THESIS TITLE:

From Control to Integration of river flooding in urban landscape
A Study of the Meuse River transformation and evolution of flood urban infrastructures in Liège Belgium

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Introduction:

Historically, rivers have shifted from being a natural element to a controlled confined channel, impacting urban landscapes. This relationship between rivers and urban development underlines the vital role of these watercourses in shaping the urban fabric. Cities are strategically positioned close to these water bodies, which are essential resources for their growth. They recognize the essential value of rivers, yet they have also been exploiting their potential by modifying their course over time. Additionally, over the years, this transformation of the urban landscape and the ongoing consequences of climate change resulted in a significant increase in river flooding. While specific infrastructures have been built to stop these floods and limit damage to the urban landscape, the recurring pattern of these floods questions the effectiveness of some of these infrastructures regarding the future of these dynamics.

This study explores the complex relationships between rivers and urban environments, particularly emphasizing how the Meuse River has changed and how flooding urban infrastructures of Liège in Belgium have evolved. Throughout history, rivers like the Meuse have been gradually shaped by human interventions from the Middle Ages onward, impacting the river's natural flow. Analyzing the shift from controlling flooding to allowing the flood to flow naturally within the city introduces a new strategy of making room for rivers with more resilient infrastructures. While certain countries have already incorporated these techniques into their urban environments, others, such as Liège, still need such interventions. Their primary focus today is on revitalizing the river banks and restoring the lost connection between the city and the river.

How have historical factors shaped the transformation of rivers in the context of the Meuse since the Middle Ages?

How have urban infrastructures evolved to incorporate and utilize the river within the city in the context of flooding Liège?

Academic context:

Numerous publications exist on the evolution of the relationship between cities and urban rivers and the understanding of more resilient flooding in urban infrastructures responding to the current flooding patterns. However, more publications are lacking in linking why such strategies have not yet been adopted in Liège, even with the future expectation of flooding. In both publications of Leguay j-P (2006) and Andreas N.Angelais (2023), the understanding of the significance of water within the city and the evolution of flooding from middle age is very clear. Andreas N.Angelais also emphasizes that climate change and human factors have generally accelerated flooding. Urban infrastructures have seen an evolution following the potential of what humankind could do, from basic manmade structures to mechanically engineered ones. In the exhibition 'Fluctuations' held in 2012, the state archives of Liège retrace the relationship between the city and the Meuse from the Middle Ages. The exhibition's main topic is the rebound between the water and the urban fabric. However, its relationship with future climate and flooding is lacking. Many publications highlight the need for resilient infrastructure to allow more room in the river. Chiu, y (2021) and Rijke, J., van Herk, S., Zevenbergen, C., & Ashley, R. (2012) discuss more nature-based infrastructures, which reduce maintenance and protect biodiversity. When it is agreed that this is the strategy for today's consequences of climate change, few mention how it could be implemented in a dense urban area.

This study uses a multidisciplinary methodology to explain the historical urban state by referencing academic literature, historical records, and urban planning papers. In addition to qualitative studies, data gathering on flood events, the effects of climate change, and physical changes to the river will be enhanced by graphical representations that show the relationships between the city and the river.

This project intends to contribute to a greater understanding of river transformation and urban infrastructures, particularly in the context of floods, by addressing the research objectives and questions stated in this proposal. By providing insight into the historical legacies and contemporary issues that cities like Liège are dealing with, this study aims to provide insightful information that may be applied to other metropolitan locations worldwide that are facing comparable problems. Ultimately, this investigation aims to clear the path for more sustainable and resilient urban futures that coexist with the environment.

Thesis Statement: Examining the shift from river control to integration in urban landscapes, this thesis investigates the transformation of the Meuse river and the evolving urban infrastructures in Liège to address flooding challenges.

Content:

Part I: Historical relationship between rivers and cities

1. Cities and Rivers - A vital relationship

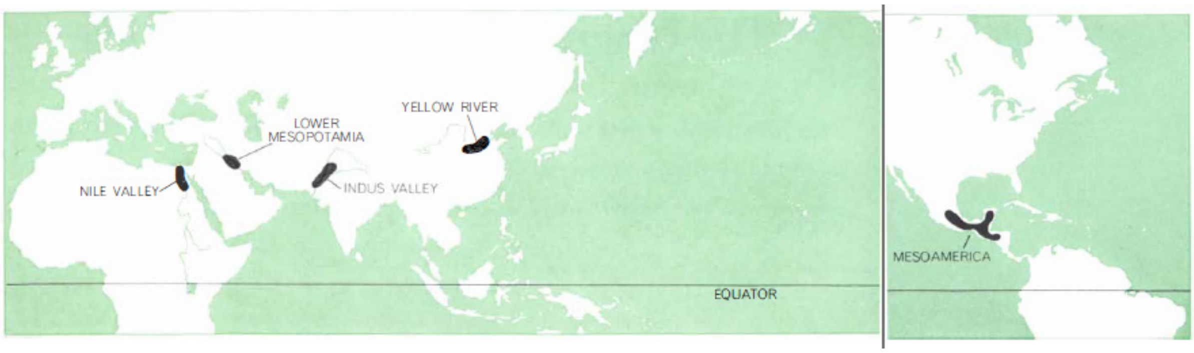
The historical relationship between rivers and cities goes back several millennia, offering a history of an unpredictable connection that integrates the evolution of urban landscapes and infrastructures built around rivers. Since the earliest days of human civilization, rivers have served as the cradle of human settlement, shaping the very foundations of societal development.

In the Paleolithic and Neolithic eras, our ancestors were drawn to the fertile banks of rivers, where water made it possible to live and farm. In a review published in Scientific American in 1965, Gideon Sjoberg mentions one of the two factors necessary for the emergence of cities: a favourable environment, offering not only fertile soil for farmers but also a sufficient supply of water for agriculture and urban consumption (Sjoberg, 1965). The first civilizations of the Old World, around 3500 BC, took shape along the Huang He, Indus, Nile, Tigris, and Euphrates rivers, as shown in Figure 1. The soil was generally dry, and the river was the only water source (Macklin & Lewin, 2015). Therefore, agriculture depended on natural flooding or controlled irrigation by the rivers. As agriculture was the primary source of food production at the time, the first settlements had to be located along the river, where the soil was more fertile.

For example, the Fertile Crescent, considered the “cradle of civilization”, is a region whose eastern segment includes several rivers, such as the Tigris, Euphrates and Nile. It was here that agriculture was born, transforming hunters into sedentary villagers. This region was considered the most fertile because of the abundance of water, which made the soil particularly fertile and led the first civilizations to settle and cultivate. Seeing the prosperity they could derive from this nutrient-rich land, more and more people came, and other settlements were created.

Figure 1

World’s earliest cities



Note. From “The origin and evolution of cities,” by G. Sjoberg, 1965, *Scientific American, 213*(3), 56-57 (https://doi.org/10.1038/scientificamerican0965-54).

In addition to being fertile land, the Fertile Crescents have enabled international trade. Access to water has facilitated the agricultural industry, but it has also provided a crossroads that has facilitated repeated contact between peoples of different cultures for thousands of years. Indeed, one of the features of this historical relationship is the role of rivers as natural transport and trade routes. Ancient civilisations recognised the strategic advantage of settling along rivers, transforming these water bodies into highways for trade and cultural exchange. Riverbanks became bustling centres of activity, lined with markets and quays to facilitate the movement of goods and people. Great historic cities such as Rome, located along the Tiber, and Baghdad, strategically positioned along the Tigris, owe much of their prosperity and cosmopolitan character to the trade routes opened up by their rivers. The fluidity of transport along the rivers stimulated economic growth and influenced the architectural expression of these cities, with waterfronts becoming dynamic zones of interaction and trade.

Since the earliest human settlements, there has been a strong link between cities and rivers. Indeed, for reasons of survival and agriculture, human settlements naturally moved closer to water sources, leading them to settle along rivers. Not only did these rivers help to create fertile land for agriculture, but they also served as trade routes, facilitating trade and commerce between different nations.

2. Middle Age: Cities were dependent on rivers

In the Middle Ages, the relationship between rivers and cities continued to be primordial and very important to developing the economy and urban centres. As an essential element of urban spaces and civilizations since Gallo-Roman times, few cities existed far from rivers or streams. This association influenced various aspects, including water supply, energy production, urban planning, economic growth, and trade, shaping the essence of medieval urban life.

During the transformations of the Late Empire and Early Middle Ages, defensive and religious functions replaced the predominant administrative and economic functions. Most Gallo-Roman towns were surrounded by defensive structures, ranging from substantial marshy areas to river canals, replacing or reinforcing stone and wooden defences. The strategic location of moats, fed by water through canals or left dry, was intended to deter opponents from the base of the walls, underlining the effectiveness of water as a means of defence, as shown in Figure 2.

Trade and commerce were still significant, with the river still serving as the main transport route between regions and providing a significant advantage for towns along the river. Regional and international trade was developed, with major road and river junctions serving as nerve centres. Bridges played an essential role, contributing to the rapid formation of suburbs on both banks and leading to double or triple cities. The river functioned as the city’s ‘breathing system’ (Leguay, 2006), influencing the orientation and layout of the streets, with the bridge serving as the gravitational centre of the urban agglomeration. Water was used for multiple functions, shaping urban landscapes, influencing defence strategies, commercial dynamics, and the very structure of towns along its banks.

Figure 2

Douai in the 17th century

Note. Historical map of the city Douai in France showing how the city is built within fortress and surrounded b water for defence. From Construire au Moyen Âge Les chantiers de fortification de Douai, by A. Salamagne, 2019, Presses universitaires du Septentrion.

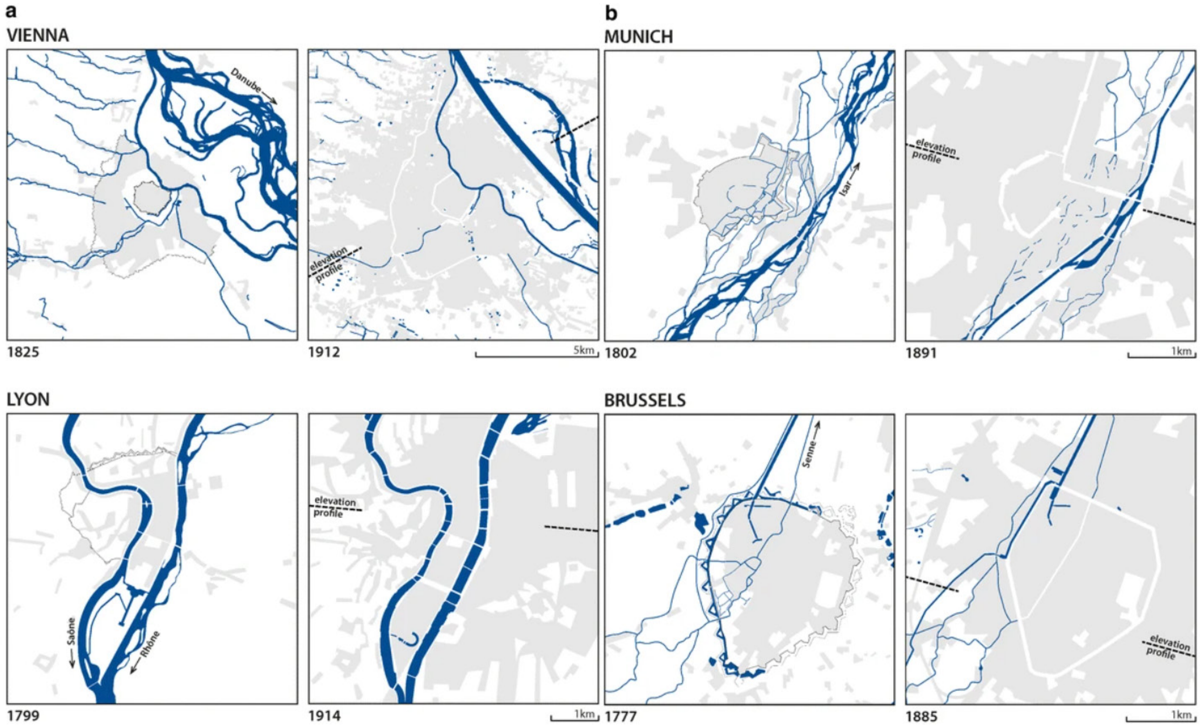
Furthermore, human and animal subsistence, hygiene, industrial activities, and civilization all require high levels of water consumption, which led to technological prowess in hydrological systems. These include wells, cisterns, fountains, and aqueducts. As far back as antiquity, urban communities, unable to rely on local resources, tried to get water from springs flowing in the countryside. Spring catchment systems, including aqueducts, small dams on rivers or at the outlets of ponds, diversions, covered pipes, and storage basins, were designed, maintained by specialists, and quickly protected by regulations. This strategic approach to water management highlights the ingenuity and foresight shown by ancient societies in meeting their diverse water needs.
The exploitation of rivers predates the Middle Ages. However, during industrialization, the transformation of landscapes accelerated significantly, exerting a profound and concerning impact on rivers.

3. Industrialization: Cities started to exploit rivers excessively

As civilizations changed over the years, the Industrial Revolution brought major technological changes that have further influenced the historical relationship between rivers and cities. Rivers, which had long been essential for transport, became crucial for industrial activities. The extensive alterations of these water bodies, including damming, channelling, and straightening (Castaneda et al., 2013), show how humans have gradually changed the natural state of riverbeds (Figure 3).

Figure 3

Evolution of urban river course in Vienna, Munich, Lon and Brussels



Note. Those diagrams are showing the modification of several river course from 1825 to 1885. From “The long-term evolution of urban waters and their nineteenth century transformation in European cities. A comparative environmental history,” by V. Winiwarter, 2016, *Water History, 8*(3), 219-220 (https://doi.org/10.1007/s12685-016-0172-z).

Factories and production units were often set up along riverbanks, using water as a source of energy and as a means of disposing of industrial waste, which deteriorated water quality. Industrialization also marked the beginning of intensive mining, which shaped and modified the land and impacted riverbeds. The landscape of riverside areas was transformed, reflecting the industrialization of urban centres. This period also saw the construction of large-scale bridges and dams, further altering the natural course of rivers.

The intensification of urbanization has posed environmental challenges to the historic relationship between rivers and cities. Rapid urban expansion has led to pollution and degradation of river ecosystems, calling into question the sustainability of architectural practices in harmony with the natural course of rivers. For example, between 1830 and 1939, Paris faced the challenges of rapid urbanization and industrialization, which profoundly impacted the quality of the Seine. Engineers and hygienists attributed the decline in water quality to discharges from streets, households, and storms (Barles & Lestel, 2007). In response to the urgent need to improve hygiene, Paris launched water supply and sewerage projects to clean up the streets during the first half of the 19th century. Paradoxically, these well-intentioned efforts unintentionally increased the discharge of polluted water into the Seine, highlighting the complex interaction between urban development, industrialization, and the environmental consequences for the quality of the river. (example of Paris, but many cities in the same situation).

Many European rivers have undergone significant and irreversible changes, often experiencing extensive channel alterations. Human impact plays a crucial role in these transformations, with factors such as the Industrial Revolution and technological advancements contributing to substantial shifts. Despite the introduction of sewage systems, pollution from industry, agriculture, and urban areas since the late nineteenth century has inflicted long-term repercussions on river ecosystems (Wolf et al., 2021). These changes underscore the complex relationship between human activities and the environmental health of river systems. The irreversible impact of human activities on river ecology has raised questions about responsible urban development, the need to find solutions to sanitary problems, and the preservation of natural watercourses.

4. Modern Time: Cities reconnecting with their rivers (1900 to now)

Cities worldwide have become aware of rivers' importance as physical features and essential elements of urban ecosystems. Compared with centuries of exploitation of rivers, mainly for flood control and urban growth, this emerging awareness represents a significant change. To re-establish a harmonious link between rivers and urban areas, urban planners are gradually turning to nature-based solutions that prioritise ecological balance and public participation.

Recent research has explored the idea of 'river culture', which promotes sustainable river management by learning from natural adaptive processes and past human interactions with river landscapes (Zingraff-Hamed et al., 2021). This approach recognises rivers as dynamic systems requiring integrated management plans considering cultural values and ecological functions.

Despite these encouraging developments, urban rivers face severe obstacles due to historical environmental constraints and poor management. The combined effects of industrial pollution, channel modification and habitat destruction must be addressed if river restoration initiatives are to be effective. Some cities, such as Copenhagen, have already begun to make peace with their rivers.

In conclusion, the trend towards re-establishing links with rivers reflects a broader understanding of the need for sustainable urban activities that respect and use the environment. Integrating green infrastructure and policies prioritising rivers will be crucial in shaping resilient and liveable urban communities as cities continue to grow.

5. Case study of worldwide urban rivers historically connected to their cities.

Every major city has its mother river like the Yellow river in China as shown in Figure 4.

For millennia, rivers and cities have shaped each other's social evolution, economic expansion, and urban environments. Rivers have played important roles throughout human history, from providing transportation and food to driving industrialization. However, the permanent harm caused by human activities emphasizes how urgently sustainable urban growth and environmental care are needed in order to reconciliate cities with their rivers.

Figure 4

Ten cities and their mother rivers

Note. Diagrams showing the city relationship with their rivers. Own work.

Part II: History of flooding & flooding infrastructures

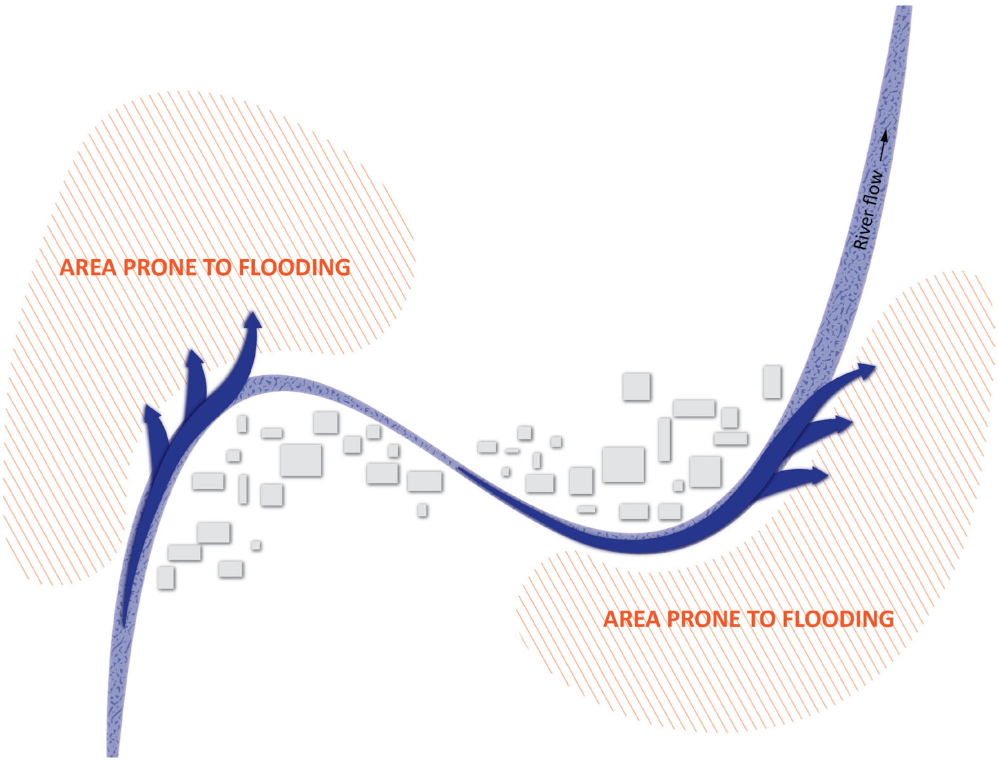
1. History of flooding and river change

The history of flooding started a long way back, shaping the evolution of human settlements and their built environments. Throughout history, communities have lived with the dynamic forces of rivers and other water bodies, witnessing the benefits and challenges they bring. Floods have brought both benefits and drawbacks to civilizations. Ancient societies were drawn to water-rich areas for the economic, accessibility, and agricultural benefits they offered. In Ancient Mesopotamia, for example, annual floods enriched the soil for farming, vital for civilization's sustenance, though they also posed threats, necessitating defensive structures against destruction.

One key aspect of understanding river floods is recognizing where floods happen in the river's curve and why they occur. The leading cause of river floods is when the river exceeds the river's capacity (Pandey & Azamathulla, 2023). Floods are more likely to occur in the meandering sections of rivers, where the river's natural flow is slowed down due to the winding path (Figure 5). This slowdown can cause water to overflow the riverbanks, especially during heavy rainfall or rapid snowmelt periods (Angelakis et al., 2023). Furthermore, the floodplain areas, flat regions surrounding the river, are particularly susceptible to flooding. These areas are formed by the sediments deposited by the river over time. They are naturally fertile, making them attractive for agricultural activities and settlement, thus increasing the impact of floods when they occur.

Figure 5

Area more prone to flooding



Note. Diagram showing the area's in which flood may occur du to the curve of the river. Own work.

During the medieval period, flooding profoundly impacted human settlements and the economy across Europe. It typically occurred in autumn and winter and posed significant threats to communities. Notably, the catastrophic flood of the Euphrates River in 1079-80 marked a turning point in flood documentation. Likewise, floods, primarily driven by the monsoon season in medieval India, presented continuous challenges.

The dynamic between rivers and urban development changed significantly when the Industrial Revolution began. Rapid urbanization often overlooks natural hydrology, contributing to increased flood risks. This issue has become more acute as growing populations in flood-prone areas, attracted by better living standards and higher property values, face escalating flood challenges. The increasing flood frequency and damage trend is mainly attributed to heightened vulnerability due to land-use changes and climate variability. Alarmingly, there has been a 35% increase in the average number of weather and environment-related disasters over the past three decades, with extreme weather events constituting 83% of all disasters in the last ten years, affecting billions globally (Douben, 2006).

The early modern era in Europe witnessed advancements in flood record-keeping, with flood levels marked to document the severity of events. The 16th century in Rome saw a decreased flood severity, attributed to the effective maintenance of rivers and urban drains. Additionally, historical floods in Turkey and India, like the Calcutta flood of 1737, illustrate this period’s widespread devastation and loss of life.

In mid-modern Chinese history (1368 AD to 1850 AD), the Yellow River saw frequent and severe floods, exacerbated by population growth and declining human-land relations. The transition to the contemporary era (1850 AD-Present) highlights flooding as a global issue, with a 35% increase in disasters over the past three decades. Contemporary Indian floods underscore the critical need for innovative flood protection measures driven by population growth, urbanization, technological progress, and human intervention in water systems.

In conclusion, the history of flooding events across the globe from the Middle Ages further accentuates this close relationship between rivers and cities. Floods, initially seen as advantageous to early civilizations for their role in enriching soils and supporting agriculture, have increasingly become phenomena societies seek to mitigate due to their destructive potential. The evolving dynamics of flooding show the urgent need for proactive flood defence measures and sustainable urban planning to address the complexities of climate change, population growth, and urbanization. Building resilient and adaptative strategies for the future becomes urgent as we move forward.

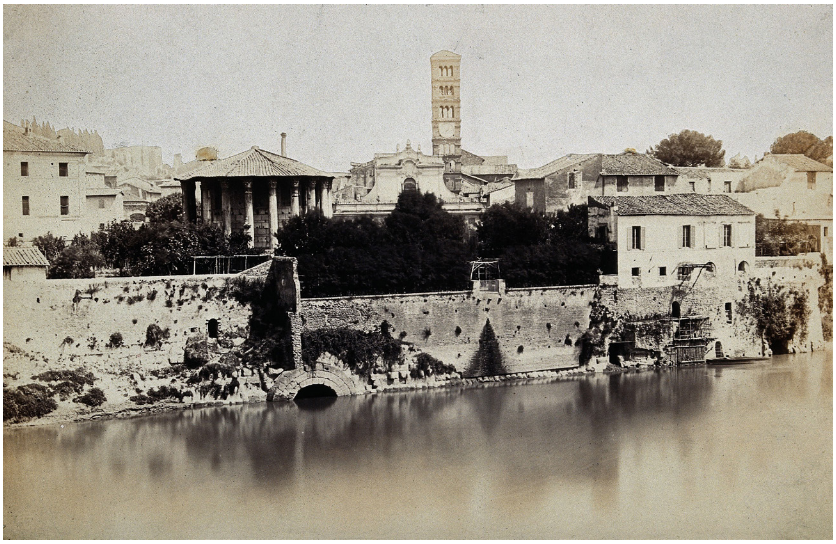
2. History of flood control infrastructures

Throughout history, flood defence strategies have evolved from traditional “grey infrastructures” or hard-engineered systems, such as seawalls, dikes, levees, and stormwater management, to more sustainable and nature-based solutions. This shift from single-function to multi-function measures is apparent in the move from hard-engineered systems to nature-based solutions, emphasizing sustainability, resilience, and climate change adaptation. While grey infrastructures allow standardization and reduced project costs, they necessitate ongoing maintenance and renovations. Global climate and socio-economic conditions have prompted a shift towards resilient, nature-based flood and water management developments.

The methods used to control river flooding were rudimentary and mainly dependent on topography. Simple earthen levees and dykes were built by communities to shield farms and settlements from flooding. The fact that these barriers were frequently built by the communities who benefited from them emphasizes a community-based approach to flood control. Weirs and dams were built for irrigation and milling during the Middle Ages, and these structures unintentionally functioned as flood control systems (Figures 6 & 7). Even though its primary purpose was to improve agriculture, these buildings also retained extra water during periods of heavy rain.

Figure 6

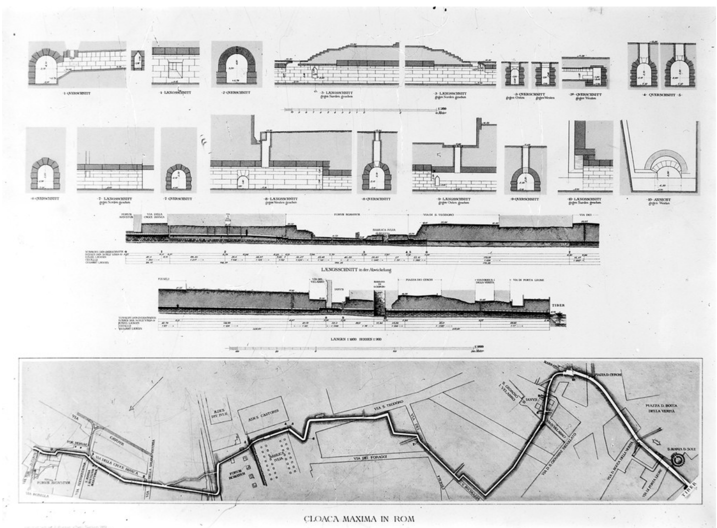
Ancient roman sewer, Cloaca Maxima



Note. Rome: view across the River Tiber, showing the Temple of Vesta and the campanile of S. Maria in Cosmedin, circa 1880-1910. Public Domain. Courtesy of the Wellcome Collection.

Figure 7

Ancient roman sewer, Cloaca Maxima



Note. From Wellcome collection, (n.d.). https://wellcomecollection.org/works/v78dw9qd

Roman engineers initially attempted to mitigate floods by building high embankments along rivers, but the inadequacy of these structures became apparent due to insufficient height. Centuriation, a Roman land division technique, aimed at fostering stable populations and improving agricultural production by guaranteeing water drainage. In medieval India, rulers constructed tanks, reservoirs, and canals for irrigation (Angelakis et al., 2023), highlighting the historical importance of water management.

One example is urban drainage; historical developments from integrated aqueducts in Ancient Rome to modern drainage systems have shaped flood control approaches. However, challenges arose during the Medieval Period in Rome as Tiber drains clogged, impacting flood defences.

The era preceding and including the Industrial Revolution witnessed a notable shift in approaches to river flood control. More advanced flood control systems were required because of technological breakthroughs and the growing complexity of developing urban areas. During this time, more robust materials like steel and concrete were used to build flood barriers and dykes, which provided more defence against the force of flooding. Additionally, the idea of “river channelization” surfaced, which refers to altering river courses to manage flow and drainage better, lowering the likelihood of flooding in nearby communities. Large-scale engineering projects, such as reservoirs and dams, could now be developed and implemented, enabling the control of river flow and storing surplus water at times of high rainfall.

In the 20th century, the construction of higher embankment walls along the river Tiber, reaching a height of 18 meters, emerged as a successful flood control measure. Egypt’s modern water infrastructure on the Nile, including barrages and the Aswan High Dam in 1960, effectively halted flooding and directed waters into the artificial reservoir of Nasser Lake. However, while reducing project costs and allowing for standardization, these grey infrastructures necessitated ongoing maintenance and renovations, highlighting the need for more sustainable approaches and those that will not cause harm to both fauna and flora.

Contemporary flood control measures have expanded to include a variety of methods, from vegetation planting and terracing to urban solutions like stormwater drains and permeable pavements. The “Sponge City” concept, mainly popularized in China, emphasizes ecological approaches to water management, aiming to hold, clean, and naturally drain water within urban environments (Xia et al., 2017). This shift towards integrating structural and non-structural approaches, evident since the 1990s, focuses on sustainable, nature-based solutions like wetland storage and floodplain reconnection. (ex of Dutch floodplain management)

Future flood infrastructures are geared towards resilience, sustainability, and multifunctionality. Nature-based solutions such as “building with nature” (BwN), “low impact development” (LID), and “green infrastructure” (GI) (Chiu et al., 2021) prioritize natural processes to manage flood risks. Initiatives like the “Room for the River” in the Netherlands exemplify this shift, moving from traditional complex structures to restoring ecosystem functions and increasing natural storage capacity.

In conclusion, the journey from ancient civilizations’ rudimentary flood defences to modern, innovative strategies shows a significant shift in flood defence methodologies. Today’s strategies are characterized by a blend of traditional knowledge and contemporary innovation, aiming to create adaptable and resilient communities in the face of environmental challenges. This evolution highlights the increasing adoption of green practices, such as rooftop gardens, sponge cities, reservoirs, and floodplains concepts, demonstrating a comprehensive approach to flood management that balances human needs with ecological sustainability.

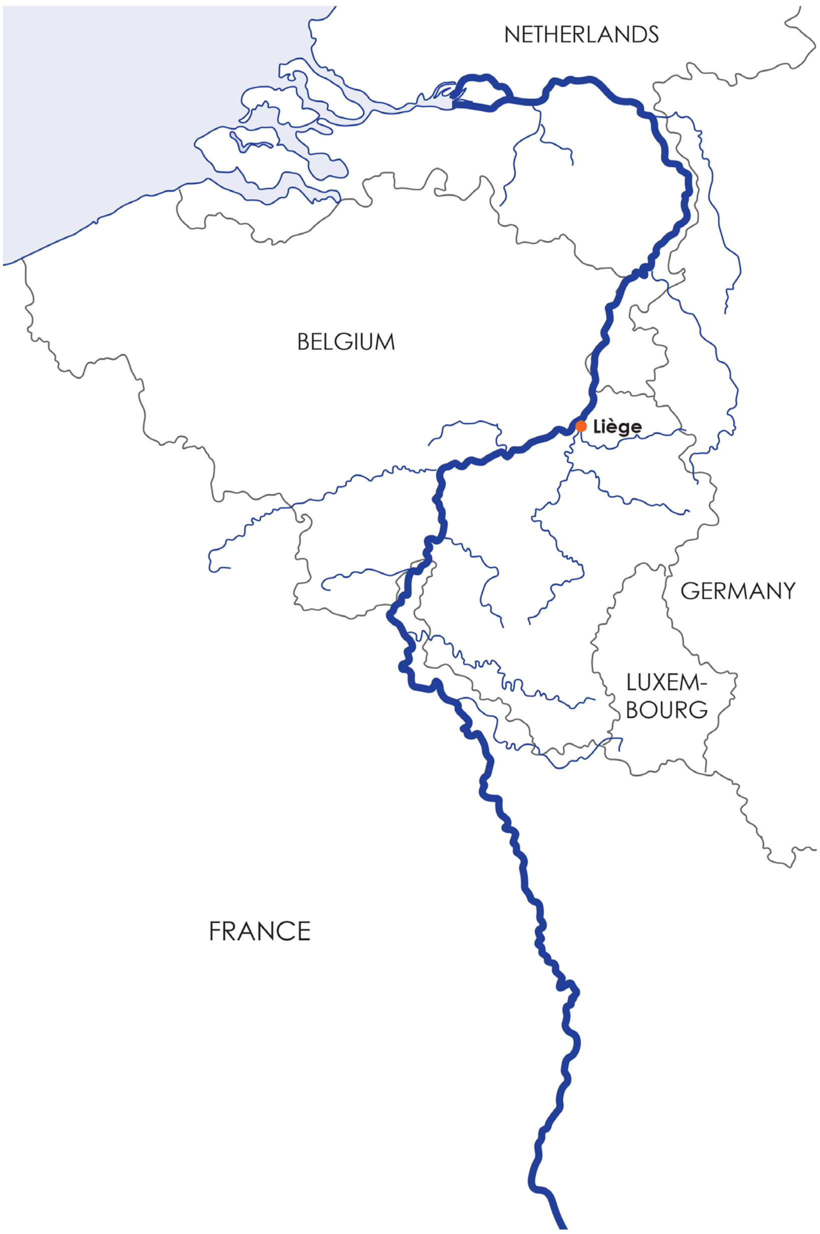
Part III: Physical transformation of La Meuse River

1. The historical importance of La Meuse River across France, Belgium, and the Netherlands

The Meuse River originates in Langres, France, and crosses Belgium and the Netherlands before merging with the Rhin and ending in the North Sea (Figure 8). It spans 900 km. Historically, the Meuse played a crucial role in the military, trade, economic, and cultural development of the regions it connected. Cities built around it depended on the river to utilize it to their advantage.

Figure 8

Meuse River crossing France, Belgium and the Netherlands



Note. Own work.

Serving as a vital water source for millions of people, the river basin covers about 56.4% of its territory dedicated to agricultural use. Moreover, its extensive network of waterways, totalling 330 kilometres of navigable routes (Bier, 2019), has facilitated trade and transportation throughout the region.

During the Middle Ages, the river played a significant role in the military. Strategically placed on the river, each settlement could control navigation. Cities would effectively control the river's traffic by building castles, bridges, and fortifications in strategic placement (Suttor, 1994). As the 15th century progressed, particularly into the 16th century, fortifications lining the banks of the Meuse facilitated the monitoring and control of passage along this vital waterway.

The Meuse River was essential to trade, facilitating the import of essential goods such as copper, tin, and wool from England, Mediterranean spices, and wine from neighbouring regions. Its navigability fostered the growth of industries reliant on heavy goods transportation, including brass production, metallurgy, and the early textile industry (Suttor, 2023). The river's influence extended beyond commerce, contributing significantly to the expansion of cities and their artisanal activities. Throughout the 12th and 13th centuries, urban centres in the valley continued to thrive, fueled by flourishing industries like textiles, metalwork, and iron mining, all of which relied on the river for transportation and trade.

The relationship between urban development and river infrastructure is exemplified by the cities along the Meuse basin, where the activities of affluent merchants drove substantial infrastructural advancements. These cities, driven by economic prosperity, saw the emergence of docks, bridges, and mills, highlighting their pivotal role within the region. Over time, the evolution of trade necessitated the development of various river structures, including towpaths, docks, quays, and levees, to facilitate transportation and commerce. Dating back to at least the 14th century, economic factors played a decisive role in the specialization of river ports, each catering to specific goods and markets.

Industrialization further transformed the landscape, with mills proliferating along the river's banks, strategically harnessing its hydraulic power for production (Suttor, 2023). The Meuse's proximity facilitated the transportation of essential raw materials such as wood, stone, and slate, which were crucial for construction. At the same time, the discovery of coal in the 12th century bolstered the region's industrial capabilities. This dynamic relationship between urban growth, industrialization, and river infrastructure has shaped the economic, social, and political fabric of cities connected with the Meuse river for centuries.

The Meuse River has been a fundamental feature of the region's geography since before the creation of cities. Its existence has greatly helped these areas, resulting in trade, increased connectivity between cities, and military and economic benefits. Despite the river's advantages, its route has changed over time.

2. River physical dynamics and its evolution

For centuries, human settlements around rivers have used these waterways for advancement and urban expansion. In the case of La Meuse, human influence has significantly transformed the river's character over the decades.

The current state of the river Meuse has undergone extensive regularization and canalization efforts, reflecting human intervention to manage its flow. Fluvial dynamics have led to minor geographical accidents such as erosion, sediment deposition, and lateral river course shifts (Suttor, 1989). However, human alterations, including canalization and other infrastructure developments, have disrupted the river's natural regime and flow patterns (ref diagram course evolution). These alterations have influenced Meuse's hydrological behaviour, impacting its water flow and overall ecosystem dynamics. Thus, while human interventions aimed to control and regulate the river for various purposes, they have also introduced changes affecting its natural processes and behaviour.

Among the cross-sectional profiles of the Meuse river, distinct features include: (ref diagram)
- The major bed, encompassing the entire alluvial plain, is susceptible to flooding.
- The minor bed or ordinary bed.
- The space between the banks. The low water bed housing the navigable channel.

While the major bed has remained unaltered during the historical period, significant changes have occurred in the current minor bed, especially when humans embarked on canalization and constructing artificial dikes along certain sections (Suttor, 1989). These modifications have considerably transformed the river's course. Furthermore, ongoing developments and adaptations continue to shape the river's morphology and dynamics in the present day.

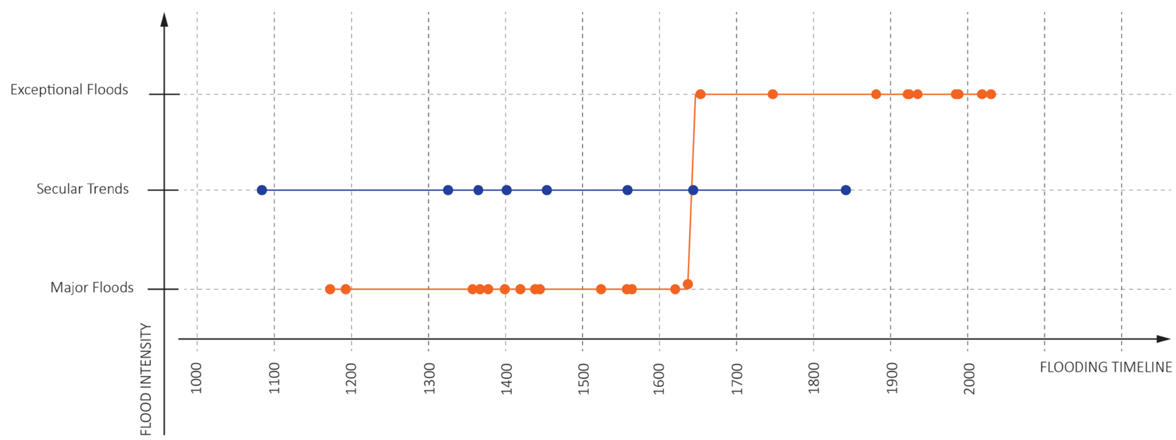
The Meuse river has undergone substantial physical alterations due to human intervention, inevitably impacting the surrounding land. Consequently, an increase in flooding occurrences within the region appears to be linked to the historical modifications made to the river.

3. Flooding timeline and evolution

Historical records and scholarly research indicate that flooding of the Meuse River has been documented since the early 12th century. Over the centuries, this region has witnessed significant flooding events, with a noticeable escalation in frequency and intensity beginning in the 15th century. (Figure 9).

Figure 9

Flood recurence of the Meuse river from Middle Age to modern time



Note. This graph shows both the dates and intensity of the Meuse river flood. We observed a shift from the 17th century when floods started to be more intense and more damaging. Own work.

Since the 16th century, human activities and the development of urban infrastructures have left the Meuse river vulnerable, stripping away its natural protection and leading to repeated floods. By the 18th century, the river faced more severe flooding due to its topography and climate change. Significant flood occurrences have marked the river's history, including those in 1947, 1983, 1993, 1995, 2001, 2006, and 2018. The Meuse basin, spanning France, Belgium, and the Netherlands, confronts flood vulnerability resulting from natural factors such as topography, hydrography, subterranean phenomena, and human activities like land use and development.

The January 1995 floods stand out as a poignant example. Multiple upstream and local floods culminated in unexpected water levels reaching 6.30 meters. The damages incurred from this event alone in the Ardennes department amounted to an estimated 225 million euros. This narrative underscores the importance of understanding the historical and cultural dimensions of flood risk associated with the Meuse basin, referencing organizations such as EPAMA and EPRI (Bier, 2019) for further insight and research.

Dedicated to sustainable water resource management, EPAMA was founded in 1995 and is primarily concerned with reducing flooding in the French portion of the Meuse River. This includes keeping and reviving aquatic habitats' biodiversity, which is essential. While concentrating mainly on the French portion of the river, EPAMA works with national and regional organizations in Belgium and the Netherlands, encouraging cross-border cooperation. Collectively, these nations create and carry out action plans to deal with the problems caused by climate change. Given that the Meuse River is a vital resource for about 9 million people who depend on it for cleanliness and proper operation, this cooperative approach is imperative.

In conclusion, there has been an increase in the frequency of floods along the Meuse River, primarily due to climate change. This phenomenon raises the risk of flooding by causing more rainfall and faster snowmelt. From the Middle Ages until the present, various urban infrastructure initiatives have been put in place to address these issues. Their goals have been to reduce the effects of floods and save populations that depend on the Meuse.

Part IV: Case Study of Liège

Figure 10

Meuse crossing Liège city in Belgium.

Note. Liège city and suburbs expanding on both side of the actual Meuse river couse. Own work.

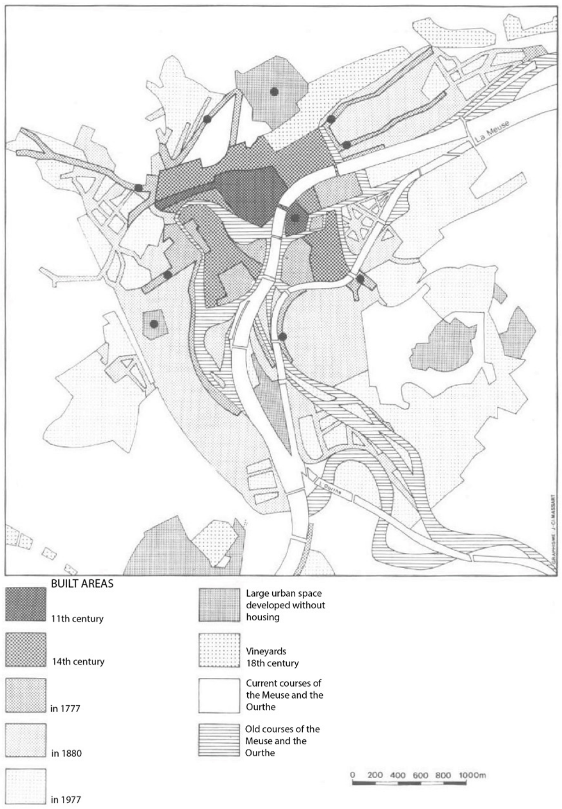
1. Liège urban development and relationship with the Meuse

Throughout the ages, Liège, a historic city in Wallonia, Belgium, has been an important hub for trade and culture. Since the 11th century, Liège has expanded on both sides of its river (Figure 11). During the Industrial Revolution, Liège prospered economically and became a central industrial hub, especially in the steel industry. During this period, essential structures were built that impacted the riverbank. The Meuse River flows directly through the city's heart, making it a central feature of its landscape. The city's development was closely linked to the river, influencing its economic prosperity and cultural exchange.

Liège, nestled along the left bank of the Meuse river, has been shaped by its strategic location within a vast floodplain, amplified by its confluence with the Ourthe River. This geographical setting, dating back to the Middle Ages, has provided the city with a unique topography characterized by a series of islands elevating certain areas (Figure 12), notably Place Saint-Lambert, above the river level. With limited natural defences (flat land), Liège's survival has long depended on its relationship with the Meuse, which has served as a vital artery for trade and commerce.

Figure 11

Liège's land use evolution



Note. From *Mérenne-Schoumaker, B., & Massart, J.-C. (1994). Évolution de l'espace bâti de Liège, du Xe siècle à nos jours [Map].* Modified by Camille Pollet.

The river Meuse has been integral to Liège's economic and social development throughout history. From the 12th century onwards, the city's prosperity was closely tied to the exploitation of coal and ore, facilitated by the Meuse's navigable waters. This economic growth was further fuelled by the city's strategic location at the Meuse and the Ourthe confluence, fostering trade with neighbouring regions and beyond.

However, the city's reliance on the river also posed challenges, particularly regarding sanitation and public health. In the 19th century, rapid industrialization and population growth exacerbated these issues, leading to outbreaks of diseases such as cholera and typhoid. These difficulties were made worse by the Meuse and its tributaries' deterioration, which turned them into open sewers and restricted the city's development despite economic gains.

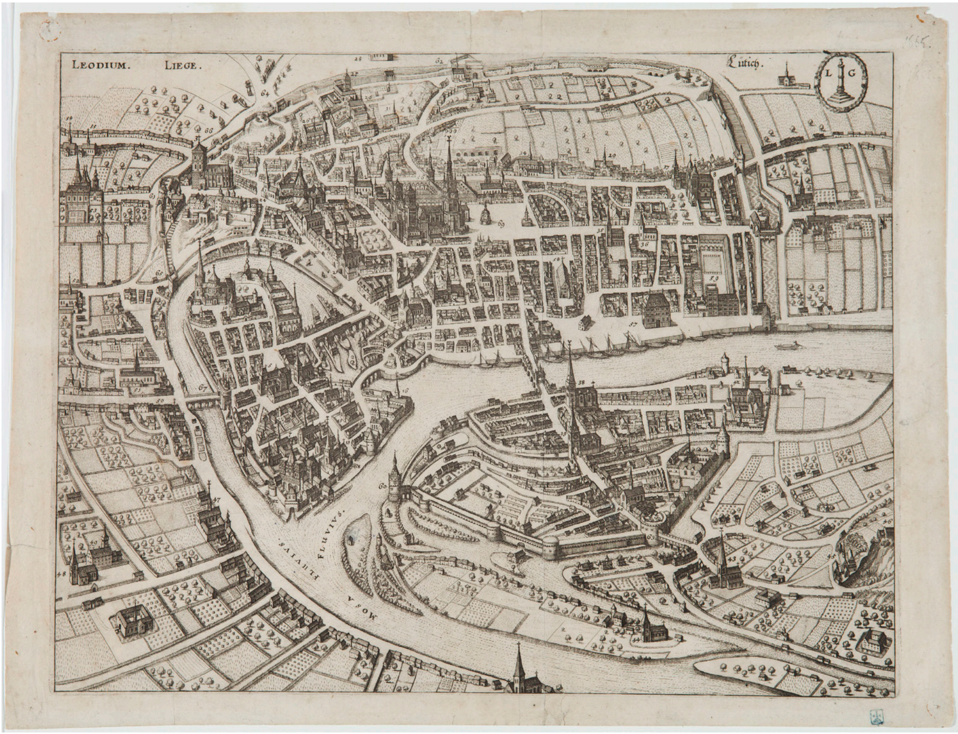
Efforts to address these issues began in the mid-19th century, with urban renewal projects aimed at improving sanitation, enhancing circulation, and improving the city's waterfront areas. The construction of quays and embankments along the Meuse, with the introduction of steamboat navigation and the development of a fluvial port, transformed the river into a bustling hub of activity, linking Liège to regional and international markets.

The early 20th century saw further transformations along the Meuse, with the hosting of international exhibitions showcasing the city's connection to water and its industrial prowess, like the one held in 1939. The exhibition was held to celebrate the construction of Canal

Albert, which provided a direct link between Liège and the port of Antwerp, strengthening the city's economic significance and further integrating it into the European trade network.

Figure 12

View of Liège in 17th century



Note. This image depicts a 17th-century view of Liège, drawn by Mathieu Merian in 1647.
Courtesy of the Cabinet des Estampes de la Ville de Liège and KIK-IRPA, Brussels.
Copyright Cabinet des Estampes de la Ville de Liège.
Copyright KIK-IRPA, Brussels.

However, the latter half of the 20th century brought about significant changes in urban planning priorities, driven by the rise of the automobile and modernist ideals, and this period witnessed the construction of highways and urban expressways that disrupted the historical connection between the city and the Meuse, prioritizing vehicular traffic over pedestrian access. Roads for vehicles were established along the banks of the Meuse, resulting in the construction of elevated riverbanks for safety reasons. Consequently, they obstructed the view for people to see the Meuse. (State Archives of Liège, 2012).

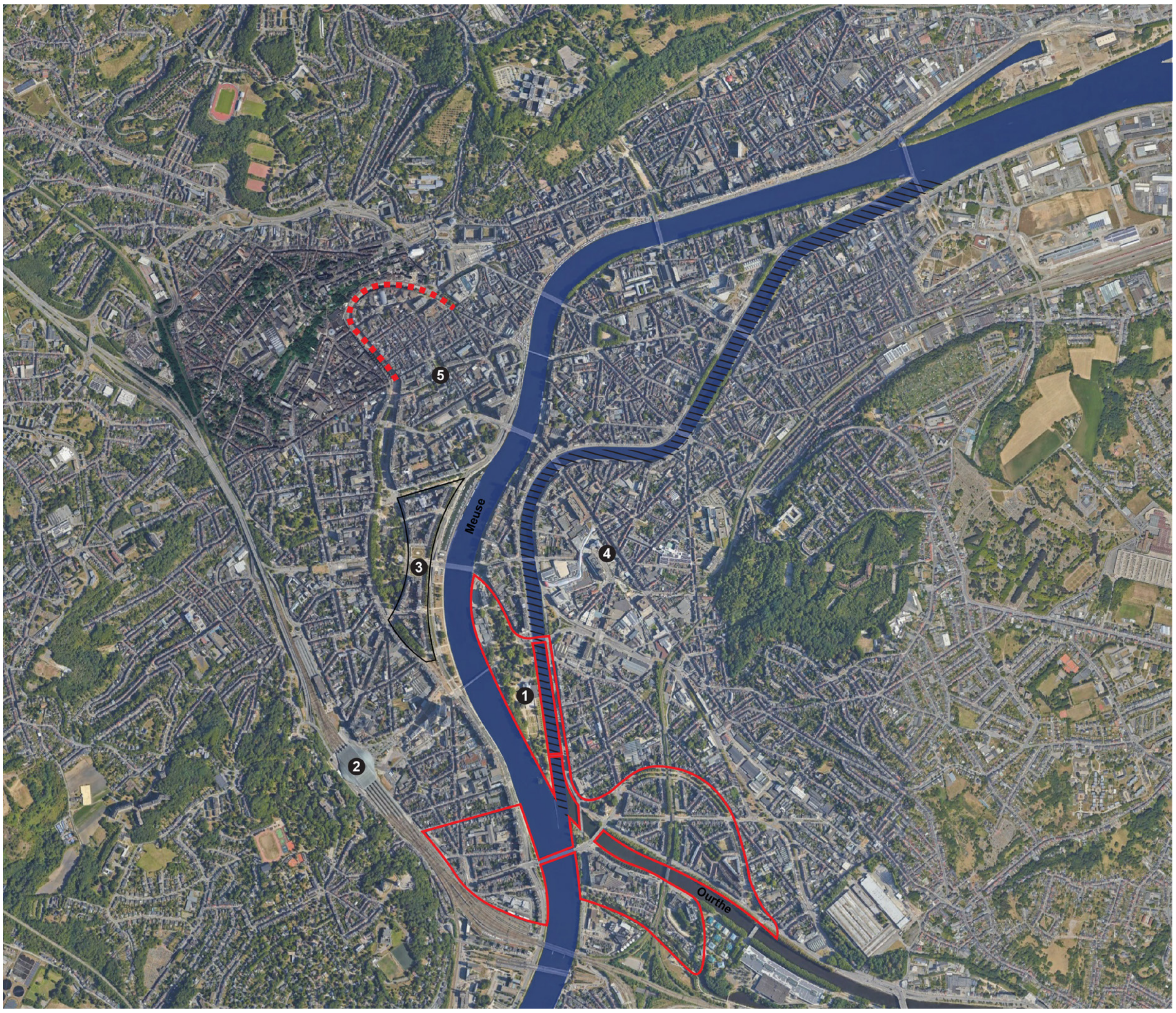
Recently, a renewed focus has been on revitalizing Liège's waterfront and restoring its relationship with the Meuse. Projects aimed to enhance accessibility, such as the construction of footbridges, riverside promenades, and bicycle lanes, seek to reconnect the city with its riverine heritage while promoting sustainable modes of transportation. Additionally, initiatives to improve the visibility and accessibility of the river, including removing concrete parapets, aim to reintegrate the Meuse into Liège's urban fabric, ensuring that it remains a central feature of the city's identity and landscape for generations to come. Indeed, the connection between Liège and the Meuse River has been restored, but it appears to focus primarily on pedestrian accessibility rather than the river's ecological health.

2. Modification of the Liege’s course and riverbank

The evolution of Liège’s riverbanks from their natural state during the Middle Ages to today’s planned, artificial landscapes shows the city’s progressive attitude toward industrial development and urban planning. This transition has occurred in multiple phases, each distinguished by notable adjustments that have radically changed how the city interacts with the Meuse River. Originally, Liège was situated on an alluvial plain, with the land sitting 7 meters above the river, making it prone to frequent flooding since its early development (DEMOLIN, et al., 2017).

Figure 13

Liège city, important landmarks and transformation



1 Boverie Parc

2 Guillemins railway Station

3 Commerce Island (now Parc d’Avroy)

4 Londoz railway Station (close in 1960)

5 Saint Paul Cathedral

6 Waterfront revitalisation (mention date)

Sauveniere river filled in the 19th Today is Sauveniere boulevard

The Meuse river

Derivation Canal

1905 Exhibition

Note. Own work.

Before the Middle Ages, the riverbanks were natural inclinations created by the river's natural erosion. Early attempts to alter the natural terrain to suit urban and economic purposes were reflected in the efforts to change the river's path when the city entered the medieval era and make it easier for boats to navigate. By the seventeenth century, these initiatives had spread to include the development of quays, the infilling of river branches, the building of new roadways, and the creation of landing spots where boats could discharge their goods (Suttor, 2016).

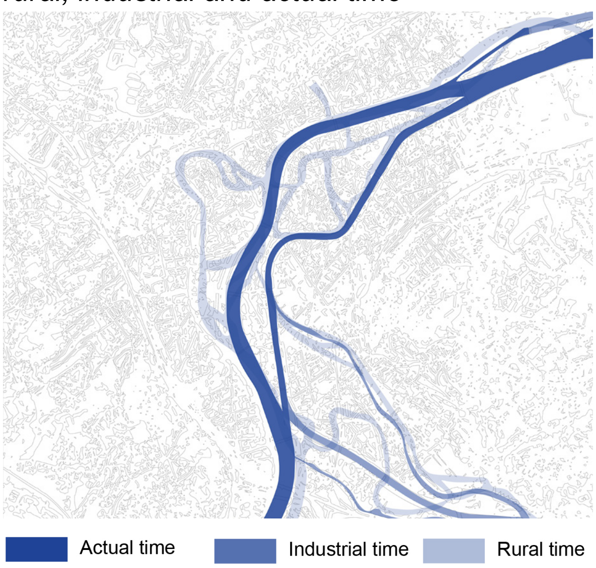
Hydraulic engineering grew in the late 19th century and was vital to Liège's industrial development, especially in the steel industry. The construction of quays by channelling the Sauvenière River (Figure 13) highlighted the city's reliance on the river for economic development. Furthermore, the Dérivation canal's construction and the Meuse's straightening between Île Colette and the Boverie bridge greatly expanded development opportunities, accelerating urbanization and industrialization.

Motivated by intentions related to the 1905 exposition, the canalization of the Meuse proceeded until the early 20th century (Figure 13). Later decisions on urban planning, such as the construction of fast highways along the quays, have worsened traffic and weakened the city's relationship with the river. In response, the city started the "Liège retrouve son fleuve" (State Archives of Liège, 2012) program in the middle of the 1990s ("Liège finds its river again") to reduce the number of cars on the city's waterfront and increase pedestrian accessibility. Though the right bank was initially prioritized, the left bank also received significant changes that improved the urban landscape.

Overall, the transformation of Meuse's course (Figure 14) and riverbanks from a simple agricultural area to the complex urban framework of today demonstrates notable changes brought about by the demands of fluvial traffic and economic growth. Urban development and preservation of historical and environmental integrity are being balanced, as evidenced by the recent attempts to revitalize the waterfront and prioritize pedestrian areas. The city's link with the Meuse River continues to be a fundamental part of Liège's urban identity as it develops.

Figure 14

Evolution of the Meuse river course from rural, industrial and actual time



Note. Own work.

The following figures (15, 16, 17, 18, 19 and 20) shows the evolution and transformation of Liege’s riverbanks from Middle Age to now.

Figure 15

Liège riverbanks in 1822

Note. This image, “Quai des Tanneurs et Pont des Arches, 1822,” captures a historical view of the Liège riverbanks as they appeared in 1822.
Copyright 1822 by Musée Wittert, ULiège.

Figure 16

Liège riverbanks quays

Note. This image, “Quai de l’Ourthe, Liège,” presents a view of the Quai de l’Ourthe in Liège.
Copyright by Province de Liège-Musée de la Vie wallonne.

Figure 17

Liège riverbanks around 1880 - 1890

Note. This image, “Chargement d’un bateau sur la Meuse près de la passerelle de la Régence,” taken between 1880 and 1890, shows the quays on the Meuse river.
Copyright by Province de Liège-Musée de la Vie wallonne.

Figure 18

Locks and docks on the Albert Canal at Île Monsin in Liège

Note. This archival image captures the construction of locks and docks on the Albert Canal at Île Monsin in Liège, dated March 27, 1935. The photograph highlights a significant phase in the canal’s development. Available at the Archives Wallonie online collection.
Copyright 1935 by the Service des Archives régionales

Figure 19

Liège riverbanks in 1963

Note. This image shows the road for automobilists directly connected to the Meuse river.

Figure 20

Liège riverbanks in 2014

Note. This image shows “Aménagement des quais de Meuse,” a project completed in 2014 by architect BE Greisch, along with Canevas, Atelier du Sart-Tilman, Transitec, and landscape work by Atelier Corajoud.

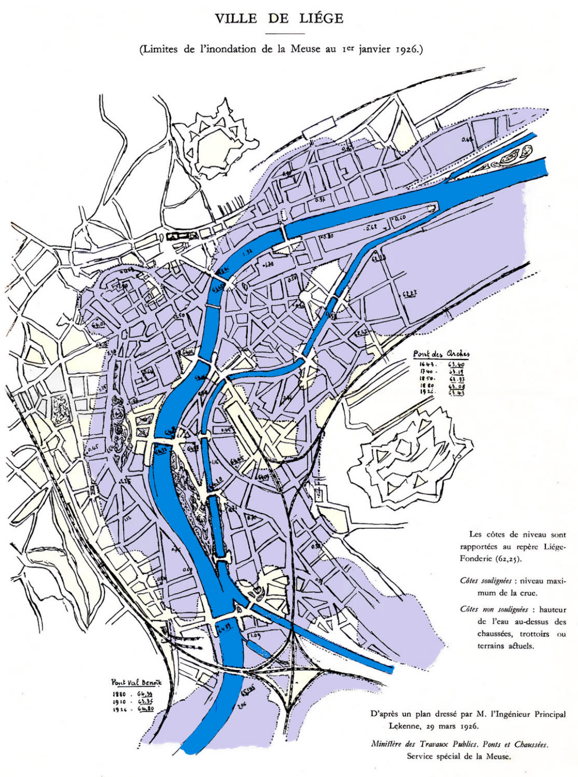
3. Flooding events of the city

In Liège, flooding has been a significant concern throughout history. Devastating events leave lasting impacts on the cities and their inhabitants. Despite efforts to mitigate flood risks, severe inundations have persisted.

One of the most notable flooding events occurred in Liège during December 1925 and January 1926 (Figure 21, 22). Intense and prolonged rainfall caused the Meuse and its tributaries like the Ourthe and Vesdre swell rapidly, surpassing previous flood records. The catastrophic flooding left over one-third of Liège submerged, devastating quays, streets, and boulevards, affecting approximately 35,000 homes. The disaster highlighted the vulnerability of the densely urbanized and industrialized floodplain. The social, economic, and political ramifications underscored the urgent need for enhanced flood management infrastructure.

Figure 21

Liège 1926 flood extend



Note. This historical map titled “Limites de l’inondation de la Meuse au 1er janvier 1926,” was drafted by Engineer Principal Lekenne and is dated March 29, 1926. It illustrates the extent of flooding along the Meuse River in the city of Liège.

Figure 22

Liège flood in 1926

Note. This image shows the catastrophic flood of 1926 in Liège.
Copyright 1926 by Archives de la Ville de Liège.

Figure 23

Liège flood in 1926

Note. Marks on the church of Seraing indicating some floods of the Meuse. From “Les inondations de Liège de 1926” by J.-P. Keimeul, 1926 (p. 2), published by IHOES (Institut d’histoire ouvrière, économique et sociale) à Seraing.
Copyright 1926 by AIDE (Association intercommunale pour le démergement et l’épuration de la Province de Liège)

This disaster prompted a renewed urgency for flood control measures and highlighted the importance of canalization projects along the Meuse. It served as a stark reminder of the ongoing threat posed by the river's unpredictable behaviour, emphasizing the need for continued investment in flood protection and urban planning strategies to safeguard against future inundations.

3. Flooding Infrastructures

This chapter explores the historical evolution of flood management strategies and infrastructure from the Middle Ages to the present day. The development of urban flood infrastructure reflects technological advancements across various eras and the evolving methodologies to mitigate flood risks. Throughout history, we can identify distinct categories of flood-related infrastructure that have emerged in response to these challenges. The journey begins with early, indirect modifications to waterways, such as the Meuse, aimed at reducing the frequency and severity of floods. This was followed by constructing physical barriers specifically designed to restrain floodwaters. Later, there came the development of specialized infrastructure for water storage. The urban infrastructures discussed here encompass all the urban developments constructed to minimize the damage from flood events.

- Middle ages to 17th century: Early Effort

Liège's approach to flood control dates back to the Middle Ages. Engineering knowledge was minimal, and technology was primitive at the time. Fortifications were a common feature of urban constructions, mostly made of stone and brick and unintentionally offered some protection from flooding. A noteworthy initial intervention occurred in 972 under Bishop Notger, who modified multiple Meuse River branches . This alteration, which made the riverbeds where contemporary boulevards like Piercot and Avroy sit deeper, was made to keep floods from destroying the city, as they had done in the disastrous flood of 858.

- 19th century: Industrialization and Urban Expansion

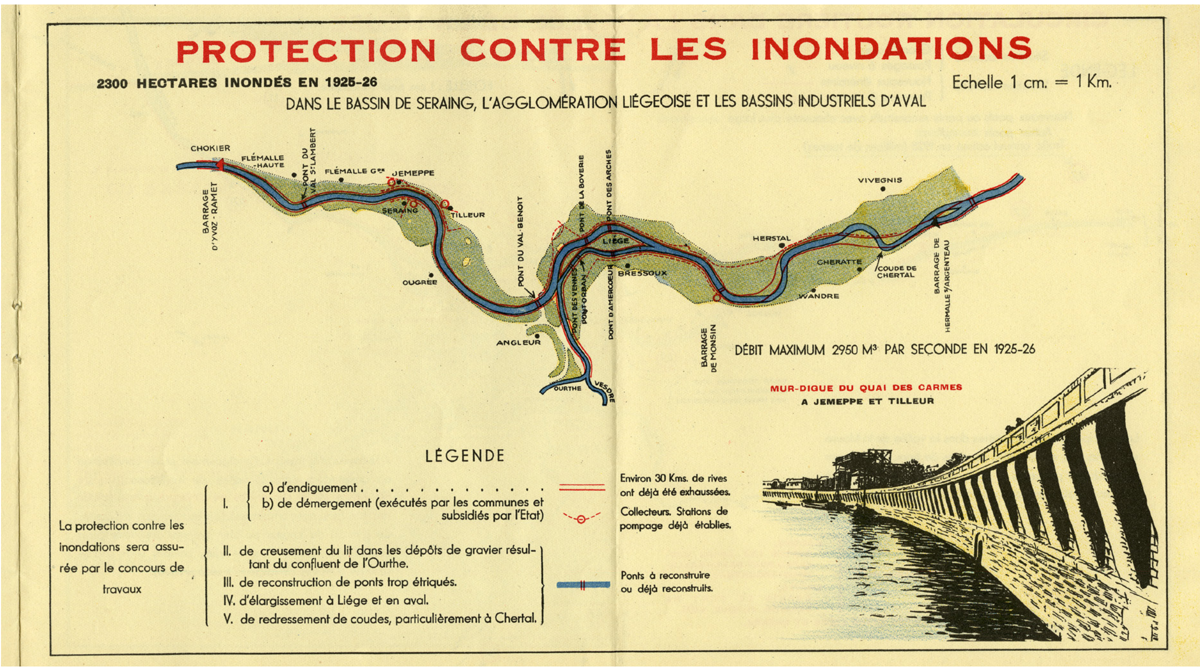
The mid-19th century marked the foundations of modern flood management in the city's urban planning history. Ulric-Nicolas Kümmer, an engineer, influenced Liège's perspective on river transportation and flood control. Kümmer suggested straightening the Meuse and building quays and embankments between 1852 and 1863 to facilitate navigation and prevent flooding. During this time, the Derivation, a parallel canal that addressed pollution and sickness, was also built, eliminating several of the Ourthe's arms in the Outremeuse area (State Archives of Liège, 2012) . The first pumping station was inaugurated in 1880. It is regarded as a "systeme demergement" (Herry, 1928) that the Cockerill society established. This system assists in resolving the enormous surface subsidence produced by coal mining in the Liège region, which locally exceeded six meters due to the non-filling of mined veins. This has resulted in well-known "mining damage" and increased susceptibility of the alluvial plain to floods, even to the Meuse's low water level.

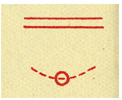
- 20th century: Modern Engineering solution

The 20th century witnessed substantial advancements in flood management infrastructure in Liège, driven by a series of devastating floods, particularly those in 1925-1926, which laid bare the inadequacies of existing defenses. In response, Liège embarked on a comprehensive flood protection initiative, starting with the construction of the first modern pipelines in 1928, followed by an extensive network of 42 pumping stations established throughout the

Figure 24

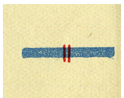
Mosin bridge-dam in Liège in 1934





Approximately 30kms of banks have alread been raised

Collectors. Pumping stations alread established



Bridges to be rebuilt or already rebuilt

Note. This document, titled “Protection contre les inondations,” is an excerpt from the “Programme d’aménagement de la Meuse liégeoise,” which outlines flood management strategies along the Meuse river in Liège. Copyright 1930 by Province de Liège-Musée de la Vie wallonne.

In 1930 a large project with the goal to protect Liege form flooding as been implemented. Including 30kms of riverbanks have been raised, bridges to be rebuilt or already rebuilt, pumping station, containment and demergemenent (Figure24). However we can see that some interventions that are heavily impacting the biodiversity does not consider futures consequences.

The construction of notable dams, such as the Monsin dam (Figure 25), built by Joseph Moutschen and inaugurated in 1930 downstream of Liège, marked this era’s architectural and engineering achievements. In addition to replacing several older locks, this structure was vital to the 1930 International Exposition. In addition, Ivoz-Ramet Dam started operating in 1938, Eupen dam was built in 1950 and Lixhe Dam was finished by 1980. These dams were positioned to maximize energy production and flood control. They were outfitted with hydroelectric power units.

The International Commission on Large Dams (Spw, 2024) . has acknowledged 15 important dams in Wallonia, including Liège. These include structures taller than fifteen meters high or ranging from five to fifteen meters and holding more than three million cubic meters of water, such as the dams at Robertville, Bütgenbach, Coo, Gileppe, and Vesdre.

In 1950 barrage d’Eupen significant impact on flood protection, located outside Liege
The Agency for Infrastructure Development in Eastern Belgium (AIDE) stated that pumping

stations alone could not stop floods, even with these improvements. This led to the need for additional research into their efficacy and a strategy for managing floods as a whole. With a strategy that targets the effects rather than the causes of these catastrophes, AIDE's continuous efforts have been concentrated on shielding the alluvial plains from the indirect floods caused by the Meuse.

Figure 25

Mosin bridge-dam in Liège in 1935

Note. This archival image shows the dam on the Meuse at Île Monsin in Liège, captured on July 18, 1934. The image is available in the Archives Wallonie online collection.

- Late 20th to 21st century: Integrated Water Resources Management

Liège implemented Integrated Water Resources Management (IWRM) techniques, emphasizing a holistic approach to water resources in the face of increasing urbanization pressures. Innovative land utilization for flood management has become necessary due to the expansion of urban areas. Flood control structures are built on expansive, grassy sites if possible. Unfortunately, the availability of such sites is frequently limited by the ongoing urban growth, which makes the installation of underground stormwater storage facilities (Girardot & Thronier, 2003) inevitable. These subsurface systems are essential in densely inhabited locations, where surface options are limited and exposed installations pose substantial logistical issues and possible nuisance.

Specific strategic locations within Liège's urban landscape are essential to the city's water infiltration and storage plan, especially during periods of high precipitation. For example, the Parc d'Avroy (1 in Figure 26), which functions as a natural sponge to absorb and temporarily store excess rainwater, is essential to the management of pluvial water. In a similar vein, the residential neighbourhood known as "Les Terrasses" (2 in Figure 26) has been carefully planned with elevation considerations to reduce the possibility of Meuse River overflow.

GreenSurf's Rain Garden at Gembloux Agro-Bio Tech ULiège, which opened in 2020 (Figure 27), is a significant addition to Liège's green infrastructure. This location, which combines delayed water release, storage, infiltration, and evaporation mechanisms, is an excellent example of a multifunctional approach to water management. The garden provides recreational and educational benefits in addition to its hydrological roles. It also acts as a habitat for the local species (Green Surf, 2023) . Liège's dedication to sustainable urban planning and flood resilience is demonstrated by how utility and aesthetics are integrated into urban design. This shows a thorough awareness of the potential and challenges associated with urban water management.

Figure 26

Key location plan

1 Boverie Parc
2 Commerce Island

Note. Own Work.

Figure 27

Rain garden in Liège

Note. This image features the WASABI rain garden, a functional structure designed for open-air courses starting in spring. The rain garden showcases sustainable urban drainage systems in practice.
Copyright 2022 by Baudoin Adrien srl.

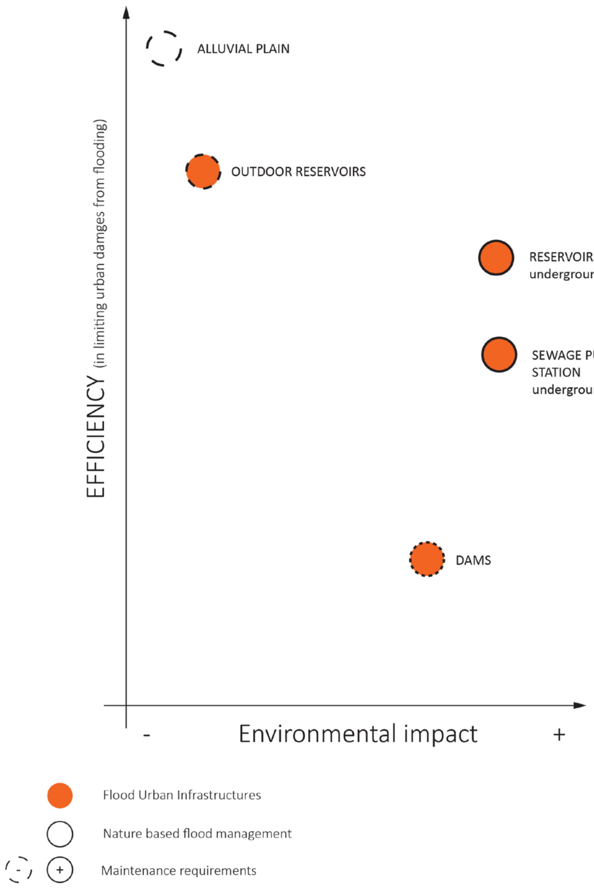
Liège has a long history of flood management through technological developments and strategic planning. From Middle Ages to the 20th century, the city has improved its flood resilience. Recently, the focus has shifted towards sustainable, nature-based solutions and integrated water resource management.

4. Existing urban infrastructures efficiency

Examples of Liège's urban infrastructure designed to resist flooding are pumping stations and dams. However, they need much maintenance and do not seem to minimize flood damage very well. Natural flood control techniques, such as rain gardens and alluvial plains, are far more successful. Once established and requiring less maintenance, these natural infrastructures provide a more sustainable and efficient means of reducing the area's risk of flooding (see Figure 28).

Figure 28

Liège's flood management startegies analsis



Note. Own work.

When considering the evolution of flood control infrastructure, it is evident that shifts in public perceptions and environmental consciousness have followed technological advancements. Early flood control infrastructure was rudimentary and unaccountable for environmental effects. The frequent construction of structures next to or immediately on top of water sources compromised the area's biodiversity. These early attempts could not resist the force of nature, even though reducing floods was urgent. They needed to understand the relationships between ecosystems and water better.

Engineered materials replaced locally produced materials as technology improved, emphasizing the reinforcement of flood barriers. However, this strategy tends to erect stronger, more substantial barriers without considering the environment. When cities move into flood-prone areas without adequate resilience planning, the issue gets worse.

Every year, more floods occur, and climate change has made it increasingly evident that one cannot control the forces of nature. This insight has changed the conversation to support more resilient tactics that cooperate with rather than oppose natural processes. Ecologically conscious solutions rooted in nature prioritize ecosystem health, biodiversity, and resilience.

Communities will be more capable of handling the flood management issues of today if they adopt a comprehensive strategy and combine traditional knowledge with modern technological methods. It is possible to create an inclusive flood infrastructure by giving priority to nature-based solutions and resilience. This will ensure that the solution meets the needs of current and future generations while protecting natural ecosystems.

Part V: Future Solutions - Utilizing the river within the city

1. Defining controlled and integrated flooding urban infrastructures

In the contemporary context of urban planning and climate change mitigation, there is a notable shift towards integrated urban flood infrastructure, reflecting a better understanding of its advantages over traditional controlled systems. This transition recognises the limitations of structures such as dams and dykes, while acknowledging the benefits of integrating natural hydrological processes into urban development.

Controlled infrastructures, such as dams and dykes, have always been favoured because of their immediate effectiveness in preventing flooding. However, their use often has significant ecological and societal consequences. These structures can disrupt aquatic ecosystems and natural water cycles and hinder the adaptability of hydrological systems to changing environmental conditions. Moreover, doubts have arisen about their long-term suitability in climate change, as they may not be equipped to cope with increasingly frequent and intense extreme weather events.

The traditional technical approach to flood risk management is evolving towards an integrated approach that combines several disciplines (Rijke et al., 2012). Integrated urban flood infrastructure offers a more sustainable and flexible approach to flood management, restoring ecosystem functioning (Chiu et al., 2021). These systems aim to mimic natural water cycles, aligning with rather than opposing nature. For example, creating wetlands and green spaces in urban areas serves multiple purposes: it provides a habitat for flora and fauna, offers recreational areas for the public, reduces runoff and relieves pressure on drainage systems. This approach considers the broader implications of urban development on water systems, striving to create cities that are more pleasant to live in and more resilient to environmental change.

However, certain aspects of integrated urban flood control infrastructure require particular attention. One such aspect is the need to find solutions to deal with the uncertainties associated with climate change. Integrated systems must adapt to changing environmental conditions and increased flood risk. Another aspect is to find the physical space to implement such infrastructure, as we are now looking into already densely built areas. In addition, it can be challenging to balance the multiple functions of integrated infrastructure, such as ensuring that green spaces designed to mitigate flooding also provide recreational and ecological benefits.

In conclusion, the shift from controlled to integrated urban flood infrastructure represents a paradigm shift towards more sustainable and holistic approaches to flood management and improving rivers to return to a more natural state (Blau et al., 2018). By adopting principles such as creating space for rivers, promoting flexibility and adaptability, considering ecosystem health and biodiversity, engaging communities in planning processes and addressing emerging challenges, cities can better navigate the complexities of urban flooding in an era of climate change.

2. Case Study of worldwide existing resilient flood urban infrastructures

The shift toward integrated flood management infrastructures is increasingly recognized globally. Numerous studies and real-world applications demonstrate their effectiveness and resilience. Cities worldwide are adopting holistic approaches to flood management, preparing for the intensity and patterns of future flood events with innovative, sustainable solutions.

In the Netherlands, a pioneer in flood management due to its unique geographical challenges of being below sea level, strategies such as widening rivers and creating floodplains are prevalent. These measures enhance the natural capacity of the landscape to create more space for rivers to discharge their flow. Additionally, multifunctional infrastructures such as the Water Square (Figure 29) exemplify innovative design in urban settings like Rotterdam. This sunken outdoor amphitheatre doubles as a reservoir during heavy rainfall (Figure 30), blending utility with urban aesthetic and recreational value.

Figure 29

Water Square in rotterdam

Note. Aerial view of a mix use outdoor infrastructure built in 2013 as an event place and stormwater storage. From Watersquare Benthemplein, by O. V. Duivenbode, 2013, DE URBANISTEN (https://www.urbanisten.nl/work/benthemplein).

Figure 30

Water Square filled with rainwater

Note. View when the square is fill with rain water. From Watersquare Benthemplein, by D. Urbanisten, 2013, DE URBANISTEN (https://www.urbanisten.nl/work/benthemplein).

Similarly, the Sponge City initiative in China leverages ecological principles to absorb, store, and reuse rainwater by upgrading traditional drainage systems using more food-resilient infrastructures (Chan et al., 2018). It mitigates the effects of heavy rainfall by integrating permeable materials and green infrastructure throughout urban areas. This approach reduces flood risk and enhances urban greenery and water efficiency.

European cities like Namur have also incorporated resilience into urban planning by designing multifunctional structures such as underground parking garages that serve as temporary water storage areas during floods. This dual-purpose strategy effectively utilizes urban space while enhancing flood preparedness.

Furthermore, cities like Amsterdam and Seoul are revisiting and restoring channelized rivers to their natural states, recognizing the benefits of allowing rivers more room. This reduces flood risks, restores natural habitats, and improves the environmental quality of urban areas.

To conclude, the emphasis on integrated urban flood infrastructures aligns with broader global sustainability and resilience goals. By planning and developing in ecologically sound, socially beneficial, and economically viable ways, cities are setting a forward-thinking course. This approach acknowledges the need for adaptive, resilient urban water management systems that effectively address both current and anticipated future challenges, ensuring sustainable urban environments in the face of climate change.

3. Liège potential future solution

Liège has the opportunity to develop more resilient urban infrastructure, drawing on historical techniques and modern examples already in use, such as those in the Netherlands. While the city faces the challenge of implementing solutions in a dense urban fabric where large-scale options such as alluvial plains are unfeasible, it can turn to small, innovative, low-maintenance, nature-based solutions (Figure 31).

Figure 31

Liege's potentiel site for resilient green flood infrastructure

1 Boverie Parc
2 Guillemins railway Station
3 Parc d'Avroy
4 Londoz railway Station (close in 1960)
5 Saint Paul Cathedral
6 Waterfront revitalisation (mention date)

Potential Implementations
Rain Garden
Resilient Urban plaza

Sauveniere river comblee au 19e
Now is Sauveniere boulevard
The Meuse river
Derivation Canal

Note. Own Work.

One plausible strategy is to modify existing parks to fulfil several functions, such as creating rain gardens. Avroy Park, which has been used effectively as a retention area, is one example. Another technique would be to design multi-purpose spaces, such as Rotterdam's Water Square, combining public spaces with rainwater reservoirs. These methods can form part of an overall system of decentralized rainwater management rather than isolated interventions. A dispersed strategy of this kind could ease the pressure on existing dams, which are expected to stop flooding and provide a more comprehensive flood protection system.

Although these urban changes are long-term projects, Liège must urgently mitigate the impact of flooding through innovative and resilient infrastructure. It is not just about protecting the urban landscape but also about adapting it to future environmental challenges.

Part VII: Conclusion

Urban growth has always been based on the dynamic interaction between cities and waterways. In the Middle Ages, rivers were initially the lifeblood of communities, supplying necessary resources for survival and expansion. The area was rich in agricultural land and provided natural defences due to its proximity to streams. But as the industrial age progressed, pollution and exploitation strained this relationship, changing the river's path and causing major alterations to the riverbanks, as demonstrated in Liège.

Since the Middle Ages, urban infrastructures have undergone a significant transformation. They have replaced natural flood barriers designed to contain and regulate rivers inside the urban landscape. According to our research, there was a shift from crude techniques using locally available materials to industrialized dam and dike building and, more recently, creative, resilient solutions in response to rising floods and climate change.

Liège's historical growth on an alluvial plain presents unique issues because of the city's natural vulnerability to water. The city's conventional tactics, which were mainly centred on building dams and dykes to prevent flooding, especially downstream of the Meuse, have shown to be unable to combat the escalating frequency and intensity of flood events. After realising these limitations, Liège has started looking at more environmentally friendly and sustainable flood control options. The city wants to disperse the burden of flood control by including smaller, decentralized facilities like rain gardens, retention parks, and stormwater reservoirs, which will relieve pressure on the current dams and dykes.

Though progressive, it is acknowledged that these actions fall short of meeting the demands of the river itself. With visually beautiful pedestrian quays, modern tactics frequently prioritize human well-being. However, ecological factors like the health and biodiversity of the river might occasionally take priority.

There is a growing trend away from concentrating only on flood prevention and toward integrating flood tolerance into urban planning as communities like Liège work to make peace with their rivers. This strategy calls for creative problem-solving and robust, natural solutions. In this shift, the roles of engineers, architects, and urban designers are vital. In densely populated places, they must assess and pinpoint options for installing infrastructure that allows human activity while honouring the river's natural cycles.

Long-term planning must precede quick repairs for urban landscapes to be resilient and sustainable. The transformation of Liège into a river-friendly city symbolises the more significant need for cities to adjust to the effects of climate change and realize that living in harmony with nature frequently produces better outcomes than trying to control it. In conclusion, cities can create a resilient future ready for the inescapable difficulties brought on by a changing climate by adopting a philosophy that balances urban expansion with the natural environment.

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