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A LANDSCAPE FORENSIC INVESTIGATION OF THE 2021 FLOOD IN THE AHR VALLEY, GERMANY

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ABSTRACT

The Ahr River experienced a catastrophic flood in July 2021, damaging or destroying nearly every home and piece of infrastructure in the valley. Though the river has had serious floods in history, contemporary methods to measure risk failed to account for the qualitative descriptions available and instead referenced a limited qualitative data set that has been collected since 1947. This drastically underdimensioned the risk of flooding for the Ahr during low pressure system “Berndt”, which led to approximately €40 billion in damages in the region and the deaths of 135 people in the Ahr Valley alone. A comprehensive plan for disaster risk reduction is necessary but still completely lacking nearly a year after the disaster. The understanding of what is needed to reduce risk has developed through history, with several paradigms that underwent major shifts in how we see nature, spaces, and people as having a role. These paradigms are used to understand the benefits and limitations of planning concepts in each, so that an optimal risk reduction plan can be produced for the Ahr Valley reconstruction.

Tourism imagery pre-flood, Walporzheim (Rheinland-Pfalz, 2020)

ACKNOWLEDGEMENTS

I was not initially admitted into the GLA program, being deemed “not qualified”. After ten years of the immigrant hustle in Norway, I am used to hearing that I am not qualified. It is a humbling term - one that (sometimes sharply) highlights personal deficiencies. But rather than a term of discouragement, I see it as one of motivation. Becoming “qualified” requires real work, and I do not take for granted the amount that is needed to reach that point, let alone excel. As an immigrant, it takes even more. I was given a gift when the admissions committee changed their mind about my acceptance. I cannot thank them enough for letting me participate in this master’s program, and I think it has been a mutually beneficial choice. This opportunity has absolutely, fundamentally changed my life trajectory. It was a risk to return to school at a complicated time in my life, but well-worth it. I now complete this degree with an exciting and relevant career to begin, a deep new knowledge bank, and two- and five-year old boys at home that are eager for a little more mamma time.

It is bittersweet to conclude my studies. Studying as a 30-something-year old was much more interesting than it was in my 20s, as evidenced by the size of this thesis. If I had years to work on this master’s thesis, I would find new things to add, discuss, or define continually, but alas (and maybe fortunately for the reader), everything must end. This thesis is done but not really finished, and I look forward to future collaborations with the GLA department on the topic.

I would like to thank Jörg Rekittke, Kerstin Pothoff, Jorg Sieweke, and Gabriella Trovato for imparting their wisdom on me throughout the semesters. I realize how fortunate I am to be in the first generation of GLA students. Our small class allowed for a much greater degree of guidance and camaraderie than will ever be possible again. My lovely new friend Molly Andrews has made the courses particularly enjoyable, a big thanks to her for all of the company, lessons, and encouragement. I would like to extend a very special thank you to Jörg for making my educational journey so fruitful, and it has been a real pleasure to know him. It was a privilege to publish a paper with him (and Molly), to receive such thought-provoking feedback in our studios, and to have his outstanding supervision for this thesis. His dedication to his work and students is exemplary and I appreciate it immensely.

Last but certainly not least, this education would not have been possible without the extraordinary support of my husband, Luis. We definitely take on too much in life, and you are my rock to help me make it through it all. Parenting, working, and schooling may be aging us prematurely, but at least it’s always interesting.

We see order out of chaos.
The more we discern, the less we seem to know (Bell, 1999)

Rivers.... Were made for wise men to contemplate, and for fools to pass by without consideration (Walton, 1653)

Immediately following the flood, Schuld (Rattay, 2021)

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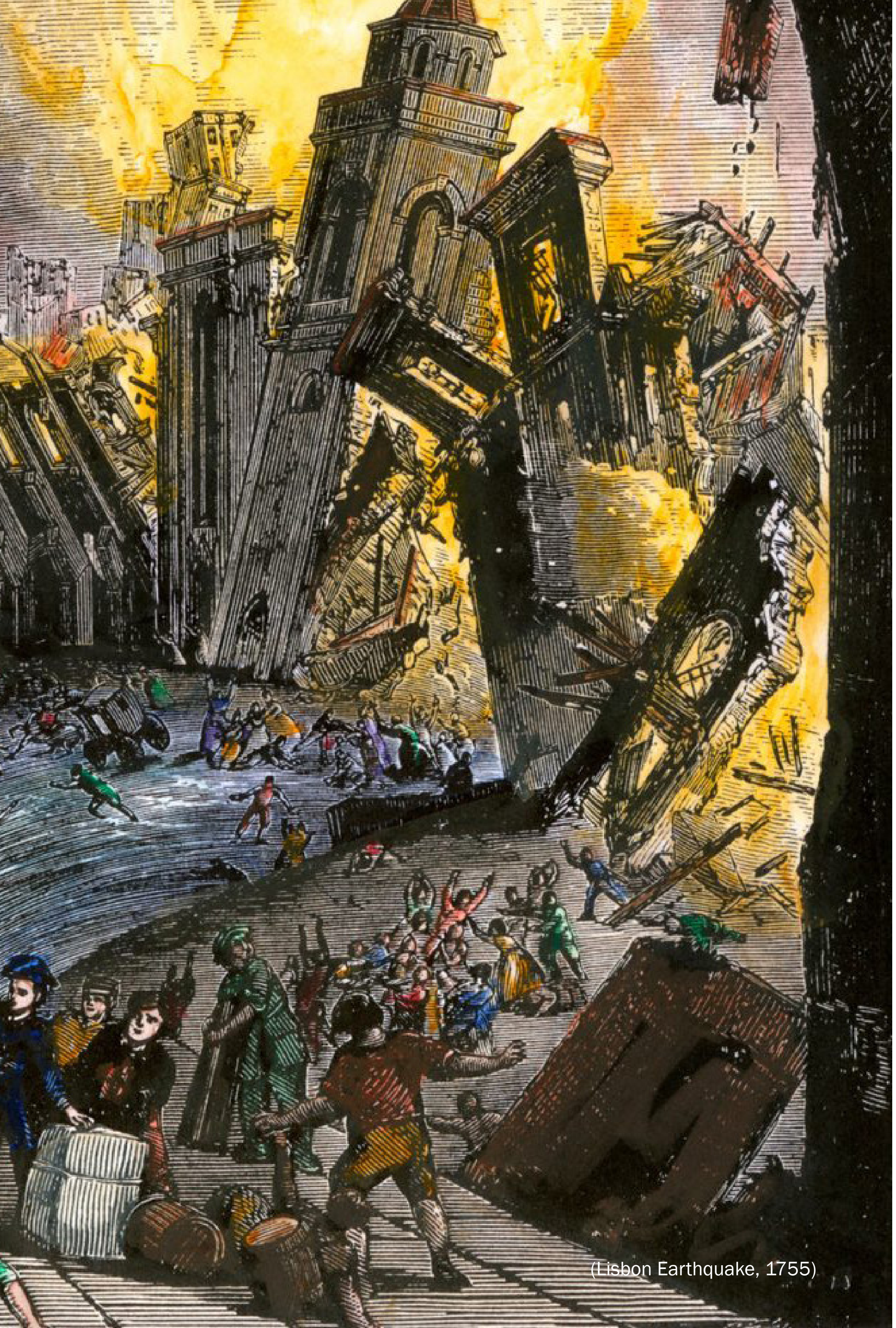
INTRODUCTION


(Lisbon Earthquake, 1755)

Unhappy mortals! Dark and mourning earth!
Affrighted gathering of humankind!
Eternal lingering of useless pain!
Come, ye philosophers, who cry, “All’s well,”
And contemplate this ruin of a world.
Behold these shreds and cinders of your race,
This child and mother heaped in common wreck,
These scattered limbs beneath the marble shafts—
A hundred thousand whom the earth devours,
Who, torn and bloody, palpitating yet,
Entombed beneath their hospitable roofs,
In racking torment end their stricken lives.
To those expiring murmurs of distress,
To that appalling spectacle of woe,
Will ye reply: “You do but illustrate
The iron laws that chain the will of God”?
Say ye, ‘er that yet quivering mass of flesh:
“God is avenged: the wage of sin is death”?
What crime, what sin, had those young hearts conceived
That lie, bleeding and torn, on mother’s breast?
Did fallen Lisbon deeper drink of vice
Than London, Paris, or sunlit Madrid?

- Voltaire, *Poème sur le désastre de Lisbonne* (Voltaire, 1755)

THE ROLE OF PEOPLE IN NATURAL DISASTERS

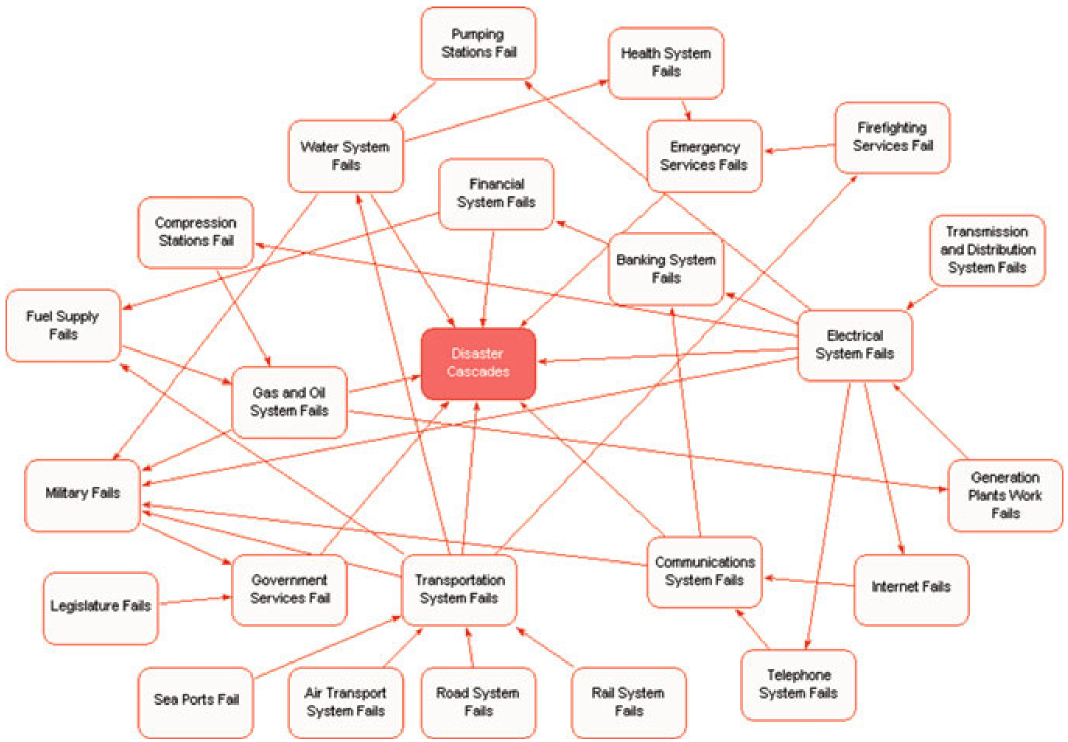
PARADIGMS OF DISASTER RISK REDUCTION MANAGEMENT

The Age of Enlightenment was a turning point in humanity's understanding of their place in nature. During church services on All Saint's Day in 1755, an earthquake devastated Lisbon - one of Europe's largest capitals at the time - killing tens of thousands of people between the quake and subsequent tsunami and fire. It had lasting ramifications on the national economy – costs were estimated to be between 32 to 48% of Portuguese GDP and prices and wages remained volatile for years despite strict controls (Pereira, 2009). The scale of the disaster led Voltaire and other intellects to begin to consider that it may not in fact be our sins and the whims of Providence that are responsible for such tragedy and hardship but it is us - the people, the state, and the environment that we build (Marques, 2005). After all, would a similar earthquake be noticed in a desert?

This thought shifted the disaster risk paradigm from "Acts of God", where people are the victims of external forces with little chance to influence the fate outside of prayer and good behavior, to a technical "Man over Nature" paradigm (Oliver-Smith et al., 2016). Engineered solutions were built purporting to reduce disaster risk, such as dams and dikes for flood control. These solutions gave a false sense of security to people, as they can fail and they cause other adverse ecological problems. In the 1900s, the next evolution in understanding disaster risk emerged as people became concerned about the protection of the environment. "Man in harmony with Nature" aimed to limit ecological degradation as a method to reduce disaster risk and included techniques such as natural conservation areas. While ecologically important, this paradigm is limited in its ability to counter natural disasters. It has since been recognized that people play an important a role in disaster risk, which led to the most recent "Resilience" paradigm. Two and a half centuries since Voltaire's reflections on disaster risk reduction, and the field is still changing.

In this latest paradigm, resilience is defined as a community's capacity and capability to minimize disaster risk. Resilience is comprised of three variables - hazard, exposure, and vulnerability. Hazards can be social constructs like poverty, as well as physical processes, like storms. Exposure is the degree to which people, infrastructure, production, wealth, natural resources, etc. are placed in a risk zone. Vulnerability is the likelihood of incurring damage and loss, including life, livelihood, and property. Identifying the hazard, exposure, and vulnerability helps to identify the underlying root causes of a disaster (Oliver-Smith et al., 2016; Pandye et al., 2015). This in turn helps to predict or explain the scale of losses.

For the past decades, disasters have become increasingly intense despite technological and scientific advancements. Scientists understand weather hazards



A model of cascading critical infrastructure failure (Taylor, 2016) better, but they are still lethal and costly. The resilience paradigm addresses the reasons for this. Natural hazards, such as storms, do not have to be disasters, but they become so when they are compounded by human decisions (Katina, 2016; Mclean, 2011; Prizzia, 2016; Taylor, 2016; Wenzel et al., 2013). The Forensic Investigation of Disasters framework (FORIN) takes it one step further: “They [natural disasters] are not merely not natural, they also don’t exist independently as things or as objects. They are only moments of space-time compression within broader social and historical processes” (Oliver-Smith et al., 2016). Natural disasters are a social construct.

Formerly conventional (and largely environmental) explanations for high-impact disasters are not sufficient, can be misleading, and may result in the misallocation of programs and funding (Burton, 2010). A correct understanding of a disaster requires understanding human decision. They are not necessarily rational, are often causal,

Table 2 An expanded mapping of different levels to support individual and group perceptions

Level of quantification	Level descriptions	Relevant observations
1: Traditional risk	Founded on the basis of probability of occurrence (O_p) and potential loss (L_p)	Besides O_p and L_p, risk calculations may involve measures of exposure, communication, perception, and vulnerability [50]
2: Individual level	A consideration of risk (i.e., O_p and L_p) and influence of individual beliefs	The individual perception measures might involve understanding the role of choice, free will, predispositions, and personal beliefs
3: Culture level	Understanding risk, individual beliefs, and a consideration of culture at the level of the system (organization) of interest	The culture at the location of system/issue at hand may be discerned through ***shared attitudes, values, goals, and practices*** involving organizational structures, knowledge base, degree of connectivity, norms, mass media, and race/ethnicity and dominant ***philosophical paradigms*** (e.g. laissez-faire and precautionary)
4: Societal level	Understanding risk, individual beliefs, culture, and influences at the societal level	Societal influences might be discerned through examination of ***shared attitudes, values, goals, and practices*** at a society level. The scale of operations for societal is at a global level involving elements of time, space and magnitude (e.g., organizational culture versus national ideology)

(Prizzia, 2016)

and have many dependencies that can cause cascading effects (Levy, 2016; Taylor, 2016). Risk drivers like population growth, migration and distribution, rural and urban land-use patterns, infrastructural construction, environmental degradation, ecosystem depletion, and poverty complicate a disaster (Oliver-Smith et al., 2016). The damages and losses in a disaster must be explicitly described and contextualized on a local level to identify the complex interwoven causes.

Reducing disaster risk has several limitations. First, there is a disconnect between the academic discourse and the understanding of the public. Media and politicians often portray natural disasters as unexpected or freak events, lacking a socially constructed aspect. Damage at a local level seldom discusses the human-caused element, and people are still seen as blameless victims. Victims are devoid of identity - history, ethnicity, gender, social status, and culture. Without understanding the deeper story, it is impossible to define their role in disaster risk reduction and to develop an appropriate a risk management strategy (Masys, 2016; Oliver-Smith et al., 2016).

A second limitation is that existing research focuses heavily on families and households, with limited information at community, regional, and national levels (Levy, 2016). Additionally, most analyses occur after an event. Disaster professionals still struggle to understand complicated causes (Levy, 2016). More focus needs to be places on risk reduction and avoidance measures rather than the response post-disaster (Masys, 2016; Oliver-Smith et al., 2016; UN ODDR, 2021). The UN’s Sendai Framework for Disaster Risk Reduction 2015-2030 was created to address this gap in research and policy.

To help illustrate the concepts of the resilience paradigm, Hurricane Katrina is an often-cited example in disaster risk reduction literature (Katina, 2016; Levy, 2016). This Category 3 hurricane stretched over 400 miles in diameter and arrived on the US south coast with a storm surge of up to nine meters. The surge overwhelmed sea walls and the heavy rainfall led to breached levees and extensive flooding. New Orleans was particularly hard hit with over 80% of the city flooded. The storm cause over $108 billion in damages and resulted in over 1800 deaths. The breached levee system has been described as the most expensive failure of an engineered system in US history (Seed et al., 2008). While it clearly had a environmental element, the root causes of the Hurricane Katrina disaster are more accurately attributed to an array of socio-cultural factors (Elder et al., 2007; Katina, 2016; Townsend, 2006).

New Orleans has a long history of racial tensions, and the population is distrustful

Post-flood chaos, “Hurricane Katrina LA1” by News Muse, CC BY-NC-ND 2.0.

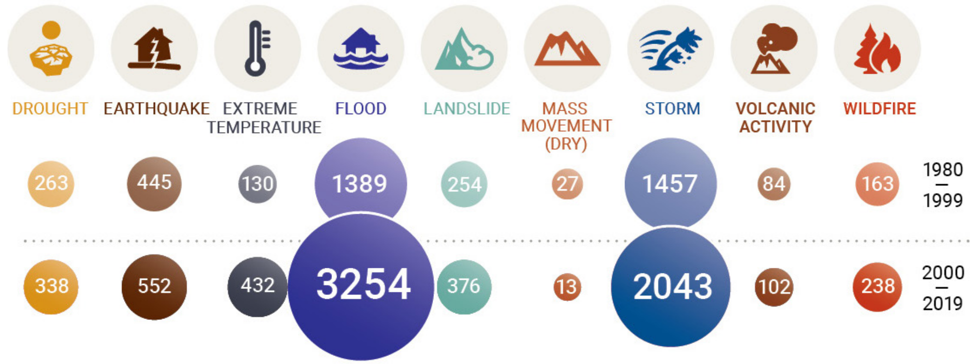
of the authorities, including those issuing evacuation orders. Locals chose to act instead based on past hurricane experiences and ride out the storm at home. Experts knew that the city's outdated and incongruous flood control “system” of levees and a seawall was bound to fail. It was built in the decades following its 1928 authorization, it had little to no modifications to reflect changing regional conditions like weather and sea level rise. But the public trusted the system and their experiences which led to an underestimation of the risk to stay. Once the disaster was underway, there was no authority in control of rescue and oversight which led to a slow and fatal rescue that only reinforced distrust with authorities. Furthermore, reconstruction has been handled poorly as aid projects and government-subsidized flood insurance schemes provided perverse incentives for reconstructing in high-risk areas (Prizzia, 2016), much to the critique of professionals.

CLIMATE CHANGE AS A RISK DRIVER

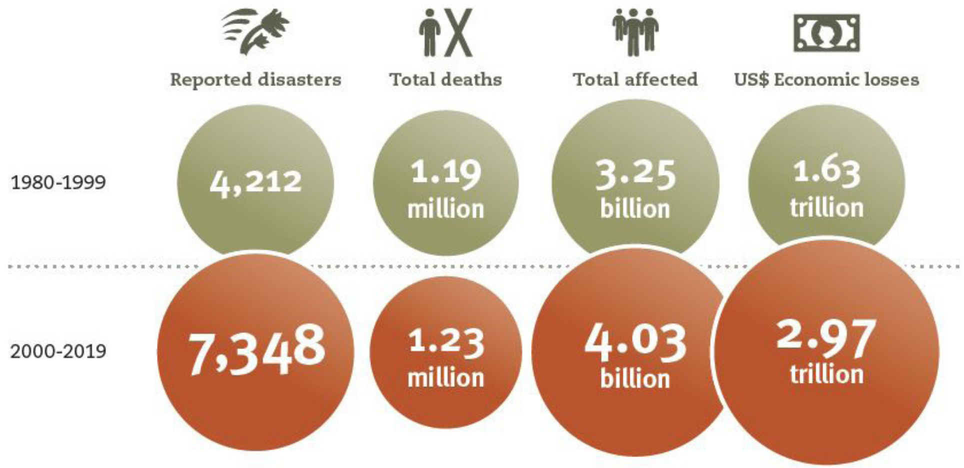
Despite decades of experience, research, and outreach, there are still enormously destructive and deadly disasters occurring at an increasing intensity (Prizzia, 2016). The resilience paradigm is being confronted by a new reality. There is an emergence of high-impact, low-probability events amid climate change that challenge our understanding of risk complexities and disaster risk reduction strategies (FORIN, 2011; Levy, 2016). These are events are known as climate disasters. Climate disasters include flood, drought, storm, extreme temperatures, landslides, and wildfire and exclude other natural disasters like earthquakes and volcanic activity. According to the UNISDR, between 1980 – 1999, there were 3,656 climate disasters resulting in 995.330 death (47% due to drought and famine). This increased to 6,681 climate disasters between 2000 – 2019, but with a lower mortality rate of 470,255. The ten deadliest natural disasters of the past two decades include four climate disasters – the 2008 typhoon in Myanmar, the 2003 heatwave in Europe, the 2010 heatwave in Russia, and a drought in Somalia in 2010. Climate disasters take an enormous toll economically – since 2000, over $2 trillion in losses have been reported, with storms and floods causing the vast majority of destruction (UN DRR, 2020). While there are discrepancies in the quality of reporting, for example only 35% of all disaster events reported figures for economic losses, there is still a clearly increasing trend. Per the 2013 UNISDR Global Risk Assessment, the worst disasters are yet to occur (Prizzia, 2016).

The increasing intensity of natural disasters can be linked to climate change as well as settlement patterns. Global temperatures are now 1.1 °C above pre-industrial period temperatures, with nearly each year of the past decade of marking new heat records (UN DRR, 2020). Sea ice is melting and seal levels are rising, aquatic and atmospheric streams are slowing as they warm, and warmer atmospheres hold larger amounts of moisture (Schäfer et al., 2021). These climatic, hydrological, and meteorological conditions increase the likelihood of more frequent and more intense weather events and with it comes a greater risk of flooding and drought (UN ODDR, 2020). About 10% of the world's population live in coastal areas that are less than ten meters above sea level and are extremely vulnerable to flooding (UN, 2017). 70% of agriculture is rainfed, feeding 1.3 billion people (UN DRR, 2020). Droughts are expected to happen with greater frequency in many areas of the world and they pose serious threats to global food security. Livelihoods in many parts of the world are already difficult if not impossible, and hundreds of millions more could be displaced as climate change continues. A new era of climate refugees is being ushered in an already tense political landscape. Even the resilience paradigm in disaster risk management will not be able to solve all of these issues.

Currently, the world is on track to warm by 3.2 °C, unless industrial nations can reduce their greenhouse gas emissions of 7.2% annually for the next decade. Even if the global temperature increase is limited to 1.5 °C, as prescribed in the Paris Agreement, it will still have severe consequences. We need to expect dramatic changes in strategies for natural disaster risk management, because climate change will dramatically alter the world as we know it (Taylor, 2016). We have reached the point where we need to learn how to adapt to the forthcoming climate change, not just try to stop it from happening. Both natural and human systems will need to be adjusted in response to actual or expected climate changes (Pörtner et al., 2022), and this will introduce new paradigm concepts to consider.



Climate-related disasters (UN DRR, 2020)



All disaster impacts (UN DRR, 2020)

“Flood and landslides in Jakarta kill 26 and displace 62,000” (Hariyadi, 2020)

FLOOD RISK MANAGEMENT

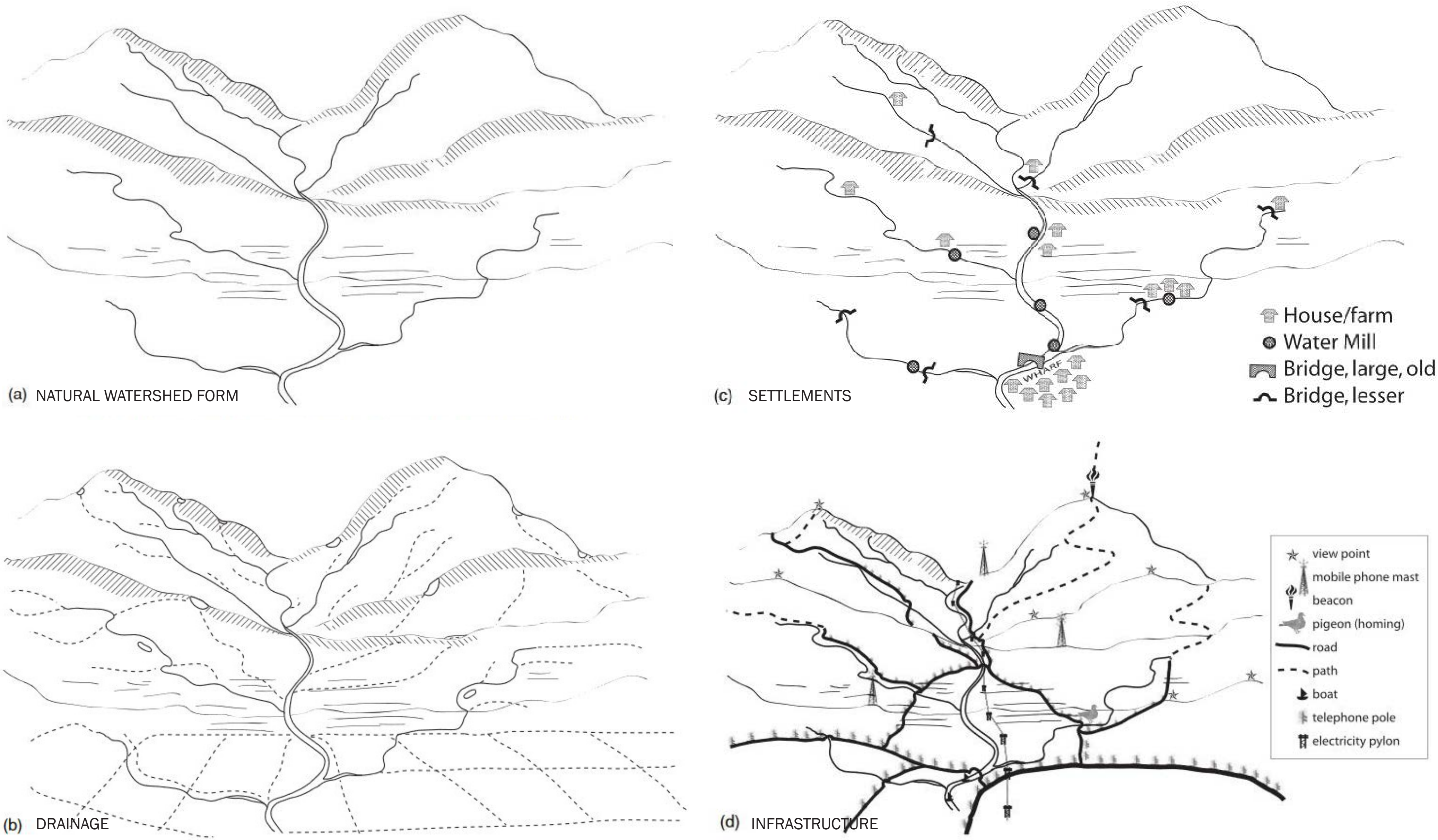
The easiest disaster type to proactively address in climate change is flooding. Flooding has extensive health and socio-economic impacts and is considered a development concern as well as a humanitarian one according to the Center for Research on Epidemiology of Disasters and the UN Department of Risk Reduction (UN DRR, 2020). It contributes to ecological degradation and poses a serious a human health risk if contaminants are released into waterways (Hartmann et al., 2006; Isaji, 2003; Lindell & Perry, 1997; Reible et al., 2006; White, 1993). Floods have relatively inexpensive strategies that can reduce their risk compared to other natural disasters. This ranges from engineered levees to policies that prohibit construction in floodplains. One of the most common reasons for fatalities in flooding is inadequate warning systems, something easily improvable (UN DRR, 2020).

Every settlement worldwide requires access to water, and their subsequent encroachment to coastlines and rivers place them in harm's way. Historically flood-prone areas will face increasingly greater flood threats due to climate change, rising sea levels, and landscape degradation (Levy, 2016). Areas that have not had historic flooding problems may soon experience them. Flood risk management is an urgent global issue.

The degradation that we have caused in the entire global landscape compounds the risk of flooding. In humanity's industriousness in fulfilling basic needs along with luxuries like diesel cars and holidays, we have caused massive ecological degradation in the landscape. This happens with deforestation, intensive agriculture, and urbanization. Ecosystems are removed, simplified, or fragmented; fields and marshes are drained; and rivers are piped or channelized (Haslam, 2008), and it disrupts normal, predictable ecologic and hyrdologic processes in natural systems. This leads to greater rates of runoff and an increased likelihood of flooding on a river.

People have tried to remedy floods with physical controls in the Man over Nature paradigm, with some success and some remarkably tragic failures. We tried to find an ecological and anthropocentric balance to reduce flooding in the Man in harmony with Nature paradigm, but we have not. We find that even planning in the Resilience

A natural river, “Ende mountain river (Flores, Indonesia 2016)” by paularps, CC BY 2.0.



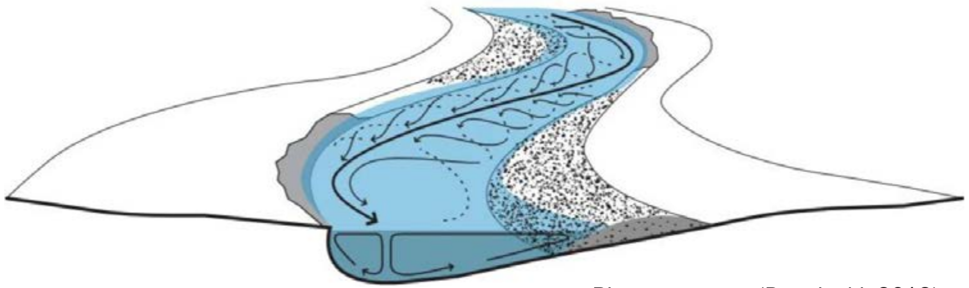
Modifications in a riverscape (Haslam, 2008) paradigm is increasingly less effective with climate change. In order to move forward in flood risk management planning, we need to first step back and obtain a comprehensive understanding about the processes of a natural river system. This can then be applied from the ground up in contemporary flood risk management.

NATURAL RIVER SYSTEMS

The term “natural” in natural river systems is controversial, in that it means to be untouched or unaffected by human impact. There is no place untouched by humans, whether directly by settlements or indirectly by the effects of climate change and air pollution. In this section, “natural” means as close to its original form and function as possible (Prominski, 2014; Riemann, 2007).

Natural river systems extend far beyond a river – it encompasses the entire drainage basin of a landscape. This includes forests, meadows, streams – all ecosystems are a part of a river system. The landscape through which they pass dictates how water moves through the system. They have a vast array of characteristics ranging from hydrologic, physical, landscape, chemical, biochemical, to plants and animals, and eventually economic and societal as well in the use of people. A natural system performs services that include accumulating water and sediment; transport; capturing carbon dioxide via plants, microorganisms, and soil; providing habitat for plants and animals; and generating energy and nutrient-rich land (Haslam, 2008). Water, and thus rivers, are the fundament of life.

A river is the lowest part of a catchment and has three basic characteristic –



River processes (Prominski, 2012)

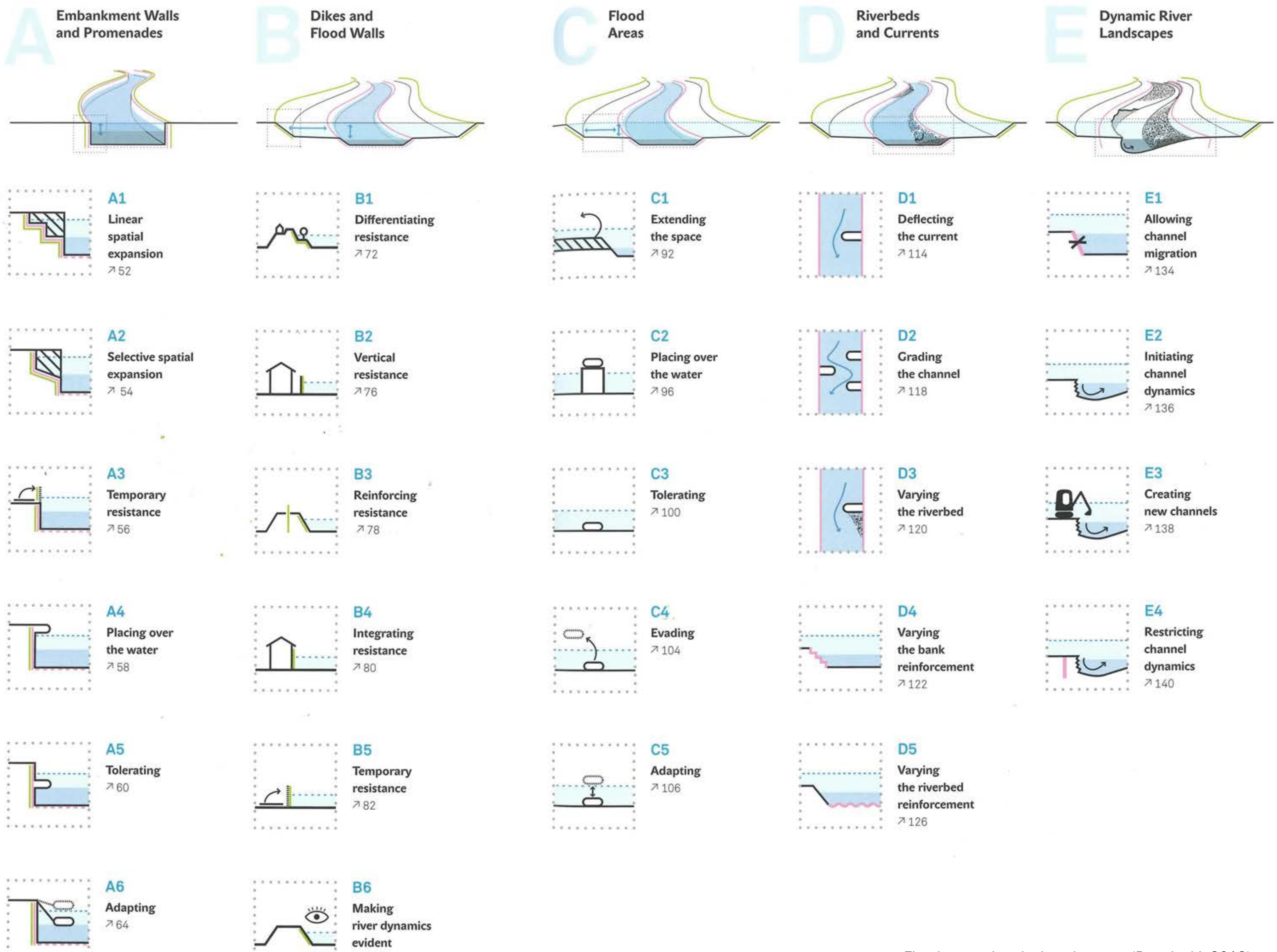
structure, function, and change. The structure is the shape, what grows in it, and what is placed in it, extending to the banks and beyond. Natural rivers are characterized by a remarkable biodiversity. There are great variations in niches – irregular bank edges, spits, bars, islands, and braided channels. Fallen trees and debris add further shelter opportunities. The vegetation of riverbanks vary from woodlands to meadows, which in affect the flow of the river in varying degrees (Bakkestuen et al., 2001; Bell, 1999). Rivers have temporal flow fluctuations both vertically and horizontally, so that much broader territory exists beyond its normal channel(s). This space can be flooded regularly, seasonally, or rarely (Prominski et al., 2012). The function of a river has constant morphodynamic, hydrological process that shape the landscape around it. A river and its system are dynamic; its path will never be permanent (Brookes & Shields, 1996; Haslam, 2008).

The three hydrologic processes of a river are erosion, transport, and deposition. Erosion can occur by force of the water wearing away weak banks, by stones carried along by water that impact beds and banks, or by the solution of fine particles into the river. There are four different ways for water to transport material. This can be as fine particles dissolved in solution, light material suspended in the water, small debris bounced along the bed, or as traction where large material like boulders is rolled along the bed. The last requires a great amount of energy in the water flow. When rivers lose energy in shallow water or as water volumes subside, the materials that are being transported are dropped and deposition occurs (Robert, 2003).

These processes result in a predictable pattern in natural river development and structure. Coarser materials are deposited first as a flow slows. Fine materials are deposited as sediment in shallow waters or inner bends. The outside of river bends experience a continuous erosion, creating widening loops that slow the flow of water by increasing the length of the river and decreasing its slope. Irregularities in the middle of the channel leave temporary islands or sandbanks during low water periods. Natural rivers tend to be shallower, which results in less damage during flash floods as water more readily spreads into floodplains (Prominski et al., 2012).

MODIFIED RIVER SYSTEMS

As has been mentioned, a river is but a small part of a much larger watershed system. In Europe, significant landscape degradation began with the Romans as they



Flood protection design elements (Prominski, 2012) dredged canals and built bridges to facilitate movement on land and water. They built watermills, fisheries, flood banks to protect towns, navigation banks to confine a river channel, while simultaneously adding pollutants like human waste. Agricultural advancements further altered watersheds and rivers by means of deforestation, altering river position, removing water for irrigation, planing or terracing, and adding more sediments and contaminants in runoff. When people use rivers and their surrounding landscape, they inevitably modify if not exploit them. Today, most rivers are not even close to resembling a natural state. An overwhelming amount of the world's rivers are ecologically dead, if not seriously degraded. Modified rivers receive greater amounts of runoff faster from their surrounding degraded landscape. These changes all contribute to an increasing risk of more forceful floods globally, incurring greater destruction and loss of life (Haslam, 2008).

Humanity has had an enormous impact on the quality of river systems, but they are still an important historic, cultural, social, perceptual, and aesthetic element. Rivers and their landscapes allow for society to flourish, providing a resource for livelihoods, trade, and inevitably art and recreation. But now, risk drivers like climate change and population growth further stress river systems, and we grapple to find effective techniques to manage flood risk that allow society and rivers to coexist. Creating a resilient landscape along with the waterfront communities that they support has many complex factors to plan for, but begins with a basic understanding of hydrology.

FLOOD CONTROL DESIGN

Flood control designs come in many forms. They range from large, brutalist forms such as dams and flood walls that restrain water to ecologically-minded techniques like broadening floodable zones and adding obstacles to slow the flow. Large interventions are not fail-proof and require extensive funding. Using ecological principles to restore a natural river functionality has many ecological benefits, but its effects on flood control are limited. Both options require vast amounts of space to achieve an optimal effect and this requires a compromise for infrastructures – bridges, access, and potentially cities. An array of both large- and small-scale options to flood control design are well-presented by Prominski et al. (2012). Developing control measures is important to help protect against minor floods, but it effectively nothing can be sufficient in protecting against climate change-driven megafloods. An overreliance on designed elements for flood protection overlooks the many

“Flood Wall” by pasa47 is marked with CC BY 2.0.

Pre- and post-flood river formations, Altenahr (LVermGeoRP, 2021b)

Pre- and post-flood river formations, Rech (LVermGeoRP, 2021b) social, economic, and political variables that contribute to destruction and death. As highlighted in the Hurricane Katrina example, the failure of the levees and seawall was far from the only cause for that particular disaster.

There is a prevalent mentality in wealthier countries to underestimate the power of Nature. Higher standards of living and more advanced flood-prevention infrastructure results in less deadly disasters (UN DRR, 2020), and gives people a false sense of security. This is exacerbated by society's disconnect to Nature, as it is difficult to comprehend Nature's severity from the comfort of an urban lifestyle. Urbanization has eliminated the need for landscape literacy, and therefore we can make risky choices because we do not understand the full potential consequences (Riemann, 2007). This can prove to be deadly, as was recently demonstrated in one of the world's most highly engineered countries – Germany.

THE JULY 2021 FLOOD OF THE AHR RIVER

Beginning on 13. July, low-pressure system "Bernd" developed across Europe. Between 100 to 150 mm fell over western German, Belgium and Luxembourg, much of it within only 15 to 18 hours (Wetterdienst, 2022). A number of measuring points failed or were washed away so actual quantitative data are not known for all regions (Schäfer et al., 2021). Comparable rainfall has never been registered in the area before (Kreienkamp, 2021). Flash floods and high flow rates resulted in the deaths of 220 people across Europe, with early estimates of €300 to 600 million of damage in the Netherlands, €350 million in Belgium, and approximately €17 billion in Germany (Koks et al., 2021). This was later revised for Germany to be €30 to 40 billion. Two states in Germany were particularly hard hit – North Rhine-Westphalia (NRW) and Rhineland-Palatinate (RLP), where up to 150-200 L/m2 of rainfall within 48 hours (SWR, 2021b), much of falling within ten hours (Wiebe, 2021). Seven districts were particularly affected by the storm, with the worst devastation in Ahrweiler on the Ahr River (Rheinland-Pfalz, 2022a).

How was it possible to so vastly underestimate the forces of Nature on this river? What root causes need to be taken into account in developing a new flood risk management plan?

"A Fine Mountain River" by MIKOFOX Reject Fear, Go Outdoors, Live Healthy CC BY-NC-SA 2.0.

Mayor of Rech, after losing his mother and family home (Mucha, 2021b)

Altenburg, 2020 (Launer, 2020)

Altenburg, 15. July 2021 (Polizei, 2021)

MATERIALS AND METHODS

Sinzig care facility, site of 13 deaths (Mucha, 2021)

MATERIALS AND METHODS

DISASTER FORENSICS

Disaster forensic analysis is an emergent research field that has been shaped for centuries by philosophical and practical developments and our understanding of society as complicit in disaster. This project uses the Forensic Investigation of Disasters (FORIN) framework, published by the Integrated Research on Disaster Risk Program (IRDR) (Oliver-Smith et al., 2016). The framework shapes cohesive research objectives, analytical themes, and research approaches. The IRDR is co-sponsored by the International Council for Science, the International Social Science Council, and the United Nations Office for Disaster Risk Reduction (UNISDR) and uses a multi-disciplinary approach to understand the factors and challenges of disasters triggered by natural hazards.

FORIN has a broad range of goals that cover topics in research, education and extension, policy, and development and equity. Its research objectives are:

- To confirm and demonstrate with strong evidence that disaster risks are socially constructed
- To identify and assess the principal contributing causes of disaster risk and to identify ways in which they can be reduced or avoided
- To adopt a diversity of approaches to research and to combine their results in such a way as to identify common causes of disaster through the meta-analysis of results
- To promote integrated and transdisciplinary research that engages the full range of stakeholders to enable a more holistic understanding of underlying causes and disaster risk

FORIN outlines two analytical themes. The first is to describe the hazard, exposure, unsafe conditions, and subsequent patterns of damage, loss and impact by asking questions about the triggering event(s); exposure of social and environmental elements; social and economic structure of exposed communities in terms of both vulnerability and resilience; and institutional governance. The second theme is to move beyond analyzing these descriptions to understand root causes and dynamic processes. Questions about population growth and distribution, urban and rural land use patterns and processes, environmental degradation and ecosystem service depletion, and poverty and income distribution help to define these root issues. A list of suggested questions can be found in Appendix I.

This project uses the FORIN disaster building scenario research approach, . In this technique selects a known hazard that preludes a possibly inevitable future event that is considered a factor in future disaster. In short, this looks for future disaster scenarios.

FORENSIC ANALYSIS METHODOLOGIES

A broad array of methodologies can be used to collect and analyze data in disaster forensic research (Architecture, 2022; Levy, 2016; Oliver-Smith et al., 2016; Prizzia, 2016; Wenzel et al., 2013). The following methods were used during this project:

- Audio analysis
- Cartographic progression
- Data mining
- Fieldwork
- Ground truth
- Pattern analysis
- Photogrammetry
- Geospatial approaches (GIS)
- Post-processing data
- Satellite imagery
- Situated testimony
- Rapid impact assessments
- Status of transportation
- Interruption to supply chains

Information was gathered through a literature review of the region, official information from local and government platforms, news articles, and social media. Mapping data was derived from open sources. Scholarly articles and reports were obtained through NMBU's Oria Library system with the search terms: Ahr River, Ahr, Ahr Valley, Ahr geomorphology, Ahr hydrologie modell, Ahr Hochwasser, landscape reconstruction ethics, landscape architecture climate disaster, disaster research, disaster forensics, and river processes. The news and media search was conducted with the Google search terms: Ahr, Ahr River, Ahr River flood, Ahr hochwasserkatastrophe, Ahr flutkatastrophe, Ahrtal. The official Rheinland-Palatinate and Ahrweiler District websites were also used, especially for their press releases. The Twitter search was structured as such: (place) until:2021-07-26 since 2021-07-14, (place, search term) until:2021-07-26 since 2021-07-14, or (search term) until:2021-07-26 since 2021-07-14. Places included Ahr, Ahrtal, RLP, NRW, Schuld, Altenahr, Rech, and Marienthal. Search terms included hochwasser, flutkatastrophe, and flut. Often, links were shared on Twitter that had original sources in Youtube, media, or government websites.

THE AHR VALLEY

Map of Rhineland by Tranchot and von Müffling, 1803-1820 (LVermGeoRP, 2021a)

THE AHR VALLEY

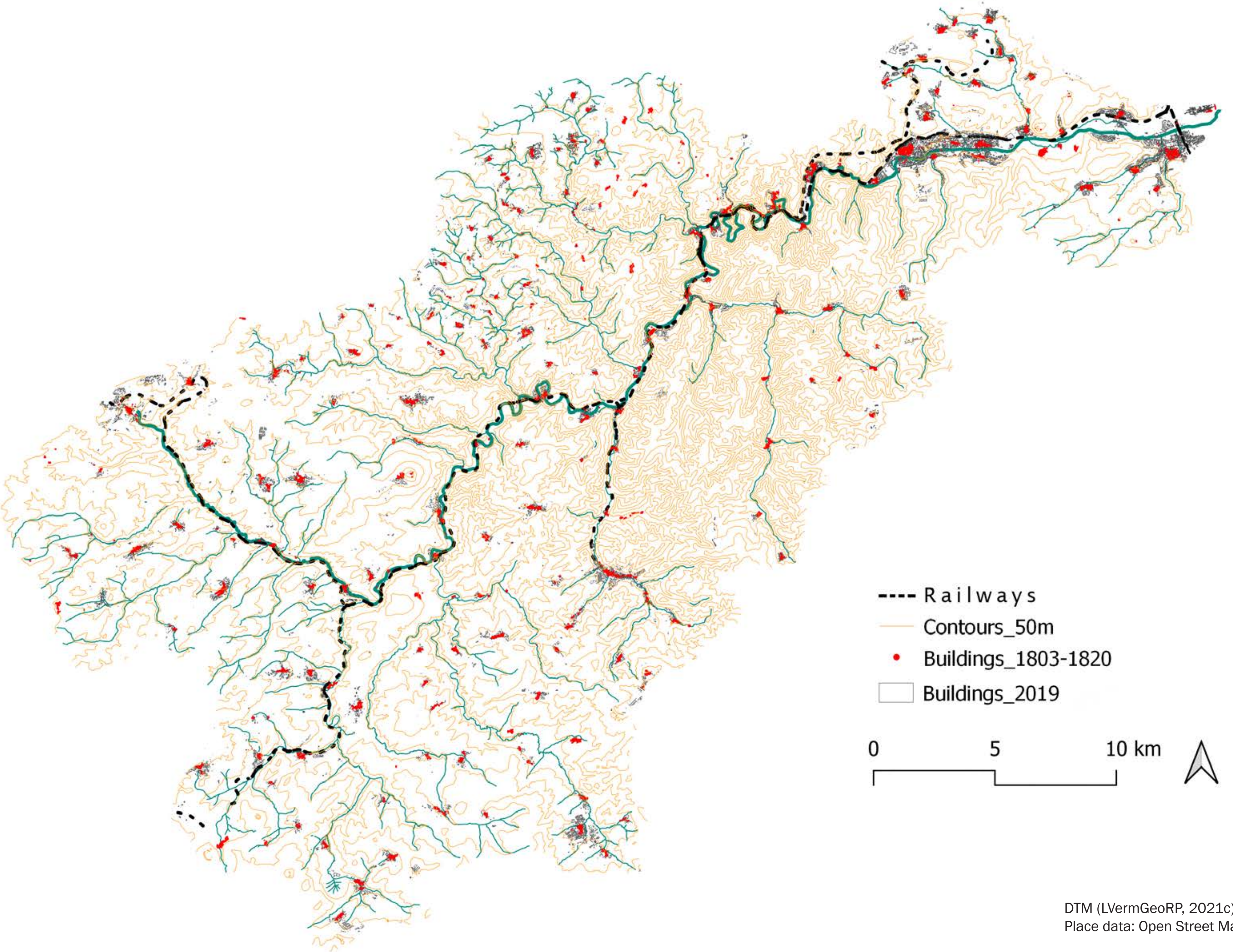
OVERVIEW

The Ahr River and its valley are located in Germany's RLP, with a portion of its watershed lying in NRW. RLP has historically been an agricultural region, with the apt nickname of the "land of vines and beets". It officially became a state in 1946, unifying a diverse and wary population with historical affiliations to the Prussian Rhine Province, Bavaria, and Hesse. The state has had a progressive political agenda and was the first in the nation to establish legal entitlement to a kindergarten place, all-day schools, and the educational leave. While the Ahr Valley is a small, relatively remote region of the RLP, the state is one of Germany's strongest exporters. Its economy is based on foreign trade, industry, and medium-sized companies and produces exports such as commercial vehicles, metal and ceramic, chemical and pharmaceutical, and environmental technologies. It is well-connected in terms of technology (98% use broadband), international air travel (four international airports), high-speed rail, and shipping on the Rhine River (Landesregierung, 2022).

Settlements in the Ahr Valley have been present for centuries. Most of the foundations of contemporary towns began in medieval times (Roggenkamp & Herget, 2014). In the city of Ahrweiler, Roman relics can be found, and a medieval walled city still stands intact. While the largest city in the valley, Bad Neuenahr-Ahrweiler, has grown substantially in modern times, the numerous other scattered villages have scarcely grown beyond their footprint from the early 1800s. Many historic half-timbered buildings and stone bridges remain, lending to a strong historic local identity.

The dominant industry of the Ahr Valley has been and is still based on viticulture. It is thought that the first vineyards were planted as early as 275 C.E., with documented evidence from the late 700s (Braatz et al., 2014). Vineyards were exclusively owned by monasteries until the 11th century and could be found in the villages of Ahrweiler, Walporzheim, Dernau, and Altenahr. Ruins of abbeys persist throughout the valley, and the Marienthal Abbey (founded in 1137) still stands today as a restaurant and concert venue (Brauksiepe, 2022).

(Google Earth, 2022)



DTM (LVermGeoRP, 2021c)
Place data: Open Street Map

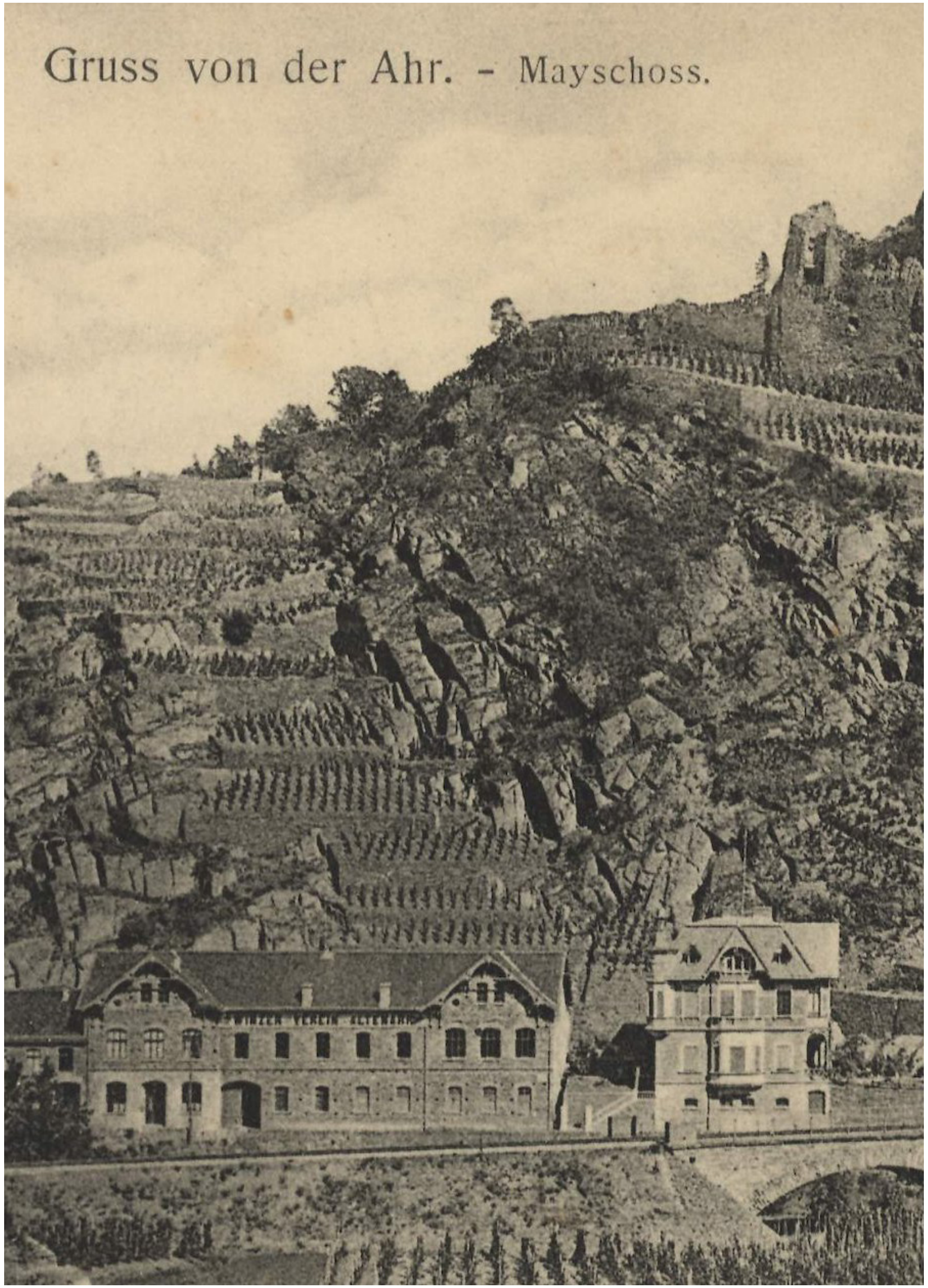
The wines of the Ahr Valley were first exported internationally following the French invasion in 1794 (Braatz et al., 2014). French variants outcompeted the local, leading to a trade with Belgium. Viticulture was an increasingly difficult livelihood and in the mid- to late-1800s, many families in the valley immigrated to America. Those that remained established one of the first winegrowing cooperatives in the world in Mayschoss in 1869 to counter population loss. Still, poor yields, pests, and viruses plagued the valley, and the total amount of hectares of vineyards in production decreased from 1087 in 1883 to 606 hectares in 1925. In 2019, 562 hectares were under production (Ahrwein, 2019; Braatz et al., 2014). Intense land parcelization, terracing, growing costs, and the increasing prices continue to impact operations today.

Post-WWII Germany discovered the region as a holiday destination due to its mild climate, natural scenery and wines and a tourism boom began. Today, the Ahr Valley's red wines have international prestige, and it is one of Germany's most attractive holiday regions. Vineyards are located in the lower 25 kilometers of the Ahr River, with the last in Altenahr (Braatz et al., 2014). The valley can be accessed by rail, car, bike, or foot, and it has an extensive network of trails. The famed Red Wine Trail connects the villages along the Ahr, showcasing the historic buildings and half-timbered houses, vineyards, ruins, and natural beauty (GmbH, 2022). Viticulture is inextricably linked to local identity and defines the Ahr Valley economically, scenically, touristically and culturally (Rheinland-Pfalz, 2022f).

LANDSCAPE

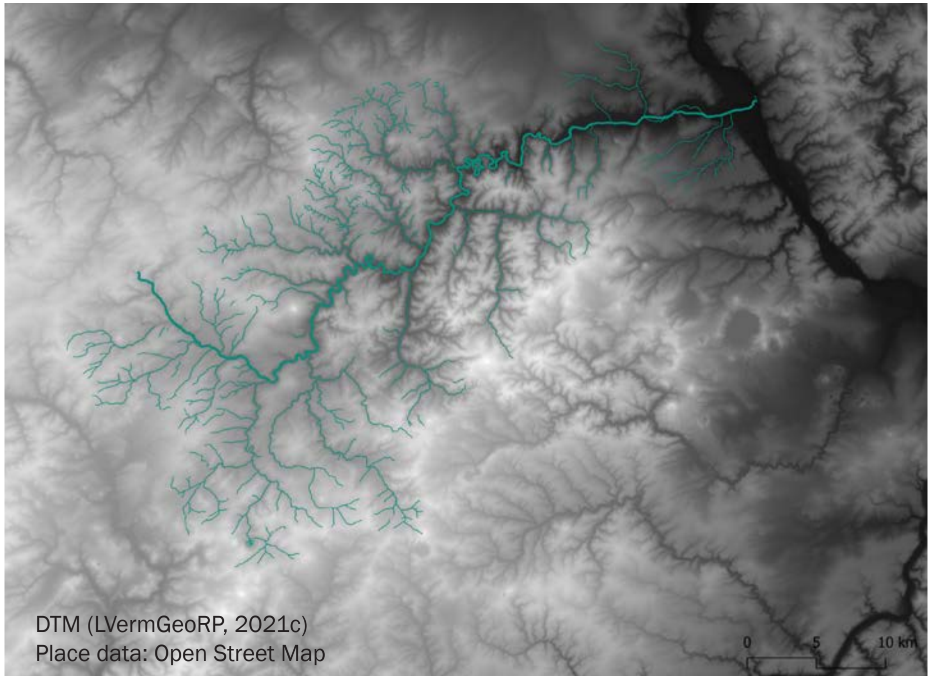
The Ahr Valley is located on the northern edge of the Central Uplands of Germany in an area called the Rhenish Massif (Braatz et al., 2014; Helmfrid & Dickinson, 1953). Deep gorges and valleys have formed through the erosion of these slatey uplands, including the Ahr Valley, which is surrounded by several mountain ranges. To the north lies the High Eifel Mountains (highest peak 747m) and the Venn Foreland, which hosts a large national park. Other Eifel ranges, like the Ahr Hills (624m), extend westward through and around the valley. To the south and east lie the Hünsrick uplands (816m). On the eastern bank of the Rhine River is Westerald (657m) and the Taunus (878m) (Helmfrid & Dickinson, 1953).

The Atlantic Ocean and Gulf Stream moderate the regional climate, but the Ahr

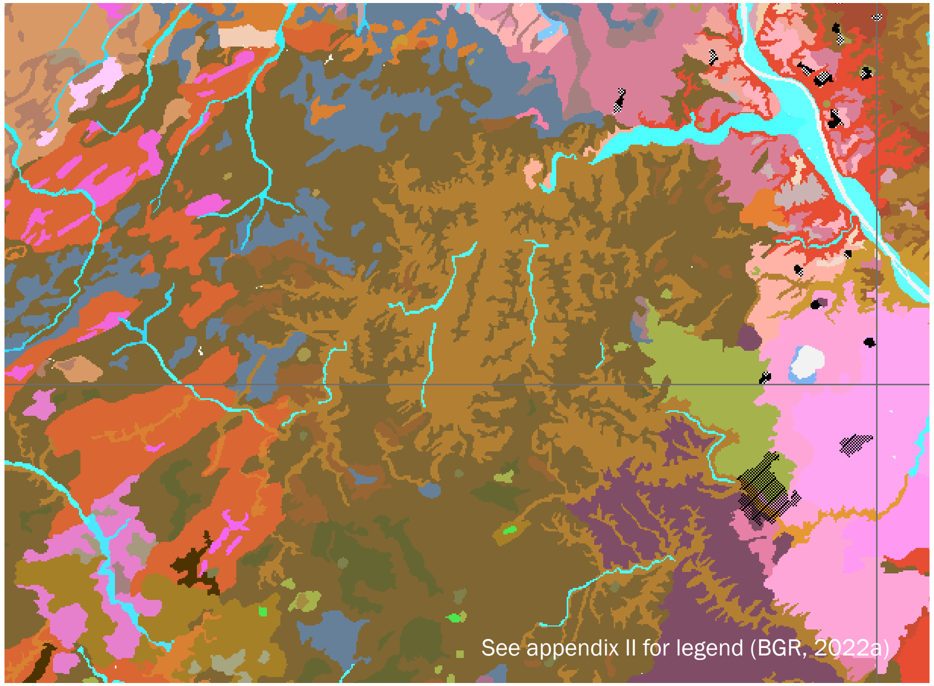


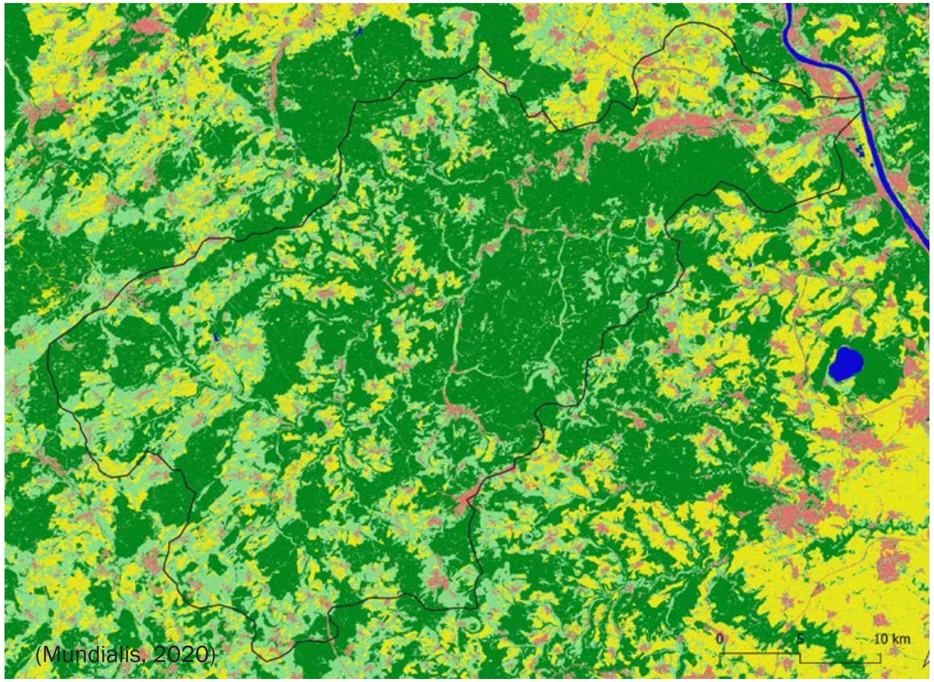
(AAWE, 2021)

THE AHR RIVER

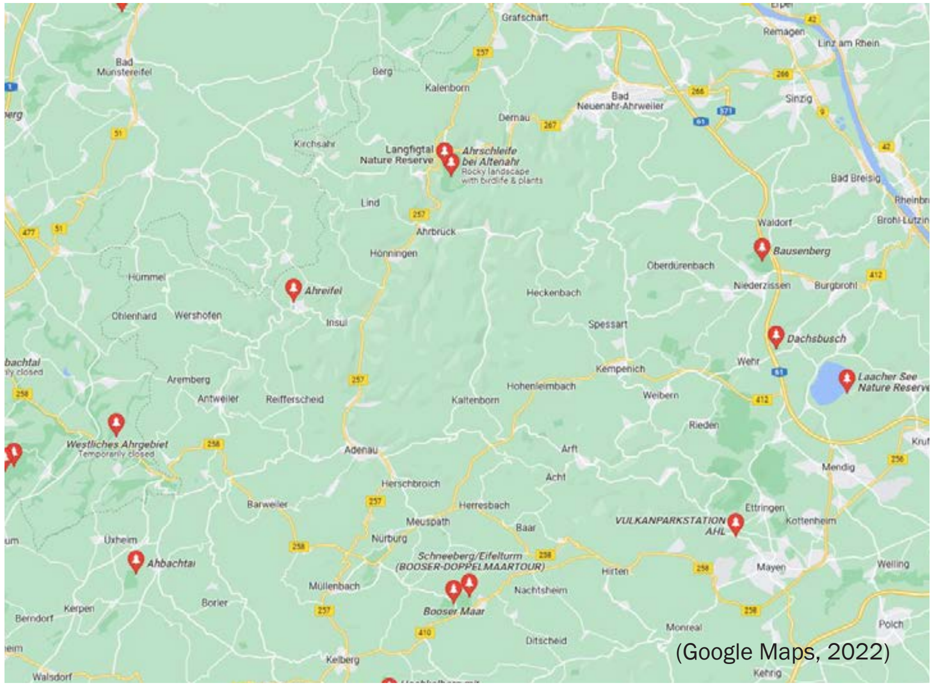


SOIL TYPES





LAND USE



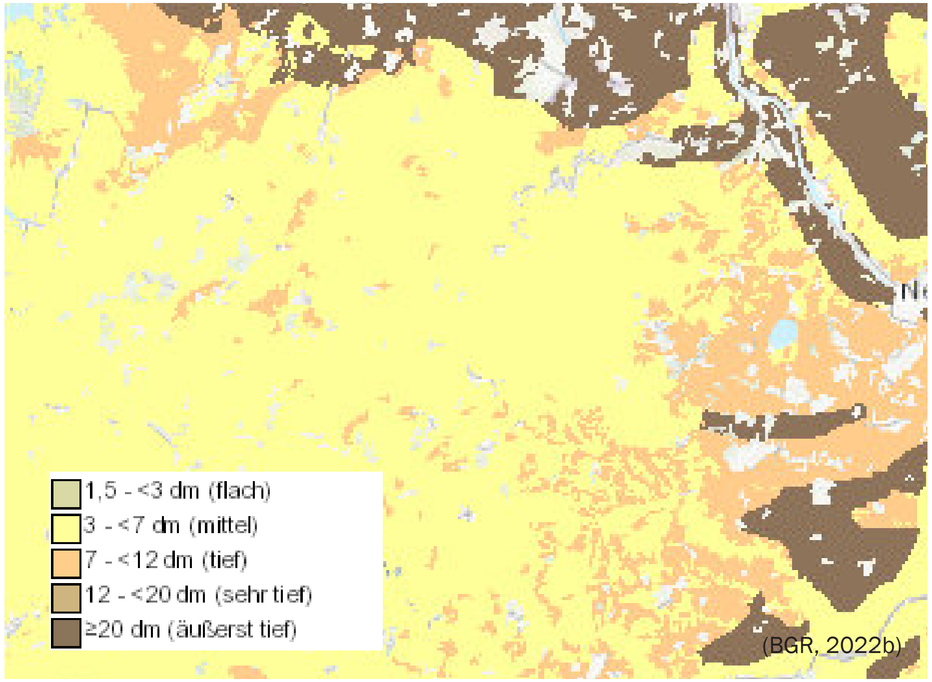
NATURE PRESERVES

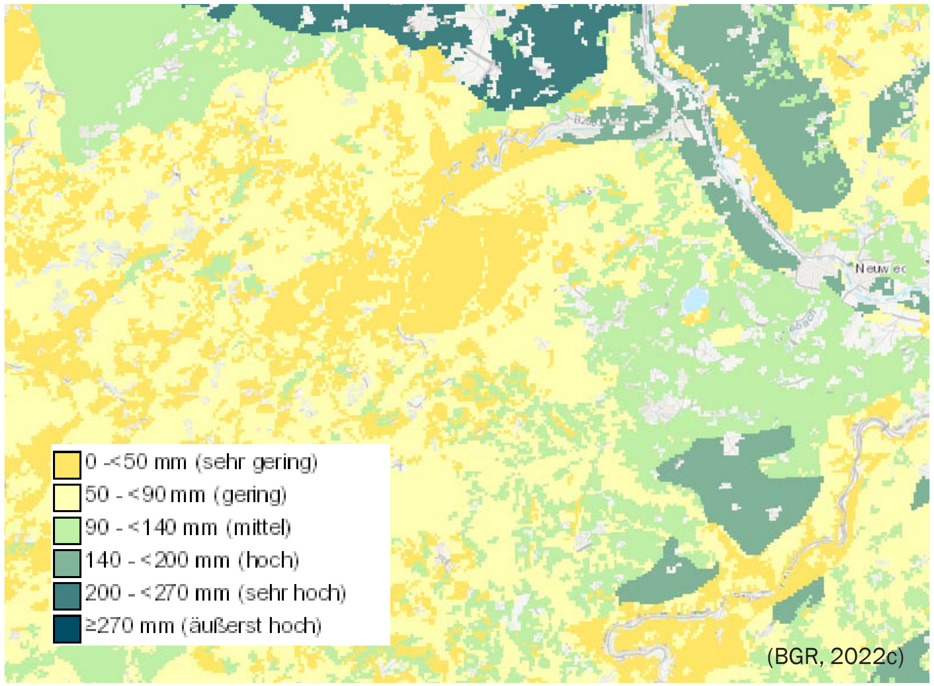
Valley has a further unique microclimate due to its geographic position. Downstream from where the Ahr River joins the Rhine, there is a large basin that is comprised of the Westphalian Lowland, the Cologne Lowland, and the Lower Rhine Plain. This basin is nestled between the mountains of the Ahr Valley and the Atlantic coast. The topography encourages a rain shadow phenomenon, dropping precipitation in the low mountains before reaching the Ahr Valley. The average rainfall is relatively low in the Ahr Valley (compared to the greater region) with 662 mm per year while the amount of sunshine is high with 1,370 hours annually, likening it to almost Mediterranean conditions. The mountains also shelter the Ahr Valley from northerly winds, contributing to the mild climate. The average annual temperature is 9.8°C (2.4°C in the winter) – comparable to Germany's southernmost regions. Despite its small size, the Ahr River itself is also a stabilizing factor in the valley's consistent climatic conditions (Braatz et al., 2014; Schäfer et al., 2021).

The Ahr Valley and its watershed is geographically and topographically divided into several parts. The watershed covers 897.5 km2, with its main tributary sources in the High Eifel Mountains (Roggenkamp & Herget, 2014). The upper catchment has rolling agricultural fields that become ravines and deeply cut mountain valleys. Many steep and dramatic rock formations carved by the river wind through villages and valleys until the terrain opens into a wider floodplain before the Rhine River. The slopes of the Ahr Mountains to the northwest are predominantly slate with loess and loam at lower levels, and fluvisols containing basalt in the floodplains nearing the Rhine River (BGR, 2022a; Braatz et al., 2014). Slate has very few pores and a low water carrying capacity, and the soil profile is typically quite shallow at less than 70 centimeters thick (BGR, 2022c; Rodenkirch & Welsch, 2022).

The landscape has been heavily modified by human activity for centuries, bit there are various nature preserves in the catchment of the Ahr. The largest are in the upper reaches, including Obere Ahr mit Mühlheimer Bach, Reetzer Bach und Mühlenbachsystem Nature Preserve (666 hectares) and Lampertstal and Alendorfer Kalktriften with Fuhrbach and Mackental Nature Preserve (1101 hectares) in Blankenheim municipality. These preserves are corridors along waterways as part of a project intending to establish coherent ecological network of special protection areas in Europe (Landesamt für Natur, 2007a; Landesamt für Natur, 2007b). In the middle reaches is the Ahrschleife bei Altenahr, a 205 hectare nature reserve that protects the unique rock formations of the river landscape and habitat for endangered species (Beckhausen, 1986). The lower reach has the 63 hectare Mündungsgebiet der Ahr Nature Preserve, which protects the estuary and habitat of rare plants and

PHYSIOLOGICAL DEPTH OF SOILS





USABLE FIELD CAPACITY IN THE EFFECTIVE ROOT AREA


BLANKENHEIM
ALTENAHR
AHR ESTUARY NATURE RESERVE
(Bertram, 2013)
(Braatz et al., 2014)
(Wenner, 2021)

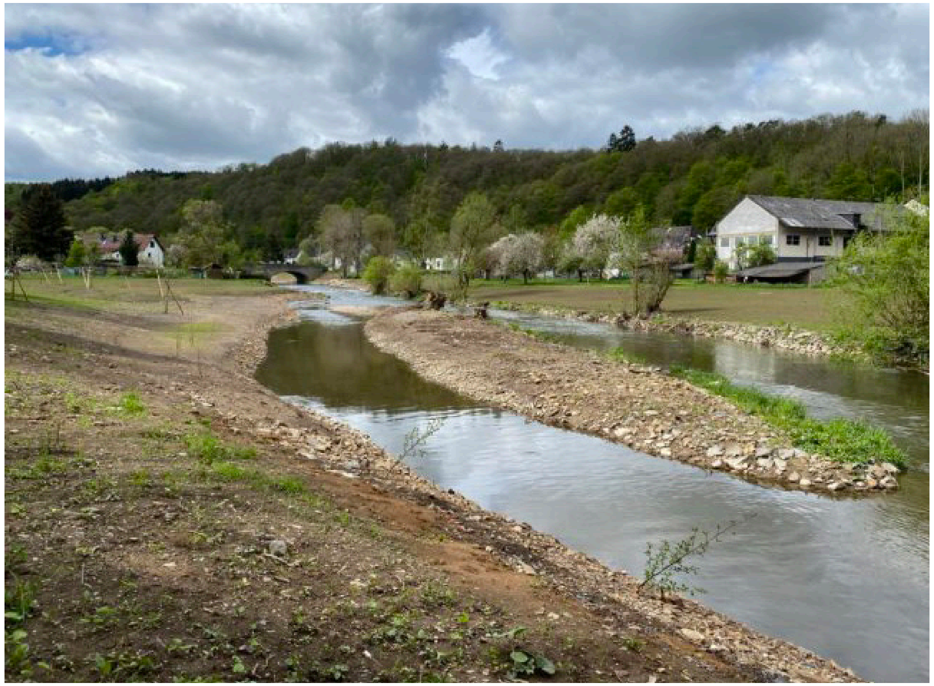
animals, especially birds (Ahrweiler, 1981). There are a handful of other small nature preserves in the Ahr River catchment, but they are highly fragmented. The upper reaches of the Ahr have benefited from various renaturation projects in the past decade, with improvements to river channel structure, reopening of piped waterways, and removal of non-native species to improve ecological function, water quality, and flood protection (Mölle, 2022). The lower reaches are heavily impacted by the terracing of viticulture.

THE AHR RIVER

The Ahr River begins in the village of Blankenheim in NRW and ends in an estuary at the Rhine River near Sinzig in RLP. There are 80 municipalities present in the catchment, 17 of which are located along the Ahr River. The river is only 82 km long, with most of its length winding through the Ahrweiler district in the RLP. There are eight large tributaries that join the Ahr River – Ahbach, Trierbach, and Armuthsbach in the upper reaches; Adenauer Bach, Liersbachtal, Kesselinger Bach, Sahrbach, and Vischelbach in the middle reaches; and no substantially sized tributaries in the lower reaches. More than 80% of the catchment is located upstream from Altenahr, where the last of the major tributaries join the Ahr (Roggenkamp & Herget, 2014).

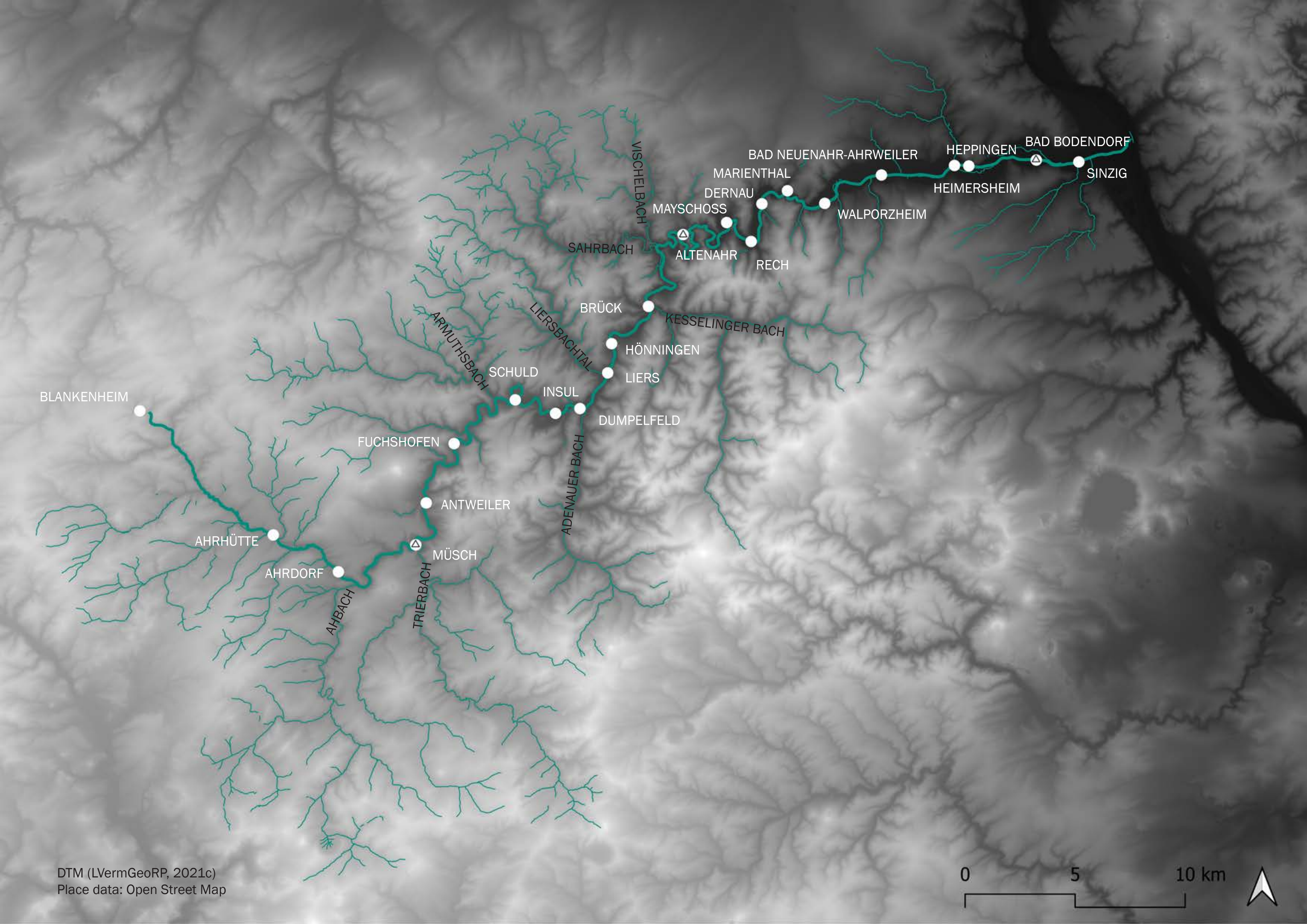
Based on historic maps from 1804, it is evident that the riverbed has been dramatically altered from its natural form. Previously, the river often had a braided system with a wider, shallower channel and islands. Various marshes are present on historic maps, many of which have been drained and built upon since. Dredging and channelization has led to a uniform, trapezoidal channel, especially within villages and it is most pronounced where the road acts as a defining boundary for the river . There are only two flood walls present in the entire watershed, located in Bad Neuenahr (Umwelt, 2022).

There are three monitoring stations on the Ahr located at Müsch in the upper reaches, Altenahr in the middle, and in Bad Bodendorf in the lower (Umwelt, 2022). These stations have been collecting quantitative data since 1947 measuring water levels, discharge, precipitation, and groundwater. The subsequent calculated mean discharge (prior to the 2021 event) was 6.98 m3/s with a water level of 0.75 meters. The highest registered peak discharge was 316 m3/s in 2016 with a peak water level of 3.71 meters. This data informed the estimation for the discharge of a 100-



Renaturation of river channel, Antweiler (Mölle, 2022)

Railway bridge, Altenahr (Delminho, 2021)



DTM (LVermGeoRP, 2021c)
Place data: Open Street Map

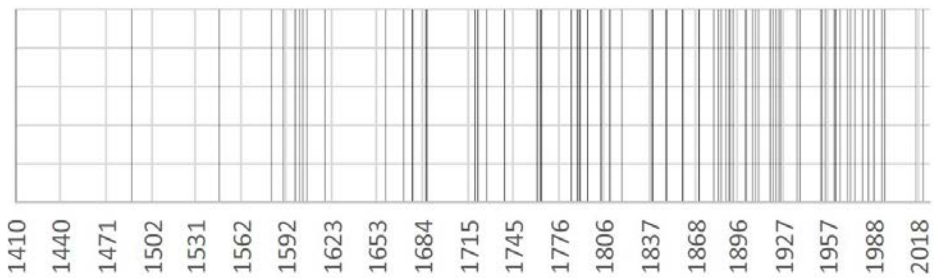
year flood for the Ahr of 241 m³/s at Altenahr (Schäfer et al., 2021; Wiebe, 2021). Based on these dimensions, the Ahr River is not large enough to be included in many hydrological and flood models in EU studies. But due to its size, hydro- and geomorphology, it has a high risk of flash flooding (Roggenkamp & Herget, 2014).

The Ahr river has a propensity to flood. On average, there is a flood event once every four years (Rodenkirch & Welsch, 2022). While the average amount of precipitation for the area for the month of July is just 69 mm (average between 1981-2010), heavy rainfall of more than 100 mm within a day or two has been recorded (Schäfer et al., 2021). There is a tendency for extreme precipitation events with increasing duration to happen more often in the mountainous regions of Germany, as expected with the rain shadow phenomenon (Junghänel et al., 2021). This is expected to intensify with climate change. Due to the region's soil conditions and steep terrain, small streams quickly become rivers during heavy rainfall with the rapid runoff (SWR, 2021b).

Since quantitative data has only been collected since 1947 for the Ahr River, many large historic floods have not been considered in hydrologic modelling. This has led to a severe undercalculation of flood risk, because a severe flood has not occurred since 1947. Several historic floods have enough qualitative data from written documents, photos, and flood level markings to be able to reconstruct their dimensions. A flash flood in 1910 had a peak discharge of approximately 500 m³/s with a water level of 5.0 meter in Müsch. Flash floods tore down buildings, scaffolding, and materials. 70 people died, many of them railway workers that drowned as debris lodged in front of bridges, blocking their escape. Bridges in Antweiler, Fuschshofen, Müsch, Schuld, and Insul were destroyed (Roggenkamp & Herget, 2014).

A much larger flood in 1804 had an estimated discharge of 1100 m³/s, which is 170 times greater than the calculated mean (Roggenkamp & Herget, 2014). According to a written testimony, the flood arrived in less than four hours and was 2.5 meters above the stone bridge at Rech. In the historical reconstructions, four out of five were comparable if not greater in size than the 1910 flood, such as in 1601, 1818, 1848, and 1920 (Schäfer et al., 2021). In total, more than 70 floods have been noted on the Ahr River over the past 500 years (Schäfer et al., 2021). Given this frequency, it is easy to see that life-threatening floods are not unforeseeable on the Ahr and should have been considered in housing and planning despite lacking quantitative data.

HISTORIC FLOODS IN THE AHR VALLEY



Adapted from von Frick (1955), Seel (1983), RLP Daten, Pegelstände) (Schäfer et a., 2021)

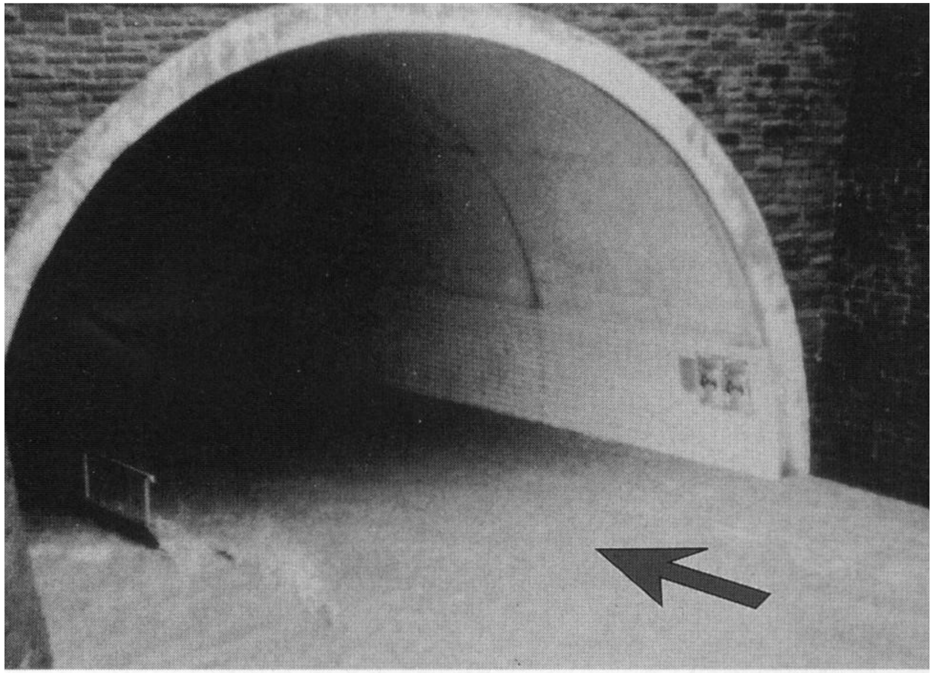
1910 flood, Mayschoss (Sinne, 2022)

2016: “Flood of the Century”, Bad Neuenahr (Welker, 2016)

1804 flood (Sinne, 2022)

1910 flood, Altenahr tunnel (Sinne, 2022)

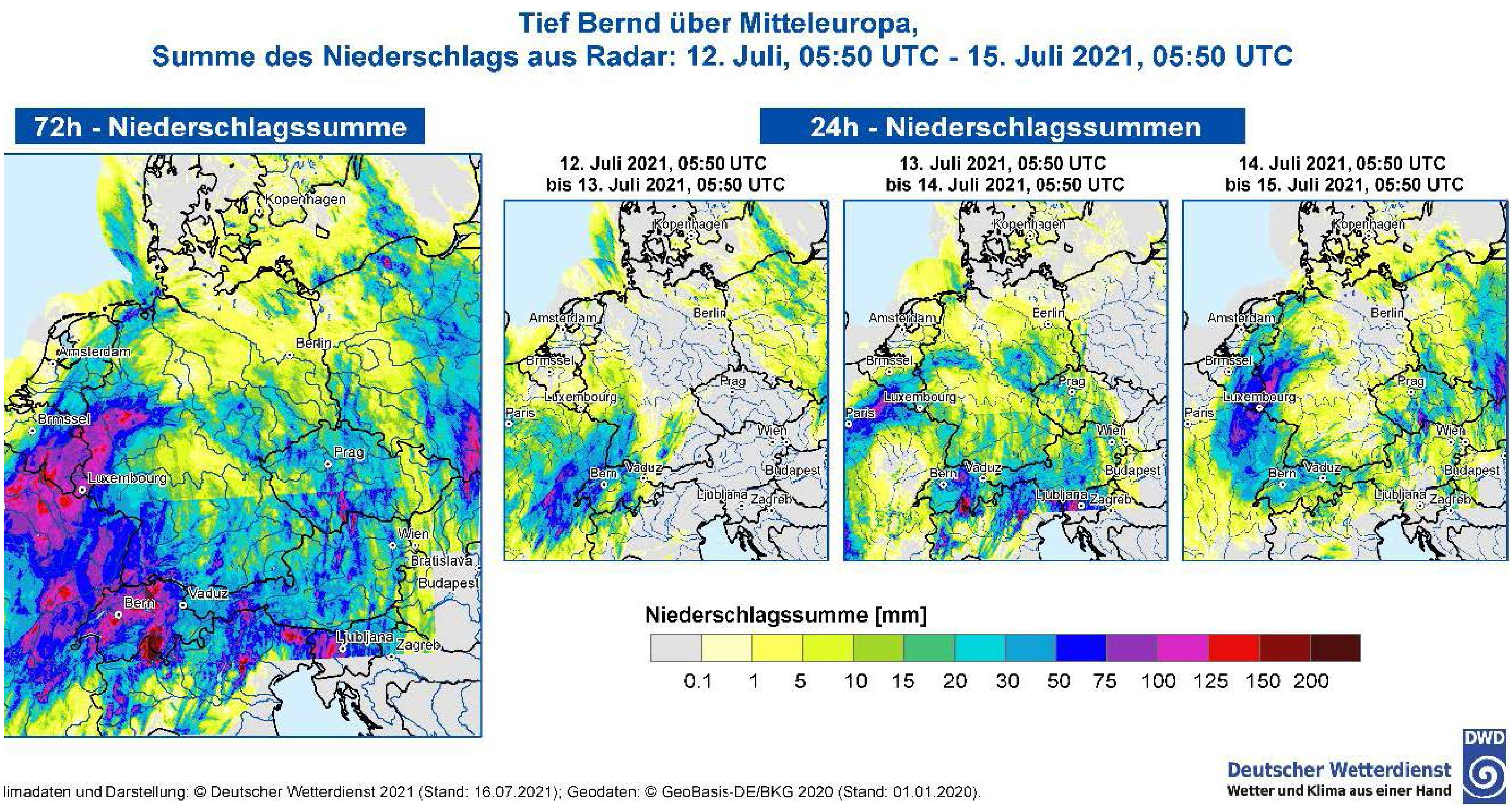
13. June, 1910, Bad Neuenahr (Roggenkamp 2014)



30. May, 1984, Altenahr tunnel (Roggenkamp 2014)

THE FLOOD:

14. - 15. JULY, 2021



Precipitation analysis based on RADOLAN for central Europe for the duration level 24 hours or 72 hours until 07/15/2021 05:50 UTC (07:50 a.m. CEST) (Junghänel et al., 2021)

THE FLOOD: 14.-15. JULY, 2021

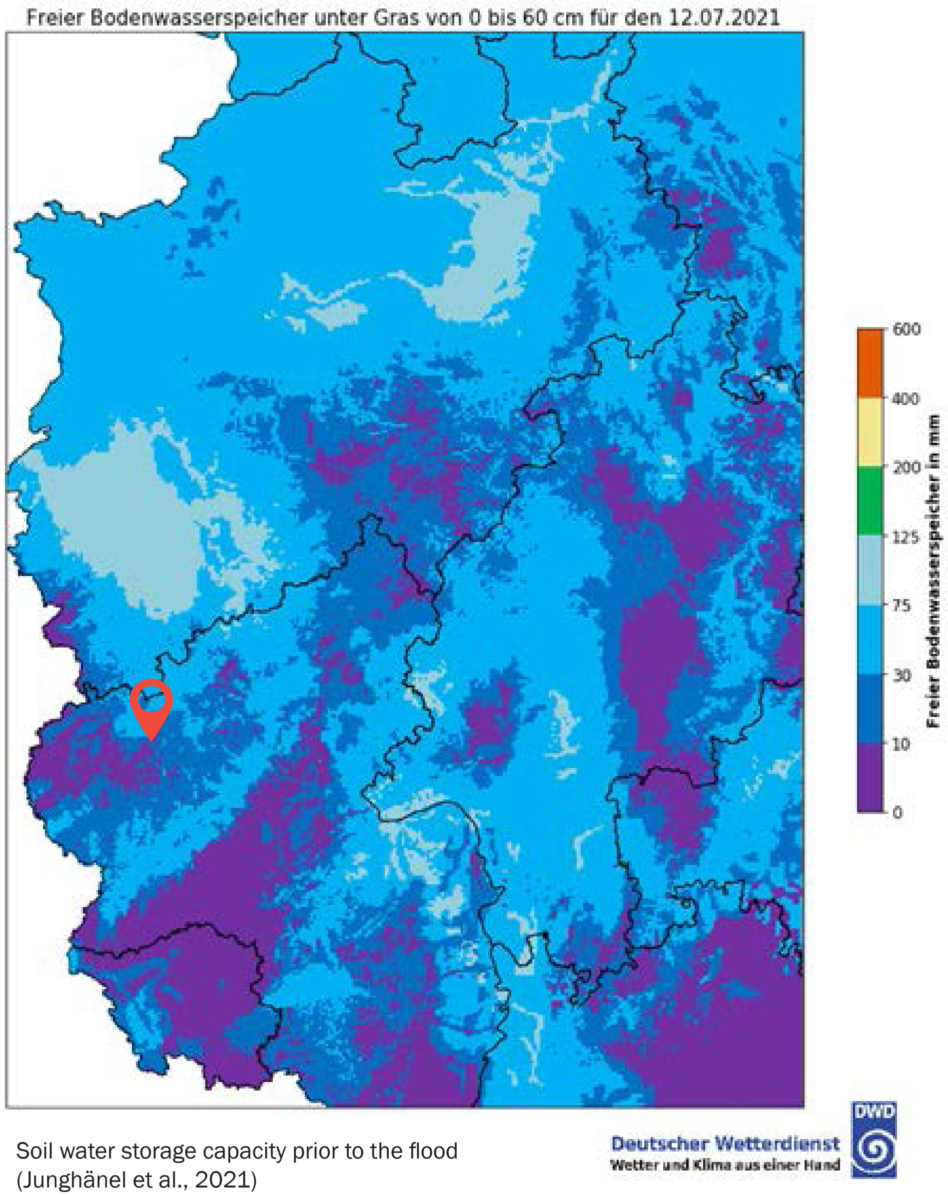
“A flood never comes suddenly” (Rodenkirch & Welsch, 2022)

INTRODUCTION

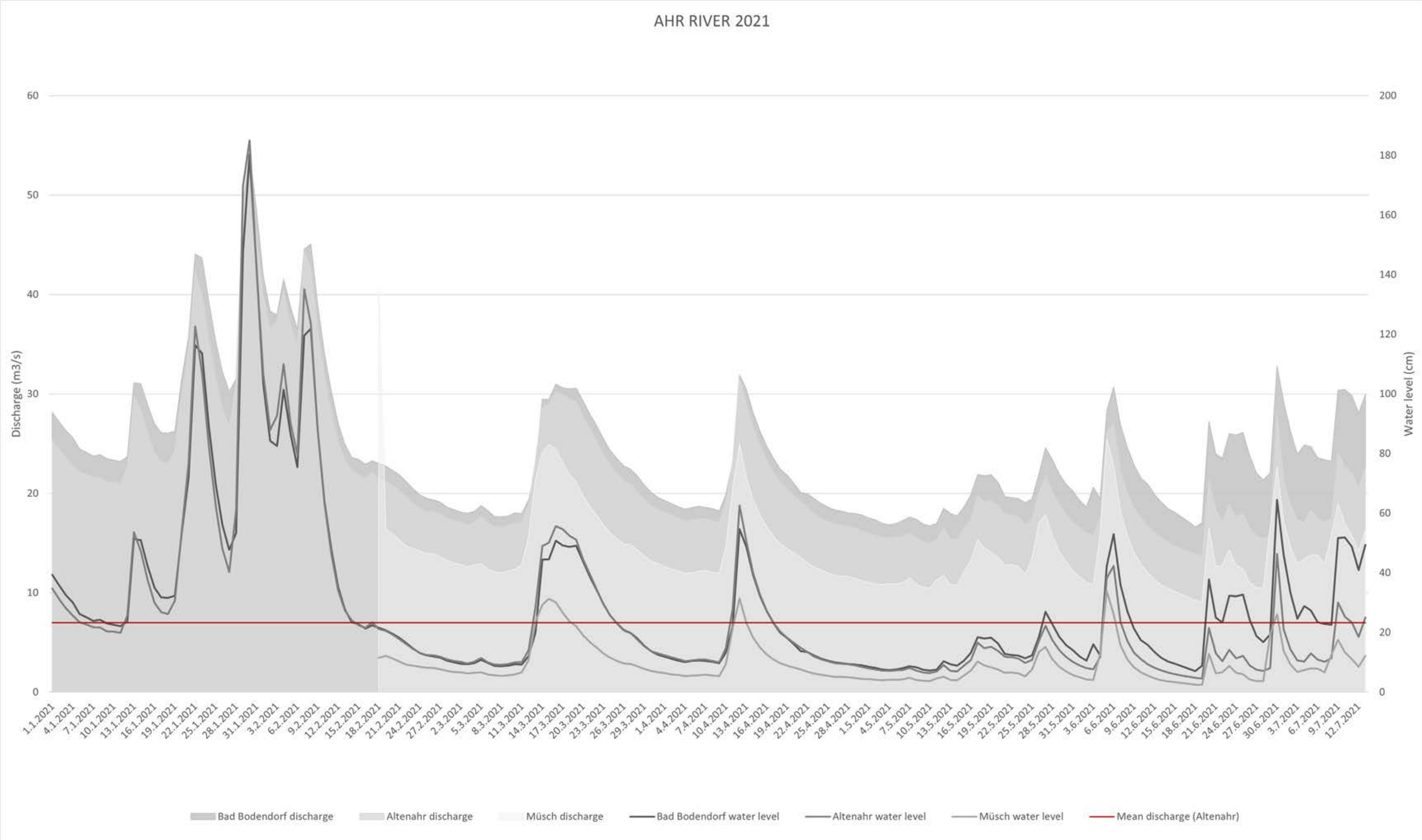
Spring and early summer in 2021 were very wet for Germany (SWR, 2021b). By July, 2021 was already listed as one of the top five years with the most individual events since 2001. In particular, the three weeks leading up to the flood were characterized by recurring bouts of rain (Junghänel et al., 2021). The thin, slate soils were approximately 50% saturated prior to the flood event, with poor water retention capacity and little ability to absorb more (Rodenkirch & Welsch, 2022; SWR, 2021b). In some places in RLP and southern NRW, including a large amount of the upper reaches of the Ahr River, ¬there was less than 10 mm free soil water storage (Junghänel et al., 2021).

Beginning on 13. July, low-pressure system “Bernd” developed across Europe. Its slow, cyclonic rotation doused large areas of Europe with rain, with Germany receiving the most (Junghänel et al., 2021). Seven districts were particularly affected by the storm: Ahrweiler, Bernkastel-Wittlich, Cochem-Zell, Eifelkreis Bitburg-Prüm, Mayen-Koblenz, Trier-Saarburg, Vulkaneifelkreis, and the city of Trier (Ehrang district) (Rheinland-Pfalz, 2022a). The most devastated area was along the Ahr River in the Ahrweiler district. While the size of the ensuing flood is not unprecedented, the villages and villagers were unprepared for what ensued. Precise data about the flood is not known because only one of the three measuring stations on the Ahr at Müsch, resisted the event. This provides important insight for classifying the flood event, along with eyewitness accounts and retrospective forensic analyses.

The following timeline and description of damages give an overview of the effect of human actions and choices conflated with a natural hazard at a regional, national, and international scale.



Soil water storage capacity prior to the flood
(Junghänel et al., 2021)



Discharge and water level of the Ahr River in 2021 prior to the flood (Data: Rheinland-Pfalz Landesamt für Umwelt)

TIMELINE

10. JULY

EFAS gives the first flood warning for storm

12. JULY

EFAS places Ahr on highest alert for potential flooding.

11:59 DWD issues a severe weather warning of continuous heavy rain and informs flood control centers of the federal states.

Meteorologist Sven Plöger expects a lot of rain. “Be careful on the rivers, watch the gauges, get away from the rivers.”

Regional dams begin releasing water as a precautionary measure in response to advance warnings from the DWD.

13. JULY

A large contiguous area with heavy precipitation formed over southwest Germany.
It moved counterclockwise from the northeast, then north, before swinging west over northern Germany to NRW and RLP. Parts of Bavaria and Saxony report heavy rainfalls and flooding.

DWD makes it clear: “The highest amounts of precipitation are to be expected in the vicinity of the Eifel.”

DWD issued the highest possible warning for flood risk before continuous rain began on July 13.

Dinant, Belgium @HerrNaumann, Twitter (Naumann, 2021)

MORNING: Data is already showing an extreme risk of a flash flood on the upper Ahr River.

NIGHT: In NRW, a zone running across Germany with heavy rain and thunderstorms manifests. Heavy rainfall is observed from the Hessian part of the Rothaargebirge across the southern Ruhr area to the Dutch border. Geverlsberg-Oberbröking registered a rainfall of 71.1 mm

14. JULY

MORNING: DWD warns again of “extreme storms with continuous rain and heavy rainfall in NRW and RLP”

MORNING: State Office for the Environment (LfU) issues flood warnings throughout the day

MORNING: Weather experts know it was 100% clear that there would be a record flas flood

11:00: LfU issues second highest warning level for flooding

11:17: LfU warns of flooding via Katwarn disaster control app

13:15: The water level of the Ahr at Altenahr is at 1.20m and it is expected to peak at 3.30m

14:30: The water level of the Ahr at Altenahr is at 1.38m

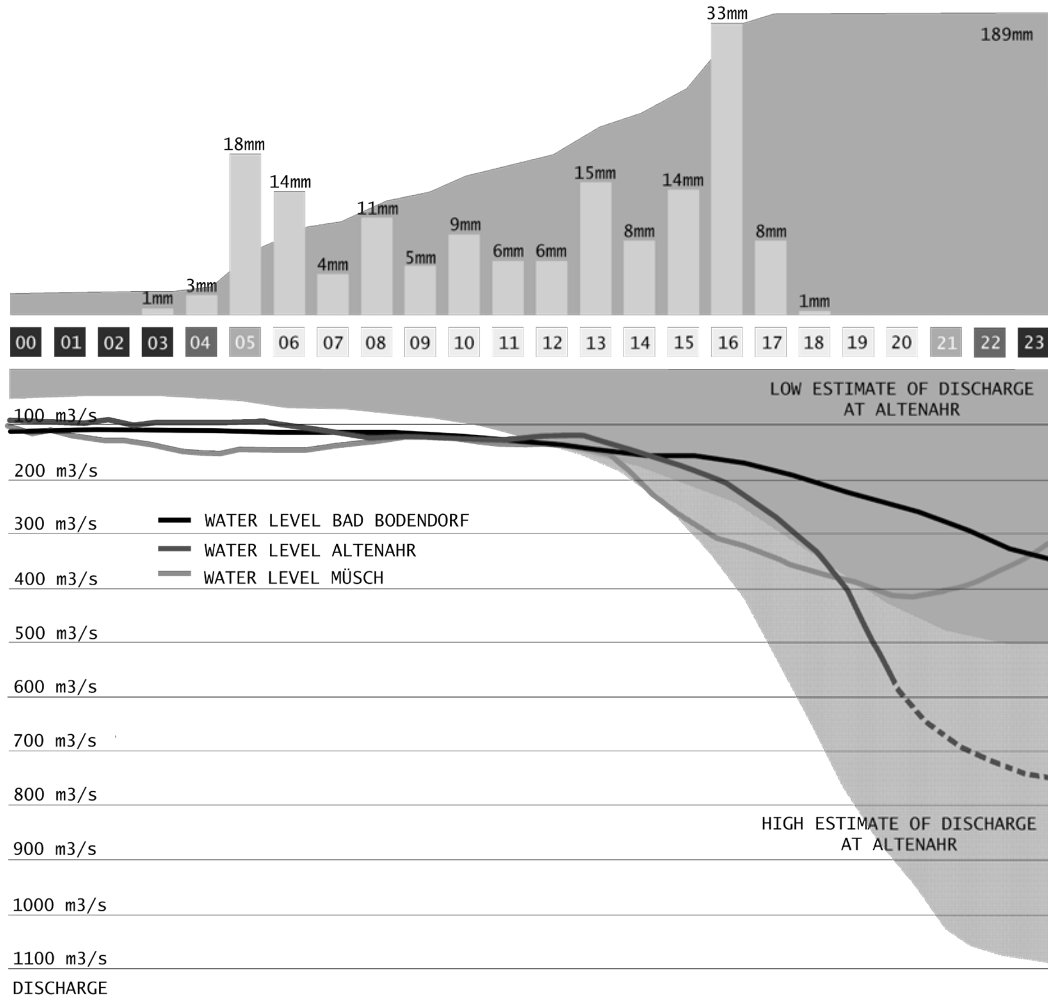
14:43: Ahrweiler district warns population via Katwarn of flooding and warns against going into basements or underground carparks

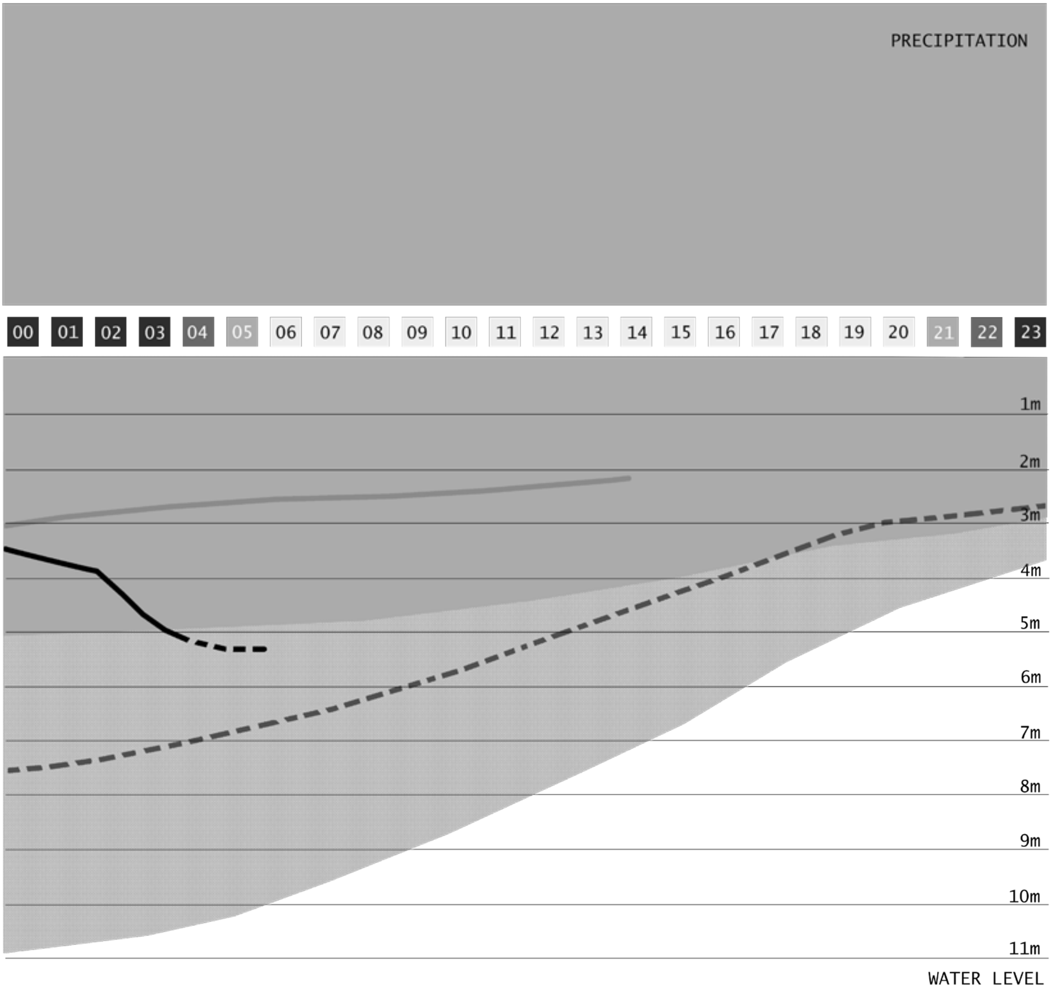
15:26: Updated forecasts predict a peak water level of 5.19m

16:00: It is clear to experts that the flood would surpass HQ100

16:20: The mayor of Altenahr asks to declare a state of emergency

17:17: LfU issues highest flood warning class





Precipitation, dscharge and water level of the Ahr River 14.-15. July, 2021 (Data: Schäfer, 2021)

17:30: The water level of the Ahr at Altenahr is at 2.36m

17:40: Ahrweiler releases a situation report following a meeting with the fire brigade, relief organizations, police, and admin

18:00: DWD lowers its forecast of expected precipitation

18:25: LfU lowers the expected river peak to 4.06m

19:00: The district crisis center has situation under control and Minister Lewentz was told all necessary precautions are taken

19:00: Basements begin to fill with flood water

19:30: The water level of the Ahr at Altenahr is 3.92m, surpassing the 2016 record

19:57: LfU recalculates a new river peak at 5.3m and the water is rising quickly

20:43: LfU recalculates a new river peak at 6.92m

20:45: The measuring station at Altenahr gives its final reading of 5.75m before it fails

20:46: The Ahrweiler district posts on Facebook of a very high risk of flooding on the Ahr and its small and medium-sized tributaries, and that more flash flooding is expected within the next few hours

20:56: The Ahrweiler district posts water level information that is 40 minutes old and at least 0.5m under the reality on Twitter

21:00: Koblenz and Mainz fire brigades are filling 800 sandbags per hour

21:30: The A61 is washed away at Bad Neuenahr-Ahrweiler

22:00: Ahrweiler's crisis team realizes that the water levels in Altenahr are not being updated due to its failure

22:24: The LfU manually restarts its calculation system and predicts a new peak at 7.07m

Flood levels in the evening of 14. July, 2021, Rech (Junge Freiheit, 2021)

23:00: The water level of the Ahr at Altenahr is approximately 7m

23:09: The Ahrweiler crisis team triggers the disaster alarm and calls for partial evacuation of buildings within 50m of the river only in Bad Neuenahr-Ahrweiler, Bad Bodendorf, and Sinzig

23:15: DWR reporter Michael Lang of Marienthal is evacuated and arrives in Bad Neuenahr-Ahrweiler. Despite documenting the event throughout the day, he neither noticed a siren alarm nor app alerts

23:23 and 23:27: Residents are told to not leave their homes and to go to higher floors on Twitter

15. JULY

00:22: DWD is again warning of heavy rainfall. Emergency services are in chaos trying to save people

02:15: The final measurements of the Ahr river at Bad Bodendorf is 4.68m with a discharge of 332m3/s

06:00: The water level of the Ahr at Altenahr is approximately 6.60m

06:39: The Ahrweiler district sends another flood warning via Katwarn app

MORNING: “In the Bad Bodendorf area, there are currently massive restrictions on drinking water supply due to the extreme flooding.”

MORNING: Daylight shows immense flooding. The operational area extends over 40 km to the left and right of the Ahr river.

MORNING: District Administrator Pföhler states, “This is the biggest disaster in the Ahrweiler District since WWII”

08:00: The water level of the Ahr at Altenahr is approximately 5.90m

08:00: At least 50-60 people are missing in Schuld alone. Many people are still sitting on rooftops waiting for rescue

08:00: Police confirm the deaths of at least four people

09:00: Rescue missions are difficult due to strong currents

09:40: Police estimate 70 people missing and 50 waiting on rooftops

10:27: The Ahrweiler district states on Twitter that around 1300 people are missing

18:00: The water level of the Ahr at Altenahr is approximately 3.00m

Sources: (BPB, 2021; Rodenkirch & Welsch, 2022; Schäfer et al., 2021; Schmid-Johannsen et al., 2021; Seidel et al., 2021; SWR, 2021; SWR, 2022b; Weidinger, 2022)


(Roessler, 2021)
Flow patterns in Schuld (Roessler, 2021)

OVERVIEW OF DAMAGES

It is expected to take years to fully rebuild the damaged facilities. This overview provides a large-scale description of losses and damages. Completing a local-scale risk assessment is necessary for better defining the event and its impacts on infrastructure, services, lives and livelihoods (Koks et al., 2021). The local-scale risk assessment follows in the next section with case studies.

220 deaths in all affected regions

- 135 deaths, 766 injured and 2 missing persons in the Ahr Valley alone
- 65 male, 70 female
- Between the ages of 4 and 97
- 106 of the deaths were over age 60
- 3 children and one youth died
- Firefighters: 1
- Adenaur: 6 deaths
- Altenahr: 33 deaths
- Bad Neuenahr-Ahrweiler: 69 deaths
- Sinzig: 12 of the 13 deaths occurred in a home for the disabled, one of the last villages downstream on the Ahr and where the tidal wave of the flood came seven hours after it peaked in the upper reaches
- 4 known suicides post-disaster as of 11. November, 2021 (not included in death statistics of the disaster)

Residential and commercial damage

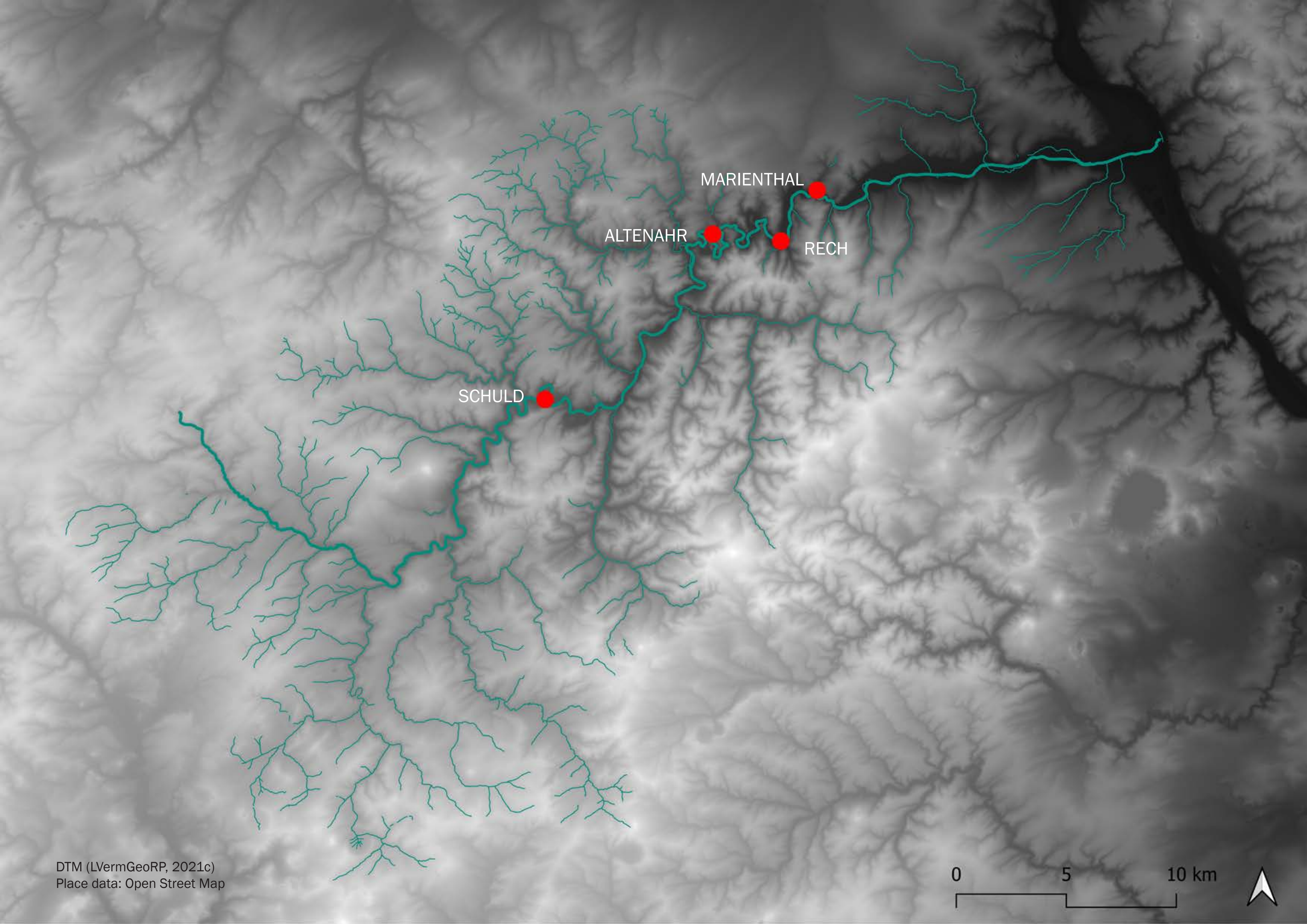
- Around 65,000 people in total suffered damages
- 9,964 buildings in RLP were affected
- Of the 56,000 people live along the Ahr, 42,000 people were affected.
    - Of those affected in the Ahr Valley, at least 17,000 lost their belongings or face significant damage
- 467 buildings, including 192 homes, were washed away in the flood
- 8000 students affected
- Businesses, tourism, winegrowers, and farmers severely impacted

Critical infrastructure damage

- 13 bridges severely damaged and 62 destroyed (112 total along the Ahr)
- All rail bridges were destroyed
- 180 rail level crossings, 40 signal boxes, over 1000 catenary and signal masts, 600 km of tracks as well as energy supply systems, elevators, and lighting in Germany
- 130 km of motorways closed in Germany
    - Of the 8 flooded motorways, only 3 had a known flood risk
- 74 km of 180 km of roads in the Ahr Valley with damage
- Electricity, water, telecommunications, access routes severely damaged or destroyed
- 200,000 people had power outages across Germany
- 133 km of natural gas pipelines (the main source of heat)
    - 8,500 gas meters and 3,400 house pressure regulators
    - 7,220 of approximately 8,000 gas network connections were destroyed
    - 31 gas pressure regulating and measuring systems were damaged or destroyed
- Drinking water and sewage treatment plants damaged or destroyed
- 100,000 damaged telephone and internet lines in RLP and NRW
- RLP was without mobile network services for 2 weeks
- 105 general practitioners offices were destroyed or unable to operate
- In the neighboring district of Euskirchen:
    - Evacuations as a dam on Steinbachtalsperre threatened to break
    - Hospital basement flooded, power supply collapsed, entire building technology was destroyed, 300 patients had to be evacuated by helicopter

Sources: (Dienstleistungsdirektion, Rheinland-Pfalz Aursichts-und, 2021; Junghänel et al., 2021; Koks et al., 2021; Rheinland-Pfalz, 2022a; Rodenkirch & Welsch, 2022; Schäfer et al., 2021; Schmid-Johannsen et al., 2021; Weidinger, 2022)

CASE STUDIES


MARIENTHAL
ALTENAHR
RECH
SCHULD
DTM (LVermGeoRP, 2021c)
Place data: Open Street Map
0
5
10 km

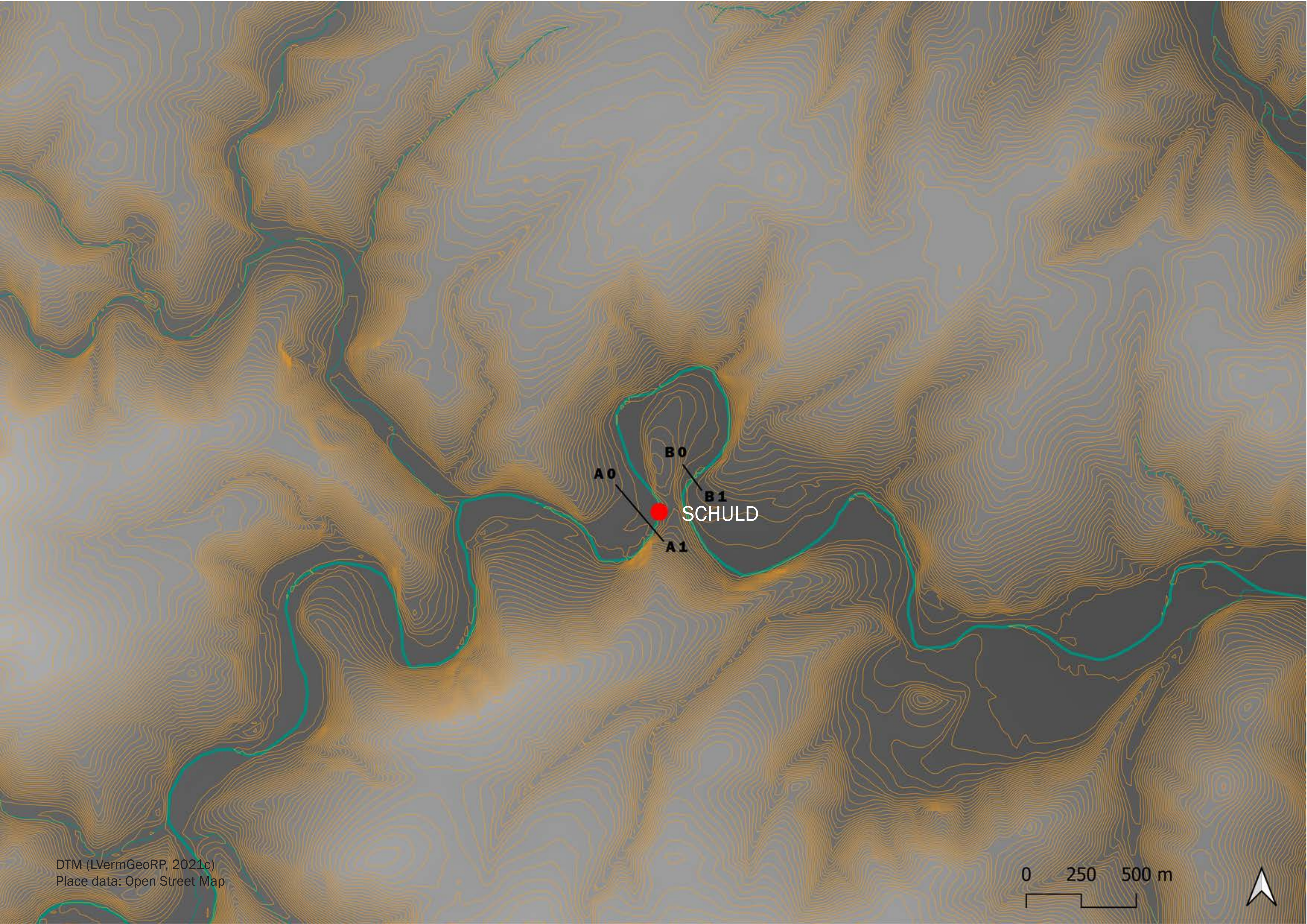
CASE STUDIES

A local investigation is necessary to assess and contextualize the flood damages beyond the general descriptions given at a national or international scale. This information is necessary to understand what role local populations had in turning a natural hazard into a disaster. Four villages are used as case studies - Schuld, Altenahr, Rech, and Marienthal. While there was widespread damage throughout the valley, these four villages were recommended as case studies due to their particularly great devastation during the flood. They vary in size, topography, shape, infrastructure, amenities, and location and give insight into the lives of local conditions and communities of the Ahr Valley.

The hydrologic details of the flood are specified for each case, and a brief local history and status report is given to provide context at a finer scale. The entire flood plain of the Ahr River has an updated flood zone map, released in September 2021. Hydrologically calculated risk zones are notably different than the real risk zones in many locations. The visual assessment of each case study uses the lens of natural river processes - transportation, erosion, and deposition – to understand the physical damage. The Ahr River acted in a predictable way according to these processes, but it was not understood what that meant for the people and infrastructure in the flood. The material in this thesis is a very condensed version of a full analysis and emphasizes the consistency of the river's hydrologic processes in each location during the event rather than identifying specific features or sites in the village. Deeper case studies in each settlement could and should be conducted to further understand how these specific features or sites in the landscape had an impact or were impacted during the flood. This is a necessary step in reconstruction planning, but beyond the scope of this thesis.

Fieldwork was conducted in late February to investigate the status of the clean-up. Seven months post-disaster, much work has been done. But there is an enormous amount of work left to do in rebuilding homes and livelihoods, infrastructures, and the river itself. The river has been largely reshaped to its previous state, and the work was conducted by volunteers with no official guidance or knowledge of landscape architecture, hydrology, or ecology. This will undoubtedly have long-term consequences on the resilience of the communities unless addressed.

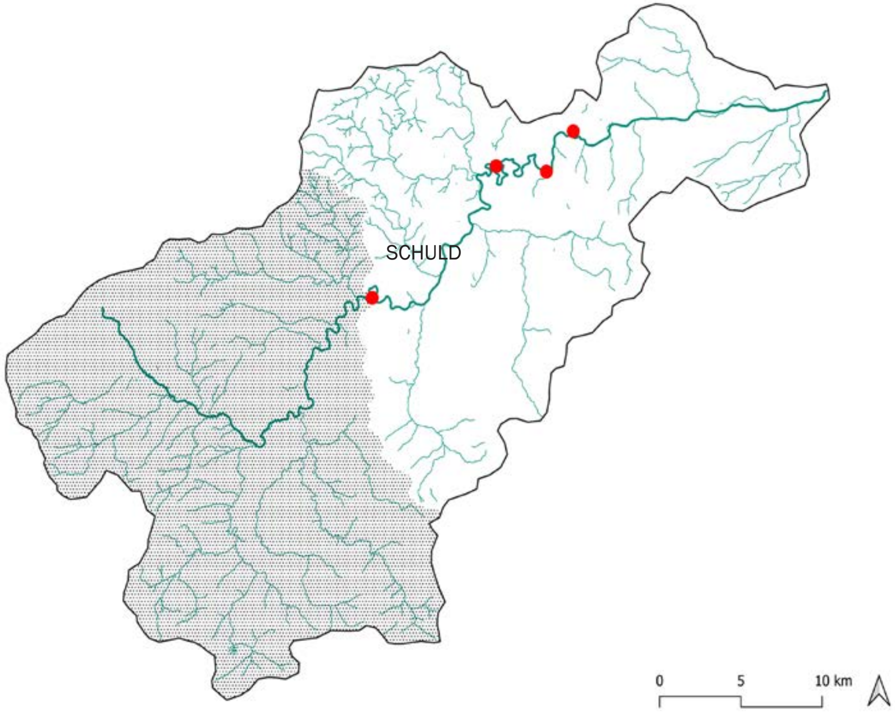
Nature created the new shape of the Ahr River for a reason, and it is important to identify what and why this shape is (or was). This shape immediate post-flood is informative for flood risk reduction planning, regulations, and design proposals because the Ahr River will inevitably go through flood events again. The residents of the valley will need to balance the realities of the natural processes of the river with their anthropocentric reconstruction goals. Not heeding natural logic is costly both for now and in the future.


A 0
A 1
B 0
B 1
SCHULD
DTM (LVermGeoRP, 2021c)
Place data: Open Street Map
0 250 500 m

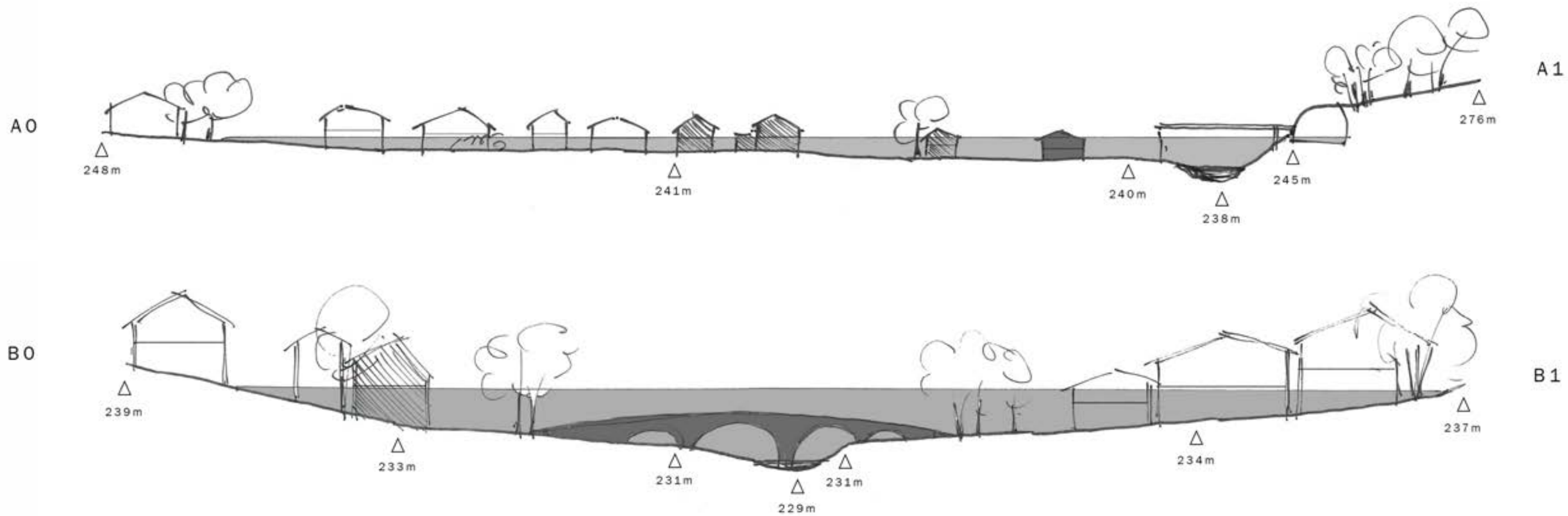
SCHULD

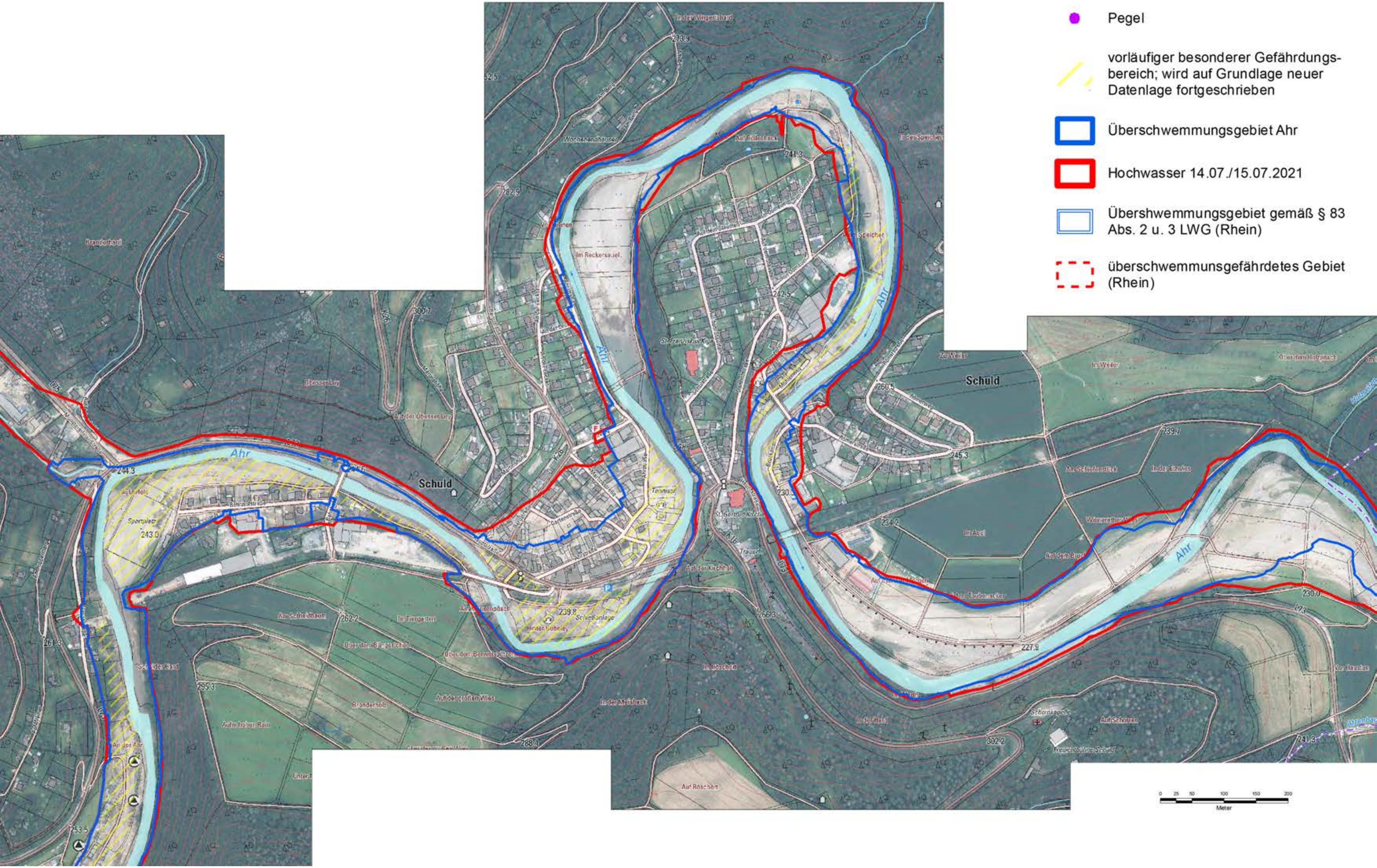
FLOOD DIMENSIONS

Flooding began around 14:30 and peaked around 20:00 on 14. July. Water levels reached 4-5 meters and caused damage to the second and in specific instances, the third floors of the lowest lying homes. Three bridges resisted collapse - two upstream of the village and a small historic bridge downstream that was badly damaged. The two bridges upstream clogged with debris which divided the river and caused it to sweep through the local pizzeria, bakery, and village, A landslide occurred under Müller Jüpp as the river channels reconverged. Schuld was particularly hard hit by the storm due to the tight loops of the river that when flooded, encapsulated and ran through the village from all sides (SWR, 2021b). Video from a tourist staying at the campsite showed debris flowing through the river channel at approximately 4 m/s during early stages of flooding (Swierzy, 2021). To put into perspective, the average human walking speed is roughly 1.5 m/s, normal running speed reaches 5 m/s, and the fastest running speeds are approximately 10 m/s. The river quickly became a



Watershed of Schuld





Rheinland-Pfalz, 2021)

1

deadly force which intensified dramatically during the event.

At Schuld, the area of the catchment is 465 km2, or 52% of the total Ahr watershed. The Armuthsbach tributary joins the Ahr at the village, which is 61 km2 or 13% of the catchment area until Schuld. This tributary drained land in the High Eifels that received amongst the heaviest precipitation in the entire region, adding an outsized amount of water into a loaded system. There is an elevation difference of the river from 247 to 229 meters above sea level from above the camp site to below the built area, resulting in a river slope of 0.3%.

No fatalities occurred in Schuld. 160 out of 396 (40%) buildings registered damages, in addition to 118 camping cabins. 12 buildings were destroyed during or after the flood.

LOCAL HISTORY

Schuld was established in 975 and has a Roman villa that dates to the second to late fourth centuries. Its population has ebbed and flowed slightly – it registered 298 residents in 1815, reached a peak in 1987 with 727, and had 660 residents in 2020 (Landesamt, 2020). After the flood, it is a ghost town with massive structural damage, many residents having relocated to temporarily stay with friends or family.

It hosted an array of businesses and facilities, many of which were damaged – a kindergarten, general practitioner, hotels, restaurants (pizzeria destroyed), holiday apartments, bakery (destroyed), grocery store (destroyed), hairdresser (damaged), car repair shop (destroyed), carpenter’s workshop (damaged), stonemason’s workshop (damaged), a campsite with 150 parking spaces (destroyed), and an antique yard (destroyed). Touristic facilities remain mostly closed, despite the reliance on the industry. Popular hiking trails pass by Schuld, such as the Ahr-Radweg and the AhrSteig. Disused railways added additional hiking possibilities. It is on the route for the “Tour de Ahr Valley”, an annual bike ride between Blankenheim and Altenahr and hosts car-free Sunday events. But it is not yet possible to welcome crowds of tourists (Schuld, 2022).

RECONSTRUCTION

During the emergency phase, reconstruction of the village was hasty, trying to reinstall critical infrastructures like roads, electricity, and sewage. New electric cables were laid 1.5 meters below the riverbed to protect against outages in future floods. The local highway was eroded away and repaired in situ despite its frequent needs for slope restabilization prior to the flood. The sewers were destroyed due to the great amounts of rubble and stone that blocked the pipes, and work to repair this was completed in the end of March 2022. Rubble was the greatest issue in restoring the river – thousands of tons were removed and reused in repairing the embankments. Notable in Schuld was the so-called “Sea of Stones” that were deposited on the inner bank as the Ahr looped around the northern side of the village. The deposits created a lip between the new channel and the former park space and were completely removed. Local testimony labeling this area as “destroyed” before and “tidy” after (Schuld, 2022; Swierzy & Meyer, 2021).

There are no plans in place for future disaster risk management, apart from the updated flood zone map and stricter requirements for bridges. Only provisional plans are in progress for the next two years. Residents have complained of being left out of any planning discussions. While most residents would like to rebuild, the village (as of February 2022) is very quiet. Riverbanks are built back to their original trapezoidal forms, covered with topsoil and sown, and this is erosion from high water and slope instability is already present. At present, Schuld is building back to how it was before, having “cleaned” the riverbeds and reshaped their banks. It is a return to the old normal.

There are very few facilities open for locals and there is very little to no infrastructure in place to accommodate tourists. It is unlikely that most camping places in the valley will ever be able to reopen, including in Schuld, due to stricter controls with the new flood map. Local farmers have repaired their buildings and were working shuttling hay for their cows during the fieldwork.

DESTRUCTION

TRANSPORTATION

EROSION

DEPOSITION


9

Arya Grill Pizzeria 10


L73 11


L73 12

Image searches

https://hochwasser-ahrtal-2021.de

Twitter: (schuld, hochwasser) until:2021-07-26 since:2021-07-15
(schuld, nrw) until:2021-07-26 since:2021-07-15
(schuld, ahrtal) until:2021-07-26 since:2021-07-15
(schuld, flutkatastrophe) until:2021-07-26 since:2021-07-15
(schuld, flut) until:2021-07-26 since:2021-07-15

1 Nix, D. (2021). Available at: https://twitter.com/galottom/sta tus/1417773431509114880 (accessed 11/03/2022). en-a-490cf803-c71a-473e-bd8d-2adda4674b65 (accessed 11/03/2022).
2 Reuters (2021). Available at: https://www.reuters.com/business/environ ment/thirty-missing-germany-house-collapses-heavy-rain-me dia-2021-07-15/ (accessed 11/03/2022).
3 Hochwasser Ahrtal 2021 (2021). Schuld: zerstörte Pizzeria und Strasse L73. Available at: https://hochwasser-ahrtal-2021.de (accessed 11/03/2022).
4 Rattay, W. (2021). Reuters. Available at: https://www.nrk.no/urix/ingen-di ode-i-schuld-1.15577583 (accessed 11/03/2022).
5 Hochwasser Ahrtal 2021 (2021). Schuld: Ausgespülter Kanal. Available at: https://hochwasser-ahrtal-2021.de (accessed 11/03/2022).
6 Hochwasser Ahrtal 2021 (2021). Schuld: Zerstörter Flusslauf. Available at: https://hochwasser-ahrtal-2021.de (accessed 11/03/2022).
7 Cherian, B. (2021). Available at: https://twitter.com/Bobby_Cherian/sta tus/1416379574850658305 (accessed 11/03/2022).
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10 Hochwasser Ahrtal 2021 (2021). Schuld: Arbeiten am Flussbett. Available at: https://hochwasser-ahrtal-2021.de (accessed 11/03/2022).
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13 Stache, C. (2021). EPA-EFE. Available at: https://www.spiegel.de/politik/ deutschland/hochwasser-katastrophe-angela-merkel-in-der-eifel-eingetroff

STATUS: 22. FEBRUARY, 2022


Ahrstraße


evidence
of play

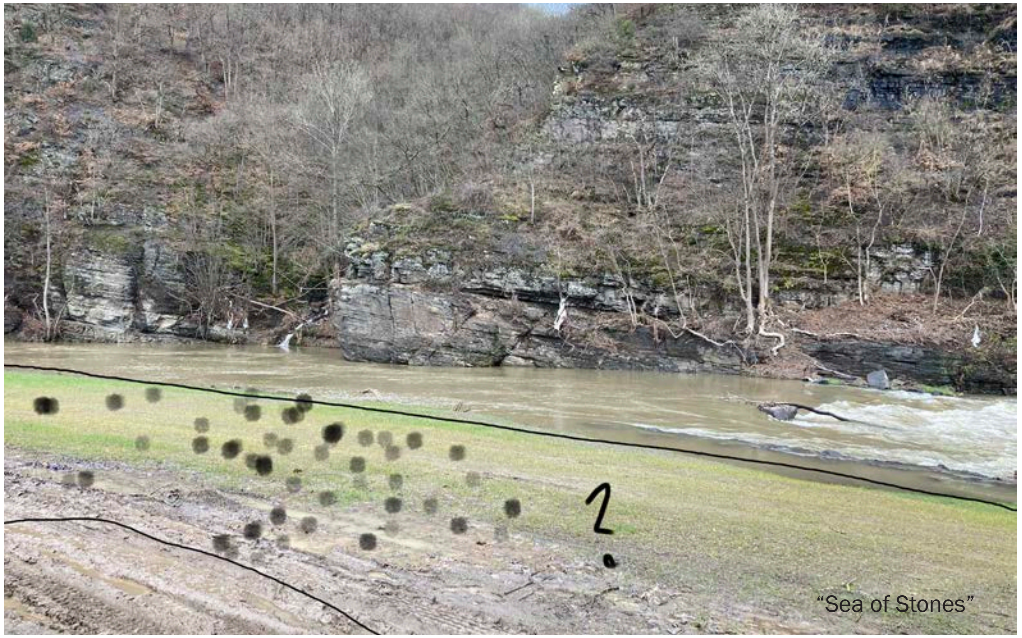

Ahrstraße


Landbäckerei
Schlösser
Frischemarkt

INFRASTRUCTURE: 22. FEBRUARY, 2022

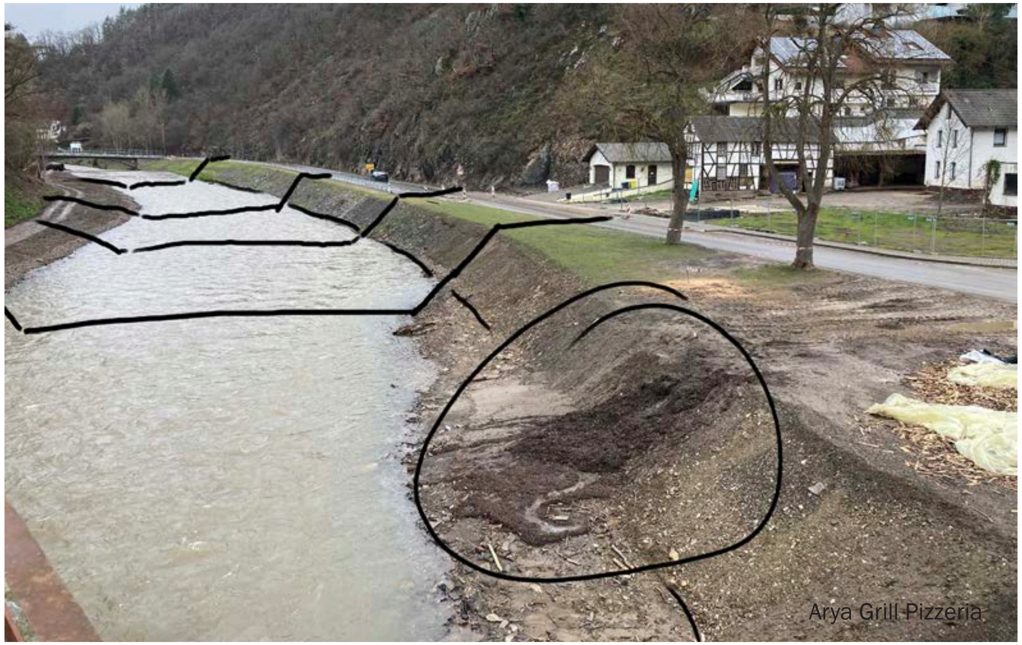
RIVER CHANNEL: 22. FEBRUARY, 2022

Tennis courts

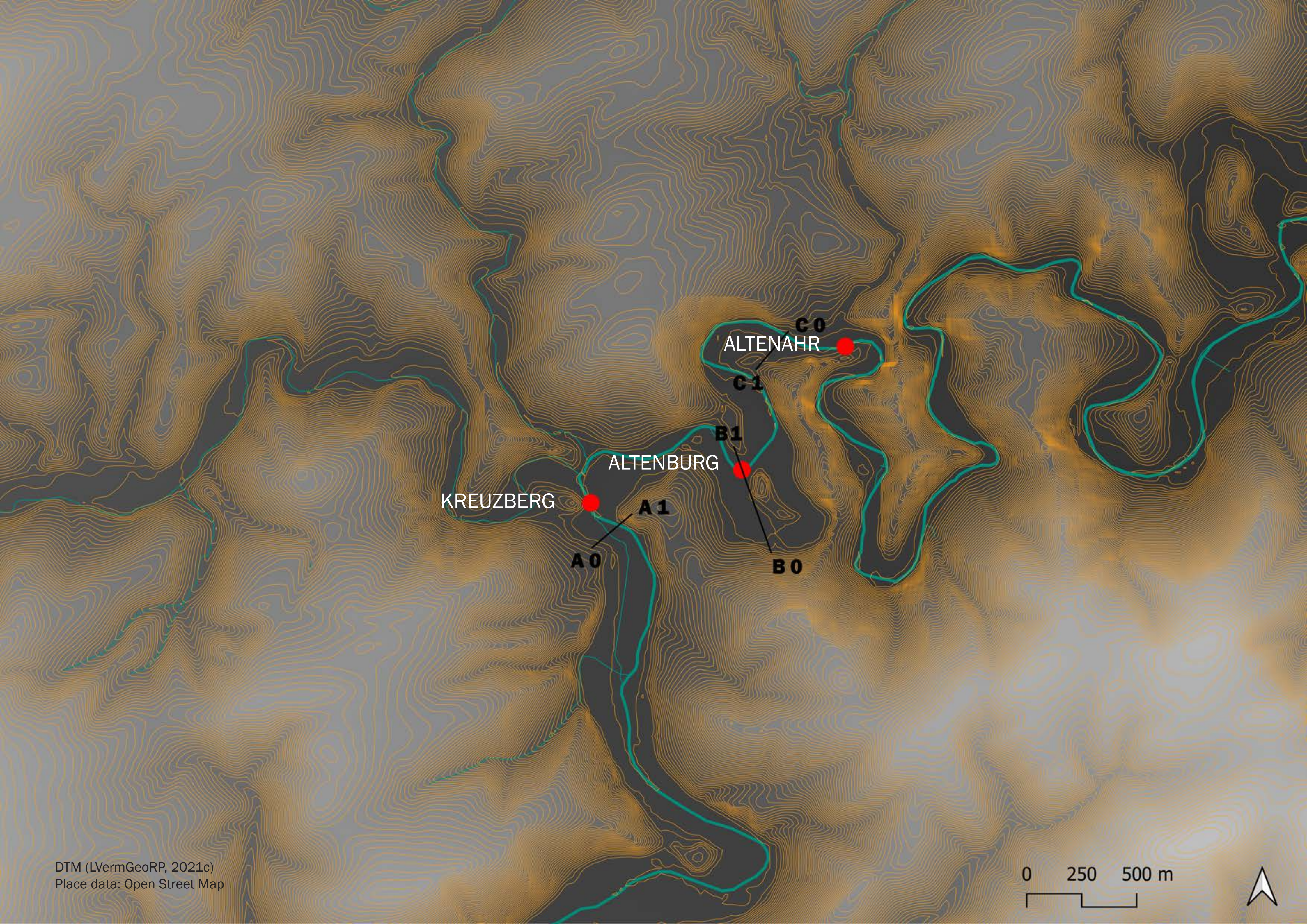


“Sea of Stones”

Tennis courts



Arya Grill Pizzeria

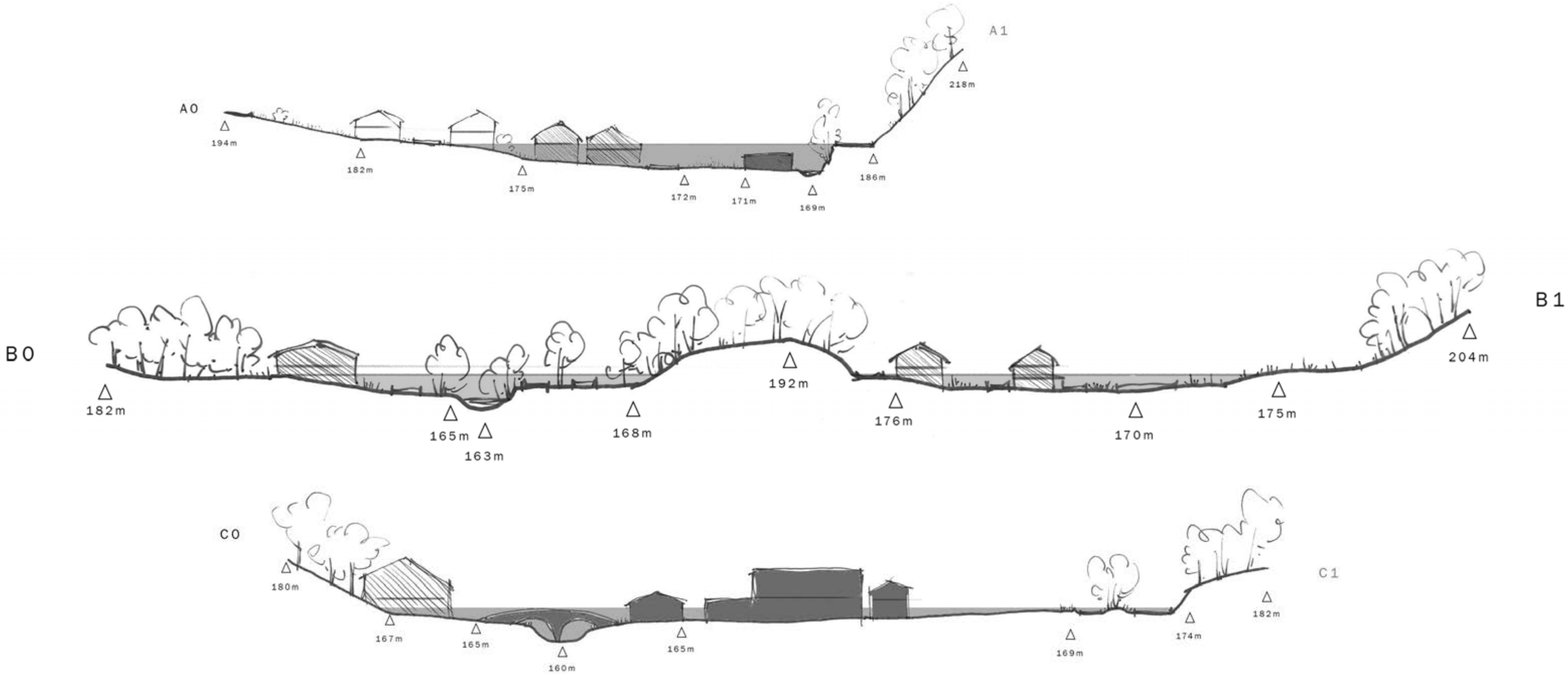

C 0
ALTENAHR
C 1
B 1
ALTENBURG
KREUZBERG
A 1
A 0
B 0
DTM (LVermGeoRP, 2021c)
Place data: Open Street Map
0 250 500 m

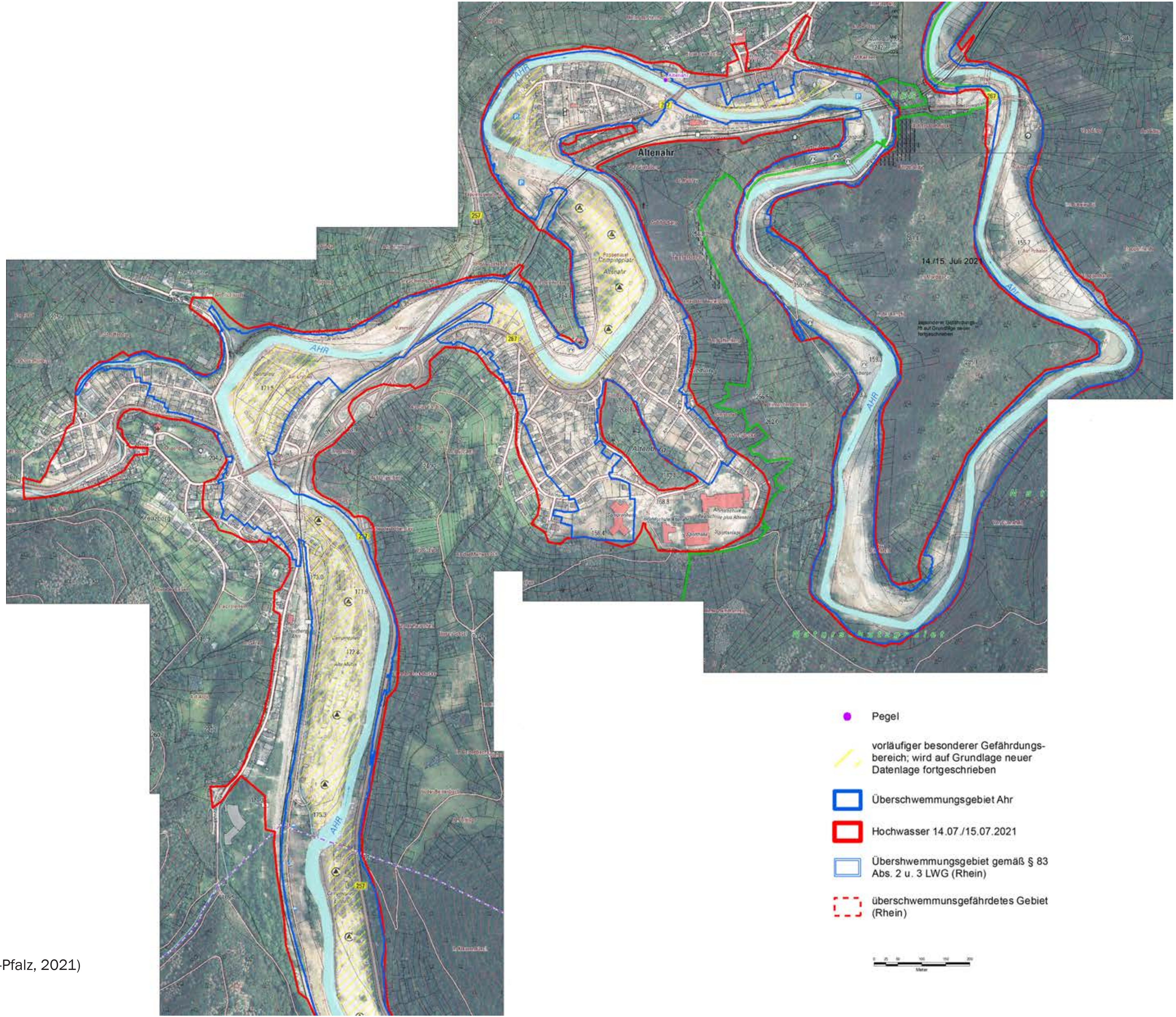
ALTENAHR

FLOODING DIMENSIONS

Flooding began around 19:00 and peaked around midnight on 14. July. Water levels reached 7-8 meters with markings on buildings reaching 10 meters at various locations. The peak average discharge is estimated to be 550 m3/s, though there is a wide range between the low estimate (400) and high (700). There was a total of 12 bridges in Altenahr for road, rail, cycle, and foot traffic, most of which failed. Detritus caused jams in the bridges, damming water until it broke in violent waves.

Watershed of Altenahr





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Rheinland-Pfalz, 2021)

The railway embankment also acted as a dam, which was crested with violent results in Altenburg. Across the entire flooded plain, the average velocity of the river was 0.65 m/s at its peak, but this varies dramatically from its deepest to its shallowest zones.

Altenahr was so badly damaged that almost no one lives there as of March 2022. Of the 1,950 residents, approximate 1,400 were affected by the flood. Around 520 of the 660 homes were damaged, 480 of them severely. Neighbors and families on rooftops witnessed the homes of their loved ones being swept away with their inhabitants inside. Thirty-three people lost their lives that night. Approximately 150 to 160 houses were destroyed either during the flood or demolished afterwards due to severe damage or oil contamination. But only nine of these fall within the newly defined yellow special hazard zone and cannot be rebuilt (Hagebölling, 2022).

The Sahrbach and Vischeltal tributaries that join the Ahr 75 meters apart, providing a large input of water that also originates in the High Eifels. Their basin size is 64 km2, or 8% of the catchment area until Altenahr. This catchment is 759 km2, or 85% of the entire drainage basin of the Ahr River. There is an elevation difference of the river from 175 to 160 meters above sea level from above the camp sites to below the built area at the tunnels, resulting in a river slope of 0.35%.

LOCAL HISTORY

The municipality of Altenahr is comprised of three villages – Altenahr, Altenburg, and Kreuzberg. Its was first mentioned in 893 and was the administrative seat for the area for 750 years. High in its hillsides are the ruins of the Are Castle who ruled the area between the 11th to 13th centuries (Görtz, 1999). According to census data beginning in 1815, the villages grew from a population of 893 in 1815 to a peak of 2,101 in 1970. It has since declined to 1,869 in 2016 (Landesamt, 2020). Local mayor predicts a population decline of 20 to 30% due to the flooding and is working to define new areas for construction. 15 plots have been deemed capable of development (Hageböllling, 2022)

Altenahr is known as one of the most scenic stops along the various hiking trails of the Ahr, including the Red Wine Hiking Trail. It is the last municipality that hosts viticulture and has a broad array of facilities to host tourism affiliated with wine. Locals are active with sports, church, and other cultural events with a variety of clubs and associations.

There are several important historic features in the villages. In addition to the Are Castle, there are two Stations of the Cross dating to 1728, an outdoor pool, and many historic buildings and bridges.

RECONSTRUCTION

Altenahr applied for funding that so far totals 145 million euros, with the majority to reconstruct bridges. Reconstruction is estimated to cost 19 million euros and includes the Ahr Valley School (4.6 million euros), the station building, the guest house (2.7 million), the cemetery (1.7 million), and the cemetery hall (1.5 million) (Hageböllling, 2022). During fieldwork in February, there were many vehicles for house repairs parked in the affected areas with ample activity. The houses many be uninhabitable now, but they will be repaired soon enough. Major work is ongoing at the tunnels and bridges.

Altenahr is one of many places where damage extended far upstream from the Ahr River. The land along the Vischeltal tributary was also badly damaged for several kilometers. Roads were completely washed out, small landslides pushed trees into the waterways, and embankments were severely eroded. This affected transport as well as utilities. This damage highlighted how agricultural practices, such as drainage tiles, can have a profound effect on flooding. Water is not retained in the higher reaches, and it causes problems downstream. Still, the infrastructure is being replaced in its previous location and form.

DESTRUCTION

TRANSPORTATION

EROSION

DEPOSITION


9


AFP
72290
CHRISTOF STACHE / A


11

Image search

Twitter: (altenahr) until:2021-07-26 since:2021-07-15

1 Lang, M. (2021). Available at: https://twitter.com/MatthiasLang2/status/1419391888419868673 (accessed 11/03/2022).
2 ZDF Landesstudio Saarland (2021). Available at: https://twitter.com/ZDFsaarland/status/1417430791248924712 (accessed 11/03/2022).
3 Der Kettenw*chser (2021). Available at: https://twitter.com/PHPmacher/status/1417177555250163720 (accessed 11/03/2022).
4 nxck (2021). Available at: https://twitter.com/nicktsx/status/1418906671154450436 (accessed 11/03/2022).
5 Laconde, T. (2021). Available at: https://twitter.com/EnergieDevlpmt/status/1418668083040894978 (accessed 11/03/2022).
6 COMPACT-Magazin (2021). Available at: https://twitter.com/COMPACTMagazin/status/1418582653654216706 (accessed 11/03/2022).
7 Hulsbeek, J. (2021). Available at: https://twitter.com/juhuls/status/1417149409503088645 (accessed 11/03/2022).
8 nxck (2021). Available at: https://twitter.com/nicktsx/status/1418906671154450436 (accessed 11/03/2022).
9 Schmidt, P. (2021). Available at: https://twitter.com/33dBm/status/1418640620395061258 (accessed 11/03/2022).
10 Stache, C. (2021). AFP. Available at: https://www.spectator.co.uk/article/flooding-is-going-to-dominate-the-german-elections (accessed 11/03/2022)
11 COMPACT-Magazin (2021). Available at: https://twitter.com/COMPACTMagazin/status/1418550966186647555 (accessed 11/03/2021).
12 nxck (2021). Available at: https://twitter.com/nicktsx/status/1418906671154450436 (accessed 11/03/2022).
13 COMPACT-Magazin (2021). Available at: https://twitter.com/COMPACTMagazin/status/1418550966186647555 (accessed 11/03/2022).

STATUS: 23. FEBRUARY, 2022

District Savings Bank
Hotel Lang Altenahr
Pension "Haus Marhöfer"
Paradies Apotheke
Guesthouse
Hotel Zum Rittersprung
Altenburger Str

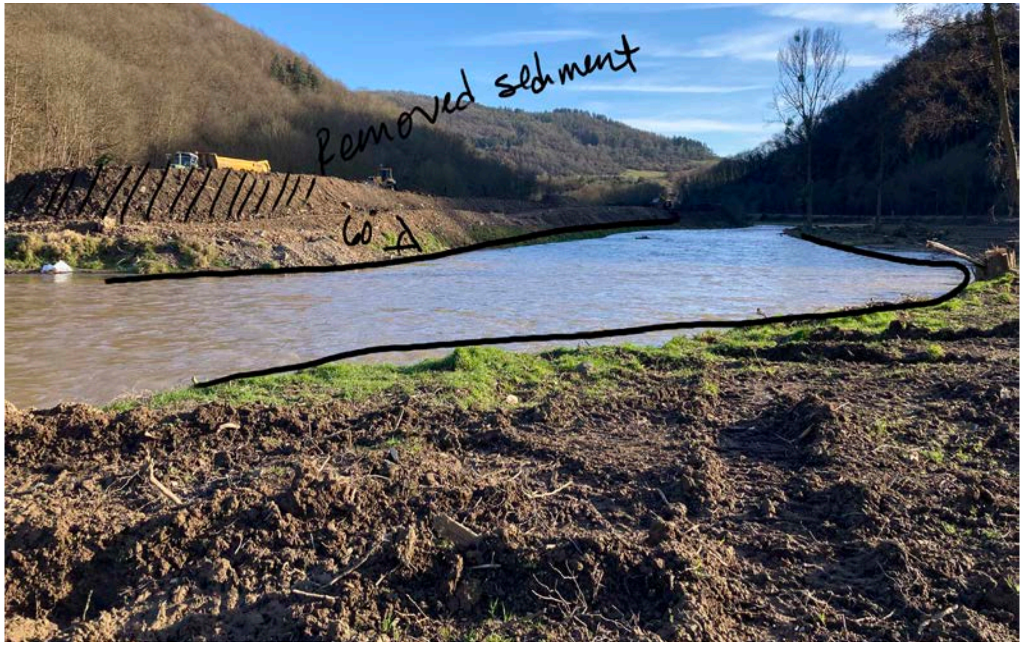
Werner Kneips Massage-Praxis
Hotel zum Rittersprung
Hotel-Restaurant Ruland
Peter Langen Weinstube
Holiday apartments Ahr-Palais
Assenmacher Guesthouse
Driving service Schmidt
Hotel Royal Santana
AHR


Cafe-Hotel-Restaurant
L 267
1 of 2 bridges handling normal traffic

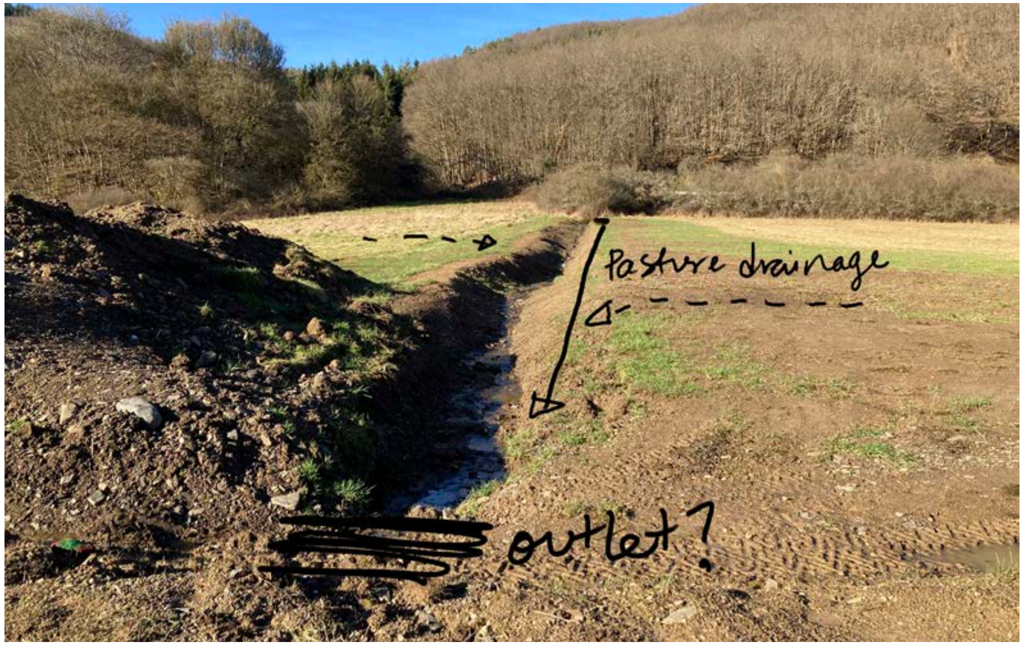

2 of 2 bridges handling normal traffic
Kreuzberg
Repaired Sewage


Hazard zone, reconstruction prohibited

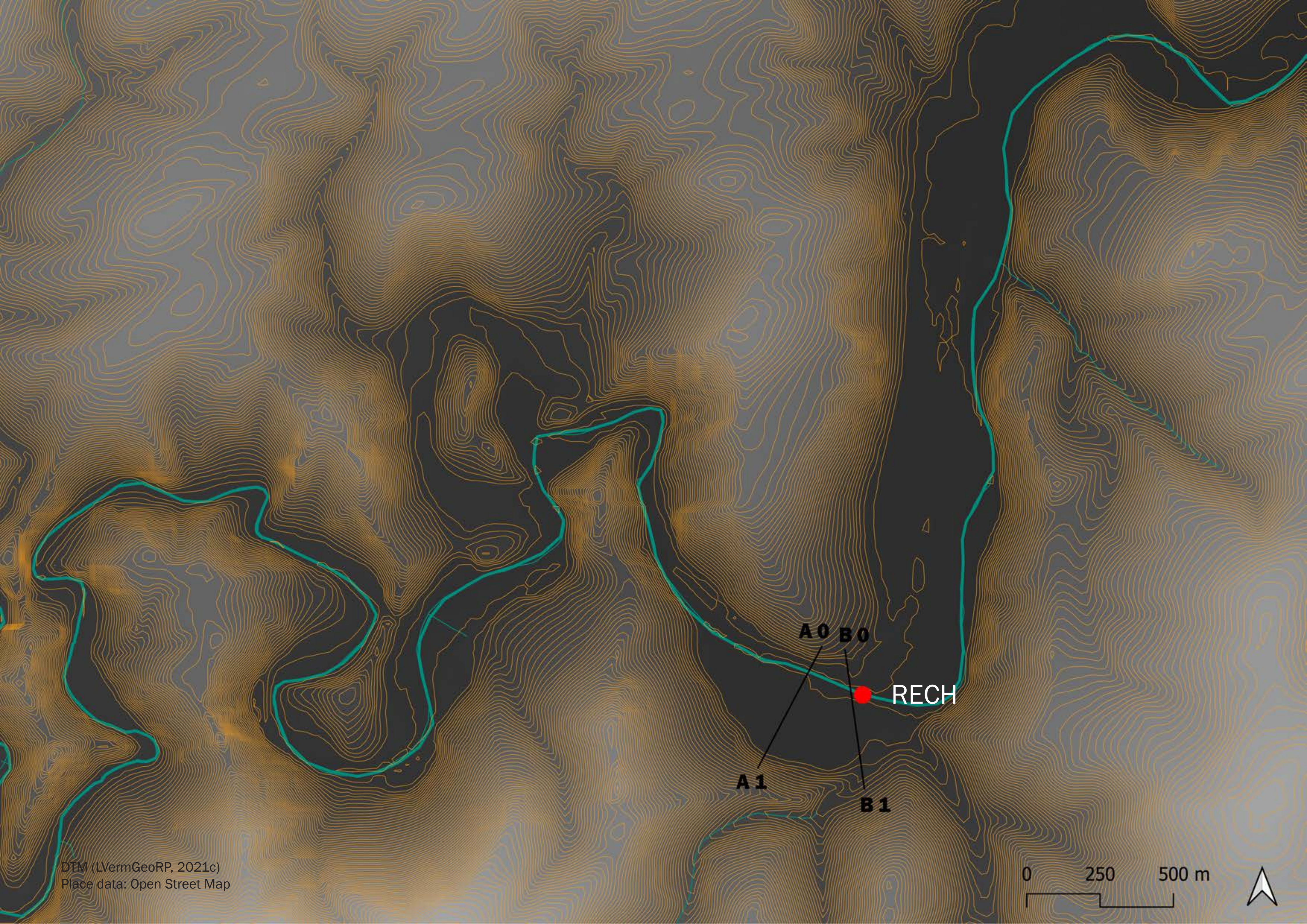
RIVER CHANNEL: 23. FEBRUARY, 2022



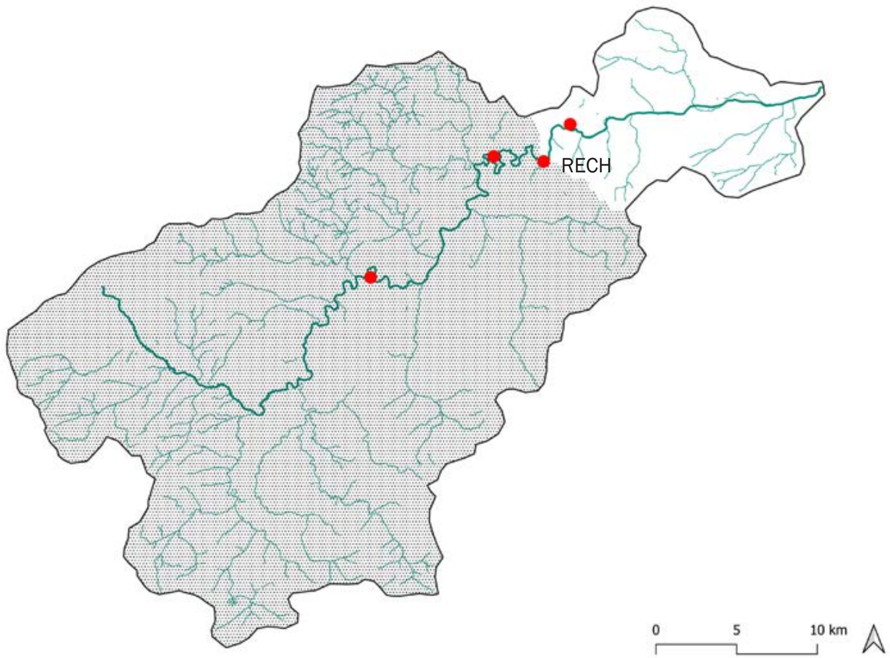
VISCHELBACH: 23. FEBRUARY, 2022



Railway embankment, Altenburg


A0
B0
RECH
A1
B1
DTM (LVermGeoRP, 2021c)
Place data: Open Street Map
0
250
500 m

RECH

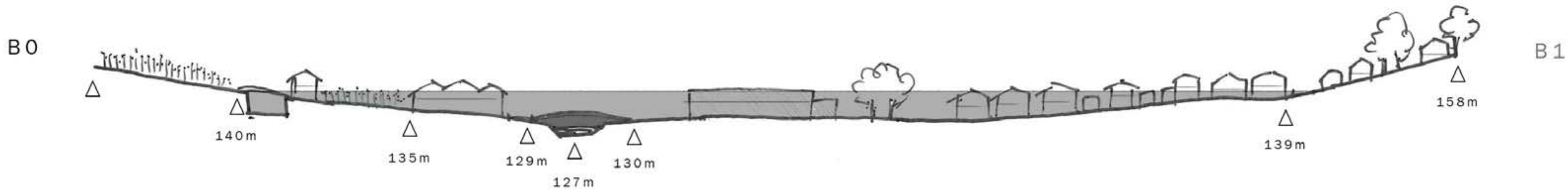


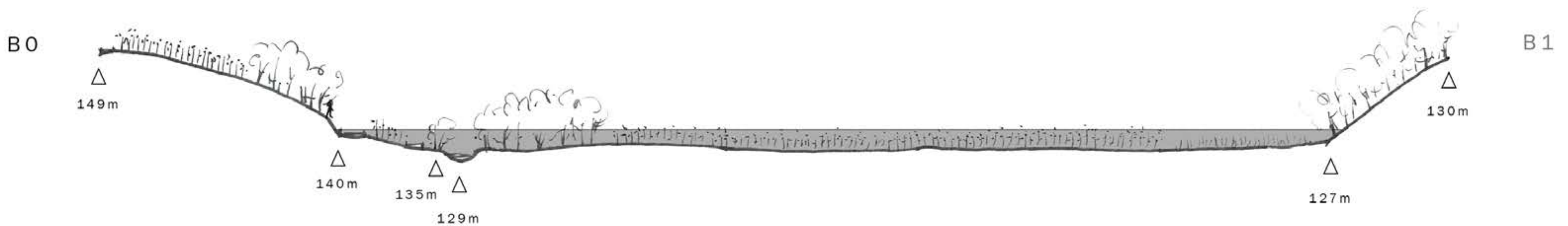
Watershed of Rech

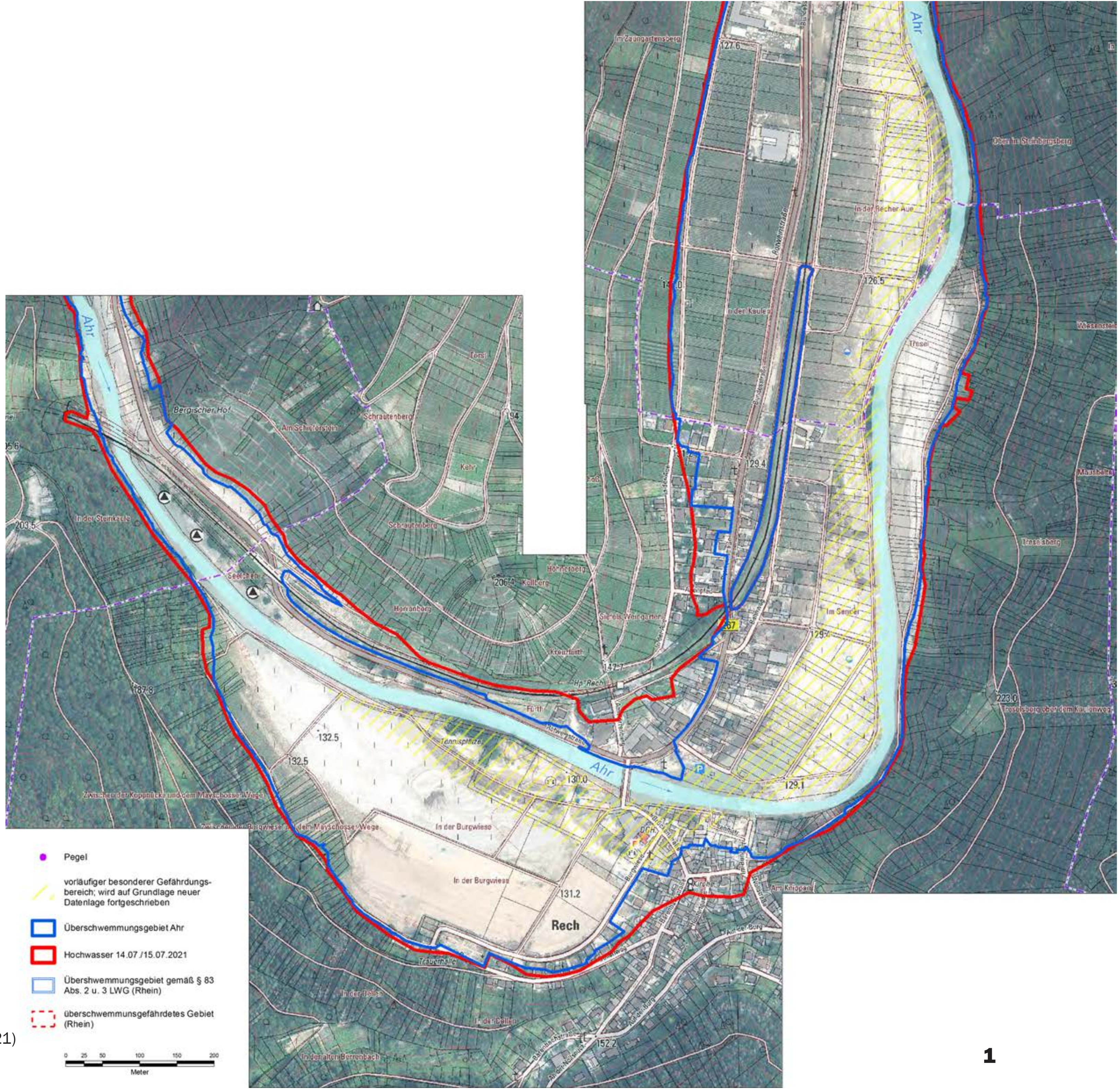
FLOOD DIMENSIONS

Rech is located about five kilometers downstream from Altenahr. Flooding began in the late evening in Rech, peaking shortly after Altenahr after midnight. The watershed is very similar to Altenahr, with 771 km2 (86% of total). Dimensions of the flood are expected to be similar as well. The slope of the Ahr River at Rech is approximately 0.35%

Of the 327 buildings in Rech, 177 registered damages. Thirteen houses washed away and six later needed to be torn down. Nine buildings, presumably related to railway utilities, were also destroyed immediately upstream from the village. Rech is unique in this report because unlike the other case studies, it does not have a tight loop of the river passing through and it has broad, unbuilt floodplains both upstream and down.







Rheinland-Pfalz, 2021)

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These spaces previously cultivated vineyards and they were almost entirely swept away. Despite a potential for slowing the river at this point, Rech was hit equally as hard as the other villages on the Ahr.

LOCAL HISTORY

The first documented mentions of Rech came in 1482. The oldest half-timbered house, The Old Winzerhaus, in Rech dates to the 17th century. The St. Lucia market dates to the Middle Ages when Rech was an important place of pilgrimage, from which pilgrims bought cloth and linen (Rech, 2022). It is home to the iconic Ahrbrücke stone bridge, which began construction in 1723. This was the only bridge on the Ahr to survive the 1910 flood and was renovated in 2008 (Koniecki, 2021). Its population has grown from 316 in 1815 to 553 in 2020, reaching a peak in 1997 at 592 (Landesamt, 2020).

Rech hosts wine festivals, a Lucia market during Advent, and Culinary Vine Hiking Days in April. There are two hotels in the village, but there has been a significant decline in tourism since 2013, leading to the closure of several accommodations and retail venues (Rech, 2022). There are twenty winegrowing companies in Rech, with 35 hectares under production. This has shrunk from 54 companies and 48 hectares in 1979 (Landesamt, 2022).

RECONSTRUCTION

Reconstruction efforts in Rech are similar to Schuld – as a small village, it takes time. Debris has been removed from the river and the banks made straight again, but destroyed and exposed infrastructure, like sewage, is still visible on eroded banks. Access to half of the village is available only with a temporary bridge. Businesses are still largely closed. During fieldwork, machinery was in action replacing sewer culverts. In the floodplains, particularly upstream from the village, there is a high presence of small debris in the soil such as Styrofoam and plastics.

As of 1. April, 2022, Rech entered a partnership with the district of Limbur-Weilburg (between the Ahr Valley and Frankfurt) for helping with financial support, provision of assistance, advice and coordination services, and to generate economic construction companies. To donation accounts have been set up for the region, collecting 158,200 euros from towns in the district and more than 166,000 euros from individuals. The Limbur-Weilburg district also donated 172,000 euros. Planning for reconstruction projects has begun, and events such as wine festivals and concerts are planned to help support the community (Rech, 2021).

DESTRUCTION

TRANSPORTATION

EROSION

DEPOSITION

EARLY RECONSTRUCTION

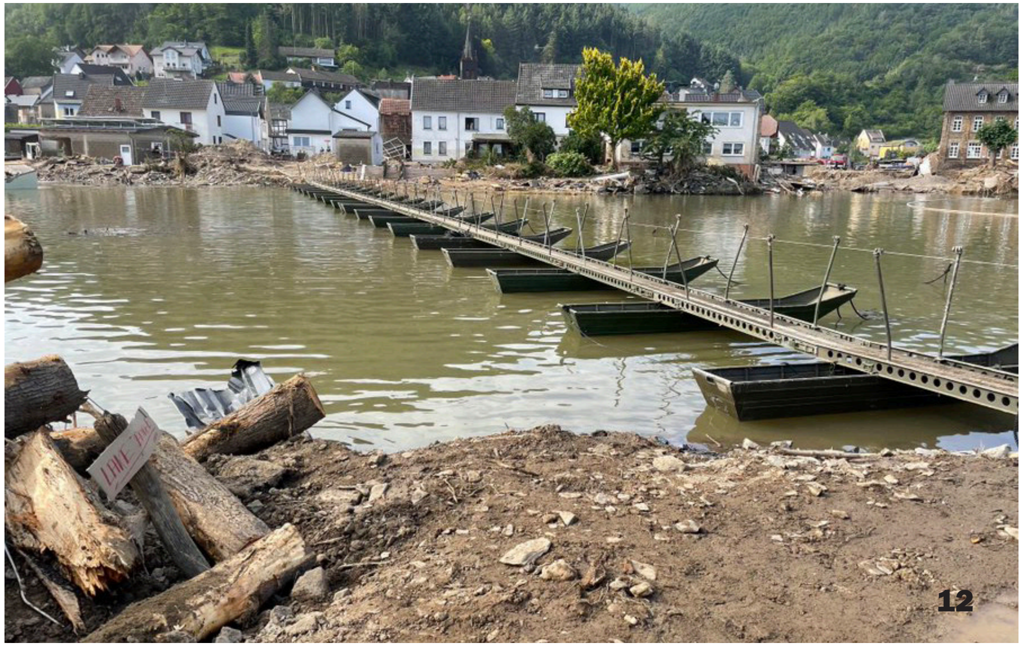

Image search

https://hochwasser-ahrtal-2021.de

Twitter: (rech) until:2021-07-26 since:2021-07-15
(rech, hochwasser) until:2021-07-26 since:2021-07-15
(rech, flutkatastrophe) until:2021-07-26 since:2021-07-15

1 Steil-TV (2021). Nach der Hochwasserkatastrophe Tag 21 -Lage vor Ort: Weindorf Rech-Landkreis Ahrweiler. Available at: https://www.youtube.com/watch?v=Yr1FPF9DS-k (accessed 13/03/2022).

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8 Vogel, F. (2021). EPA. Available at: https://twitter.com/epaphotos/status/1417839578942263297 (accessed 13/03/2022).

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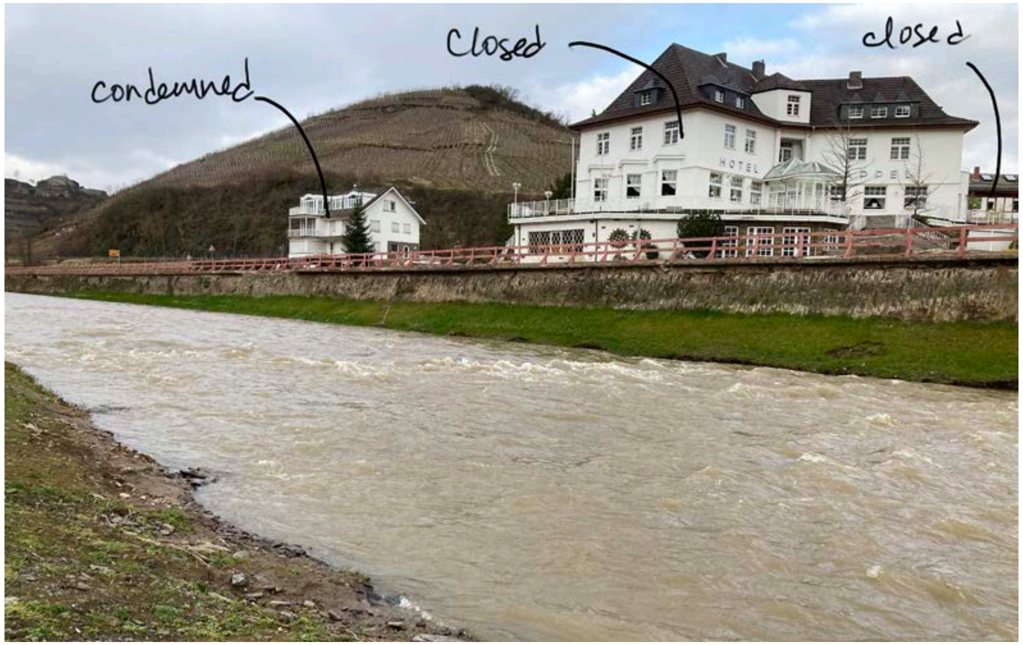
12 Bell, C. (2021). Available at: https://twitter.com/Kottem1/status/1418127841657511939 (accessed 13/03/2022).

13 Rideoak (2021). 23.07.21 Rech an der Ahr: Auf der St. Nepomukbrücke. Available at: https://www.youtube.com/watch?v=HCLkAA_wods (accessed 13/03/2022).

STATUS: 24. FEBRUARY, 2022


13 houses missing


condemned
closed
closed
HOTEL


19.7/86 hectares = 22.9%

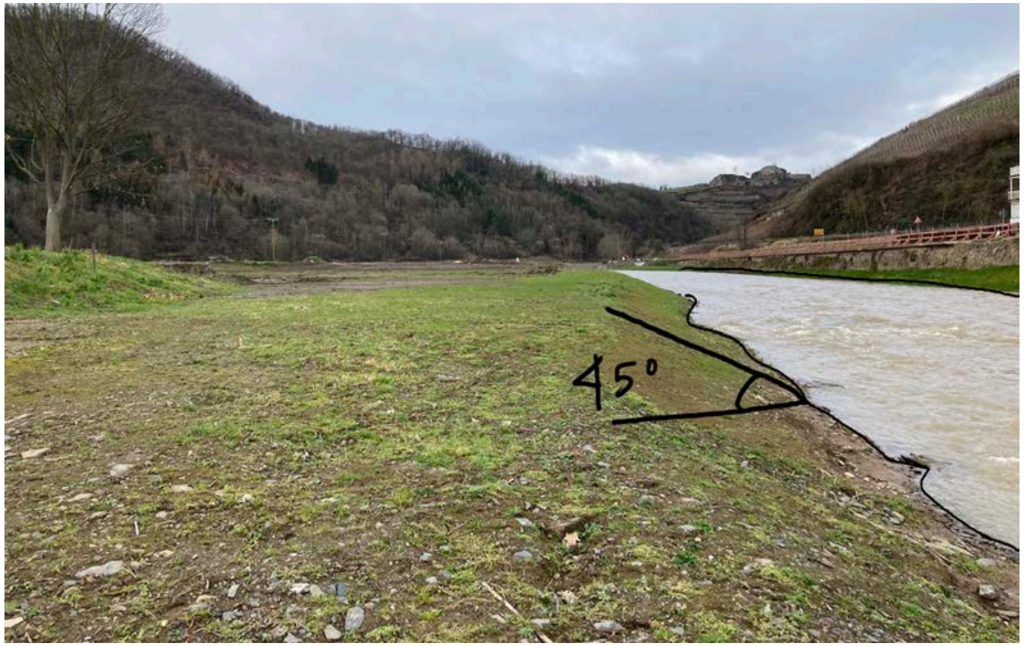

RESTAURANT Ahrblume WEINHAUS
closed
closed
former terrace


Resisted 1910 flood
Renovated in 2008


perspective
from N
sewage
Electric

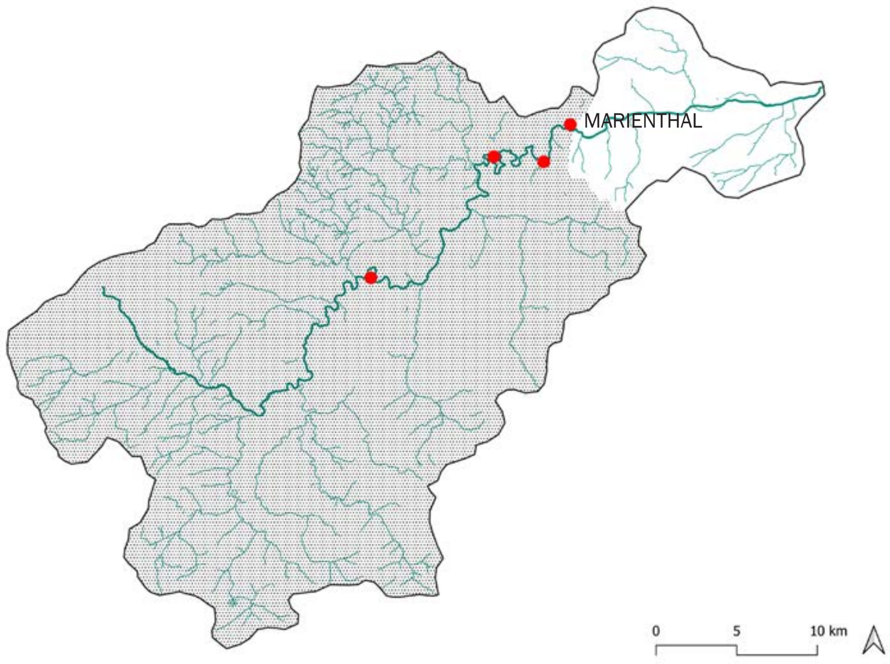

perspective from S

RIVER CHANNEL: 24. FEBRUARY, 2022



DTM (LVermGeoRP, 2021c)
Place data: Open Street Map

MARIENTHAL

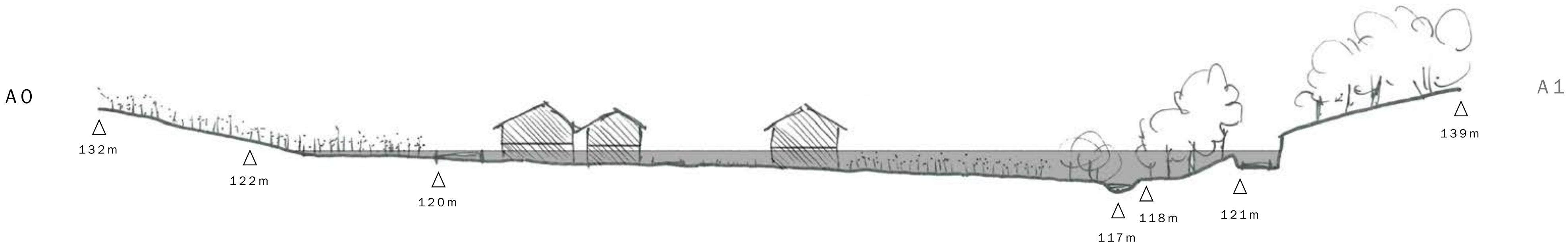


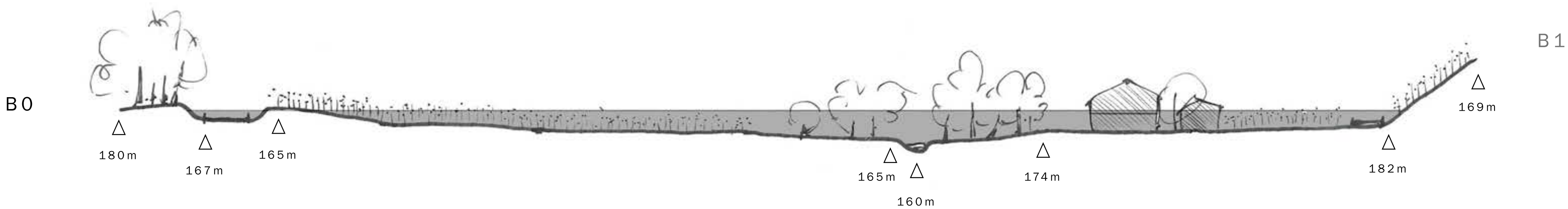
Watershed of Marienthal

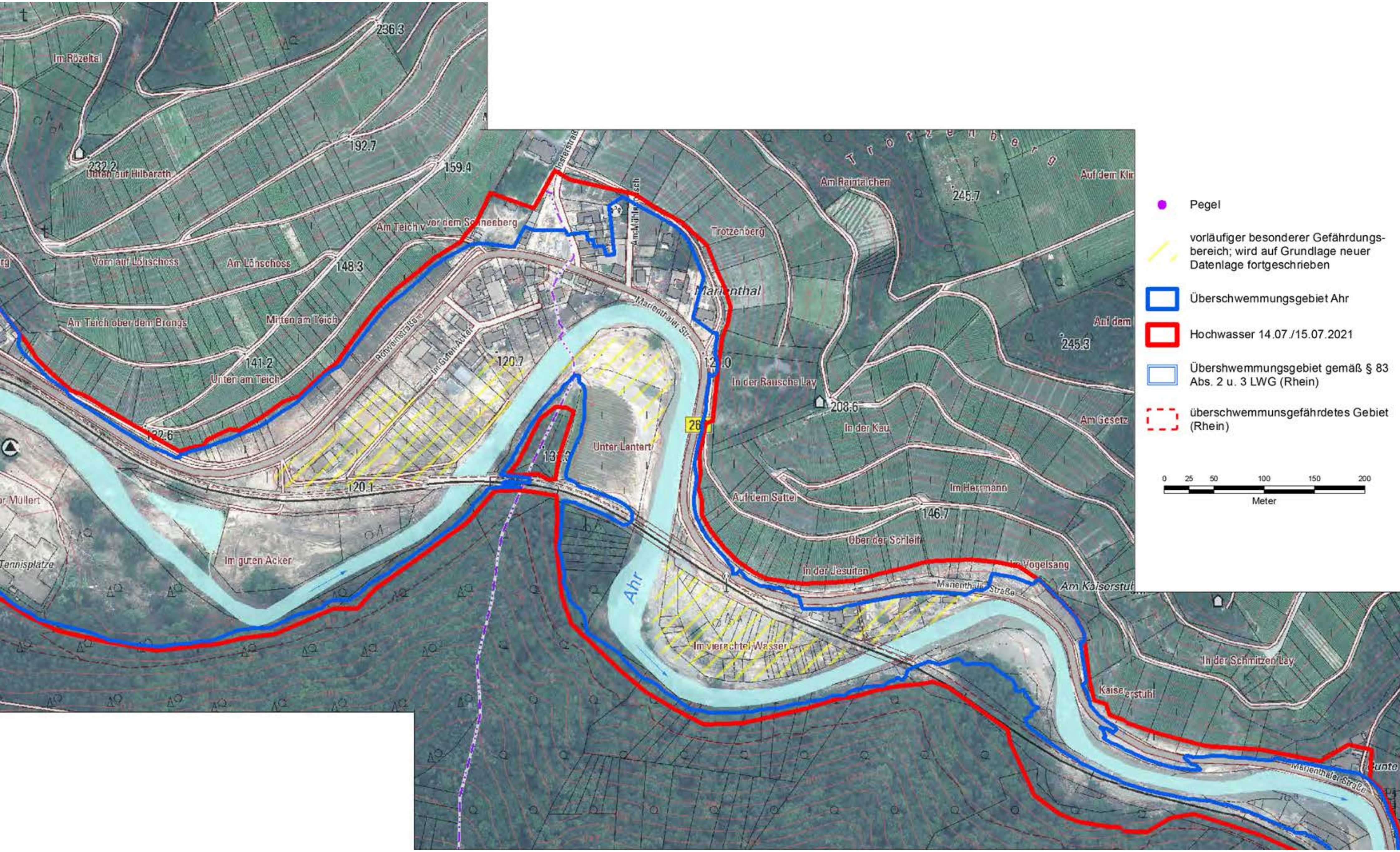
FLOOD DIMENSIONS

Marienthal is located about four kilometers downstream from Rech. Again, it has very similar flood dimensions to Altenahr as well as Rech. Flooding began in the late evening in Rech, peaking shortly after after midnight. Videos are available online that show pedestrians standing at the bridge in the evening while rushing water nears the top of the arches. The watershed is 780 km2 (87% of total). Discharge and water levels are expected to be similar to Altenahr. The slope of the Ahr River at Marienthal is approximately 0.33%.

Marienthal is a very small village. Of the 62 total homes, 56 reported damages and at least 3 were demolished. Among the only buildings without damage are the various structures affiliated with the Marienthal Abbey.







Rheinland-Pfalz, 2021)

LOCAL HISTORY

Marienthal residents live from viticulture and tourism. It is a tiny village, though the exact number of residents was not found because it in part incorporated into neighboring Dernau to the west and in part to Walporzheim to the east. It is best known for its abbey, which is a restaurant, winery, and concert venue. The abbey is the largest producer of wine in the hamlet, owning 19 hectares and producing 100,000 bottles annually. The village previously had a station on the Ahr Valley Railway between 1920 to 1955. The Rhenish Railway Company opened the first section of the Ahr Valley Railway to Ahrweiler following a royal decree in 1880. By December 1886 it stretched to Altenahr and was completed to Adenau in 1888. It was a double track railway, carrying both goods and passengers. The railway was heavily damaged in the 1910 floods. Damage was estimated at approximately 18.3 million euros and resulted in the death of 53. The railway was also severely damaged by Allied air raids and German explosions in WWII and was not fully in function again until 1951. In 1985, the section between Hönningen-Adenau was closed. The stretch between Ahrbrück-Hönningen was closed in 1999 (Kemp, 2013). The disused second tracks and disused routes are used for the Ahr Cycle Way (Ahr-Radweg), a 77-kilometer path that connects to the Erft Cylcle Path and Rhine Cycle Path to form a 300 km long circuit (Ahrtal-Tourismus, 2022).

RECONSTRUCTION

Marienthal is small but bustling with reconstruction activity. Many workers' vehicles are parked along the main road, and excavators and dump trucks sort through and transport the large piles of soil on the western side of the village. These plateau-like features where the sediments washed down from the upper reaches have been gathered. They are present all along the river. It is difficult to estimate their sizes, but in total it would be many tens of thousands, if not hundreds of thousands of cubic meters still remaining in the valley seven months after the floods.

Following the July 2021 flood, 91% of the 85 voters voted in favor of merging completely with Dernau to simplify administrative processes. A new heating plan is being developed, which will source 20% of energy from solar panels and the rest from wood pellets (Schulze, 2022).

DESTRUCTION

TRANSPORTATION

EROSION

DEPOSITION

EARLY RECONSTRUCTION

Image search

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(rech, hochwasser) until:2021-07-26 since:2021-07-15
(rech, flutkatastrophe) until:2021-07-26 since:2021-07-15

1 Rideoak (2021). 22.07.21: Dernau/Marienthal, Höhe Hotel “Zum Sänger” DIREKT am Fluss, Teil 3, Ahr Flutkatastrophe. Available at: https://www.youtube.com/watch?v=cYhezLnxCww (accessed 14/03/2022).

2 Rideoak (2021). 29.07.21: Marienthal, Teil 13, Update Ahr Flutkatastrophe. Available at: https://www.youtube.com/watch?v=tkGc6ELQQGI (accessed 14/03/2022).

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7 Rideoak (2021). 29.07.2021: Marienthal, Teil 11, Update Ahr Flutkatastrophe. Available at: https://www.youtube.com/watch?v=rIG_0TWEd_0 (accessed 14/03/2022).

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11 Rideoak (2021). 29.07.2021: Marienthal, Teil 12, Update Ahr Flutkatastrophe. Available at: https://www.youtube.com/watch?v=I1XjGR3capg (accessed 14/03/2022).

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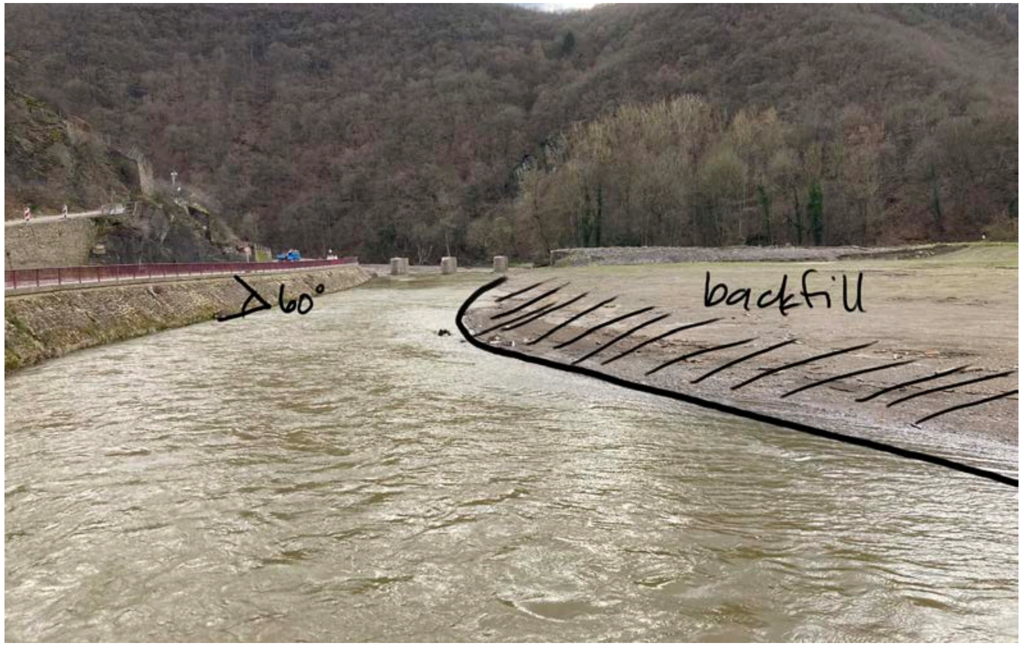
STATUS: 24. FEBRUARY, 2022

LIVELIHOODS: 24. FEBRUARY, 2022

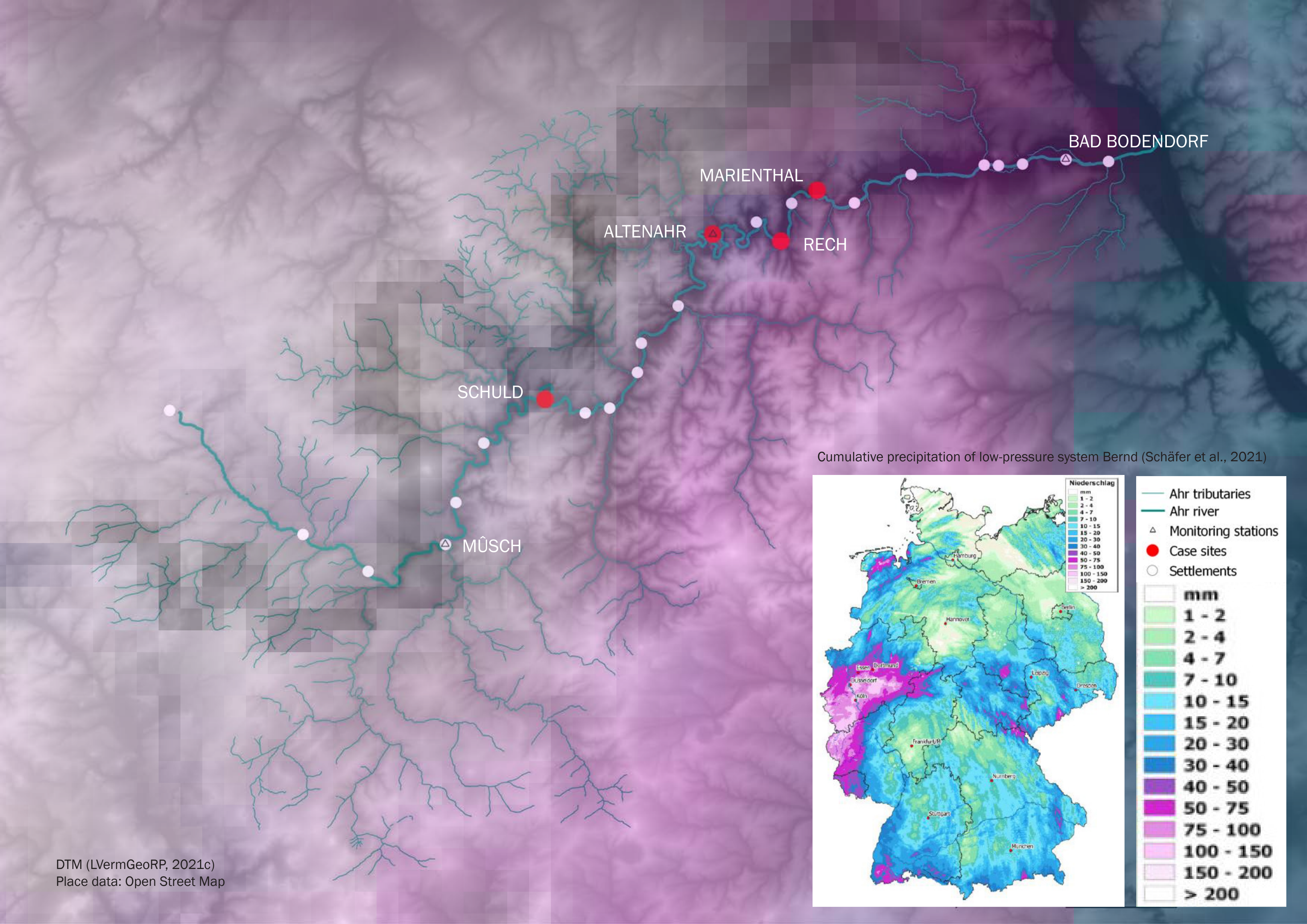
INFRASTRUCTURE: 24. FEBRUARY, 2022


60°
backfill


unsifted sediments


removal of obstacle


DANKE
missing vineyards



BAD BODENDORF
MARIENTHAL
ALTENAHR
RECH
SCHULD
MÛSCH
Cumulative precipitation of low-pressure system Bernd (Schäfer et al., 2021)
Niederschlag
Hamburg
Bremen
Hannover
Berlin
Essen
Dortmund
Düsseldorf
Köln
Leipzig
Dresden
Frankfurt/M
Nürnberg
Stuttgart
München
Ahr tributaries
Ahr river
Monitoring stations
Case sites
Settlements
mm
1 - 2
2 - 4
4 - 7
7 - 10
10 - 15
15 - 20
20 - 30
30 - 40
40 - 50
50 - 75
75 - 100
100 - 150
150 - 200
> 200
DTM (LVermGeoRP, 2021c)
Place data: Open Street Map

IDENTIFYING ROOT CAUSES

The flood had an obvious climatic factor, in that it was a particularly heavy rainfall that fell. But the root causes were far more complicated than that. They ranged from systematic failures in warning, localized issues with infrastructures, topographic and ecologic reasons, and economic factors.

The rescue operation in the Ahr Valley was the largest and longest in national history. Tens of thousands of volunteers came to assist post-disaster, including US forces stationed in Germany (Rheinland-Pfalz, 2022a). 100 Bundeswehr solders participated in the rescue on land and by air as well as 200 firefighters from the greater region. Rescue missions were difficult if not impossible in many places due to strong currents. Critical infrastructures were decimated by the force of the flood. New channels were created through cuts in hillsides for the rail lines and through car tunnels at tight loops. Much of the Ahr Valley was cut off by transport from the outside world during the disaster until waters receded by 17. July and temporary bridges were able to be installed. Telecommunications were also severed and not able to be restored at a basic level for two weeks.

The high death toll shows a failure in the warning system (Rodenkirch & Welsch, 2022). The seriousness of this storm was known and reported by weather agencies with ample time to implement evacuation plans. Approximately every third resident in the Ahr Valley did not feel sufficiently warned or stated that they had not been warned. Only one in seven understood that the floods would be extreme. The failure to adequately communicate the warnings to Ahr Valley residents has instigated an investigation by the public prosecutor's office against the former district administrator and a member of his crisis team for negligent homicide (Dienstleistungsdirektion, Rheinland-Pfalz Aufichts-Und, 2021).

The amount of flood warning sirens has decreased since the 1990s, something that experts have counselled against. Authorities suggested to modernize and expand the network of warning sirens so that are not reliant on internet or mobile networks for years prior to the flood (BPB, 2021). There was a clear failure of communication, both in literal terms and in peoples' perceptions of the impending danger. Kalruhe meteorologist Bernhard Mühr stated that the explosive nature and pressure to act described by the DWD was not obvious to everyone – "There were too many weather warnings in Germany." Evacuation orders were late and limited, and flooding in some places extended hundreds of meters beyond the administration and crisis team's expectations (Rodenkirch & Welsch, 2022). As one news interview stated, "Nobody on site had any idea that the water level would break all records on the night of July 14th and 15th" (Schmid-Johannsen et al., 2021). Life-threatening natural hazards are generally not expected to become disasters in Europe. Residents did not know how to behave in the case of a severe flood. And certainly not least, despite a historic precedence, an amnesia of past events is also problematic in understanding the gravity of the situation.

The flooding on 14.-15. July, 2021 far exceeded any measured event since data collection began in 1947 and it was well above the 100-year flood level by a factor of 2.1 to 2.4. This classified the flood as over a 10,000-year flood level per calculated risk assessment (Schäfer et al., 2021). The hydrological modelling based on quantitative data was enormously erroneous. Much of the flooded area from July 2021 was not a known risk area, including nationally and internationally surveyed highways.

Some of the hardest hit villages received a cumulative amount of precipitation of over 200mm over the course of "Bernd." Discharge rates on the upper Ahr River at Müsch were estimated to be between 506 to 578 m^3/s (Schäfer et al., 2021). The discharge in the middle reaches of the Ahr River at Altenahr were estimated at between 400 to 700 m^3/s with peak water levels breaching seven to eight meters (Schäfer et al., 2021). This flooded second stories of buildings, with locals giving testimony of flood heights reaching up to ten meters high, potentially marking the depth as detritus dams broke. Still, this places the 2021 event as only the second greatest flood discharge in the past 220 years, and still potentially only half of the 1804 event (Schäfer et al., 2021). Researchers reported this information in 2016 and earlier, but it was not incorporated into any flood risk management plan. It is important to look at the discharge rates and not the water levels, because the landscape has been heavily

modified over the centuries. A flood in today's context would have very different results than the same historic flood. Landscape modification, especially for the sake of viticulture and agriculture efficiency play a large role in the landscapes inability to retain or delay runoff.

Early assessments from 21. July from CEDIM estimated between €11-24 billion in damage. Later estimates predict the damage to private property and public infrastructure to be €20 billion in RLP alone, with a total of €30 to 40 billion nationally (Rheinland-Pfalz, 2022a). These updated values dramatically outweigh early estimates of the costliness of flooding because models typically do not capture data for the pluvial flooding, flash flooding, and landslides that cause the most damage. For example, a 500-year flood event is predicted to have damages of only €4 to 29 million (van Ginkel et al., 2021). In the Ahr Valley, only 37 to 47% of residential buildings were insured against flooding (Schäfer et al., 2021) and uninsured property will account for approximately €16 billion of the damage in RLP, to be covered by the recovery fund (Rheinland-Pfalz, 2022a). While there is massive structural damage to buildings that were close to the river, much of the claims are related to severe oil contamination from the floodwaters. There is a severe flaw in financial risk models, which in turn creates an economic exposure to the local population.

The Ahr Valley's economy is heavily based on tourism, which already suffered immensely prior to the flood due to Covid-19 restrictions. Many of the facilities that were used by tourists – hotels, apartments, restaurants, wine cellars – were located in the flood zone and were heavily damaged if not destroyed in the flood. Without the tourism and viticulture industries, there are few other employment opportunities in the valley and a large amount of residents commute. The expected financial losses after one or multiple seasons of failed tourism, will certainly take a large toll on the local economy.

Most of the damage from "Bernd" was caused by relatively small rivers, some of which were too small to be represented in national and European flood hazard data. This includes the Ahr (van Ginkel et al., 2021). The locals were naive to their environmental exposure as well. Villages located at the convergence points of tributaries of the Ahr coming from the High Eifel mountains were especially hard hit. It is likely that climate change will make this issue more severe. Warmer atmospheres holding more moisture move slower, so storms will deposit more intense precipitation over longer periods of time. The High Eifels already cause a noticeable rainshadow effect, and it is very possible that they will receive extreme precipitation that can drain into the Ahr Valley in the future.

Apart from the loss of life and material damages, the Ahr River deposited enormous amounts of debris, ranging from trees and stones to oil tanks and houses. Vast amounts of soil that washed down from the agricultural upper reaches, coating floodplains and villages in mud tens of centimeters thick. Intensive agriculture inherently degrades native ecosystems and create a greater flood risk. This was noticeable during fieldwork with field drainage systems as well as the denuded soil surface of the vineyards. The Ahr River occupies a small area of land in its catchment, but the problem with flooding is systemic and the fault extends far beyond the communities that were severely flooded.

PARADIGMS OF PLANNING

Map of Rhineland by Tranchot and von Müffling, 1803-1820 (LVermGeoRP, 2021a)

PARADIGMS OF PLANNING

There is already an enormous amount of work that has been completed in the clean-up of the Ahr Valley. Critical infrastructure is being repaired or rebuilt. Debris has been removed and the old river channel has been re-established. Badly damaged buildings have been demolished, and restoration work on thousands of homes is in full swing. People are choosing to stay. At present, the work they are doing does nothing to reduce flood risk, and people are exposing themselves physically and financially to a recurrent flood.

The many root causes have not adequately being addressed yet in planning, because there is no plan. The root causes extend far beyond the characteristics of the Ahr River and the ubiquitous, natural, predictable processes that occur. But the only new information guiding reconstruction regulation is the recalculated hydrologic flood risk maps from the Water Management Agency, released in September 2021, which give the majority of residents the right to rebuild their homes in the same location. There are special “extreme hazard” zones where theoretically no reconstruction is allowed, but still there are exceptions under grandfathering clauses. There are no specific requirements regarding flood protection design for homeowners, and it is likely that their private reconstruction projects will be finished long before a cohesive plan and any large-scale public flood protection plans are implemented. Whatever plans come will need to consider a wide-ranging list of issues to rebuild viable villages.

Each person and community has important historic, social, and cultural connections to the landscape that are used to rationalize their choice to stay, but inadequate regulations will cause recurrent tragedy. The urgency in rebuilding is understandable, but painfully short-sighted. The risk of a 100-year flood is statistical, not literal, and every year has the same probability of a serious flood. It will happen again; it is merely a matter of time. How much damage and loss of life will happen the next time? Will there be adequate risk reduction measures in place? What will this look like in the landscape? To what extent should the government be expected to protect people in the Ahr Valley in the future - physically, culturally, or financially? These are big questions that require novel solutions. Reconstruction measures will need to be adaptive to a new planning paradigm, one that reflects a changing environmental, social, and economic reality.

The economic aspect plays an important part in the reconstruction of the Ahr Valley. The German government has committed to a €30 billion recovery fund, without establishing plan to reduce the wide range of risks of a recurrent flood. Providing such an exorbitant amount of money at this stage may not be financially rational, just politically necessary. What is the incentive for such a large recovery fund and for the government and what is it actually investing in? Tourism, the basis for the Ahr Valley economy, has struggled immensely, proving to be unresilient, yet it is precisely what is being rebuilt – the hotels, restaurants, and wine cellars. The status of the industry was described in May 2020 as “precarious” to “alarming” (Ahrtal, 2020), long before the decimation of the flood and before Covid-19 restrictions were lifted. It is likely that many businesses will close in the Ahr Valley despite the relief funding, undermining regional vitality. Does it make sense to invest in the same, struggling economic infrastructure? €30 billion is an enormous figure – who will be held responsible for damages after the next inevitable flood? Does it make fiscal sense to rebuild at all?

Following the trajectory of philosophical developments in disaster risk management, I explore landscape reconstruction design concepts in the four established paradigms along with two new alternatives: Acts of God (Nature?), Man over Nature, Man in harmony with Nature, Resilience, Succumbence, and Inaction. Each paradigm has its own way to think about disaster risk reduction, and each subsequent paradigm grows in complexity and interwovenness. This section could provide years of work to complete, but I give a brief overview of what each paradigm is, what we might consider in each, and how principles of design can be seen within specific aspects of their planning concepts (or not). I reference a relevant few of the 125 universal principles of design as defined by Lidwell et al. (2010).

A wise friend of mine recently quoted to me the philospher Ludwig Wittgenstein, saying, “The limits of my language mean the limits of my world.” This entire thesis has changed and expanded my capability to discuss landscape architecture projects - from disaster risk reduction and hydrology to philosophy and design - and are necessary for providing a convincing argument. Merging them all to make a cohesive plan will be a challenge for the Ahr Valley, but it is absolutely critical to do so to move forward intelligently.

Altenburg, February 2022

ACTS OF GOD (NATURE?)

In the rhetoric of the “Acts of God” paradigm, people lived their lives in ignorance. In the 1700s, scientific fields that play large roles in disasters like geotechtonics, meteorology, and microbiology were unknown. The only way that normal people could make sense of disasters was by attributing it elsewhere – in Western countries this was God. Thus, it makes sense to abide by available information (the Bible) for answers and solutions. There was no better-known alternative to the layman than pray and have better moral behavior. They believed themselves victims to God’s will.

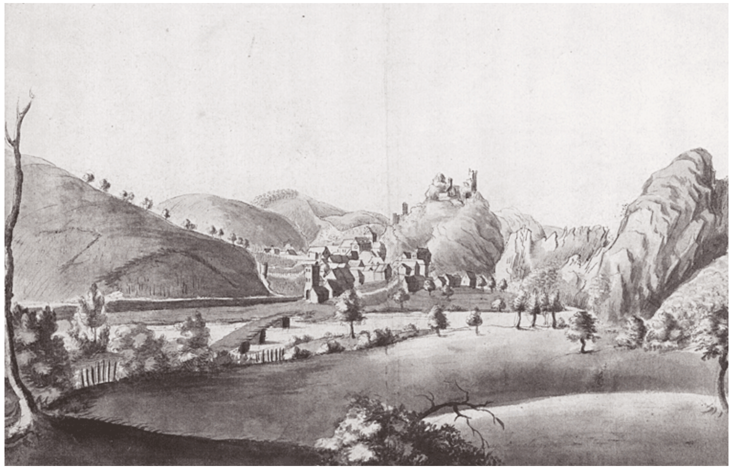
Locals in the Ahr Valley are quick to point out that they are not victims. They do not want pity and do not want to be a spectacle. The people of the Ahr Valley know why their valley flooded so violently – poorly issued or late warnings, inadequate flood models, ecological degradation, and possibly climate change. The fault of the disaster is very human, and they know it even if they don’t possess a keen landscape literacy. But is this reflected in how they are reconstructing? Homes are being rebuilt in situ and without a requirement for flood adaptations. Gas lines and busy roads are restored, continuing the use of fossil fuels. The Ahr River was hastily reshaped into its former self. The locals are working hard to return to the life and space that they had before, hoping that a better solution will come. This is not dissimilar to the logic before the Age of Enlightenment. It is not a logic that will adapt to climate change.

PRINCIPLES OF DESIGN

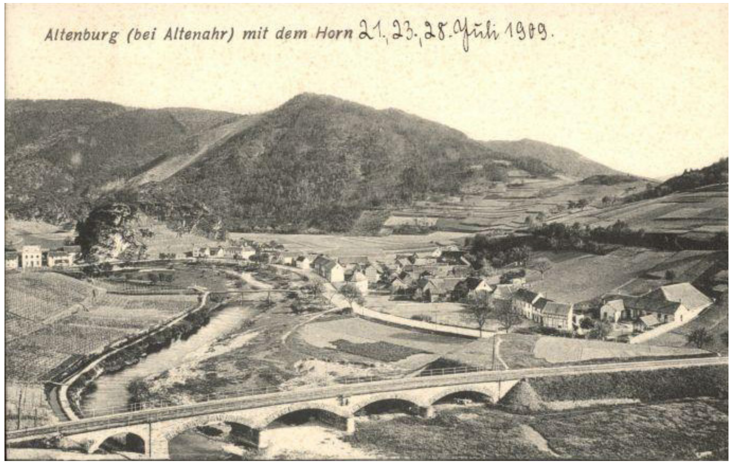
Contemporarily, the Acts of God paradigm is not so much of a design paradigm but more of inability or unwillingness to adapt to change. But the reconstruction that results from it can still show principles of design. The 80/20 Rule is useful as a descriptor. Feedback Loop and Prospect-Refuge are principles that are implemented passively.

The 80/20 Rule states that a high percentage of effects in any large system are caused by a low percentage of variables. The precise percentage may not be exactly 20 percent, but varies between 10 to 30 percent. It helps to focus resources and

1910 flood, Müsche (Sinne, 2022)

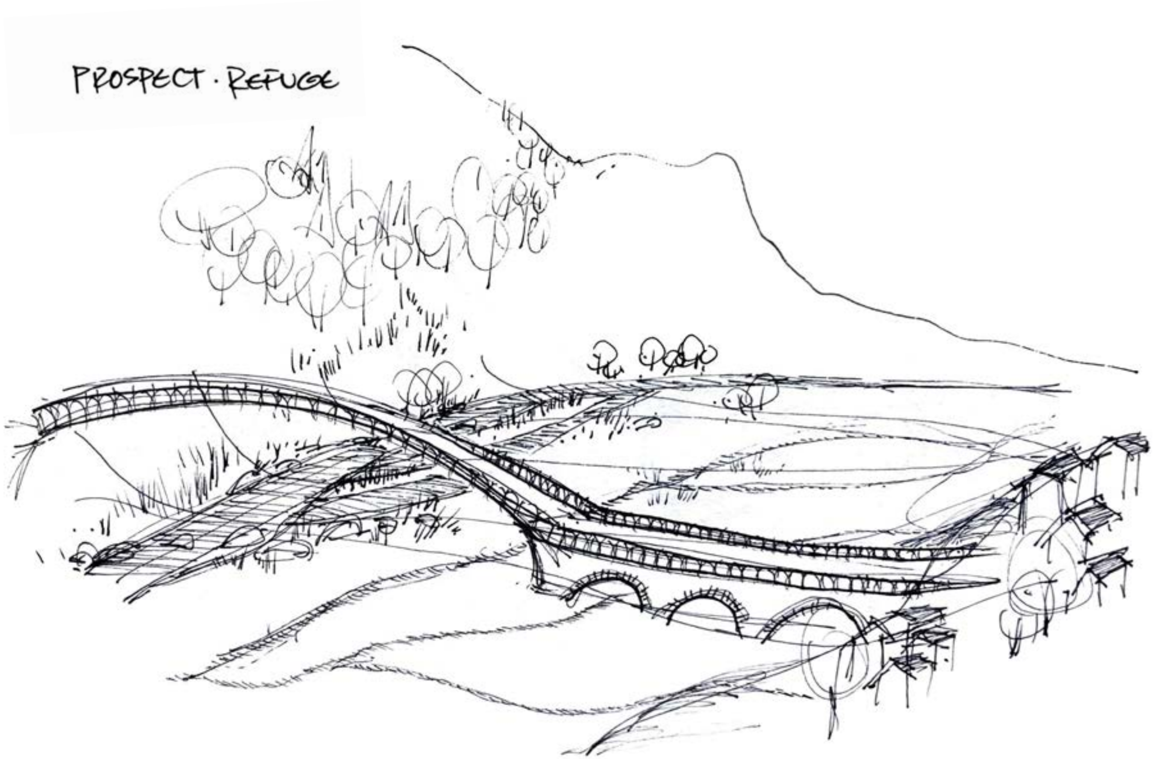


(Roidkin, 1725)



(Boeger, 2022)

Feedback Loop, Altenahr 1725, 1909, and 2021 (Mirgeler, 2021)

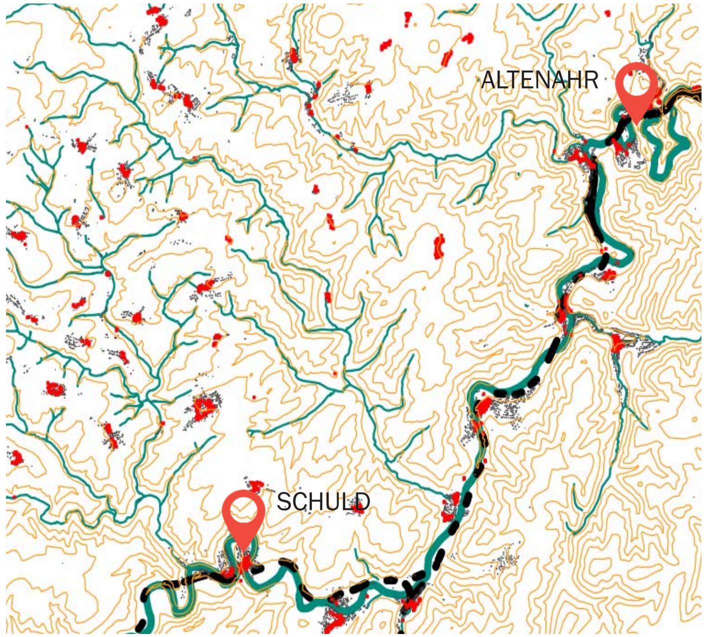


achieve greater efficiency in design. In the case of the Ahr Valley, this design principle explains why the flood was as large as it was without going deeper into a design.

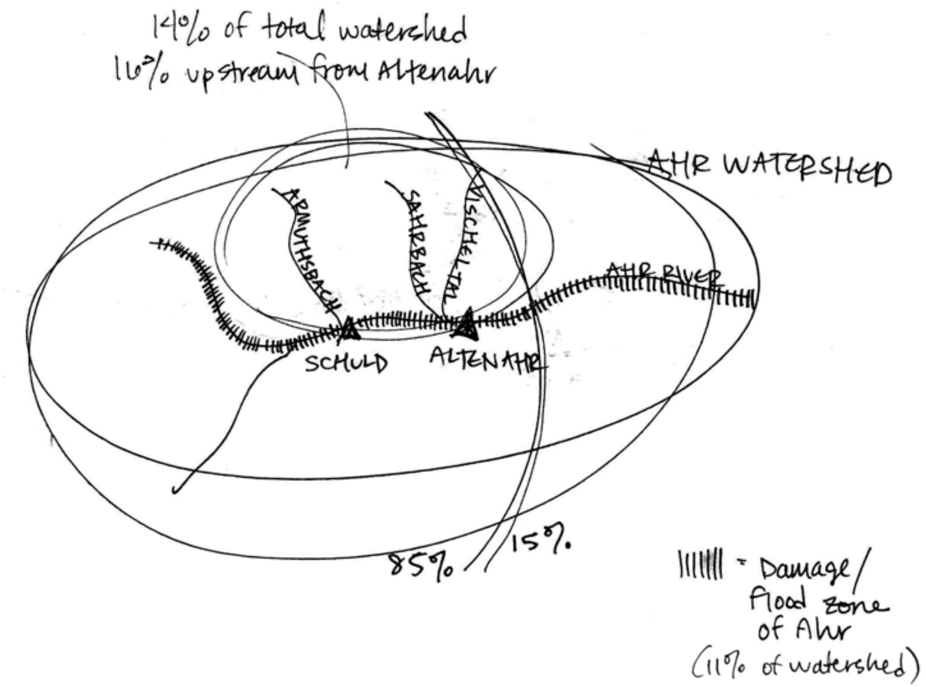
The watershed of the Ahr Valley is a large system, and the breakdown of its size and structure correspond well to 80/20 Rule. These variables may be coincidental, but it is worthy to consider in a discussion. The main damage zone in the Ahr River watershed accounts for approximately 11 percent of the area. The vast majority of the watershed (85%) of the watershed exists above Altenahr. Within this area, three large tributaries - Armuthsbach that joins at Schuld and Sahrbach and Vischeltal at Altenahr - originate in the High Eifel mountains and comprise 16 percent of the catchment. There are few settlements along their path, contrasting the settlement pattern of the Ahr River. In part due to topographical conditions, these three tributaries received amongst the highest amounts of precipitation for the entirey of “Bernd”. It is likely that a similar situation will happen again. But, understanding where risks originate does not necessarily translate into action. It is debatable how useful interventions will be in this valley, but would be a lost opportunity to neglect the landscape conditions of flood’s source in the upper reaches, and at present much of the focus is on the immediate territory of the Ahr River.

The Feedback Loop is a relationship between variables in a system where the consequences of an event feed back into the system as input, modifying the event in the future. Little planning or design related to flood protection has been done along the Ahr River as of yet, but people are fervently rebuilding. Landscape elements have been built, destroyed, and rebuilt along the Ahr in iterations through history. For example, some bridges resisted 2021’s flood, but most will need to be rebuilt. Rebuilding bridges is expected to receive the most amount of money from the €30 billion recovery fund. The new design will be engineered better, but they are still an experiment. Only time will tell if the newest versions can withstand a forceful flood and if they will create obstructions.

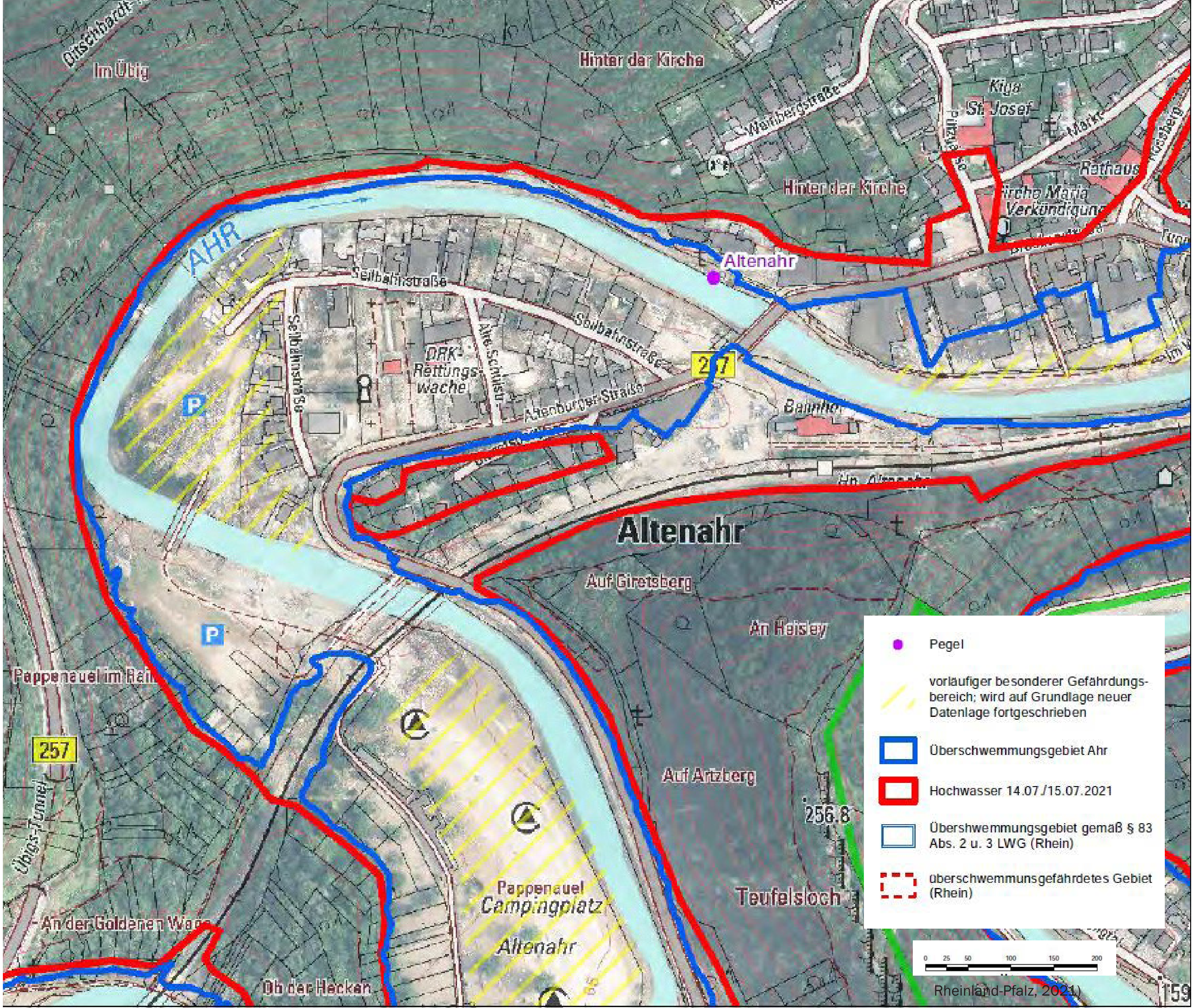
The flood deconstructed the landscape and provided a space reflective of the principle of Prospect-Refuge. Prospect-Refuge is a tendency to prefer environments with unobstructed views (prospects) and areas of concealment and retreat (refuges). The opened landscape in the valley gives a savannah-like quality, which has a natural appeal to people. The deconstruction was provided for free by the flood, and gave a new, useful shape to the river, but much time and energy was spent in “cleaning it up”.



Settlements on the three major tributaries of the Ahr River



80/20 Rule


Im Übig
Hinter der Kirche
Kiga
St. Josef
Rathaus
Kirche Maria Verkündigung
Weinbergstraße
AHR
Altenahr
Seilbahnstraße
Alte Schulstr.
DRK-Rettungswache
Altenburger Straße
Bahnhof
257
Altenahr
Auf Giretsberg
An Heisley
Auf Artzberg
256.8
Teufelsloch
Pappenauel im Rain
Übigs-Tunnel
An der Goldenen Waage
Pappenauel Campingplatz Altenahr
Ob der Hecken
Pegel
vorläufiger besonderer Gefährdungsbereich; wird auf Grundlage neuer Datenlage fortgeschrieben
Überschwemmungsgebiet Ahr
Hochwasser 14.07./15.07.2021
Übershwemmungsgebiet gemäß § 83 Abs. 2 u. 3 LWG (Rhein)
überschwemmunsgefährdetes Gebiet (Rhein)
0 25 50 100 150 200
Rheinland-Pfalz, 2021)

MAN OVER NATURE

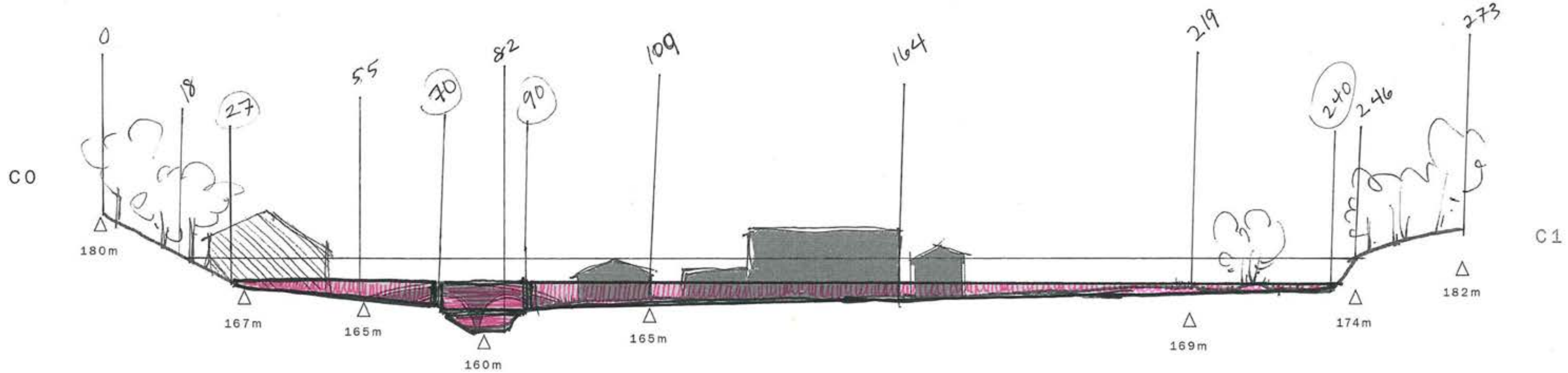
Power is central to the "Man over Nature" paradigm. This has led to widespread ecological degradation by deforestation, overfishing, pollution, and more. It is how colonists conquered the world in past centuries and why we continue unsustainable practices like fossil fuel extraction today. The belief that we can completely control (or fix) Nature with engineering is outdated, but still very much in practice.

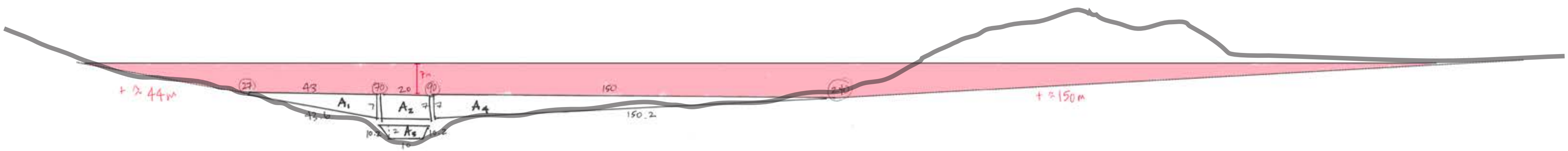
Water is simultaneously a critical resource and threat. There is a need to control it by means of dams and levees in times of excess and wells, irrigation channels, and heat reflectors in times of drought. These have helped to build societies in improbable locations, like Rotterdam or Dubai. Hydrology is an important field in understanding how to dimension these infrastructures and it is increasingly relevant for the problems that come with climate change, but it is not a perfect science.

New flood zone maps were released in September 2021 based on updated hydrologic models. The maps specify the official flood zone of the Ahr (blue), as well as the real extent of the flood event from 14.-15. July (red). There are significant discrepancies between the two lines. It is erroneous to say that the river territory stops at either of these lines but yet they define where it is allowed to rebuild and where it is not. Rivers are dynamic entities, and in the Ahr Valley case, it is very challenging to define the boundaries and risk of the river. There is a mismatch between models, maps, and real events that reveals the flaw of trying to calculate and control Nature. This is the technical oversimplification of the landscape.

The 2021 flood is not the largest in history. 1804 had a much larger flood in terms of discharge, but it had lower flood levels due to different landscape characteristics. As I will discuss in the next section, a similar discharge rate today would cause devastation far beyond last year's tragedy due to the degree of landscape degradation and modification in the catchment. Is it reasonable to plan for this scale of flood instead? This question is important given that €30 billion will be spent in the valley for reconstruction. How big will infrastructures need to be to handle the 2021 flood or a bigger monster flood? What is the acceptable level of financial risk in investing in flood protection infrastructure? It will be impossible to fully protect

Failure in controlling Nature, Highway 265 near Erfstadt in the neighboring district (WDR, 2021)





Flood extent from 2021, Altenahr.
Simplified shape of the 2021 flood zone.
Simple calculated levels of the 1804 flood in the 2021 context, with terrain overlay.

Ahr settlements against such massive events, but going through the mathematical exercises gives context to their physical and economic benefits and risks.

APPLICATION OF HYDROLOGY

Roggenkamp & Herget (2014) made a compelling case with their historic reconstruction of floods on the Ahr. They warned that the flood zone calculations based on quantitative data since 1947 were underdimensioning the real risk, but their warnings and numbers were not taken into consideration into new models nor heeded by authorities. Unfortunately, their predicted catastrophe came less than a decade after their research. But their work does not go far enough in warning about the risk of flooding.

The reconstruction of the river discharge is based on Manning's Equation, an important formula in hydrology:

Manning's Equation

$$Q = \frac{1}{n} A R^{2/3} s^{1/2}$$

In the equation, the variables represent the following:

Q = the river discharge in cubic meters per second

1/n = roughness or friction applied to the water flow by the channel (Manning's coefficient (M))

A = the cross-sectional area of a river channel

R = the hydraulic radius (area / wetted perimeter)

s = slope of channel

There has been extensive modification to the landscape in the upper agricultural and forest reaches. This has changed decreased the resistance to runoff, adding water more quickly into drainage ways. The Ahr River itself is heavily modified by the grooming and management of its riverbed, banks and floodplains to accomodate infrastructures like buildings, bridges, roads, and rail. The shape of the riverbed has been changed by dredging, making a uniform trapezoid form that reaches capacity quickly with higher discharge rates. Nearly all variables in Manning's Equation have changed in today's context than for the 1910 or 1804 flood events.

It is possible to apply the historic flood discharges to the modern context and see how high water flood levels could be for the next catastrope. The calculations can be broken down as the following (see Appendix II for the line-by-line breakdown of the mathematics): We have an estimated discharge from the 2021 event (Qaverage = 550 m3/s). Using Altenahr as an example, we can find the cross-sectional area and radius of the river at the bridge nearest the former train station in combination with estimated flood heights. The slope at this location is obtained from GIS data approximately 0.35%. All of this can be used to identify M, or Manning's coefficient which defines the roughness of the flooded area. M was also be estimated based on descriptions of terrain (Arcement, 1989). Similar calcuations are applied to use the modern context's M to the historic flood of 1804.

These calculations are interesting to pursue in further analyses by qualified hydrologists, because the results yield alarmingly high floods. Flood markings from 1804 indicate that the water levels were similar to the 2021 flood despite having two to three times greater discharge. If the 1804 discharge occurred in today's context it could reach levels seven meters above last year's seven-meter flood. Also, given that my calculations assume for consistent shapes and not varied terrain, the reality would almost certainly be even worse.

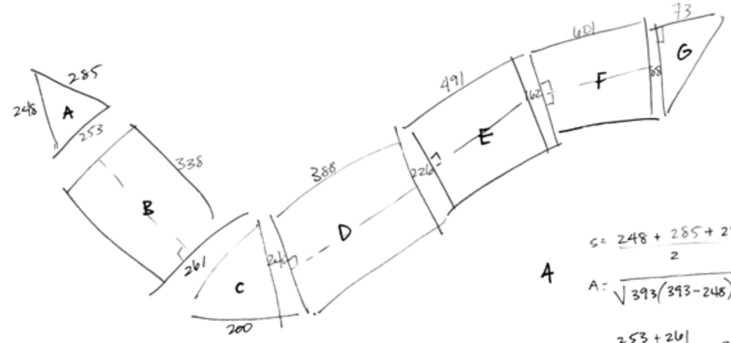
Flood protection is rightfully a concern of everyone in the Ahr Valley, but I have not encountered any predictions in news or literature anticipating an event that can be worse than the flood of 2021. Based on prior assessments of flood frequency, the river discharge in 2021 were beyond the 10,000-year flood (Schäfer, et. al, 2021). History shows that it may be more accurate to think of it as the flood of a century. But with climate change and a strong degree of uncertainty such a localized event as what happened on the Ahr, who really knows what to expect? What will be the real "monster flood"?

AN ENGINEERED RESPONSE

While there are many options available to attempt to control water, there is one that shares a stylistic and functional similarity to an existing feature in the valley – dikes.


EXTENT OF 2021 FLOOD
0
100
200 m


EXTENT OF 1804 FLOOD IN 2021 CONTEXT
0 100 200 m



$A = \frac{a+b}{2} \cdot h$

$A = \frac{x \cdot y}{2}$

$s = \frac{a+b+c}{2}$

$A = \sqrt{s(s-a)(s-b)(s-c)}$

A

$s = \frac{248 + 285 + 253}{2} = 393$

$A = \sqrt{393(393-248)(393-285)(393-253)} = 29{,}353\ m^2$

B $A = \frac{253 + 261}{2} \cdot 338 = 86{,}866\ m^2$

C

$s = \frac{261 + 240 + 200}{2} = 350.5$

$A = \sqrt{350.5(350.5-261)(350.5-240)(350.5-200)}$

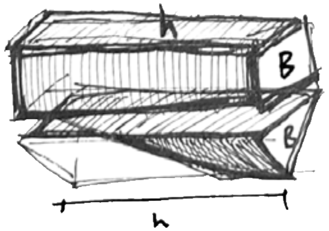
$A = 22{,}840\ m^2$

D $A = \frac{240 + 226}{2} \cdot 388 = 90{,}404\ m^2$

E $A = \frac{226 + 162}{2} \cdot 491 = 95{,}254\ m^2$

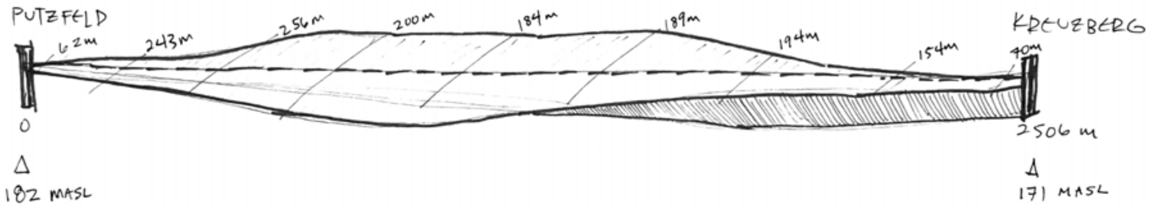
F $A = \frac{162 + 88}{2} \cdot 601 = 75{,}125\ m^2$

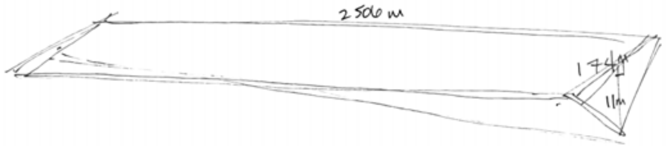
G $A = \frac{73 \cdot 88}{2} = 3{,}212\ m^2$



$V = Bh$

$V = \frac{Bh}{2}$





$V = \frac{Bh}{2}$

$V = \frac{\left(\frac{174 \cdot 11}{2}\right) \cdot 2506}{2}$

$\boxed{V = 1{,}199{,}121\ m^3}$

Simplification of basin area above Kreuzberg with 8 meter dikes and without excavation (see plan on page 136).
Estimate of basin volume at full capacity.

The railway is an important piece of infrastructure for the valley and will be rebuilt, and it is unrealistic to change it significantly. Regardless of how it is rebuit, it will be enormously expensive. The embankments to support the railway can be rebuilt taller as an intentional part of the flood protection in the valley. Other dikes can be built to help protect particularly vulnerable communities – at least to an extent. These dikes can be included in a green transport concept, de-emphasizing the use of vehicles and investing in railways and biking. There is obvious recreational pleasure in the scenic journey by train and bike, but a plan should be developed to promote biking as an easy, daily commute.

Three campsites were demolished upstream from Altenahr during the flood, along with the highway on the opposing bank. The largest campsiet has reinstalled electrical fixtures already and the road has been repaired, but there is a strong hydrologic argument to say that this should not have happened. By developing this area as a floodable space without permanent infrastructures, it provides a regulatable retention basin upstream from an important settlement in the Ahr Valley. Relocating the highway provides greater ecological connectivity to the nearby nature reserve, which is one of few remaining forests in the region that is reflective of the local native ecotype. And relocating the campsites ensures the safety of tourists.

A retention basin would give a large degree of protection to Altenahr during heavy rainfall, but a small degree of protection during extreme, according to my calculations. But even during extreme rainfall, a small degree of protection can be critical in giving people time to get reach safety. Dikes and dams are not fail-proof, but can be utilized in more places along the Ahr for a cumulative effect. If the dike system is dimensioned larger than the calculations provided in this project, it will displace the Ahrbrück community. Larger technical protection infrastructures will need to consider this possibility.

APPROXIMATIONS FROM CALCULATIONS

Retiontion basin above Kreuzber:

Total area = 403,054 m2

In the basin with a closed outlet:

1,199,121 m3 fills in 36 minutes when Q = 550 m3/s

For each additional meter in height to a dam:

403,054 m3 fills in 12 minutes when Q = 550 m3/s

Railway embankment, Altenburg

“Netherlands - Enclosing Dyke” by roger4336, CC BY-SA 2.0.

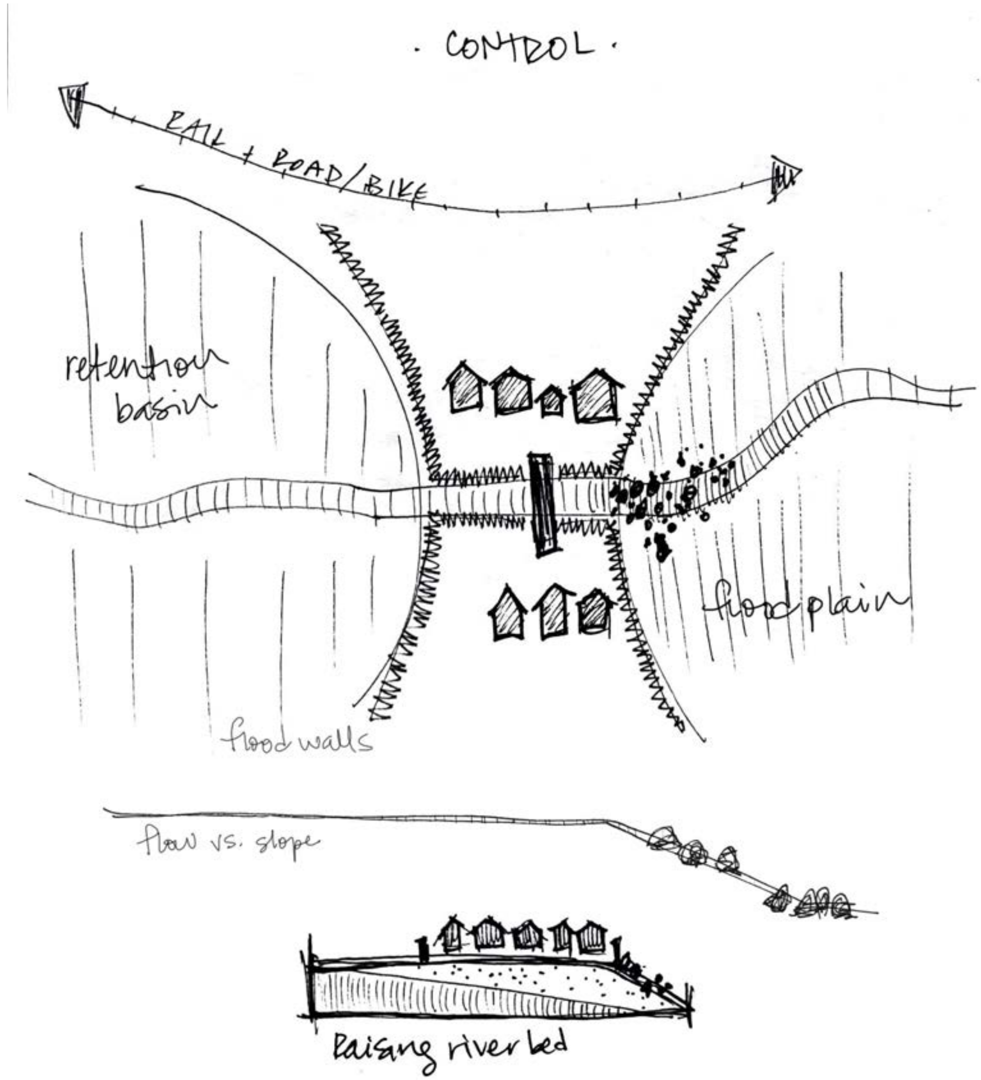
Walled city, Ahrweiler (ETfoto, 2022)

PRINCIPLES OF DESIGN

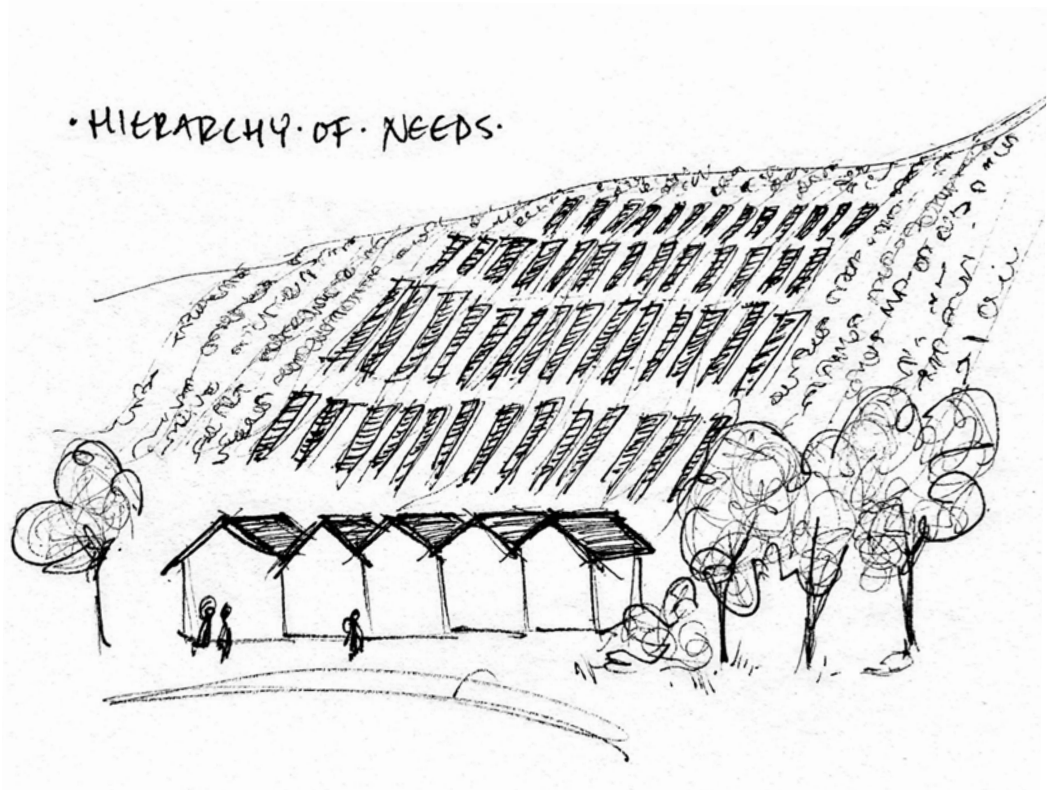
Control is an important principle of design in the Man over Nature paradigm. Lidwell, et. al (2010) describe it as such: the level of control provided by a system should be related to the proficiency and experience levels of the people using the system. In the Ahr Valley, engineers will have the responsibility to provide a flood control protection system because of their technical. But this does not necessarily mean that others cannot make an impact. Villages could implement their own smaller protection measures that could offer a degree of resistance to flooding. For example, there were hundreds of thousands of cubic meters of debris and sediment that washed down from the upper reaches, and locals are still dealing with it. Floods do not make a tabula rasa, washing away everying. There are real volumes of material to deal with. Using these sediments and deposits, local changes can be made to the riverbed that alter how channelized water flows through villages. Flood dikes can be built around a village's perimeter. These measures do not require such a high level of engineering to accomplish and it puts power in lower levels of governance for flood protection design.

The Ahr Valley hosts several engineered marvels that have withstood the tests of time. One example of this the Medieval walled city in Ahrweiler. Stylistic elements that celebrate the history of the valley can be used in flood protection design as Mimicry. Mimicry is the act of copying properties of familiar objects, organisms, or environments in order to realize specific benefits afforded by those properties. These walls were originally built as a defense against invaders, but their stoutness could offer a degree of protection against flooding after some modification.

The Hierarchy of Needs principle can be used to meet the government's sustainable reconstruction objectives in this paradigm. For a design to be successful, it must meet people's basic needs before it can attempt to satisfy higher-level needs. Energy is an absolute necessity in the Ahr Valley (and the world). €20 to 30 million will be needed to restore the gas network, so why not invest in renewable solar energy instead (SWR, 2021a)? It could be beneficial for local resilience by creating local energy sources as well as profitable for the viticulture industry. There is a reference project of agrivoltaics in France that is testing the efficiency of a version of dual cropping - energy and viticulture - with good success (Rollet, 2020). The solar panels reduce the heat experienced by the vines, mitigating the effects of climate change. Excess heat effects the sugar productivity of grapes, which risks changing the flavor profile of the notorious Ahr Valley wines. The landscape of the future will require an intensification of local resources – from food to energy and beyond – and the terrain



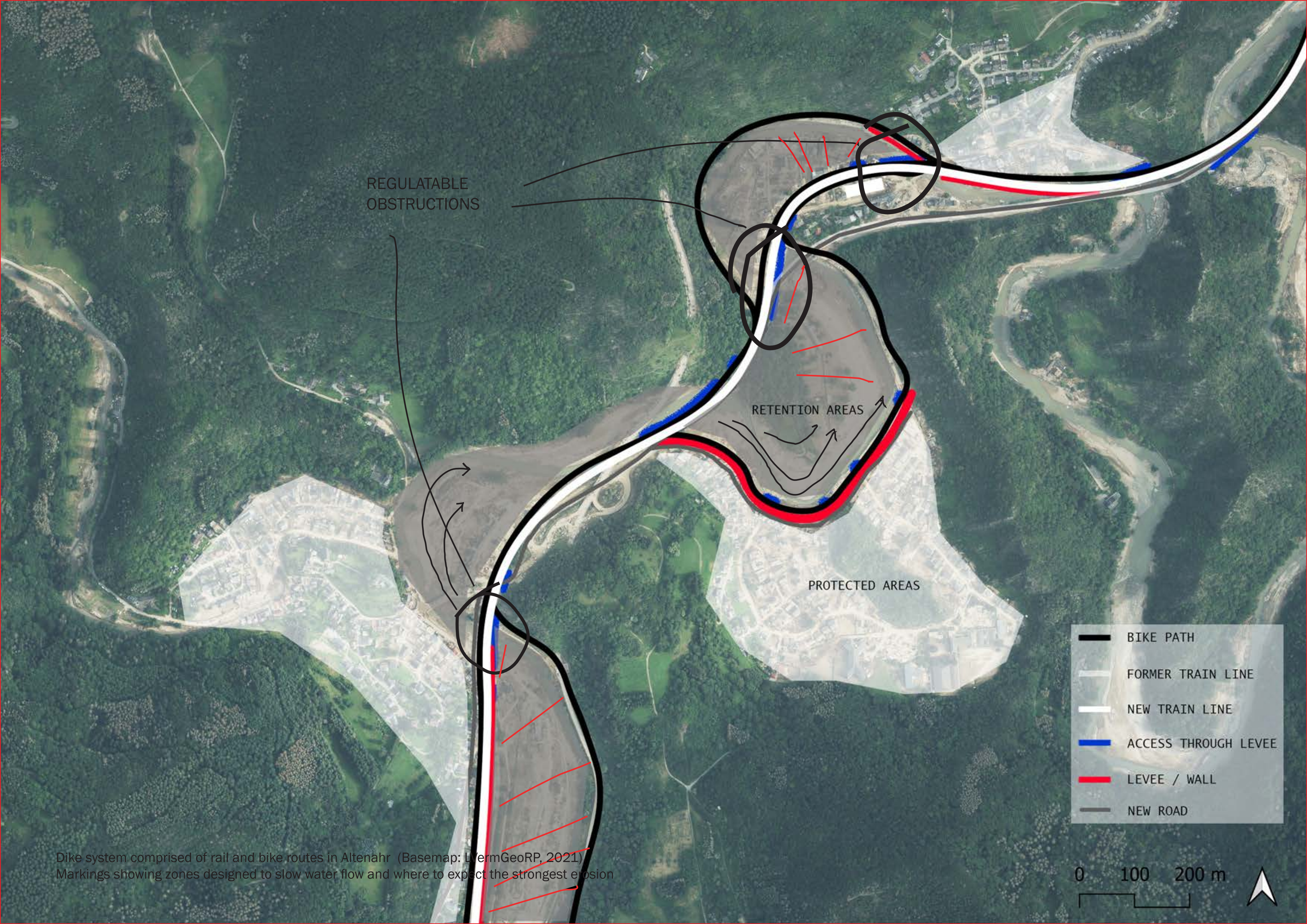
Agrivoltaic vineyard, Piolenc, France (Bolcato, 2020)



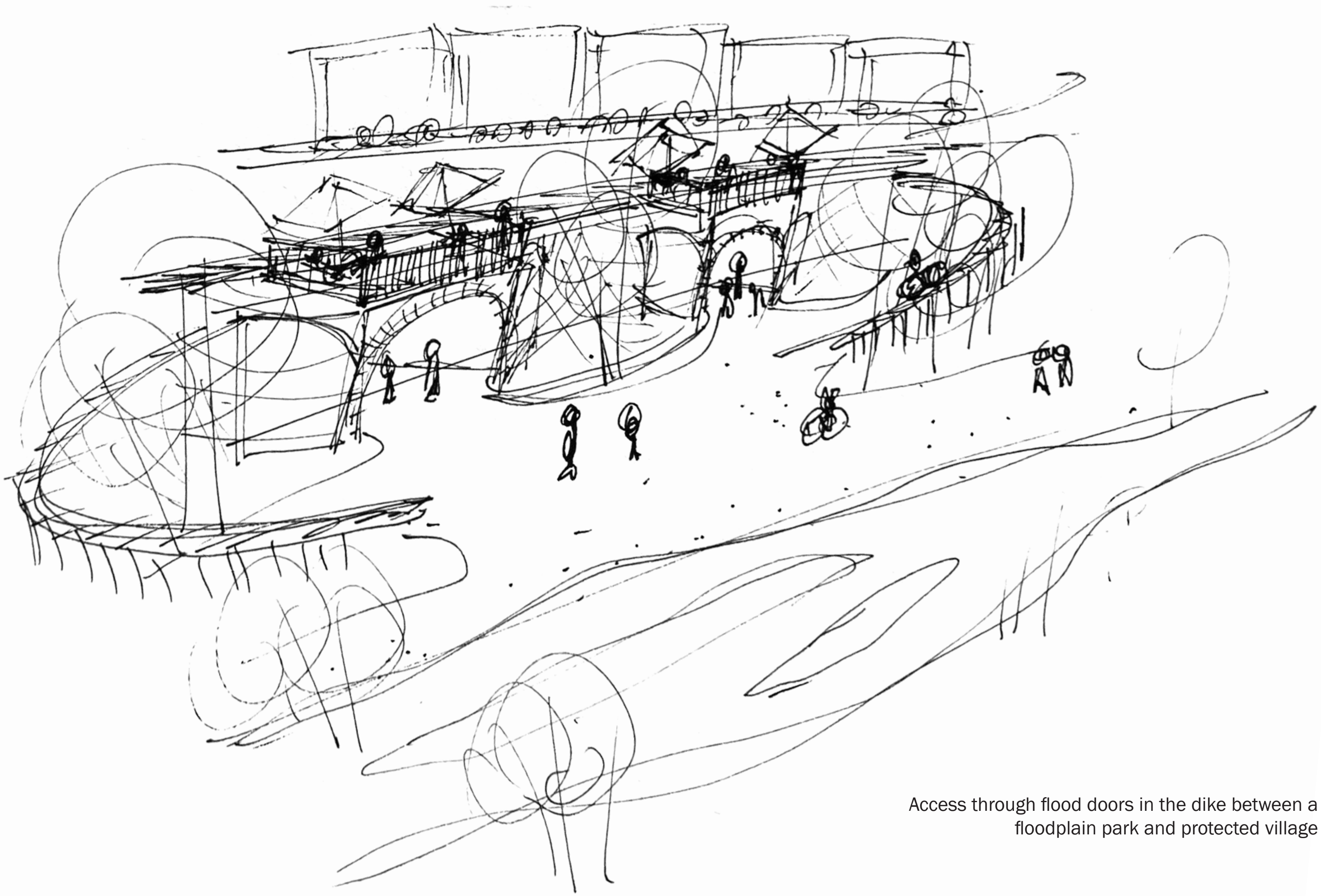
of the Ahr Valley can be a model for Germany and the world.

A fourth design principle that can be found in Man over Nature is visibility. In visibility, the usability of a system is improved when its status and methods of use are clearly visible. For the majority of people, it is not obvious that renaturation projects of a river channel are flood control technique. Contrarily, built features like walls, dikes, and dams have an obvious function. The physical presence of something built is something that visually connects people to the reality that they live in a floodplain. They are made aware and may be more likely to heed evacuation warnings when flooding is imminent. But their physical presence can be a double-edged sword in that people assume a false sense of security, as has been demonstrated in many tragedies globally, like Hurricane Katrina. Also, if there are large (and thus visibile) features, there is a greater degree of disconnect between residents and the river. With a big dike system, people in the valley cannot see or access the river anymore, which is a concern that will need to be addressed. In the design proposal below, a large retention basin upstream from Kreuzberg isolates the tourist / residential infrastructure on the slopes above it, having a negative effect on community cohesiveness.

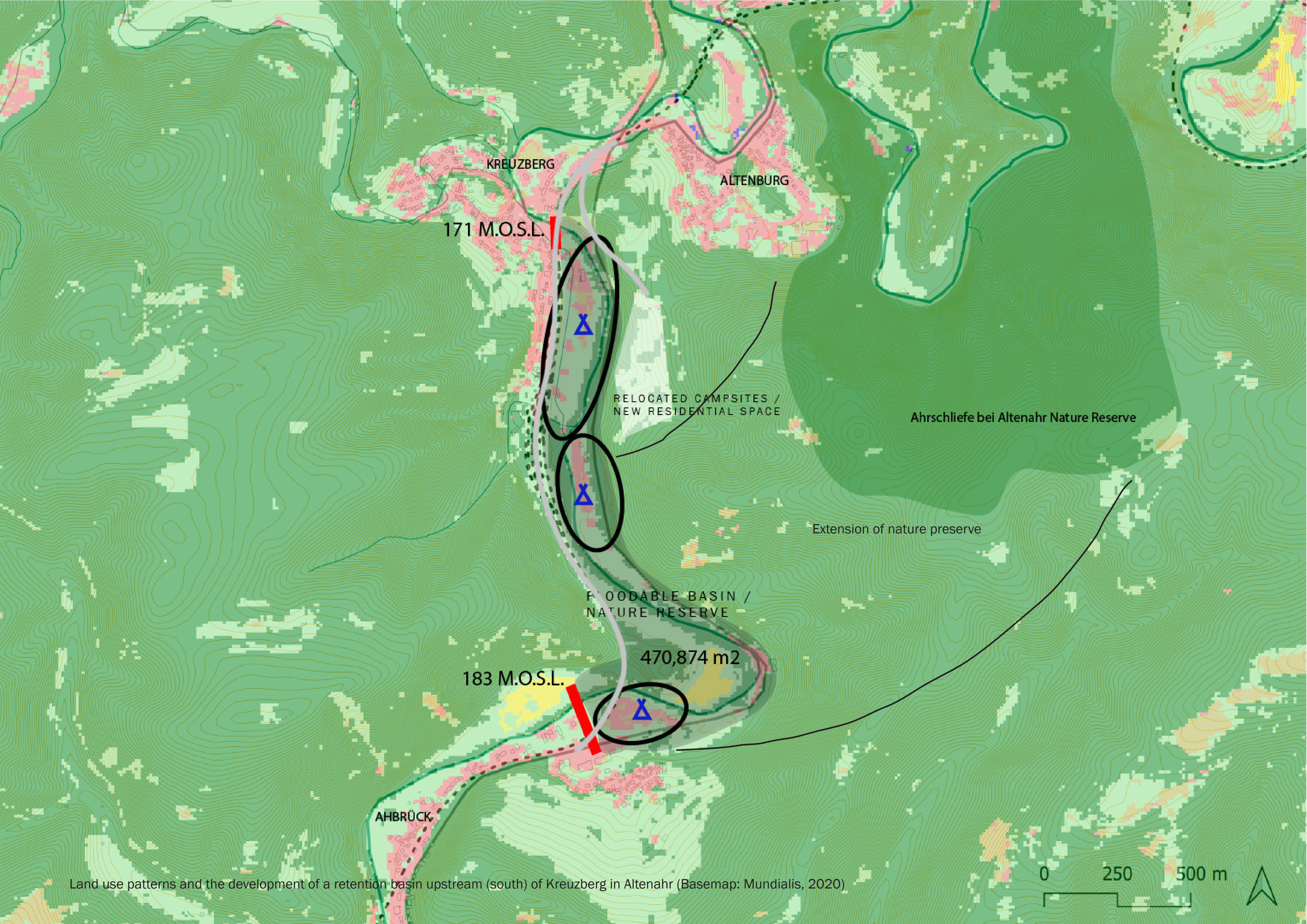
A last example of design principles that can be found in this paradigm is satisficing. Satisficing means that it is often preferable to settle for a satisfactory solution, rather than pursue an optimal solution. The degree of protection can be calculated, and there will be a point in which it is deemed good enough. Massive infrastructure is very expensive, and when “good enough” protection has been achieved, it is the point when costs balance with the benefits and no more will be paid for. In this case, that value seems to be set at approximately €30 billion. As has been stated many times, the Ahr Valley will never be completely protected from flooding. There will always be a risk in living in the valley, no matter what infrastructures are installed. Man over Nature is the paradigm best suited for implement real, physical flood protection measures in that it addresses the river and water system directly, even if it restrict. But it will not be good enough. Further paradigms explore other aspects of resilience that will be necessary in a flood protection plan.



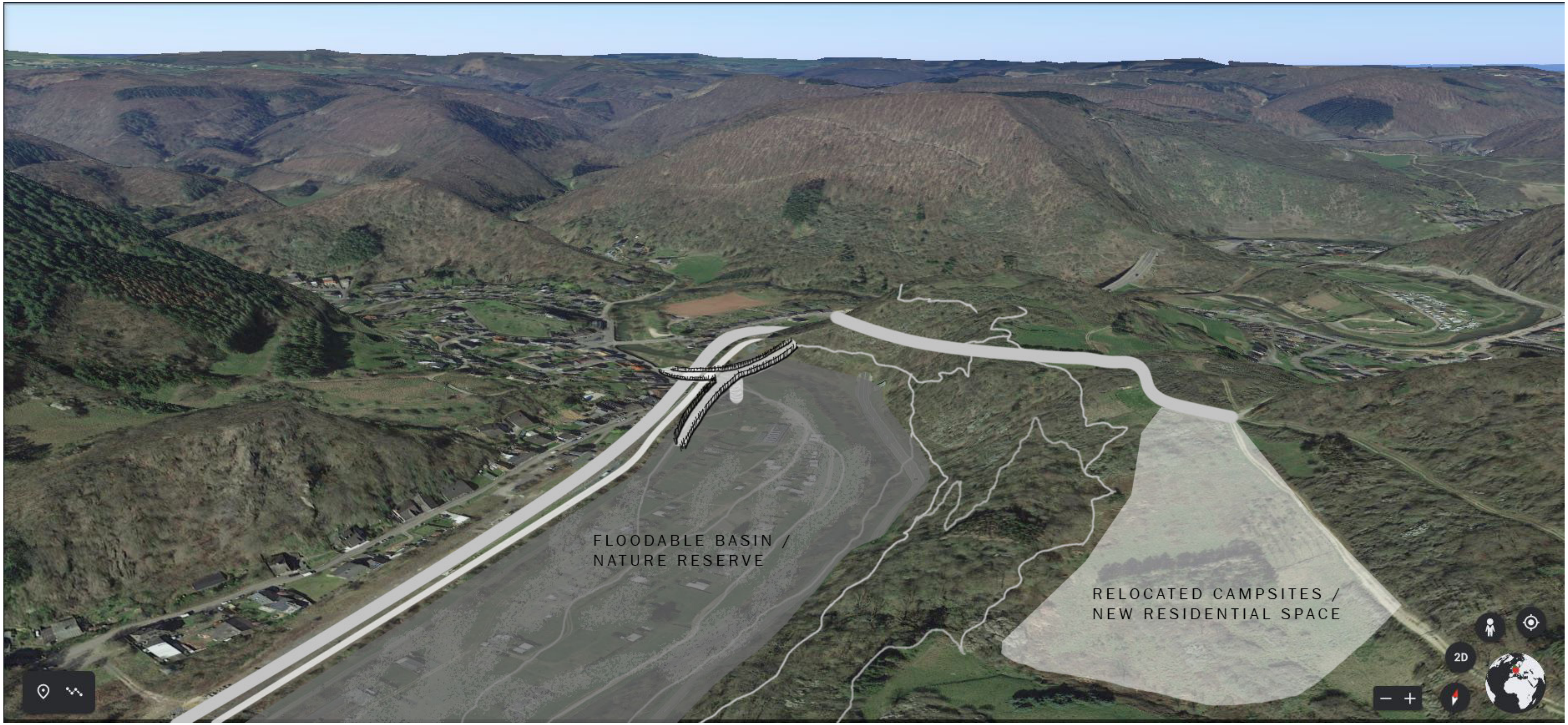
Dike system comprised of rail and bike routes in Altenahr (Basemap: LVermGeoRP, 2021)
Markings showing zones designed to slow water flow and where to expect the strongest erosion



Access through flood doors in the dike between a
floodplain park and protected village



Land use patterns and the development of a retention basin upstream (south) of Kreuzberg in Altenahr (Basemap: Mundialis, 2020)



Flood retention basin with new space for development at safe elevations.
Relocated highway to parallel the railway, minor access road to upland development east of the river.
(Basemap: Google Earth, 2022)

Renaturation of the River Aire, Geneva (Chironi, 2016)

MAN IN HARMONY WITH NATURE

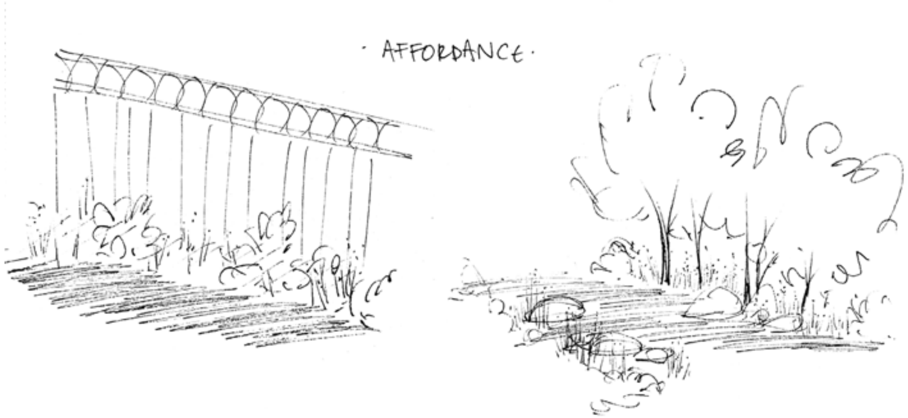
Beginning in 2007, the major conservation program Upper Ahr High Eifel has been securing valuable habitats in the upper reaches of the Ahr and around Adenau by land acquisitions. The goal is to re-establish a near-natural water body and forest development and allow for careful agricultural use of the meadows. Structural improvement measures have been completed, such as renaturing riverbanks, reshaping river channels, removal of weirs and pipe systems, and removing non-native species. These efforts have a very positive effect on ecology as well as synergistic effects in climate regulation, flood protection and recreation (Mölle, 2022).

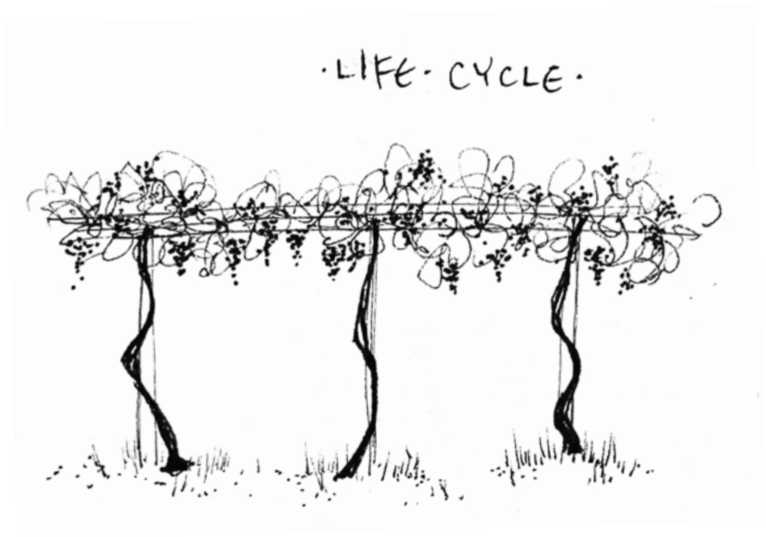
This conservation program is a textbook example of the “Man in harmony with Nature” paradigm. It is difficult to refute its value, because of its extensive positive effects. It is likely that the conservation program will be expanded acros the entire watershed of the post-flood Ahr River. Even though the hasty clean-up process of the river led to poorly formed banks in terms of flood protection, there are already stretches that are being rebuilt in a purposeful manner, beginning upstream from Lier. This is a simple solution for the spaces nearest the Ahr. But this will not provide nearly enough protection during extreme rainfall in the future, as the greater catchment still has extensive modification and/or degradation that contributes to runoff. Even if the entire catchment is restored to a near-natural state, it is evident by the flat topographic shape of the valley that massive floods happened long before people settled there and they will happen again. Still, it is important to protect the ecological functionality between those moments with renaturation.

A NATURAL, HYDROLOGIC RESPONSE

Manning’s Equation is again useful in describing how landscape characteristics slow water flow. It is very much a mathematical approach to understand nature, which has already proved to be with limitations, but useful in giving context to design concepts. Manning’s Coefficient (M or 1/n) represents the hydraulic roughness of a water system, or the degree to which flow is inhibited. It is the basis of Manning’s Equation. n is actually the average of nine different variables, which can be used to describe

Nature-based solutions: reopening of piped streams at Kottenborner Mühle (Mölle, 2022)





the conditions of a waterway:

n = (n1 + ... + n9)m

n1 = surface roughness: the friction difference between metal and grass against water
n2 = vegetation: the friction difference between grass and trees against water
n3 = channel irregularity: changing depths, bed materials, etc.
n4 = channel alignment: from straight to winding river paths
n5 = silting and scouring: the rate of sedimentation and erosion
n6 = obstruction: debris or blockage points impacting flow
n7 = variations of stage and discharge: high to low water levels
n8 = sediment load (density of water): amount of suspended sediment in the water
n9 = seasonal changes: impacts of temperature and ice
m = correction factor for meandering of the channel

Renaturing projects increase these values, leading to a greater roughness coefficient and a slower stream. Slower streams hold water back for longer, lessening the effects of minor floods downstream, or tidal wave situations like what happened during the July 2021 flood. It is effective to a point, but absolutely insufficient as a flood control mechanism during extreme events. Increasing these variables repeatedly throughout the catchment produces the optimal effect.

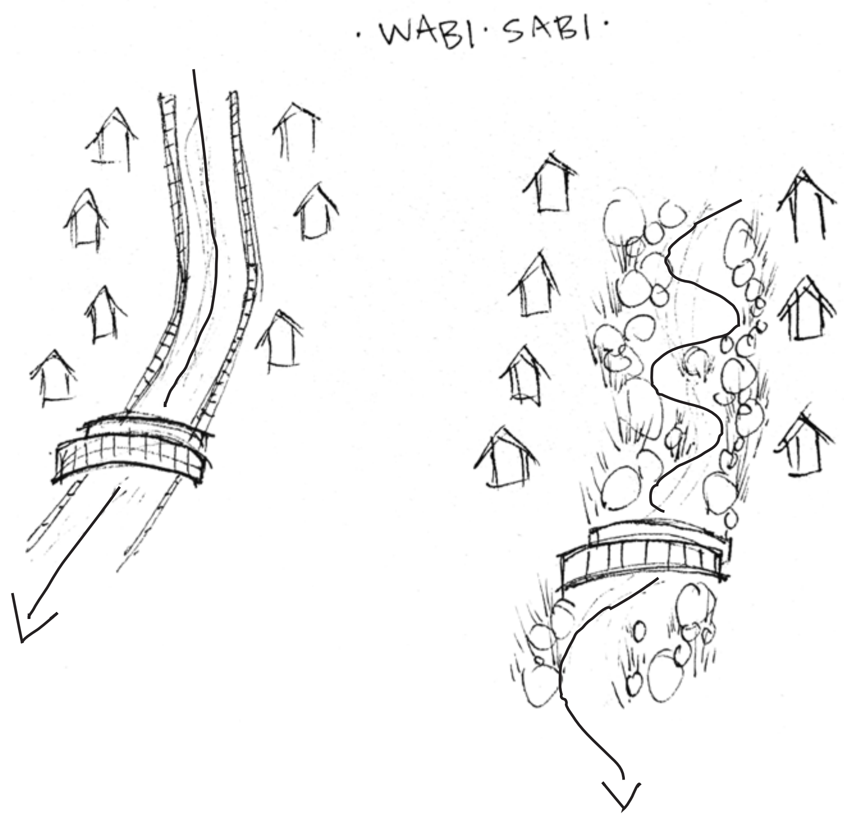
PRINCIPLES OF DESIGN

Within the Man in harmony with Nature paradigm, several design principles are relevant. But perhaps the most critical is the Scaling Fallacy. This is the tendency to assume that a system that works at one scale will also work at a smaller or larger scale. It is not possible to look at design options only at the local scale, for example only one village. There is no possible way for a local intervention to be sufficient, it needs to be applied at a systems level. Additionally, raingardens, retention basins, revegetating river banks, and the adding channel obstructions or irregularities will simply not be effective against a large flood.

The Scaling Fallacy highlights the biggest flaw of this paradigm, but there are still ways to design with it. To begin, Affordance is a useful principle. It is when the phsyical characteristics of an object or environment influence its function. Adding stones, jetties, or items of obstruction make the water slow down. It may require deconstructing built elements, like canals. Using coarser vegetative elements also slow water, and it this benefits on ecological function. Vegetation provides habitat, food sources and niches for wildlife. It provides habitat connectivity as a green corridor which can help with biodiversity loss. Affordance is a way to include Nature in the built environment and it is a relatively inexpensive technique.

Wabi-Sabi is a principle of design as well as a world view and philosophy of life. It states that objects and environments that embody naturalness, simplicity, and subtle imperfection achieve a deeper, more meaningful aesthetic. Natural materials are favored for their perishability and impermanence. Western values that typically prefer symmetric, manufactured forms but they are not effective in flood control. This includes linear, walled canals and steeply trapezoidal banks. To contrast, the use of organic shapes and materials increase the hydrologic variables in Manning's Coefficient to reduce water flow as well as create a natural aesthetic. Wabi-Sabi is a design principle that allows for the dynamic agency of the river beside a village.

It is easy to identify the Life Cycle in the physical Ahr Valley landscape. All products progress sequentially through four stages of existence: introduction, growth, maturity, and decline, quite like the ecological stages of succession: nudation, invasion, competition and coaction, reaction, and stabilization. But I would like to instead discuss the economic landscape of the Ahr Valley as a relevant humanistic dimension to balance with Nature. The tourism boom that began post-WWII created a massive infrastructural machine to accommodate visitors along with grapes. As local wines became internationally renowned, the tourism system achieved maturity. But tourism is not an industry to form an overreliance to, as the floods have demonstrated and as other international examples have shown. Take the case of Spain - tourism has led to extensive ecological degradation, especially in the south where holiday homes line the coastline, contributing to heatwaves and drought. In 2017, tourism accounted for 11.8% of Spain's GDP and provided 13.5% of employment (OECD, 2022). With the pandemic in 2020, it fell to 5.5% of GDP (INE, 2020). In good times there will be tourists, but the market volatility that has been prevelant since the 2008 global economic crash is continuing. Tourism is a luxury, in the end. While the scale of the tourism economy in Ahr Valley pales in comparison to Spain's, the lesson is similar. Balancing local economic productivity comes at a cost to Nature, but its presence is not garaunteed to last indefinitely.

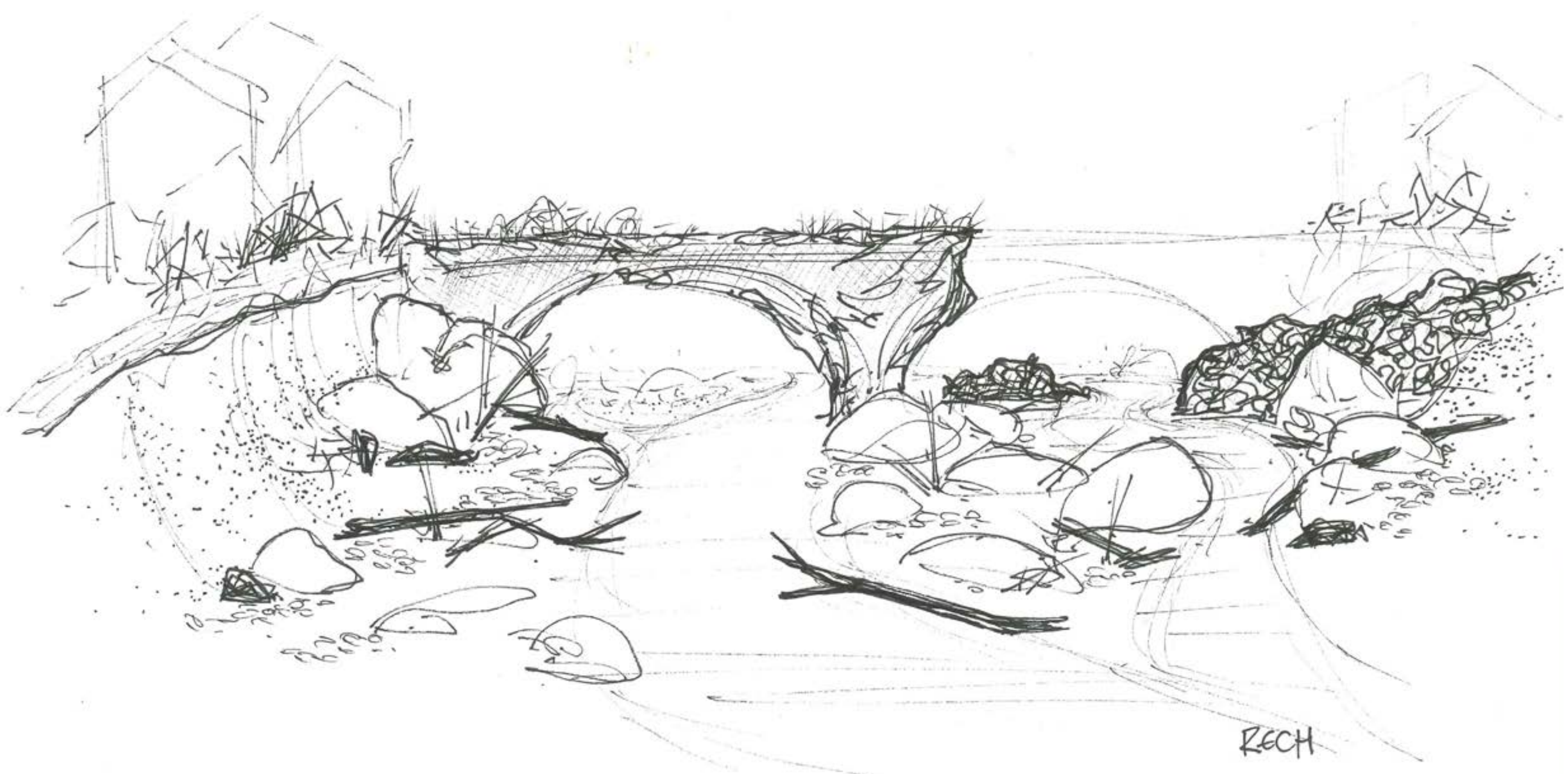


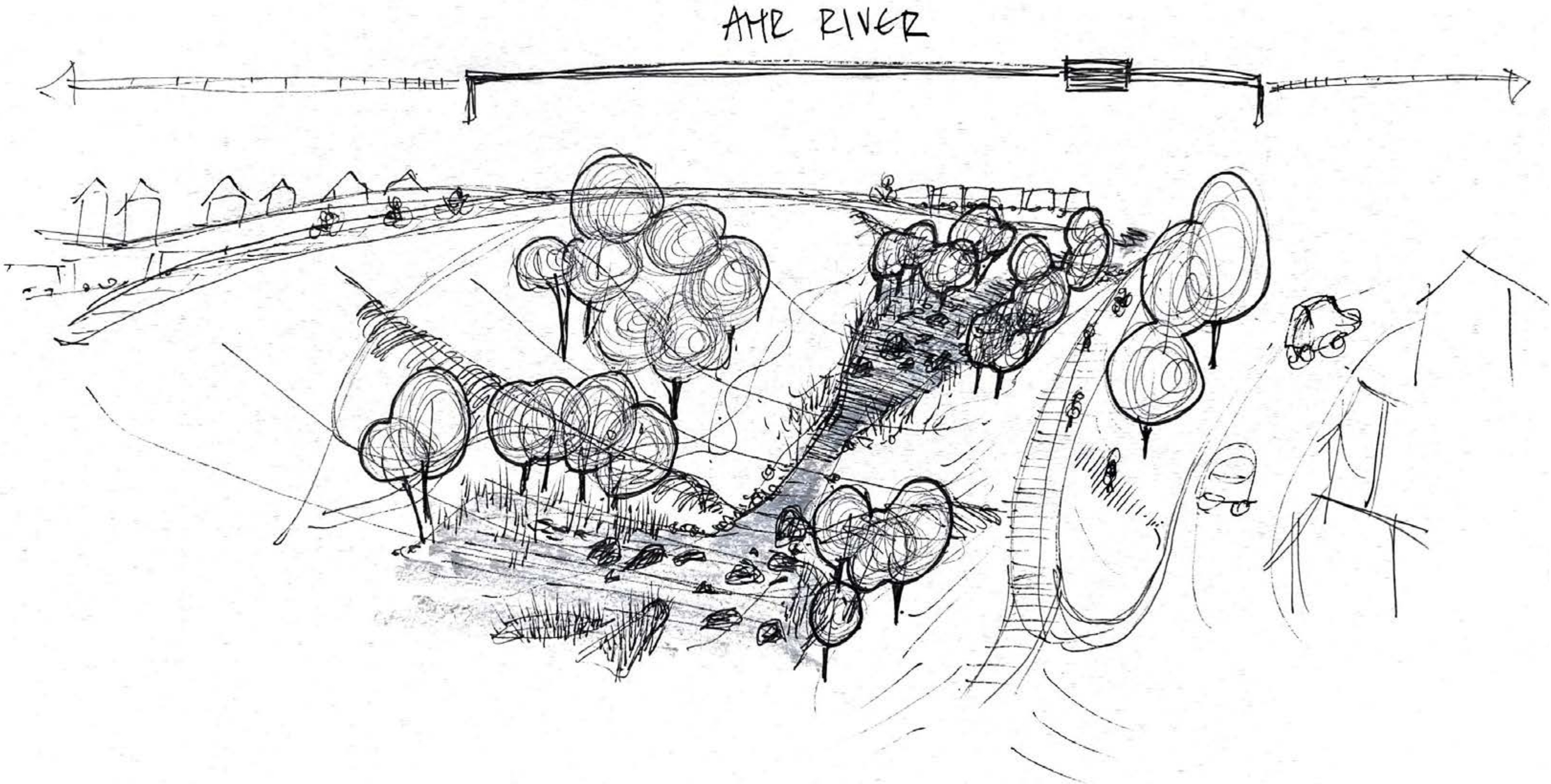
Rech after the flood (LVermGeoRP, 2021b)

RESILIENCE

Resilience relies on reducing vulnerability and exposure of a community. These factors have been described throughout this report, and the deeper-seeded root drivers have been identified. Building resilience in the Ahr Valley will need to be factors into all reconstruction elements - landscape, infrastructure, economic, and social. The social element is simultaneously the easiest fix as well as the most difficult. Warning systems are easily improved - adding more sirens and diversifying the methods that send warnings to locals. But the mentality of Europeans that don't expect for extreme weather to turn into disaster is harder to change. As time passes and the valley is repaired, it will be harder to comprehend the scale of the flood. It will be even more difficult to remind people that they continue to live in the river territory. Without seeing the damage, it is too abstract. Amensia is lethal. It will be important to give visual reminders of the danger of the flood, something that cannot be ignored or misinterpreted.

One possible remedy is to create a specific, larger definition to the river territory with the dike concept. It takes an abstract idea and gives it physical boundaries, even if those boundaries are not totally correct. Residents still need to realize that it is not a fail-proof system and that there is still a risk of flooding. But the viewpoint from atop can give a relatively safe way to see the dynamicism of the river when it's high, and in the case of severe floods, it can hold back stormwater just long enough for residents to





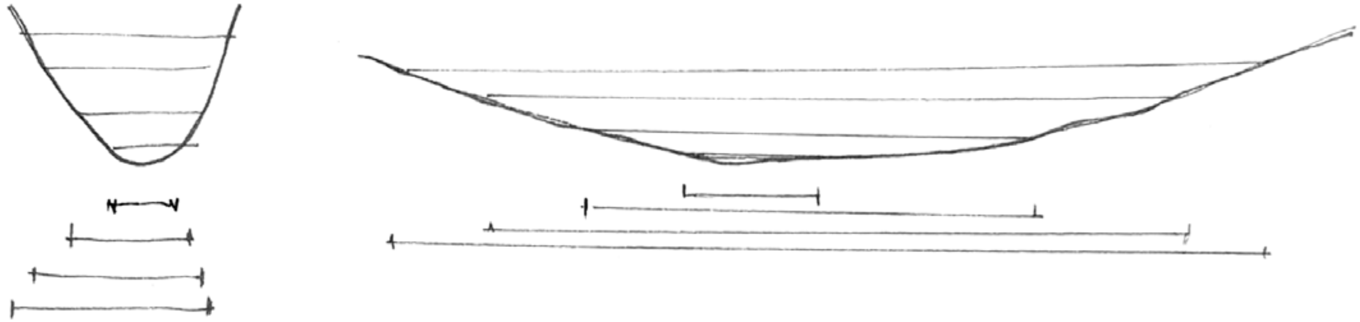
Expanding the visual definition of the Ahr River territory retreat to safety, if they have not already done so.

The reconstruction of the valley will take years. Infrastructure has been (foolishly?) rebuilt, and it almost certainly will not withstand the next massive flood. There is a desperate need to add resilience to the local economy and the opportunities this presents in regards to the physical landscape. This issue has been touched upon already, but it is worthwhile to take a look at what the German government is actually investing in for this disaster recovery - the livelihoods in the Ahr Valley.

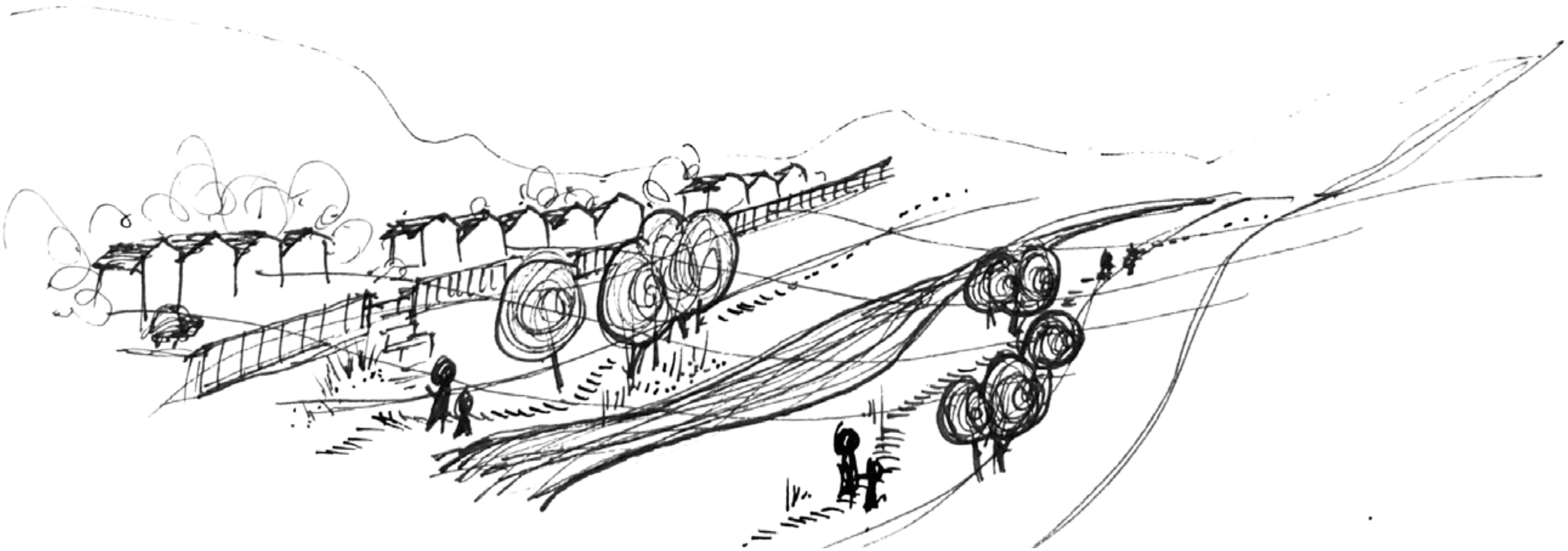
The valley was destroyed by the flood, but its economy suffered beforehand. The viticulture that fuels the tourism industry has been regularly losing hectares of production for decades, despite the post-war economic boom in the region. The Covid-19 pandemic hit the tourism sector particularly hard, and the flood of 2021 undermines the likelihood that businesses will return. Around 80 to 85% of tourism businesses in the district were affected by the flood. In Bad Neuenahr-Ahrweiler, it was over 95%. There are very few overnight accommodations open at present, and those that are open are often used to house displaced locals. Normally there are 3,500 beds in the valley but in February there were fewer than 400 available. As of early March, only one-fourth of the 300+ business owners related to tourism were open, though another quarter expect to reopen later this year. 80% of businesses want to reopen (Stadler, 2022), but out-of-pocket costs despite insurance can still be inhibitive. A total of only 65% of tourism businesses expect to reopen, leaving at least 105 companies without plans to reopen or an unforeseeable reopening date. The RLP Ministry of Economics will give €1 million to support the industry, and there is a common clear goal: the Ahr Valley should once again become a tourist hotspot (SWR, 2022c). How can this industry diversify to make it less vulnerable in the future?

The Ahr Valley needs to consider the exposure risk of their tourism industry, given that an overwhelming majority are located within the floodplain. Relocation out of the river territory should be done, and it is possible to use the floodplain to generate revenue in another manner. Much of the rural spaces between villages on the Ahr were pastures or vineyards before the flood, but this can be reconsidered. One option is to use it to capture solar energy, if it is possible to build so it is resistant to flooding. Other options could include camping sites without permanent cabins, pop-up markets or different kinds of agricultural systems than viticulture. In Rech alone, nearly a quarter of the vineyard area was destroyed in the flood. Grapes are a time-intensive crop, requiring up to three years before they bear fruit. There are many other seasonal cash-crops that can be grown instead in the flood zone, lowering the long-term economic risk.

Two blocks from the Ahr River, Bad Neuenahr-Ahrweiler, February 2022



THREAT · DETECTION



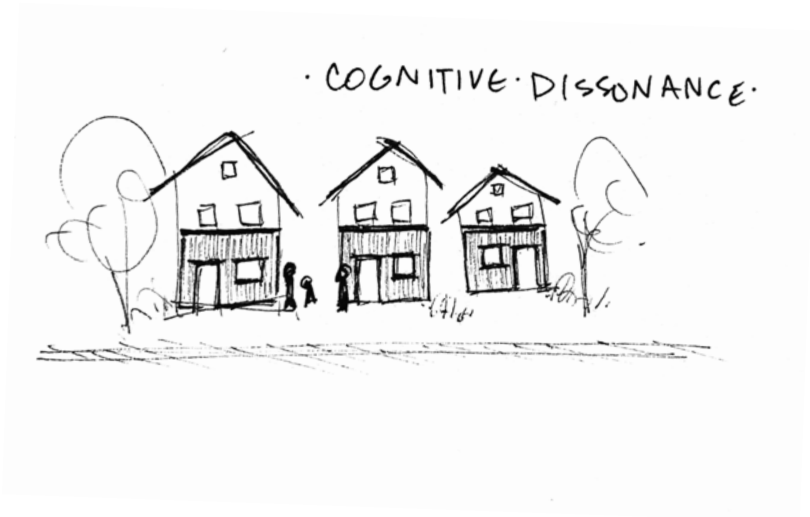
Generating new space for local food production helps RLP and Germany to improve food self-sufficiency goals.

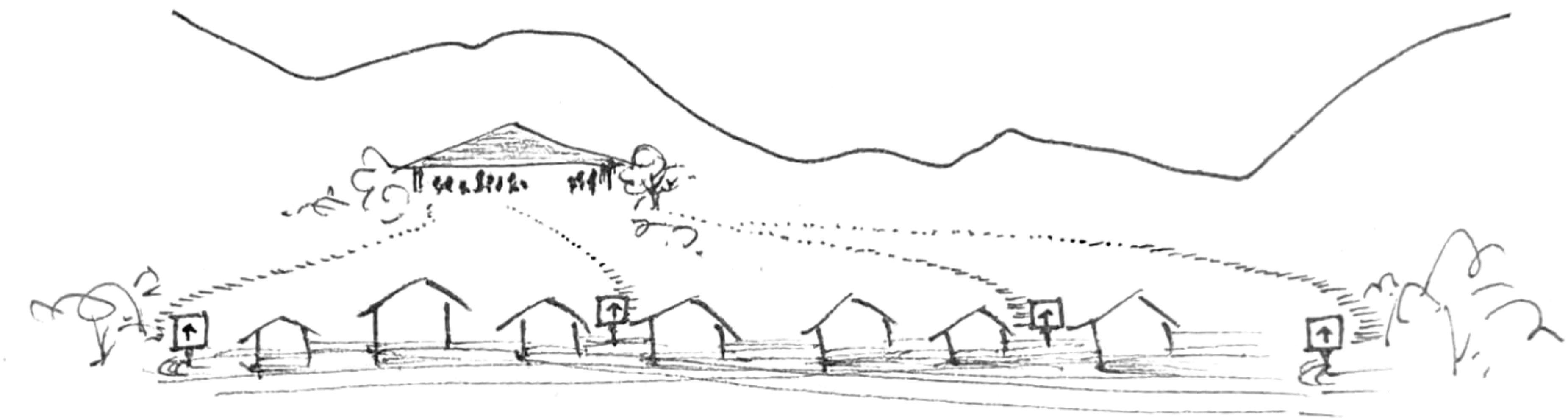
50.8% of German land is used for agriculture, 30% is forested or used for wood production, and urban areas or traffic infrastructure account for 14.4% (Bundesamt, 2022). In theory, German has enough land to be 90% self-sufficient in food production, but instead it is the third-largest foodstuff importer. Its produce footprint (biomass, land and water usage, and climate impacts) domestically was just over 10 million hectares in 2020, but imported foreign foodstuffs had a footprint of around 35 million hectares (Bringezu et al., 2020). The unsustainability and potential exploitation of other countries to produce food for Germany is critiqued in the media, and producing food locally is of growing importance, particularly with the new supply chain complications arising from the war in Ukraine. While the total hectares to convert in the Ahr Valley is not great, it can provide a change within the local economy while contributing to national food security goals. It nicely compliments the existing tourism culture by appealing to foodie-tourism.

PRINCIPLES OF DESIGN

The attitudes and understandings of safety in the Ahr Valley will be an issue in the future, once the immediate visual impact of the flood is rectified. This is reflected by the design principle Cognitive Dissonance. Cognitive Dissonance is the tendency to seek consistency among attitudes, thoughts, and beliefs. It is difficult to look at a pleasant, rebuilt landscape and comprehend the scale of destruction possible. It is difficult to understand the the small Ahr River can become 1,700 larger than its normal self in a day's time. It will be increasingly challenging for residents to understand their vulnerability for living in the floodplain. The visual cues from dams or dikes will be useful, and there are much smaller-scale opportunities to remind people of the omnipresent threat. Consistent markings of the peak water levels from the flood should be shown. This can be as simple as lines on buildings or informational signs. If an entire village participates in this, there will be a constant visual effect. Cognitive Dissonance can be offset by Visibility design principles.

Visual cues are also useful for Threat Detection. This is the innate ability to detect threatening stimuli more efficiently than non-threatening stimuli. It can be inferred that one reason that people did not evacuate the valley was because it was not possible for them to comprehend how fast the river was rising in many places. There




·FORGIVENESS·

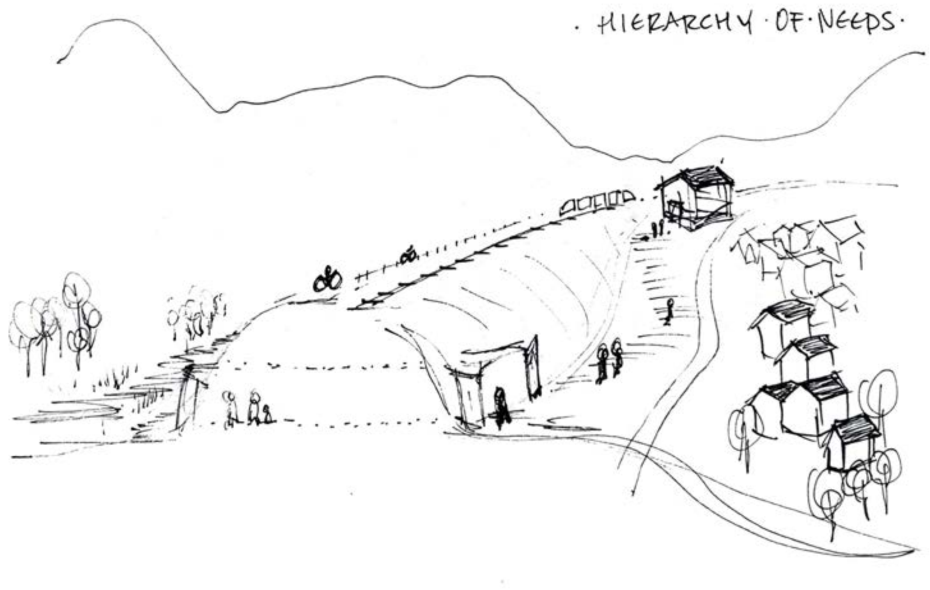
was a disconnect between society and nature and understanding threat risk, but also because they couldn't really see the event unfolding until it was far too late. It was difficult to see how much bigger the channelized river was growing because it was hardly growing wider. Especially inside the villages, the Ahr River stayed inside its narrow channel until it was raging and high. If people can see the changes occurring in the river, it is more likely that they will seek safety sooner.

The Hierarchy of Needs is again useful. The local economy should diversity, but part of that diversification can be in other forms of tourism. Foodie, nature-based, or cycling tourism can be promoted with good rail and bike services.

The design principle that is the most poetically beautiful for this case is Forgiveness. Forgiveness states that designs should help people avoid errors and minimize the negative consequences of errors when they do occur. People make bad or illogical decisions, as has been mentioned in the introductory chapter of this report. But they should not die for them. It is difficult to give people an escape route during a raging flood. Household measures, like storing lifevests and handsaws in attics may seem silly, but it could mean the difference between life and death for those trapped in attics and on rooftops. There should be escape routes to higher elevations that are extremely accessible, as not everyone can drive, hike, or simply walk. These routes should be frequent, visible, and known.

Accessibility is in and of itself a design principle. Objects and environments should be designed to be usable, without modification, by as many people as possible. There is a strong argument for encouraging people to use the Ahr River as a recreational space. The river should be used in order to destigmatize it. Many of the largest and most effective infrastructures that reduce flood risk restrict river access from settled areas. Design will need to consider ways up, over, under, or through them so that they remain connected and usable for local population. This can also be useful in considering the Hierarchy of Needs. Accessibility and connectivity is important for locals to be able to commute to their jobs and for tourists to be able to access the valley. Accessibility should be considered by foot, bike, rail, and vehicles.

The most important design principle for reducing flood risk in the Ahr Valley is with the Factor-of-Safety. For this principle, the use of more elements than is thought to be necessary to offset the effects of unknown variables and prevent system failure. There will be a need to incorporate a variety of engineered and nature-based solutions. It will need to protect the built environment, include social aspects, and present opportunities in economic diversification to ensure safety and resilience.



Consolidation of villages of the Ahr Valley (Basemap: LVermGeoRP, 2021)

SUCCUMBENCE

“The devastating flood catastrophe in July made it clear to us that there can be no more of the same when it comes to averting danger. Conventional flood protection measures reach their limits in such extreme weather events. We need new approaches and must move away from pure risk prevention towards a comprehensive, forward-looking risk culture. Efforts must be significantly increased both in climate protection and in adapting to climate change - because the more effective our current climate policy is, the greater the chances of future generations of being able to cope with the consequences of climate change. The likelihood of extreme rainfall events, such as those that caused the July disaster, has increased as a result of climate change. Theoretically, heavy rain events can occur anywhere and cause small bodies of water and ditches to swell into torrents in a very short time. In addition, we face further climate risks in the future, such as periods of heat or drought. Concrete conclusions must be drawn in order to best protect our population from the consequences of climate change. Rules of flood prevention, such as the ban on construction in flood areas, must be implemented consistently. Building in flood areas may only be carried out in exceptional cases that have been carefully examined. We now have to take this into account when rebuilding in the Ahr Valley, but more generally in all regions in Rhineland-Palatinate and Germany.”

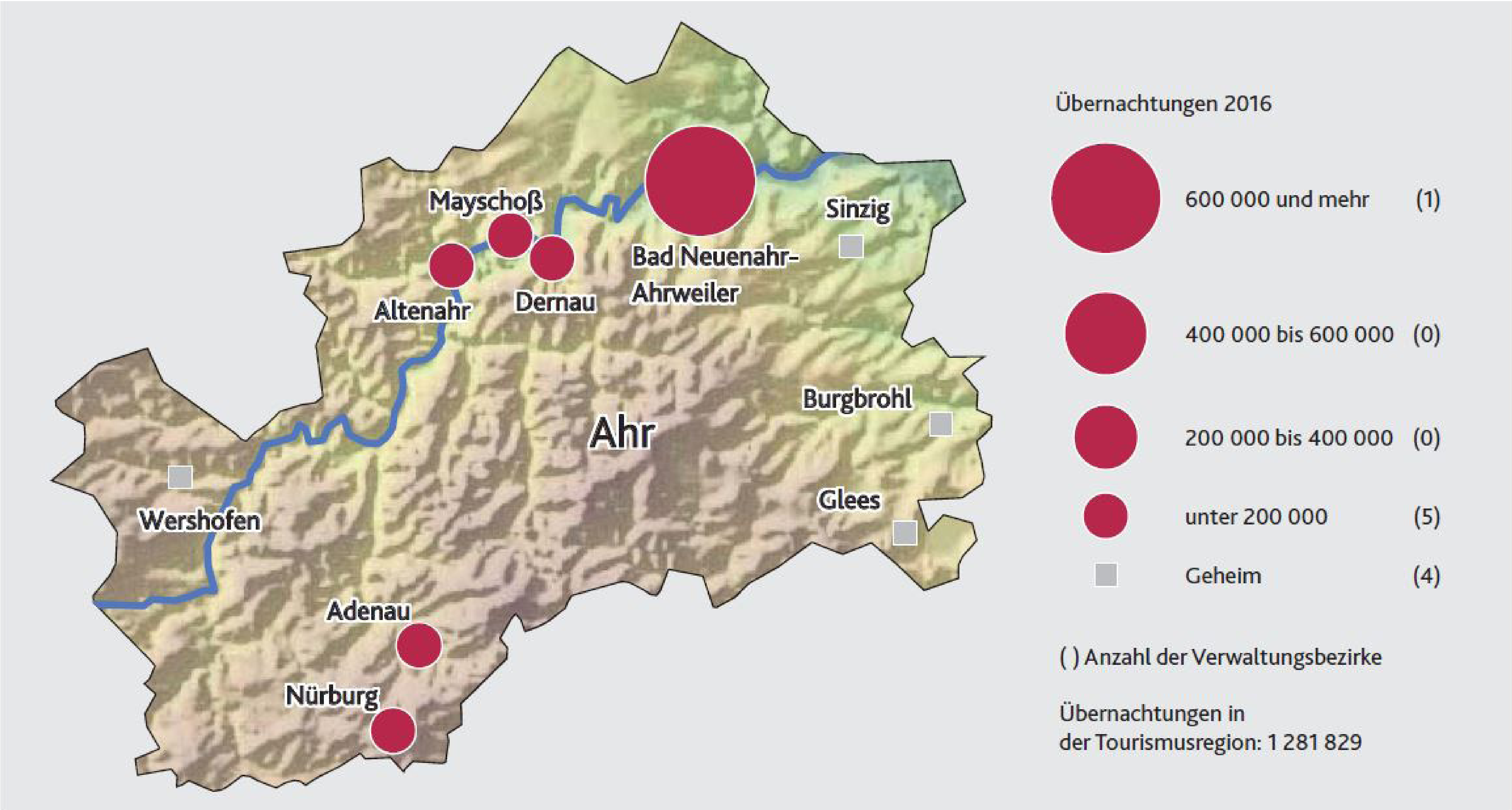
– Climate Protection Minister Anne Spiegel (Dienstleistungdirketion, 2021)

SHOULD WE REBUILD THE AHR VALLEY?

The German government is investing an extraordinary amount of money into the reconstruction of the Ahr Valley. The only reason reconstruction is possible is because of this funding, both because the damage is so great and because most locals were not insured against flooding. But, as has been discussed in earlier sections, without any formal plans for ensuring flooding damage is minimized from here on out, what sense does this have? Removing, reducing, or even waiting to announce funding would destroy local communities, leading to a depopulation. This is succumbence. Succumbence means to failing to resist pressure or a negative force. It is giving in or giving up. If there is no stimulus helping locals rebuild, many locals would have to succumb. They would never be able to afford to rebuild.

This opens an entirely different debate - what if funding didn’t exist? It is very likely

“A Fine Mountain River” by MIKOFOX Reject Fear, Go Outdoors, Live Healthy. CC BY-NC-SA 2.0



Overnight stays in Ahrweiler (Ellermeyer, 2018) that a similar flood will happen again, potentially with similar consequences, and then who would provide the recovery fund again? What measures can locals take to move forward in this scenario?

The Ahr Valley has beautiful natural areas and scenery, which is already an attraction for tourists. It is very challenging for villages with minute populations, like Marienthal, to remain viable. Resettling scattered, depopulated communities into consolidated villages would improve local resilience while allowing larger stretches of the valley to be returned to natural conditions. An extreme model could be to relocate all settlements out of the valley, freeing space for a long natural park. The practice of consolidating or relocating villages was used during WWII in the district, so it is not unprecedented. It is not an impractical solution to an enormously expensive problem.

As Climate Protection Minister Anne Spiegel aptly stated, now is the time for bold new ideas in adapting to climate change. The residents of the Ahr Valley are not the first to be displaced due to climatic disaster, and it might just be the correct response.

ASSIGNING VALUE TO A DEPOPULATED VALLEY

Just because a valley is depopulated does not mean it has to eliminate its productivity. It is likely that the most resilient residents are owners of vineyards, forests, or farmland, and they would require staying to maintain their livelihoods. A renaturized space does not have to be unuseful.

The landscape in much of the Ahr Valley would revert back to its native decidious forest if settlements are abandoned. Forests provide valuable ecosystem services: raw timber material, non-timber products like medicines, wild foods, climate regulation, soil and water retention, pollination, act as barriers to natural hazards, enhance biodiversity, recreation, and aesthetic values (Grammatikopoulou & Vackarova, 2021). The economic valuation of these services is a contentious topic because the numbers make a simplification of a complex subject. It also opens natural spaces to degradation as politicians or developers can quantify and justify their projects economically. But, it is still a useful concept for comparing the investment in the reconstruction of Ahr Valley and its tourism industry versus succumbence.

According to a report on Ahr tourism 490,599 visitors came in 2016. Most stayed for an average of 2.6 days. 69% stayed in hotels, and the figures exclude camping tourism. Bad Neuenahr is by far the most important touristic destination, followed by Altenahr. 90% of the overnight stays take place in only ten locations (Ellermeyer, 2018). Primarily people visit for wellness retreats (spas), wine tourism, and nature.

While it was not possible to find figures that showed what this meant in financial terms for the Ahr Valley, I extrapolated from data available for all of RLP. Tourism in the state generates €7.2 billion and there were a total of 22,558,496 overnight stays (Rheinland-Pfalz, 2016). This corresponds to approximately €319 per overnight stay, and would place the estimated annual revenue generated in the Ahr Valley to be around €157 million. This industry has been practically non-existent since the flood. Recently, the RLP Economics Minister announced that the state will give €1 million to promote tourism in the valley (Francke, 2022). It is just a drop in the bucket.

Ninan & Inoue (2013) estimated a wide range of values for ecosystem services depending on forest types and regions. Their values ranged from $8/hectare to $4080 (in 2010 USD). There were approximately 100 hectares affected by the July 2021 flood in the Ahr Valley. If this space is converted to forest, the total valuation would only be between $800 to $408,000 annually. Purely based on ecosystem services, this would never be a financially viable option. But there are other ways to consider value, especially the enormous costs that are required just to rebuild.

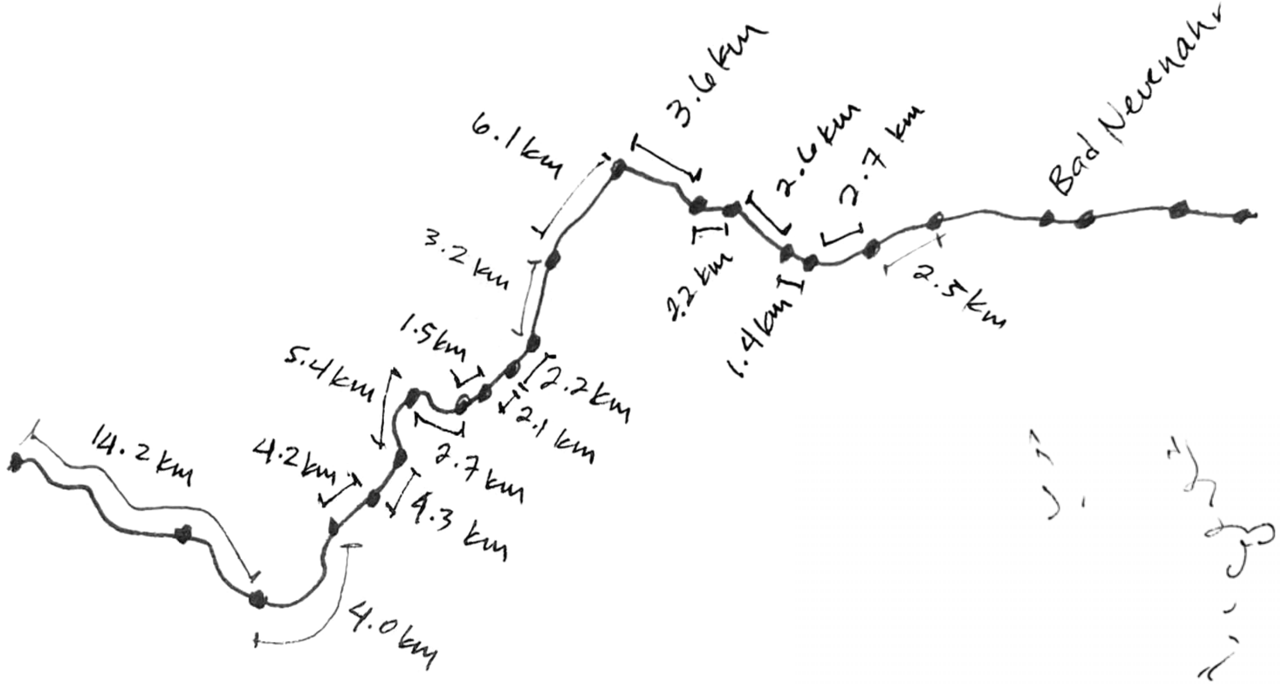
There are important global references of economic opportunities in nature conservation areas – for example, the immensely popular Yellowstone National Park in the USA. In 2019, four million people visited the park, spending $507 million within the park and in local communities which supported 7,000 jobs. It is essential to the economies of three largely rural, neighboring states. Nationally, the impact of parks benefits the US economy with $41.7 billion, 340,500 jobs, and 327 million park visits that directly generated $21 billion via fees such as entrance permits and restaurant visits (Warthin, 2020). Rather than Germany investing in reconstructing infrastructure along the Ahr that will inevitably face floods again, it could seize the opportunity to change its approach to livelihoods and tourism in the valley. Nature-based tourism is already a top reason for people to visit the Ahr Valley.

Succumbing to the flood and resettling some of the least resilient villages (or all) would also give much more space for managing storm- and floodwater. The most profitable touristic hub in the Ahr Valley is Bad Neuenahr-Ahrweiler, located at the lowest reaches of the Ahr River. Using vast extents of the valley to build resevoirs, retention basins, and other ecologically sound design principles would be extremely effective in reducing flood risk in the important city of Bad Neuenahr-Ahrweiler.

PRINCIPLES OF DESIGN

Financial support is the only reason why residents of the Ahr Valley are able to rebuild. Money is what is driving the reconstruction machine. The funding is not infinite though. Efficiency will need to be prioritized and the biggest flood protection

·HORROR·VACUI·



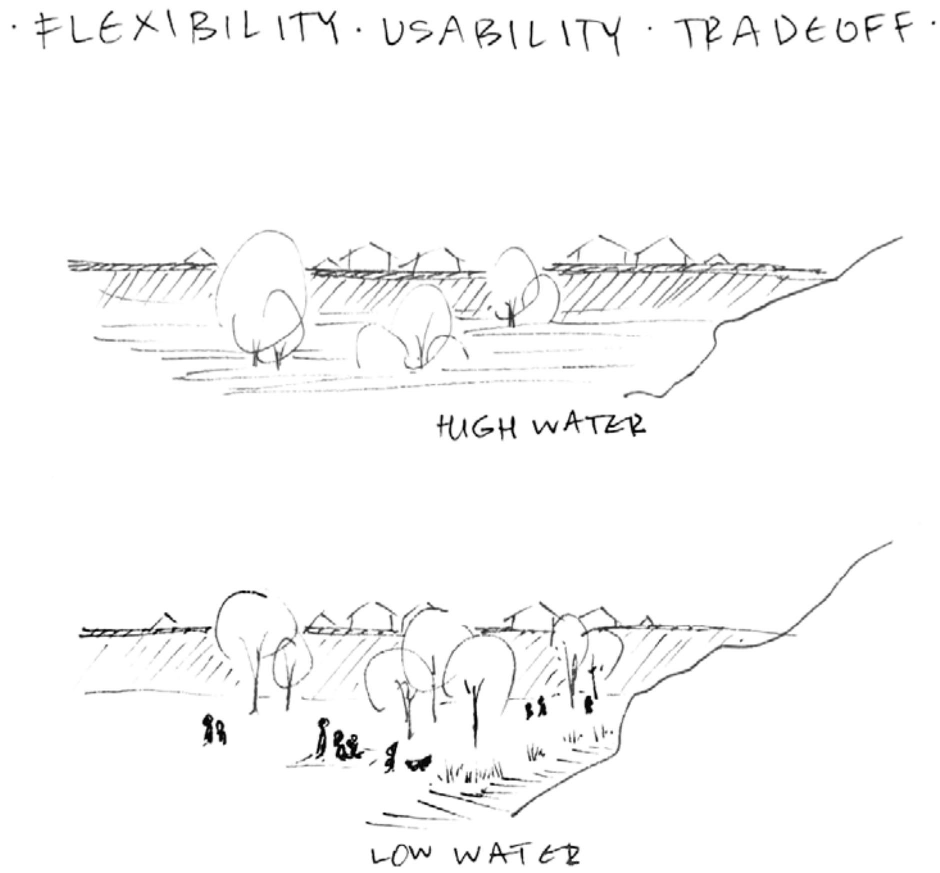
·IMMERSION·

measures may need to be down-sized or not built at all, exposing residents to a greater risk. This is the discussion of the design principle Cost-Benefit. An activity will be pursued only if its benefits are equal to or greater than the costs. €30 billion can be useful in a lot of different ways other than rebuilding the Ahr Valley.

The idea of using retention basins in the valley is very practical. But, as the river system is given a greater degree of flexibility in its space, its usability decreases. During high water periods, much of the land will be inundated and would drastically reduce its usability. The Flexibility-Usability Tradeoff states specifically that - as the flexibility of a system increases, the usability of the system decreases. Lidwell, et al. (2010) expand further on this principle by saying, “It is a common assumption that designs should always be made as flexible as possible. However, flexibility has real costs in terms of complexity, usability, time, and money. It generally pays dividends only when an audience cannot clearly anticipate its future needs.” This is notable, given that the Ahr Valley will likely face more flooding, but it is unclear to most people how severe it will be. Larger flood protection features that limit flexibility may be an economically advantageous investment in the long term.

Settlement patterns of the valley show a consistent scattering of villages. Most are between two to five kilometers apart. This equal distribution shows a critical distance that was assumed to maintain contact with neighboring communities during their historic establishment. It is a pattern that works, giving the relatively consistent population of the villages over time, and is in a way, reflective of the design principle Horror Vacui. Horror Vacui is the tendency to favor filling blank spaces with objects and elements over leaving spaces blank or empty. But, the flood provides an opportunity to fundamentally reconsider this - our contemporary modes of traffic are much faster than horses or foot, is it illogical to consider merging them? How much will locals object to this idea because of the gaps in space it creates? Will it negatively impact the cultural connectivity of the valley? Is it possible to find an appropriate Cost-Benefit ratio in village consolidation in order to implement large-scale flood protection systems?

Following on this idea, a de-urbanized valley could create a more immersive feeling in nature. Immersion is the state of mental focus so intense that awareness of the “real” world is lost, generally resulting in a feeling of joy and satisfaction. Nature-based toursim uses this principle, as do wellness facilities. It is possible to use Immersion as an argument for allowing Succumbence to occur.



Errors and Horror Vacui in action, Schuld

INACTION

How much did the immediate, hasty clean-up phase cost? Volunteers and locals intensely worked for weeks, expending time, energy, and fuel while exposing themselves and their equipment to hazards, wear, and contaminants. This action was meant with good intentions, but workers reshaped the river landscape in perhaps the least appropriate way possible. What is the point to put things back exactly as it was before? A great flood will inevitably come again, washing out the same river banks, roads, and homes. It is like Greek mythology's Sisyphus, pushing his boulder up a hill only to have it fall once he nears the top, for eternity.

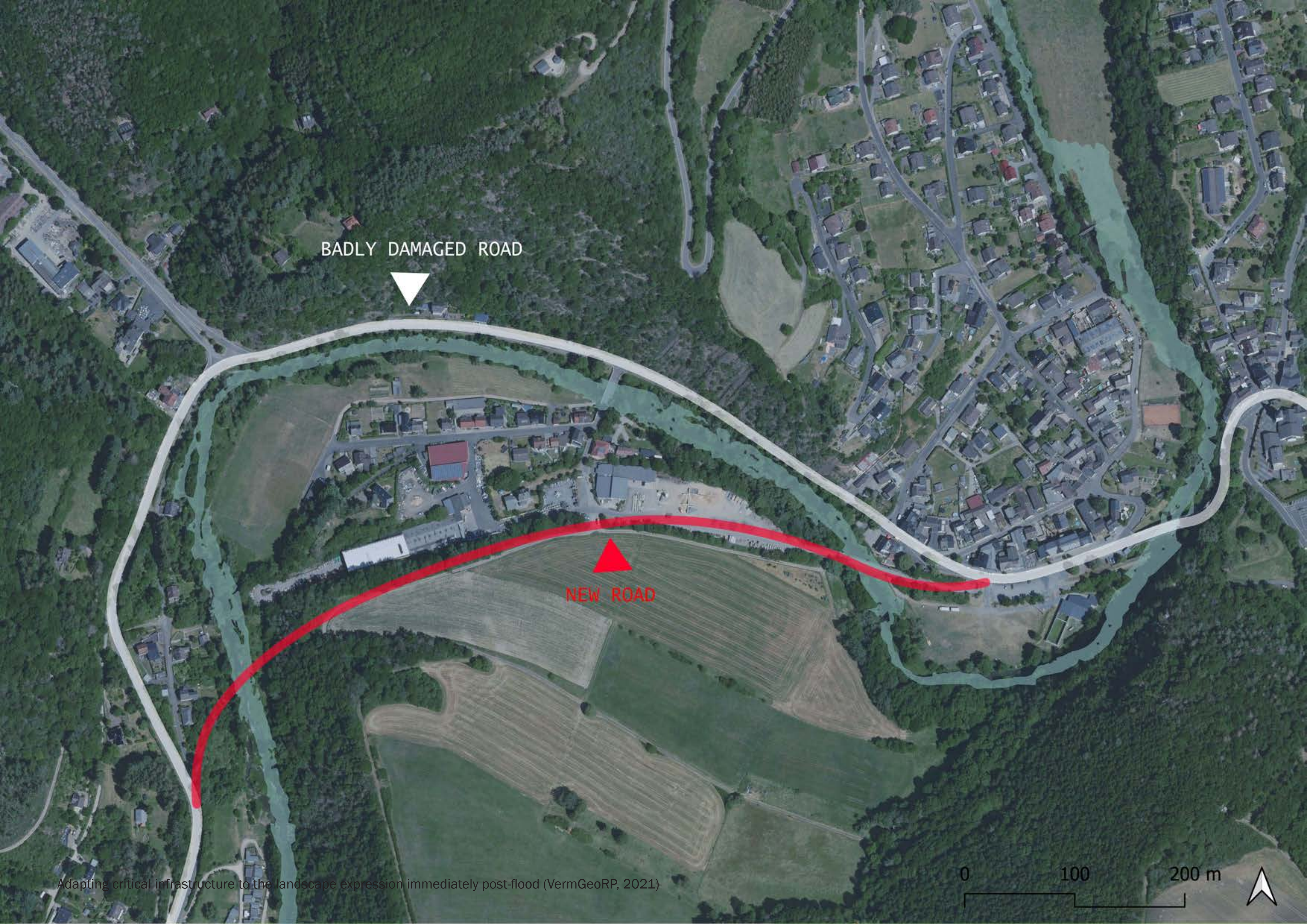
Landscape architecture as a discipline uses three different theories to explain its work: explanatory, resistance, and normative (Herrington, 2017). Explanatory theory describes why something is the way it is and is featured heavily in site descriptions and analyses. An example is classifying landscape types, which is necessary in understanding ecology and natural processes. Resistance theory challenges the status quo, which is important in creating new ways to adapt to climate change and the increasingly complex social and political landscape. The third theory is normative theory, or how it should be. This applies to the ecological costs of materials in landscape design, as well as to the rightness or wrongness of an intervention in a landscape. Should the landscape, especially the river, in the Ahr Valley have been rebuilt in such a way?

The river needed to be cleaned of waste, but the reshaping of it was extreme and unnecessary. The Ahr Valley should be moving critical infrastructures like the road, rail, and settlements to adapt to natural processes and not be moving Nature to fit their needs. The need to control Nature leads to an endless cycle of reconstruction. Nature made its most desirable shape, and it should have been left.

PRINCIPLES OF DESIGN

An easily identifiable design principle in Inaction is Cost-Benefit. Volunteers took months to reshape the river. The result was an Error, also a principle of design.

Errors and Horror Vacui in action, Schuld



Adapting critical infrastructure to the landscape expression immediately post-flood (VermGeoRP, 2021)

Errors in this context mean an action or omission of action that yield an unintended result. The reshaped slopes may be aesthetically pleasing to many, but it is extremely ineffective in handling floodwater. The people helping didn't know any better, but used thousands of hours and liters of fuel with good intentions.

Part of the problem in their river reconstruction is their perception as to what is beautiful. As was discussed earlier with Wabi-Sabi in Man in Harmony with Nature, Westerners tend to prefer symmetric forms and synthetic materials. This is evident in the channelization of the river, cleaning it so it has an even trapezoidal form or one entirely contained between walls. But there is an undeniable aesthetic beauty (and logic) in how Nature shaped the river. It created its optimal form, and this form is impermanent. There are other expressions of this concept in an array of German references: Old Nidda-Meadows Airfield in Frankfurt (Prominski, 2014), spontaneous Fourth Nature (Riemann, 2007) in many parks in Berlin including the Südgelände Railway and the former Nordbahnhof Railway Station (Kowarik, 2013). If volunteers knew about this principle and embraced it, the whole form of the valley would be different and it would show its dynamicism.

If there was a leadership to the clean-up that knew this concept and could convince people to use it, an Exposure Effect would come. This is the phenomenon that repeated exposure to stimuli for which people have neutral feelings will increase the likeability of the stimuli. Familiarity plays a primary role in aesthetic appeal and acceptance; people like things more when frequently exposed to them. Even if a Wabi-Sabi plan encountered resistance in the start, complaining of untidiness and ugliness, it is likely that they would learn to appreciate it.

This section would not be complete without the inclusion of Horror Vacui. Germans are notorious for their industriousness, and there was not a moment of respite and reflection before clean-up work began following the flood. Volunteers drove from far away to help, and doing nothing was not possible. It was not possible to leave a mess, but was the Ahr Valley disaster really a mess? Working for the sake of working does not necessarily lead to progress.

CONCLUSION

Clean-up process February 2022, Altenahr

CONCLUSION

The Ahr Valley has experience an enormous tragedy and it is just beginning a long reconstruction phase. Residents have suffered extraordinary physical and emotional fatigue and are eager to piece their lives back together. Until now, nothing apart from an updated flood hazard map provide a higher level of protection against severe floods, even as people rebuild their homes and businesses in situ without any new construction codes. Much work has been done to return the Ahr River back to its former self, but this is a fundamental misunderstanding of natural processes. This does not reduce disaster risk. It does provide any social, ecological or economic benefit to improve community resilience. It is understandable that people want to return to normalcy, but their methods are completely illogical.

Reconstruction for many is only possible due to generous relief funds provided by the government. €30 billion has been promised thus far, despite lacking a plan to reduce the risk of future flood disaster. Most is intended to replace damaged or destroyed infrastructure, from houses to bridges and roads to gas lines. The financial and physical exposure to both the state and people is absurd.

Implementing the best flood mitigation techniques that actually offer a large degree of protection to the Ahr Valley will be expensive. The valley has such a small population to protect and a unresilient economic ecosystem, that is it worth it to invest in its reconstruction? I expect that a variety of concepts that I have presented will be implemented in upcoming flood reduction plans, but I think that the final two disaster risk reduction paradigms are particularly valuable to consider, even if retroactively.
A severe will eventually happen again, and the Ahr Valley will again be tasked with reconstruction - or abandonment. In a world that has such a rapidly changing climate and has been degraded so extensively for human gain, we should consider giving Nature more space to reclaim and be allowed its processes. It is vanity to try and control it.

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APPENDICES

APPENDIX I: FORIN RESEARCH QUESTIONS

The triggering event(s):

- What was the scale or intensity of the primary triggering event and what was its supposed period of return in historical terms?
- Was sufficient and adequate information available from reliable sources to identify realistic return periods of the triggering event?
- To what extent were the physical triggering events “naturally” or “socio-naturally” constructed? How were the events described or explained by public authorities, the press, private sector groups, the insurance industry, communities, etc., after the event?
- How well developed and disseminated was knowledge of the physical threats? Was it translated into public knowledge and how – through public discussion, through incorporation in planning instruments and local building norms, etc?
- How accurate were the predictions or projection of future events by government, universities, or other monitoring systems? What were the principal failures in terms of understanding and prediction?
- What was the public perception of the triggering physical event? Was risk perception and interpretation considered for disseminating knowledge of the physical threats?
- What were or are the existing levels of consciousness, perception and knowledge of existing physical threats and how was this distributed between: different segments or sectors of the population, national and local government; different components of civil society; the private sector; different age groups, by gender, etc?
- What were the major anomalies as regards the events and their manifestations as compared to what had been projected or predicted?
- Were there contrasting and even conflicting projections of event occurrence amongst different social groups, including academia, government, civil society, and private sectors? How did these play out in the public and governmental arenas?
- Was the primary event succeeded by related, but different physical events (for example earthquakes succeeded by landslides and fracturing of dams and flooding)?

Exposure of social and environmental elements

- Where exposure is or has been measured according to the intensity or magnitude of an event, what as the spatial distribution of different social elements when faced with the differing levels of intensity predicted or suffered? This question may be answered according to different socio-economic strata and groups, types of infrastructure and housing, critical infrastructure such as schools and hospitals, ect. And is intended to show if spatial segregation of exposure levels exists, in ways that disfavor or favor different social elements.
- How has the distribution of exposure evolved through time and space in relation to (un) planned territorial development and the occurrence of specific types of physical threats?
- What was/is the nature of the social controls, norms, legal provisions, etc. that exist in relation to the restriction or promotion of location in hazard-prone areas? And, examining the patterns of loss and damage, to what extent were these norms obeyed or disregarded, and to what degree?
- Were zoning regulations, land use controls, and infrastructural codes adequate for the levels of risk existing in different places?
- How updated were the existing controls when disaster occurred, when were such controls updated and what were the major changes in exposure that had occurred over time and the nature of the controls introduced or not introduced to accommodate them?
- Were changes in exposure levels and patterns due to social decisions on location or rather to changes in the physical environment related to the hazard-inducing effects of social actions (deforestation, urban design and construction, etc) or to such things as climate change?
- How were controls over exposure and construction in situ defined? Were these back up by risk analysis and evaluation that adequately evaluated current exposure of social elements when faced with different hazard intensity or magnitude?

Social and economic structure of exposed communities: Vulnerability

- How were loss and damage, impact and effect differentially distributed between different areas, social groups, types of infrastructure and production?
- Were there notable aberrations in the sense that less exposed and hazard-prone social and economic elements suffered greater impacts than more exposed and hazard-prone elements? In what sense was this materialized?

- What were the principlal pre-disaster differentiated expressions of livelihood and human vulnerability, and what were the principal manifst, immediate, symptomatic causal factors? This could include such things as: building collapse with loss of life or loss of livelihood inputs and support infrastructure; loss of transport and energy infrastructure and its impact on livelihoods, health and employment, etc.
- How were the post-impact relief and rehabilitation processes carried out, and how just, equitable and efficient were they with regard to different social groups and their needs? Did the existing political agenda play a role in the response and rehabilitation processes?

Social and economic structure of exposed communities: Resilience:

- What resources access pathways were available to the community that facilitated an adequate response to the events and processes of hazard impact?
- How did material components (housing and infrastructure) as expressions or results of social priorities and choices fare in the disaster?
- In the case of successive place-based disaster events, were there identifiable response/ recover processes and pathways that axacerbated the likelihood of loss – or, conversely, contributed to reduced damage and hardship?
- What role, if any, did insurance play in loca resilience?
- Were there notable differences in the ability of different social and economic grouips to fact up to and recover from the disaster and its secondardy impacts? How can these be depicted, and what were the man elements that explain the social and spatial differentiation in such processes?
- What was the role of social organization, social ties and networking in building resilience? What specific social organizational forms and practices were activated by the hazard and its impact that enabled the community to organize and work on its own behalf to adequately respond to the disaster? How are these institutions and actions related to questions of root and underlying causes?
- What were the specific dimensions of resilience for a given population?
- What was the composition of societal disaster response networking and coordination?
- Did social conflicts or tensions regarding development priorities, disaster risk, employment, agriculture and/or tourism affect resilience?
- What was the balance between the resilience of communities and loca goverbnmental policy and practice?
- What, if any, were the cases of social groups that clearly were highly vulnerable to hazard impacts but which also showed important capabilities and capacities to recover an reconstruct their livelihoods and lives? What were the defining charactersistics of their vulnerability and, on the other hand, their resilience, when faced with damage and loss?

Institutional and governance elements:

- Does appropriate legislation exist at national and local levels, including additional regulation s such as building codes, degree of enforcement and their specificity on risk management issues, as well as policies and programs?
- Is insurance against loss and/or liability available? Is it required?
- Did organizational arrangements (whether focused on risk or emergency management) exist and at what level of authority, multi-sectorial and multi-stakeholder involvement, degree of participation in policy- and decision-making?
- Was DRM integrated into other relevant policy areas such as urban and land-use planning, environmenta management, insurance, etc.?
- Are there research and educational capacities focusing on risk issues, awareness and insurance cover, etc?

The move from analytical and systematizing “description” to understanding underlying, root causes and dynamic processes: Population growth and distribution:

- What were the major trends in population movements, migration and settlement in hazArd-prone areas, and the driving factors and underlying causes of them?
- In existing populated hazard-prone areas, what were the dynamics of natural growth in those areas and role of the provision of new housing for new family structures?
- In the dynamics of population growth in different areas what were the principal factors that explain the sequences of territorial expansion (land use planning norms, cost, urban rent considerations, pre-existing settlement, etc.), and were the more safe areas occupied first, to be followed by the more hazard-prone areas?
- Are there any areas not susceptible to hazards near the exposed human settlements?

The move from analytical and systematizing “description” to understanding underlying, root causes and dynamic processes: Urban and rural land use patterns and processes:

- How did spatial and land-use organization and planning evolve in the area? Had there been organization and planning since an early stage? Was territorial use improvised, and if so, for how long?
- Who are the actors/decision makers for the organization and planning of land? Have they ever been linked to DRR and DRM concerns? Have they ever considered risk deriving from

exposure or vulnerability to natural events in their planning?

- Were there any legal frameworks related to land-use planning – either urban or rural? If so, are they enforced?
- In relation to hazard-prone areas, what was the logic behind the location of different socio-strata, businesses and industry, infrastructure, etc.?

The move from analytical and systematizing "description" to understanding underlying, root causes and dynamic processes: Environmental degradation and ecosystem service depletion:

- Where environmental change and degradation can clearly be related to impacts on hazards, livelihoods and human security in general, what were the principal motivating factors and actors involved in such degradation and change, and who were the beneficiaries as opposed to the victims of this?
- Did environmental law and norms in the area establish concerns and processes to avoid hazard and vulnerability conditions affecting the population?
- What is the relationship between economic growth and overall business considerations and human security and disaster risk concerns in terms of the generation of environmental degradation in affected areas?
- What were the pre-existing levels of knowledge and debate on the relations between environmental degradation and disaster risk in the affected areas?

The move from analytical and systematizing "description" to understanding underlying, root causes and dynamic processes: Poverty and income distribution:

- In what concrete and provable ways did poverty and income distribution amongst affected groups influence their levels of disaster risk, taking into consideration their impacts on hazard, exposure and vulnerability as well as potential or actual resilience of the population?
- Was there any clear relationship between exposure to hazards and the levels of poverty of affected population? How did the existence of chronic, everyday risk factors such as unemployment, poor health, drug addiction, personal and social violence increase disaster risk and impact?

APPENDIX II: SOIL LEGEND

00 Gewässerflächen

01 GG-RZ, RZ-GG, cGGn, hGGn: f-eu,el(Uhf,Lhf)/,//f-esk(Gt)

02 GG-BB, BB-GG, GGn: f-s

03 GGn, BB-GG, GG-BB: f-s,l//f-es,el

04 cAOn: fo-es,esk,kw; AZn: fo-es,eu/fo-es,esk

05 AZn: fo-es,esk; cAOn: fo-es,esk,kw

06 AZn: fo-es,eu/,//fo-es,esk; GG-AZ: fo-et,eu,es,esk

07 cABn, cGG-AB, cAB-GG, cGGa: fo-eu,es,el,et

08 cGGa, GG-AZ: fo-eu,el,es,keu,kes

09 cGNn: fl-es,eu; cGHn: og-Hn\fl-es,eu; HNn: og-Hn

10 GMn, GHn, GNn: f-s,l//f-es,el; HNn: og-Hn/,//f-es,el

11 RRn, RZn, BB-RR, BB-RZ: fg-esk,euk(Gt)

12 RZn, BB-RZ: f-eu(Uhf)\,/fg-esk,euk(Gt)

13 BBn, LLn: f-(k)l/,//fg-esk,euk(Gt); f-(k)l\fg-esk,euk(Gt)

14 BBn, SS-BB: fgl-s,u

15 HNn: og-Hn, HHn: og-Hh; GMn: f,p-u,s/fg,fgl,g-eu,kel; GHn: og-Hn\fg,fgl,g-eu,kel

16 HHn, HNu, HNn: og-Hn

17 OO-RZ, RZn, BBn: u-(k,z)u,s,lk,lz(Xhg)

18 RRn, RZn, BB-RR, BB-RZ: p-kel\g-euk,esk(Gu,Gs)

19 BBn, LLn: u,p-(k)l,t/g-esk(Gs)

20 BBn, LLn: u,p-(k)l/g-esk(Gs)

21 BBn, LLn, SS-BB, SS-LL: u,p-(k)l,t/g-euk,keu(Gu,Ug)

22 BBn, LLn, SS-BB, SS-LL: u,p-(k)l,t/g-euk,esk,ekl(Gu,Gs)

23 BBn, PP-BB: u,p-(k,z)s,(k,z)l/g-euk,esk,elk(Gu,Gs); BB-RZ: u,p-(k,z)s,(k,z)l\g-euk,esk,elk(Gu,Gs)

24 BBn, LLn, GGn: u,p-(k)l/,//g-euk,keu(Gu,Ug); HNn: og-Hn/,//g-euk,keu(Gu,Ug)

25 BBn, LLn, SS-BB, SS-LL, GGn: u,p-(k)l/g-euk,keu(Gu,Ug)

26 SS-BB, SS-LL: u,p-(k)l,t/g-euk,esk,elk(Gu,Gs)

27 BB-SS, SSn, GGn: u,p-(k)l,(k)t/g-(k)eu,(k)etu(Ug,Ut)

28 GGn, BB-GG: u,p-(k)l/,//g-kel,keu,ket,euk(mor); HNn: og-Hn/g-kel,keu,ket,euk(mor)

29 GGn, cGGn, GG-YK, cGG-YK: f-u,l,(z)u,(z)l//f-eu,el,(z)eu,(z)el; f-eu,el,(z)eu,(z)el; f-u,l,(z)u,(z)l

30 cGGn, cGMn, cSHn: fgl-es,eu,et; GGn, GMn, SHn: fgl-s,u,l/,//fgl-es,eu,et; HNn: og-Hn/,//fgl-es,eu,et

31 GGg, GGq: u,p-(z,k,n)s,u,l/c,p-(z,k,n)l,t,el,et

32 BBn, LLn: p-l,(k)l,(k)t(v,Lol)//g-elk,kel(mor)

33 BBn, pBBn, LLn: p-(k)u,(k)l,kl,kt(v,Lol)//fg-esk,elk(Gt)

34 BBn, LLn, SS-BB, SS-LL: p-u,l,t(Lol); YKn: uk-u,l(Lou)

35 BBn: u,p-ls,l//s,p-(z)s,(z)u(^s,^mk,s); u,p-(k)ls,(k)l,ks,kl(^c)

36 BBn: u,p-(k,z)ls,(k,z)l(^c,^s); SSn, GGn: u,p-(k,z)ls,(k,z)l(^c,^s,^mk)/p,c-eu,t(^mk)

37 BBn: u,p-(z)u,(z)l/c,p-(z)u,eu,(z)eu,t(^mk,^t); BB-RZ: u,p-eu,(z)el\c,p-(z)u,eu,(z)eu,t(^mk,^t)

38 BBn, PP-BB: u,p-(z)ls,(z)l(v); SS-BB: u,p-(z)u,(z)l,(z)t(v)

39 BBn, hBBn: uz-u,l,(z,n)u,(z,n)l

40 BBn, SS-BB: u,p-(z)u,zu,(z)l,zl,(z)t(v)

41 SSn, SSg: u,p-(z)sl/u,p-tl,ut; SHn: u,p-tl,ut; GGn, GGg: u,p-(z)sl,tl,ut

42 SSn, SHn, GGn: uz-u,l,(z)l,t

43 OOn, OOp: n-^car; FFn: og-O\n-^car; RRn: c,u-euz,esn\n-^car

44 FFn: og-O\,/n-^car; RRn: c-eun,esz\n-^car; BBn: p-u,l(Ua)\,/n-^car; BB\CF, BB/CF: p-u,l(Ua)\,/c-t(Tr)/n-^car

45 FFn, OOn: n-^car,^u,^t,^i; OLn, RRn, RZn: u,uk-eun,esn(^car,^u,^t,^i); AOn: f-n,w,k(^car,^u,^t,^i)

46 FFn, FSn: u-n(Bhg); RRn, RZn: u-esn\u-n(Bhg); BBn: u-(z)l/u-n(Bhg)

47 OLn, FSn, RRn, RZn: u-eun,esn,zn(Xhg)

48 RRn, RZn: u-eun,esz\n-^car; FFn: og-O\n-^car; FSn: og-O\u-n(Xhg); OOn, OOp: n-^car; OLn: u-n(Xhg)

49 RZn, hRZn: f,uz-eu,u,(k)u,el,l

50 RRn, BB-RR: g-esk,euk,wn(^car); BBn: u,p-uz,un,zl/g-esk,euk

51 RRn, BB-RR: c,u-neu,nel\n-^k; c,u-neu,nel\c,u-n(^k); BBn: u,p-u,l\,/c,u-n(^k); BB\CF, BB/CF: u,p-u,l\,/c-t(Tr)/n-^k

52 RRn, BB-RR: c,u-zes,zeu\c,u-z,n(^d); c,u-zes,zeu\n-^d; BBn: u,p-u,l\,/c,u-z,n(^d)

53 RRn, BB-RR: c,u-zes,neu\c,u-z,n(^d,^k); BBn: u,p-u,l\,/c,u-z,n(^d,^k)

54 RRn, RZn, BB-RR, BB-RZ: uz-esz,elz,esn,eln(^car); BBn: uz-l,(z)l/uz-elz,eln(^car)

55 BBn, RRn, RZn: fgl-keu,euk,esz,kw; SSn, GGn: p-(z,k)l,t/fgl-keu,eu,et

56 BBn: u,p-u,l(v,Ua)/c,u-n,eun(^k); BB\CF, BB/CF: u,p-u,l(v,Ua)\,/c-t,nt(Tr)/c,u-n,eun(^k); BB-RR, RRn: c,u-eun,eln(^k); u-eun,eln\n-^k

57 BBn, BB-CF: u,p-u,l,t/u,p-esz,eun,nel(^k,^d,^mk); BB-RR, RRn: u,p-eun,esz(^k,^d); RZn, BB-RZ: u,p-nel(^mk); u,p-eu,el\u,p-nel(^mk)

58 BBn, PP-BB, BB-PP: u,p-(k)l\g-esk,euk/n-^d; RRn: c,u-esz,euz; c-esz\n-^d; FFn: og-O\,/n-^d

59 BBn, SS-BB: u,p-(z)u,(z)t(^u,^t,^car)

60 BBn, SSn, SHn, GGn: u,p-(z)u,(z)t(^u,^t,^car)

61 SSn, SHn, BB-SS: u,p-(z)u,(z)t(^u,^t,^car)

62 SSn, SSg, SHn, GGn, GGg, GNn: u,p-(z,n)u,(z,n)t(^u,^t,^car); HNn: og-Hn

63 BBn, SS-BB: u,p-(z)u,(z)l,(z)t(^mk,^u,^t); BBn, pBBn: u,p-(z)ls,(z)l(^sa,^mk)

64 SSn, GGn: u,p-(z)u,(z)l,(z)t

65 BBn, RZn, BB-RZ: u,p-l,(z)l,zl(^ik,^ra,^mk,^k)

66 BBn, pBBn: c,u-(z)l,zl,lz,sz(^ik,^ra)

67 BBn, pBBn: c,u,p-zs,zl(^s,^s,k)

68 BBn, SS-BB: u,p-l,t,(z)l,(z)t,zl,lz(^ik,^ra,^mk,^k)

69 SSn, BB-SS, GGn: u,p-l,t,(z)l,(z)t,zl,lz(^ik,^ra,^mk,^k)

70 Abbau- und Rekultivierungsflächen des Kohlebergbaus

APPENDIX III: HYDROLOGIC CALCULATIONS

$$\boxed{Q = M \cdot A \cdot R^{\frac{2}{3}} \cdot I^{\frac{1}{2}}}$$

Q = between 400 – 700 m^3/s

$Q_{average}$ = 550 m^3/s

$h_{estimate}$ = 7.00 m

$$A_1 = \frac{43 \cdot 7}{2} = 150.5 \ m^2$$

$$A_2 = 20 \cdot 7 = 140 \ m^2$$

$$A_3 = (10 \cdot 2) + 2 \cdot \left(\frac{5 \cdot 2}{2}\right) = 30 \ m^2$$

$$A_4 = \frac{150 \cdot 7}{2} = 525 \ m^2$$

$$A = A_1 + A_2 + A_3 + A_4 = 845.5 \ m^2$$

$$R = \frac{A}{P}$$

$$P = P_1 + P_2 + P_3 + P_4 + P_5$$

$$= 43.6 + 10.2 + 10 + 10.2 + 150.2$$

$$P = 224.2 \ m$$

$$R = \frac{845.5}{224.2} = 3.77$$

$$I = \frac{elevation_1 - elevation_2}{distance}$$

$$I = \frac{162 - 161}{139} = 0.0072$$

$$\boxed{Q = M \cdot A \cdot R^{\frac{2}{3}} \cdot I^{\frac{1}{2}}}$$

$$Q = M \cdot A \cdot R^{\frac{2}{3}} \cdot I^{\frac{1}{2}}$$

$$550 = M \cdot 845.5 \cdot 3.77^{\frac{2}{3}} \cdot 0.0072^{\frac{1}{2}}$$

$$M = 3.17$$

Flood height 2021 (m)	Height over 2021 flood (m)	Q/M/I	A^(5/3) / P(2/3)	Total area	Length 1	Length 2	A1		A2	A3	A4	Total perimeter	P1	P2	P3	P4	P5
7	0	4089,5	2045,875178	845,5	43	150	150,5	20	140	30	525	224,6287446	43,56604182	10,2	10	10,2	150,6627028
7	1	4089,5	2347,434158	962	49,14285714	171,4285714	172	20	160	30	600	252,3757081	49,78976208	10,2	10	10,2	172,185946
7	2	4089,5	2649,32198	1078,5	55,28571429	192,8571429	193,5	20	180	30	675	280,1226716	56,01348234	10,2	10	10,2	193,7091893
7	3	4089,5	2951,448916	1195	61,42857143	214,2857143	215	20	200	30	750	307,8696351	62,2372026	10,2	10	10,2	215,2324325
7	4	4089,5	3253,755165	1311,5	67,57142857	235,7142857	236,5	20	220	30	825	335,6165986	68,46092286	10,2	10	10,2	236,7556758
7	5	4089,5	3556,199333	1428	73,71428571	257,1428571	258	20	240	30	900	363,3635621	74,68464312	10,2	10	10,2	258,278919
7	6	4089,5	3858,75186	1544,5	79,85714286	278,5714286	279,5	20	260	30	975	391,1105256	80,90836338	10,2	10	10,2	279,8021623
7	7	4089,5	4161,391069	1661	86	300	301	20	280	30	1050	418,8574891	87,13208364	10,2	10	10,2	301,3254055
7	8	4089,5	4464,100705	1777,5	92,14285714	321,4285714	322,5	20	300	30	1125	446,6044527	93,3558039	10,2	10	10,2	322,8486488
7	9	4089,5	4766,868338	1894	98,28571429	342,8571429	344	20	320	30	1200	474,3514162	99,57952416	10,2	10	10,2	344,371892
7	10	4089,5	5069,684301	2010,5	104,4285714	364,2857143	365,5	20	340	30	1275	502,0983797	105,8032444	10,2	10	10,2	365,8951353
7	11	4089,5	5372,540962	2127	110,5714286	385,7142857	387	20	360	30	1350	529,8453432	112,0269647	10,2	10	10,2	387,4183785
7	12	4089,5	5675,432216	2243,5	116,7142857	407,1428571	408,5	20	380	30	1425	557,5923067	118,2506849	10,2	10	10,2	408,9416218
7	13	4089,5	5978,353121	2360	122,8571429	428,5714286	430	20	400	30	1500	585,3392702	124,4744052	10,2	10	10,2	430,464865

Calculations based on Manning's Equation to find the dimensions of the 1804 flood with a 2021 landscape context

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