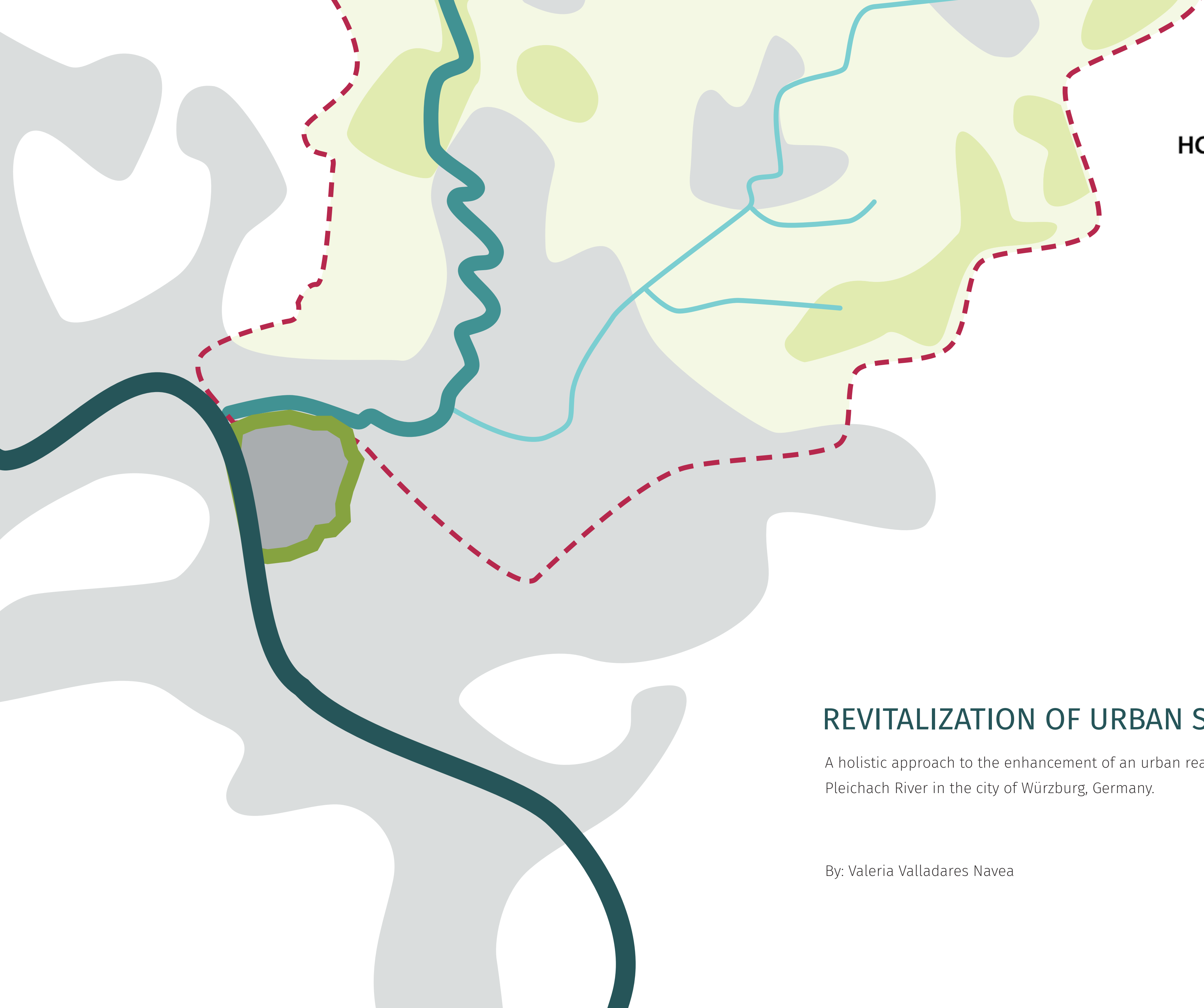


HafenCity Universität Hamburg

REVITALIZATION OF URBAN STREAMS

A holistic approach to the enhancement of an urban reach of the Pleichach River in the city of Würzburg, Germany.

By: Valeria Valladares Navea

A thesis presented to the Hafen City Universität Hamburg in partial fulfillment
of the requirements for the degree of:

MASTER OF SCIENCE IN RESOURCE EFFICIENCY IN ARCHITECTURE AND PLANNING

First Advisor: Prof. Dr.-Ing. Wolfgang Dickhaut

Second Advisor: Diplom-Ing. Katrin Mauer

DECLARATION OF AUTHORSHIP

I, Valeria Valladares Navea, hereby declare that I have written this thesis without any help from others and without the use of documents other than those here stated and cited according to the established academic rules.

-- Place and Date

-- Signature

ABSTRACT

This thesis focuses on the topic of urban stream river revitalization and how to maximize beneficial outcomes while minimizing potential risks when approaching this type of projects. It hypothesizes that through a holistic approach, based on the principles of ecosystem services, it is possible to develop and assess restoration strategies that find an adequate balance between ecology and human development.

To sustain this assumption, a theoretical research was developed regarding river ecosystems and their processes, and how these have been affected by urbanization and human activities. This knowledge base was complemented by a review of the Ecosystem Service Framework; used as a tool that enables uncovering the potentialities and risks involved in any given decision related to the management of natural resources for human benefit. Additionally, through an empirical analysis, best practice examples that successfully integrate ecological, social and flood protection objectives were studied. From this analysis, a set of fundamental strategies and principles common to all projects were abstracted in order to aid the development of future revitalization efforts.

The knowledge acquired was applied to the case study of the revitalization of an urban reach of the Pleichach River, located in the city of Würzbug, Germany. Through a systematic design process, three option for restoration were proposed and assessed. It was concluded that all of these options represented ecological improvements when compared to the current status of the river, however, one of them offered a better balance between ecosystem services benefits and risks.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Historically, human settlements have been developed in locations closely related to water bodies. Rivers have been especially valued due to the wide range of services they are capable of providing. However, centuries of exploitation and technical modifications for the fulfillment of human needs resulted in an extensive degradation of urban streams worldwide (Addy et al., 2016).

In Europe, since the late 19th century, urbanization and industrialization processes subjected rivers to a wide range of physical alterations in order to facilitate flood protection, land reclamation, and sewage discharge. The strengthening, channelization, paving, and culverting of natural river courses, as well as the construction of technical embankments and dams, were amongst the many measures implemented for said purposes. Additionally, as riverside areas were commonly used for commercial or industrial activities, roadways and train tracks were often built along the floodplains (Bender, Bigga, & Maier, 2012). As a consequence, rivers suffered a severe loss of natural structure, biodiversity, and many other ecological functions, hence becoming one of the most vulnerable habitat types in the continent (Addy et al., 2016).

By the end of the 20th century, the combination of an increased awareness regarding such ecological problems and technical progress in the field of wastewater management resulted in significant water quality improvements. However, the issue of recovering the natural structure and ecological functions of streams only began to be taken into consideration recently (Addy et al., 2016). In Germany, revitalization projects that dealt with such matters started being developed in the '80s, when environmental concerns began to become relevant for decision-makers. Since then, aspects related to the preservation of water bodies were gradually incorporated into German legislations and policies, hence pushing forward the materialization of plans aiming at restoring water quality and the structure of degraded rivers (Bender, Bigga, & Maier, 2012). These efforts were accelerated in 2000 with the introduction of the European Water Framework Directive, which expanded the scope of water protection and aims at achieving a good ecological status for all water bodies (European Comission, 2017).

Nonetheless, it is not only the recovery of the original ecological status of rivers that restoration projects should be concerned with; technical solutions for stream control have also deteriorated or completely impaired the social, cultural, and spatial functions of river spaces, especially in highly urbanized cities where these are most needed. Lack of accessibility, unfeasible public use, unattractiveness, and urban disconnection are some of the most noticeable deficiencies presented nowadays regarding the aforementioned functions (Bender, Bigga, & Maier, 2012). In this context, biological restitution measures responding solely to environmental assessments may lead to river spaces being dedicated only to nature protection, thus neglecting or discouraging human use and other ecosystem services that are vital in the urban realm (van den Brink, Bruns, Tobi, & Bell, 2017).

In response, the Millennium Ecosystem Assessment declared the need to change the way in which development has approached and managed ecosystems. It encourages decision-makers to develop new strategies considering all the potential services that an ecosystem can provide and seeking to minimize trade-offs between them. In that way, holistic and sustainable solutions for managing ecosystems can be established, and a balance between nature and development can be found (Ranganathan et al., 2008).

RESEARCH AIMS AND SCOPE

The general aim of this thesis is to examine the revitalization potential of heavily modified streams within complex inner-city contexts. Special focus will be given to the fundamental considerations required to develop integrative strategies suitable for ecological recovery, flood protection, and recreational use.

This research has been developed in collaboration with Gerber Architekten, a multidisciplinary practice based in Germany, and has been conceived as the initial step towards developing a revitalization project for an urban reach of the Pleichach River, located in the City of Würzburg, Germany. In this context, it is also the purpose of this investigation to offer a knowledge base capable of informing the design process of the previously mentioned case study as well as other revitalization projects within comparable settings.

By extending the knowledge base related to the restoration of urban rivers, the aims of this thesis align with those of the 2030 Agenda for Sustainable Development. To fulfill this agenda, 17 United Nations Sustainable Development Goals (SDGs) were established in 2016, each with specific targets (United Nations, 2017). The scope of this research falls within several of them:

- "Ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services..." (Sustainable Development Goals: Goal 15, 2017)
- "Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species." (Sustainable Development Goals: Goal 15, 2017)
- "Integrate ecosystem and biodiversity values into national and local planning..." (Sustainable Development Goals: Goal 15, 2017)
- "Integrate climate change measures into national policies, strategies, and planning." (Sustainable Development Goals: Goal 13, 2017)
- "Strengthen efforts to protect and safeguard the world's cultural and natural heritage." (Sustainable Development Goals: Goal 11, 2017)
- "Substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change." (Sustainable Development Goals: Goal 11, 2017)
- "Provide universal access to safe, inclusive and accessible, green and public spaces... (Sustainable Development Goals: Goal 11, 2017)

HYPOTHESIS AND RESEARCH QUESTIONS

This thesis hypothesizes that through a systematic and holistic approach, sustainable revitalization solutions can be developed for urban rivers in order to maximize the benefits they can provide while minimizing negative ecological impacts.

The following questions provide the logical structure of this research and intend to substantiate its presumptions and findings:

- Which elements of a river ecosystem are fundamental for its appropriate biological function?

- What urban circumstances present the main opportunities and challenges for stream revitalization and to what extent can an urban stream be returned to its pre-development conditions?

- Is there a framework that supports the development of multi-purpose river revitalization projects?

- How have ecological and societal objectives been successfully reconciled in best practice examples and what can be learned from these experiences?

- Which guidelines and tools support the development process of urban stream restoration in Germany?

- How can ecological and societal services be optimized in the presented case study or projects in comparable conditions?

STRUCTURE AND METHODOLOGY

This thesis has been structured following a logical sequence in which the fundamental aspects and principles considered for the revitalization of an urban stream are presented from the most general to more specific ones.

The first part of the study examines the natural processes and functions performed by river ecosystems, how these have been directly or indirectly affected by urbanization, and what are their potentials within urban contexts. Then, the Ecosystem Service Framework is presented as a valuable guideline to support the development and assessment of strategies in order to reconcile ecological and socio-economic needs and optimize potentialities.

The second part focuses on the empirical analysis of best practice examples that apply the principles of multi-functionality in river restoration projects. Through a systematic review, three cases were selected, studied in detail, and compared to provide some insight on different valid approaches and to establish common principles that could aid the development of future projects.

Lastly, an investigation was developed on the current conditions of the Pleichach River, the restoration site, and the social, economic and political circumstances pertinent to its revitalization. The results of this site analysis were combined with all the knowledge previously acquired in order to present three proposals on how the project could be approached. These options were assessed and compared in order to offer a valuable understanding and a set of recommendations for the further development of the project.

RIVER ECOSYSTEMS: NATURAL PROCESSES AND FUNCTIONS

River ecosystems are comprised of the biotic and abiotic elements of both the channel and its riparian zone (Speed et al., 2016). The synergy between these two factors, and their interaction with other landscape and climate conditions create a series of processes that arrange the physical structure of stream corridors (Speed et al., 2016).

These processes are interdependent and occur simultaneously at various dimensions and scales. Therefore, the multidimensional approach is regarded as a suitable method to facilitate the comprehension of water courses and their dynamics (Prominski, Stokman, Zeller, Stimberg, & Voermanek, 2012). This approach enables the distinction of river ecosystem processes within the following dimensions: longitudinal, lateral, vertical and temporal (Fryirs & Brierley, 2013).

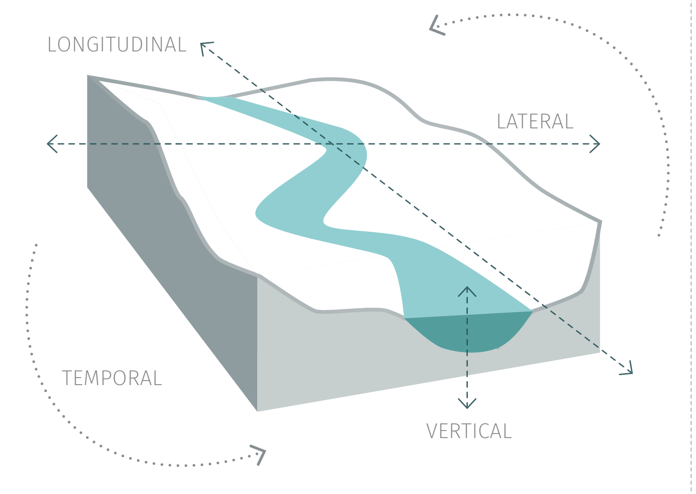


Figure 1. Multidimensional Framework for River Ecosystems (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision)

LONGITUDINAL DIMENSION

Fluvial systems originate from the interaction between hydrological processes and the topographic conditions of a given landscape (Speed et al., 2016). As superficial water drains from upper to lower geographic levels, a series of headwaters encounter; combining their flows resulting in streams of greater order. These combined streams follow the same behavior until the repeated process creates a network that ultimately discharges all the drained water into another reservoir (Fryirs & Brierley, 2013).

This networked behavior entails a high degree of connectivity between all the tributaries of a system, and also between the processes that take place in the territory that they drain, denominated catchment area (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision).

All developments taking place within the catchment area of a fluvial system will have a potential impact on it. However, due to the hierarchical organization of the network, upstream developments will have greater effects on the entire system that those occurring downstream (Allan & Castillo, 2007).

Catchment-scale processes are responsible for the main inputs of organic matter, nutrients, sediment and water into a river channel. They might be affected by hydrologic, geologic and climatic phenomena, as well as by land use practices (Speed et al., 2016).

In turn, they regulate further in-stream features such as the temporal, quantitative and qualitative variability of water flow. This variability is known as flow regime, and it is regarded as the driving force of river ecosystems; largely affecting its physical, chemical, and biological structure (Allan & Castillo, 2007).

In that sense, water flow is a major driver of the geomorphological processes that shape and modify river channels. Since the power with which water flows downstream, influenced by slope changes and discharge, varies along the longitudinal profile, erosion and sediment transportation capacity of the stream will vary as well (Fryirs & Brierley, 2013).

It is through these processes and their variability that channel sinuosity, pool-riffle sequences, flow diversity, sediment heterogeneity, and an overall diversity of features are attained. This physical variability along the stream will largely determine the range of species able to dwell within it (Prominski, Stokman, Zeller, Stimberg, & Voermanek, 2012).

The river continuum theory integrates the notions of energy sources, food networks, and biodiversity changes into the longitudinal dimension of a stream.

It hypothesizes that the set of species that can be found at a given point of the basin is determined by microhabitat characteristics, riparian vegetation, and available inputs of sunlight, which will affect in-stream primary production and water temperature (Allan & Castillo, 2007).

Generally speaking, narrow and shaded headwaters will mainly support biota that can survive of external inputs such as fallen foliage. As the stream widens, sunlight exposure and the variability of temperature niches increase, enabling in-stream primary production. These aspects, together with processed organic matter flowing from upstream, potentially enables a broader variety of species (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision).

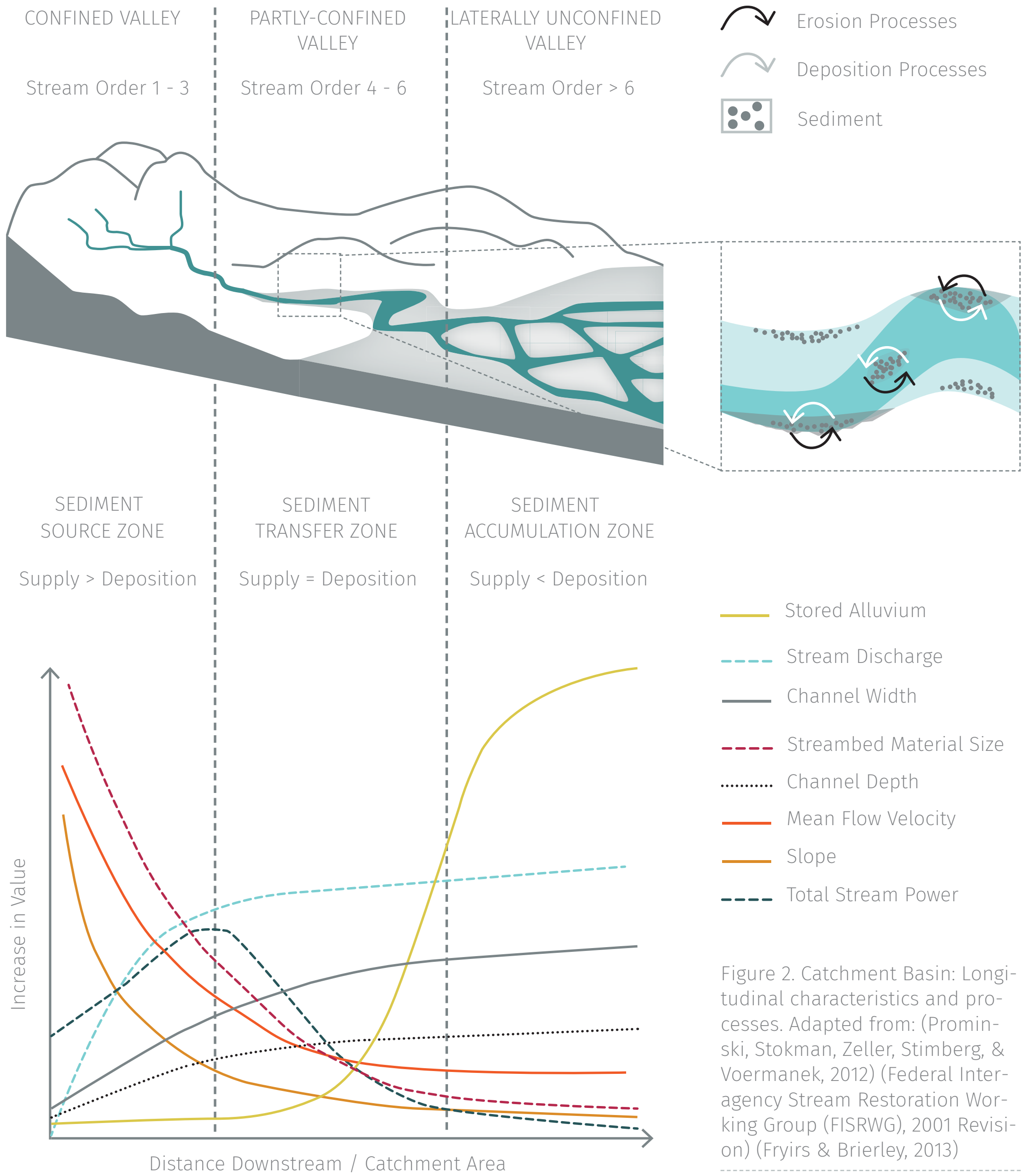


Figure 2. Catchment Basin: Longitudinal characteristics and processes. Adapted from: (Prominski, Stokman, Zeller, Stimberg, & Voermanek, 2012) (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision) (Fryirs & Brierley, 2013)

LATERAL DIMENSION

The lateral dimension of river ecosystems attempts to describe the relationship and the processes that occur between the channel (river banks and river bed), the floodplain, the riparian zone and the transitional upland fringe (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision).

The tional dimension of the channel determines the amount of water able to run through it without overflowing. As it was previously mentioned, the morphology channel will depend on landscape slope, sediment discharge, sediment characteristics, and water flow (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision). However, channel structural features have an adaptive capacity that is triggered when any of these factors go off-balance. This adaptation process depends on the erodibility of the streambed and the embankments, and it occurs over prolonged periods of time (Allan & Castillo, 2007).

Therefore, during particular events of mid-to-high water discharge, the overflow engulfs the marginal area of the channel denominated flood plain, which offers temporary storage for water and sediment surplus (Prominski, Stokman, Zeller, Stimberg, & Voermanek, 2012). As a result, the floodplain can gain new hydraulic units (back swamps, oxbow lakes, splays, etc.) and experience soil moisture variations, thus providing more diverse habitats for flora and fauna. When the stream is effectively connected to its floodplain, the exchange of nutrients and organic matter between the channel and its adjacent land is enabled by regular flood events (Allan & Castillo, 2007).

A vegetated and well-connected riparian zone will also have a significant influence on the lateral functionality of the ecosystem. Roots give stability to the river banks while fallen branches and trunks create in-stream microhabitats and flow variations. Inputs of leaves and other kinds of organic matter into the stream serve as energy sources as well. Tree foliage regulates water temperature, preventing excessive warming and evaporation (Allan & Castillo, 2007). In general, plant communities along the river margins

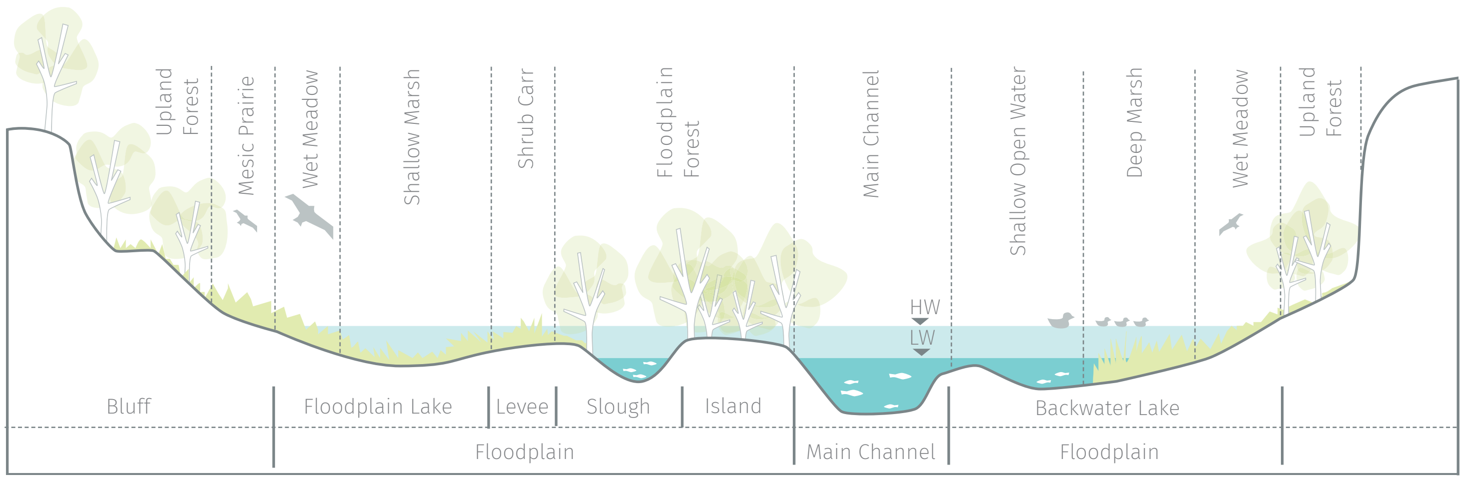


Figure 3. Stream Channel - Lateral Dimension. Adapted from: (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision) P.1-13

play a decisive role in maintaining the natural structure and biodiversity of rivers, affecting them in multiple ways (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision).

The uppermost level of the lateral section, denominated transitional upland fringe, is the ultimate limit between the floodplain and the overall landscape. In spite of being considered part of the river corridor, it will not be morphologically affected by in-stream processes as much as it can be by land use practices (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision).

VERTICAL DIMENSION

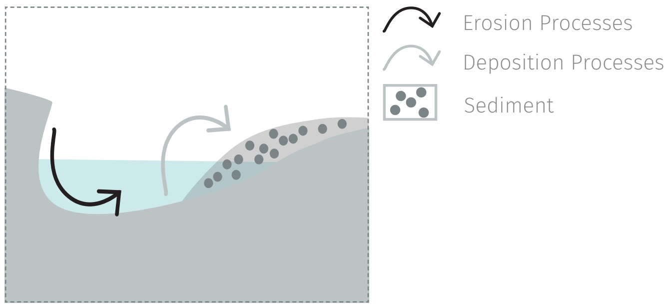
The vertical dimension mostly refers to the interactions between superficial water, underground water, and riverbed substrate. They occur mainly through infiltration and percolation processes (Fryirs & Brierley, 2013), which are largely dependent on the structure and permeability of the streambed (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision).

Channel substrates can be constituted of diverse materials such as sand, silt, clay, gravel, cobbles and organic matter. Each material will perform differently when it comes to enabling vertical connectivity and harboring biodiversity (Allan & Castillo, 2007).

In certain gravel-bed streams, for example, the hyporheic zone (area beneath the substrate/water interface) can be considered as an added habitat, given its capacity to accommodate and protect communities of small benthic invertebrates (Allan & Castillo, 2007). On the other hand, sand and silt substrates are generally the least capable of supporting a broad range of aquatic organisms (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision).

Streambed composition, climate conditions, and water table depth can vary along the watershed or through time. Therefore, the nature of vertical interactions is also subjected to modifications.

Depending on how these factors are presented in a given section of the channel, the stream might experience water losses or water gains to or from underground sources respectively. This gains or losses will regulate the base flow of the stream (Allan & Castillo, 2007).



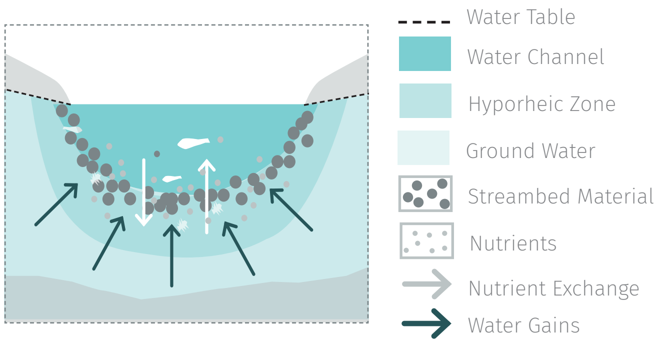


Figure 4. Erosion and Deposition Processes Altering the Riverbed. Adapted from: (Prominski, Stokman, Zeller, Stimberg, & Voermanek , 2012)

Figure 5. Vertical Interactions of a Stream. Adapted from: (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision)

SCALE	EVOLUTIONARY ADJUSTMENT TIMEFRAME (yrs)	NATURAL DISTURBANCE EVENT FREQUENCY (months)
Catchment	$10^{5} - 10^{6}$	10^{3}
Landscape Unit	$10^{3} - 10^{4}$	10^{2}
Reach	$10^{1} - 10^{2}$	10^{1}
Geomorph. Unit	$10^{0} - 10^{1}$	10^{0}
Hydraulic Unit	$10^{-1} - 10^{0}$	10^{-1}

Table 1. A nested hierarchy of geomorphic scales, adjustments, and disturbance events. Adapted from: (Fryirs & Brierley, 2013)

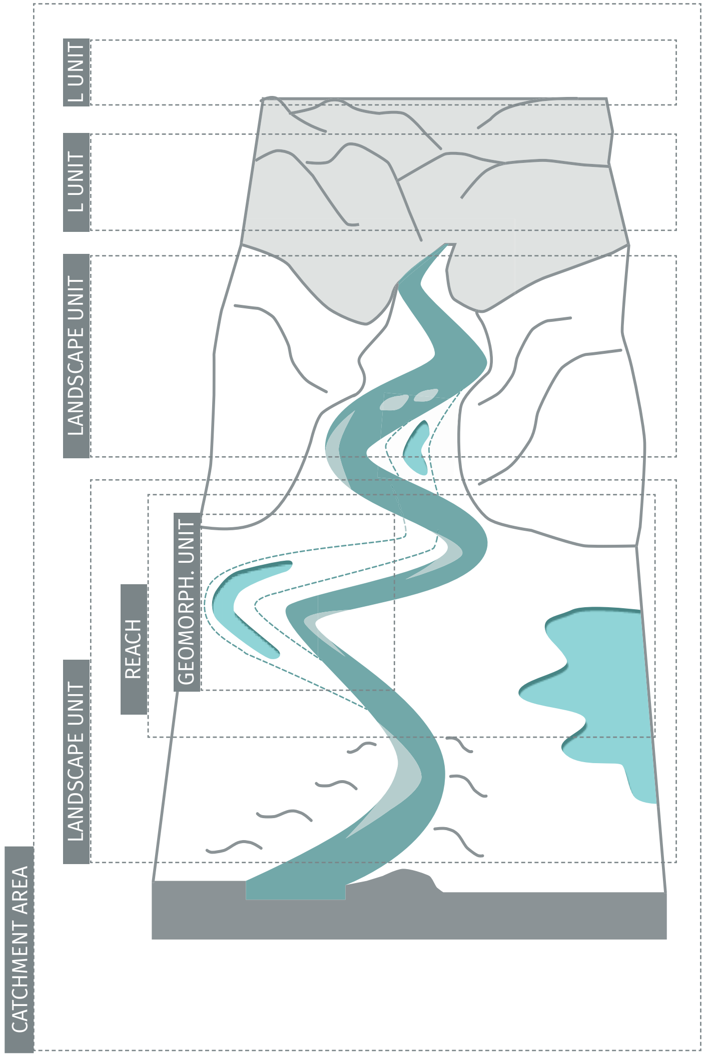


Figure 6. Scales of River Structure. Adapted from: (Fryirs & Brierley, 2013)

SCALE AND TIME

All the aforementioned dynamic processes and interrelations occur hierarchically and at different spatial scales that are nested within others in a higher level of the hierarchy. This means that conditions established by higher scale units will be dominant over those of the smaller units. Therefore, it is the interaction between the elements of each scale and between scales what defines the nature of the entire system (Fryirs & Brierley, 2013).

The broader scale in which a single fluvial system and their processes can be understood is the catchment basin, given that it includes the complete network (Allan & Castillo, 2007). The next scale category is the differentiated landscape units existing along the basin, each comprised of an area with a characteristic topographic pattern. Within these, individual reaches are defined as homogeneous river sections that share a set of regulatory conditions (Fryirs & Brierley, 2013). Reaches can, in turn, contain several geomorphic units or macro-habitats, consisting of a variation of erosional and depositional forms (e.g. pools, riffles, bars). Finally, distinct patches of accumulated materials such as leaves and gravel, conform unique microhabitats (Allan & Castillo, 2007).

All the adaptive processes and natural disturbances that are involved in river dynamics can also be examined over differentiated and nested time frames (Fryirs & Brierley, 2013). In that sense, temporal and spatial hierarchies are correlated most of the time (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision). For example, catchment-scale processes such as climate or geomorphology may take thousands of years to experience changes. However, alterations related to land use practices within a smaller landscape unit may occur in centuries, decades or even in a couple of years (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision).

On the other hand, flood events affecting the morphological structure of the channel also occur in differentiated and cyclical time scales. In general, frequent and smaller flood events tend to have an impact on smaller scale units, while sporadic but larger flood events have an impact on a larger spatial scale (Fryirs & Brierley, 2013).

In any case, the overall transformation that a river corridor experiments through its natural reactionary processes, also called dynamic equilibrium, is hardly perceptible over short periods of time. However, when analyzed using historical and geological maps, the great dynamism of watercourses can be grasped (Prominski, Stokman, Zeller, Stimberg, & Voermanek, 2012).

SUMMARY

Rivers are very complex and dynamic systems. Their functions and conditions are constantly changing as a result of a variety of processes that occur simultaneously and at different scales. Although these processes are not easy to recognize, given their dynamic character, their consequences can be observed and quantified through changes in the main physical elements of river ecosystems: habitat diversity, water quality, and biodiversity.

The following figure illustrates, in a simplified way, the hierarchical influence between the different elements of river ecosystems. Although only the main sequence of influence is shown, it must be noted that components of a lower category can affect others belonging to higher categories.

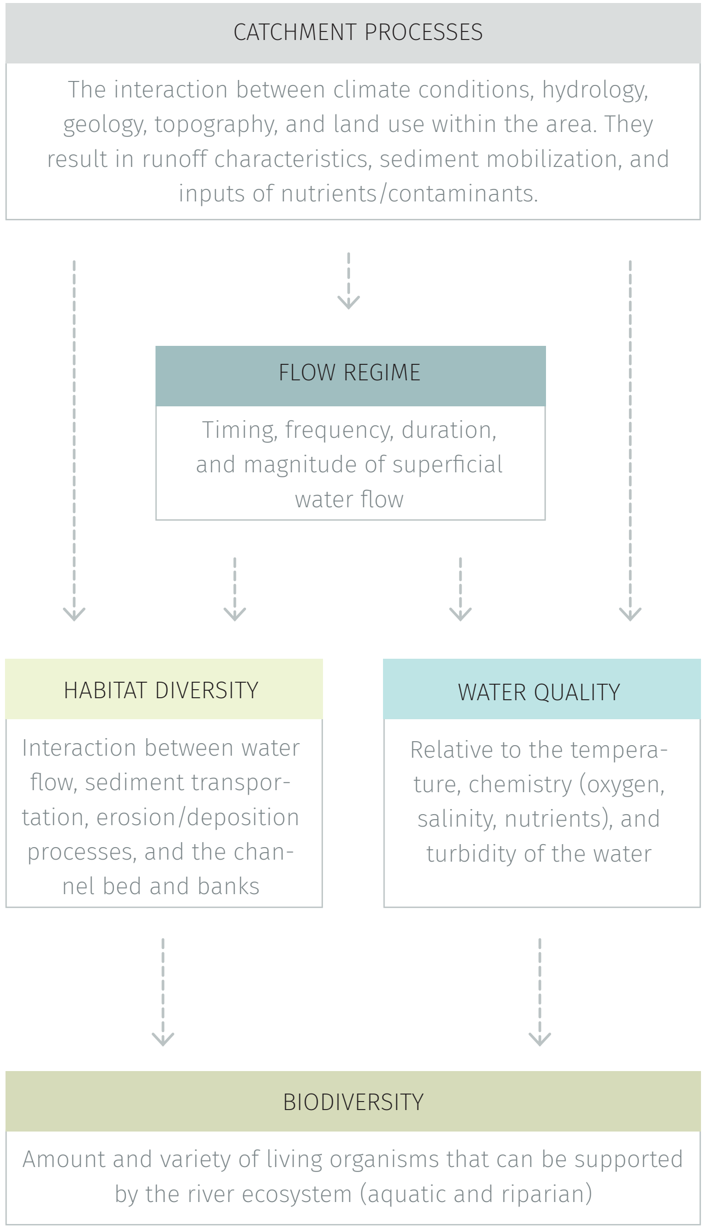
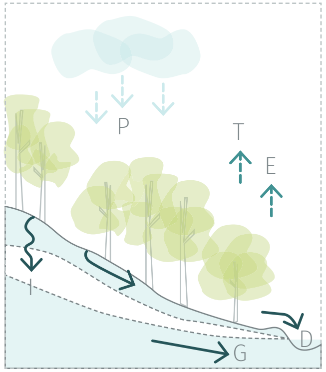
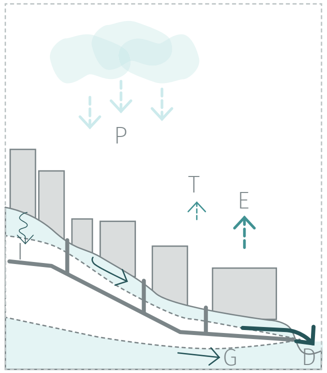


Figure 7. River Ecosystems: Processes and Interrelations. Adapted from: (Speed et al., 2016)





P = Precipitation
T = Transpiration
E = Evaporation
I = Infiltration
G = Groundwater
D = Discharge

Figure 8. Forested Catchment area vs. Urbanized Catchment area. Adapted from: (Walsh, Papas, Crowther, & Sim, 2004)

URBAN STREAMS: DISTURBANCES AND CONSIDERATIONS

Urban streams are commonly defined as those within a catchment area with more than 10% of its land covered by impervious surfaces such as paving, asphalt roads, and roofs (Speed et al., 2016). As recent research suggests, streams that fall into this category, or have a larger percentage of impervious area, will present dramatic differences when compared to their natural counterparts (Schueler & Brown, 2004).

These differences are often related to the detriment of river health and its incapability to adjust to changing conditions or to natural disturbances, that occur as a consequence of a wide range of urban-related stressors and human-made alterations, both at catchment scale and in-channel.

Most of these modifications respond to the necessity of providing a variety of services and controlling negative impacts on human settlements. However, in many cases, the constant damage caused by technical alterations and urban stressors end up impeding the utilization of the stream for the purposes it was modified in the first place (Speed et al., 2016).

In these cases, sustainable restoration strategies that aim at reestablishing such services while also preventing further damage on river ecosystems are deemed necessary. For that purpose, the character and scope of the impacts caused by urbanization must be understood regarding the natural processes described in the previous chapter (Schueler & Brown, 2004).

INDIRECT DISTURBANCES: URBANIZED CATCHMENT AREA

Urbanized areas have a significant percentage of impervious surfaces that restrict water infiltration into the soil and water storage. This condition, together with drainage systems that lead large amounts of collected water to river channels, results in substantial modifications to the hydrological regime influencing urban streams.

With the obstruction of permeability and a reduced roughness of surface cover, an increase in surface runoff can be expected during rainy seasons, in both amount and velocity. Consequently, the lag time between rain events and stream peak discharge is reduced, therefore increasing the probability of flash flood events and overall flood frequency. Moreover, flood risk is aggravated by the reduction in evapotranspiration rates that follow intense urbanization.

Likewise, soil imperviousness intensifies the risk of drought during the dry seasons given that groundwater recharge is limited or completely hampered, thus severely reducing river base flow.

Driven by these flow regime changes, the river channel, when unrestricted, will experience certain morphological and ecological alterations through the natural adaptation processes explained in the previous chapter. In fact, studies have labeled a set of characteristics consistently observed in rivers that undergo the stresses of urbanization as the “urban stream syndrome.” However, it must be noted that as in any generalization, these can be present in higher or lower degrees depending on the case (Walsh et al., 2005)

Some of the most common responses to flashier flow regimes are cross-sectional enlargement and streambed down cutting, given that erosion processes are triggered by large and more frequent flood events (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision). At the same time, the reduction of coarse sediment inputs from the watershed and the clearance of riparian vegetation, which leaves the river banks more exposed to erosive forces, contribute to channel widening (Rutherfurd, Jerie, & Mars, 2000).

When coupled with decreasing base flow levels, these responses create entrenched and oversized channels that, during regular climate conditions, hold shallow waters and have a reduced connection with the flood zone (Everard & Moggridge, 2012). This impoverishes the ecological status of streams due to the reduction of longitudinal/lateral connectivity, loss of morphological complexity and the downstream fine-sediment overload produced by bank erosion (Rutherfurd, Jerie, & Mars, 2000).

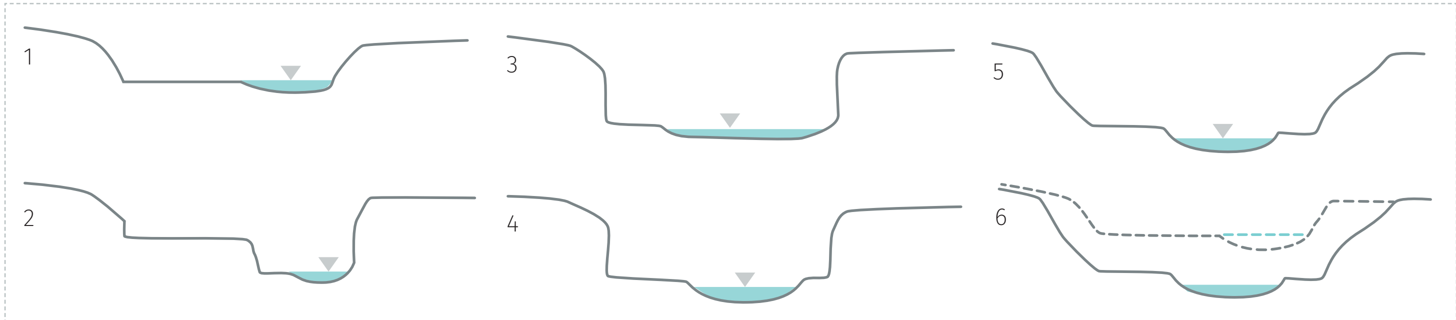
Although, after land-use alterations, these morphological adjustment processes might conclude in the eventual recovery of channel stability, studies have found that for urban streams this seems particularly difficult. The main reason for this is that urban buildup appears to be a non-ending process that keeps expanding and gaining terrain within river watersheds.

Therefore, most urban streams might fail to regain morphological equilibrium for many decades (Schueler & Brown, 2004).

On the other hand, catchment processes not only impact river health regarding morphology but also in terms of water quality. In that sense, urbanization and human activities are recognized as the most relevant stressors when it comes to the deterioration of the chemical status of streams. Once a stream falls under these influences, it tends to present an increase in conductivity, amount of suspended particles, hydrocarbons, nutrients, metals, and oxygen depletion (Paul & Meyer, 2001).

Contaminants and toxic agents produced by human activities enter urban streams though point source pollution and by water runoff that washes them away from surfaces like roads and parking lots. These pollutants might include heavy metals, oils, and a broad variety of synthetic chemicals

Excessive amounts of nutrients can also be introduced into urban streams by the same means. Although these are not inherently poisonous, in large amounts and under certain conditions, they might cause eutrophication and an increment of oxygen depletion that could seriously endanger aquatic biota.



1. Pre-Impact
2. Incision
3. Widening
4. Re-established Baseflow
5. Streambank Erosion
6. Before/After

Figure 9. Progressive Stages of Channel Incision. Adapted from (Schumm, 1999)

The discharge of non-natural and fine sediments into rivers poses a threat to water quality as well, especially when coming from mining, construction, and industrial residues. These not only pollute the water but also augment turbidity, which restricts in-stream primary production, cover the streambed and choke animals (Rutherfurd, Jerie, & Mars, 2000).

Lastly, changes in water temperature are also expected as a consequence of urbanization given that paved or constructed surfaces tend to accumulate heat, which is later absorbed by runoff water and transported into the stream. An increment in water temperature is likewise fostered by the loss of vegetation along the riparian zone, leaving the stream highly exposed to sunlight. Changes in water temperature are also related to changes in the level of dissolved oxygen and can, therefore, be threatening for aquatic organisms (Walsh et al., 2005).

From all of the above, it can be seen how, consistently with what was explained in the previous chapter, changes at catchment level impact the whole behavior of rivers by altering their water regime, morphological condition, and water quality; all which in turn affects biodiversity.

As a generalization, it has been estimated that for catchments with an urbanized area of at least 10% of the total, the diversity of algal ensembles, invertebrates and fish species has been negatively impacted by water quality degradation and irregular flow regimes (Addy et al., 2016)

The following figure graphically summarizes some of the most consistent manifestations of urban stressors on each of the river ecosystem elements and their interrelations.

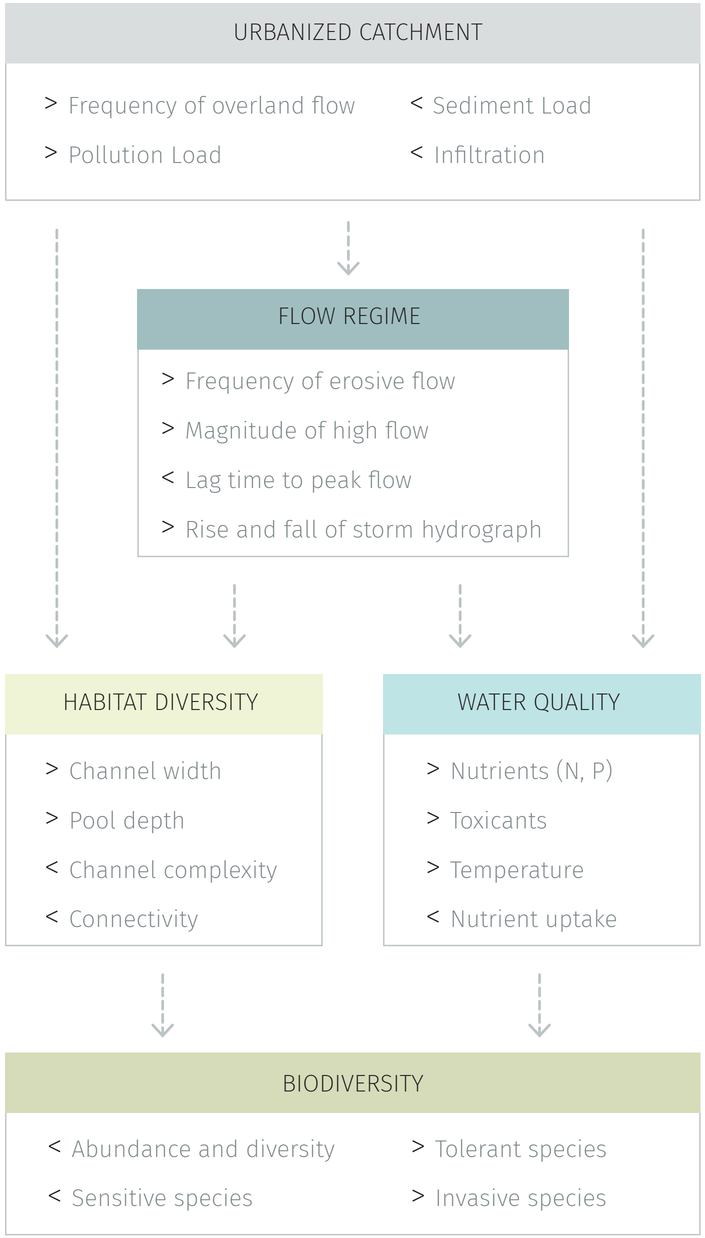


Figure 10. Impacts of Urbanization on the Elements of a River System. Adapted from: (Speed et al., 2016)

DIRECT DISTURBANCES: RIVER CHANNEL MODIFICATIONS

Further urban-related pressures on river ecosystems come as consequence of direct modifications to the river channel. These usually occur at section or reach scale and respond to local needs such as flood protection, land reclamation or water use (Fryirs & Brierley, 2013)

Just like with catchment-level stressors, direct channel modifications and constraints cause loss of connectivity, nutrient supply, and habitat diversity, amongst many others. However, unlike with indirect disturbances, the most severe impacts of in-channel technical solutions come from the river's incapability of naturally adjusting to changing conditions (Federal Interagency Stream Restoration Working Group, 2001).

Many different human-made interventions have been applied to freshwater courses over the years, impacting their ecological status. However, an overview of only those that are most relevant to urban streams and this thesis's case study will be presented next.

- CHANNELIZATION:

Consists on diverting, strengthening and deepening streams for the purpose of land reclamation, agricultural land drainage, and local flood frequency reduction.

Although a straight and smooth channel conveys water faster thus avoiding overflow on the local floodplains, it radically changes the natural flow regime of the river and causes higher flood risk in downstream sections of the channel. The lack of morphological heterogeneity also reduces flow variability within the streams, which is needed to support different groups of invertebrates.

Due to the deepening of the channel, the lateral connection between the stream and its floodplain decreases. This results in a reduced exchange of organic matter and nutrients, as well as in the loss of hydrological units and flood-related microhabitats. Furthermore, this disconnection hampers the possibility of storing or infiltrating water overflow along the floodplain, which worsens downstream flood risks (Kondolf et al., 2006).

- RIVERBANK AND RIVERBED REINFORCEMENT

Many types of structures have been used to reinforce channels in order to halt natural erosion and control the movement of the river, with the main objectives of protecting infrastructure and preserving a certain land use.

In the case of concrete reinforcements, they are also largely implemented to eliminate surface roughness inside the channel to increase flow velocity, thus decreasing local flood risk. However, as with other technical solutions that augment flow speed, this one also increases the risk of flood in lower sections of the river.

Regardless of the chosen material, all bankside reinforcements restrict the capacity of rivers to adjust to changing flow regimes and sediment inputs, which can worsen downstream flood risk and promote local flooding as well. Additionally, these constructions eliminate bankside heterogeneity, habitat complexity, lateral connectivity and flow variability. Riverbed covering has the same consequences, plus the lack of vertical connectivity which also affects base flow and nutrient exchanges (Addy et al., 2016).

- DREDGING AND GRAVEL EXTRACTION

River channelization is commonly maintained with the aid of

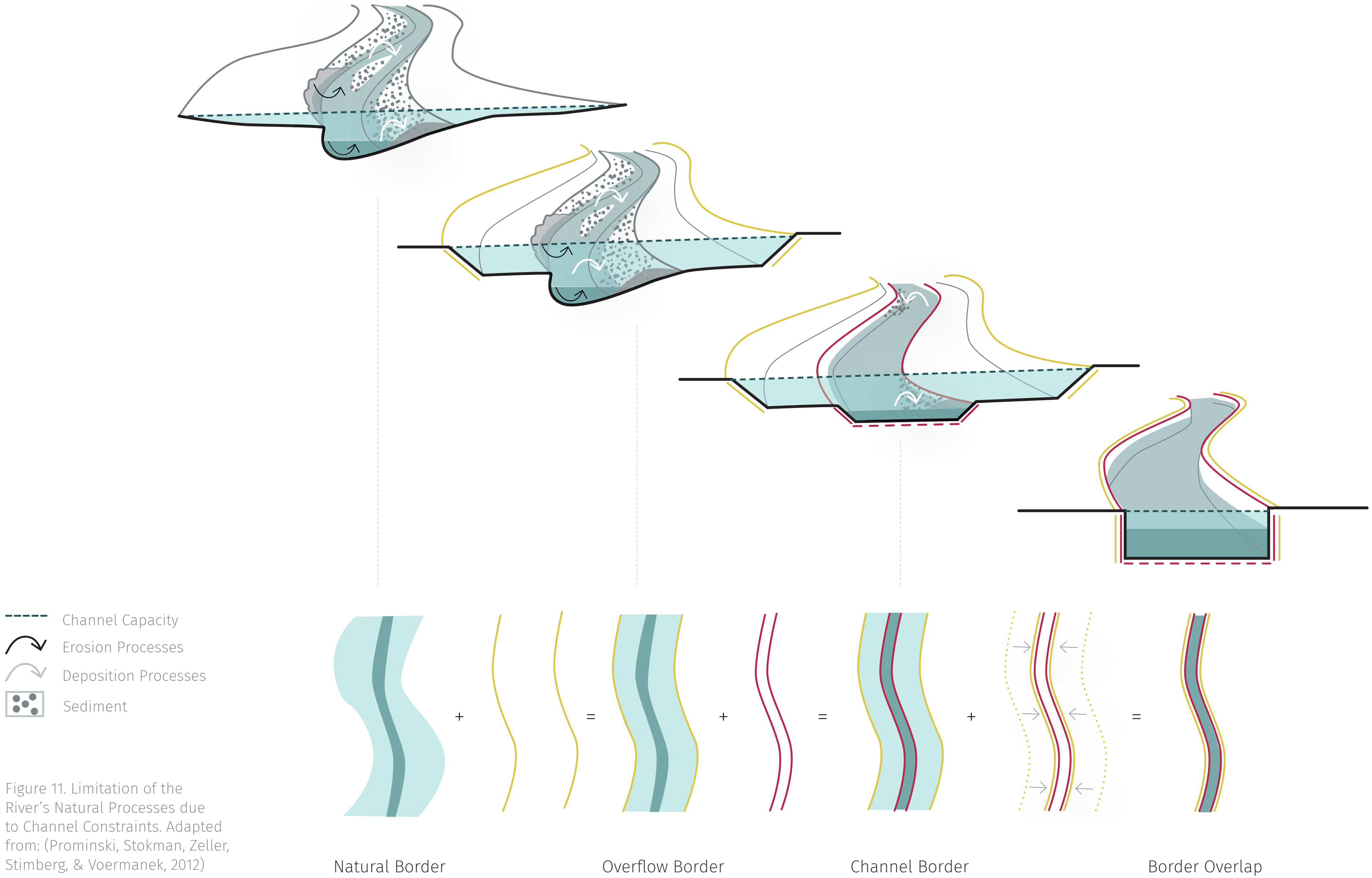


Figure 11. Limitation of the River's Natural Processes due to Channel Constraints. Adapted from: (Prominski, Stokman, Zeller, Stimberg, & Voermanek, 2012)

dredging. This practice not only directly affects in-channel habitat but also weakens the streambed and stream banks, leaving them more exposed to erosive forces. As a consequence of heavy erosion, fine sediment is produced in greater quantities, leading to siltation in downstream reaches and consequently threatening aquatic organisms.

On the other hand, gravel extraction is another common method to reduce flood risk and, less commonly, to supply material for construction. Similarly to dredging, this practice also has adverse effects on the health of the river (Addy et al., 2016).

- COARSE DEBRIS AND VEGETATION REMOVAL

In-channel clearance of rocky and woody debris usually comes together with channelization, again with the intention of fostering a faster water flow. It was also thought to benefit longitudinal connectivity, regarding animal migration and aid drainage.

However, it is now known that some of the ecological impacts of eliminating these elements include the loss of morphological heterogeneity, a decrease in flow variation, and the reduction of habitats; resulting in a less bio-diverse stream (Addy et al., 2016).

Eliminating riparian vegetation also increases channel erosion while decreasing bank stability, woody debris input, sediment trapping, input and retention of organic matter, and stream shading. All of which greatly affects water quality and biodiversity (Allan & Castillo, 2007).

- ARTIFICIAL LEVEES AND FLOOD EMBANKMENTS

Levees consist of the elevation of natural riverbanks, using a variety of natural materials such as earth and rocks or artificial materials such as concrete. Their main purpose is to increment the capacity of the channel to retain larger amounts of water, thus reducing overflow onto the floodplain and enabling its agricultural or urban development (Addy et al., 2016).

Locally, artificial levees reduce the lateral connectivity between the stream and the floodplain, which disables material exchange and backwaters formation. Nonetheless, during extreme flood events, any eventual backwater will stay trapped behind the levees and runoff will not be able to drain into the river.

Off-site negative impacts of levees include increased peak-flow and aggravated downstream flood risk (Fryirs & Brierley, 2013).

- FLOW REGULATING STRUCTURES

Weirs, dams, and locks are the most commonly used measures to regulate river water flow. They serve various purposes such as the creation of reservoirs that facilitate water supply, the habilitation of navigation, and the production of hydropower, among others.

The main ecological impact related to regulating structures is the total or partial loss of longitudinal connectivity regarding water flow. This, however, also translates into the loss of other longitudinal river processes such as sediment and nutrient transportation as well as fish migration (Fryirs & Brierley, 2013).

By disrupting the natural movement of all the aforementioned elements, the proper functioning of both the upper and the lower section of the river is equally compromised. On the one hand, water retention promotes the submersion of riverbanks, hence, also the loss of certain species of vegetation and habitats. Moreover, material deposition increases upstream, resulting in nutrient and

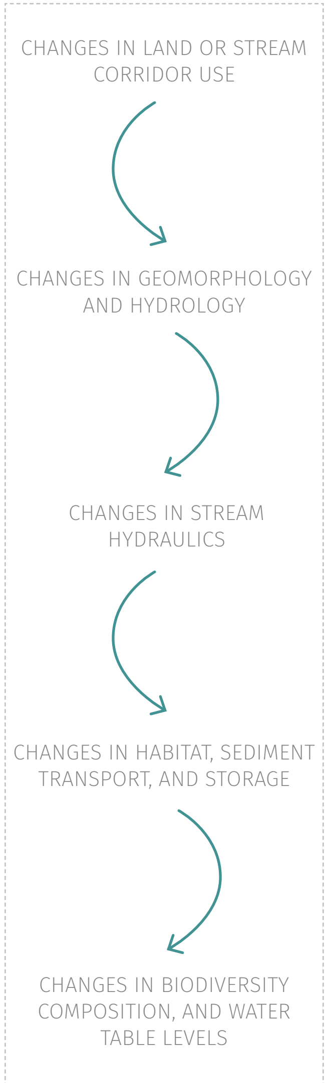


Figure 12. Chain of Events due to Disturbance. Adapted from: (Federal Interagency Stream Restoration Working Group (FISRWG), 2001 Revision)

sediment saturation levels that can be fatal for aquatic fauna. Inversely, downstream habitat availability and biodiversity are negatively impacted by the severe reduction of water flow, nutrients, and sediments (Addy et al., 2016).

- RESTORATION-RELATED STRUCTURES

Modern water management practices have acknowledged the negative impacts that heavily artificial and single-purpose measures have had on river ecosystem health. In an attempt to reverse these impacts, other types of engineering structures, such as flow deflectors, have been introduced into degraded streams to recover heterogeneity and flow variation (Addy et al., 2016).

However, at times, these type of solutions have also negatively affected the natural processes of rivers and delayed its recovery, especially in cases when passive strategies, such as simply eliminating artificial disturbances, would have sufficed. Besides passive and catchment-management measures, other environmentally sensitive methods such as riparian vegetation management and placement of more flexible materials as deflectors have shown a smaller degree of structural degradation than hard engineering (Fryirs & Brierley, 2013).

In that sense, the most important lesson to learn from all the presented measures is that any disturbance to the natural state of the river might develop into a chain of alterations that could further harm its structure. Therefore, to understand restoration measures as yet another human-made modification and develop river adjustment scenarios before implementation is a practice that could largely reduce adverse or unwanted effects.

REVITALIZATION OF URBAN STREAMS: CHALLENGES AND OPPORTUNITIES

At first, stream restoration practices sought to return degraded streams to their original conditions (Federal Interagency Stream Restoration Working Group (FISRWG),, 2001 Revision). In fact, in the early ’90s, the National Research Council defined river restoration as the “reestablishment of pre-disturbance aquatic functions and related physical, chemical, and biological characteristics” (National Research Council (NRC), 1992).

However, it has become clear that in urban settings this is not entirely possible and very unpractical (Smith et al., March 2016). The main reasons are, firstly, the impossibility of fully mitigating the adverse effects of subwatershed modifications and, secondly, the variety of services that urban rivers must also provide, such as flood protection and recreation (Schueler & Brown, 2004). Consequently, full restoration aims have reasonably transformed into mitigation, improvement or revitalization objectives. These type of goals are more closely related to the reality of urban rivers and, therefore, more likely to be attained (Cockerill & Anderson, 2014).

In that sense, to be able to develop realistic objectives and effective measures for urban streams, it is vital to understand how the ecology of rivers is regulated by natural adjustment processes and how these processes are affected by urban stressors and river channel interventions. Nevertheless, it must also be taken into consideration how further aspects related to urbanization can positively or negatively contribute to the restoration potential of degraded streams. Such aspects can be of spatial, social, economic, or politic nature (Speed et al., 2016),

Some of the most important challenges and opportunities related to the implementation of revitalization projects in urban settings will be presented next. These have been gathered from several investigations based on case studies and the experiences of river restoration practitioners.

CHALLENGES:

- URBANIZATION EXTENT

There is a significant relationship between the extent of urbanized areas within a watershed and the ecological state of the streams that drain it. In other words, rivers that are less surrounded by urbanization present better health conditions than those that are more surrounded by it. Moreover, the same relationship also applies to the recovery potential of urban rivers (Speed et al., 2016).

According to the Impervious Cover Model (ICM), impacted rivers (10%-25% impervious cover (IC)), have a good potential of being repaired, while more urbanized types do not. Non-supporting rivers (25%-60% IC) have more limited possibilities for ecological recovery, so the main repair objectives related to this type are often associated with societal needs such as flood protection. The urban drainage type (60%-100% IC) has reduced possibilities of being repaired; however, measures can be applied to reduce the negatives impacts that are produced on lower reaches (Schueler & Brown, 2004).

Sensitive rivers (< 10% IC) are not considered urban streams, but their healthy ecological conditions make them useful as a reference point to develop repair goals. Nonetheless, this will only apply to partially-degraded urban rivers. The rest have been so se-

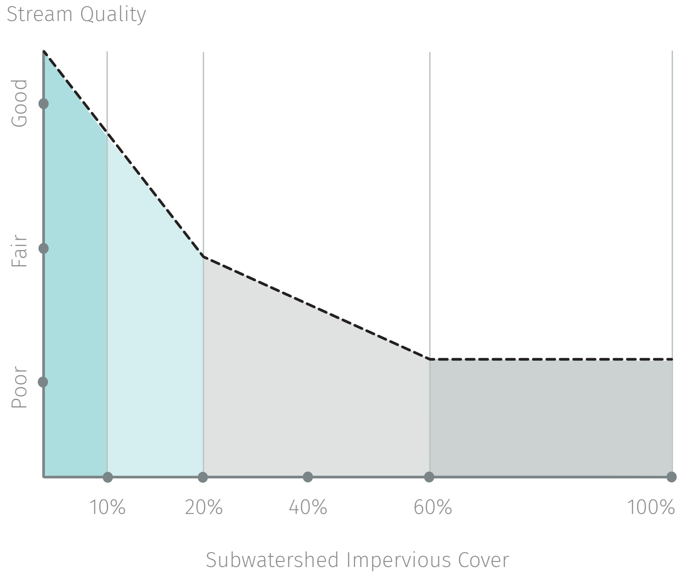


Figure 13. Impervious Cover Model Diagram. Adapted from: (Schueler & Brown, 2004)

verely modified, that their natural counterparts no longer provide meaningful information for its future development. In that case, the particularities of the urbanized conditions are a better basis for any attempts of improvement (Fryirs & Brierley, 2013).

- UPSTREAM LAND-USE PRACTICES

Even though the recovery potential of rivers in less urbanized areas is regarded as higher, because upstream reaches are in more “natural” conditions, other land-use practices taking place in rural settings can be likewise threatening. Activities such as agriculture, mining, forestry and livestock grazing are considered some of the most common when it comes to the alteration of the ecological state of rivers, when not sustainably managed (Federal Interagency Stream Restoration Working Group, 2001).

This means that no matter if urban or rural, the character of upstream land-use practices will strongly determine the general ecological state of the river. Consequently, punctual interventions, within any setting, are prone to have little or no effect if upstream stressors are not likewise addressed. This is why, in order to be successful, urban stream revitalization projects should be integrated into a broader catchment-scale effort that includes both urban and rural water sensitive management (European Centre for River Restoration, 2014).

- MULTIPLE AND CONFLICTING INTERESTS

Flowing waters have always been heavily contested due to the diversity of human needs that they are capable of satisfying. These needs, however, can often be in conflict with one another and cannot be simultaneously or equally satisfied.

In urban areas, the clash between needs gets even stronger. Firstly, because there is a higher amount of people that must be served by a particular river section. Secondly, because the requirements that urban streams must fulfill are considerably higher than those of rural ones. The former include, for example, flood protection, nature conservation, navigation, landscape attractiveness, safety, recreation, etc. (Speed, et al., 2016)

For this reason, rehabilitation measures for urban streams shouldn't be exclusively focused on ecological improvements but also on community needs (Schueler & Brown, 2004). In fact, as it was previously explained, the potential of improving the ecological status of an urban river is often limited, and certainly way lower than the potential of improving the community services it can provide.

In that sense, when trade-offs between restoration goals are required, development and socio-cultural services are often prioritized over ecological improvements (Speed, et al., 2016). This does not have to be the rule for all projects but to evaluate and compare the existing potentials for each service is definitely essential for the development of suitable objectives (European Centre for River Restoration, 2014).

- SPACE AVAILABILITY

The level of urban density near streams intensifies the difficulty of implementing repair practices given that, in occasions, the floodplain has been entirely covered with constructions above ground and holds infrastructure and service pipelines underground. In worse scenarios, the stream itself has been culverted and streets or buildings have been constructed above.

In this cases, restoration possibilities rely on long-term planning projects that slowly free the areas along urban streams until finally attaining the minimum necessary space to improve its conditions (Bender, Bigga, & Maier, 2012).

- ECONOMIC FEASIBILITY

The monetary costs of improving urban streams are reasonably higher when compared to rural ones. On one hand, this is due to the greater level of degradation that is generally presented by this type of river, which has to be met with more cost-intensive measures. On the other hand, the prices of land that might be necessary to acquire for restoration purposes are very high in urban settings, especially in city centers (Speed, et al., 2016).

Other additional problem for project financing, is the complexity of calculating the quantitative economic benefits of river rehabilitation, given that some of them are of a socio-cultural nature. This can affect cost-benefit analyses that may ultimately conclude that the price of restoration in too high when compared to the potential profits (Ranganathan et al., 2008).

- LACK OF PUBLIC SUPPORT

Public participation and support have been identified by practitioners as key aspects for project success (European Centre for River Restoration, 2014). However, under certain circumstances it can be very challenging to create a positive opinion on the public regarding the rehabilitation of a river.

Some of these circumstances include: The lack of interest due to the unawareness of the river's existence when it is culverted or hidden. The perception of negative impacts resulting from the interventions, such as flood risk or bad odors. And the fear of private properties and land tenancy being affected by policies supporting river recovery (Speed, et al., 2016).

- FUTURE UNCERTAINTIES: URBANIZATION & CLIMATE CHANGE

Objectives and measures designed taking into account only present-day conditions will likely become obsolete in a near future if the effects of climate change and rapid urban expansion are not taken into consideration (Speed, et al., 2016).

In order to develop river repair plans that are sustainable in time, it must be understood that streams subjected to urbanization experience a superior level of uncertainty when it comes to future stressors. In that sense, investigating the extent and intensity of expected upland development and climate pressures, and relating them to river adjustment scenarios is highly recommendable (Federal Interagency Stream Restoration Working Group, 2001). On the other hand, fixed and inflexible elements for ecological improvement are less likely to meet future demands than adaptive and more flexible ones (European Centre for River Restoration, 2014).

OPPORTUNITIES:

- URBAN LANDSCAPE ENHANCEMENT

Rivers, when properly managed, can be vital features within the urban landscape and have the potential of greatly upgrading its spatial quality (European Centre for River Restoration, 2014). Accordingly, rehabilitation projects create the opportunity of developing to a full the potential of rivers as urban amenities (European Centre for River Restoration, 2014).

On one hand, the restoration of floodplains enables the possibility of creating green corridors along the city. Then, further landscape elements such as pedestrian paths, bike paths, parks and urban furniture can be integrated into this corridors. By doing this, several ecological aspects of the city can be improved, for example, air quality and heat island effect. Also, former abandoned or unused places can regain purpose and become lively (Bender, Bigga, & Maier, 2012).

On the other hand, daylighting culverted rivers and highlighting the presence of otherwise hidden streams increases the attractiveness of the city as a whole and enhances its public image. A better integration of streams into the urban fabric also enables the implementation of decentralized drainage systems and water sensitive urban design projects.

Finally, by eliminating control elements that augment the speed of water and substituting them for retention and infiltration elements integrated into the landscape, flood events and their related damages can be avoided (European Centre for River Restoration, 2014)

- SOCIETAL IMPROVEMENTS

Urban rivers are related to a greater amount of people than rural ones are. Therefore, improving their conditions and aesthetics will positively impact a large share of the population. Studies have associated waterscapes with well-being and lower stress levels, which are great social benefits, especially within urban areas (Speed, et al., 2016). River spaces allow people to quiet down, rest, recreate, exercise, and enjoy themselves (European Centre for River Restoration, 2014).

It is therefore highly recommendable for revitalization projects to integrate measures that foster some of the above-mentioned activities. Only by improving the river's visibility from buildings, houses, roads and open spaces, a higher degree of urban enjoyment can be attained. However, facilitating direct access to the water and the possibility of experiencing it in diverse ways exceptionally improves all societal benefits (European Centre for River Restoration, 2014).

- ECONOMIC BENEFITS

Many of the aspects that are improved through urban stream restoration also procure economic benefits. The most relevant one, of course, are those related to flood protection and the consecutive protection of infrastructure and further assets. But the enhancement of urban landscape might also bring economic benefits such as touristic activity and upgrading the image of the city, which can lead to further investments (Bender, Bigga, & Maier, 2012).

Moreover, soft location factors might also increase as a consequence to river restoration (Speed, et al., 2016). A study in Australia showed a value increase of up to 17% for properties neighboring a rehabilitated river when matched to other properties in the area (Torre & Hardcastle, 2004)

- STAKEHOLDERS AND PUBLIC ENGAGEMENT

A large number of people and assets are related to urban areas, which could be translated into advantages for rehabilitation projects in terms of the number of interested stakeholders and funding possibilities. In turn, a larger amount of stakeholders and particular interests can result in more open, transparent and inclusive discussions. This could be a major driving force for the development of more comprehensive solutions (Speed, et al., 2016).

Restoration projects in urban settings offer the opportunity to involve and consult citizens, local experts, foundations, and academic or research centers. This raises the potential of developing suitable measures for the entire community that will be impacted by the project's outcome (Bender, Bigga, & Maier, 2012) Moreover, political interest and participation is likely to be higher for urban-related projects (Speed, et al., 2016).

In general terms, when exploring different options for restoration proposals, identifying the potential beneficiaries for each of them can lead to the discovery of funding opportunities (Speed, et al., 2016).

- IMPULSE OTHER PROJECTS AND ECOLOGICAL IMPROVEMENTS

As previously explained, to attain meaningful ecological improvements, rehabilitation projects must be conceived and implemented at catchment-scale. However, this does not mean that in urban reaches there is no opportunity for ecological enhancement. For Example, floodplain recovery creates new habitats for vegetation and fauna, while improving climate conditions for the city and its overall ecological quality. In-channel habitat conditions and fish migration can also be improved when hampered by barriers and structural homogeneity (Bender, Bigga, & Maier, 2012). Finally, measures can also be implemented to reduce the negative impacts of urbanization on flow regime (Speed, et al., 2016).

Moreover, the enhancement of urban rivers may play a key role in raising awareness regarding the importance of river health (European Centre for River Restoration, 2014) , providing environmental education (Bender, Bigga, & Maier, 2012), and encouraging further revitalization efforts (Smith et al., March 2016). Urban reaches can be restored to serve as model and display project benefits in order to persuade decision-makers to support successive actions (Bender, Bigga, & Maier, 2012). A study has even concluded that short-term solutions focusing on societal benefits might result in higher public and governmental support to develop more long-term ecological improvements (Smith et al., March 2016).

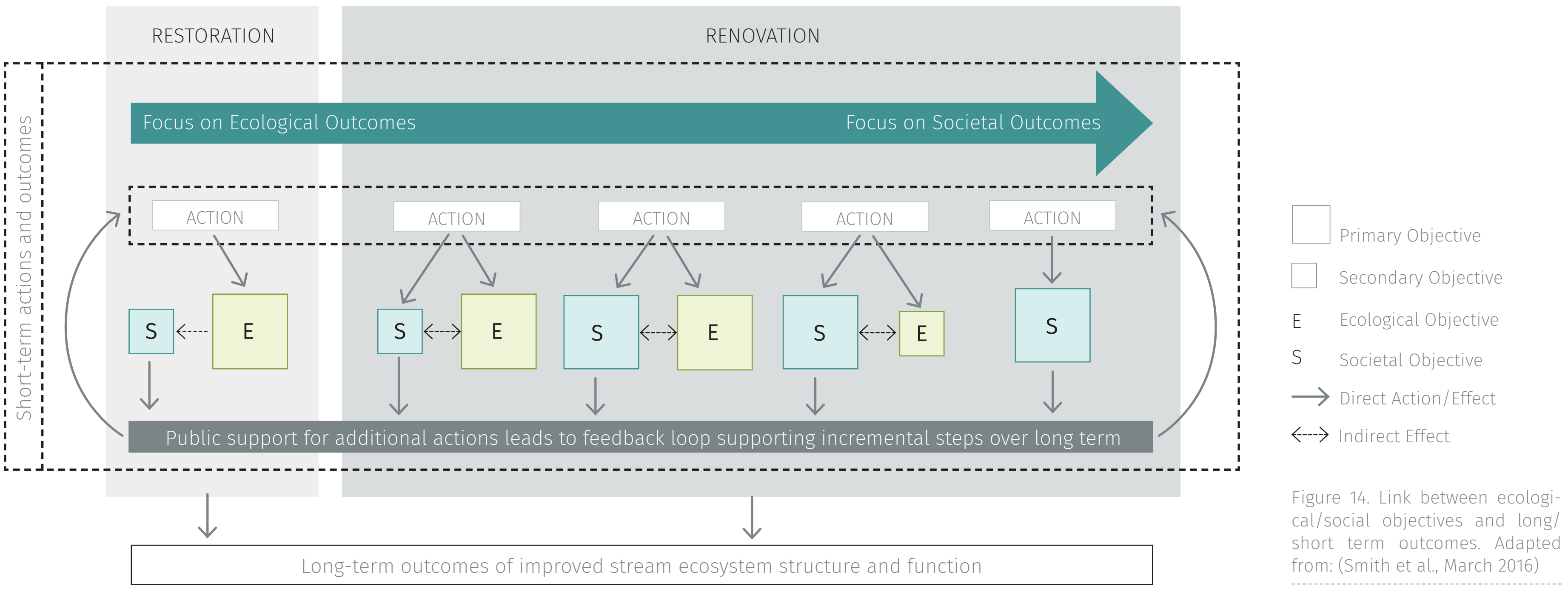


Figure 14. Link between ecological/social objectives and long/short term outcomes. Adapted from: (Smith et al., March 2016)

APPROACHING REVITALIZATION PROJECTS : THE ECOSYSTEM SERVICE FRAMEWORK

Urban rivers have been, for many years, managed from a traditional perspective that seeks to fulfill a locally critical need through a single-purpose solution. However, as discussed in the previous chapter, this approach disregards the systemic nature of rivers and often results in unwanted negative impacts, both locally and at catchment scale (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014). Furthermore, this type of projects have often been implemented at the expense of other potential services that urban rivers could provide, thus undermining their importance (Walsh, et al., 2005).

In that sense, urban river rehabilitation projects should also be developed from a broad understanding of all the needs and potentials involved, and not with the single-focus of ecological recovery (Cockerill & Anderson, 2014). Through a more integrated vision, further social, cultural and economic aspects related to urban streams can be aligned with ecological recovery efforts on an early project developing phase (Smith, et al., March 2016). This would result in streams and spaces that live up to their full potential of supporting both nature protection and human well-being in urban settings (Walsh, et al., 2005).

Nevertheless, reconciling river ecology and urban development can be very challenging. In part, this is because for a long time these two aspects have been framed in separate academic disciplines, governmental departments, and policies/laws. Hence, a framework that seeks to integrate both aspects could notably strengthen the development process of comprehensive revitalization strategies (Ranganathan et al., 2008).

Accordingly, the Ecosystem Service Framework (ESF) has been recently incorporated into the decision-making process of certain revitalization projects, for being regarded as a good tool to understand the multiple aspects involved, assessing trade-offs, optimizing benefits and reducing risks (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014). Furthermore, it is thought to be an integrating concept for different environmental sectors, by offering a common ground for European policies such as the Water Framework Directive., the Floods Directive, the Habitats Directive, etc. (Wallis, Seón-Massin, Martini, & Schouppe, 2011).

In the following sections, the main aspects of the ESF will be described and linked to their potential use in urban river revitalization projects.

BACKGROUND AND RELEVANCE

The concept of Ecosystem Services was originally developed in the 1970s as a tool to communicate and elucidate how dependent society is on nature. Later on, the notion of economic values, as well as other values related to biodiversity, was incorporated in an attempt to quantify the provided benefits and justify ecological preservation efforts.

The 2001 Millennium Ecosystem Assessment was the first global program that implemented the Ecosystem Services Approach (ESA) with the aim of emphasizing the importance of ecosystem and biodiversity protection to support human well-being. Since then, the growing relevance of the Ecosystem Services concept has been reflected in several recent international conventions and policies. Furthermore, European and national programs are setting targets and elaborating strategies based on this notion

(Wallis, Seón-Massin, Martini, & Schouppe, 2011).

An example of this is the 2010 Conference of the Parties to the Convention on Biological Diversity, in which all parties were urged to "rehabilitating and restoring degraded inland water ecosystems and their services" and to develop mitigation strategies that "...take into account the needs and opportunities to sustain and/or enhance the services provided by inland water ecosystems and contribute, thereby, to the improvement of human well-being" (United Nations Environmental Programme, 2010). More recently, in the 2016 United Nations Biodiversity Conference was declared that in order to live in harmony with nature and sustain human well-being, biodiversity must be preserved as well as the ecosystem services it supports (United Nations Environmental Programme , 2016).

THE ECOSYSTEM SERVICES CONCEPT

Ecosystem Services are defined as the collective goods and amenities derived from ecosystems that support and enhance human well-being. Ergo, it is essentially an anthropocentric concept that categorizes ecological processes according to the impact and type of benefits they offer to human welfare (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014).

However, the Ecosystem Service Framework is grounded on the notion that there is a correlation between the ecological status of an ecosystem and its capacity of provisioning such goods and services. In that sense, the framework highlights that healthy ecosystems are primary guarantors of human wellbeing and that their conservation is imperative (Wallis, Seón-Massin, Martini, & Schouppe, 2011)

Furthermore, to facilitate a better understanding of the ways in which different aspects of the natural environment affect us, the Millennium Ecosystem Assessment has suggested categorizing ecosystem services into four broad groups: provisioning services, regulatory services, cultural services and supporting services. The latter are not direct services from which human being benefit but are recognized as the mechanisms that support the provision of all the other services, thus having and indirect but very powerful effect (Millennium Ecosystem Assessment, 2005).

The definitions of each type of service and some short examples are presented below:

- PROVISIONING SERVICES

Refer to services related to the material outputs that are naturally produced by a given ecosystem and that humans consume or use for several purposes (Wallis, Seón-Massin, Martini, & Schouppe, 2011). These include food, fiber, timber, biofuel, medicines and pharmaceuticals, ornamental resources, and fresh water (Millennium Ecosystem Assessment, 2005).

- REGULATING SERVICES

These type of services are defined by the way in which a given ecosystem affects the functioning of a broader system, all which in turn, has an effect on human well-being (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014). Ecosystems are important regulators of local climate, air quality, carbon sequestration, pollination, diseases, natural hazards, erosional processes, and water purification (Wallis, Seón-Massin, Martini, & Schouppe, 2011) (Millennium Ecosystem Assessment, 2005).

- CULTURAL SERVICES

Are defined by all the non-material benefits that humans obtain from using or simply by being close to a given ecosystem. These include recreational activities, relaxation, sports, aesthetic pleasure, spiritual experience, inspiration for diverse art forms, and mental/physical health (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014) (Wallis, Seón-Massin, Martini, & Schouppe, 2011).

Accordingly, a positive perception of the landscape is vital for people to be able to enjoy such services. This is often translated into a higher sensibility to the image of the river and its surrounding elements (green areas, shade, flowers, birds, etc.), than to its ecological characteristics (ONEMA: The French National Agency for Water and Aquatic Environments., 2017)

- SUPPORTING SERVICES

Supporting services are natural processes that are not directly used by people but sustain all the aforementioned services (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014). This type of service also differs from the others in that their impact on well-being is not easily perceptible given that changes in these processes occur over long periods of time. Soil formation, photosynthesis, primary production, nutrient cycling, and water cycling are some examples of this type of services. Also, some regulatory services, such as erosion, could also be categorized as supporting depending on the scale and time-frame on which they operate (Millennium Ecosystem Assessment, 2005).

Intensity of the Linkage:

Weak

Medium

Strong

Potential for Mediation by Socioeconomic Factors:

Low

Medium

High

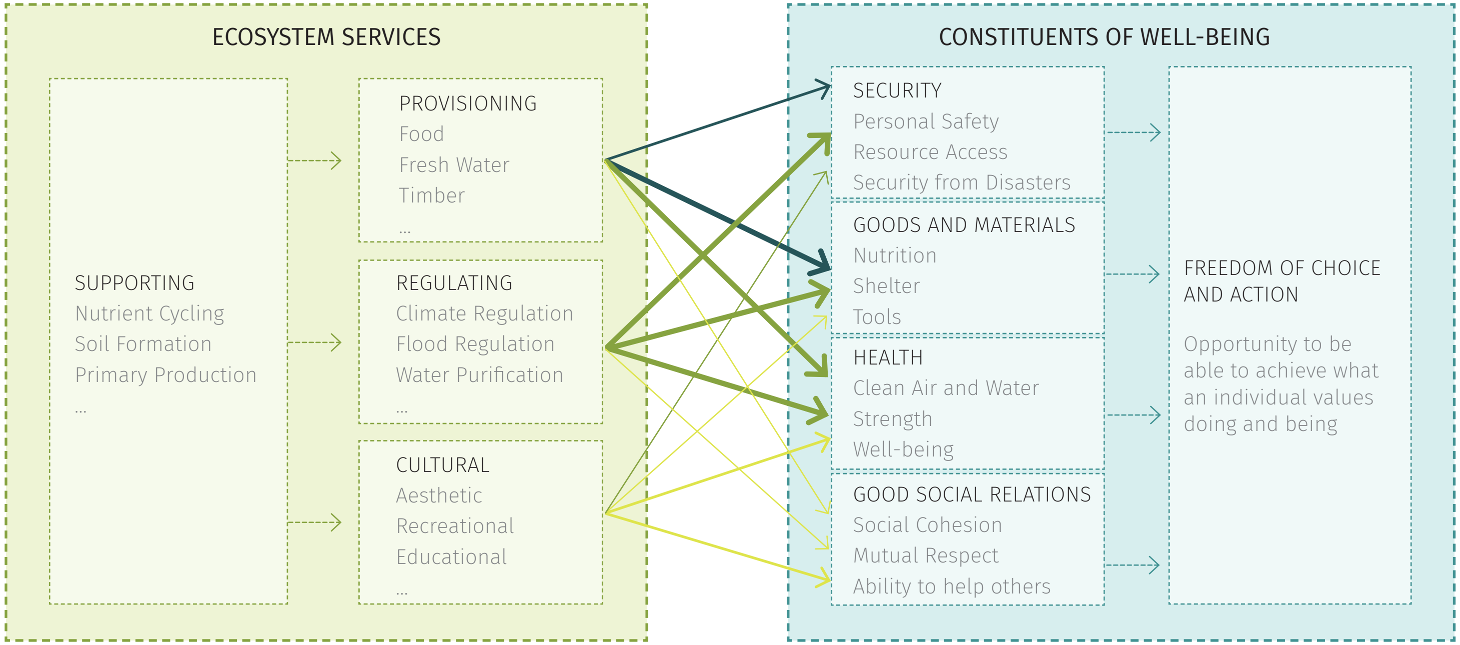


Figure 15. Linkages between Ecosystem Services and the Constituents of Well-being. Adapted from: (Millennium Ecosystem Assessment, 2005)

ECOSYSTEM SERVICES SUPPORTED BY RIVER ECOSYSTEMS

The broad characterization of ecosystem services suggested by the Millennium Ecosystem Assessment has been further developed by several studies and researches focusing on river ecosystems.

Although there is currently no specific categorization for the services that urban rivers provide, there have been assessments of ecosystems services within the urban environment. These mostly refer to services supplied by natural places within the city such as green areas, gardens, and parks, which offer similar services to those related to river ecosystems (Ranganathan et al., 2008). This might respond to the fact that forested or vegetated riparian zones are included as part of river ecosystems and, within urban areas, perform the same functions as green spaces.

The following table presents an overview of the main services that river ecosystems have the capacity to offer in each category:

SUPPORTING • Habitat provisioning (riverbed, riverbanks, riparian zone) • Water cycling (conveyance, evapotranspiration) • Nutrient cycling (nutrient spiraling and transformation) • Photosynthetic oxygen generation (diversified habitat) • Soil formation (accretion and fertility) • Animal migration (water flow and green corridors)	PROVISIONING • Fresh water (drinking, domestic, agriculture, industry) • Aquatic and riparian animals and their outputs (food, medicine and other products.) • Aquatic and riparian vegetation and their outputs • Hydropower (electricity) • Navigation (transportation, trade) • Timber, gravel, and sand (construction)
REGULATORY • Flood regulation (rainwater Storage and Infiltration) • Water flow (channel morphology, slope, materials, structure) • Water quality (nutrient removal, purification) • Groundwater regulation (recharge and discharge) • Climate regulation (local temperature, CO^2 sequestration) • Air quality regulation (vegetation diversity and density) • Erosion regulation (riparian vegetation and roots)	CULTURAL • Recreation (recreational bathing, water games, etc.) • Sports (fishing, rafting, kayaking, canoeing, running, etc.) • Relaxing (quietness, water sounds) • Tourism and ecotourism (attract non-locals) • Aesthetic value (enhance overall image of the area) • Social relations (meeting point for activities and groups)

Table 2. Ecosystem Services provided by River Ecosystems. Adapted from: (Everard, Shuker, & Gurnell, 2011) with additional information from (Everard & Moggridge, 2012), (ONEMA: The French National Agency for Water and Aquatic Environments, 2017), (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014)

IMPLEMENTING THE ECOSYSTEM SERVICE FRAMEWORK IN URBAN STREAM REVITALIZATION PROJECTS

The Millennium Ecosystem Assessment took a step further from the original concept of Ecosystem Services by developing a conceptual framework that explores the complex relationship between natural ecosystems and development. That is, acknowledging that not only do ecosystems have a significant impact on human wellbeing but that human activities are direct drivers of change for ecosystems as well, which can result in the loss or enhancement of services. Furthermore, the framework also includes the socio-economic component of development as an indirect driver of change, specifically related to the notion of value, which is very powerful on moving forward any kind of project

By linking ecosystem services to human welfare and then human activities back to ecosystem services, this framework promotes a feedback loop that, within a decision-making process, aids supporting both nature conservation and human development (Bolund & Hunhammar, 1999).

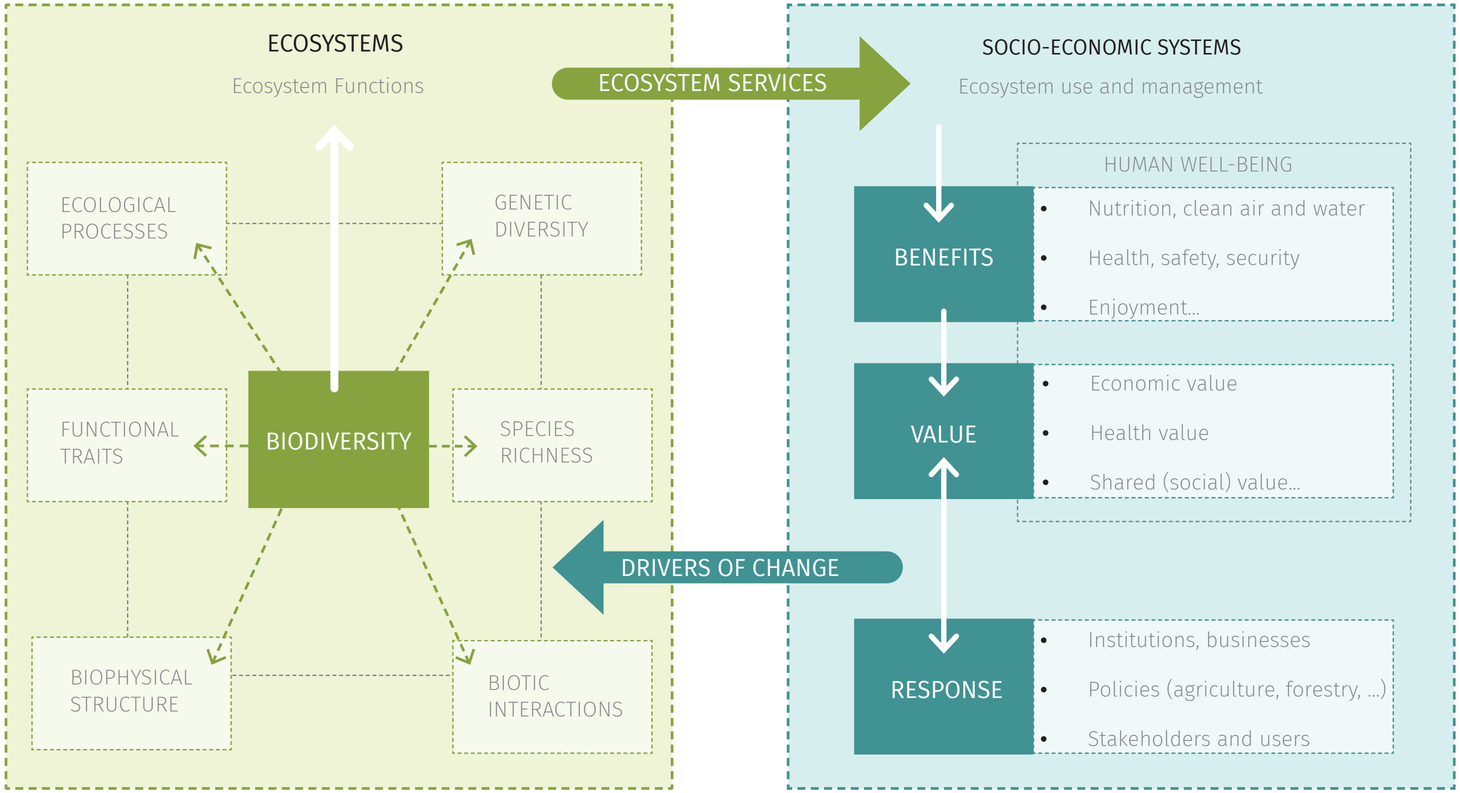


Figure 16. Conceptual Framework for EU-Wide Ecosystem Assessment. Adapted from: (Biodiversity System Information for Europe, 2017)

Consequently, the World Resource Institute developed an assessment guideline to facilitate the integration of this framework into real decision-making processes.

The guideline is structured in five steps that are linearly organized, however, in reality, decision makers should use this framework going back and forth amongst the steps as information is collected and preliminary decisions are tested.

Furthermore, a vital aspect of the framework is also the incorporation of multiple temporal and spatial scales. This means that decisions must be evaluated locally and regionally, as well as in short term and long term time periods

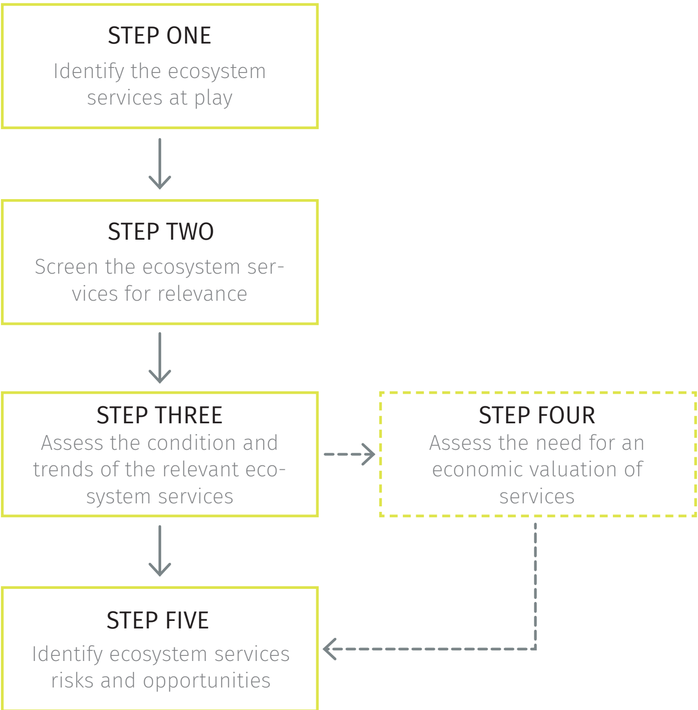


Figure 17. Overview of Steps in Assessing Risks and Opportunities Related to Ecosystem Services. Adapted from: (Ranganathan et al., 2008)

- STEP 1:

Detection of all the different ecosystems services that a decision might depend on or affect to discover opportunities that might not be obvious at first sight.. This contributes to realizing multiple benefits in such a way that none of them unintendedly deteriorates a functioning service (Ranganathan et al., 2008).

- STEP 2:

Not all the detected potential services will have the same impact on human wellbeing. It is therefore recommended to identify which ones are the most relevant in order to set priorities for the assessment process. This part of the process also informs at which spatial and temporal scale to intervene (Ranganathan et al., 2008).

- STEP 3

After prioritizing services, a more exhaustive study of the selected ones should be developed. The aim is to detect their current condition as well as their development trend. This includes underpinning the major driver of change and their real potentials for being improved (Ranganathan et al., 2008).

- STEP 4

Depending on the goals of the stakeholders, a monetary valuation can be useful in order to quantify benefits under a common metric and compare potential gains and losses (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014). However, it is not always necessary to monetize benefits to support operational decision making (Everard, Shuker, & Gurnell, 2011). Non-monetary weighting schemes, based on different qualitative and quantitate methods, are useful to examine needs and preferences expressed by users, experts and decision-makers (Kelemen, García-Llorente, Pataki, Martín-López, & Gómez-Baggethun , 2016).

- STEP 5

With all the information gathered from the previous steps, stakeholders can make a final assessment of the risks and opportunities that a certain decision regarding ecosystem services involves. This result can be in the form of results drawn from several scenario analyses or even cost-benefit analyses (Ranganathan et al., 2008).

BENEFITS OF IMPLEMENTING THE ECOSYSTEM SERVICE FRAMEWORK IN URBAN STREAM REHABILITATION PROJECTS

The Ecosystem Framework has been used in different projects involving water resource management and river basin management. The following features are regarded as the main benefits of applying this framework in such projects:

- Promotes more sustainable and integrative decisions that go beyond the single-scope of environmental issues and considers the importance of regulating and cultural aspects.
- Acknowledges the necessity for simultaneous economic, societal and ecological progress, especially in urbanized areas(Everard & Moggridge, Rediscovering the value of urban rivers, 2012).
- Incorporates elements from risk-informed management.
- Facilitates the management of complex and interconnected aspects related to ecosystems.
- Simplifies the selection of trade-offs amongst clashing interests, objectives or decisions.
- Reduces the degree of uncertainty by promoting better-informed decision-making processes.
- Identifies interested parties and potential stakeholders that could provide new funding options.
- Encourages the participation of stakeholders and citizens by putting complex ecological issues regarding services and human wellbeing. This also facilitates communication amongst all the parties involved (Brils, Brack, Müller-Grabherr, Négrel, & Vermaat, 2014).
- Optimizes the range of benefits that can be obtained by a single ecosystem.
- Aids with the implementation of the WFD by targeting ecosystem good ecological quality as the main enable of all other services (Wallis, Seón-Massin, Martini, & Schouppe, 2011).

INTERNATIONAL BEST-PRACTICE EXAMPLES FOR URBAN STREAM REVITALIZATION PROJECTS

The previous chapters present a theoretical knowledge base on the topic of urban stream revitalization. The purpose of this chapter is to complement that knowledge through empirical research based on case study analyses.

This type of investigation is particularly useful in fields such as architecture, urban planning, and landscape architecture, where real context responses are highly valuable as learning tools (Francis, 1999).

According to *A Case Study Method for Landscape Architecture*, there are four main categories around which case studies can be organized: type of project, type of problem, geographic location, or by designer. Each one of them serves a particular purpose and offers different benefits (Francis, 1999).

For this investigation, case studies were selected by type of project to provide a better understanding on how a variety of aspects related to urban river restoration can be addressed. Also, by choosing international examples, an overview of the state of the art on the matter is presented.

After analyzing numerous examples related to the topic, a selection criterion was developed in order to create a common ground for the projects to be analyzed. The criterion takes into consideration the concepts and principles presented in the previous chapters as well as practical aspects to make it comparable to the case of Pleichach River, which is the subject matter of this thesis:

- Pre-restoration condition of the stream: Concrete channel or tunnel
- Location: Urban setting and urban catchment
- Scale: Reach scale
- Objectives: Multi-purpose (address multiple categories of ecosystem services)
- Construction date: Minimum 5 years ago
- Information Availability: Bibliographic, web and archival material (photos, videos, drawings)

It must be noted that aspects related to location and climate are not part of the selection criteria, given that to be able to compare river processes many other aspects, such as the type of river, type of sediment, flow regime, etc. have to be comparable as well. In that sense, additional information on reference reaches comparable to the Pleichach River will be presented in the next chapter.

Finally, based on the aforementioned aspects, three international best practice examples were selected to be presented in detail and be reflected upon. While they all comply with the criteria, each one of them represents one of the three main strategies found throughout the analyzed examples:

1. IN-CHANNEL RESTORATION
2. CHANNEL IMPROVEMENT
3. CHANNEL REMOVAL OR STREAM DIVERSION

1. IN-CHANNEL RESTORATION:

SOMER RIVER AT MIDSOMER NORTON

- **Location**: Midsomer Norton, Somerset. England
- **Rainfall:** Annual average 814 mm
- **Temperature:** Annual max. 14.3 °C – Annual min. 6.6 °C
- **Name:** Somer River
- **Type:** Low energy, clayey substrate
- **Total catchment area**: 8.3 Km²
- **Total length:** 7.7 Km
- **Restoration site within catchment**: Downstream
- **Restoration length:** 167 m
- **Culmination date:** May 2011
- **Construction costs:** 40,000 British Pounds
- **Main topics:** Sediment transportation, biodiversity, townscape.

Figure 18. Somer River at Midsomer Norton after Restoration. Taken From: (Tootlepedal, 2017)

2. CHANNEL IMPROVEMENT

SAW MILL RIVER AT YONKERS (PHASE I)

- **Location:** Yonkers, New York. United States
- **Rainfall:** Annual average 1,173 mm
- **Temperature:** Annual Average 11.5 °C
- **Name:** Saw Mill River
- **Type:** Till, drift and alluvium sediment
- **Total catchment area:** 68.6 Km²
- **Total length:** 37.8 Km
- **Restoration site within catchment**: Downstream
- **Restoration length:** Approx. 250 m
- **Culmination date:** 2011
- **Construction costs:** 19 Million Dollars (Phase I)
- **Main topics:** Fish migration, economic/social revival, public spaces.

Figure 19. Saw Mill River in Yonkers after Restoration. Taken from: (PS&S Integrated Services, 2017)

3. CHANNEL REMOVAL OR STREAM DIVERSION

KALLANG RIVER AT BISHAN-ANG MO KIO PARK

- **Location:** Bishan, Singapore
- **Rainfall:** Annual average 1,327mm
- **Temperature:** Annual Average 30°C
- **Name:** Kallang River
- **Type:** -
- **Total catchment area:** 140 Km²
- **Total length**: 10 Km
- **Restoration site within catchment**: Upstream
- **Restoration length**: 3.2 Km
- **Culmination date:** 2012
- **Construction costs:** 45 Million Euros
- **Main topics:** water supply, flood management, biodiversity, recreational space.

Figure 20. Kallang River at Bishan-Ang Mo Kio Park after Renaturation. Photo: Bingham-Hall, P. Taken from: (Australian Design Review, 2017)

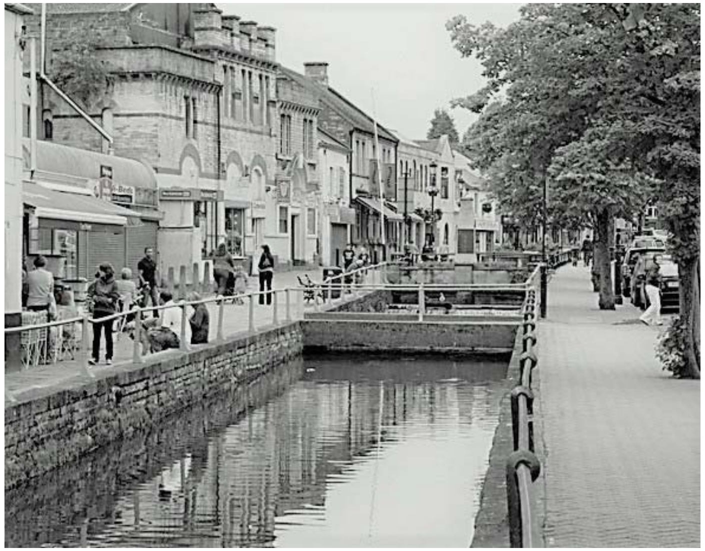


Figure 21. Somer River at Midsomer Norton before Restoration. Adapted from: Pullin, M Taken from: (Geograph, 2017).

Figure 22. Somer River at Midsomer Norton after Restoration. Photo: Woodland Water & Gardens and D. Longley. Taken from: (The River Restoration Centre)

1. SOMER RIVER AT MIDSOMER NORTON SOMERSET, ENGLAND

The Somer River is a small stream, tributary of the Bristol Avon, located in the County of Somerset, England. It originates from several small springs in the area near to the Chilcompton Village. From there, it flows in direction North East until reaching the town of Midsomer Norton. Finally, the Somer River crosses through the town, until ending in the Wellow Brook, still within the urban area (Somerset Rivers, 2017). It has a total catchment area of 8.3 Km^2 and a length of 7.7 Km (Environment Agency, 2017).

The restoration project takes place in the center of the Midsomer Norton town, which in 2013 was reported to have a population of about 11,000 inhabitants and an area of 517 ha^2 (Ofice for National Statistics, 2017). It addresses a channeled reach of the river which is 167m long and flows between the High Street and a pedestrian boulevard with a commercial front (The River Restoration Centre, 2017).

PRE-RESTORATION CONDITIONS:

This urban reach of the Somer River was a point of concern for the locals of Midsomer Morton for many years because of its poor ecological conditions and unpleasant features (Restoring Europe's Rivers, 2017).

Regarding its physical structure, the stream flows in between two vertical stone walls all along the High Street and it is culverted at both ends. The riverbed is mostly made up of natural bedrock, but concrete coverings have been applied at specific points to facilitate the construction of further in-channel structures. These include two small pedestrian bridges that crossed over the channel and three concrete weirs that impound the stream (The River Restoration Centre, 2017).

Currently, the city is not exposed to floods originating from the Somer River, given that a flood alleviation tunnel was constructed as part of a regional flood management plan (Capita Symonds, 2009). However, this measure resulted in a severe increment in the amount of sediment, especially silt, accumulating along the High Street reach. This effect was reinforced by the weirs, which halted the natural flow of sediments downstream (The River Restoration Centre, 2017).

As a result of the increased silt accumulation, in-channel habitat diversity and availability were severely affected (Restoring Europe's Rivers, 2017). Furthermore, accumulations of detritus were a cause of bad odor in the adjacencies of the channel (Woodland Water & Gardens, 2017). The frequent silt-extraction works were not efficient and signified high maintenance costs; therefore, a more sustainable solution for the problem was needed (Midsomer Norton Town Council, 2017).

Additionally, no vegetation or wildlife was present along the urban reach, giving it the appearance of a sewer more than a lively stream. In this conditions, the channel did not seem to be a feature appreciated by the locals, as the presence of litter was also very common (Midsomer Norton Town Council, 2017).

PROJECT AIMS:

The main aim of the rehabilitation project was to improve the overall conditions of the heavily silted and over-widened urban reach of the Somer River to meet the needs of the ecosystem's native species, the local community, and flood protection plans (The River Restoration Centre, 2017). In order achieve all of that, several objectives were developed in compliance with the ones set by the WFD (The River Restoration Centre, 2017). These can be divided into three categories:

Ecological:

- Enhance habitat features for native fish (especially trout) and invertebrates.
- Improve morphological dynamics to enable the natural movement of sediment downstream.
- Enable temporary water retention during extreme drought conditions.
- Restore sinuosity and water flow variation (The River Restoration Centre, 2017).
- Increase the channel's longitudinal connectivity.
- Offer a natural environment for vegetation to sustainably flourish and to reclaim the margins of the channel (Woodland Water & Gardens, 2017)

Figure 23. Somer River with concrete weirs before restoration. Photo: Shoosmith, N. Taken from: (Geograph, 2017)

Economic:

- Reduce maintenance costs by eliminating the need for constant de-silting works.
- Maintain the channel's retention capacity to avoid increasing flood risk (The River Restoration Centre, 2017).
- Use of flood resistant construction methods to secure the investment (Woodland, Water & Gardens, 2014).
- Use of local materials to support the local economy (The River Restoration Centre, 2017)

Social:

- Maximize the aesthetics of the town center (Woodland Water & Gardens, 2017).
- Enable the locals to encounter and enjoy wildlife diversity within the town.
- Raise awareness (The River Restoration Centre, 2017).
- Create opportunities to involve the locals (Woodland Water & Gardens, 2017).

DEVELOPMENT STRATEGIES:

The main strategy was to develop uncomplicated measures that would be adaptive to changes and sustainable through time. In words of Mr. Kozak, the designer and responsible contractor of the project:
"The channel was designed as a feature of engineering and we are restoring it so that it becomes a natural river by introducing a more natural process." (SomersetLive, 2011). Further project strategies addressed research and management aspects:

- Conduct an extensive channel survey to maximize potential benefits (Woodland Water & Gardens, 2017).
- Use of a natural and healthy reach of the Somer River as a reference for the development of the new geomorphology (reference condition) (Restoring Europe's Rivers, 2017).
- Reuse of the extracted silt for the new development.
- Include locals in the construction and maintenance of the project (The River Restoration Centre, 2017).

MEASURES

The main implemented measures can be divided into four categories, following the scheme of the project's construction phases: weir removal, berm construction, bed raising and adjusting, and planting aquatic margins.

- Weir removal:

After eliminating the accumulated silt in the channel, the first major intervention was to remove the three concrete weirs that obstructed the natural sediment flow. However, these were not dismantled in their totality. The two ends of each structure were kept

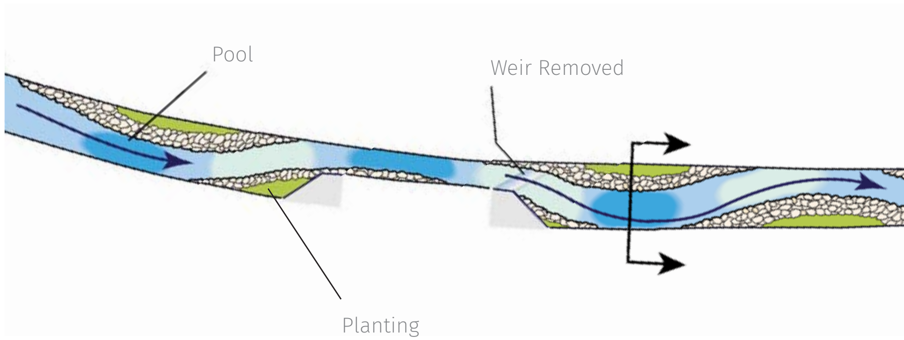


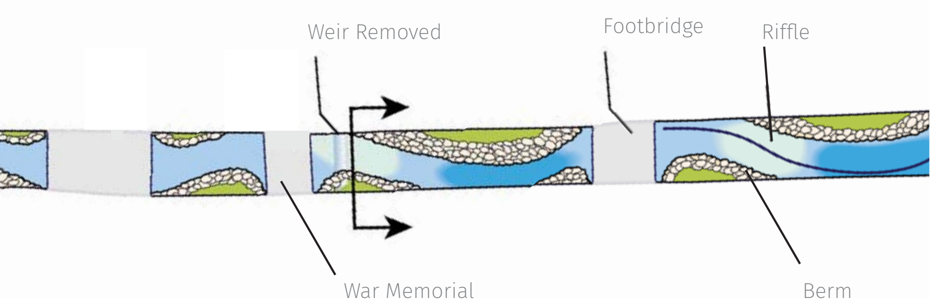
Figure 24. Plan View of New Channel Design. Adapted From: (The River Restoration Centre)

in the channel to aid the installation of temporary boards, which would again retain water in case of extreme drought. These partial structures, key for adaptive management, were incorporated into the berms (see next point) to make them less visible (The River Restoration Centre, 2017).

- Berm construction:

Sinuous berms were constructed to both sides of the channel to mimic the course of the river, help reestablish its meandering nature, and provide habitats for aquatic animals (SomersetLive, 2011). They were constructed using locally obtained limestone blocks with a maximum size of about 40x30x15 cm. These were manually placed to rebuild a sinuous edge while allowing the necessary gaps for the existing drainage pipes.

The berms also help to augment flow diversity and reduce its velocity when the river is at regular water level. However, due to being very flat elements, the stream will be able to flow over them when the water level raises. This, together with the lowering of the riverbed, ensures that the capacity of the channel is not compromised (The River Restoration Centre, 2017).



- Bed raising and fine adjustment:

After the construction of the berms, a mix of 40 to 60 mm gravel mix, obtained from a local supplier, was used to cover the top part. The same mix was also used to create natural riffles as a replacement of the old concrete weirs. These were designed as part of a pool-riffle sequence that covers the riverbed all along the restored site. The dimensioning and spacing of the pool-riffle sequence were based on the ones found in a reference reach (The River Restoration Centre, 2017).

- Planting aquatic margins:

When the riverbed adjustment was finished, the berms were lined with matting and turned into huge grow bags to be planted with vegetation native to the river (SomersetLive, 2011). The selection of the native plants was also informed by surveying a reference reach. Another selection criterion was the compulsory use of vegetation that would be visible and attractive to the users, but that would also compress in case of high flow, thus maintaining conveyance capacity (The River Restoration Centre, 2017). The planting phase was completed by local volunteers (Restoring Europe's Rivers, 2017)

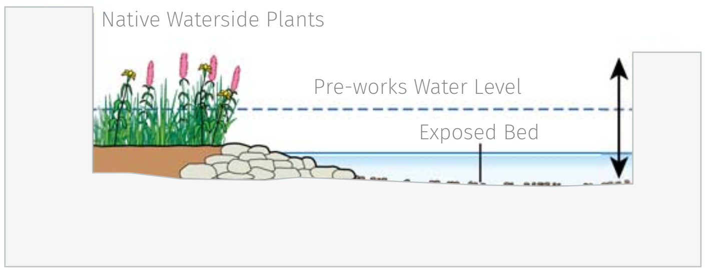


Figure 25. Cross Section through Berm. Adapted from: (The River Restoration Centre)

Figure 26. Construction of the berms

Figure 27. Silt used to fill the berms

Figure 28. Soil laid for planting

Figure 29. Members of the community working of the planting phase

Photos: Woodland Water & Gardens. Taken from: (Restoring Europe's Rivers, 2017)

RESULTS

After the restoration hed been completed in 2011, the Town Council commissioned three follow-up surveys to assess the success of the project. The most recent report, issued in May 2014, concludes that the overall diversity supported by this isolated stream in such urban conditions is remarkable, especially when compared to its pre-restoration status.

Regarding aquatic biodiversity, the report states that a major indicator of success has been the presence of the bullhead trout in all of the assessment surveys. Also, the populations of aquatic invertebrates, which were very few before the project, increased in abundance and biodiversity. All this indicates an improvement of habitat availability and diversity. Furthermore, even though the scope of the study did not include terrestrial animals or birds, evidence such as otter droppings and fish bones suggests that these communities have incorporated to the ecosystem as well (Woodland, Water & Gardens, 2014).

Flood events have been endured by the new channel, and reports have concluded that, afterward, the berms and the overall installation were in good conditions. Some minor silt accumulations have been found in low energy areas after such events. However, the channel can still be considered as a self-cleaning structure, which does not need sediment-extraction works.

Plant communities have also responded well to their new environment and high water levels. Moreover, although the greening of the space has been much appreciated by the locals, there have also been remarks about the river looking messy because of the fast growing weeds. Nevertheless, maintenance has constantly been carried out by volunteers to help keep the vegetation controlled and remove litter (Restoring Europe's Rivers, 2017)

The involvement and commitment showed by the community in volunteering and taking care of the river demonstrates the value that they give to it. Also, the Council has referred to the former lifeless river as one of the town's most important features (Midsomer Norton Town Council, 2017). The project won the civic "Pride of Place" award for environmental enhancement (Midsomer Norton Town Council, 2017) and was recognized as best project of 2011 by the Wild Trout Trust because of the quality of its design and functioning (Wild Trout Trust, 2011).

Figure 30. Somer River after Restoration. Taken from: (Wild Trout Trust, 2011)

KEY ACTORS

- Environment Agency
- Technical Experts: Woodland Water & Gardens
- Citizens' Initiative: Midsomer Norton Society who created the River Somer Management Team.
- River Somer Management Team: Representatives from the Chamber of Commerce, Redfield Residents Association, Midsomer Norton Society, B&NES Local partnerships, Midsomer Norton Town Council and local residents (Midsomer Norton Society, 2017).

FUNDING

The cost of the project was estimated around 40,000 British Pounds, which in April 2017 would be the equivalent of approximately 47,000 Euros. The funds were mostly provided by the Bath Council, the North East Somerset Council and the Midsomer Norton and Radstock Chamber of Commerce (SomersetLive, 2011).

The collaboration from these institutions was coordinated by the Midsomer Norton Society, who additionally organized a fundraising concert in the Town Hall to further support the project and involve local residents (SomersetLive, 2011).

MAIN CHALLENGES

According to the project developers, some of the main challenges were the on-site restrictions, typical of urban areas, which severely hindered the scope of the project and the measures to be implemented (The River Restoration Centre, 2017). On the other hand, although the project is technically uncomplicated, political and logistic obstacles were abundant, as it is usual in urban projects (Wild Trout Trust, 2011).

MAIN FACTORS FOR SUCCESS

Some of the main factors that facilitated the implementation of the project were:

- Silt removal prior to construction left a "blank canvas" that facilitated the implementation of the developed measures (SomersetLive, 2011).
- The flood alleviation channel allowed water flow to be easily diverted during the construction phase.
- The Midsomer Norton Flood Alleviation Scheme offered the opportunity to develop a design less constrained by the pressures of flood risk.
- The availability of a suitable reference reach within the catchment area highly informed the design process (The River Restoration Centre, 2017).
- Biological Monitoring before and after project implementation enabled evaluation and adjustments (Restoring Europe's Rivers, 2017).
- Tenacity and insistence were key drivers to overcome the overwhelming need for permits.
- Attention to detail made the project very successful amongst locals and earned it recognition and prizes. (Wild Trout Trust, 2011).
- Stakeholder engagement and community collaboration.

About the last aspect, the secretary of the Midsomer Norton Society said: "*When members voted sorting out the River Somer as our number one priority back in June 2007, we could never have imagined the amount of work required to get us to this point. In the event, the River Somer Management Project required the whole community to come together to produce a solution which will literally transform the town centre.*" (SomersetLive, 2011).

2. SAW MILL RIVER AT YONKERS (PHASE I)
NEW YORK, UNITED STATES OF AMERICA

The Saw Mill River, a tributary of the Hudson River, lies entirely within the County of Westchester in the city of New York. It originates in the town of New Castle and flows in direction southeast through several towns before reaching the city of Yonkers, where it finally flows into the Hudson. It has a total length of 37.8 Km and a catchment area of 68.6 Km², mostly comprised by heavily developed suburbia.

For most of its path, the river has been channelized and flows parallel the Saw Mill River Parkway, which is a major vehicular artery within the area. Furthermore, a 2.4 Km of the lower river section was buried inside a concrete tunnel as a measure to prevent flood events in the area of Yonkers. All this has severely impacted the river's health and its capacity of supporting aquatic life and enabling fish migration (Rogers, 1984).

In response to this, the restoration project seeks to bring back to the surface a 250 meters long section of the tunneled stretch, with the hope of improving certain ecological aspects of the river. The area selected for the daylighting project is located in the center of Yonkers and, at that time, was occupied by a small park and a big parking lot.

The main concept of the proposal is to use this strategic location for the creation of an improved public space by integrating the uncovered river with green areas and urban amenity features (Urban Waters Learning Network, 2016).

Figure 31. Larking Plaza and parking lot before restoration project. Taken from: (Kensinger, 2017)

Figure 32. Saw Mill River at Yonkers after Restoration. Taken from: (SOYO, 2017)

PRE-RESTORATION CONDITIONS

The Saw Mill River had been flowing through a large concrete tunnel or “flume” since 1920, which means about 90 years until the restoration project started in 2010. This long interval of being in the dark and flowing very rapidly resulted in the impoverishment of the river’s ecological functions (Hoeger, 2010).

A survey carried out in 2008, revealed that the river was no longer suitable for fish spawning, which is one of the most significant ecological roles of this type of stream. The amount and diversity of fish collected in this study were very low in comparison to other tributaries of the Hudson. It was suggested that the fish were mainly discouraged by the darkness, fast flows, lack of refuges, and in-channel obstacles that prevented migration (Saw Mill River Coalition, 2017).

Figure 33. Construction of the Underground Flume through which the Saw Mill Flows since 1922. Taken from: (Saw Mill River Coalition, 2017)

However, the heavily modified morphology of the river was not the only aspect affecting biodiversity. Surveys realized between 2004 and 2007 determined that the water quality index of the Saw Mill was also poor. The main problems were high levels of phosphorous, high mineral content, turbidity, and lack of plant life, which resulted in low levels of dissolved oxygen. Fecal coliform bacteria also exceeded indicator values at certain points, allegedly due to the limited sunlight exposure.

The report concludes that municipal waste water, sewage overflow, fertilizers from gardens and agriculture, and urban runoff are major sources of contamination for the river (Saw Mill River Coalition, 2017). Additionally, heavy loads of solid waste, carried from the urban and suburban areas, were also commonly found, which aggravates the quality of the water and endangers aquatic species (Hoeger, 2010).

PROJECT AIMS

The overall aim of the project is to create a central feature within the city that boosts social and economic progress while also supporting the environmental improvement of the Saw Mill River (PS&S Integrated Services, 2017).

Relative to the mixture of these three aspects as project targets, Caroline Bacle, who has examined several daylighting projects for the documentary Lost Rivers, says: “The Yonkers story is special, because it could have just been creating a fountain in the middle of a park…” “But it was about bringing back habitat for animals, which was incredible” (Kensinger, 2017).

Specific objectives addressing each one of the targeted areas to be improved are:

Ecological:

- Establish a self-sustained ecology for the uncovered stretch of the river.
- Maximize ecological functioning and create a new habitat for the largest possible amount of species.
- Foster the improvement of the river's health.
- Preserve and enhance habitats that shelter existing species, most notably, the American eel.
- Restore historically known habitats to attract absent species.
- Reestablish the connection of this river section with its upstream watershed and its downstream estuary.
- Provide safe passes for migratory fish.
- Restore submerged aquatic vegetation.
- Restore attractive habitats at the mouth of the river to encourage animals to go into the daylighted stretch of the Saw Mill instead of bypassing it when traveling up and down the Hudson.
- Avoid undesired negative impacts due to water temperature rise.
- Avoid further detriment on water quality and provide water quality enhancing features (Hoeger, 2010).

Economic & Urban Planning:

- Create a centerpiece that reflects the urban renewal plan of Yonkers (Hoeger, 2010).
- Attract more people to the city and the downtown area by making it more livable (Kensinger, 2017).
- Provide a catalyst for investment and economic development
- Link the city center to the Hudson River waterfront esplanade (Saratoga Associates, 2017).
- Make economical reuse of the existing infrastructure (PS&S Integrated Services, 2017)

Social:

- Bring nature back into the city and bring people closer to it.
- Provide an enjoyable relief in the town center (Kensinger, 2017).
- Make the river attractively visible and audible throughout the year, even during low-flow conditions (PS&S Integrated Services, 2017).
- Reconnect people with the city and the community life.
- Provide features that will encourage locals to spend time downtown (American Rivers, 2017).
- Educate the public about ecological principles and issues (Hoeger, 2010).

DEVELOPMENT STRATEGIES

- Commission surveys regarding water quality and the biological condition of the river prior to the design phase.
- Build a cooperative design process between engineers, ecologists and landscape architects.
- Evaluate the viability and sustainability of integrating desirable ecosystem features into the engineering design.
- Explore the restoration potential of several ecosystem components by building different scenarios.
- Base the channel design on future function and not as a re-

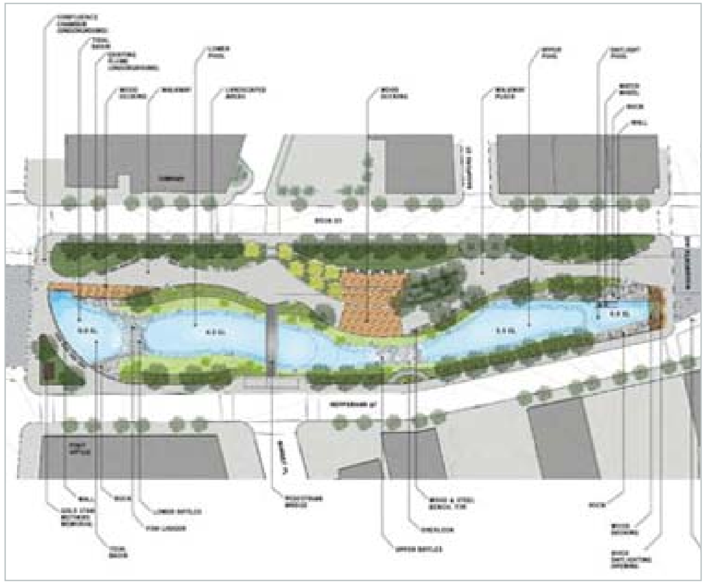
plication of the past, given the high level of urbanization within the catchment area and its growth tendency.

- Inform habitat components based on the type of ecosystems in which the river's species are commonly found.
- Employ adaptive management techniques to address changing conditions or undesired responses (Hoeger, 2010).
- Reuse the underground tunnel, which will be parallel to the new stretch, as an overflow bypass to prevent floods in the area (Urban Waters Learning Network, 2016).

MEASURES

To provide a better overview, the measures applied in the project will be presented in relation to the construction phases:

- Creation of the new river channel:



Something that differentiates this daylighting project from others is that the buried channel was not brought to the surface. It was left almost intact to be used as an overflow bypass and allow more freedom to the design of the superficial channel. The latter was excavated parallel to the original tunnel, and a chamber was built with the purpose of diverting part of the flow into it.

For the most part, the external boundary of the channel was engineered as a traditional stone wall with a translucid fence to provide safety and enable visibility. Finally, because of historical contaminants on the site's soil, the new superficial channel was lined up with heavy vinyl to prevent water contamination (Urban Waters Learning Network, 2016). Material for the riverbed and embankments had to be brought to the construction site (Hoeger, 2010).

- Arrangement of the riverbed and riverbanks:

Figure 34. Site Plan of the Daylighting Project. Taken from: (Saratoga Associates, 2017)

Figure 35. Vinyl Cover with New Riverbed Material on Top. Taken from: (Yonkers Government, 2017)

Although the river's vertical connectivity was impaired by the vinyl covering, the function of the riverbed as habitat was meant to be kept. For this purpose, a variety of soils and sediments from coarse rock and gravel to fine sand were laid down on top of the vinyl (Hoeger, 2010). The riverbed was engineered to feature rapids, pools, riffles and small waterfalls in order to create flow variation and maximize habitat availability (PS&S Integrated Services, 2017). Additionally, elements such as a fish ladder, also called Alaskan steep-pass, were included in sections that might have caused difficulties for fish migration (Saw Mill River Coalition, 2017).

For the same purpose, riverbanks with more natural features were built inside the channel's walls to be in direct contact with the water. They were designed to have a high structural variation by incorporating openings, overhangs, snags, and shallow to steep slopes. Riparian and aquatic plants were integrated into the riverbanks throughout the channel to provide habitat, shadow, and improve water quality (Hoeger, 2010).

- Urban furniture and amenity features:

Elements such as walkways, furniture, overlooks, a gathering plaza, and a pedestrian bridge were built within the project's area to enable experiencing the new space in a variety of ways. Furthermore, at some points, people can be in direct contact with the water (Saratoga Associates, 2017). This, together with adequate lighting and safety measures, encourages the residents to make use of the space (American Rivers, 2017).

Figure 36. Bio-Engineered River Banks and Disturbing Riverbed Elements. Taken from: (Groundwork Hudson Valley, 2017)

Figure 37. Public Spaces on the River Side. Taken from: (Saratoga Associates, 2017)

RESULTS

The daylighting project for the Saw Mill River successfully created almost 1300 m^2 of aquatic habitat in the middle of a highly urbanized environment (Urban Waters Learning Network, 2016). Only six months after culmination, the river was full of life and supported a wide variety of species. Some of them are the blue crab, the black-nosed dace, a diversity of ducks and turtles, and the endangered American eel. Furthermore, many species of insects were populating the native vegetation that was planted along the river margins (Urban Waters Learning Network, 2016).

Regarding water quality, a single small project is not enough to make positive changes in such an urbanized catchment. In the latest survey made by the United States Environmental Protection Agency in 2014, the status of the Saw Mill River was still labeled as "Impaired" all along the stream (United States Environmental Protection Agency, 2017).

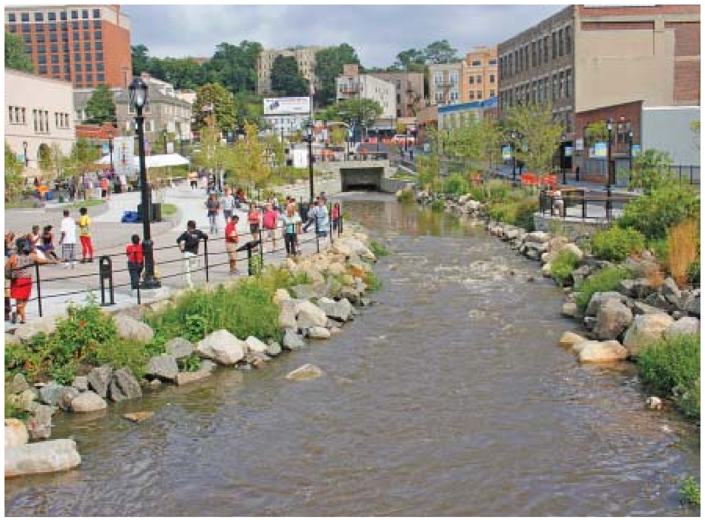


Figure 38. Daylighted Saw Mill River in Downtown Yonkers, NY. Photo: Ses7 Taken from: (Spacing Atlantic, 2017)

However, the project might have a long-term impact, given that its success has already resulted in further project phases. In 2015, another section of the river was uncovered at Mill Street and integrated into a pocket park, completing phase II of the project. The same year a third phase was announced to be built along the New Main Street in order to connect phase I and II (Garcia, 2017).

On the economic side, the new park has been recognized by The City as one of the main triggers for new private investments and construction projects that will redevelop the area. Some of the abandoned buildings along the park will be turning into the headquarters of tech companies, mixed-use complexes, and apartment towers. All of which also bring jobs to the city (Urban Waters Learning Network, 2016).

Finally, the beauty of the park and the possibility to experience water has been a major attraction within the city center. The park has hosted several events such as tours, shows, public art, and weekly markets. Also, the location has been used as an outdoor classroom by local educators to teach about the American eel (Urban Waters Learning Network, 2016). When no events are taking place, the park has been regarded as a great place to sit and relax in the downtown area, given that the sound of the flowing water blocks the noise of the city's busy traffic (Kensinger, 2017).

Overall, the project can be considered as being highly successful. The Mayor of Yonkers, Mike Spano, has celebrated it and says that "It is nothing short of inspiring, seeing the positive changes that we're seeing here in our downtown," he said. "It is truly a destination for the region." (Garcia, 2017).

KEY ACTORS

The Groundwork Hudson Valley organization partnered with the Saw Mill River Coalition started moving forward the idea of this project almost ten years before it was finally built. Along the way, many organizations, governmental offices, technical experts, and local collaborator joined the venture and collaborated with the project's development. Some of them are (Saw Mill River Coalition, 2017):

- Environmental Protection Agency Office of Water
- NY-NJ Harbor Estuary Program
- Groundwork Hudson Valley
- The Saw Miller River Coalition
- The City of Yonkers
- Project for Public Spaces, Inc.
- PS&S Engineers
- Saratoga Associates Landscape Architects, Architects, Engineers, and Planners.
- Local businesses and local community (students, teachers, artists, community groups)

FUNDING

The project formally kicked off with the designation of 34 million dollars from the Government of New York. From that point on, many other organizations and programs collaborated with the funding of the three phases the Saw Mill River's daylighting. Some of the most important mentions are the Hudson River Foundation and the Environmental Protection Agency (Saw Mill River Coalition, 2017). The monetary involvement of the latter was regarded as critical to achieving environmental outcomes and sustaining community participation (Urban Waters Learning Network, 2016).

MAIN CHALLENGES

- The proximity to traffic circulation, community resources and historical symbols (PS&S Integrated Services, 2017).
- The many existing infrastructures to be considered in the engineering design.
- Not having a natural reference for the design process given the high degree of modification of the river all along its path (Hoeger, 2010).
- Ensuring that the design will effectively enhance aquatic habitat and water quality.
- The coordination process of the many stakeholders involved in the project.
- Dealing with insecurity, vandalism and unwanted activities during the night (Urban Waters Learning Network, 2016).

MAIN FACTORS FOR SUCCESS

- Establishing a shared a clear vision from the beginning of the project with the participation of all the partners and not developing ideas in isolation.
- Involving the whole community and the people that are to be impacted by the project.
- Maintaining the project alive and connecting with different audiences through regular events and publications.
- Seeking for support by advertising the value of the project in terms of ecology, health, education, economy, and employment.
- Actively searching for the needed resources regarding time, funding, and technical expertise.
- Offering reliable evidence on costs, design, cleanup, and habitat issues (Urban Waters Learning Network, 2016).

3. KALLANG RIVER AT BISHAN-ANG MO KIO PARK BISHAN, SINGAPORE

The Kallang River is the longest stream in the island of Singapore. It originates in the center of the Island, in the Lower Peirce Water Reservoir, and flows 10 Km in direction southeast until discharging into the Marina Water Reservoir. For the most part, the Kallang flows through highly urbanized areas (ASLA, 2017).

Between the 1960s and 1970s, the Kallang was forced into a concrete channel as part of a flood alleviation program to protect these urban areas from inundations caused by monsoons. The channelized river was also one of the main infrastructures serving the system that provides fresh water to the city (ASLA, 2017). However, due to changing climate conditions and the expansion of urbanization, the conveyance capacity for which the channel was designed in the past, no longer fulfilled the requirements of today (Phyo, 2017). Additionally, the concrete was already presenting signs of deterioration and needed to be renovated (Design Singapore, 2017).

The naturalization project of the Kallang in the Bishan-Ang Mo Kio Park was born from the coincidence of the aforementioned needs and the fact that the Bishan Park, a major green area crossed by the channel, also needed to be upgraded. In that sense, the governmental entities for water and green spaces decided to join forces and recreate a floodplain concept which would free the river from the concrete channel and integrate it into the park. Hence, the green areas would serve as a flood zone when needed and as recreational space during regular conditions (Ramboll Group, 2017).

PRE-RESTORATION CONDITIONS

The Bishan Park is a large green area that was left as a buffer zone between the two highly urbanized towns of Bishan and Ang Mo Kio. However, the park seemed to be detached from the community given that the large Kallang channel was running all along its edge, acting as a strong spatial barrier (ASLA, 2017).

Also, given that the channel was designed to convey large amounts of water in case of monsoons, it seemed to be almost empty during regular conditions, which was most of the time. This gave it the appearance of being almost like a highway in the middle of a green area and made it an unpleasant feature to look at, both from the park and from the high-rise buildings around it.

On the other hand, the negative ecological impacts that such homogeneous and enlarged concrete channels are already very well known (Sand Prints- Akshardhool Archives, 2017). In the footage of the old channel, it can be perceived that no vegetation and very little biodiversity were being supported by the Kallang River.

AIMS

The overall aim of the project is to address the dual need for water supply independence and flood protection while creating access to a thriving waterscape within a dense urban area (ASLA, 2017). Specific objectives addressing each one of the targeted areas to be improved are:

Ecological

- Free the Kallang River from the concrete channel and integrate it into the park.
- Create natural, soft, and vegetated river banks.
- Increase aquatic and riparian biodiversity.
- Meet the challenges and uncertainties posed by climate change and the expansion of urbanization (World Landscape Architecture, 2017).
- Take an exemplary step to fulfill the vision of becoming a city of gardens and water.
- Increase the number and types of microhabitats.
- Promote the resilience of the species and guarantee their long-term capacity to survive (Landezine, 2017).
- Prevent soil erosion from reducing the green and recreational spaces within the park (3vsheji, 2017).
- Provide multiple and flexible water storage facilities (Design Singapore, 2017).
- Accommodate the river's natural processes without compromising the use of the park and its recreational spaces (Ramboll Group, 2017).

Economic & Planning

- Increase the capacity of the Kallang River along the Bishan-Ang Mo Kio Park (PUB Singapore, 2014).
- Utilize the channel's demolition material to build the new design and further amenities.
- Improve water quality to reduce the need for particle extraction in the Marina Reservoir.
- Increase conveyance capacity and reduce velocity to better protect the urban areas from flood events (World Landscape Architecture, 2017).
- Ensure that the constructed infrastructure will resist floods and remain in good conditions (PUB Singapore, 2017).
- Maximize land, monetary, and human resources (ASLA, 2017).

Figure 39. Kallang River Channelized at Bishan Park. Photo: Atelier Dreiseitl. Taken from: (Landezine, 2017)

Figure 40. Kallang River at Bishan Park before Renaturation. Photo: Atelier Dreiseitl. Taken from: (Landezine, 2017)

Figure 41. Kallang River Naturalized at Bishan Park. Photo: Atelier Dreiseitl. Taken from: (Landezine, 2017)

Figure 42. Kallang River at Bishan Park after Renaturation. Photo: Bingham-Hall, P. Taken from: (Australian Design Review, 2017)

Social

- Create a new space for different communities to encounter.
- Provide generous open spaces for recreational purposes
- Bring people closer to water.
- Transform the vision of water bodies being only drainages and water supply facilities (World Landscape Architecture, 2017).
- Create a positive perception and sense of stewardship towards the environment.
- Offer a space in the heart of urbanity where people can observe, preserve and nurture wildlife.
- Contribute to the livability of the city (Landezine, 2017).
- Encourage citizens to slow down and enjoy nature.
- Design friendly spaces for all kinds of visitors, especially for children, pet owners, and seniors (Phyo, 2017).

DEVELOPMENT STRATEGIES

- Involve all stakeholders in a series of workshops, tours, and discussions to establish a shared vision.
- Assume an interdisciplinary approach when dealing with water in an urban environment (Landezine, 2017).
- Have a multi-functional approach to the design of the landscape.
- Develop on-site research to inform the design process.
- Being open to exploratory proposals and innovative design solutions (Design Singapore, 2017).
- Carry out extensive on-site tests of the proposed measures and techniques before implementation (Phyo, 2017).
- Develop 3D and 2D hydraulic modeling studies to understand or predict the behavior of the developed stream (ASLA, 2017).

MEASURES

As previously mentioned, the river was developed with the idea of a natural flood plan in mind. During dry to regular weather, the stream will flow through a bio-engineered narrow channel, which maximizes green recreational space for users and enables direct contact with the water. In the event of a storm, the marginal green areas will serve as a flood plain to slowly convey the water downstream or to retain it for bio-treatment (PUB Singapore, 2017).

The design measures that enabled the implementation of this idea can be divided into 4 categories:

- Soil bio-engineering techniques:

After demolishing the old concrete channel, a new riverbed was excavated. The proposed design integrates meanders and width variations with the purpose of creating differentiated flow patterns and slowing down water velocity. Further characteristic features of natural streams such as pools, riffles, and rocky obstacles were also incorporated to enhance flow and habitat diversity (PUB Singapore, 2017).

Bio-engineering techniques were implemented in order to create seamless, stable, and erosion resistant riverbanks. However, as these techniques had not been applied in the tropics before, several on-site tests were developed months before project construction (PUB Singapore, 2017). More than ten different types of systems and plants were evaluated along a 60-meter test reach to one side of the park (World Landscape Architecture, 2017).

Figure 43. Site Plan of the Renaturation Proposal for the Kallang River at Bishan Park. Taken from: (3vsheji, 2017)

Figure 44. Progress of Soil Bioengineering over a one-year period. Photo: Ramboll Studio Dreiseitl. Taken from: (ASLA, 2017)

From these experiments, seven techniques were selected to be used in the final design according to vegetation growth, root strength, and desired slope (ASLA, 2017). Some the selected measures for bank stabilization include geotextile, geotextile wrapped soil-lifts, geotextile with plantings, rip-rap with cuttings, fascines, brush mattresses with fascines and planted gabions (World Landscape Architecture, 2017).

Additionally, a strategic selection of plants were integrated into these bio-structures to further prevent erosion and to create habitats for flora and fauna (Design Singapore, 2017).

- Decentralized water management features:

The vast amount of green areas surrounding the channel enabled the implementation of other sustainable water management facilities. These include green roofs on top of shading structures, vegetated swales, and cleansing biotopes.

While the green roofs reduce runoff by storing rainwater, the vegetated swales are used to convey the remaining run-off into the river, thus replacing conventional drains.

On the other hand, water is then pumped from the river into a 15-cell cleansing biotope to be filtered and discharged into ponds, from where it slowly flows back to the river through a cascading system.

Some of the filtered water is additionally treated with UV techniques to be used safely water playgrounds (PUB Singapore, 2014).

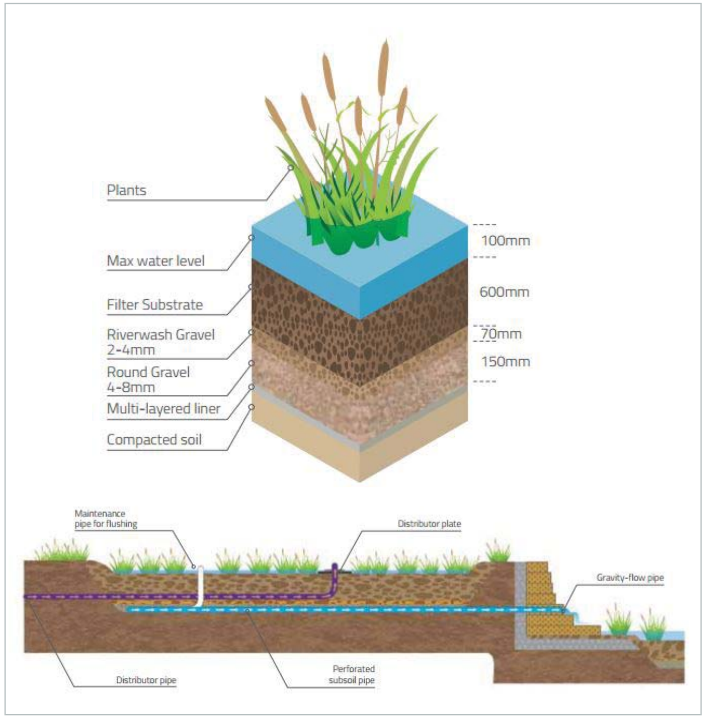


Figure 45. Details of a Biotope Water Cleansing System. Taken from: (PUB Singapore, 2014)

Figure 46. Biotope System implemented in the Bishan Park. Taken from: (Australian Design Review, 2017)

- Recreational spaces and connectivity:

The gently sloped river banks allow visitors to have direct contact with the stream and to walk along its edges (PUB Singapore, 2014). Connectivity from one side of the river to the other has been guaranteed by building three new bridges, river platforms, and stepping stone crossings, which are located all along the park (ASLA, 2017).

Additional facilities for recreational purposes include three thematic playgrounds, three plazas, a riverside gallery, sports fields, a promenade, community gardens, a dog park, and plenty of green spaces (ASLA, 2017) (PUB Singapore, 2014). A lookout point was also integrated into the design to offer a privileged view of the whole park. It was constructed using recycled concrete slabs from the demolition of the old channel (World Landscape Architecture, 2017). Finally, services such as restaurants and restrooms offer the possibility of a long and comfortable stay in the park (ASLA, 2017).

- Safety:

To ensure the public's safety, especially in the event of heavy rainfall, the floodplain area was designed to be slowly filled and provide enough time for people to easily move away to higher grounds (ASLA, 2017).

Nonetheless, a broad monitoring and warning system was also installed all over the park, which plays a vital role when it comes to making people feel safe, comfortable, and relaxed (3vsheji, 2017).

The system is comprised of elements such as water level sensors, red markings, floating indicators, sirens, warning lights, and speakers for voice announcements (ASLA, 2017).

Additionally, a safety buoy with a line, a 24 hours inspection patrol, and a television surveillance system strengthen the safety plan (3vsheji, 2017).

Figure 47. Water Park operating with recycled water from the biotopes. Taken from: (ASLA, 2017)

Figure 48. Water level indicators implemented as part of a comprehensive flood control and warning system. Taken from: (Sand Prints- Akshardhool Archives, 2017)

RESULTS

By taking the Kallang River out of the concrete channel and returning it to a naturalized flood plain, its maximum width capacity augmented from 24 m to almost 100m. This means that the conveyance capacity of the river was augmented by 40% by means of a sustainable solution costing 15% less than the original concrete channel (ASLA, 2017).

The green spaces surrounding the river have also been key elements to help reduce run-off and enhance water quality. Also, the elimination of the channel and integration of the water into the landscape has helped reduce the heat island effect and created a cooler area in the middle of such a dense city (Phyo, 2017).

Regarding biodiversity, the creation of interconnected and diverse aquatic and riparian habitats resulted in a 30% increase in the number of supported species. More than 66 new species of flowers, 59 species of birds and 22 species of dragonflies have been spotted in the park since the naturalization of the river (World Landscape Architecture, 2017). Furthermore, a few species non-native to the area have also been identified, as is the case of a family of otters, which were previously only found around the coast. This presents a significant testimony concerning the level of ecological success that the project has achieved (ASLA, 2017).

On the other hand, the renovation of the Bishan-Ang Mo Kio Park has been widely praised by the city's residents. It is now one of Singapore's most visited parks, receiving more than 3 million users per year (PUB Singapore, 2014). It now functions as a gathering space that connects the once separated neighborhoods around it (Phyo, 2017) and it cultivates a sense of belonging and stewardship towards the river (3vsheji, 2017).

Overall, the park could be considered as an exemplary case of how to maximize the benefits of an ecological infrastructure by integrating water conservation, flood management, biodiversity protection and public spaces (3vsheji, 2017). The project has the potential to influence the region into developing similar solutions and serves a reference for the use of bio-engineering techniques in tropical climates (Design Singapore, 2017).

Figure 49. Locals spending time in the naturalized Kallang River. Photo: Dreiseitl. Taken from: (Landezine, 2017).

Figure 50. A family of otters has returned to the naturalized river after years of being absent in the area. Photo: Khoo, M. Taken from: (ASLA, 2017)

KEY ACTORS

The project was a joint initiative between Singapore's Public Utilities Board (PUB) and the National Parks Board (NParks) with the collaboration of international technical experts:

- Singapore's Public Utilities Board (PUB) + ABC Waters Program
- Singapore's National Parks Board (NParks)
- Ramboll Studio Drestil Design (Germany)
- CH2M Hill Engineers (Global company with headquarters in The United States)
- Peter Geitz & Partner Biological Engineering (Germany)

FUNDING

The project was co-financed by Singapore's Public Utilities Board (PUB) and National Parks Board (NParks) (Beatley, 2016).

MAIN CHALLENGES

According to the involved stakeholders and technical experts, the main challenges related to the project were:

- Redefining the boundaries of the two main agencies involved given the highly integrative approach of the project (ASLA, 2017).
- Protecting the park area from being reduced by the river's natural erosion processes (PUB Singapore, 2017).
- Applying bio-engineering techniques for the first time in a context like Singapore, which required intensive testing and experimental works (Sand Prints- Akshardhool Archives, 2017).
- Ensure safety for park users in case of abrupt storms and food events (Design Singapore, 2017).

MAIN FACTORS FOR SUCCESS

According to the involved stakeholders and technical experts, the main factors for success were:

- Political will and leadership from the responsible governmental institutions.
- The collaboration between institutions to address multiple aspects in one single project.
- The holistic vision of the ABC Program, which understood the project as part of a bigger management plan that addressed the entire water loop of the island.
- The support of various partners including the private and public sector.
- The support of community partners that organize activities to keep the general public constantly engaged (PUB Singapore, 2017).
- Continuous monitoring of the efficacy of the implemented techniques and adjusting them when necessary (Beatley, 2016).
- Combining on-site tests and digital simulations to inform the design process.
- Investing in intensive training for the construction team to ensure the quality of the project (ASLA, 2017).

COMPARATIVE ANALYSIS OF THE BEST RRACTICE EXAMPLES

The three presented projects are successful examples of how degraded stream reaches, within an urban setting, can be enhanced through a multi-functional approach. That is, instead of focusing on one single aspect, the projects strive to maximize benefits by taking into consideration all the potential services that the ecosystem can provide.

In all cases, these potential benefits were translated into specific project objectives, mostly related to local ecological rehabilitation (supporting services), flood protection (regulatory services), spatial quality and human well-being (cultural services). Aspects related to provisioning services such as obtaining primary materials or water are less represented in this type of urban project. Only in the case of the Kallang River in Singapore, provisioning services were considered in the form of water feed for playgrounds and water games.

Given this holistic approach, the proposed solution for each project manages to offer significant improvements compared to the pre-restoration state of each river. However, when compared to each other, it can be noted that each project presents a different degree of improvement for the aforementioned services. This is because, even though the aims might be similar, each project responds to specific opportunities and limitations, which can be of ecological, spatial, social or economic nature.

In that sense, objectives and measures were developed based on what was desirable and at the same time feasible, instead of on pre-conceived ideas that might not apply to the circumstances. This does not mean that practical examples such as the ones presented cannot be used as valuable sources of information for future projects. On the contrary, they are of much value to understand processes, opportunities, and difficulties that can be encountered. However, it is important to use this information under the premise that best practice solutions should be first critiqued, tested and adapted instead of directly transferred into another project.

For example, the practice of developing solutions based on a referential river reach or pre-development conditions was not applicable for all the presented cases. It was applied in the case of the Somer River because a healthy reference reach was available within the catchment and because the catchment was not heavily urbanized. Nevertheless, in the case of the Saw Mill River, a reference reach was not available, and the catchment area was so heavily urbanized that mimicking pre-development features would not have been a suitable response to current and future conditions. Instead, the designers focused on the targeted species and the characteristics of their natural environments to develop habitats while channel capacity and morphology were based on the current behavior of the urbanized river channel.

Many differences of the sort can be found between the presented projects and, as previously said, this answers to the fact that each one focused on developing site-specific solutions. However, coincidental aspects were also found amongst the projects, mostly related to the way in which the development process was approached than to the specific measures selected.

In that sense, through the systematic analysis that was developed, it is possible to abstract the basic coincidental aspects between projects as generalizable knowledge on how best practices have approached urban stream restoration projects. These are:

AIMS: Ecological: • Enhance habitat availability and diversity • Restore sinuosity • Promote flow variability • Enable longitudinal connectivity • Improve water quality (turbidity, temperature, etc.) • Improve biodiversity Economic: • Avoid increasing flood risks • Use flood resistant construction methods • Use local or recycled materials • Reuse available infrastructure Social • Provide a new way of experiencing urban waterscapes • Contribute to the livability and aesthetics of the city • Raise ecological awareness	MEASURES (general aspects to be improved) • Remove or enhance technical surfaces (concrete walls, weirs) • Diversify riverbed materials and structure (pool-riffle sequences, boulders, etc.) • Restore aquatic vegetation and habitats • Restore riparian vegetation and habitats • Prevent erosion processes or floods from damaging the project • Use existing infrastructure as overflow channel • Ensure the safety of users • Enable accessibility and recreational use (indirect or direct)
	KEY ACTORS AND FUNDING: Multiple stakeholders and investors
	MAIN CHALLENGES: • On-site restrictions and infrastructure • Logistics between multiple stakeholders • The lack of initial site-specific information and data (having to produce them themselves)
DEVELOPMENT STRATEGIES • Multi-functional approach (ecosystem services) • Perform evaluations before and after project implementation • Develop site-specific solutions • Develop adaptive measures • Create a team of specialists from different disciplines • Include the local community in the design process	MAIN FACTORS FOR SUCCESS: • Participative development process between all the experts and partners involved • Community engagement • Investing time and resources seeking information/data, technical experts, stakeholders, staff training, etc.

Table 3. Coinciding Basic Principles between the Presented Best Practice Examples.

From the analysis developed in this investigation, a few remarks can also be made regarding the process of analyzing and comparing restoration projects. On the one hand, it was important for the purpose of this project to choose examples that applied a multi-functional approach to their proposals. However, this came with the challenge of having to develop the analysis using a great number of documents and sources.

The reason for this being that project reports and evaluations are commissioned to different technical specialists, depending on the evaluated topic, and the results are not compiled into a final report but have to be researched topic by topic. Sometimes only a few of the project's topics are adequately monitored after implementation while others were not even evaluated through systematic scientific methods but on the base of general observations or public success. All this makes it problematic to assess if, overall, the proposed objectives were accomplished.

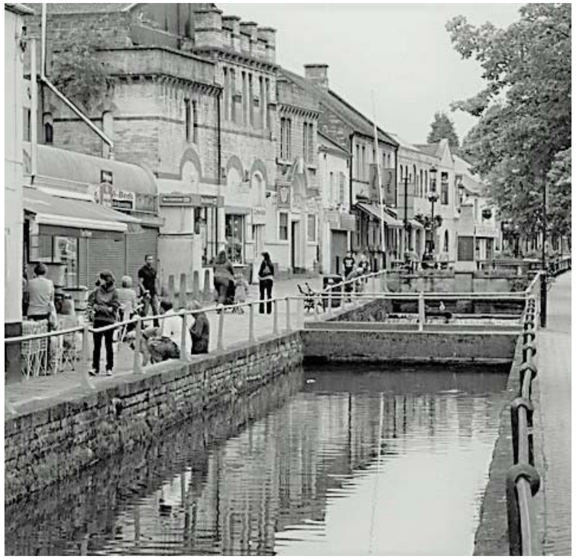
On the other hand, different opinions were found in the literature regarding when a restoration project can be considered as successful. In the case of the presented projects, evaluations were only performed on the site of the restoration and relative to the specific objectives that each case had. This means that the presented projects can be considered successful in attaining their specific goals, but their long-term impact on the overall health of the river is not clear.

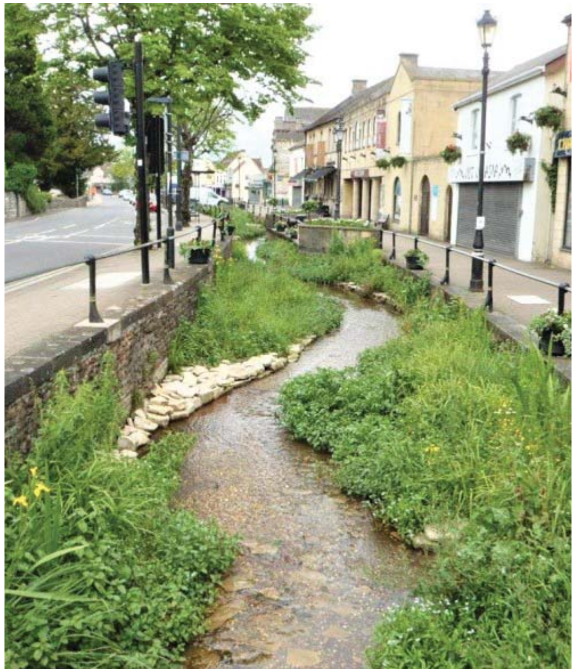
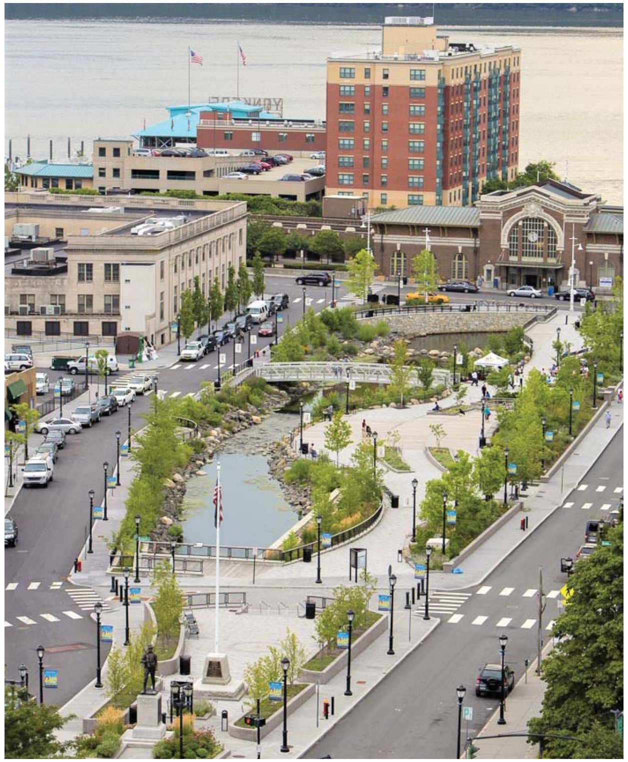
Scientific researchers that focus on environmental aspects have regarded reach-scale restoration projects as being limited when it comes to improving the overall conditions of the river (Lorenz & Feld, 2013). This is because these projects do not address catchment scale variables, which are more influential in the ecological status of the river than local habitat. In that sense, it is said that site-scale measures are likely to be unsuccessful if catchment conditions are not addressed (Lorenz & Feld, 2013)

However, when projects are evaluated through a holistic approach, taking into consideration socio-economic variables, reach scale projects in urban settings are regarded as major drivers for stakeholders to support further restoration efforts. In that way, site-specific projects do have the capacity to support long-term improvements in the ecological conditions of a river (Smith et al., March 2016).

This was the case of two of the presented case studies. The first phase of the Saw Mill River in Yonkers, which was located in the heart of the city, was so well received by the local and national community that it boosted two more restoration phases in which more stretches of the river will be daylighted and enhanced. Even though after project implementation official evaluations still labeled the river as impaired, the project was a key aspect of boosting further restoration efforts that could result in overall improvements for the river.

The same can be said for the Kallang River Project in Singapore. It was not only the first of many projects related to a better and more natural water management strategy for the region but also enabled the development of bio-engineering tests in the tropics. In that sense, reach-scale restorations also serve as testing phases for new technology that could be later implemented in projects of larger scale and have a greater impact in rehabilitating the ecology of urban rivers.




CASE STUDY: REVITALIZATION OF AN URBAN REACH OF THE PLEICHACH RIVER

This thesis was motivated by the forthcoming daylighting of an urban section of the Pleichach River, located in the Central Station area of Würzburg, Germany, and the associated opportunity to develop strategies to enhance its ecological and urban functions. So far, an overview of the most important aspects to take into consideration when facing urban stream revitalization projects has been presented, which is vital for the general understanding of the problem. In this section, the specific information regarding the Pleichach River and the restoration site will be presented, in order to complete the necessary knowledge base to develop restoration objectives and proposals.

The revitalization project is part of an overall plan proposed by the City of Würzburg to refurbish the Central Station and redevelop the facilities and open spaces that surround it. The general scheme contemplates shifting the current Bus Terminal to a nearby plot, enabling the extension of the Ring Park, the re-design of the Station's forecourt, and the renewal of its pavilions.

Also, several new buildings will occupy a former industrial area to the east of the station, amongst them an exhibition hall (1), a student residence (2), and a hotel with new parking facilities (3). The city of Würzburg will be responsible for the coordination and development of these projects, together with private investors (Rötter, 2015).

To complete the development plan, some of the old existing buildings must also be dismantled. This is the case of the parking building Quellenbachparkhaus (4), which is located to the east of the Central Station and stands on top of a nearly 270-meter-long stretch of the Pleichach. The decision to demolish the Quellenbachparkhaus responds to both its poor structural condition and the intention to make the Pleichach visible again, thus enhancing

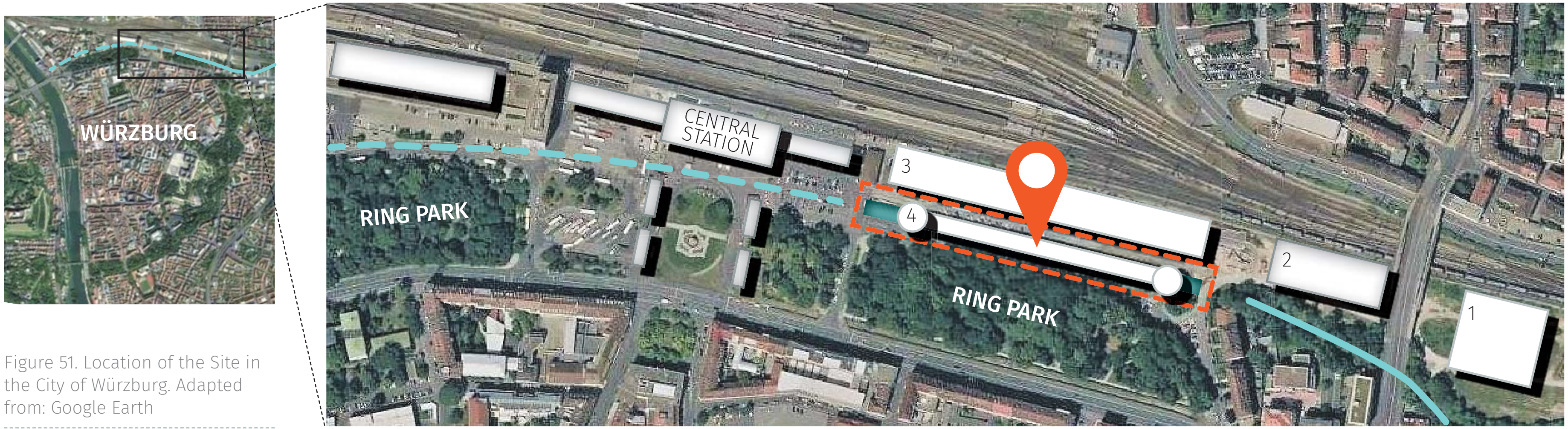


Figure 51. Location of the Site in the City of Würzburg. Adapted from: Google Earth

the overall design quality of the area (Wötzel, 2016).

However, in its current condition, the stretch of the Pleichach that runs under the Quellenbachparkhaus does not stand as an enjoyable landscape feature. On the contrary, only a shallow and turbid layer of water runs along the 4-meter deep and 15-meter wide channel, which is visibly crossed by pipes and further technical elements.

Regarding vegetation, only scarce patches of moss and climbing plants can be seen near the uncovered ends of the channel, where sunlight reaches. No other river-characteristic elements such as rocks, woody debris and coarse organic matter are noticeable, and a diverse aquatic fauna is also missing. Therefore, in order to turn the stream into a pleasant feature, it must not be only uncovered but also restored.

According to the director of the Planning Department, Christian Baumgart, a plan to enhance this section must be developed in order to offer the citizens a different and enjoyable way of experiencing the water. However, a full renaturation of the uncovered stretch will not be feasible due to the high expenditures a project like this would require. In that sense, after negotiations between the City and the private investor planning to build the new hotel and parking garage, it was agreed that the latter would be in charge of financing the revitalization project. For that purpose, one million euros will be made available (Wötzel, 2016).

Even though it is clear that the current budget stands as an important limitation regarding the measures to be selected, the scope of this thesis aims to go beyond the current monetary circumstances and explore the full revitalization potential of the Pleichach after the demolition of the Quellenbachparkhaus.

In the following sections, a detailed analysis of the Pleichach River will be developed in order to inform potential revitalization solutions. This analysis takes into consideration all the aspects that were deemed relevant according to the information that has been presented in this investigation. This includes catchment processes and conditions, site-specific conditions, relevant policies and framework, and previous restoration projects.

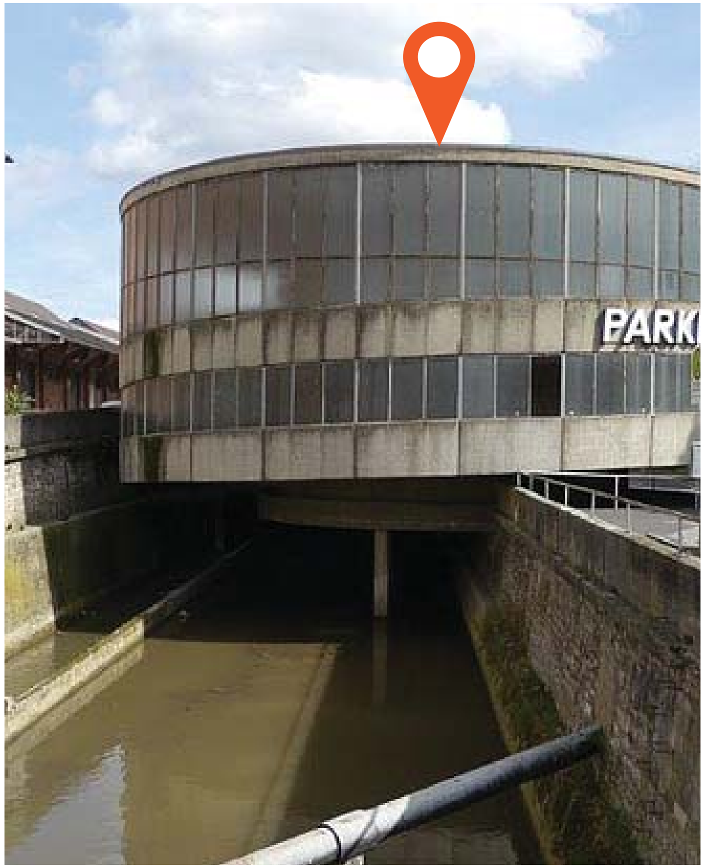


Figure 52. Ideas and plans for the development of the Central Station and its surroundings. Adapted from: Google earth and (Rötter, 2015).

Figure 53. View of the Pleichach River under the Quellenbachparkhaus. Taken from: (Gerber Architekten, 2016)

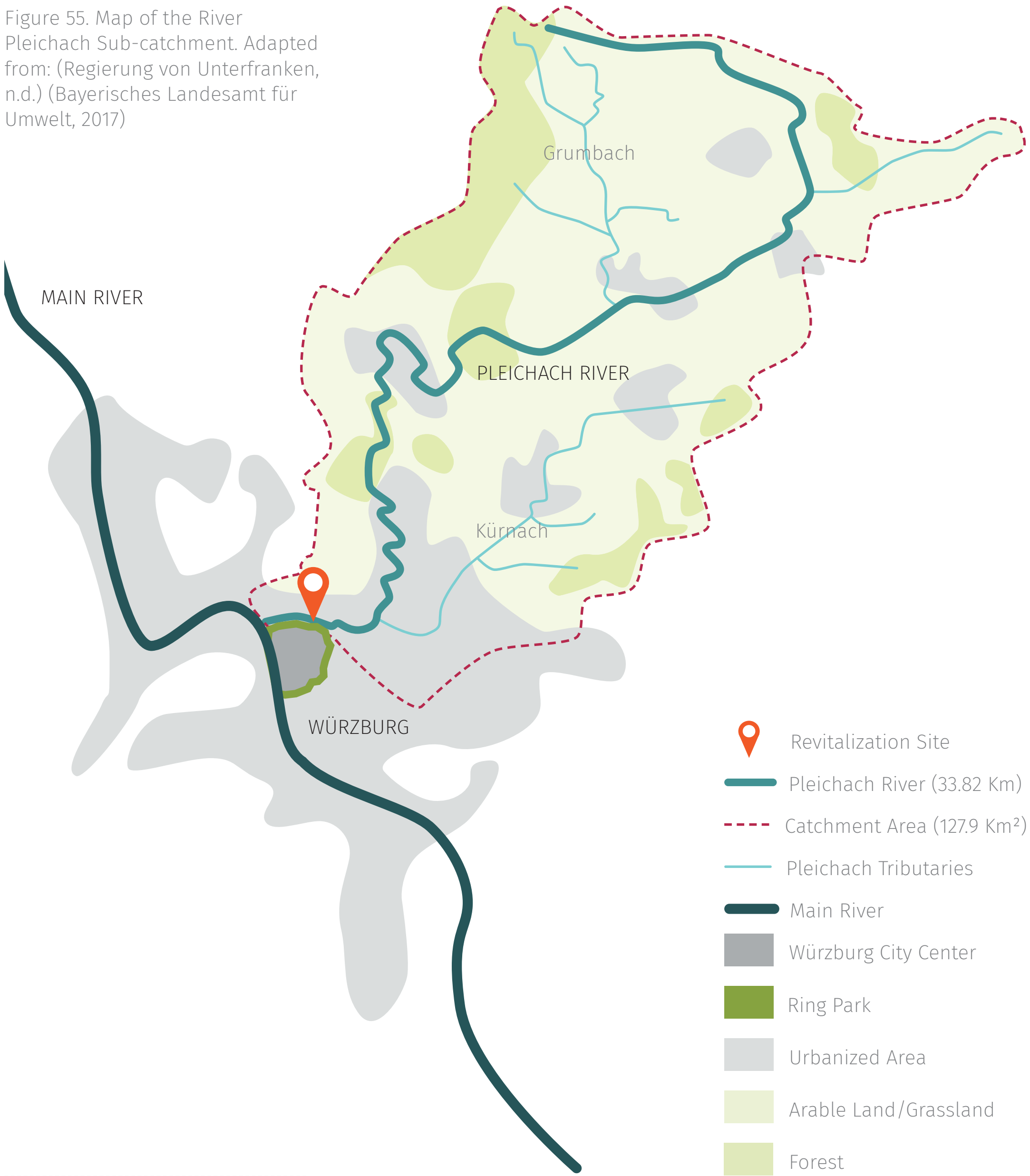
Figure 54. Photographic Analysis of the Pleichach River at Quellenbachparkhaus. Taken from: (Gerber Architekten, 2016)







Figure 55. Map of the River Pleichach Sub-catchment. Adapted from: (Regierung von Unterfranken, n.d.) (Bayerisches Landesamt für Umwelt, 2017)



THE PLEICHACH RIVER: CHARACTERISTICS, PROCESSES AND MANAGEMENT

The Pleichach is a perennial stream, tributary of the Main River, which flows through the Würzburg district. It has a total catchment area of 127.9 Km^2 and a total length of 33.82 Km (Bayerisches Landesamt für Umwelt, 2012).

From its origin in Fährbrück, close to the Gramschatzer Forest, to the influx of the Grumbach River about 14 km downstream, the Pleichach is a third-order waterway. From this point on, it turns into a second-order stream and keeps flowing in direction southwest for another 20 Km before discharging into the Main. This last section is called "Lower Pleichach," and as a second order stream, it falls under the responsibility of the Water Management Agency of Aschaffenburg (arc.grün Landschaftsarchitekten & Stadtplaner, 2014). Besides the Grumbach, other main tributaries of the river are the Quelbach, the Eselsbach and the Kürnach (Wasserwirtschaftsamt Aschaffenburg, 2016).

LAND USE

Land use in the catchment area of the river varies along its course. In its higher zone, forests, orchards, and gardens cover the terrain. On flatter areas, arable land and grassland are the predominant uses. In the valley area, agricultural practices intensify, and there is no buffer zone to separate the river from the arable land, other than an occasional and interrupted arbored border (Wasserwirtschaftsamt Aschaffenburg, 2016).

Agricultural practices and the high level of exposure of the river have caused chemical deficits related to oxygen-depleting organic substances and nutrients (nitrogen, phosphorus) that enter the stream through discharges from this activity, as well as from wastewater (Bayerischer Landtag, 2016).

The Pleichach also crosses through urbanized areas. Some of them are small, like Maidbronn or Rimpar, and some bigger like the city of Würzburg. In all of them, however, long sections of the river have been modified to flow through straight and narrowly confined channels with paved riverbeds and strengthened embankments. Additionally, most of these concrete structures are already timeworn. (Wasserwirtschaftsamt Aschaffenburg, 2016).

The last section of the river flows alongside the city center of Würzburg, parallel to the continuous green area of the Ring Park. However, the Pleichach cannot be seen or experienced given that it is culverted for the most part. Along the reach on which this project is focused, it is not culverted but covered by a Parking Facility, completely neglecting its potential as a public recreational space able to offer the experience of nature within an urban environment (Wasserwirtschaftsamt Aschaffenburg, 2016).

TOPOGRAPHY

Throughout its path, the Pleichach crosses a hillside with a height difference of approximately 160 m, that when divided by the length of the river, results in a mean gradient of around 0.47% (Wasserwirtschaftsamt Aschaffenburg, 2016).

In the upper section of the catchment area, the river substrate consists of gypsum covered by loess and loess-loam. In the middle section, a regular layer of limestone and claystone, called upper Muschelkalk, lies beneath the loess. Here, the valley presents a deeper cut and sediments tend to accumulate. In the bottom of the valley, alluvial soils with calcareous and clayey deposits are found (Wasserwirtschaftsamt Aschaffenburg, 2016).

CLIMATE & HIDROLOGY

Climate conditions in the catchment area are characterized by a mean yearly temperature that oscillates between 8.3 and 8.6 °C, with an increase of up to 9.4 °C in the urban area. Throughout the year, July is the warmest month with a mean temperature of 18.7°C, whereas January is the coldest month with an average temperature of -0.2°C (Climate-Data.org, 2017).

Regarding precipitation, the area is one of the driest in Bavaria due to the rain shadow created by the Spessart Mountain Range (Landratsamt Würzburg, 2017). Average yearly precipitation falls between 550 and 600 mm in Würzburg, being February the driest month with an average of 37mm and June the rainiest with 72mm. In comparison, Munich has an average yearly precipitation of 950mm (Stadt Würzburg, 2017).

Mean rain intensity for regular 15-minute events is 106 l/s*ha, however less frequent occurrences with the same duration could have an intensity of up to 218,7 l/s*ha (10 years) or 331,9 l/s*ha (100 years) (Stadt Würzburg, 2017). The Pleichach flows into the Main River with an average discharge of 60 m³/s (Wasserwirtschaftsamt Aschaffenburg, 2016).

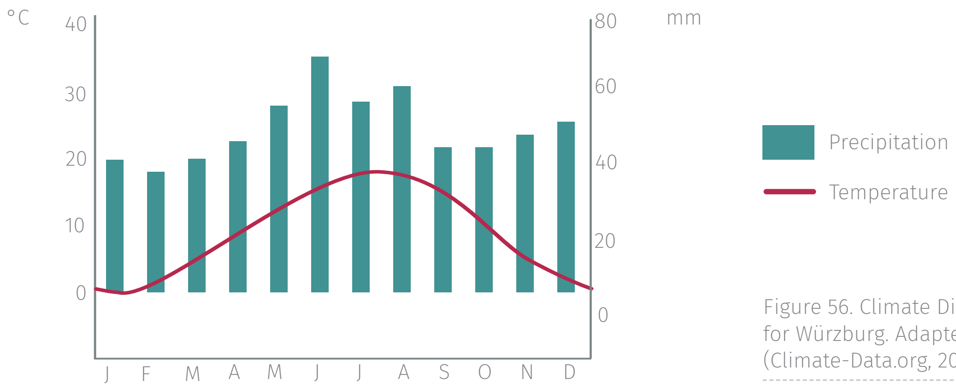


Figure 56. Climate Diagram for Würzburg. Adapted from: (Climate-Data.org, 2017)

FLOOD RISK

Due to the many technical modifications made to the channel and the land surrounding it, for example, the extensive sealing of soil within the urban areas, the potential adverse effects of heavy rainfall events has increased. According to the Bavarian State Office for Environment, the section of the Pleichach flowing from the mouth of the Grumbach to the Main River, 19.7 kilometers in total, represents a significant flood risk (Bayerisches Landesamt für Umwelt, 2011).

The area marked as HQ100 in the following figure has been designated as the fixed flood zone for the Pleichach within the urban area of Würzburg. In order to reduce the negative impacts of flood events in water quality, the city developed the "*Ordinance of the City of Würzburg in the flood area on the Pleichach On the municipality of Würzburg from river kilometer 0,00 to river kilometer 8,96.*" This ordinance is based on water protection measures presented in the Water Resources Act (WHG) and the Bavarian Water Act (BayWG) (Stadt Würzburg, 2013).

The most important protection measures that apply to the marked area are related to:

- Special requirements for construction areas.
- The prohibition of locating facilities that handle water hazardous substances.
- Regulation of structures or objects that could hamper water drainage or that could be washed away and endanger the citizens (Stadt Würzburg, 2013).

Revitalization Site

Ring Park

Superficial Stream

10-year flood event (HQ 10)

100-year flood event (HQ 100)

Extreme flood (HQ Extrem)

Figure 57. Flood hazard and occurrence probability map for the Lower Pleichach in the Würzburg city center (Bayerisches Landesamt für Umwelt, 2017)

ECOLOGICAL STATUS

The two-sided concrete embankment and the sealed riverbed have severely restricted water dynamics and flow variability, and most of the natural processes explained in Chapter 1. Hence the ecological status of the river has been critically affected.

The survey realized under the Water Framework Directive principles classifies the ecological potential of the "Lower Pleichach" as "unsatisfactory" with regard to water structure, structure development capacity, and connectivity.

Consequently, the ecological status of the river was assessed as "not good," based on the criteria of trophic, saprobity, hydro-morphology and pollutants (arc.grün Landschaftsarchitekten & Stadtplaner, 2014).

Despite the fact that the aforementioned characteristics apply for the Lower Pleichach as a whole, specific data related to the restoration site, available due to the nearness of the measurement station "Km 1.7 uh Pegel Eropastern / Pleichach", also categorizes the state of the natural structure as "far from natural" (Bayerisches Landesamt für Umwelt, 2016).

Further characteristics related to the ecological status such as water level and diluted oxygen will be presented and discussed in the section "Climate Change and its Impacts."

The following table and figure present precise information on the structure, morphology, materiality and dimensions of the channeled stretch of the Pleichach at the restoration site:

CHANNEL STRUCTURE AT QUELLENBACHPARKHAUS

CROSS SECTION PROFILE	rectangular
CHANNEL WIDTH	15m
WIDTH VARIABILITY	none
CHANNEL DEPTH:	4m
DEPTH VARIABILITY	none
HIGH WATER LEVEL	2m
CHANNEL CURVATURE	straightened
RIVERBANK SLOPE	90° from sole
RIVERBANK LINING	stone wall (closed)
RIVERBANK EROSION	missing
BOTTOM LINING	concrete/asphalt
ALLUVIAL DEPOSITS	none
ACCESSIBILITY	unavailable
WATER USE	none
RIPARIAN ZONE MATERIAL	cobble stones/asphalt
NATURAL STRUCTURE	unnatural/far from natural
GROUNDWATER INFLUENCE	not known

Table 4. Channel Structure at Quellenbachparkhaus. Adapted from: (Gewässerkundlicher Dienst Bayern, 2002)

Figure 58. View of the Channel at Quellenbachparkhaus. Taken from: (Gerber Architekten, 2016)

CLIMATE CHANGE AND ITS IMPACTS

The region of Bavaria has been experiencing climate change with a general increase in temperature and redistribution of rain patterns, including increased precipitation and reduced snow cover. In the near future, the trend of temperature rise will most likely continue. A rise between +1 and +2 degrees Celsius is expected for annual averages, which could go up to between +2 and +4.5 in a distant future (Umwelt Bundesamt, 2017).

According to the report prepared by the Federal Environmental Agency on "Germany's vulnerability to climate change," the City of Würzburg is expected to experience strong temperature changes, mostly related to the rise of "heat stress" (Buth et al., 2015). These changes will undoubtedly have an impact on water resources and will need to be addressed when defining sustainable management concepts and strategies.

In recognition of that, a collaboration between the governments of the southern region of Germany has started the project "Climate Change and its Consequences for Water Resources" (KLIWA Klimaveränderung und Wasserwirtschaft, 2016).

The data collected by the project specialists show that the region has been going through a long-lasting drought, which together with higher temperatures, resulted in a low-water period. This especially affected the areas north of the Danube, including Würzbug. One of the most relevant low-water periods of the last years occurred during summer 2015 when new temperature highs were recorded in all of Bavaria. Similarly, during this period up to 87% of the measured water levels were classified as "low" or "very low." As a consequence, severe impacts were recorded in the regional water ecosystems, such as the drought of smaller streams and the devastation of its aquatic biota (KLIWA Klimaveränderung und Wasserwirtschaft, 2016).

Another report developed by KLIWA on the topic "Impact of climate change on river water quality" concludes that with the increase of water temperature, the levels of diluted oxygen tend to decrease. This effect does not have a significant impact on upper stream reaches because of the relatively high velocity with which water tends to flow down the terrain.

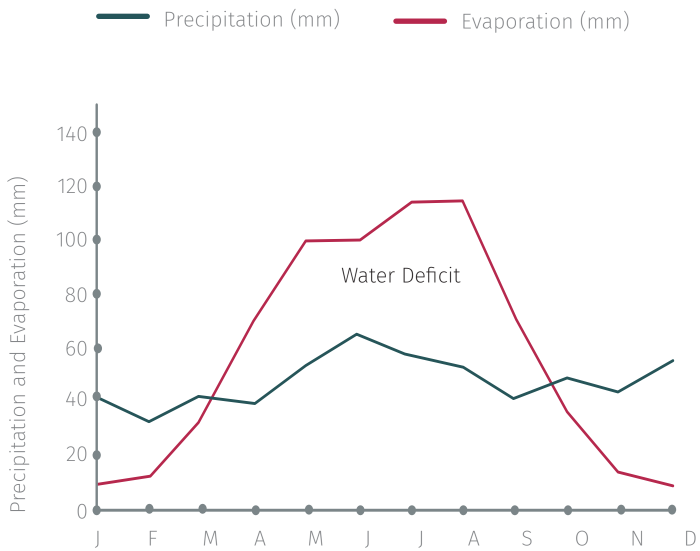
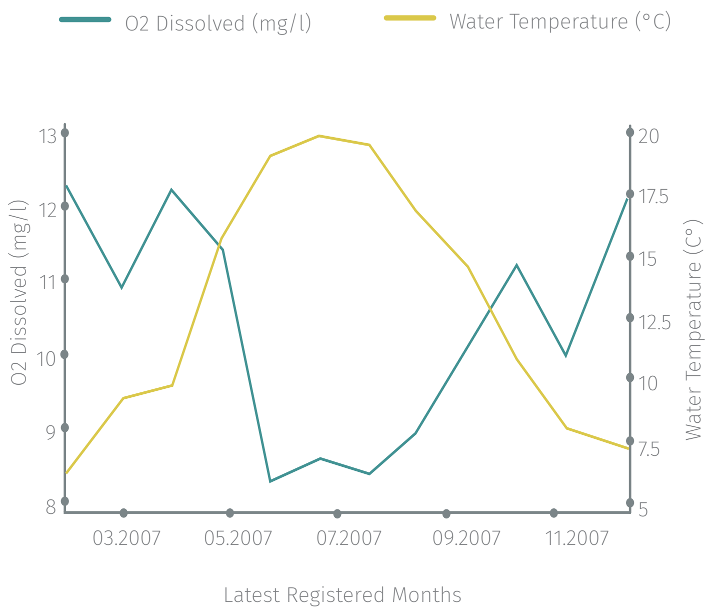


Figure 59. Mean Yearly precipitation and evaporation in Würzburg (Stadt Würzburg, 2017)

However, in lower reaches such as the urban section of the Pleichach, where water flows slowly and is more exposed to solar radiation, the levels of diluted oxygen can be more compromised, hence the capacity to support aquatic organisms (Jähnig et al., 2010).

Overall, the impacts of climate change are harder to pinpoint in the lower reaches of a stream due to the multiple variables that can influence its conditions, including all the processes occurring within the upper catchment area. For example, levels of diluted oxygen in the Pleichach can be responding to a combination of temperature increase and, as it was previously mentioned, the discharge of oxygen-depleting nutrients from agricultural practices.



Therefore, the effects of climate change will be more evident when studied in upper reaches of a river. This effects can be subsequently projected into the lower sections, as a way of trying to isolate them from other catchment processes and their impacts (Jähnig et al., 2010).

NATURAL ECOLOGICAL STATE AS REFERENCE

To assess the ecological status of a stream and develop recovery strategies, specific reference conditions of its natural or semi-natural state are required. Hence, the characterization of all the different surface water body types is an essential step for the implementation of the EU Water Framework Directive.

Consequently, the German Working Group of the Federal States on Water Issues (WGWI) commissioned the classification and description of the relevant stream types in the country (Pottgiesser & Sommerhäuser, 2014). In addition to this profiling, which describes the ideal characteristics of the biotic and abiotic components of a given water body type, further descriptions of the expected hydro-morphological features and behaviors for each case were developed (Dahm et al., 2014).

According to the map of the relevant stream types for Germany, the Pleichach River falls under the category of a Type 6 river, which refers to “small fine substrate dominated calcareous highland rivers” with a catchment area between 10 and 100 m² (Umweltbüro Essen, 2003).

When in excellent ecological conditions, this type of stream is characterized by a sinuous to meandering morphology that results from the erosion of its soft and diverse substrate, predominantly composed of silt, loess, clay, and fine sand. The channel tends to be embedded on the ground and to present undercut banks. Its width and depth are variable along the stream, embracing high structural diversity. The riversides are predominantly accompanied by alder and ash trees, which provide shadow to a large portion of the channel (Dahm et al., 2014).

Figure 60. Yearly values for dissolved oxygen and water temperature at Measuring point km 1,7 uh Level Europastern/ Pleichach (Bayerisches Landesamt für Umwelt, 2017)

Additional features such as coarse woody debris and clusters of organic matter are common. Moreover, suspended material and nutrients are abundant in this type of river, producing turbidity in the water but also supporting high macrophyte populations, especially mosses. The macroinvertebrate community is comprised by rheophilic hard substrate dwellers and fine substrate dwellers in equal shares. The fish community is characterized by highland species such as the brook trout, bullhead, and brook lamprey. (Pottgiesser & Sommerhäuser, 2014).

When comparing the presented typological features with the Pleichach, it can be noted that some coincide, such as sediment composition and its behavior. However, differences can also be identified, as it is the case of the typical catchment area, which for the Pleichach is larger than the characteristic maximum. In that sense, it is important to note that the LAWA profiles are general characterizations and cannot substitute thorough on-site measurements. However, their use as preliminary reference regarding the natural processes related to a particular type of river can be highly valuable for the development of revitalization projects (Pottgiesser & Sommerhäuser, 2014)

On the other hand, experts have agreed on the fact that retunring a stream to its pre-development condition is sometimes neither possible nor feasible, particularly in urban areas where multiple ecosystem services must be provided, and further landscape or climate changes must be considered. Nevertheless, understanding the behavior of the stream in its natural condition is indispensable when it comes to designing measures and evaluating restoration success (Smith et al., March 2016).

Figure 61. Schematic top view and section of a Type 6 River in very good ecological condition (Dahm et al., 2014)

REVITALIZATION EFFORTS AND PRECEDENTS

Motivated by the requirements of the European Water Framework Directive, the State of Bavaria has developed an action plan to improve the conditions of its waters. The plan includes a selection of strategic measures for each water body, based on the LAWA Catalogue of Measures.

These measures are generalizations and must be further defined in a subsequent planning phase taking into consideration all the involved local concerns. The list of measures is legally regulated by Article 71a of the Bavarian Water Act (BayWG) (Bayerisches Staatsministerium für Umwelt und Verbraucherschutz, 2015).

The report Program of measures for the Bavarian share of the River Rhine suggests the following measures for the Pleichach River (Bayerisches Staatsministerium für Umwelt und Verbraucherschutz, 2015):

- Measures for the reduction of hazardous inputs related to agricultural practices (e.g., installation of water protection buffers).
- Measures to enable natural stream dynamics (e.g., land acquisition to foster meandering behavior, installation of natural flow regulation elements).
- Measures for connectivity improvement (e.g., remove obstacles and build slides, passages).
- Restructuration of the water profile in a natural way.
- Removal or reduction of massive structures in the riverbed and riverbanks.
- Conservation of the riparian zone (develop natural vegetation and reed beds along the margins).
- Measures to introduce flow variation by introducing disturbing elements on the embankments and the riverbed.
- Measures to improve habitat in the existing profile.
- In-depth investigations and controls.
- Developing and updating water development concepts.

In support of this, the Aschaffenburg Water Management Authority and the City of Würzburg have expressed to have the shared long-term goal of upgrading the ecological status of the Pleichach as far as possible, especially along the inner city area (Wasserwirtschaftsamt Aschaffenburg, 2016).

Also, a citizens' initiative entitled Ring Park in Danger (Ringpark-in-Gefahr) has put pressure on the matter by preparing the exhibition "Freedom for the Pleichach." The purpose was to raise awareness regarding the current condition of the river and to show examples of similar cases in Germany where rivers have been improved by opening and restoring their streams (Göbel, 2009). Further proposals were developed in the 2014 Würzburg Architecture Workshop, which was titled "The RINGpark - refining a faded jewel" and was exhibited in the Würzburg City Hall in 2015.

Responding to all of these endeavors, plans for revitalization began being executed by the Water Management Authority with the freeing of a river section from its concrete bed in the upper section of the channel, between Mühlhausen und Maidbronn. The rectilinear and monotonous course was structured more naturally by branching and alternating velocities, as well as by building flatter bank slopes, thus reducing the flow velocity during high water periods (Göbel, 2009).

CONCEPTUAL STUDY ON THE DEVELOPMENT OF THE PLEICHACH BETWEEN QUELLENBACHPARKHAUS AND EUROPASTERN

Later on, the city began making plans to strongly develop the inner-city area near the train tracks, from the Novum Business Center to the Würzburg Central Station. Given that the Pleichach flows parallel along these areas, the opportunity to include revitalization plans linked to the city project was seized.

In that sense, a general concept for the restoration of the Pleichach between the Quellenbachparkhaus and Europastern was commissioned to be developed by the landscape architecture and city planning firm "arc.grün." Although the project is not built yet, it must be taken into consideration given that is located immediately upstream from the Quellenbachparhaus. Therefore, it is important for projects to be congruent with one another.

The proposed design aims to provide a coherent overall concept for ecological enhancement, user appreciation, experience, accessibility, and connectivity for both the river and its waterfront areas (arc.grün Landschaftsarchitekten & Stadtplaner, 2014). Additionally, it also had to incorporate the following requirements of all the private and public stakeholders involved (arc.grün Landschaftsarchitekten & Stadtplaner, 2014):

1. Requirements from Private Investors: Coordinate with the development of a student residence, a multifunctional hall, a hotel, and parking facilities. Serving as green areas and public spaces for the facilities while paying special attention to flood protection measures.
2. Requirements from the City of Würzburg: Bike path and walking access along the Pleichach, developed as an inner-city green corridor. Taking into consideration the Landscape Plan of the City, the river must be upgraded as a main inner-city water feature, attractive and accessible for the citizens.

Quellenbachparkhaus

Figure 62. Conceptual Plan for the restoration of the Pleichach between the Quellenbachparkhaus and Europastern. Taken from: (arc.grün Landschaftsarchitekten & Stadtplaner GmbH, n.d.)

3. Requirements from the Water Management Administration of Würzbug, in accordance with the Water Framework Directive's objectives and the Program of measures for the Bavarian share of the River Rhine:

- Ecological upgrading according to the guidelines of the Water Framework Directive.
- A Green buffer zone of +/- 30 meters width along the stream.
- Promotion of natural dynamics by removing massive structures in the riverbed and riverbank.
- Increase structural diversity of the entire corridor.
- Enable the continuous and uninterrupted movement of aquatic fauna.
- Enable a recreational experience and accessibility for residents and recreation seekers.
- Avoid creating additional discharge and an overall worsening flood potential.

Taking all of these requirements into consideration, the developed measures for the revitalization of the Pleichach between Quellenbachparkhaus and Europastern were divided into three action-zones as follows (arc.grün Landschaftsarchitekten & Stadtplaner, 2014):

RIVERBED

- Development of a rich and rough bed structure (2-5 m).
- Removal of structural attachments and concrete lining.
- Expansion of the flow channel and promotion of natural dynamics.
- Development of a varying, curved water course with high flow variability.
- Structural enrichment by interfering substances such as stones, wood debris, and rootstocks
- Enabling access/crossing in defined areas only.

RIVERBANKS

- Creation of open riverbanks with greenery.
- Removal of steep slopes, replacing them with flatter ones according to spatial conditions.
- Expansion of the channel cross section and flood protection improvement.
- Adjust woody debris to assist the channel modeling process
- Place built-in seating elements such as seating steps when ever suitable.
- Ensure public accessibility and the possibility to experience the landscape.

RIVERSIDE AND FLOODPLAIN

- Expansion between 1 to 5 meters on both sides.
- Formation of shallow bank zones and transitional areas with moistened structures.
- Development of a richer border-structure through the targeted planting of site-specific bushes and wild herbaceous vegetation.
- Preservation of distinctive and typical trees.
- The upgrade and continuity of a zone for amphibious fauna.
- Creation of intermittent inaccessible shore areas for nature protection.
- Sectioning of different degrees of naturalness according to the intensity of use and neighboring land uses.
- Enable access for maintenance.

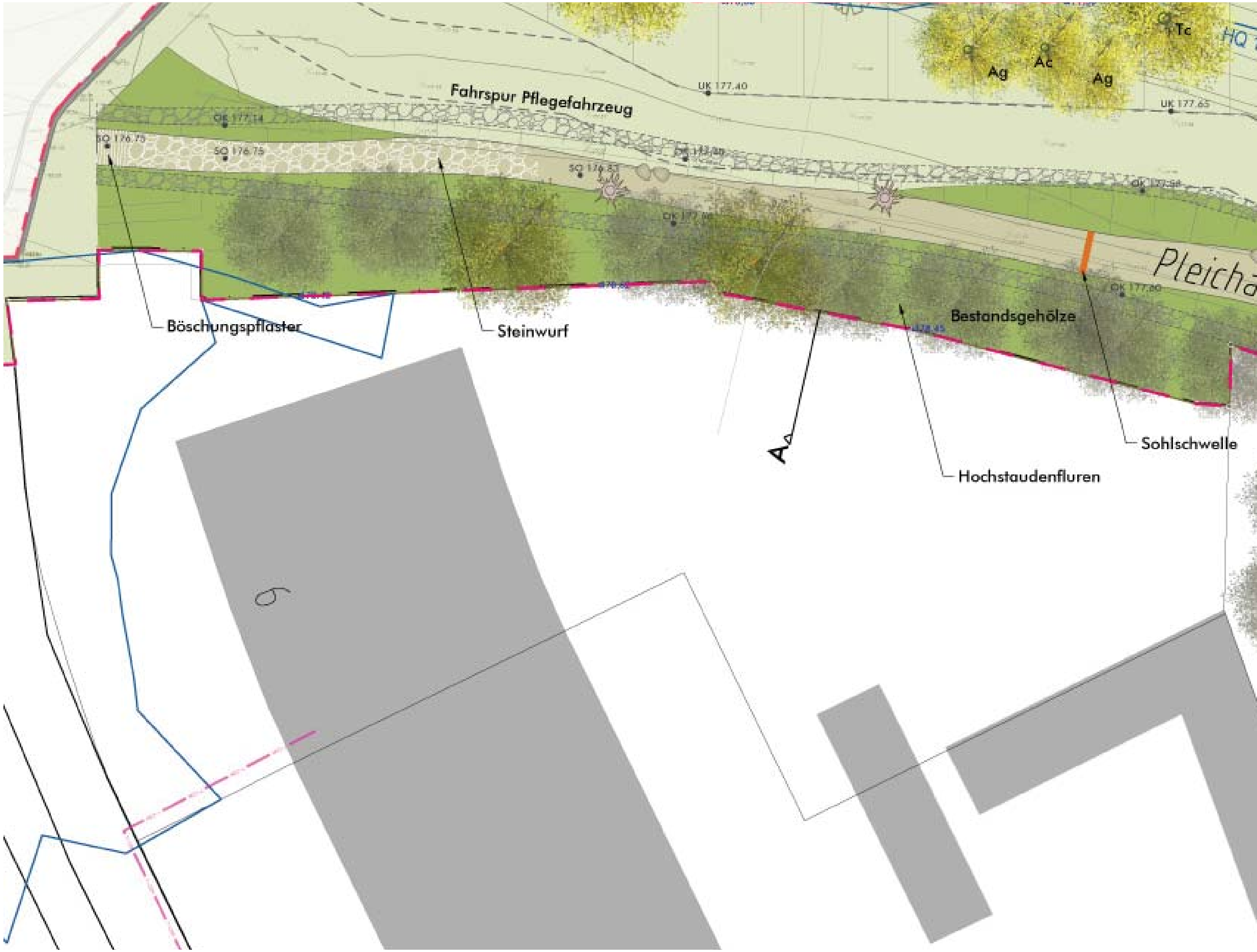
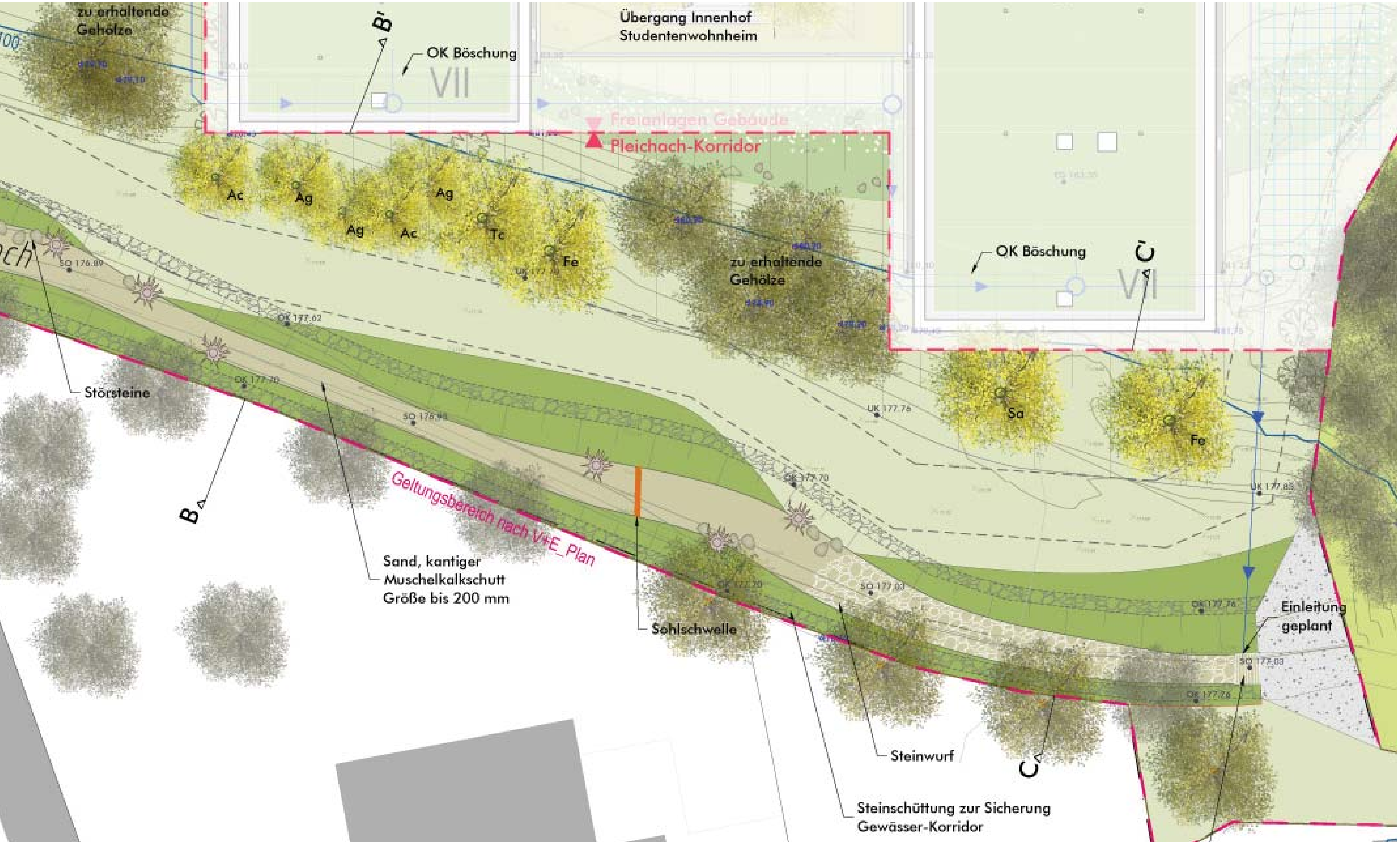


Figure 63. Conceptual design for the rehabilitation of the Pleichach River between Quellenbachparkhaus and Europastern. Elaborated by arc.grün. Taken from: (arc.grün Landschaftsarchitekten & Stadtplaner, 2017)


zu erhaltende Gehölze
B'
OK Böschung
VII
Übergang Innenhof Studentenwohnheim
Freianlagen Gebäude
Pleichach-Korridor
Ac
Ag
Ag
Ac
Ag
Tc
Fe
zu erhaltende Gehölze
OK Böschung
C'
VI
SO 176.89
OK 177.62
OK 177.70
SO 176.98
UK 177.76
UK 177.70
UK 177.83
Störsteine
Sa
Fe
B
Geltungsbereich nach V+E_Plan
Sand, kantiger Muschelkalkschutt Größe bis 200 mm
SO 177.03
OK 177.76
SO 177.03
OK 177.76
Einleitung geplant
Sohlschwelle
Steinwurf
C
Steinschüttung zur Sicherung Gewässer-Korridor

Given that the project is not finished yet, it is not possible to evaluate its effectiveness regarding biological enhancements. However, calculations made by the planning and engineering consultant Kling Consult, indicate that the proposed design may have a positive impact on flood prevention, especially north-east of the railway and in the south-western floodplain area for a 100-year precipitation event (Kling Consult Planungs- und Ingenieurgesellschaft für Bauwesen mbH, 2015).

Figure 64. Comparison of the current condition of the Pleichach River and proposed rehabilitation. Render: Gerber Architekten. Taken from: (arc.grün Landschaftsarchitekten & Stadtplaner, 2017)

KEY ACTORS, REGULATIONS, AND FRAMEWORK

Societal demands on water are diverse and prone to conflict. For this reason, all human influences on water bodies have to be carefully coordinated and monitored (Bayerisches Staatsministerium für Umwelt und Verbraucherschutz, 2017). In Germany, regulations and guidelines relative to water management follow the hierarchical structure of the federal government and encompass all the different administrative levels. In this way, it is ensured that implementation strategies developed for a particular case will be consistent with those developed at higher administrative levels and thus relevant to the achievement of the WFD goals (Bender, Bigga, & Maier, 2012).

According to evaluations of the planning process of revitalization projects, the involvement of such diverse entities allows the planner to search for case-specific guidelines knowing that these meet the requirements and objectives of higher administrative levels. Also, a vast amount of information, data, and recommendations have been developed on different levels and can be combined to support detailed planning. However, the lack of a centralized source of information makes the planning process complicated and time-consuming. Even the implementation itself can be slowed down due to the necessity of complying with the many different regulations (Bender, Bigga, & Maier, 2012).

Also, restoration projects must consider other frameworks, plans, and regulations that deal with aspects such as urban planning, landscape, and nature protection. The first table shows and overview of the regulatory plans related to urban river restoration. In the subsequent table (next page) the specific water management regulations and framework that apply to the Pleichach River are presented.

PLANNING LEVEL	SPATIAL PLANNING	WATER MANAGEMENT	LANDSCAPE PLANNING
NATIONAL PLANNING	Federal State Regional Planning Programme (Regional Development Program)	Water Development Program National Water Management Plan	Landscape Program
REGIONAL PLANNING	Regional Plan (Plan of the District Area)	Waterway Development Concept Water Management Framework /Measures Special Plans	Landscape Framework
URBAN LAND-USE PLANNING	Preliminary Urban Land-use Plan (Zoning plan)	Waterway Development Plan Waterway Maintenance Plan	Landscape Plan Spatial Development Plan
OBJECT PLANNING	Preliminary Urban Land-use Plan (Zoning plan)	Design Scheme Maintenance Scheme	Development and Maintenance Plan

Table 5. Overview of the Regional and Sectoral Frameworks Involved in Planning Urban Waterways in Germany. Adapted from: (ATV-DVWK Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V., 2000)

KEY ACTORS	ROLE/FUNCTION	REGULATIONS/FRAMEWORK
EUROPEAN UNION	Set common objectives and develop policies for water management in Europe	• Water Framework Directive ● • Flood Directive ● • Habitats Directive ●
FED. REPUBLIC OF GERMANY / FED. ENVIRONMENTAL AGENCY	Set objectives and develop policies for water management in Germany	• Water Resources Act, Waste Water Act, Water Association Law, Wastewater Ordinance and Groundwater Ordinance
WORKING GROUP ON WATER ISSUES OF THE FEDERAL STATES AND GOVERNMENT (LAWA)	Develop general implementation strategies for water management	• LAWA catalog of measures for the WFD implementation • LAWA Profiles of German Stream Types
FREE STATE OF BAVARIA	Set objectives and develop policies for water management in Bavaria	• Bavarian Water Act ● • Ordinance on plants for the treatment of water-endangering substances and by specialized firms ● • Drinking water regulation ●
BAV. MIN. OF THE ENVIRONMENT AND CONSUMER PROTECTION	Highest state authority for water management	• Program of measures for the Bavarian share of the River Rhine • Flood protection program 2020plus
BAV. AGENCY FOR THE ENVIRONMENT	Advises the Ministry of the Environment and Consumer Protection and acts as a scientific and technical specialist, serving other authorities and institutions in the water sector.	• Example for the conceptual implementation of hydro-morphological measures according to the WFD for flowing waters
GOV. OF LOWER FRANCONIA	Coordinates lower governmental authorities on water management efforts	• Flood Risk Management Plan: Catchment Area Bavarian Main
ASCHAFFENBURG WATER MANAGEMENT AUTHORITY	Assists/advises local authorities on technical aspects related to water management tasks	• Water Portraits • Water Development Concepts
CITY OF WÜRZBURG / LOWER WATER AUTHORITY	Enforcement authority in the fields of water management and nature protection.	• Ordinance of the city of Würzburg on the flood area of the Pleichach within the Würzburg municipality from river kilometer 0,00 to river kilometer 8,96. ●
EXPERTS & SPECIALISTS	Commissioned to develop/consult specific plans and measures.	• Conceptual study on the development of the Pleichach between Quellenbachparkhaus and Europastern (arc.grün Landschaftsarchitekten & Stadtplaner, 2014) ●
PRIVATE INVESTORS	Allocation of capital for project implementation.	
CITIZENS	Raise awareness and make pressure on local authorities.	• Citizen Initiative and Exhibition “Ring Park in Danger”

● Legally binding

● Most specific guideline relative to the revitalization of the Pleichach in the urban area of Würzburg

Table 6. Regulations and Plans that Influence the Development of Revitalization Plans for the Pleichach River at Quellenbachparkhaus.

THE PLEICHACH RIVER: REVITALIZATION POTENTIAL & OPTIONS

With all the knowledge, technical, and practical information that has been developed throughout this investigation, it is possible to assess the restoration potential of the Pleichach River at Quellenbachparkhaus. Based on this assessment, general objectives will be developed, and a set of preliminary options will be presented in order to show how these objectives could be achieved in different ways and degrees.

The development process of the design options begins with summarizing all the relevant aspects related to the site analysis in the form of the main challenges and opportunities encountered for restoration. The results of this analysis will be then contrasted with the following three key aspects in order to set general objectives: potential ecosystem services that can be provided, the coinciding basic principles between the presented best practice examples, and the applicable regulations and requirements from the related water authorities.

The proposed general objectives will be further analyzed through the lens of the design strategies used in the best practice examples and the conceptual restoration project developed for an upstream reach of the Pleichach. The intention is to explore the applicability of the implemented strategies and the possibility to adapt them to the specific circumstances of the site.

Every step of the development process will be informed by the knowledge base presented at the beginning of this investigation regarding river ecosystems, their processes, and responses to urbanization.

The following figure depicts how each of the aspects discussed in this investigation supports the development process of revitalization solutions for the Pleichach:

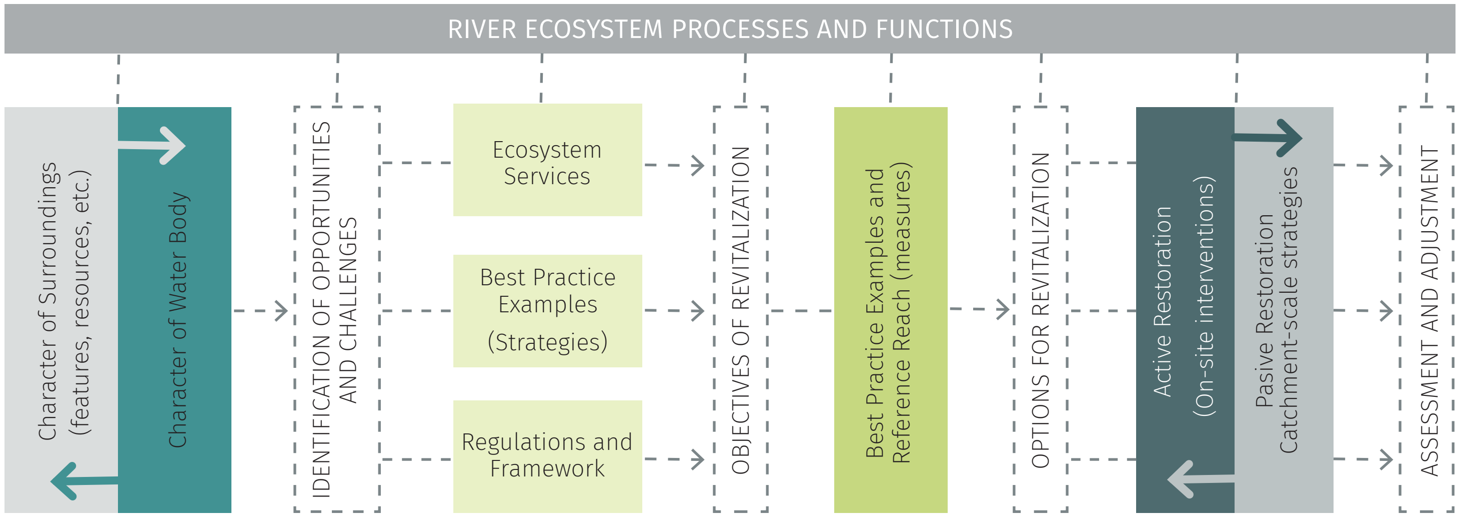


Figure 65. Schematic Approach to Developing Objectives and Options for the Revitalization of the Pleichach River at Quellenbachparkhaus. Based on: (Bender, Bigga, & Maier, 2012) and (Speed, et al., 2016)

CHALLENGES AND OPPORTUNITIES FOR REVITALIZATION:

After carefully analyzing all the gathered information from the previous chapter, related to the ecological, spatial, social, and economic circumstances that surround the site and the river, the following opportunities and challenges for restoration were encountered:

ECOLOGICAL ASPECTS

Opportunities:

- The catchment area of the Pleichach is approximately 20% to 30% urbanized. Thus the river is exposed to a medium-to-low amount of urban runoff.
- The restoration project between Quellenbachparkhaus and Europastern sets a precedent and offers valuable information for the development of the project at Quellenbachparkhaus.
- The restoration project between Quellenbachparkhaus and Europastern will improve the ecological state of an immediate upstream section of the river.
- The longitudinal connection of the river is not impaired at the restoration site by structural elements, on the contrary, there is a fish passage to enable migration when water levels are too low.
- The rough texture of the channel's walls enables the growth of vegetation and moss.

Challenges

- The restoration site is located at the lowest section of the river thus is highly affected by upstream activities, such as agriculture, which have affected water quality.
- The river has been straightened and channelized almost entirely, meaning that upstream conditions for biodiversity are also unfavorable.
- At the restoration site, the channel has no vertical connection to the soil and groundwater, and no longitudinal connection to green areas.
- The structure of the channel is completely homogeneous and has no variation in width, depth, materiality, among others. This results in a lack of habitats for aquatic and riparian species.
- The oversized channel is problematic for water levels, fish migration, and water temperature.
- The stream will be severely exposed to sunlight and heat after the Quellenbachparkhaus is removed. This can cause an increase in water temperature and a decrease of diluted oxygen.
- The remaining section of the stream that flows between the Quellenbachparkhaus and the Main River is buried underground and under more precarious conditions that those presented at the restoration site.
- Changes in climate, which have increased both flood risks during rainy seasons and drought risk during dry seasons.

SPATIAL ASPECTS

Opportunities

- The channel is located in an area that is very frequented by citizens and visitors, and it is currently of interest for developers (Central Station).

- After the removal of the Quellenbachparkhaus, the channel will be a central feature in the area, located in the middle of the Ring Park and the newly developed Hotel.
- The absence of buildings on the southern border of the river enables to open or expand the channel towards that direction.
- The channel has a big capacity, and it only overflows during a 100 years rain event.
- The channel overflows towards the area of the Ring Park instead of towards the northern buildings, which decreases the risk of damaging nearby infrastructure.

Challenges

- The closely located buildings and infrastructure in the northern border of the river do not allow any expansions towards that side.
- There are visible pipelines crossing the channel and further maintenance elements as well.
- Rapid urban expansion and changes in land-use may negatively impact or modify the conditions to which the river is exposed.

SOCIAL ASPECTS

Opportunities

- Community efforts have been already made supporting the idea of opening the channel and renovating it (Ringpark-in-Gefahr initiative).
- Citizens have already presented proposals of how they would like the river to look like and function for recreational purposes (Ringpark-in-Gefahr initiative).
- Further proposals including the renovation of the Ring Park at the restoration site were developed in the 2014 Würzburg Architecture Workshop, titled “The RINGpark - refining a faded jewel,” and was exhibited in the Würzburg City Hall in 2015.

Challenges

- The area is not used by the locals to spend time but to change between different means of transportation.
- The area is currently not lively and has an unattractive appearance.
- The river is culverted or hidden along most of its path, and many citizens are not aware of the issue.

FINANCIAL ASPECTS

Opportunities

- Seeking financial support for the project from the private investors interested in developing and refurbishing the areas around the channel.
- The project already has an approved budget of one million euros from one of the investors that will be constructing several buildings in the area.

Challenges

- The City of Würzburg is currently not perusing restoration to the fullest due to high costs.
- The City of Würzburg is currently not contributing to the financing of the project.
- The project has currently only one stakeholder giving financial support.

PROPOSED GENERAL OBJECTIVES FOR REVITALIZATION:

To develop suitable objectives that maximize the potentials of the Pleichach at the restoration site and comply with the established regulations and requirements, the aforementioned challenges and opportunities were analyzed in the light of:

(1) Requirements from the Water Management Administration of Würzbug, in accordance with the Water Framework Directive objectives and the Program of measures for the Bavarian share of the River Rhine (see section "Conceptual study on the development of the Pleichach between Quellenbachparkhaus and Europastern")

(2) Coinciding basic principles between the presented best practice examples (see Table 3).

Potential Ecosystem Services that can be supported by the project (see table 2):

(3) Supporting Services

(4) Regulatory Services

(5) Cultural Services

It must be noted that according to the research, provisioning services are not commonly provided by streams in such urban conditions. Consequently, this type of service was not included in the objectives but should be kept in mind in case there is the opportunity to integrate it in any of the options.

Lastly, from this analysis, the following project objectives were developed:

ECOLOGICAL OBJECTIVES:

- Promotion of the natural dynamics of the river (vertical, lateral, and longitudinal connectivity) (1)(2)(3)(4)
- Promote sinuosity and flow variability (2)(4)
- Restore local riparian and aquatic vegetation (2)(3)
- Increase local structural diversity and habitats for flora and fauna (1)(2)(3)
- Enhance resiliency of aquatic species and fish migration (1)(2)(3)
- Protect or improve water quality (temperature, turbidity, etc.) (1)(2)(4)

SOCIETAL OBJECTIVES:

- Contribute to the livability and aesthetics of the area (2)(5)
- Enable safe access to the water (direct or indirect) (1)(2)(5)
- Promote recreational activities related to waterscapes (1)(2)(5)
- Renew sense of place and belonging (2)
- Raise ecological awareness and stewardship towards river ecosystems (2)

ECONOMIC & PLANNING OBJECTIVES

- Avoid creating additional water discharge into the river (1)(4)
- Avoid worsening flood risk (1)(2)(4)
- Recover buffer green areas at the margins of the stream (1)(2)
- Enhance water conveyance, water infiltration and retention capacity in response to future climate challenges (2)(4)
- Secure the investment by using flood and erosion resistant construction methods (2)(4)
- Make economical reuse of residual materials and infrastructure (2)

Table 7. Proposed General Objectives for Revitalizing the Pleichach River at Quellenbachparkhaus.

OPTIONS FOR ACTIVE REVITALIZATION:

ON-SITE INTERVENTIONS

Based on the proposed objectives, three preliminary design options were developed for the revitalization of the Pleichach at Quellenbachparkhaus. The aim of developing three variations is to explore the suitability of each of the approaches studied in the best practice examples: in-channel restoration, channel modification, and stream diversion and naturalization.

All these strategies are applicable to the restoration site of the Pleichach given that the dimensions of the existing channel enable intramural interventions and that the proximity of the Ring Park allows to expand or divert the stream towards it. Furthermore, the plans to renovate the whole area around the Hauptbahnhof offer the possibility to propose changes to the landscape surrounding the river and not just to the channel itself.

Even though each proposal has a different approach, there are certain aspects or measures that are equally applied to all of them. For example, all the options must be coherent with the design developed for the restoration of the Pleichach between Quellenbachparkhaus and Europastern, located upstream.

Hence, in all the proposals the streambed is designed to have a meandering behavior and a width between 2 m and 5 m. Also, in all cases, flow variability is to be fostered by modeling the riverbed into a sequence of pools and riffles as well as by introducing coarse substrate material and scattered boulders.

Regarding the riverbanks, all the proposals seek to create softer slopes and greener margins for the stream. Native bushes and herbaceous vegetation are proposed to be planted on the upper part of the bank while native aquatic plants are proposed to be planted on the lower part.

Additionally, the lower border of the banks is suggested to be secured from erosion using a rocky armor, also known as rip-rap. This will protect the riverbanks and planted vegetation from being washed away due to heavy flows, which can be very frequent in urban rivers. Stony borders, when carefully constructed, can also facilitate access to the channel for maintenance purposes without damaging the vegetation and riverbank habitats.

Apart from all these elements, it is vital for the new design to provide some shadow to the recently opened channel. These waters have been flowing underground for many years without solar exposure, which means that by opening the channel there is a risk of increasing water temperature and changing the levels of dissolved oxygen available for aquatic species. It is therefore recommended in all proposals to place trees or bushes along the streambed to cool the air around it and provide shadow.

Finally, all the proposals strive to provide direct or indirect access to the river and possibilities for recreational use. Nevertheless, under the circumstances of the site and its location, it is imperative to ensure safety, especially when it comes to children. Therefore, whenever it is not possible to create soft-sloping riverbanks, it is necessary to have a fence or a handrail for protection. This fence is proposed to be as light and see-through as possible in order to leave the green banks and the river still visible but not accessible.

The following figures give an overview of the proposed options and of how they differentiate from each other.

1. IN-CHANNEL RESTORATION:

In this option, all of the aforementioned measures will be implemented inside the existing channel. In that way, the infrastructure around it will not be affected, and the available budget can be used in enhancing structural diversity without having to invest in dismantling the channel and refurbishing the area.

A portion of the concrete bed is proposed to be opened to enable vertical connectivity while the concrete walls will be covered with climbing plants. Green berms are suggested to be built along the edges to shape sinuosity and provide refuge for fauna. These should be as flat as possible to avoid decreasing channel capacity. Finally, a bridge that crosses over the river, see-through handrails, and urban furniture enable indirect accessibility and enjoyment.

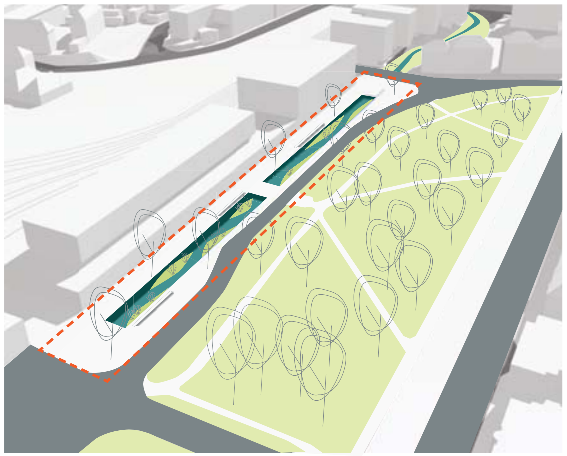


Figure 66. Active Restoration: Option 1 – In-Channel Restoration.

2. CHANNEL MODIFICATION

This option proposes to open the concrete bed and the southern wall, thus integrating one side of the river to the Ring Park through a green bank with a softer slope. This bank would be built using bioengineering techniques and natural materials, thus functioning as an extension of the park and enabling people to get closer to the river. Additional accessibility features could be incorporated such as seating steps on top of the banks to increase recreational value.

This proposal would entail eliminating the street between the park and the river, but it would also reconnect the river to a green floodplain and greatly increase the channel´s capacity, thus reducing flood risk.

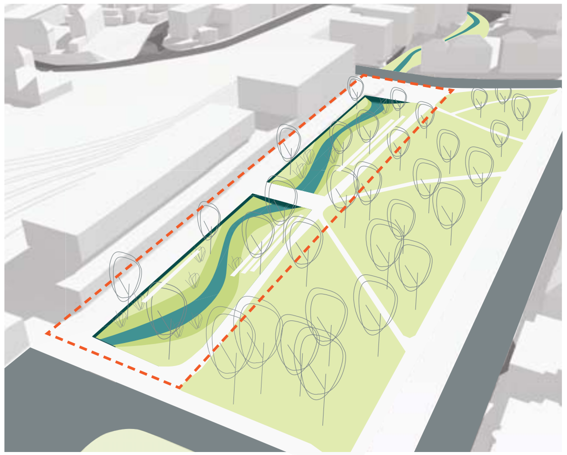


Figure 67. Active Restoration: Option 2 – Channel Modification + One-side Soft Riverbanks.

3. STREAM DIVERSION & NATURALIZATION

This option suggests to divert the stream from the concrete channel and completely integrate it into the Ring Park by shaping a new river channel. This offers the possibility to recreate green and softly-sloped river banks on both sides, through bioengineering techniques, which would increase lateral connectivity and direct access to the water. By doing this, the cannel´s capacity will greatly improve, and the whole park would serve as a floodplain. Furthermore, the concrete channel could be used as overflow conduit to reduce flood risk even more and ensure the safe use of the park.

In this case, the area of the original channel can be re-designed into a more urban space, and the street could be kept if desired.

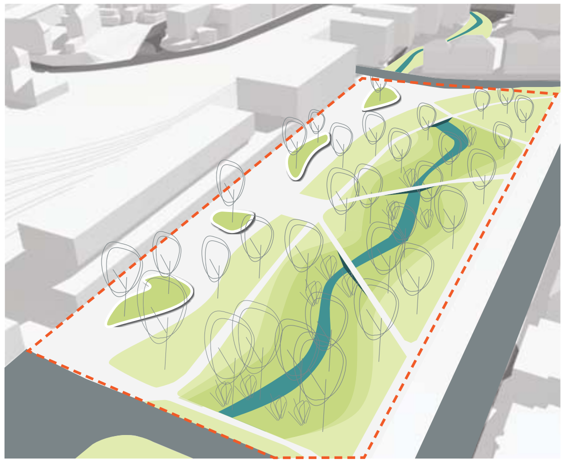
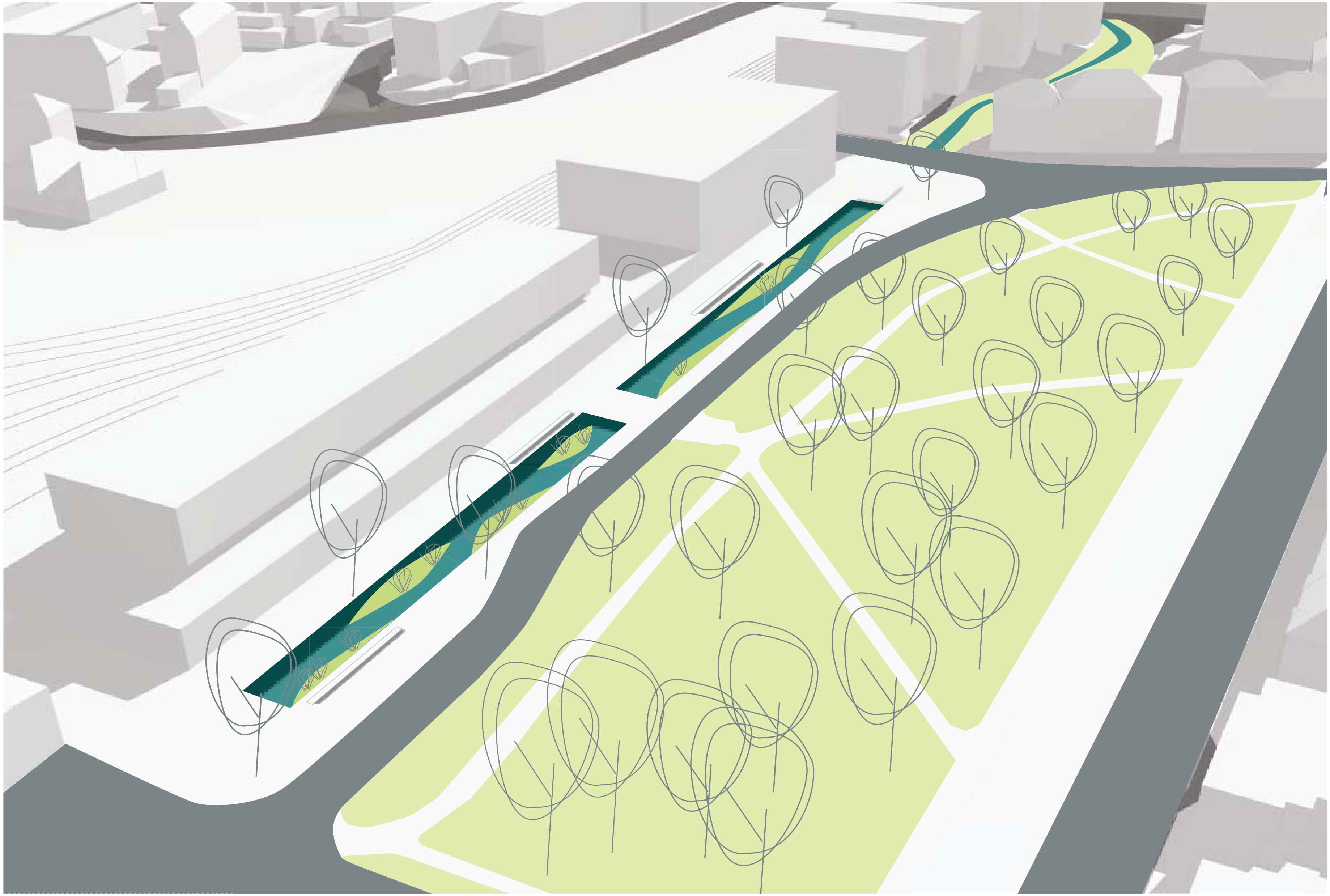


Figure 68. Active Restoration: Option 3 – Channel Diversion + Naturalization.

OPTION 1: IN-CHANNEL RESTORATION



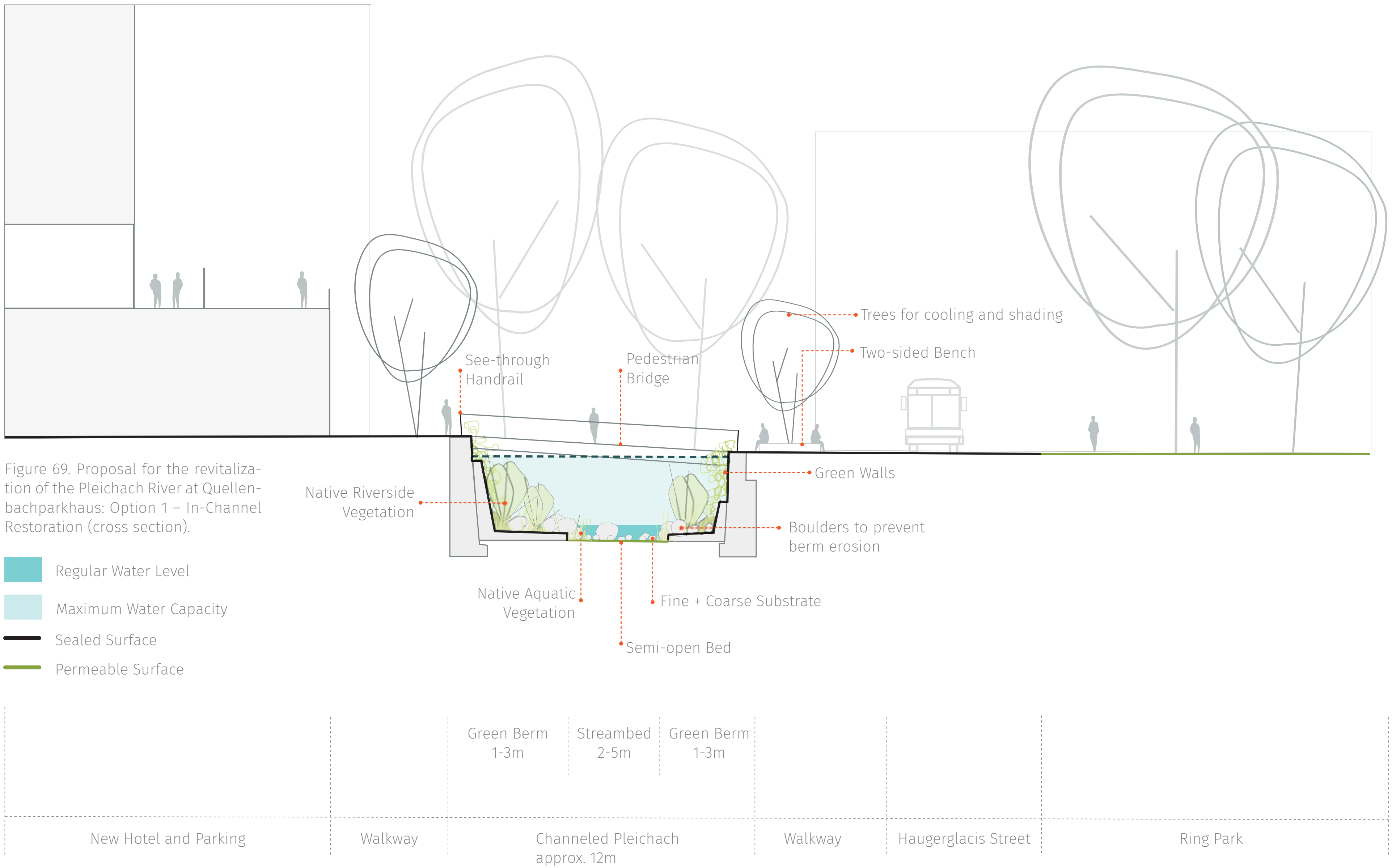
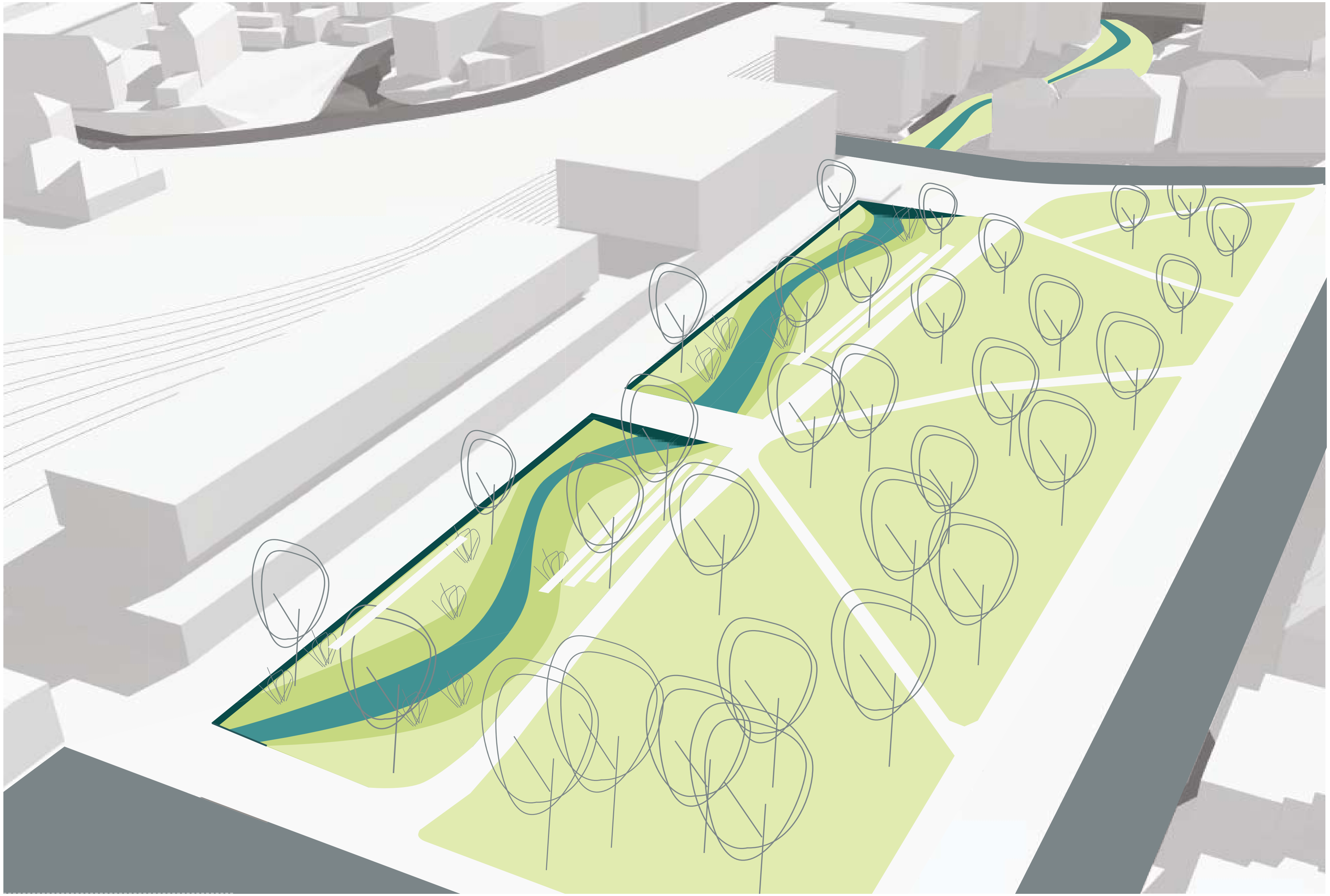


Figure 69. Proposal for the revitalization of the Pleichach River at Quellenbachparkhaus: Option 1 – In-Channel Restoration (cross section).

OPTION 2: CHANNEL MODIFICATION



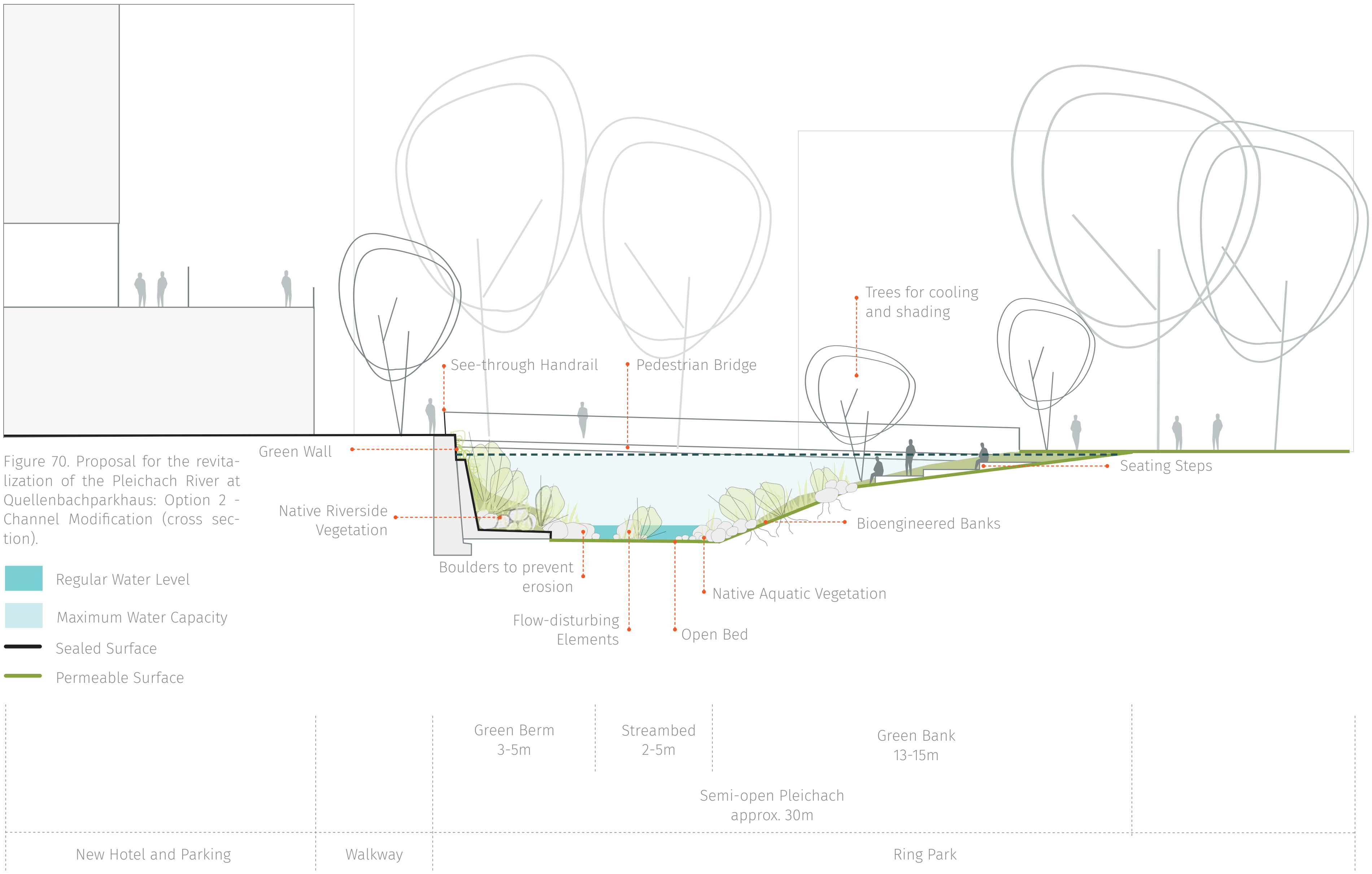
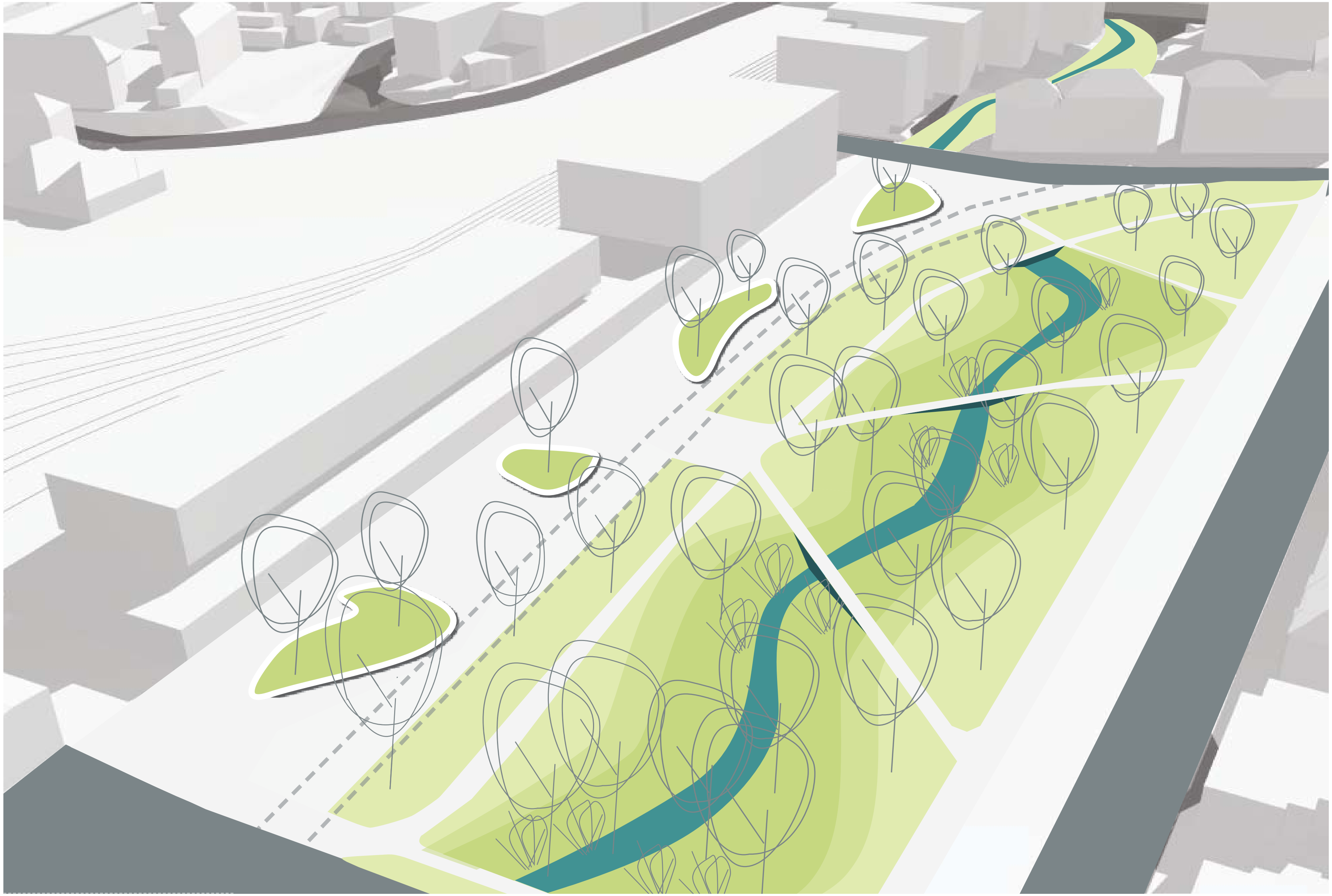


Figure 70. Proposal for the revitalization of the Pleichach River at Quellenbachparkhaus: Option 2 - Channel Modification (cross section).

OPTION 3: CHANNEL DIVERSION AND NATURALIZATION



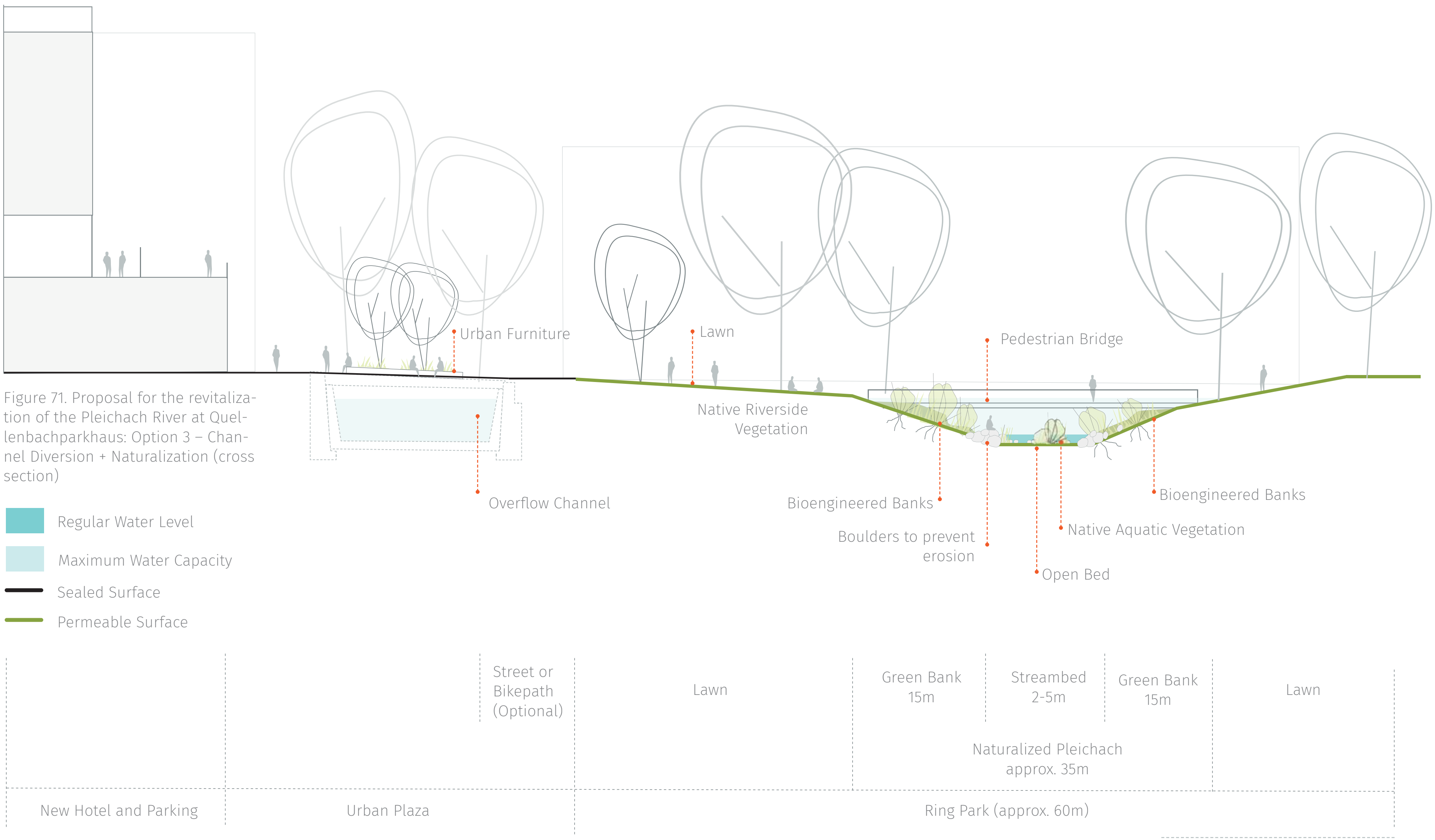
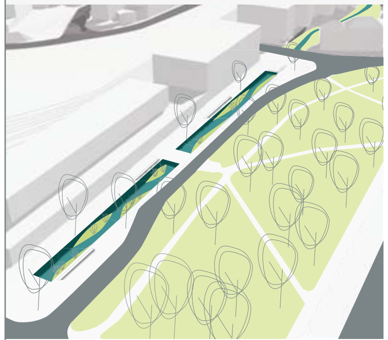
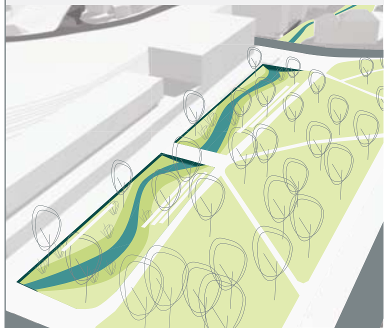
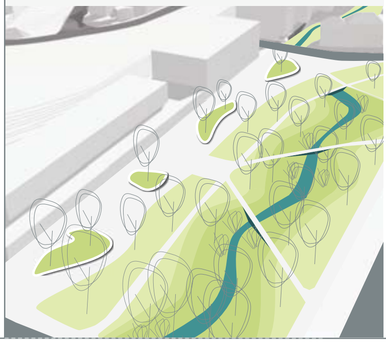


Figure 71. Proposal for the revitalization of the Pleichach River at Quellenbachparkhaus: Option 3 – Channel Diversion + Naturalization (cross section)

COMPARATIVE SWOT ANALYSIS BETWEEN REVITALIZATION APPROACHES

APPROACH	STRENGTHS	WEAKNESSES
IN-CHANNEL RESTORATION 	• Improvement of stream width and flow variability. • Creation of habitats for flora and fauna. • Promotion of vertical connectivity between the stream and underground water bodies, securing base flow during dry seasons and preventing the river from drying out. • Avoidance of worsening flood risk by opening part of the bed and creating flat berms. • Unaffected infrastructure and functionality of the surrounding landscape elements. • Enhancement of the overall aesthetics and livability of the area. • Support of the societal functions of the river by making it more visible and enabling to cross over it and to sit around it. • Make use of an existing infrastructure and offer ecological improvements with reduced costs.	• Lack of longitudinal connectivity between the river and a floodplain. • Unimproved channel capacity and local flood protection. • Insufficient space to plant abundant trees along the stream to provide shadow and regulate water temperature. • Use of the already worn-out channel as a structural base for the project. • Impossibility to have direct access to the stream for recreational purposes. • Difficulty in accessing the channel for maintenance. • Limited adaptive capacity to changing conditions.
CHANNEL MODIFICATION 	• Improvement of the capacity of the channel to store and infiltrate water, thus mitigating flood risk and securing base flow. • Reconnection of the stream (on one side) to a flood plain, thus fostering the creation of backwaters and nutrient exchange during floods. • Improvement of stream width and flow variability. • Creation of habitats for aquatic and riparian flora and fauna and enabling interaction between them. • The increase of infiltration surfaces and the decrease of water pollution sources by turning the close-by street into an extension of the park. • Provision of shade and improvement of the temperature and air quality of the area by planting new trees along the stream and the newly created extension of the park. • Enhancement of the overall aesthetics and livability of the area. • Support of the societal functions of the river by making it more visible and creating both direct and indirect access to it.	• Elimination of the Haugerglacis Street, which would require re-thinking the vehicular circulation in the area. • Protection or reconnection of pipes and utilities that might be located under the Haugerglacis Street. • Lateral connectivity would only be enabled on one side of the river. • Shading trees can only be planted on one side of the stream. • High costs due to the necessity of removing part of the existing channel and making major changes in the area.
CHANNEL DIVERSION 	• Enable the utilization of the concrete channel as overflow conduit, thus offering a safe use of the park during heavy rain events. • Improvement of the capacity of the channel to store and infiltrate water, thus mitigating flood risk and securing base flow. • Full reconnection of the stream with a naturalized flood plain, fostering the creation of backwaters and nutrient exchange in the event of a flood. • Protection of the stream from sunlight exposure by the existing trees. • Improvement of stream width and flow variability. • Creation of habitats for aquatic and riparian flora and fauna and enabling interaction between them. • Enable the use of the Haugerglacis Street for its current functions or as a bike path if desired. • Enable the refurbishment of the area where the channel is now located to turn it into an urban plaza with functions adequate to the new development (terraces, seating groups, hardscape, etc.).	• The probable need to remove or relocate some of the existing trees in the park to be able to construct the new riverbed and sloped banks. • Negative ecological impacts on the park and its biodiversity during the construction phase of the naturalized channel. • Division of the park into two due to the stream flowing in the middle, thus changing the character and use of the green spaces. • Moving the stream closer to the densely urbanized area, which is also the main direction towards which the river overflows. • High project costs due to the amount of area impacted and the complexity of the required measures. • Lose the opportunity to get financial support from the investor in charge of developing the new hotel and park facilities, given that the stream would be outside of his building scope. • Lose the possibility to enhance the area around the Central Station through the integration of a natural water feature.

OPPORTUNITIES	THREATS
• Finance the project with the collaboration of the investor in charge of developing the new hotel and parking facilities. • Improvement of the structural conditions of the channel. • Raise awareness regarding river ecosystems and the importance of preserving them. • Attract public and political support for implementing further revitalization projects along the river. • Promote the daylighting of the tunneled section of the river that flows between Quellenbachparkhaus and the Main River.	• Communicate a false idea of what a naturalized river is and promoting solutions that offer limited ecological improvements in other sites with high revitalization potential. • Lack of adequate maintenance resulting in an unappealing appearance • On-site negative impacts due to human behavior (trash dumping, etc.). • Changing climate conditions that could increase flood risk, drought risk, and temperature. • Expansion of urbanization which may increment water discharge into the river and water pollution. • Changes in upstream land-use that can negatively impact water quality and biodiversity in the entire downstream section. • Lack of species upstream that could recolonize the new habitats. • Lack of public and political interest to make further efforts to revitalize the entire stream and to achieve major positive impacts on its ecological conditions.
• Attract or include stakeholders related to the improvement of green spaces, biodiversity, tree planting, etc. to financially contribute to the project. • Finance the project with the collaboration of the investor in charge of developing the new hotel and park facilities. • Finance the project with the public budget for revitalizing the Ring Park. • Raise awareness towards river ecosystems and the importance of preserving them. • Attract public and political support for implementing further revitalization projects along the river. • Promote the daylighting and naturalization of the tunneled section of the river that flows between Quellenbachparkhaus and the Main River.	• On-site negative impacts due to human behavior that could affect the newly exposed section of the river (trash dumping, etc.). • Changing climate conditions that could increase both flood risk and drought risk. • Expansion of urbanization which may increment water discharge into the river and water pollution. • Changes in upstream land-use that can negatively impact water quality and biodiversity in the entire downstream section. • Lack of species upstream that could recolonize the newly created habitats. • Lack of public and political interest to make further efforts to revitalize the entire stream and to achieve major positive impacts on its ecological conditions.
• The interest of the City to renovate this area of the Ring Park. • Finance the project with the public budget for revitalizing the Ring Park. • Attract or include stakeholders related to the improvement of green spaces, biodiversity, tree planting, etc. to financially contribute to the project. • Finance the development of a new urban plaza with the contribution of the investor in charge of developing the new hotel and parking facilities. • Raise awareness towards river ecosystems and the importance of preserving them. • Attract public and political support for implementing further revitalization projects along the river. • Promote the daylighting and naturalization of the tunneled section of the river that flows between Quellenbachparkhaus and the Main River.	• On-site negative impacts due to human behavior that could affect the newly exposed section of the river (trash dumping, etc.). • Changing climate conditions that could increase both flood risk and drought risk. • Expansion of urbanization which may increment water discharge into the river and water pollution. • Changes in upstream land-use that can negatively impact water quality and biodiversity in the entire downstream section. • Lack of species upstream that could recolonize the newly created habitats. • Lack of public and political interest to make further efforts to revitalize the entire stream and to achieve major positive impacts on its ecological conditions.

Table 8. Comparative SWOT analysis between revitalization approaches for the Pleichach River at Quellenbachparkhaus.

CONCLUSIONS AND RECOMMENDATIONS BASED ON THE COMPARATIVE STUDY OF THE REVITALIZATION OPTIONS

The three presented proposals were comparatively assessed based on the ecosystems services provided and affected by each option. This analysis was developed using the SWOT methodology, which enables to distinguish the internal strengths and weaknesses of each proposal but also the external factors that may pose opportunities or threats for their implementation and effectiveness.

It can be concluded from the analysis that, with each of the options, the ecological improvement of the addressed section of the river can be achieved, in comparison with its current condition. However, the degree in which the natural processes of the river and the ecosystem services it provides are rehabilitated varies between the options.

Through an in-channel restoration approach (option 1), it is possible to restore local flow variability and structural diversity, which are vital supporting services for promoting biodiversity. Regulatory services related to the connectivity between the stream, the soil and underground water bodies can also be rehabilitated by fully or partially opening the concrete-lined bottom. Nevertheless, the walls of the channel hamper the possibility of rehabilitating lateral connectivity and all the processes related to the interaction between the stream and its floodplain. Cultural services such as visibility and indirect access can be enhanced regardless of the stream being still inside the concrete channel.

On the other hand, by taking this option one step further and opening one side of the channel towards the Ring Park (option 2), it is possible to obtain all the aforementioned benefits plus the reconnection of the channel to a green floodplain. This would require the creation of a green and softy-sloped riverbank in replacement of the current street that runs along the river. As a result, not only a source of water pollution is being eliminated but also the possibility of developing more green areas and planting more trees is created. In terms of ecosystem services, this would enhance the regulatory services provided by the river and also those provided by urban parks such as water infiltration, air quality regulation, temperature regulation, among others. Flood regulation will also be enhanced by increasing the capacity of the channel and connecting it with infiltration surfaces. Regarding cultural services, a softer slope into the river would enable a more direct access to the water and a more natural environment for enjoyment and recreation, free of vehicles and noise.

Finally, by diverting the stream from the channel and fully integrating it into the Ring Park (option 3), the ecological benefits for the stream will be maximized in comparison with the other presented options. In this case, lateral connectivity will be enabled on both sides of the river, which magnifies structural diversity, the input of organic matter, creation of backwaters, the interaction between aquatic and riparian biodiversity, to name a few. Also, the possibility of experiencing water in a natural environment and being in direct contact with it is greatly improved by having even softer slopes on both sides.

Despite all that, it was also concluded that this option (option 3) is the only one that could negatively impact some of the ecosystem services that are provided by the Park. For example, it is probable that some trees have to be removed or relocated in order to build the naturalized river channel along the park. Also, construction processes and machinery can result in soil compaction which decreases the capacity of infiltrating water and would also endanger the nurturing and growing capacity of the trees and plants. Additionally, the current recreational functions of the park will be modified by the spatial division that the river would represent and the area of the central station would lose the opportunity of being enhanced by a natural water element.

Considering all that was previously mentioned, which is based on the comparative study of the presented proposals, it is concluded that the approach of opening one side of the channel towards the park (option 2) is the most balanced option in terms of ecosystem services benefits and risks.

However, this does not mean the contributions of other options have to be lost. On the contrary, the developed analysis offers the opportunity to take the channel modification approach (option 2) as the starting point of an iterative design process in which the strengths of the other proposals can be integrated. The most important aspect is to keep systematically assessing the risks that any design decision can have concerning the river‘s natural processes and its ecosystem services.

Furthermore, the selected option is the most beneficial regarding services but not necessarily the most feasible in financial and practical terms. Indeed, opening the concrete channel and extending the park would be very costly and probably out of reach if the project is only financed by the contribution of the private investor (which is set to be 1 million Euros). Yet this option offers the possibility to include both private and public financing given its integrative scope.

Consequently, it is recommendable to develop further supporting analyses, such as feasibility and cost-benefit studies to seek the inclusion of further stakeholders and aid the development of a final design concept. Additionally, if the financial situation does not allow the implementation of costly measures, it is also possible to develop the revitalization project in several phases. For example, the in-channel proposal (option 1) could be designed as a first project phase that enables a future expansion (option 2).

Lastly, through the SWOT analysis, it could also be determined that there are some coincidental aspects between all the proposals. On the positive side, all the options have the potential of raising public and political awareness regarding the benefits of healthier rivers and the importance of preserving them. This could be ultimately translated into further efforts to rehabilitate other degraded sections of the river such as the culverted reach that flows at one side of the Ring Park from the Central Station to the Main River. On the negative side, threats related to external factors such as catchment processes and land use activities were equally detected in all of the proposals. This means that it is unlikely for any small restoration project to successfully enhance the overall health of the river if broader measures to mitigate catchment-scale threats are not taken into consideration.

Therefore, to secure the effectiveness of any reach-scale revitalization project, it is recommended to insert it into a broader water management plan that addresses the entire catchment, especially urban areas. This plan could include decentralized and water-sensitive strategies such as green roofs, retention or infiltration basins, and permeable pavers. In the case of the Pleichach River, it would also be necessary to promote more sustainable and water sensitive agricultural practices to reduce the input of hazardous amounts of nutrients and pollutants.

RESULTS AND DISCUSSION

Urban streams have the potential to offer many services to society, and their capacity to provide these services will largely depend on their good ecological status. However, in urbanized settings, it is a necessity to manage streams in such a way that citizens and infrastructure are protected from the harms that can be caused by floods. This means that in order to safely and effectively incorporate rivers into the urban landscape, compromises between ecology and human development have to be made.

Consequently, the aim of this investigation was to offer insights on the fundamental aspects that have to be taken into consideration to balance such trade-offs and promote restoration strategies that aim at maximizing benefits while minimizing risks. The conclusions drawn from this study can be summarized as the answers to the initial research questions:

Which elements of a river ecosystem are fundamental for its appropriate biological function?

All the elements of river ecosystems are highly dynamic and interdepend with each other. They are constantly modified by processes that occur at many different scales as a response to changing conditions. These processes are key in enabling the river to adapt to future challenges and ensure the resiliency of the species they support. Therefore, in order to improve the ecological conditions of a river, it is more important to rehabilitate its longitudinal, lateral and vertical processes than to focus on isolated elements.

What urban circumstances present the main opportunities and challenges for stream revitalization and to what extent can an urban stream be returned to its pre-development conditions?

Urbanization and development have had direct and indirect negative consequences in urban streams. While direct structural modifications can be reversed through restoration projects and their impacts can be mitigated, the external conditions to which the river is exposed will remain affected by the built environment and the human activities that occur in it. In that sense, effective restoration projects must address the local structural conditions of streams as well as the catchment-scale processes affecting it.

Although the negative impacts of urbanization can be mitigated, the opportunities of recovering the social and cultural functions of rivers, in combination with flood protection strategies, are greater than those of recovering its full ecological functions. Therefore, it is vital to integrate these aspects into restoration projects to maximize potential benefits.

Is there a framework that supports the development of multi-purpose river revitalization projects?

The Ecosystem Service Framework establishes a circular relationship between natural ecosystems and human well-being. That is, it recognizes that ecosystems are capable of providing many services that are vital to human well-being and that through the use and management of these services, ecosystems will be impacted and also their future provisioning capacity.

Based on this framework, an assessment guideline has been developed by the World Resource Institute in order to integrate this logic into decision-making processes dealing with natural ecosystems. It proposes to study all the potential services that can be initially provided by a given ecosystem and how can they be optimized or negatively impacted by a proposed decision. In that way, through an iterative assessment process, the benefits procured by a project can be optimized and the risks minimized.

How have ecological and societal objectives been successfully reconciled in best practice examples and what can be learned from these experiences?

Many international best practice examples have successfully integrated ecological, societal and flood protection benefits into a single project of urban river restoration. Although each case developed measures that respond to the specific needs of the river, the site, and the socio-economic circumstances, common aspects were found on the strategies used to approach the projects.

Some of the most relevant are:

- Approaching the project with a holistic view (target several ecosystem services).
- Focusing on enabling the natural processes of rivers as far as possible.
- Building multidisciplinary working teams.
- Integrating the community into the design and implementation process.
- Engaging multiple stakeholders.
- Making efforts to evaluate river health indicators before and after project implementation.

Which guidelines and tools support the development process of urban stream restoration in Germany?

There are several regulations and guidelines related to the management of water bodies that give direction and coordinate river revitalization efforts in Germany. These follow a hierarchical organization that mirrors the different administrative levels of the Government.

The basis for all these regulations are the ones proposed by the European Union, which are the Water Framework Directive, the Floods Directive, and the Habitat Directive. At a national level, the most relevant is the Water Resources Act while in the State of Bavaria (where the case study is located) the most relevant one is the Bavarian Water Act. Then, at different administrative levels within the State other guidelines and models are provided such as the Program of measures for the Bavarian share of the River Rhine, the Flood Risk Management Plan: Catchment Area Bavarian Main and Water Development Concepts.

All these can be further supported by specialized and technical information such as the LAWA profiles developed for German rivers and the LAWA catalog of measures for the WFD implementation. Furthermore, to develop revitalization projects within urban areas, all the aforementioned frameworks have to be coordinated with regulations and guidelines related to urban development and landscape planning.

How can ecological and societal services be optimized in the presented case study or projects in comparable conditions?

By following a systematic analysis that includes all the knowledge obtained through the theoretical and empirical research developed in the project, it was possible to propose and assess three preliminary approaches, from which one was selected as the most balanced in terms of ecosystems services. The process to develop optimal proposals started with recognizing the main opportunities and challenges derived from the site analysis. These were further studied under the light of the ecosystem services at play, the principles found in the best practice examples, and the regulations and guidelines pertinent to the case, which served as a base for the development of objectives. Based on the strategies implemented in the best practice examples and another revitalization project related to the same river, three design options were finally developed.

The three proposals were assessed based on the principles of the ecosystem service framework using the method of the SWOT analysis. The results showed that one of the options was more optimal in terms of ecosystems services than the others. This does not mean that it is the most feasible, but it gives an indication of what could be achieved and can be used as the starting point of the project. The same systematic development and assessment process could be applied to other projects in order to develop options or to evaluate preliminary decisions.

REFERENCES

- 3vsheji. (2017, April 15). Bishan-Ang Mo Kio Park and Kallang River Restoration. Retrieved from 3vsheji: http://www.3vsheji.com/a/h1/2013/0808/20917.html
- Addy, S., Cooksley, S., Dodd, N., Waylen, K., Stockan, J., Byg , A., & Holstead, K. (2016). River Restoration and Biodeversity: Nature-Based Solutions for Restoring the Rivers of the UK and Republic of Ireland. Aberdeen: CREW.
- Allan, J. D., & Castillo, M. M. (2007). Stream Ecology: Structure and Function of Flowing Waters. Dordrecht: Springer.
- American Rivers. (2017, April 13). American Rivers - Daylighting Streams - Report . Retrieved from American Rivers: http://americanrivers.org/wp-content/uploads/2016/05/AmericanRivers_daylighting-streams-report.pdf
- arc.grün Landschaftsarchitekten & Stadtplaner. (2014). Konzeptstudie: Gewässerentwicklung Pleichach zwischen Quellenbachparkhaus und Europastern. Stadt Würzburg.
- arc.grün Landschaftsarchitekten & Stadtplaner. (2017, March 04). Pleichach: arc.grün - Landschaftsarchitekten und Stadtplaner. Retrieved from Arc.grün Landschaftsarchitekten & Stadtplaner: http://www.arc-gruen.de/konzept/gewaesserkonzepte/pleichach/
- arc.grün Landschaftsarchitekten & Stadtplaner GmbH. (n.d.). Würzburg. Gewässerentwicklung Pleichach. Konzeptstudie. Würzburg: Bader Wohnbau GmbH.
- ASLA. (2017, April 15). 2016 ASLA Professional Awards . Retrieved from American Society of Landscape Architects (ASLA): https://www.asla.org/2016awards/169669.html
- ATV-DVWK Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (2000). Gestaltung und Plfege von Wasserläufen in Urbanen Gebieten. Merkblätter 252/2000. ATV-DVWK Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.
- Australian Design Review. (2017, April 18). Bishan Park by Atelier Dreiseitl. Retrieved from Australian Design Review: https://www.australiandesignreview.com/architecture/bishan-park/
- Bayerischer Landtag. (2016). Schriftliche Anfrage der Abgeordneten Dr. Christian Magerl, Kerstin Celina BÜNDNIS 90/DIE GRÜNEN. Bayerischer Landtag.
- Bayerisches Landesamt für Umwelt. (2011). Gewässerabschnitte mit potenziell signifikantem Hochwasserrisiko in Bayern. Bayerisches Landesamt für Umwelt.
- Bayerisches Landesamt für Umwelt. (2012). Verzeichnis der Bach- und Flussgebiete in Bayern: Flussgebiet Main . Augsburg.
- Bayerisches Landesamt für Umwelt. (2016, December 29). Stammdaten Messstelle km 1,7 uh Pegel Europastern / Pleichach. Retrieved from Gewässerkundlicher Dienst Bayern: http://www.gkd.bayern.de/fluesse/chemie/stationen/stammdaten/index.php?thema=gkd&rubrik=fluesse&produkt=chemie&gknr=0&msnr=103430&zr=&msprg=0&mpnr1=1018&mpnr2=1680&prbstnr=103430&sp=de
- Bayerisches Landesamt für Umwelt. (2016). Umsetzungskonzept „Hydromorphologische Maßnahmen“ nach EG-WRRL für den Flusswasserkörper. Bayerisches Landesamt für Umwelt. Retrieved March 05, 2017, from http://www.lfu.bayern.de/wasser/gewaesserentwicklung/index.htm
- Bayerisches Landesamt für Umwelt. (2017, March 02). Daten km 1,7 uh Pegel Europastern / Pleichach. Retrieved from Gewässerkundlicher Dienst Bayern: http://www.gkd.bayern.de/fluesse/chemie/stationen/diagramm/index.php?thema=gkd&rubrik=fluesse&produkt=chemie&gknr=0&msnr=103430&zr=jahr&typ_nr=0&msprg=0&mpnr1=1018&mpnr2=1680
- Bayerisches Landesamt für Umwelt. (2017, March 02). Hauptwerte Pegel Würzburg / Pleichach. Retrieved from Gewässerkundlicher Dienst Bayern: http://www.gkd.bayern.de/fluesse/abfluss/stationen/statistik/index.php?thema=gkd&rubrik=fluesse&produkt=wasserstand&gknr=0&msnr=24374805
- Bayerisches Landesamt für Umwelt. (2017, March 05). IUG Bayern. Retrieved from IÜG: Informationsdienst Überschwemmungsgefährdete Gebiete: http://geoportal.bayern.de/bayernatlas-klassik/kN-Ces_bGbytgEEqqTVD1-OamwdDAWZNFHi8faSX-DhXDm80O11d-w9oHH-p8-cUIUtQHLMwWZZmT2Owxrd04Gh4tRStlwKJWc04vUTll9tyyDOtcJ9BItcwee2NsRw0KVG-CjhdEXN7aWmCxdoBmu0A-_AYm_TznuAkfzEnqhDEI/kN-f9/tcJ9a/tcJ9a/tcJ9a
- Bayerisches Staatsministerium für Umwelt und Verbraucherschutz. (2014). Hochwasserschutz. Munich: Bayerisches Staatsministerium für Umwelt und Verbraucherschutz. Retrieved from http://www.bestellen.bayern.de/application/stmug_app000008?SID=1458274780&ACTIONxSESSxSHOWPIC(BILDxKEY:%27stmuv_wasser_002%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27)
- Bayerisches Staatsministerium für Umwelt und Verbraucherschutz. (2015). Maßnahmenprogramm für den bayerischen Anteil am Flussgebiet Rhein: Bewirtschaftungszeitraum 2016–2021. Munich: Bayerisches Staatsministerium für Umwelt und Verbraucherschutz.
- Bayerisches Staatsministerium für Umwelt und Verbraucherschutz. (2015). Maßnahmenprogramm für den bayerischen Anteil der Flussgebietseinheit Rhein. Bewirtschaftungszeitraum 2016–2021. Munich: Bayerisches Staatsministerium für Umwelt und Verbraucherschutz.
- Bayerisches Staatsministerium für Umwelt und Verbraucherschutz. (2017, March 05). Rechtsgrundlagen zum Thema Wasser. Retrieved from Bayerisches Staatsministerium für Umwelt und Verbraucherschutz: http://www.stmuv.bayern.de/themen/wasserwirtschaft/recht/index.htm
- Bayerisches Staatsministerium für Umwelt und Verbraucherschutz. (2017, March 05). Organisation im Bereich Wasserwirtschaft. Retrieved from Bayerisches Staatsministerium für Umwelt und Verbraucherschutz.: http://www.stmuv.bayern.de/themen/wasserwirtschaft/wasserwirtschaft_in_bayern/organisation.htm
- Bayerishes Landesamt für Umwelt. (2016). Verzeichnis der Gewässer zweiter Ordnung (vgl. Anlage 1 der Bekanntmachung) . Bayerishes Landesamt für Umwelt.
- Beatley, T. (2016). Handbook of Biophilic City Planning & Design. Island Press.
- Bender, E., Bigga, L., & Maier, W. (2012). Urban Rivers - Vital Spaces. Manual for Urban River Revitalization: Implementation, participation, benefits. REURIS.
- Biodiversity System Infromation for Europe. (2017, April 19). Mapping and Assessment of Ecosystems and their Services (MAES). Retrieved from Biodiversity System Infromation for Europe: http://biodiversity.europa.eu/maes/#SERVICES
- Bolund , P., & Hunhammar , S. (1999). Ecosystem services in urban areas. Ecol Econ, 29:293–301.
- Brils, J., Brack, W., Müller-Grabherr, D., Négrel, P., & Vermaat, J. E. (2014). Risk-Informed Management of European River European River Basins. n.d.: Springer.
- Buth, et al. (2015). Vulnerabilität Deutschlands gegenüber dem Klimawandel. Dessau-Roßlau: Umwelt Bundesamt.
- Capita Symonds. (2009). Strategic Flood Risk Assessment of Bath and North East Somerset . Bath ans North East Somerset Council.

- Climate-Data.org. (2017, March 1). Klima & Wetter in Würzburg . Retrieved from Climate-Data.org: https://de.climate-data.org/location/166/
- Cockerill , K., & Anderson, W. (2014). Creating False Images: Stream Restoration In An Urban Setting. American Water Resource Association, Vol. 50, No. 2.
- Dahm, V., Kupilas, B., Rolauffs, P., Hering, D., Haase, P., Kappes, H., . . . Wagner, F. (2014). Hydromorphologische Steckbriefe der deutschen Fließgewässertypen Anhang 1 von „Strategien zur Optimierung von Fließgewässer-Renaturierungsmaßnahmen und ihrer Erfolgskontrolle“. Umwelt Bundesamt.
- Design Singapore. (2017, April 15). Bishan-Ang Mo Kio Park. Retrieved from Design Singapore: https://www.designsingapore.org/pda/award-recipients/2012/bishan-ang-mo-kio-park
- Environment Agency. (2017, April 13). Environment Agency - Catchment Data Explorer. Retrieved from Environment Agency: http://environment.data.gov.uk/catchment-planning/WaterBody/GB109053022251
- European Centre for River Restoration. (2014). New approaches for integrating river restoration in basin management. European Centre for River Restoration. Retrieved April 2017, from http://www.ecrr.org/Portals/27/Publications/ECRR%20December%202014%20Newsletter,%20Special%20Edition%20ERRC2014.pdf
- European Comission. (2009). Common Implementation Strategy for the Water Framework Directive (2000/60/EC). n.d.: European Communities.
- European Comission. (2017, January 28). Introduction to the new EU Water Framework Directive . Retrieved from European Comission: Environment: http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm
- Everard, M., & Moggridge, H. (2012). Rediscovering the value of urban rivers. Urban Ecosystems, Vol.15:293–314.
- Everard, M., Shuker, L., & Gurnell, A. (2011). The Mayes Brook Restoration in Mayesbrook Park, East London: An Ecosystem Services Assessment. Bristol: Environment Agency.
- Federal Interagency Stream Restoration Working Group. (2001). Stream Corridor Restoration: Principles, Processes and Practices. n.d.: FISRWG.
- Francis, M. (1999). A Case Study Method for Landscape Architecture. Washington, DC: Landscape Architecture Foundation.
- Fryirs, K., & Brierley, G. (2013). Geomorphic Analysis of River Systems: An Approach to Reading the Landscape. West Sussex: Wiley-Blackwell.
- Garcia, E. (2017, April 13). Yonkers uncovers new portion of Saw Mill River. Retrieved from Lohus: http://www.lohud.com/story/news/local/westchester/yonkers/2016/06/30/uncovered-saw-mill-river/86522184/
- Geograph. (2017, April 17). 2009 : River Somer, Midsomer Norton. Retrieved from Geograph: http://www.geograph.org.uk/photo/1457525
- Geograph. (2017, April 17). Midsomer Norton High Street. Retrieved from Geograph: http://www.geograph.org.uk/photo/432264
- Gerber Architekten. (2016). Gerber Architekten Fotographic Archives. Hamburg.
- Gewässerkundlicher Dienst Bayern. (2002). Stammdaten Messstelle km 1,7 uh Pegel Europastern / Pleichach - Bogen für erweiterte Stammdaten. Gewässerkundlicher Dienst Bayern.
- Göbel, M. (2009, September 14). Freiheit für die Pleichach: Endlich wieder Wasser vor den Bahnhof. Main Post.
- Groundwork Hudson Valley. (2017, April 18). News from Groundwork Hudson Valley, Spring 2012. Retrieved from Groundwork Hudson Valley: http://archive.constantcontact.com/fs066/1102642116294/archive/1109690114299.html
- Hering, D., Aroviita, J., Baattrup-Pedersen, A., Brabec, K., Buijse, T., Ecke, F., . . . Kail, J. (2015). Contrasting the roles of section length and instream habitat enhancement for river restoration success: A field study of 20 European restoration projects. Journal of Applied Ecology, 52: 1518–1527. doi:10.1111/1365-2664.12531.
- Hochwasserrisikomanagement-Plan Einzugsgebiet bayerischer Main. (2017, March 05). Maßnahmen. Retrieved from Hochwasserrisikomanagement-Plan Einzugsgebiet bayerischer Main: http://www.hopla-main.de/index.php/massnahmen
- Hoeger , S. (2010). Saw Mill River Daylighting Project At Larkin Plaza, Yonkers, NY: A Review of Ecological Opportunities and Physical Limitations (Final Draft). Retrieved from http://www.harborestuary.org/grants/2008-09/SMR%20Dayl%20Report%202008.pdf
- Jähnig, S., Haase, P., Hering, D., Domisch, S., Früh, D., Gies, M., . . . Westermann, M. (2010). KLIWA - Einfluss des Klimawandels auf die Fließgewässerqualität – Literaturauswertung und erste Vulnerabilitätseinschätzung. Gelnhausen: Bayerisches Landesamt für Umwelt, LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg , Landesamt für Umwelt, Wasserwirtschaft und Gewerbeaufsicht Rheinland-Pfalz.
- Kelemen, E., García-Llorente, M., Pataki, G., Martín-Lôpez, B., & Gómez-Baggethun , E. (2016). Non-monetary Techniques for the Valuation of Ecosystem Services. In M. a. Potschin, OpenNESS Ecosystem Services Reference Book. n.d.: Openness: Operationalisation of Natural Capital and Ecosystem Services: From Concepts to Real-world Applications .
- Kensinger, N. (2017, April 13). Daylighting the Saw Mill River - Curbed NY. Retrieved from Curbed NY: http://ny.curbed.com/2016/12/15/13963898/yonkers-saw-mill-river-photo-essay
- Kling Consult Planungs- und Ingenieurgesellschaft für Bauwesen mbH. (2015). Stellungnahme zur Veränderung des Überschwemmungsgebiets Pleichach bei Hq100 nach Renaturierung. Bader Wohnbau GmbH.
- KLIWA Klimaveränderung und Wasserwirtschaft. (2016). Klimawandel in Süddeutschland: Veränderungen von meteorologischen und hydrologischen Kenngrößen. Klimamonitoring im Rahmen der Kooperation KLIWA. Deutschen Wetterdienst, Umweltministerium Baden-Württemberg, Bayerisches Staatsministerium für Umwelt und VerbraucherschutzMinisterium für Umwelt, Landwirtschaft, Ernährung, Weinbau und Forsten Rheinland-Pfalz.
- Kondolf, G., Boulton, A., O’Daniel, S., Poole, G., Rahel, F., Stanley, E., . . . Cristoni, C. (2006). Process-Based Ecological River Restoration: Visualizing Three-Dimensional Connectivity and Dynamic Vectors to Recover Lost Linkages. Ecology and Society, 11,5.
- Landezine. (2017, April 15). Bishan Park by Ramboll Studio Dreiseitl. Retrieved from Landezine: http://www.landezine.com/index.php/2012/06/kallang-river-at-bishan-ang-mo-kio-park-by-atelier-dreiseitl/
- Landratsamt Würzburg. (2017, March 1). Zahlen & Fakten. Retrieved from Landkreis Würzburg: http://www.landkreis-wuerzburg.de/Unser-Landkreis/Zahlen-Fakten
- Lorenz, A., & Feld, C. (2013). Upstream river morphology and riparian land use overrule local restoration effects on ecological status assessment. Hidrobiologia, 704: 489–501.
- Met Office. (2017, April 13). Midsomer Norton Climate Information - Met Office. Retrieved from Met Office: http://www.metoffice.gov.uk/public/weather/climate/gcn5z2ng8
- Meteoblue. (2017, April 15). Climate Bishan Park. Retrieved from Meteoblue: https://www.meteoblue.com/en/weather/forecast/modelclimate/bishan-park_singapore_1884298
- Midsomer Norton Society. (2017, April 10). Midsomer Norton Society. Retrieved from River Somer Project: http://www.midsomernortonsociety.co.uk/Projects%20River.htm

- Midsomer Norton Town Council . (2017, April 17). River / Midsomer Norton Town Council. Retrieved from Midsomer Norton Town Council : http://www.midsomernortontowncouncil.co.uk/the-river/
- Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-being: Synthesis. Washington, DC.: Island Press.
- National Research Council (NRC). (1992). Restoration of aquatic ecosystems: science, technology and public policy. Washington, DC: National Academy Press.
- Ofice for National Statistics . (2017, April 13). Lead View Table. Retrieved from Ofice for National Statistics : http://neighbourhood.statistics.gov.uk/dissemination/LeadTableView.do?a=7&b=11126561&c=Midsomer+Norton&d=16&e=61&g=6387897&i=1001x1003x1032x1004&m=0&r=1&s=1492079412409&enc=1&dsFamilyId=2491&nsjs=true&nsck=false&nssvg=false&nswid=1366
- Ökologisch-Demokratische Partei. (2017, March 04). ÖDP Würzburg Stadt und Land: Pleichach - „Auf zu neuen Ufern". Retrieved from Ökologisch-Demokratische Partei: http://www.oedp-wuerzburg.de/aktuelles/blog/nachrichtendetails/news/pleichach-auf-zu-neuen-ufern/
- ONEMA: The French National Agency for Water and Aquatic Environments. (2017, January 22). River Restoration in France. Retrieved from The French National Agency for Water and Aquatic Environments: http://www.river-restoration.onema.fr/
- ONEMA: The French National Agency for Water and Aquatic Environments. (2017, January 22). Why Restore? Retrieved from ONEMA : http://www.river-restoration.onema.fr/content/why-restore
- ONEMA: The French National Agency for Water and Aquatic Environments. (2017, February 12). Many services to society depend on the quality of aquatic environments. Retrieved from ONEMA: http://www.onema.fr/sites/default/files/EN/EV/publication/qualite-milieux-aqua-UK.pdf
- Paul, M., & Meyer, J. (2001). Streams in the Urban Landscape. Annual Review of Ecology and Systematics, Vol. 32:333-365.
- Phyo, W. (2017, April 15). How Bishan Park Became "The Central Park" of Singapore. Retrieved from Landscape Architects Network: https://landarchs.com/how-bishan-park-became-the-central-park-of-singapore/
- Poppe, M., Kail, J., Aroviita, J., Stelmaszczyk, M., Giełczewski, M., & Muhar, S. (2016). Assessing restoration effects on hydromorphology in European mid-sized rivers by key hydromorphological parameters. Hidrobiologia, 796: 21-40.
- Pottgiesser , T., & Sommerhäuser , M. (2014). Profiles of German Stream Types. n.d. Retrieved March 2017, from http://reform.gisinternet.nl/images/2/2b/Pottgiesser_Sommerhaueser_2004.pdf
- Prominski, M., Stokman, A., Zeller, S., Stimberg, D., & Voermanek , H. (2012). Fluss. Raum. Entwerfen.: Planungsstrategien für urbane Fließgewässer. Bassel: Birkhäuser.
- PS&S Integrated Services. (2017, April 13). Saw Mill Rivers - PS&S Integrated Services. Retrieved from PS&S Integrated Services: http://www.psands.com/saw-mill-river
- PUB Singapore. (2014). Active Beautifl Clean Waters: Design Guideline. Public Utilities Board (PUB), Singapore.
- PUB Singapore. (2017, April 15). ABC Waters Kallang River at Bishan-An Mo Kio Park. Retrieved from PUB Singapore: https://www.pub.gov.sg/abcwaters/explore/bishanangmokiopark
- Ramboll Group . (2017, April 15). Bishang-Ang Mo Kio Park - Ramboll Group . Retrieved from Ramboll: http://www.ramboll.com/projects/singapore/bishan-park
- Ranganathan, J., Raudsepp-Hearne, C., Lucas, N., Irwin, F., Zurek, M., Bennett, K., . . . West, P. (2008). Ecosystem Services: A Guide for Decision Makers. n.d.: World Resources Institute.
- Regierung von Unterfranken. (n.d.). Trinkwasser für Unterfranken: Wege zu einer nachhaltigen Wasserwirtschaft in der Region. Regierung von Unterfranken.
- Restoring Europe´s Rivers. (2017, April 12). Restoring Europe´s Rivers. Retrieved from Case study:River Somer channel enhancement, Midsomer Norton - RESTORE: https://restorerivers.eu/wiki/index.php?title=Case_study%3ARiver_Somer_channel_enhancement,_Midsomer_Norton
- REURIS. (2009, February). Eight Projects of Urban River Revitalisation Now Under Way. REURIS Newsletter, pp. 1-2.
- River Somer: Midsomer Norton High Street. (2017, April 12). Retrieved from Somerset Rivers : http://somersetrivers.org/index.php?module=mediashare&func=browse&aid=37
- Rogers, R. (1984). Chemical Quality of the Saw Mill River, Westchester County, New York, 1981-83. Albany, NY: U.S. Geological Survey .
- Rötter, K. (2015, July 07). Am „hässlichsten Bahnhof Deutschlands" ist viel passiert. Main Post.
- Rötter, K.-G. (2015, August 15). Bahnhofsareal: Zwischen Vision und Wirklichkeit. Main Post.
- Rutherfurd, I., Jerie , K., & Mars, N. (2000). A Rehabilitation Manual for Australian Streams. Cooperative Research Centre for Catchment Hydrology. University of Melbourne.
- Sand Prints- Akshardhool Archives. (2017, April 15). Restoring an urban river bed to its natural Eco-system; A Singapore experiment. Retrieved from Sand Prints: Akshardhool Archives: https://chandrashekharasandprints.wordpress.com/2012/05/11/restoring-an-urban-river-bed-to-its-natural-eco-system-a-singapore-experiment/
- Saratoga Associates . (2017, April 13). Saw Mill River Daylighting. Retrieved from Saratoga Associates : http://www.saratogaassociates.com/saw-mill-river-daylighting/
- Saw Mill River Coalition . (2017, April 13). Water Quality Data - The Saw Mill River Coalition. Retrieved from Saw Mill River Coalition : http://www.sawmillrivercoalition.org/about-the-saw-mill-river/scientific-information-and-reports/water-quality-data/
- Saw Mill River Coalition. (2017, April 13). Daylighting the Saw Mill River in Yonkers. Retrieved from Saw Mill River Coalition: http://www.sawmillrivercoalition.org/whats-happening/daylighting-the-saw-mill-river-in-yonkers/
- Schueler , T., & Brown, K. (2004). Urban Stream Repair Practices. Center for Watershed Protection.
- Schumm, S. (1999). Causes and controls of channel incision. In D. a. Simon, Incised River Channels—processes, forms,engineering and management (pp. 19-34). New York, NY.: John Wiley & Sons.
- Smith, R. F., Hawley, R. J., Martin, M. W., Vietz, G. J., Diaz-Pascacio, E., Herrmann, J., . . . Utz, R. M. (March 2016). Urban stream renovation: incorporating societal objectives to achieve ecological improvements. Freshwater Science, 35, no. 1: 364-379.
- Somerset Rivers. (2017, April 13). River Somer, Somerset. Retrieved from Somerset Rivers: http://somersetrivers.org/index.php?module=Content&func=view&pid=22
- SomersetLive. (2011, May 05). Somerset town river work flows on. Retrieved from http://www.somersetlive.co.uk/town-river-work-flows/story-12326265-detail/story.html
- SomersetLive. (2011, April 14). Stream of music for river project. SomersetLive. Retrieved from http://www.somersetlive.co.uk/stream-music-river-project/story-12286309-detail/story.html
- SOYO. (2017, April 18). SOYO- History. Retrieved from SOYO: http://www.soyony.com/history.

html
- Spacing Atlantic. (2017, Aprl 18). A River Runs Under it: Daylighting Sawmill River. Retrieved from Spacing Atlantic: http://spacing.ca/atlantic/2014/11/10/river-runs-daylighting-sawmill-river/
- Speed, R., Tickner, D., Naiman, R., Gang, L., Sayers, P., Yu, W., . . . Zhongnan, Z. (2016). River restoration: a strategic approach to planning and management. Paris: UNESCO .
- Stadt Würzburg. (2013). Verordnung der Stadt Würzburg über das Überschwemmungsgebiet an der Pleichach. Stadt Würzburg. Retrieved from http://www.wuerzburg.de/media/www.wuerzburg.de/org/med_9444/414255_vo_ueberschwemmungsgebiet_pleichach.pdf
- Stadt Würzburg. (2017, March 02). Kennzahlen zu Regenhäufigkeit und Regenmenge in Würzburg. Retrieved from Stadt Würzburg: http://www.wuerzburg.de/de/themen/umwelt-verkehr/wasser--abwasser/niederschlagswasser/15325.Kennzahlen-zu-Regenhaeufigkeit-und-Regenmenge-in-Wuerzburg.html
- Stadt Würzburg. (2017, March 03). Wissenswertes zur Hydrogeologie in der Stadt Würzburg. Retrieved from Stadt Würzburg : http://www.wuerzburg.de/de/themen/umwelt-verkehr/wasser--abwasser/hydrogeologie-in-wuerzburg/404960.Wissenswertes-zur-Hydrogeologie-in-der-Stadt-Wuerzburg.html
- Sustainable Development Goals: Goal 11. (2017, February 01). Retrieved from United Nations: http://www.un.org/sustainabledevelopment/cities/
- Sustainable Development Goals: Goal 13. (2017, February 01). Retrieved from United Nations: http://www.un.org/sustainabledevelopment/climate-change-2/
- Sustainable Development Goals: Goal 15. (2017, February 01). Retrieved from United Nations: http://www.un.org/sustainabledevelopment/biodiversity/
- The River Restoration Centre. (2017, April 12). Midsomer Norton . Retrieved from The River Restoration Centre: http://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/3.10_Midsommer_Norton.pdf
- The River Restoration Centre. (n.d.). Manual of Restoration Techniques . The River Restoration Centre.
- Tootlepedal. (2017, April 17). May / 2012 / Tootlepedal's Blog. Retrieved from Tootlepedal's Blog: https://tootlepedal.wordpress.com/2012/05/
- Torre, A., & Hardcastle, K. (2004). River rehabilitation in southwest Western Australia. Proceedings of the 4th Australian Stream Management Conference (pp. 609–17). Tasmania: Department of Primary Industries, Water and Environment.
- Tuhin K. Das, Sushil K. Haldar, Ivy Das Gupta and Sayanti Sen. (2014). River Bank Erosion Induced Human Displacement and Its Consequences. Living Reviews in Landscape Research, 8.
- Umwelt Bundesamt. (2017, March 07). Bundesland Bayern / Umwelt Bundesamt. Retrieved from Umwelt Bundesamt: https://www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/bundesland-bayern
- Umweltbüro Essen. (2003). Karte der biozönotisch bedeutsamen Fließgewässertypen Deutschlands. Länder-Arbeitsgemeinschaft Wasser. Retrieved from http://www.fliessgewaesserbewertung.de/downloads/typ_typenkarte_dez_2003.pdf
- United Nations. (2017, February 01). Sustainable Development Goals. Retrieved from United Nations: http://www.un.org/sustainabledevelopment/development-agenda/
- United Nations Environmental Programme . (2016). Conference of the Parties to the Convention on Biological Diversity. The Cancun Declaration on Mainstreaming the Conservation and Sustainable use of Biodiversity for Well-Being (p. 02). Cancun : United Nations.
- United Nations Environmental Programme. (2010). Conference of the Parties to the Convention on Biological Diversity. Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Tenth Meeting: Inland Waters Biodiversity (p. 2). Nagoya: United Nations.
- United States Environmental Protection Agency. (2017, April 14). Waterbody Search / Water Quality Assessment. Retrieved from United States Environmental Protection Agency: https://iaspub.epa.gov/tmdl_waters10/attains_index.search_wb?p_cycle=2014&p_area=NY&p_huc=02030101
- Urban Waters Learning Network. (2016). Reclaiming Urban Waterways - Daylighting the Saw Mill River. Urban Waters Lerning Network. Retrieved from http://www.urbanwaterslearningnetwork.org/wp-content/uploads/2016/05/GWHV-Impact-05_17_16.pdf
- van den Brink, A., Bruns, D., Tobi, H., & Bell, S. (2017). Research in Landscape Architecture: Methods and Methodology. New York: Routledge.
- Wallis, C., Seón-Massin, N., Martini, F., & Schouppe, M. (2011). Implementation of the Water Framework Directive when Ecosystem Services Come into Play. ONEMA Meeting. Brussels.
- Walsh, C., Papas, P., Crowther, D., & Sim, P. (2004). Stormwater drainage pipes as a threat to a streamdwellingamphipod of conservation significance, Austrogammarus australis, in southeastern Australia. Biodiversity and Conservation, 13: 781–793.
- Walsh, C., Roy, A., Feminella, J., Cottingham, P., Groffman, P., & Morgan, R. (2005). The urban stream syndrome: Current knowledge and the search for a cure. The North American Benthological Society, 24(3):706–723.
- Wasserwirtschaftsamt Aschaffenburg. (2016, November 26). Flüsse und Seen - Gewässerportraits: Die Pleichach. Retrieved from Wasserwirtschaftsamt Aschaffenburg Web site: http://www.wwa-ab.bayern.de/fluesse_seen/gewaesserportraits/pleichach/index.htm
- Wild Trout Trust. (2011). Background to the 2011 Awards: Judges Report. Wild Trout Trust Newsletter.
- Woodland Water & Gardens. (2017, April 12). Woodland Water & Gardens , Wincanton Somerset. Retrieved from Woodland Water & Gardens : http://www.woodlandwaterandgardens.co.uk/projects.php
- Woodland, Water & Gardens. (2014). Midsomer Norton Towcentre - River Wildlife. Midsomer Norton Towncouncil.
- World Landscape Architecture. (2017, April 14). Kallang River Bishan Park | Singapore | Atelier Dreiseitl. Retrieved from World Landscape Architecture: http://worldlandscapearchitect.com/kallang-river-bishan-park-singapore-atelier-dreiseitl/
- Wötzel, P. (2016, October 17). Quellenbach soll bald sichtbar werden. Main Post.
- Yonkers Government. (2017, April 18). City of Yonkers, NY: Daylighting of the Saw Mill. Retrieved from Yonkers Government: http://www.yonkersny.gov/work/department-of-planning-development/projects/daylighting-of-the-saw-mill-river