

Excursion guide

International water security symposium:
Flood and integrated catchment management

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Versions

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1. Introduction

Flood management in the Netherlands

Since many centuries, the Netherlands gathered experience in protection against flooding danger coming from the North Sea and from the rivers Rhine and *Maas* (Meuse). With 26 % of the Dutch land surface lying below sea level, it is not surprising that 59 % of the land surface is prone to flooding (see Fig. 1.1).

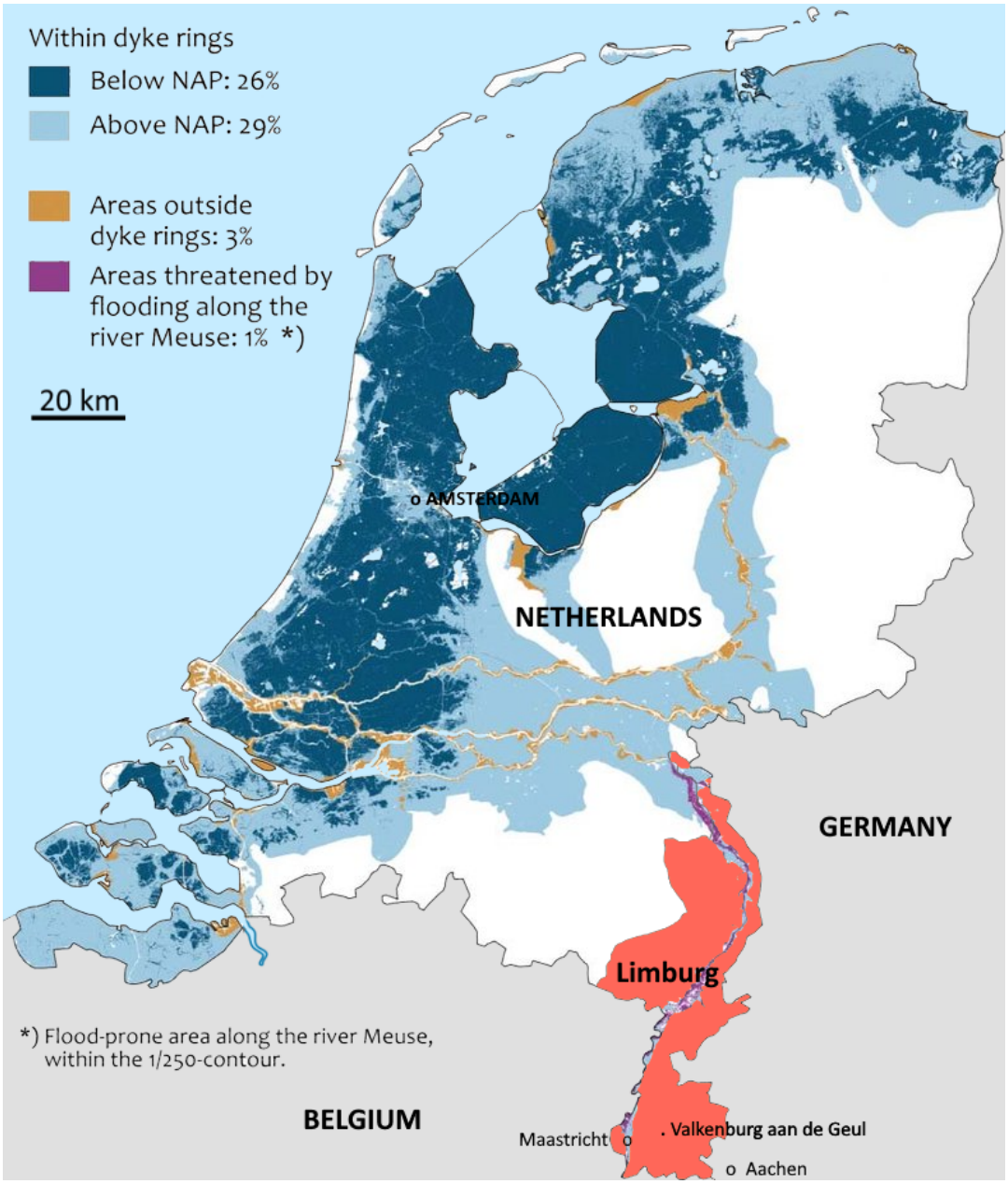

Figure 1.1.: Map of the Netherlands showing the flood prone areas, with the dutch province of Limburg shown in red (modified from [1]; NAP = Normaal Amsterdams Peil, which corresponds roughly to the average sea level).

During the winter of 1953, a storm tide breached the sea dykes in the southwest part of the country and the devastating flood that followed claimed over 1800 lives and caused more than 700 million Euros worth of damage. This catastrophe initiated the *Delta works* and an extensive reinforcement of existing dykes and levees. To deal with the flooding problems along the main rivers, the Netherlands has been carrying out programs that create more space for those rivers since a few decades. However, the relatively short data series on rainfall and river discharge do not yet allow us to fully capture long term climate variability and related extreme events, also exacerbated by the effect of climate change. Consequently, also due to known and unknown limits of protective structures, flooding can never be ruled out completely. **The ecorisQ event in South Limburg**

As a result of extreme rainfall (with record values of 207 mm in 9 h and 271 mm in 48 h), the floods of 14 to 16 July 2021 in the area covering the northwest of Germany, the province of Liège in Belgium (Fig. 1.2) and the most southern part of the Netherlands were very catastrophic. As a result, ecorisQ decided to dedicate the theme of its 8th general assembly to international exchange of knowledge and expertise in the field of flooding and integrated river basin management in regions with fast flowing rivers. The aim of the event is for the participants to learn from (different) approaches and experiences from abroad and to get ideas for new solutions. Together with the *Waterschap Limburg* (provincial water board) and the municipality of Valkenburg aan de Geul, with support from the BFH-HAFL, ecorisQ therefore organised the excursion and symposium on 22 and 23 June 2022 in Valkenburg aan de Geul in the province of Limburg (see Fig. 1.1) in the Netherlands.



Figure 1.2.: Collapsed house in Pepinster (BE) due to the shear stress and extreme water level, indicated by the colour differences in the brick walls (photo: Christophe Licoppe, European Commission, July, 2021).

The province of Limburg

Limburg is the southernmost of the 12 provinces of the Netherlands. The province is bordered by the province of Gelderland to the north and by North Brabant to the west. Its long eastern boundary forms the international border with the state of North Rhine Westphalia in Germany. To the west is the international border with the similarly named Belgian province of Limburg, part of which is delineated by the river Maas. The Vaalserberg, with a height of 322.4 m above NAP, is the highest point in the European part of the Netherlands and marks the tripoint of the Netherlands, Germany and Belgium.

The current province Limburg of the Netherlands (for simplification, from this point onwards referred to as Limburg) only came into existence in 1839, after the finalization of the separation of Belgium from the Netherlands which had begun in 1830. The strategic location of the current province, stretching along the Maas, made it a much desired region among Europe's major powers. Romans (53 BC to ca. 350), Merovingians (until about 751), Carolingians (800 to 888), the Duchy of Burgundy (1430-1477), Habsburg Spaniards (1477 to 1713), Prussians (1701 to 1815), Habsburg Austrians (1713 to 1794) and France (1794 to 1814) have all ruled parts of Limburg.

The capital of the province of Limburg is Maastricht (derived from its Latin name *Trajectum ad Mosam*), which has approximately 120'000 inhabitants. The total population of the province is around 1.1 million (in 2019). The province covers an area of 2'210 km^2 (850 square miles). This results in a population density of 521 inhabitants per km^2. The population of the Netherlands as a whole adds up to 17.6 million (January 2022). Concerning religion in Limburg, a study from 2015 revealed that 64.5 % was Catholic, 27.9 % not religious, 3.3 % Islamic and 2.2 % Protestant.

Although standard Dutch is the official language, Limburg has its own dialect called *Limburgs*. It has been an official regional language since 1997. Before the 20th century, most newspapers were in French or in German, schools in Maastricht taught French, as the city has historic ties with the Belgian city of Liège. Other parts of the province taught German. Limburgs is spoken by an estimated 1.6 million people in Dutch Limburg, Belgian Limburg, and Germany. There are many different dialects of Limburgs, almost every town and village has its own. Because of the language differences between German, French and Dutch, which all influenced the dialect, no single dialect variant fully represents Limburgs as a whole.

2. Program of the excursion

1. Bus departure from the Pavilion parking at Château St. Gerlach, Valkenburg aan de Geul (08h00)
2. General introduction to the Geul catchment in Fromberg (08h30)
3. Introduction to flooding problems in Meerssen and coffee break (09h50)
4. Flood prediction and measures in Meerssen (local measures, erosion control, flood retention) (10h30)
5. Lunch in Brasserie *De Blokbreker*, Valkenburg aan de Geul (12h30)
6. Visit of the 2021 flood hotspots in the center of Valkenburg aan de Geul (14h15)
7. Guided tour through the underground limestone quarry *Gemeentegrot Valkenburg* (16h15)
   Note that the temperature underground is constantly around 12 °C !.
8. Aperitif in the Pantheon in the Gemeentegrot Valkenburg (17h00)

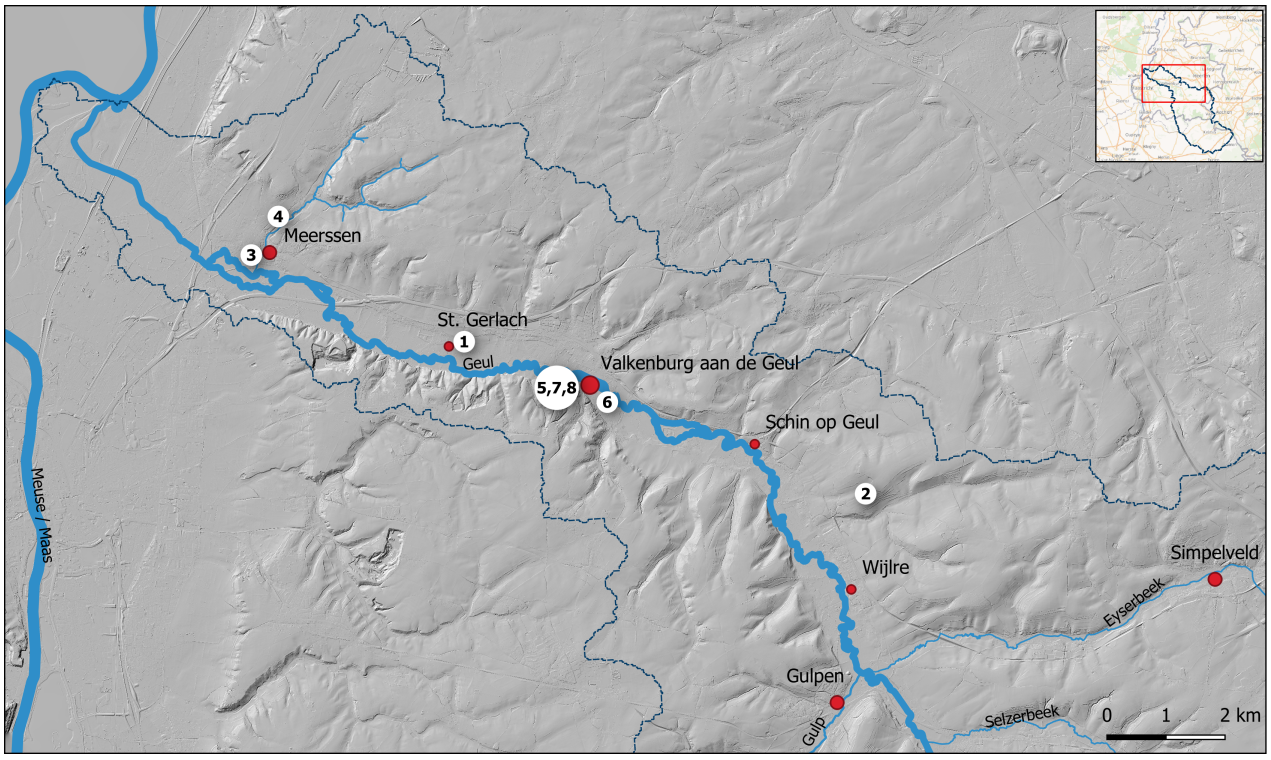

Figure 2.1.: Map of the excursion stops corresponding to the numbered list above.

3. General introduction to the Geul catchment

Description of the catchment area

The Geul is a tributary river of the Maas and has a total catchment size of 344 km^2 (of which 182 km^2 is in the Netherlands, 143 km^2 in Belgium and 19 km^2 in Germany). The source of the Geul is at about 300 m above sea level (a.s.l.) in northeastern Belgium near the German border (see Fig. 3.1). An important factor in the long term landscape development of the Geul catchment during the Quaternary has been the river Maas. In the late Pliocene and Pleistocene, the Maas had an easterly flow direction, thereby crossing the present day Geul catchment. Due to tectonic uplift of the Ardennes and South Limburg, the river started to shift towards its current south to north position, thereby creating a number of terraces and depositing gravel and sands [2]. Subsequently, the Geul and its tributary streams incised in this Maas terrace landscape. As such, the southern part of Limburg (especially the Geul catchment) is rather a 'valley landscape' than a hilly landscape.

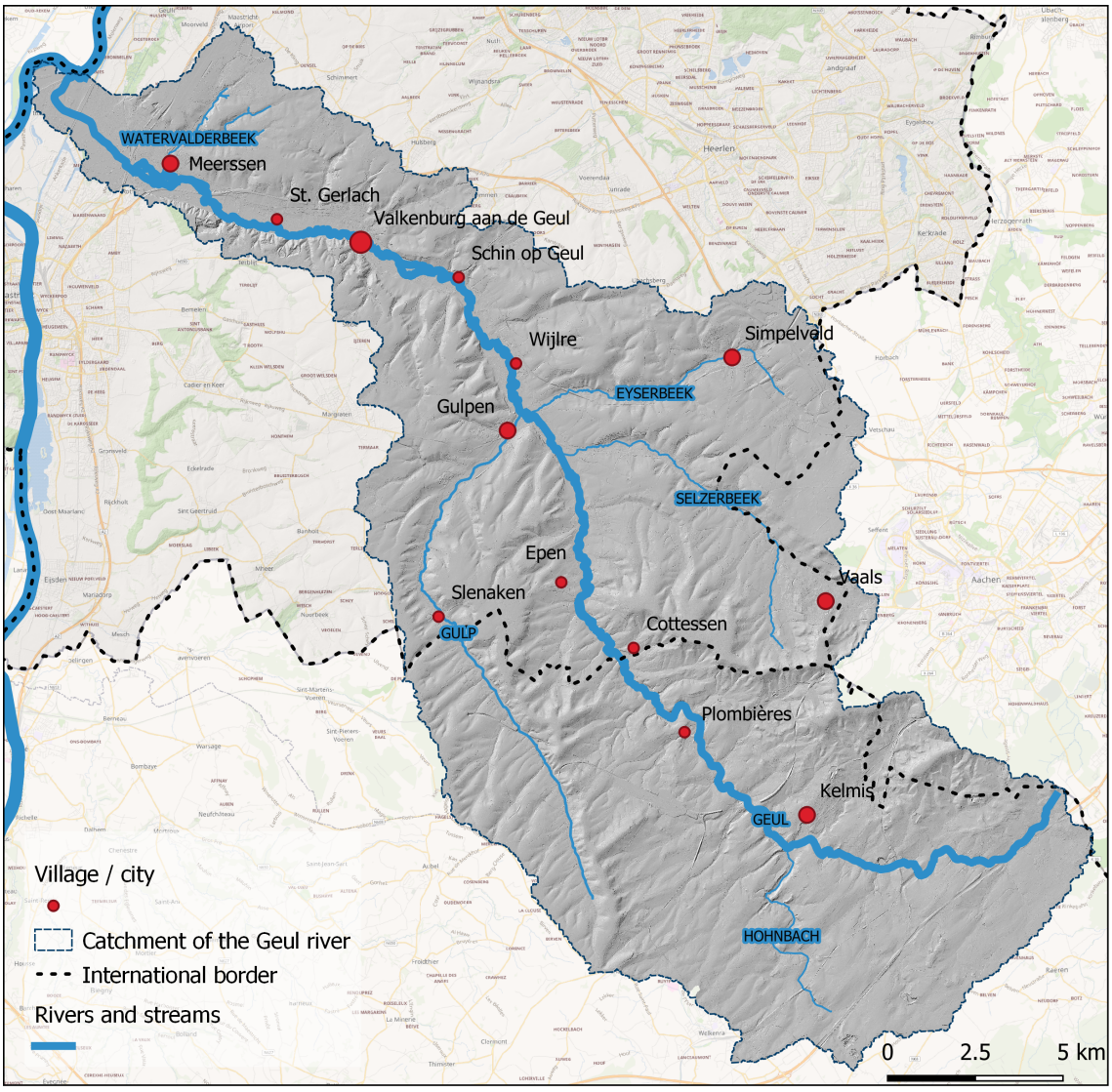

Figure 3.1.: Map of the Geul catchment.

The underlying bedrock is dominated by formations of yellow limestone which are 45 to 90 m thick (Maastrichtien; 72 to 66 million years B.P.), but also Glauconitic sands of the Formation of Vaals (Campanien; 83 to 72 million years B.P.), both deposited during the late Cretaceous [3]. In the southwestern, Belgian part of the catchment, older carboniferous sandstones, shales and limestones are exposed.

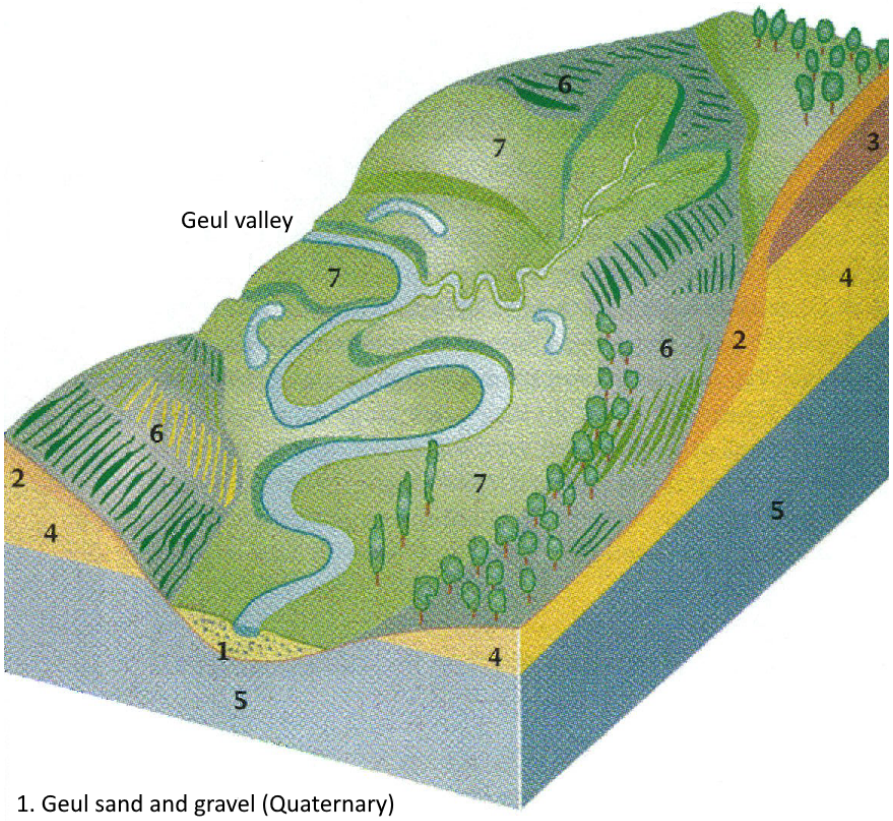

Figure 3.2.: Geological/topographical sketch of the Geul valley (after [4]).

Typical landscape features

A typical landscape feature in the Geul catchment is the dry valley. These are valleys in which today no stream or river flows. These valleys were created during the Elsterien (465 to 418 ka B.P.), Saalien and Weichselien (respectively 200 to 130 ka B.P. and 100 to 10 ka B.P.) ice ages. In the tundra type climate of those periods, melt water could not infiltrate into the ground and consequently runoff eroded the topsoil.



Figure 3.3.: High discharge in the dry valley of the Vrakelbergerweg during the July 2021 flooding event (photo: ANP/Marcel van Hoorn).

During the last two ice ages (the Saalien and the Weichselien), a north wind brought erosion material from Scandinavia. The heavier sand was deposited in the northern part of the Netherlands, but the fine loess (silt loam) was deposited in the hilly landscape in southern Limburg. This loess is particularly fertile. The relatively flat parts formed by the plateaus and stream valleys proved to be suitable as arable land, with the exception of the strips of land along the river and stream banks. The steeper slopes, which were more difficult to cultivate, were mainly used for grazing cattle. Since the farmers left strips of woodland across the slope, both for delimiting their plots and for firewood, so called lynchets (called *graft*) in the local language) were formed. These are the vegetated fronts of slope terraces. The erosion reducing effect of the vegetation roots resulted in long term accumulation of soil material upslope of the vegetation strips and formed terraces over time. The graft is another very typical landscape feature in the Geul catchment. Finally, the steepest slopes in south Limburg mostly remained completely forested [4].

Although the loess (consisting of more than 70% silt and up to 20% clay) provides fertile soils, it is also highly erodible [5, 6, 7, 8]. Intense rainfall on slopes regularly leads to sheet, rill and gully erosion and subsequently to concentrated mudflows in the villages in the valley bottom (as exemplified by Fig. 3.5 and 3.7).



Figure 3.4.: Typical *graften* (lynchets) in the landscape of South Limburg.



Figure 3.5.: Gully erosion from loess soils on agricultural fields and sediment deposition in the dry valley of the Vrakelbergerweg on 26 April 1987.

Many graften have been neglected or removed, mostly due to land reparcelling, during the transition from small-scale agriculture to more efficient agricultural practices since the 1950s [9]. The association Nederlands Cultuurlandschap estimates that roughly half of the graften present in 1900 in in South Limburg have disappeared [10]. A large body of scientific work [e.g. 8, 11, 12, 13] demonstrates that this exacerbates the soil erosion process. On top of this, soil compaction due to heavy agricultural machinery has led to reduced infiltration and storage capacity [5, 9, 8, 14] (see Fig. 3.6). To mitigate the impact of the consequences, increased stormwater runoff with transported sediment, the water board of Limburg started around 1990 with the construction of stormwater detention ponds, following some severe mudflow events in 1982 and 1987. At present, more than 400 of such basins have been constructed and more are planned (e.g., Fig. 3.8).



Figure 3.6.: Limited infiltration capacity on compacted loess soils in Terblijt during a local summer storm.



Figure 3.7.: Deposits after a mudflow in Terblijt (21 May 2018; Photo: Nimfoma). Unfortunately for the inhabitants, another rainfall event leading to a mudflow with similar consequences occurred only 6 days later.



Figure 3.8.: Visualisation of the planned stormwater detention ponds in the dry valley of the Vrakelbergerweg not far from the picture shown in Fig. 3.3.

Characteristics of the Geul river

The Geul river has its source near the village of Lichtenbusch in Eastern Belgium. It crosses the Belgian and Dutch border close to Cottessen and joins the river Maas west of Meerssen. The total length of the river is 56 km and the catchment area covers 380 km^2 (see Table 3.1. The gradient of the Geul varies from 0.02 m/m near the source to 0.0015 m/m at Meerssen with a total fall of about 250 m. In the catchment area, the average precipitation surplus is 300 mm/y [15], which produces an average discharge of 3.4 m^3/s at the river mouth. The discharge at the entrance of the centre of Valkenburg reconstructed from the July 2021 event however is 135 m^3/s [16]. For Dutch standards, the Geul is a fast flowing river with active meandering. Lateral erosion rates are high (up to 2 m/yr), therefore several stretches of the river have been stabilized and channelized in the past [17]. As a engineering biological measure, poplars and willows have been planted to mitigate bank erosion (see Fig. 3.11).

Due to an accident with a cracked silo in Belgium, a large amount of manure ended up in the Geul in the summer of 2018. This caused a massive fish mortality which only five percent of all fish survived. It seems that rare species such as brown trout and grayling have completely disappeared from the river as a result. Furthermore, the water of the Geul is seriously polluted with heavy metals zinc and lead and as a result it is also is a source of heavy metal inflow into the Meuse. This pollution is a result of former zinc and lead mining activities near the Belgian towns of Kelmis and Plombières (formerly named Bleiberg). The last one of these mines have closed early in the 20th century. One of the reasons for giving up mining activities in Plombières was the occasional flooding of the mine by the Geul.

Table 3.1.: Key figures of the Geul catchment and river [after: 17, 18]

Variable	**Description**	**Value**	**Unit**
Average annual water surplus	precipitation minus evaporation	300	mm
Catchment size	total	380	km^2
	until Valkenburg	303	km^2
Altitude	min	38	m
	max	359	m
Slope gradient in the catchment	median	5	°
	90 % quantile	24	°
River length	total	56	km
Height difference	total	245	m
Discharge	annual mean at Dutch-Belgian border	1.6	m^3/s
	annual mean at river mouth	3.4	m^3/s
	reconstructed max. in Valkenburg (15 July 2021)	135	m^3/s
Grain size sediment	River bed	gravel	-
	Floodplain	silty-clay	-

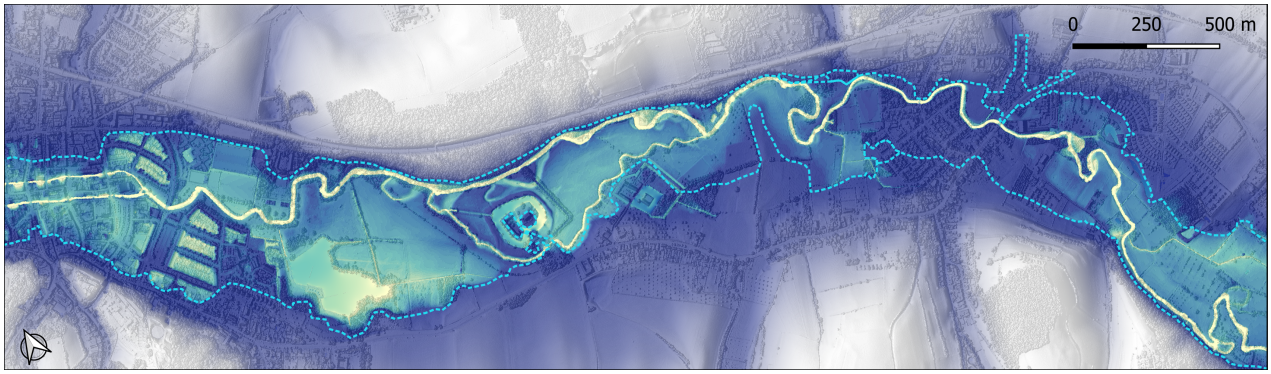

Figure 3.9.: A relative elevation model (REM; after [19]) of the meandering Geul (the white line) between Schin op Geul and Valkenburg with the relative elevation to the valley sides shown in blue. The extent of the area flooded in July 2021 is shown by the blue dotted line.

The following photos show impressions of the Geul river along its course from the source to the mouth.



Figure 3.10.: The river Geul incising in limestone from the Seilles formation south of Kelmis/Calamines approximately 7 km from its source (gradient 0.01 m/m).



Figure 3.11.: The river Geul north of the Belgian and Dutch border near Cottessen with planted poplar trees for reducing bank erosion (gradient 0.005 m/m).



Figure 3.12.: The flooded Geul river close to Wijlre (view towards Stokhem) on 14 July 2021 (gradient 0.004 m/m).



Figure 3.13.: The river Geul close to Ingendael east of Valkenburg (gradient 0.003 m/m).



Figure 3.14.: The mouth of the Geul at the river Maas (gradient 0.0015 m/m).

4. Flood management in Meerssen

Flooding in Meerssen is caused by 1) overland runoff from the Watervalderbeek draining the catchment upslope of the centre (Fig. 4.1) and 2) the Geul river which occasionally floods parts of Meerssen in the Geul valley.

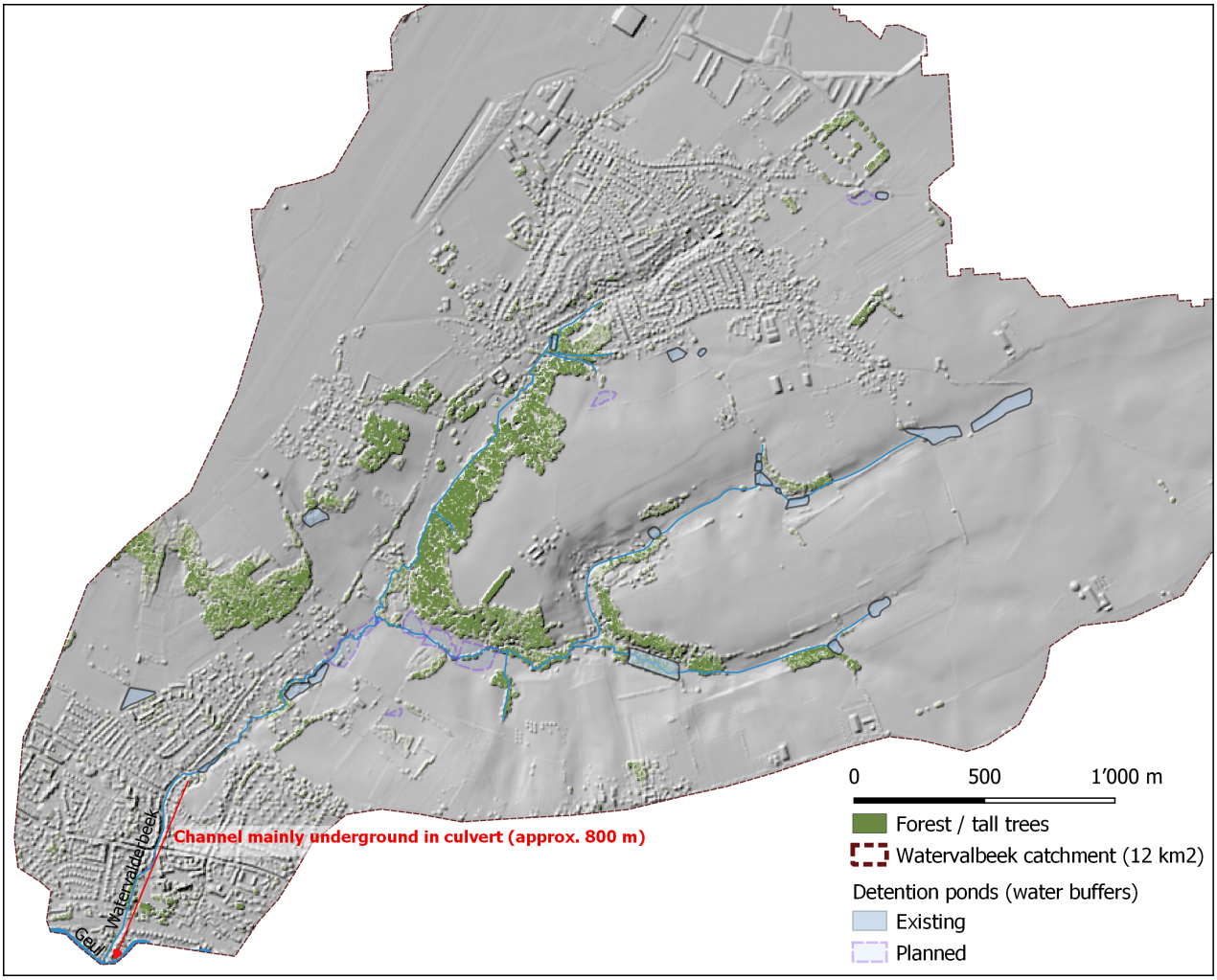

Figure 4.1.: Map showing the 12 km^2 catchment of the Watervalbeek flowing through Meerssen.

The list below provides some key information for the field visit on the flood situation in Meerssen.

- Catchment area of the Watervalbeek: 12 km^2
- Flood protection standard (FPS): once in average 25 y water inside buildings
- Rainfall event matching the FPS (climate 2050): 47 mm in 2 h
- Hydrological model used by the Waterboard Limburg: 3Di
- Available digital terrain model: AHN4 (cellsize 0.5 m times 0.5 m)
- Runoff after infiltration: 180'000 m^3

- Capacity of the existing culvert: 1.2 m^3/s (45'000 m^3 in approx. 10 h)
- Planned additional detention capacity in the source areas (both rural and urban): 45'000 m^3.
- Remaining task for the Waterboard Limburg: buffering another 90'000 m^3.



Figure 4.2.: Flooding of the Geul in the lowest parts of Meerssen on 15 July 2021.

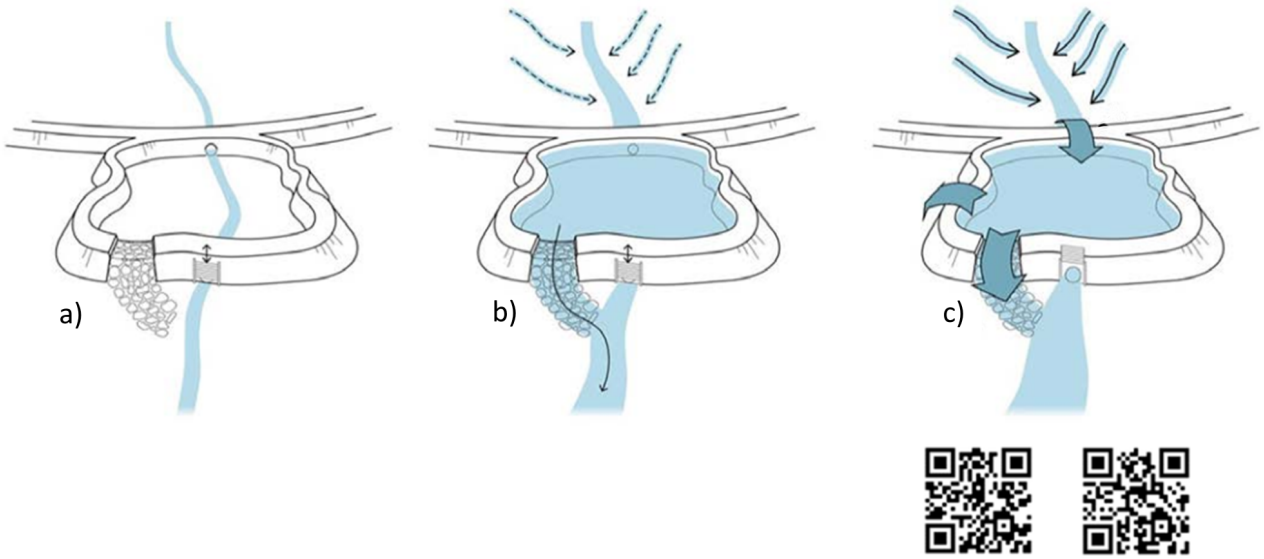

Figure 4.3.: Functioning of the detention ponds during a) normal runoff, b) regular storms and c) the rainstorm event of 29 June 2021.



Figure 4.4.: Consequences of the rainstorm event in Meerssen with 90 mm rainfall in 2 h on 29 June 2021. Upper left: Stormwater runoff after in the center. Middle left: Overview of the damage to the dam of the water detention pond at Visweg (WDPV). Lower left: Erosion damage at the overflow of the WDPV. Upper right: Overview of the filled WDPV. Middle right: Detail of the damage to the dam of the WDPV. Lower right: flooding of the Stationstraat.



Figure 4.5.: Photo from 1905 showing the Watervalderbeek in the Gasthuisstraat 20 in Meerssen.



Figure 4.6.: Stationsstraat in Meerssen (Date unknown).

5. 2021 Flooding hotspots in Valkenburg

Key information on the July 2021 event

In July 2021 the town of Valkenburg aan de Geul and other areas in the Geul valley were severely affected by the floods. In Valkenburg, several streets in the town centre were flooded as well as an area to the west of the town centre where an emergency evacuation took place in three care homes. Damage was estimated at at least 400 million Euros, half of which was physical damage and half being business losses. 2'300 families were affected in the town, 700 homes were rendered uninhabitable and a bridge had collapsed. In total, the municipality of Valkenburg has 16'470 inhabitants (January 2019).

In contrast to Germany and Belgium, there were fortunately no casualties during the July 2021 floods in the Netherlands. The total insured damages in the Netherlands, mainly in the Geul catchment and around the river Maas, were 250 million Euros. Estimates of the total damages add up to more than 1 billion Euros. In Belgium, 39 people died as a result of the floods (mainly in the commune of Pepinster) and on 25 July 2021 five people were still missing. Today, many conclude that, with a precautionary release of the water in the Eupen dammed lake, the worst could have been avoided. The total damage caused was estimated at 2.8 billion Euros. In Germany, at least 186 people died in the flood disaster and Munich Re estimated the damage at 33 billion Euros.

In July 2021, on average 128 mm and maximum 160 mm of rainfall was recorded in 48 h in the Geul catchment. The reconstructed peak discharge in Valkenburg was 135 m^3/s, which largely exceeded the expected 84 m^3/s for a 100 year return period event in the Geul in Valkenburg. The report of [16] mentions an estimated return period of 500 y. The discharge capacity of the Geul at the entrance point of the centre of Valkenburg is about 60 m^3/s.

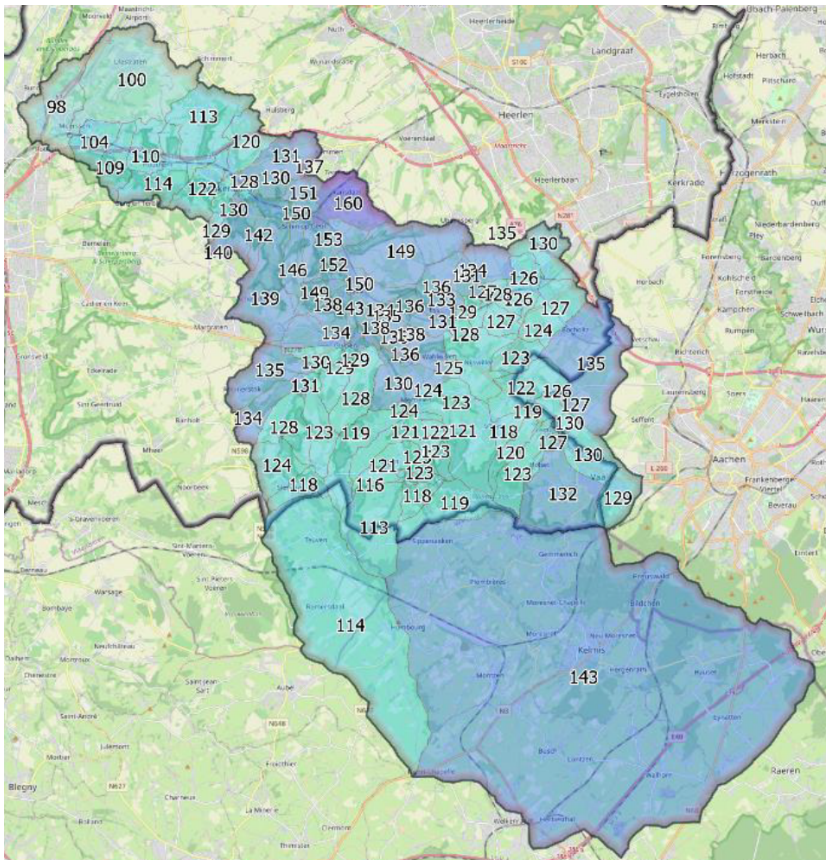

Figure 5.1.: Cumulative rainfall in mm from 13 until 15 July 2021 in the Geul catchment ([16]).

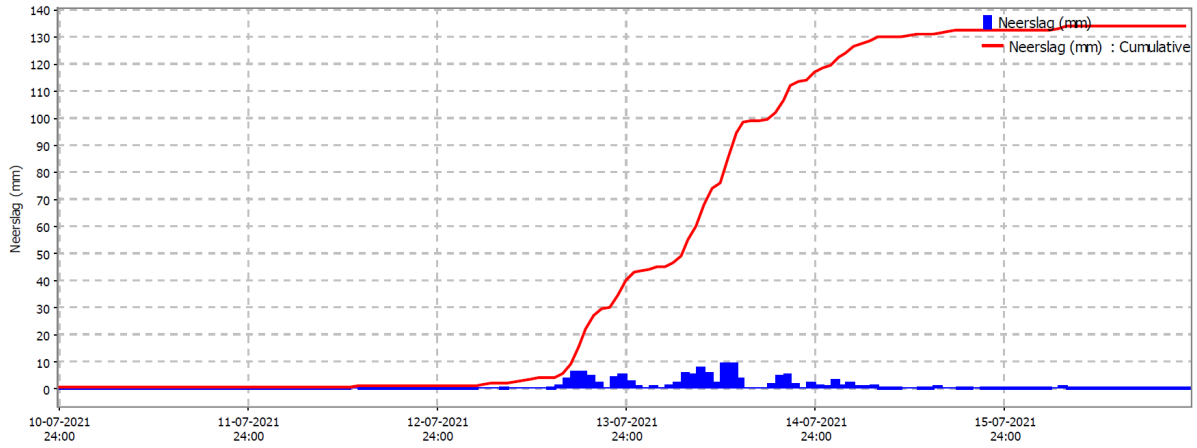

Figure 5.2.: Average hourly rainfall in mm from 11 until 16 July 2021 in the Geul catchment ([16]).

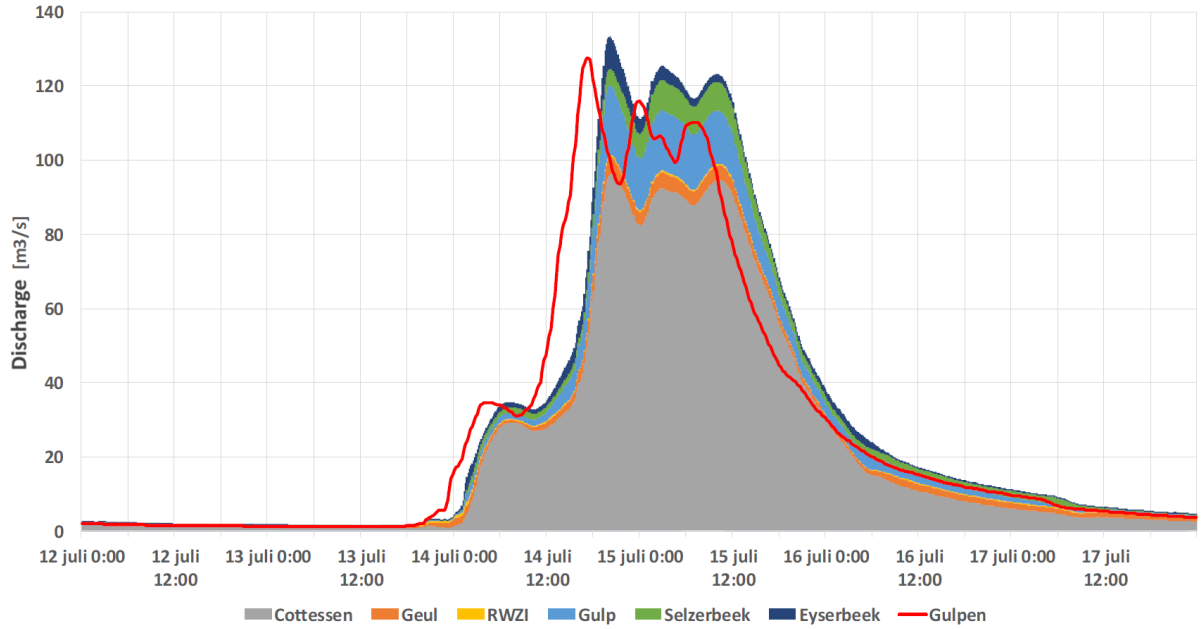

Figure 5.3.: Discharge of the Geul and its tributaries at the entrance of the centre of Valkenburg (and in Gulpen depicted by the red line) between 12 and 17 July 2021 ([16]).

With a catchment area of 303 km^2 and a peak discharge of 135 m^3/s, the specific peak discharge of the Geul is 0.45 (m^3 per second and km^2). When comparing this to other river catchments in Northwest Europe (compare Fig. 5.4), it becomes obvious that the July 2021 event in the Geul catchment is above the average of the many observed specific peak discharges with similar catchment size, but more extreme events cannot be excluded.

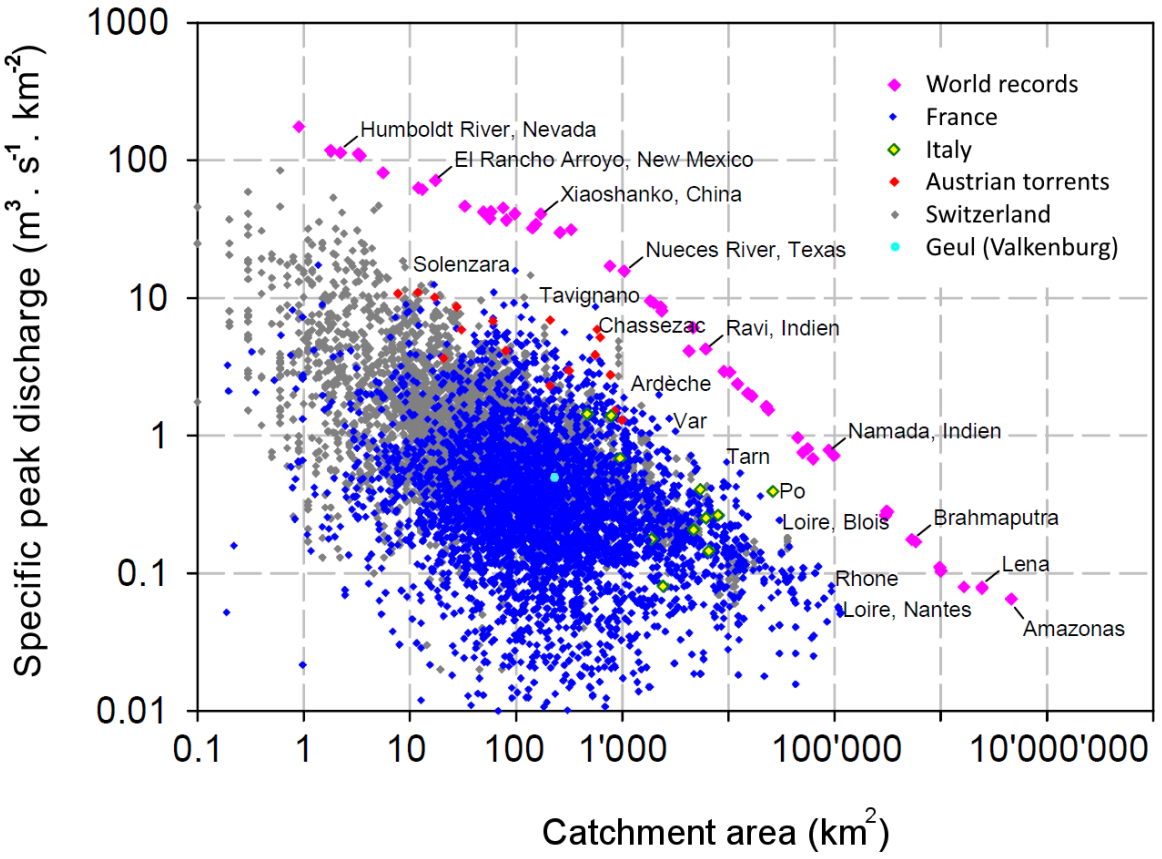

Figure 5.4.: Catchment area versus specific peak discharge for many river systems including the Geul at the entrance of Valkenburg on 15 July 2021 indicated by the blue dot (0.45 m^3 per second and km^2)

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Past flood, excessive surface runoff and mudflow events

Although flooding and and excessive surface runoff events as well as mudflows occurred before in the centre of Valkenburg (see table 5.2 as well as the photos below), the intensity of the July 2021 event was not observed before. A special note deserve the almost flooding events due to problems with the so called *Erken* river lock, upstream of the Walramplein. In August 1977 and January 2011, it was not possible to open the lock immediately, which almost led to flood problems. Although the fish pass constructed in 2008 mitigates the consequences of such technical problems, it is something that should always be taken into account in the flood management strategy.

Based on observations and the available information in newspaper articles [20] and photographs, it was possible to come up with a reconstruction of flood levels of the Geul at the corner of the Theodoor Dorrenplein, which is shown in Fig.5.5. Interestingly, in the Dutch newspaper articles until 1984 the Indonesian word for flooding (*Bandjir*) was often used (see [20]).



Figure 5.5.: Estimated (based on newspaper articles; dashed lines) and observed (solid lines) flood levels of the Geul at the Theodoor Dorrenplein in the centre of Valkenburg.

Table 5.1.: Relevant flooding events of the Geul in Valkenburg

Date	Description	Meteo
28 March 1906	Walramplein and Odapark flooded.	No information.
5 January 1908	Walramplein and Gosewijnstraat flooded. Water in the church reached the level of the seats	Unknown.
10 January 1914	Walramplein and Gosewijnstraat flooded.	Continuous rainfall during several days in combination with temperaure rise from 2 to 10 °C and snowmelt.
31 December 1916	The Walramplein changed into a large pool of water in short time. In all streets the water flowed with great force as it was over 75 cm high and makes it impossible to cross the bridges. Some of them were swept away by the many trees, which came drifting down the Geul with great force. In the church, chairs and benches floated around.	Continuous rainfall during several days.
17 May 1926	Almost complete flooding of the Walramplein and the Gosewijnstraat. Knee deep water in the streets of Geulhem, downstream of the centre of Valkenburg.	Exceptional rain during several days (80 mm in the previous 24 hours).
5 March 1956	Flooding in the Geul valley, especially between Schin op Geul and Valkenburg.	No information.
10 December 1966	In the centre of Valkenburg some roads were flooded; estimated peak discharge of 65 m^3/s.	Continuous rainfall during several days, 30 mm on the flooding day itself.
6 February 1984	Flooding in the Geul valley, especially near Schin op Geul. Garages and cellars flooded in Valkenburg, in addition to local mudflows.	Approx. 57 mm rain in 24 h.
28 February 1987	Worst flooding since 70 years. Sudden rise of the Geul, which was not flowing but swirling, leading to flooding of the center of Valkenburg and erosion of the bank protection of the Geul. Water level in the center 44 cm higher than the flood of December 1966.	Approx. 50 cm of snowfall followed by continuous rainfall during one day in large parts of the Geul catchment.
15 September 1998	All traffic in the centre of Valkenburg prohibited. Discharge in the Geul 57 m^3/s; water level approx. 10 cm below the flood event of February 1987.	Continuous rainfall during several days in large parts of the Netherlands.
15 July 2021	Record flood since beginning of existing records of floods and discharge in the Geul in Valkenburg. Discharge in the Geul 135 m^3/s; Total estimated damage: 500 million Euros.	Record rainfall during 48 hrs in Limburg (NL), NRW (DE) and the province of Liège (BE).



Figure 5.6.: Flooding of the Walramplein, Valkenburg (31 December 1916).



Figure 5.7.: Flooding of the lower part of the center of Valkenburg (photo shows the former Hotel Continental at the Koningin Julianalaan; 10 December 1966).



Figure 5.8.: Flooding of the Geul near Hotal Walram and the *Erken* river lock in Valkenburg on 28 February 1987).



Figure 5.9.: Bank erosion along the Geul in Valkenburg (28 February 1987; from: `https://youtu.be/UQBY2PBzQpU?t=720`).



Figure 5.10.: Flooding of the Geul at the bridge of the Burg. Henssingel at the entrance of Valkenburg on 15 July 2021 (photo: Sem van der Wal/ANP).



Figure 5.11.: Flood level at the Walramplein in Valkenburg on 15 July 2021 (photo: Robin Utrecht/ANP).



Figure 5.12.: Flood level at the Theodoor Dorrenplein / Gosewijnstraat in Valkenburg centre on 15 July 2021.



Figure 5.13.: Bridge over the Geul collapsed by bank erosion (Emmalaan, Valkenburg, 15 July 2021).



Figure 5.14.: Areal photo of the centre of Valkenburg flooded by the Geul taken on 15 July 2021.

Table 5.2.: Relevant excessive surface runoff and mudflow events in Valkenburg

Date	Description	Meteo
11 June 1914	The Grotestraat Centrum covered with up to 10 cm of mud.	No information.
7 August 1982	Destruction of the road surface and damaged houses in the Hekerbeekstraat. Cellars filled with water and mud.	No information.
25/26 April 1987	Cellars filled with water and mud. Again damage to side walls of the Geul	About 55 mm of rain in 2 h including 30 mm in 30 min.
1 May 1993	Decimeter thick mudflows entered and deposited in the centre of Valkenburg.	No information.
25 July 1994	Mudflows entering Valkenburg, especially Grendelplein, Koninginneweg, Wilhelminalaan en Neerhem via the Daelhemerweg and Sibbergrubbe. Fortunately less damage than in May 1993	No information.
16 August 2020	Excessive runoff and small mudflows on the Daelhemerweg, Grendelplein, Neerhem and Koningswinkelstraat	About 27 mm/h rainfall.
22 June 2023	Excessive runoff on the Cauberg, Grendelplein and Grote straat.	Approx. 35 mm/hr rainfall between 17:00 and 18:00.



Figure 5.15.: Mud deposited after a summer storm on 11 June 1914 in the Grotestraat Centrum, Valkenburg.



Figure 5.16.: Damaged houses and road surface due to stormwater runoff in the Hekerbeekstraat in Valkenburg (7 August 1982).



Figure 5.17.: Mud deposited after a summer storm on 2 May 1993 in the Koninginneweg, Valkenburg.

6. Limestone quarry Gemeentegrot

Limestone in Limburg and its usage

The first reports on the use of limestone date back to Roman times, when its use as a fertiliser in the surroundings of South Limburg was described in chronicles. The use of limestone as a building material must also have been known at that time, but the origin of the underground quarry systems we know today (Fig. 6.1) dates from the late Middle Ages (early 13th century). These resulted from a strong demand for building materials for repair work and for the construction of fortifications. Since it was not possible in the late Middle Ages to remove the thick cover layers including overgrowth, quarrying began in those places where suitable limestone was exposed in the slopes. The used technique had its origin in Normandy in the 11th century and consisted of using quite simple tools such as saws, chisels and pickaxes to break blocks out of the wall [21]. Therefore, the persons carrying out this profession were and are still called *blokbrekers* (block breakers; Fig. 6.2). In total, the underground limestone quarries in Dutch and Belgian Limburg had a total gallery length of more than 600 km. Nowadays, quite some galleries collapsed or entire parts of quarries were removed in open pits by the cement industry until 2018 (Fig. 6.3). Nowadays, a handful of block breakers are still active, in quarries outside the center of Valkenburg, to provide blocks for restoration of older buildings and in exceptional cases for building new houses with this traditional stone. Clearly, this led to a significant reduction of the total exploited volume of limestone blocks (fig. 6.4).



Figure 6.1.: Typical passage in a limestone quarry in Limburg for extracting building blocks.

In between the limestone layers in the Maastrichtien that are suitable for building blocks, flint (also called chert) is found systematically in very concentrated layers. The exact mode of formation of flint is not yet clear, but it is thought that it occurs as a result of chemical changes in compressed sedimentary rock formations during the process of diagenesis. One hypothesis is that a gelatinous material fills cavities in the sediment, such as holes bored

by crustaceans (crab, lobster and shrimp like animals) or invertebrate animals and that this becomes silicified. This hypothesis certainly explains the complex shapes of flint nodules that are found. The source of dissolved silica in the porous media could be siliceous sponges (flint consists of almost 100 % SiO_2). The flint stones were mined since neolithic times (5000 to 2000 y B.C.) to be used for axes, tools for tillage and woodworking and later for building foundations of roman villas as well as for sparking (firestarter) or use in firearms.



Figure 6.2.: A group of block breakers at work (location, date and photographer unknown).



Figure 6.3.: The ENCI cement production open pit mine in Maastricht removed tens of kilometers of galleries between 1928 and 2018.

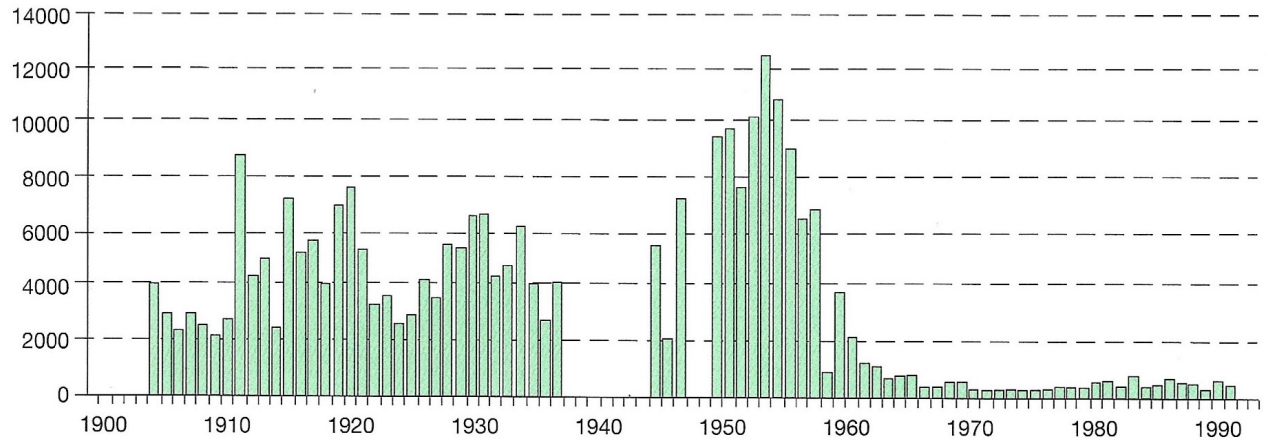

Figure 6.4.: Total volume (in m^3) of limestone block extraction from the quarries in Limburg between 1900 and 1994 (from: [3]; there is quite some missing data between 1937 and 1948).

Tourism and the limestone quarries

Since the completion of the railway between Maastricht and Aachen in 1853, tourism slowly emerged in Valkenburg. Around 1885, the number of hotel stays in Valkenburg had risen to such an extent that the municipality as well as the tourists expressed need for an official body that regulated all aspects of tourism. This task was entrusted to Vereeniging Het Geuldal (association of the Geul valley and co-founded by Theodoor Dorren). One of the committees within the association was engaged in, among other things, the decoration of the gallery system with sculptures and drawings, the improvement of the roads in the quarry, the appointment of guides, the regulation of the entrance fees, the organisation of torchlight processions and concerts in the quarry.

A more extreme examples of adapting the gallery systems for tourism are the chapels that can be found in various gallery systems. From 1797 until 1802, it is believed that a small number of Catholic priests founded secret chapels inside the gallery systems. The reason was the French occupier, and from 1799 onwards Napoleon, who closed down all the churches and firstly forced Roman Catholic priests to swear hatred to kingship and later allegiance to the French constitution, including the obligation to pray for the well-being of the head of state. Those who refused were exiled, but some offered resistance by holding secret masses underground. Amnesty was given by Napoleon to all Roman Catholic priests in May 1802, after signing the concordat of August 1801 with Pope Pius VII in Paris. Today, it is believed that those priests did hide in the gallery systems, but that the chapels were made in remembrance of the religious persecution and to add weight to the story told to the tourists.

In 1880, the block breakers were denied access to the quarries due to conflicts around stability of the galleries, while tourists could visit them in masses. This led to a small protest among the block breakers. However, there was plenty of work to be found in other quarries in the area, so the protests soon died down. When a major collapse occurred in 1886, the Valkenburg quarry was closed down again for block breakers. The quarry was therefore only accessible for tourism. In the winter of 1887 to 1888, an iconoclasm occurred in the Valkenburg quarry, during which statues and drawings were destroyed or seriously damaged [22]. From 1891 onwards, the municipality of Valkenburg started to exploit (for touristic purposes) the gallery system itself after withdrawing the exploitation rights of the Vereeniging Het Geuldal [21]. From then on, the Valkenburg quarry was called the *Gemeentegrot*. In 2018, approximately 60'000 tourists visited the Gemeentegrot for guided tours. The yearly Christmas markets in the gallery systems in Valkenburg attract approximately 300'000 visitors.

Bokkenrijders

A special mention in relation to the limestone quarries and the provinces of Limburg both in the Netherlands as in Belgium are the *Bokkenrijders* (goat buck riders). This group of thieves were seen as ghosts or demons, who rode through the sky on the back of flying goats during the 18th century. Using the name Bokkenrijders, these criminal bands launched raids on farms across the region. Because of the link to the occult, authorities accused a large number of potentially innocent men of being Bokkenrijders and a number of them confessed after torture, analogue to the witch hunts. Several confessed Bokkenrijders were convicted and sentenced to death. During the time of growing tourism in Valkenburg (around 1880), visitors were told that the Bokkenrijders met in the underground quarries, which is actually never proven.



Figure 6.5.: Illustration of a Bokkenrijder created for a theatre play in 1919.

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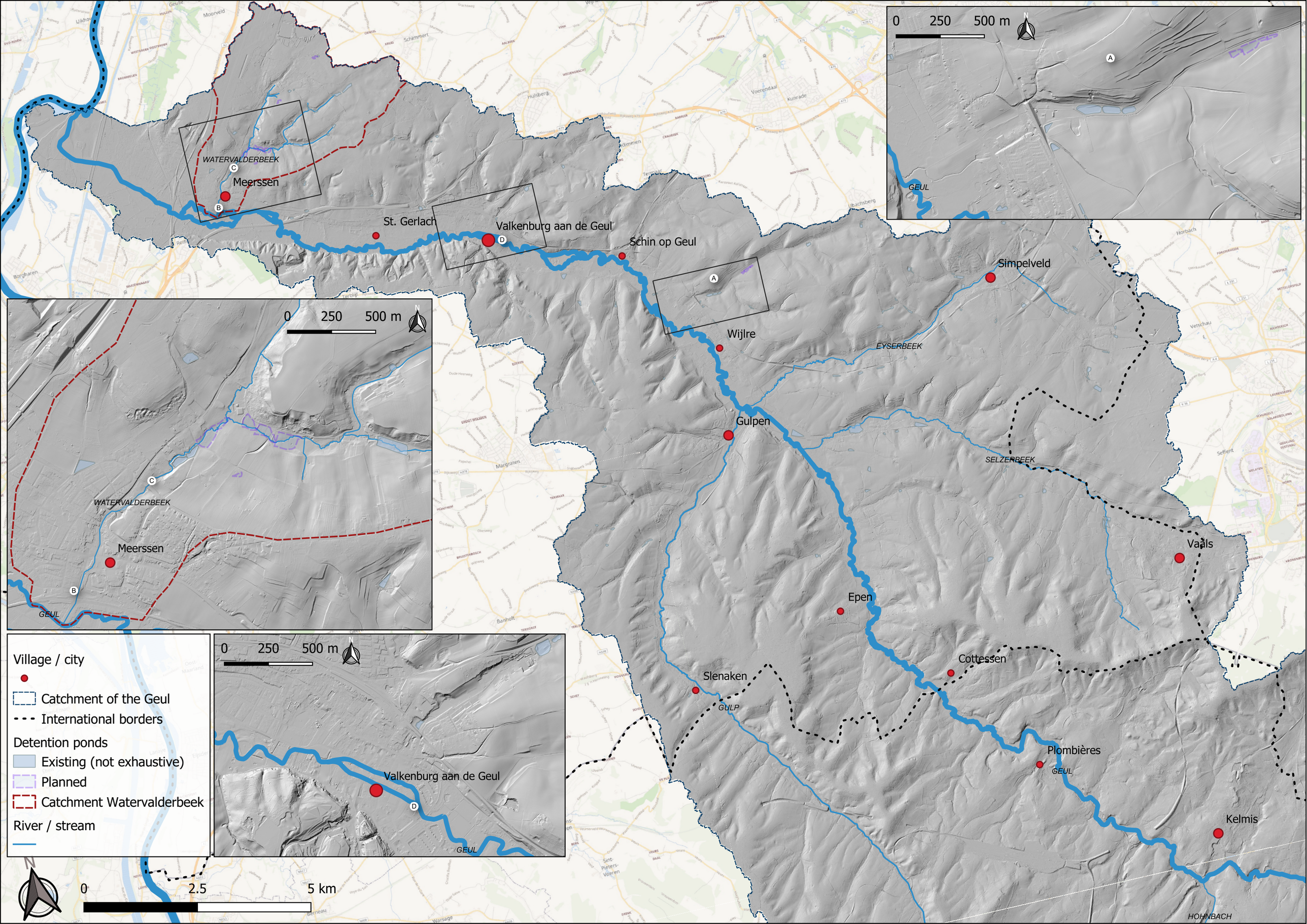
A. Annexe I - List of excursion participants

Family name	First name	Organisation	Country
Alne	Ingrid	Skred AS	Norway
Arnold	Philippe	Federal Roads Office FEDRO	Switzerland
Asselman	Nathalie	Deltares	the Netherlands
Berger	Frédéric	INRAE	France
Berghs	Marlie	Waterschap Limburg	the Netherlands
Bergkamp	Ger	ARCOWA SA	Switzerland
Brekke	Ingvild	Skred AS	Norway
Burkhard	André	Geoformer AG	Switzerland
Cohen	Denis	CoSci Ltd.	United States
Dorren	Luuk	Bern Univ. of Applied Sciences - HAFL	Switzerland
Fallon	Catherine	Univ. Liège	Belgium
Finch	Bryce	Univ. Lausanne	Switzerland
Giadrossich	Filippo	Univ. Sassari	Italy
Hermans	Simone	Waterschap Limburg	the Netherlands
Hoffer	Maaike	ecorisQ office	the Netherlands
Hollard	Niels	Bern Univ. of Applied Sciences - HAFL	Switzerland
Janssen	Aldo	Waterschap Limburg	the Netherlands
Kingma	Nanette	Univ. Twente	the Netherlands
Losey	Stéphane	Federal Office for the Environment FOEN	Switzerland
Luijten	Marco	Waterschap Limburg	the Netherlands
Maier	Bernhard	Stand Montafon	Austria
Marras	Elisa	Univ. Sassari	Italy
May	Dominik	Bern Univ. of Applied Sciences - HAFL	Switzerland
Murgia	Ilenia	Univ. Sassari	Italy
Phillips	Chris	Landcare Research	New-Zealand
Prevoo	Daan	Municipality Valkenburg aan de Geul	the Netherlands
Raymond	Pierre	Terra Erosion Control Ltd	Canada
Sandri	Arthur	former head of section FOEN	Switzerland
Schmidt	Kevin	U.S. Geological Survey USGS	United States
Schwarz	Massimiliano	Bern Univ. of Applied Sciences - HAFL	Switzerland
Simoni	Silvia	Mountain-eering Srl	Italy
Teunissen	Paul	Waterschap Limburg	the Netherlands
Van Brussel	Josef	Ministry of Infrastructure and Water Management	the Netherlands
Vuaridel	Marceline	Bern Univ. of Applied Sciences - HAFL	Switzerland

B. Annexe II - Map with excursion stops


0 250 500 m
A
GEUL
0 250 500 m
C
WATERVALDERBEEK
Meerssen
B
GEUL
0 250 500 m
Valkenburg aan de Geul
D
GEUL
Village / city
Catchment of the Geul
International borders
Detention ponds
Existing (not exhaustive)
Planned
Catchment Watervalderbeek
River / stream
0 2.5 5 km
St. Gerlach
Valkenburg aan de Geul
Schin op Geul
Wijlre
Gulpen
Simpelveld
EYSERBEEK
SELZERBEEK
Vaals
Epen
Slenaken
GULP
Cottessen
Plombières
GEUL
Kelmis
HOHNBACH