4 and 5). The steepest and more extensive sloping areas can be found in the area where the Geul and its tributaries crossing the border of Belgium and The Netherlands. The steeper areas are mainly forested.

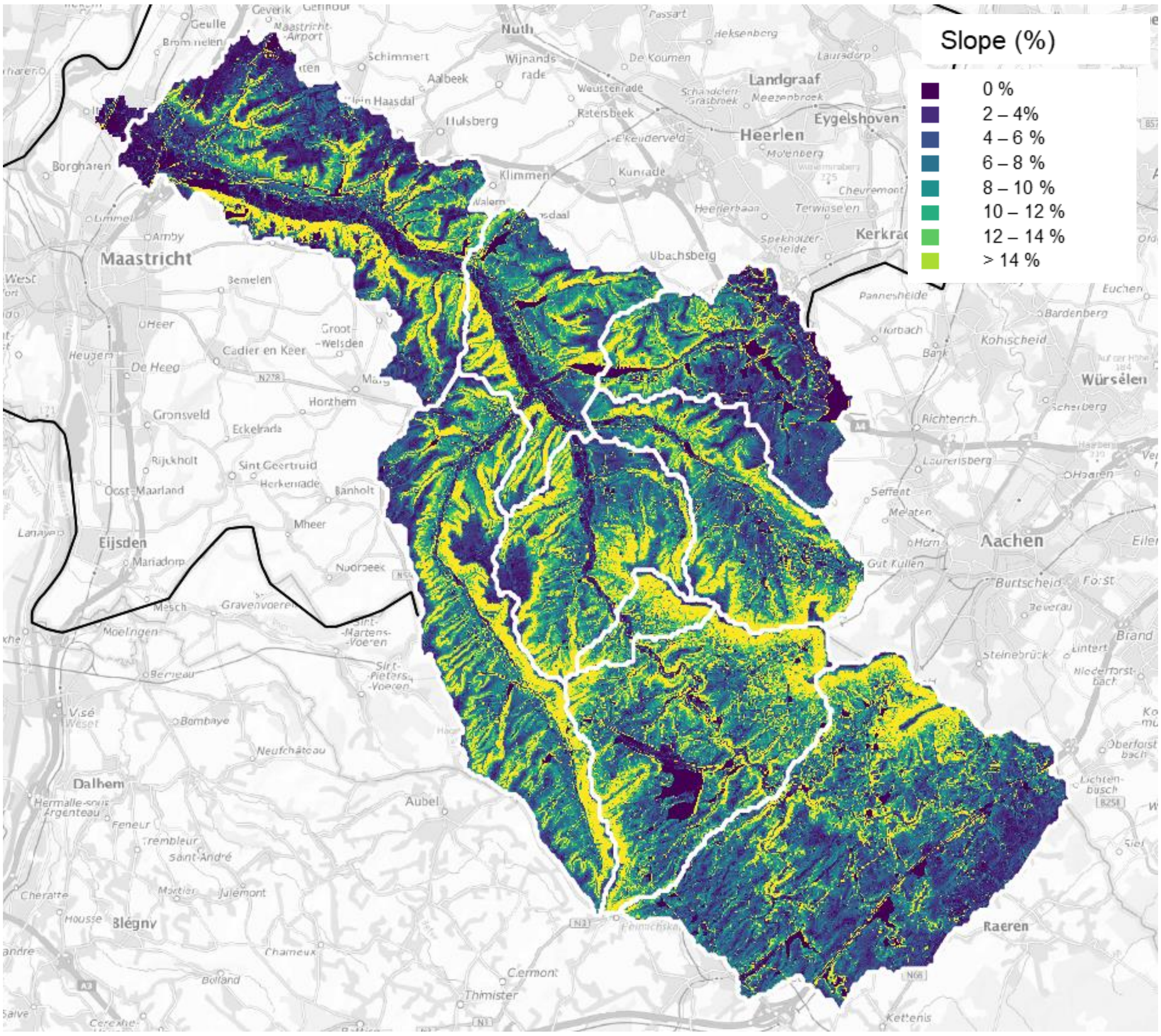

Figure 4: Slopes in the Geul river basin, based on most actual detailed DEMs freely available

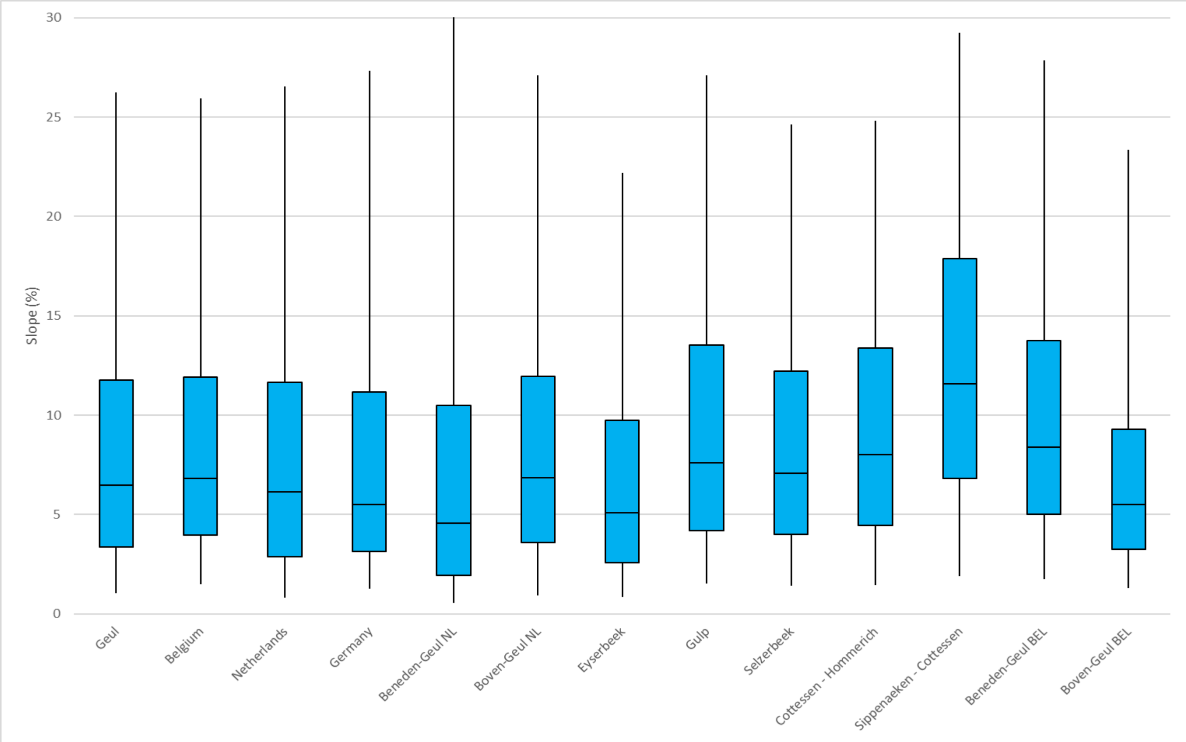

Figure 5: Spatial distributions of slopes per (sub-)basin where the error bars represent the 95% value distribution. Note that the size of the (sub) basins vary considerably.

Land use

> *(4) Differences in land use played a role in the contribution from sub-basins, but land use differences between larger sub-basins are relatively small. For larger areas the main difference is between arable land in Belgium (8%) and The Netherlands (28%). We assess that these differences had a smaller effect on observed discharge differences than the rainfall distribution and the differences in geology.*

Differences in land use influence interception, infiltration, rooting depth and the resistance against surface flow. Interception, rooting depth, infiltration, organic matter in forested areas and on pastures as well as resistance to surficial flow is normally higher than on arable land[3]. Infiltration and resistance to surface flow is (very) low on roads and in build up areas with traditional urban drainage. In figure 6 a detailed and actual land use map of the Geul river basin is provided (see appendix 3 for more information on its construction).

[3] There are a lot of undocumented drainage systems along arable land in the basins. It is unclear what is the exact amount and impact on the local drainage situation.

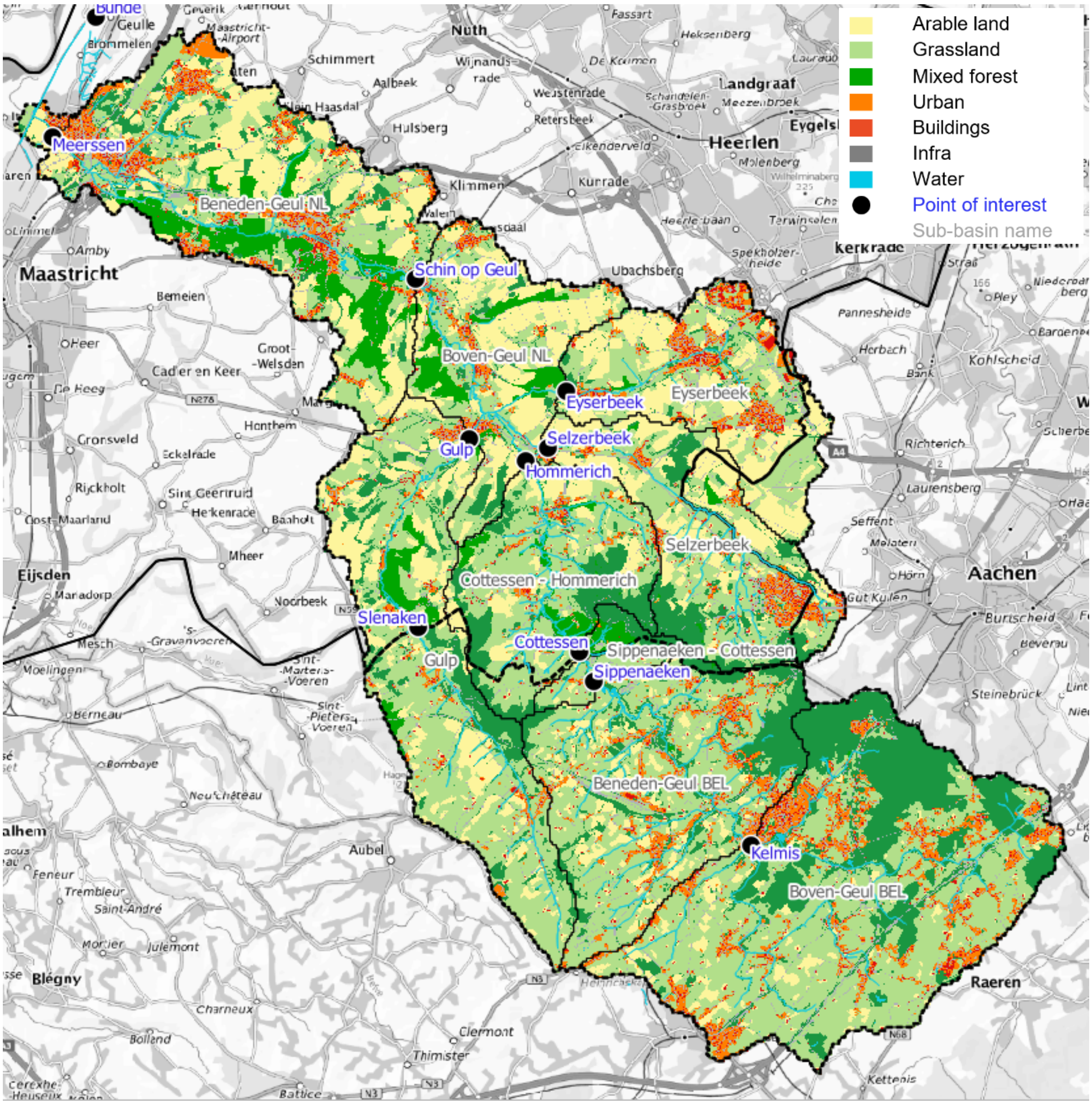

Figure 6: Detailed land use map of the Geul river basin

In figure 7, the land use distribution between the different catchments is provided. A striking difference between the Belgian and Dutch part of the basin is that in the Netherlands, much more area is covered and used as arable production land – up to 28% compared with up to 8% in Belgium. Urban fractions are not very different between the two countries. More differences can be found between sub-basins. Be aware that sizes of sub-basins differ.

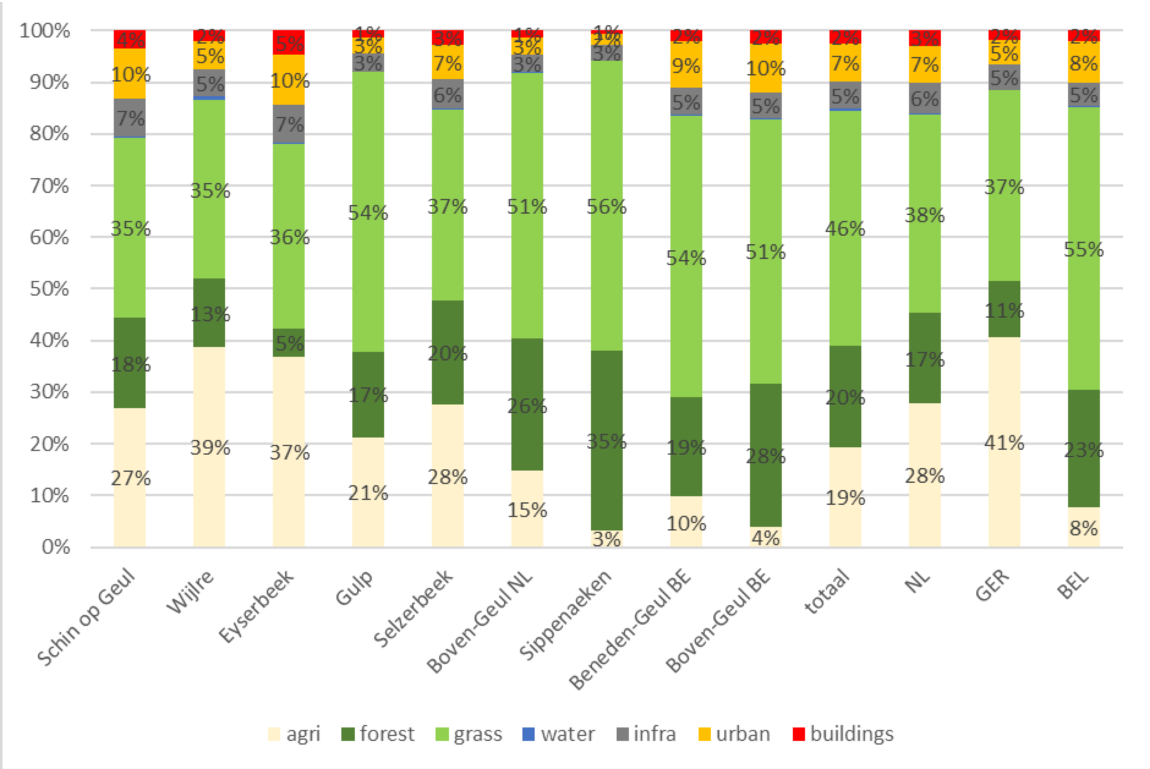

Figure 7: Land use distribution of the different sub-basins in the study area

In order to assess the sensitivity of the differences in hydrological response for land use in the river basin we executed a series of simulations using a combined hydrological and hydro-dynamic model (see appendix 4 and 5 for more details). In a series of model simulations we assumed that for the entire catchment:

(1) ***forest***: all grassland and arable land on the hills and plateaus would be replaced by mixed forest;
(2) ***100% forest***: all grass, arable and urban land on the hills and plateaus would be replaced by mixedforest;
(3) ***forest, also in the river valleys*** as (1), with additional total reforestation in the floodplains;
(4) ***100% urban***: all forest, arable and grass land on the hills and plateaus would be replaced by urbanized area.

A comparison of the results of these simulations with the current land use – reference – (figure 8) shows that a complete reforestation (also in the river valleys) could have reduced (and delayed) the peak of the flood wave at location Valkenburg, to approximately 75m3/s.

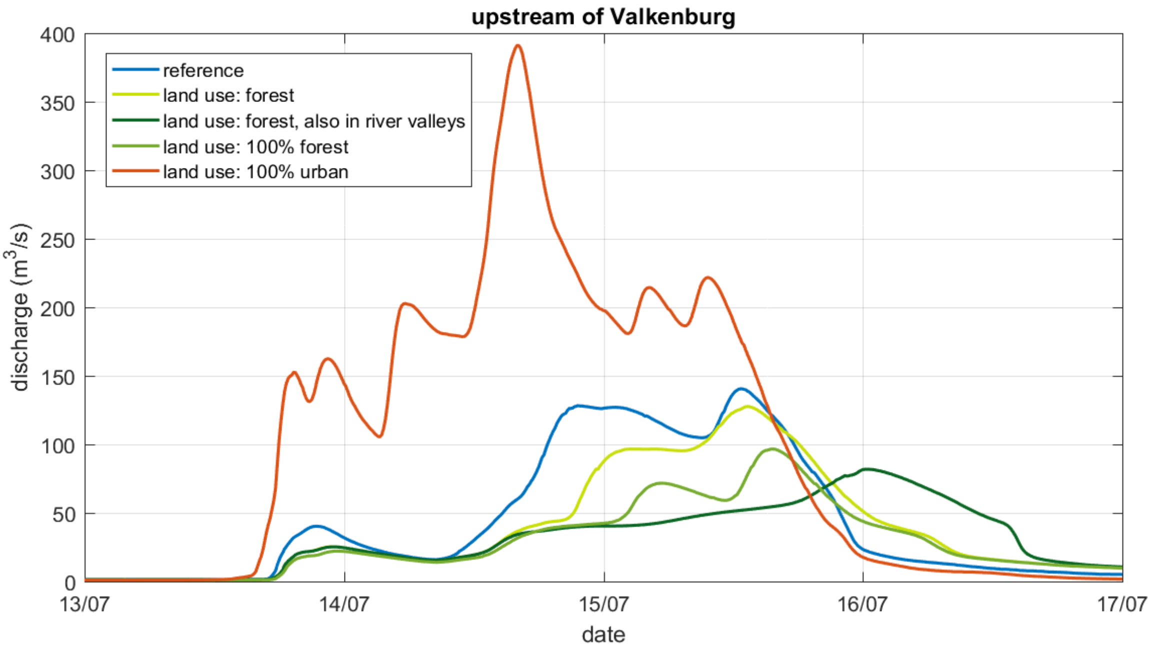

Figure 8: Hydrographs at Valkenburg for the flood event in July 2021 as simulated by a combination of the hydrological WFLOW model and the hydraulic SOBEK models. For the simulations different land use cover area were assumed in the Geul basin upstream Valkenburg (at Valkenburg – Hertenkamp).

On the other hand, extension of the urban area would lead to an extreme flashy response and would have increased the peak to almost 400m3/s. The peak at Valkenburg is in this model setup estimated between 120 and 140m3/s. The difference between the simulation assuming a completely urbanized basin and the reference simulation, representing the current land use, illustrates that the current natural characteristics of the basin successfully would reduce the peak flow to approximately one third of the theoretical maximum when fully urbanized.

Observations during heavy downpours affirm these model results. Steep roads turn into rapidly flowing small rivers during heavy rainfall, bare arable land shows substantial sediment transport by flowing water, where surface runoff is hardly observed in densely forested areas or on pastures.

On the other hand, even in basins that have a more natural vegetation severe flooding is possible. Most damage and casualties during the event in July 2021 were regrettable in the basins of the Ahr in Germany and Vesdre in Belgium. Both basins are much more forested than the Geul (despite considerable parts of vegetation cover in the Vesdre basin were cut recently) and have less build up area. These basins received a lot more rainfall than the Geul (up to 250mm), the relief of the basins is steeper and unconsolidated sediments are less than in the (Netherlands) Geul basin.

Associated flood-affected areas with adverse flood consequences

> *(5) The largest flood damage and affected households are measured in the Netherlands. In Belgium only incidental media reports on floodings and damages within the Geul basin were found. The difference in damage can be attributed to the smaller flood-affected area in Belgium and the fewer buildings located in the flood prone area, than in The Netherlands.*

Once the water enters the rivers, vegetation differences in the flood plain, the presence of obstacles and river meanders influence the propagation of the flood wave downstream and thus the response of the river. Locally obstacles (such as bridges or culverts) have caused local flooding and may have limited flooding further downstream (e.g. anecdotal evidence at Rochus-Kapelle at Kelmis, Gulpen and Schin op Geul). But except from the area where the river Geul passes urbanized areas and where roads cross the river by bridges, the river and its valley have broad floodplains, with a lot of storage and flood attenuation.

Several parts of the river valley in Belgium were flooded during the event. Clear examples with substantial inundations are the surroundings of the Rochus Kapelle, Kelmis and La Soue, south of Plombières. By visual inspection of flood hazard maps on the same scale, published by the Wallonian Government (geoapps.wallonie.be with 1:100 year probability) and ENW (2021)[4] it is estimated that the flood-prone areas of the river valleys in the Netherlands is probably more than twice as large than in Belgium.

Studies in Belgium concentrate on the consequences in the Vesdre where the flooding caused massive damage and a large number of casualties. For the Geul basin we found hardly any reporting about damage in Belgium, where the damage in The Netherlands, particularly in Valkenburg, Schin op Geul and Bunde, was substantial and in the order of 200 – 400 Million Euro (ENW, 2021). Further, it is estimated that more than 4000 inhabitants along the Geul in the Netherlands were more or less directly affected (ENW, 2021). Fortunately, the flood in the Geul basin did not lead to casualties in this event, although the flood hazard at Valkenburg had characteristics that could have led to victims (e.g. high velocities, rapid rise rates, night conditions, low evacuation and warning rate etc.).

Despite some incidental reports (see textbox below), we did not find evidence that the damage in Belgium was of comparable size as in the Netherlands, which cannot be explained by the difference in magnitude of the flood. In the entire Geul basin, the percentage of area covered by villages and roads is not very different between both countries. Also the total number of buildings (around 50 – 55 thousand buildings in both countries) is comparable.

Due to missing empirical data on flooded area at the Belgian side, we could not estimate how many buildings were exactly affected in July 2021. As a compromise, we did some initial map overlays with publicly available modelled hazard maps Belgium. Assuming this is a good representation, considerable differences can then be observed between the indicative area flooded (see figure 9) as well as for the number of buildings located in flood-prone areas in the main Geul river valley.

[4] In ENW (2021) a best effort is done to visually identify the flood hazard area of the July 2021 floods

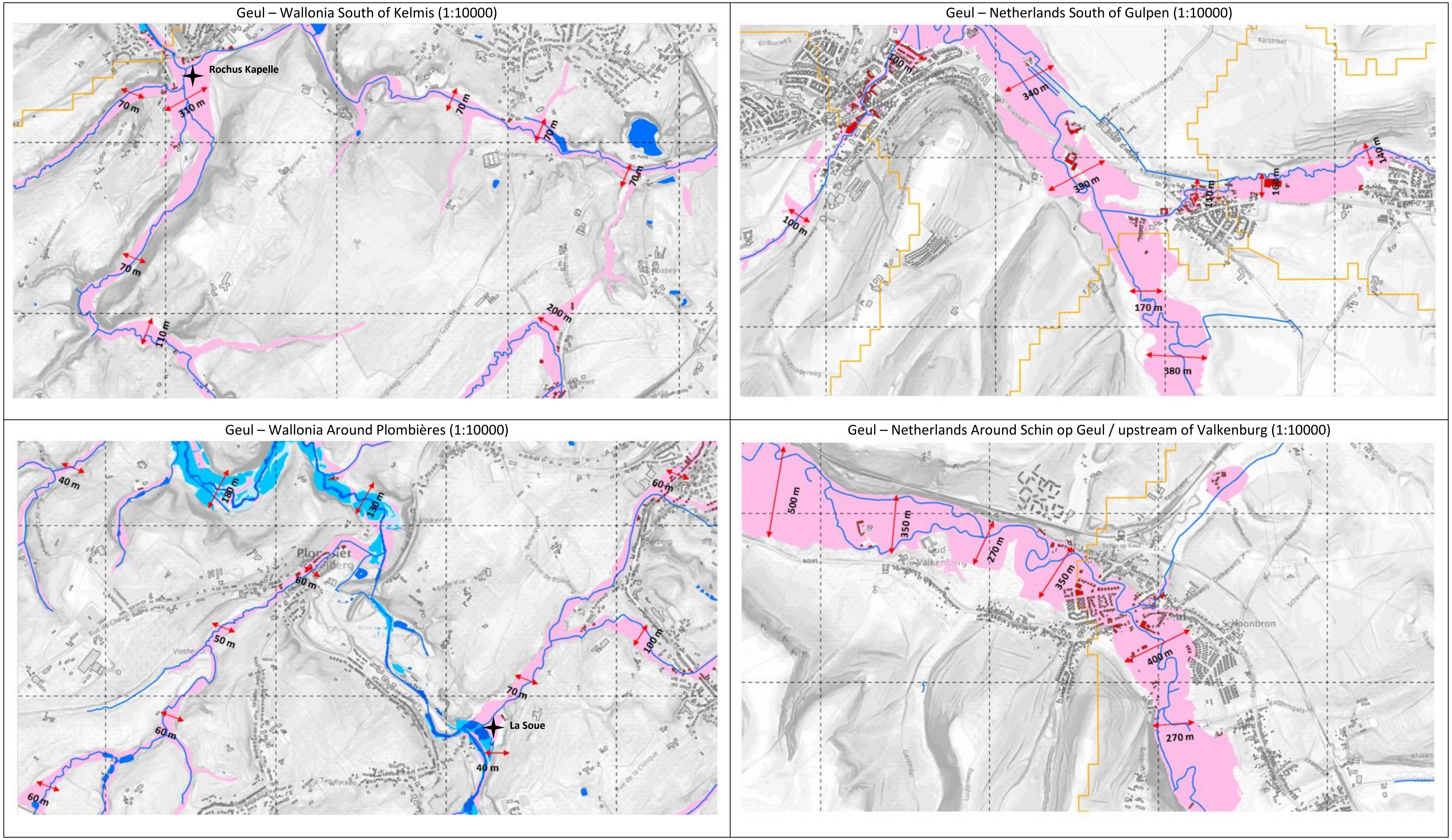

Figure 9. Examples of 'natural' floodplain inundation (in purple and blue) in Belgium (Wallonie - SPW) for modelled t=100 situation (left) and in Netherlands during July 2021 flood event (right) -ENW: buildings are colored red when situated in flooded area during July 2021 flood event

Local newspaper articles in Belgian part of the Geul-basin

An internet search for news articles on flood impacts during July 2021 event in the Geul river basin resulted in only a couple news articles in local newspapers. These newspapers reported on more than 100 households being affected in areas around the larger villages / cities in Wallonia; e.g. Plombières and Moresnet.


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"Une centaine de ménages inondés" à Plombières

Une centaine de ménages touchés par les inondations et des dégâts aux structures. Plombières ne fut pas épargnée non plus...

Pierre Lejeune
Publié le 11-08-2021 à 13h06

Les ouvriers de Plombières sont intervenus à Dolhain, sans oublier les dégâts chez eux. ©ÉdA LABEYE Philippe


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Moresnet sous eaux, mais le Pays de Herve a moins écopé

Le centre de Moresnet était noyé au pied du viaduc. - Commune

The mayor of Kelmis (the largest settlement in the Belgian part of the basin) reported the following on the website of the municipality (kelmis.be/aus-dem-gemeindehaus):

"*Kelmis, Hergenrath und Neu-Moresnet sind im Vergleich zu der Lage in anderen Ortschaften der DG bzw. der Provinz weniger von Überschwemmungen getroffen worden. "Abgesehen von der Gegend um die Rochuskapelle, der Asteneter Straße, dem Bauweg, SchievenhÖvel, Schnellenberg, und dem Viertel Hof haben wir im Vergleich zu den Anderen Glück gehabt", so Frank.*"

When we just also consider the modelled flood map for the Netherlands, and used indicative maps with medium probability of flooding (1/100 per year) in both countries we counted around 1400 buildings in flooded areas in the Netherlands and around 860 buildings in Belgium. For more extreme circumstances (low probabilities e.g. 1/1000 per year) the number in flood-prone area is ~2600 buildings in the Netherlands and ~1000 buildings in Belgium[5]. 40 to 50% of the buildings in the flood-prone area in these extreme conditions in the Netherlands are located in the municipality of Valkenburg a/d Geul (the wider area around the city of Valkenburg), including houses and recreational businesses.

It is important here, though, that probably also buildings along the headwaters or foothills may have been affected throughout the basin. Only some incidental reports in the Netherlands are available, which are excluded from this assessment.

Potential measures to reduce flood damage at Valkenburg

> *(6) A broad package of measures is needed to reduce flood hazards and risk in the Geul river basin. In this study, we focused on large-scale land use change and river system interventions. Considering this flood event, land use changes in the basin and in river valleys, as well as urban rainwater diversion might have reduced peak flows for Valkenburg. However, the scale needed for these single measures to be effective is large. Other considered measures, such as increasing runoff water storage at the foothills in Belgium up to a same volume as currently implemented in The Netherlands (7 Mm^3) would reduce the peak discharge by in the order of up to 8%. Re-meandering of the main river only has limited effect. In theory, more water storage in the valley can be achieved by forestation of the floodplains and/or creating a large reservoir in the river valley at Schin op Geul in the Netherlands, and thus locally allowing greater inundation depth. The reducing effect on peak discharges downstream is however strongly dependent on the correct operation of such a reservoir. Besides that, there is already a large storage volume in the river valley, so increasing that volume is a relatively small increment, with subsequent relatively small effect (estimated up to in the order of 16% discharge reduction at Valkenburg).*

With estimated return periods of 100 to 500 years in the current climate the flood volume that flowed through the Geul and its tributaries was extremely large. Deltares (2022) earlier assessed about the potential effectiveness of other civil engineering interventions like a tunnel - two tubes of 3.5 m diameter - under Valkenburg, rising flood walls up to 3m in Valkenburg, and floodplain broadening within the centre ('accoladeprofiel'). It was concluded that the measures would be potentially locally very effective. The flood walls come with additional requirements for the foundation and should be extended into upstream area. It was also clear that the measures would alter the view of the town centre drastically. Measures like dry-proofing or wet-proofing of buildings within Valkenburg area ((Suijkens, 2022) and timely warning (Godlewski, see appendix 1) also seem to be effective , also in less extreme conditions.

As a further illustration, to prevent flood damage of the 2021 flood in Valkenburg an additional 6-10 million m3 of water needs to be stored upstream in the basin (Deltares, 2022). Inevitably the size of any single measure or combination of measures, no matter that these are nature-, engineering- or spatial-planning based, that could effectively prevent the impact of such events will be very extensive and/or expensive/complicated to implement.

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[5] It was difficult to give an indicative count of the number of buildings in flood-prone areas for the low probability in Belgium, as the published map layer on extreme probability floods at the SPW website is restricted to zoom further than 1:25000. The number of buildings were estimated by counting the number of buildings from OpenStreetMap situated in the flood-affected areas (model results for Floods directive hazard maps from website in Belgium and Netherlands)

In order to obtain more insight in the potential of a selected set of different largescale measures throughout the basin, we updated WFLOW and SOBEK flood models and ran a series of simulations. We did not consider the theoretical maximum change (e.g. a basin covered for 100% by forests) as is shown in figure 8, but applied a change of 10 and 20% of the basin. We linearly scaled the impacts of the different measures and assumed that individual effects can be superimposed.

The following selected number of measures are investigated here:

1. Reforestation of hills and plateaus (10 to 20% of river basin area)
2. More vegetation in the river floodplains and valleys (for 10 to 20% of river valley area)
3. Urban rainwater diversion (of 10 to 20% urban area)
4. Rainwater retention at foothills in Belgium (80,000 to 160,000 m^3)
5. River Geul re-meandering (20% longer)
6. Large dam with reservoir upstream of Schin op Geul (operated on time / wrongly operated)

The resulting values below should be considered indicative and based on the models and knowledge of the river basin available at this moment. Sensitivity analyses on model input parameters, preferably based on empirical evidence, could provide an uncertainty range and should be part of further research.

<u>We assess that a reforestation of 10 to 20% of all arable land (incl. pastures) on the hills and plateaus in the river basin would have reduced the flood peak discharge at Valkenburg by 1 to 2%, respectively.</u>

This measure would reduce the velocity of water flowing over the surface and as such provide more time for the water to infiltrate into the subsurface as well as to temporally store the water on the surface. We do not see a clear signal (for this event) in the simulated peak discharge at Valkenburg that the effectiveness of reforestation of hills and plateaus on peak reduction would substantially differ between the countries. While similar conclusions have been reported previously for large river basins, such as the Meuse and the Rhine (e.g., Pfister et al., 2004), it has to be noted that land use change impacts on floods remain poorly understood at catchment scale (e.g., Rogger et al., 2017).

<u>We assess that the potential for further rainwater retention in the headwaters in Belgium – basically extending current policy in Limburg to Belgium – may lead to a reduction of 1 to 2% of the flood size in Valkenburg.</u>

Constructing rainwater retention areas of 80,000 to 160,000 m3 storage capacity in Belgium (10 to 20% of the current total of the basin in Limburg) will potentially reduce discharges at Valkenburg with another 1 to 2 %. These rainwater retention basins – though not designed for these types of events and amounts of water – seem to be able to temporarily store an amount of water. In order to reach a full potential, it would require optimal operation of these reservoirs. As a matter of fact, without proper operation and robustness they may have no or locally adverse effects.

<u>We assess a potential peak reduction of 2 to 4% that can be attributed to additional urban rainwater diversion into forest or grassland – in any form – throughout the basin.</u>

It is estimated that increasing this diversion with 10 to 20% throughout the urban areas in the catchment may potentially lead to reduction in flood size of 2 to 4% at Valkenburg. Diverting urban rainwater and slowing down its runoff to the river could be beneficial when rainwater could successfully be diverted into vegetated areas. In practice, this is however a complex measure to implement, as well as that urban rainwater system are mainly effectively designed to digest much shorter and more frequent rainfall events. We do not see a clear signal (for this event) in the simulated peak discharge at Valkenburg that the effectiveness of urban rainwater diversion on peak reduction would substantially differ between the countries.

> *(7) Measures implemented in the valley in The Netherlands seem most effective to reduce the flood peak discharge at Valkenburg in this extreme rainfall event.*

<u>We assess that the potential for measures that slow down the propagation of the flood wave or more storage in the floodplain in order to significantly reduce the damage in Valkenburg is around 4 to 8% for forestation of the river valley and up to 16% with a large dam.</u>

Our analysis shows that re-meandering (by increasing length of the river with approx. 20%) has hardly any measurable impact at all, while re-forestation of the main river valleys (10 to 20% of the area) would potentially reduce the flood size with another 4 to 7%. The impact is limited, as the valley has already a natural character and high storage capacity. The measure seems more effective in the Netherlands than in Belgium. This is because (a) the valleys are wider than in Belgium and therefore their potential for storage is greater and; (b) the effectivity is less dependent from spatial rainfall differences (in timing and intensity) upstream.

Extra storm water storage can only be achieved by allowing larger water depths since large parts of the valley were already flooded. For example, building additional large scale water retention in the valley in the Netherlands would need substantial infrastructure, like a 3 to 5 m high dam over the entire width of the valley. To effectively reduce the flood wave downstream (up to 16%) means that the storm water reservoir needs to be operated during the flood for timely use of the storage. This requires a reliable flow forecast. If operated at the wrong time, the dam may not be effective at all. The reservoir created by this dam would become 5 m deep stretching up to 1.5 km upstream.

(8) A preliminary quantitative assessment for a sequence of suitable and selected number of measures is provided below. This figure illustrates the potential to reduce or prevent flood damage in Valkenburg by reducing the flood peak (observed in 2021) from 130 m3/s to a maximum of 60 m3/s. In our assessment we assumed that 10 to 20% of maximum land use transformation would be suitable to be implemented, as well as that the modelled effects of measures can be simply added together. Our assessment shows that combining all measures would potentially lead to a reduction of the discharge at Valkenburg in the order of up to 30%. None of the measures are suitable for the short-term, as the implementation period for these measures is typically very long to be in full effect (est. > 10 years up to more 30 years for nature-based and spatial planning etc.). On the other hand, largescale application of these 'source control' measures have strong co-benefits for drought control, nature management and will probably be more effective in less extreme flood conditions.

The potential cumulative peak discharge reduction at Valkenburg is summarized in the figure 8 below. The measures are ordered from measures to be taken upstream to downstream. The values should be considered indicative and based on the models and knowledge of the river basin available at this moment. Sensitivity analyses on model input parameters, preferably based on empirical evidence, could provide a uncertainty range and should be part of further research.

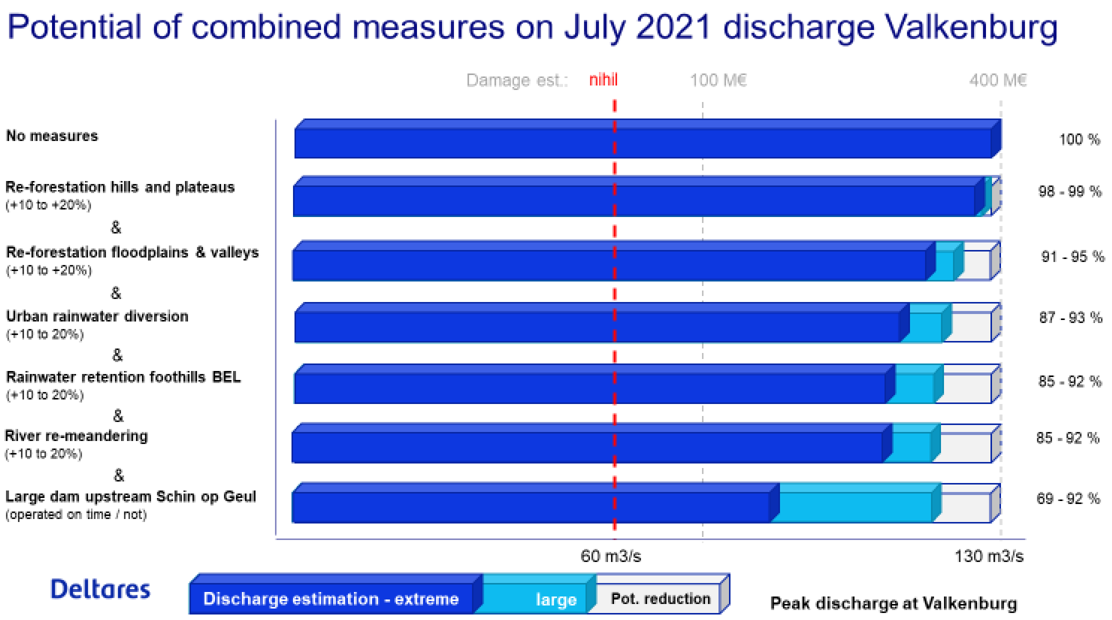

Figure 8. Potential to a cumulative decrease on peak discharge at Valkenburg and associated flood damages; dark blue = extreme large package of measures; light blue = large package of measures

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