Towards an Active Living Environment: Evaluating the Impact of Stream Daylighting on Pedestrian Networks in Zurich

by

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Author’s Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Statement of Contributions

I (Anya Ingram) am the primary author of this thesis which follows the manuscript option for Master's students in the School of Planning at the University of Waterloo. Accordingly, this thesis consists of a single manuscript which will subsequently be submitted for publication with Dr. Luna Khirfan as co-author.

This thesis is situated within Dr. Luna Khirfan's broader research project, entitled "The Potential of Daylighting (Deculverting) Urban Streams for Climate Change Adaptation and Mitigation and for Place-Making: Amman's Seil and Seoul's Cheonggyecheon", which is funded by The Social Sciences and Humanities Research Council of Canada (SSHRC) via the successful procurement of the SSHRC Insight Grant competition #435-2016-0243. This research grant funding enabled me to participate in online space syntax training webinars offered by the Space Syntax Laboratory at the University College London. These webinars, and the supervision and guidance of Dr. Luna Khirfan, contributed to the development of this manuscript's theoretical and conceptual frameworks. Additionally, Dr. Khirfan has provided feedback and editorial comments to the entirety of this thesis.

The spatial data used in this thesis are a combination of open data, previous efforts from Dr. Luna Khirfan and her research team, and my own contributions. Dr. Luna Khirfan obtained a georeferenced 1984 historic map of Zurich and contemporary spatial datasets of surface water, roads, and pedestrian paths from the City of Zurich Open Data Portal. I significantly modified the contemporary pedestrian path spatial data as they do not include many residential areas around streams. The contemporary road network data and the 1984 map were used by Sophie Wang (a co-op student hired by Dr. Luna Khirfan) to create a 1984 road network layer, which I later reviewed and edited. I produced the pedestrian path and stream

layers for 1984. The data was analyzed and interpreted in consultation with both Dr. Luna Khirfan and Dr. Jeremy Pittman. I also produced all of the figures shown herein except where indicated by citation.

Abstract

The burial and culverting of urban streams to make way for twentieth-century urbanization has disconnected nature from the built environment and led to the loss of ecosystem services. As waterways are inherently lateral obstacles to movement that must be overcome, it can be understood that reintroducing water features into the urban landscape through daylighting may contribute to a loss in route network connectivity and a negative impact on active mobility. However, reintroducing streams through the practice of daylighting has demonstrated benefits associated with active mobility by re-establishing urban environment connections with nature and place-making for residents. To better understand if stream daylighting can support the development of an active living environment, despite urban streams being traditionally understood as barriers to movement, the City of Zurich, Switzerland is used as a case study because of its widespread stream daylighting initiatives. Specifically, this study evaluates how stream daylighting impacts active mobility by focusing on route network connectivity change at stream sites before and after daylighting. This is done using metric reach, a measure of connectivity that utilizes a configurational approach computed in a GIS platform. To facilitate such a study, waterways and route centerlines were digitized using a georeferenced historic map of Zurich from 1984 (pre-daylighting). These were compared with 2020 open-access spatial data for the City of Zürich (post-daylighting). Spatial data results are complemented using photography to better understand how urban design choices involved in daylighting projects influenced route networks. Findings reveal that in most cases daylighting streams did not negatively impact connectivity. On the contrary, this study's finding reveals that daylighting in Zurich is commonly part of broader urban design interventions that improve or create new spaces for pedestrians while maintaining existing route connections through the incorporation of small footbridges. While stream daylighting is well established as a nature-based solution that supports infrastructure resilience and effective stormwater management, these findings help demonstrate the cultural ecosystem services the practice of urban stream daylighting can contribute.

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Finally, I would like to take this opportunity to acknowledge that the opportunity to pursue graduate studies is not available to all who wish to do so. While completing this thesis required a significant effort, it has also been an enormous privilege.

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1.0 Introduction

Rapid twentieth century urbanization has placed significant strain on the relationship between the built and natural environments. To make room for development, extensive land reclamation efforts were undertaken, including fluvial reclamation which involved the culverting and burial of urban streams (Khirfan et al., 2021). In addition to reclaiming land for human activities, stream burial has been motivated by misguided attempts to hide water pollution, and reduce flooding risks (Wantzen et al., 2022). This has resulted in significant damage to natural hydrological processes, and the loss of ecosystem services associated with urban streams fall into four categories: 1) provisioning services, representing benefits that can be extracted from nature (e.g. food, water); 2) regulating services, which moderate natural phenomena (e.g. flood control); 3) supporting services, required to produce other services (e.g. nutrient cycling and provisioning of habitats); and 4) cultural services, the nonmaterial benefits nature provides humans (e.g. recreation and sense of place)(Chan et al., 2012; Yeakley et al., 2016). More recently, there has been a concerted effort to revive buried streams through a practice known as stream daylighting. This reversal of stream burial reintroduces streams to the surface and restores the ecosystem services they provide which "directly or indirectly enhance the ecological, economic and/or socio-cultural well-being of a region and its inhabitants" (Khirfan, Peck, and Mohtat, 2020, p.10).

The discourse on stream daylighting has focused largely on the numerous regulating and supporting ES that have often motivated this practice, such as improving water quality, enhancing habitats and biological processes, reducing erosion, and increasing resilience against flooding (Baho et al., 2021; Neale and Moffett 2016; Cadenasso et al., 2008). However, urban planners and other agents of change have also been interested in the cultural ecosystem services of urban waterways restored through stream daylighting, notably

contributions to overall health and wellbeing by reconnecting urban residents with nature, providing recreational opportunities, and fostering a sense of place and community (Chan et al., 2012; Waste and Recyling Zurich [WRZ], 2013). This study seeks to discern if stream daylighting has a measurable negative impact on pedestrian network connectivity. If no negative impact on connectivity is identified, even though waterways have conventionally been seen as barriers, then daylighting may help create a more connected public realm that supports active mobility by restoring lost ecosystem services. Connectivity is identified as the focus of this study, as it is a characteristic of the built environment which is considered key to a built environment spatial structure which enables and encourages active mobility (Forsyth et al., 2008; Ozbil et al., 2011). This contributes to an improved understanding of the relationship between reintroducing urban streams and changes to spatial structure, an area of stream daylighting research that Khirfan, Mohtat, and Peck (2020) identified as having received limited attention.

Specifically, this study uses Zurich, Switzerland as a case study to investigate how stream daylighting impacts route connectivity for active mobility. Historically the City of Zurich has significantly altered or buried streams, which has led to a reduction in the total length of streams from approximately 160km in 1850 to about 60km by 1980, mostly within forested areas (WRZ 2003). In 1988, Zurich initiated its "*Bächkonzept*" (‘stream concept’) program to reverse stream burials, through daylighting. This was part of a larger stormwater management strategy, providing a viable way to store stormwater runoff, thus mitigating combined sewer overflows into Lake Zurich in an important effort to protect drinking water (Conradin and Buchli 2004). These benefits of stream daylighting can help decrease vulnerability and improve the resilience of urban environments from the impacts of climate change (Hawley and Korth, 2014; Wild et al., 2019). As of 2013, Zurich had daylighted

around 20 kilometers of streams distributed in over 60 stream segments throughout the city (Wantzen et al., 2022). This widespread implementation creates an opportunity to compare conditions when they were still buried to those after they were daylighted and gain a unique perspective on the long-term effects of stream daylighting initiatives and their implications for urban development over several decades.

This paper adopts a comparative approach, analyzing route networks around streams in 1984, before the *Bächkonzept* implementation, and comparing these conditions with those around the same streams that have been daylighted by 2020. To achieve this, four strategies are used as part of the methodology: identification of stream daylighting sites and path networks using spatial data acquired by digitizing Zurich's historical maps and from contemporary maps (using ArcGIS Pro); metric reach spatial analysis of route networks around streams (using ArcGIS Pro); Difference in Difference statistical evaluation of metric reach results; and last, evaluation of urban design interventions for the daylighted streams using photography. The subsequent section of the paper provides a brief overview of the connections between urban form and urban streams, and the challenges with defining and measuring walkability and connectivity. Then a detailed overview of Zurich as a case study, the research methodology, and the analysis of findings are presented, followed by discussion, limitations and concluding remarks.

2.0 Reviewing the Literature: Evaluating Spatial Structure

2.1 Urban Form and Urban Streams

Urban morphology is a dimension of urban design concerned with the study of urban form and the unique and everchanging spatial configurations of human settlements (Kropf, 2011; Carmona, 2021). It is concerned with the relationship between the three components of a settlement's urban form: first, the town plan which consists of the spatial arrangements of the streets and their networks, the lots and blocks, and building footprints; second, the building fabric in reference to the three-dimensional built form; and third, land and building uses (Conzen, 1960). By examining the relationships between components of urban form rather than individual features, urban morphology considers the underlying spatial organization and arrangement of elements within the built environment known as spatial structure (Carmona et al. 2021).

The natural context influences urban form because geographical features must either be altered to accommodate development or accepted as guides (Kropf, 1996). The degree of influence a waterway may have on urban form is largely dependent on its spatial scale, as this determines to what extent it may be modified (Kondolf and Pinto, 2017). Because of their smaller scale, streams that are not allowed to flow naturally can be buried or channelized relatively easily to accommodate development, thus altering the natural context. Daylighting streams reverses this removal of the natural context, reintroducing waterways, and their associated characteristics to the surrounding urban form.

Because streams act as natural pathways within the urban landscape, multi-use trails are often incorporated into the greenspace adjacent to streams (Kearns, 2011). These types of walking paths are examples of activities that Kondolf and Pinto (2017) describe as 'prior programming', which differs to spontaneous activities where passers-by may make use of

natural features in unplanned ways. These opportunities for socialization and recreation afforded by access to nature, are examples of non-material cultural ecosystem benefits to health and well-being (Chan et al. 2012). Forsyth (2015) describes that natural or vegetated environments encourage walking for rest, relaxation, and health. The smaller spatial scale of streams also means they can easily accommodate interactions between people on either side of the banks, encouraging the development of vibrant public spaces which facilitate social connectivity along and across the water (Kondolf and Pinto, 2017). However, as streams are relatively easy to modify, development which has occurred near streams may create spatial constraints which often prohibit the subsequent establishment of walking paths or green spaces on both sides of stream banks (Kondolf and Pinto, 2017). Where the connectivity and integration of public spaces near urban waterways is achieved, and recreational opportunities are made possible, streams influence patterns of movement and co-presence – essential factors for promoting active mobility and contributing to the socio-dynamics of the urban environment (Junker and Buchecker, 2008; Garau et al., 2020; Shafray and Kim, 2017). However, there is limited research that connects active mobility, path network change, and urban stream daylighting (Khirfan, Mohtat, and Peck, 2020).

2.2 Understanding Walkability

Walkability is a term often used to try and describe some element(s) of a built environment's capacity to accommodate, facilitate and encourage pedestrian – and sometimes other non-motorized – activity. However, walkability is interpreted in many ways and used to describe a wide range of phenomena as identified by Forsyth (2015) who, to distinguish between these varied definitions of walkability, identified three clusters of how walkability is understood within the literature (Figure 1). The first cluster are definitions focused on themes or

characteristics of the built environment that act as drivers to both facilitate necessary travel, and encourage optional travel: traversable, compact, physically enticing, and safe. Definitions within this first cluster are considered the 'means', a set of preconditions for the second cluster, which includes definitions that pertain to the perceived 'outcomes' of an environment which facilitates and encourages walking, such as generating lively and sociable spaces, encouraging exercise, and promoting sustainability through urban form and the facilitation of non-motorized transportation modes. The final cluster includes definitions that consider walkability as a "proxy for better design", a set of dimensions with measurable indicators, or a "holistic solution to improving urban areas" (p.285).

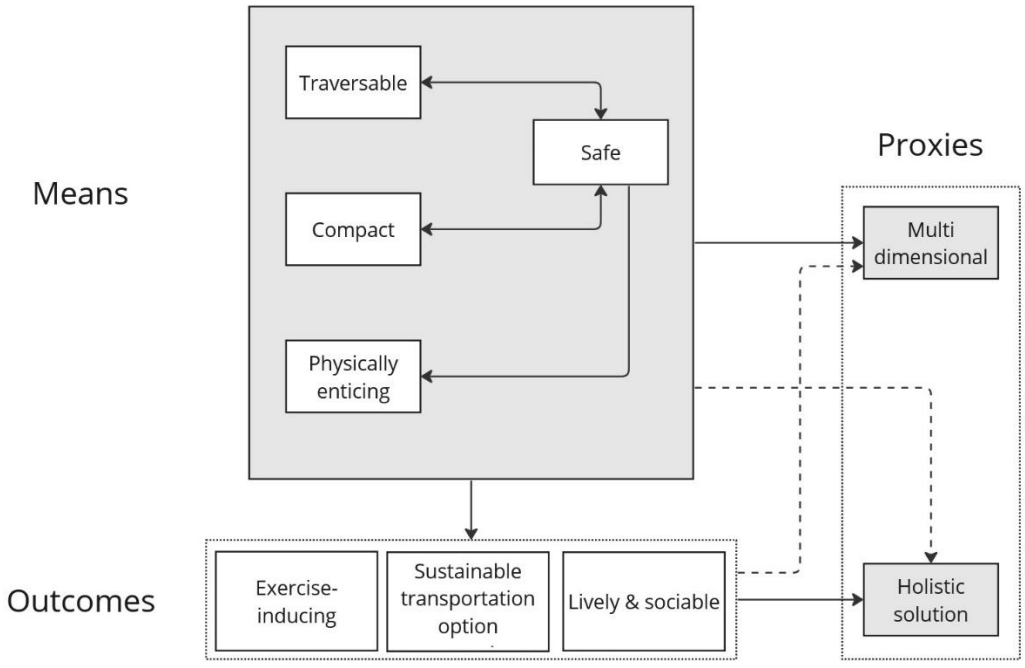


Figure 1: Framework linking definitions of walkability and walkable places (copied from Forsyth 2015)

In response to this wide range of definitions, concepts such as Neighborhood Active Living Potential (NALP) (Gauvin et al., 2005) and an Active Living Environment (ALE) have been proposed (Tobin et al., 2022). Both concepts recognize the intricate interplay between spatial characteristics and patterns of active mobility. While these conceptual definitions attempt to supersede the term walkability entirely, they have similar characteristics to the proxy definitions of walkability identified by Forsyth (2015) in that they are multi-dimensional and/ or holistic.

Gauvin et al. (2005) define NALP as "aspects of the neighborhood that regulate the likelihood of active living in individuals and populations", in which active living "is a way of life that integrates physical activity into daily routines" (p.127). In presenting the term NALP, they identified two main criticisms with the term walkability. First walking is not the only form of active mobility which is associated with certain environment characteristics and is thus an unsuitable term to use if not excluding these other types of activities (e.g. cycling, wheelchair use, and strollers). This is a challenge as walkability may implicitly be understood to include these other uses, but it is left unclear by definitions limited to pedestrian activity. For example, Mezoued et al. (2021) refer to the potential of public spaces to accommodate walking; and Foltête and Piombini (2007) considered walkability as a description of pedestrian ease of movement. Conversely, some explicitly broaden the meaning, such as Ellis et al. (2016) who described walkability as an environment's conduciveness to physical activity. The second challenge with walkability identified by Gauvin et al. (2005) is that environmental characteristics reflect a potential rather than a capacity for movement as human agency "is a key factor of the outcome of complex interactions among individuals, populations, and environments" (Gauvin et al., 2005, p.127).

The development of the ALE concept was in part motivated by these same two criticisms of walkability, and by the general lack of a true conceptual rather than operational definition (Tobin et al., 2022). Hence, ALE is defined as "the emergent natural, built, and social properties of neighbourhoods that promote physical activity and health and allow for equitable access to health-enhancing resources" (Tobin et al., 2022, p.1). It is like NALP in that it identifies the neighbourhood scale, and active living; however, it explicitly integrates a health and equity lens, and distinguishes between built, natural, and social properties.

2.3 Assessing Route Networks

There are many approaches to measuring the built neighbourhood properties, representing the 'means' walkability definitions as presented by Forsyth (2015). D'Orso et al. (2023) categorize these approaches into those focused on macroscale (neighbourhood or city-wide) assessments that use quantitative indicators and microscale (site specific) assessments that use either quantitative or qualitative indicators.

Microscale assessments focus on conditions of pedestrian routes, and indicators which may be objective or related to pedestrian perception including factors like vegetation, pedestrian crossing design, streetlights, sidewalk maintenance, and streetscape aesthetics (D'Orso et al., 2023). An example of microscale assessment is a framework proposed by D'Alessandro et al., (2016) comprising of several indicators divided into four key categories: practicability, safety, urbanity, and pleasantness. These relate to the two categories of walkability definitions identified by Forsyth (2015): physical attractiveness and safety.

Spatial structure characteristics that influence active mobility are the focus of macroscale assessments, and many are centered around connectivity (D'Orso et al., 2023). These types of assessments operationalize what Forsyth (2015) identified as 'traversable' and 'compact'

definitions of walkability. Connectivity refers to the degree to which urban form facilitates or restricts movement based on the number of connections between points in a network (Koohsari et al., 2014). A highly connected network promotes active mobility by reducing travel distance, expanding route choices, and enabling direct movement between destinations, making it a critical built environment characteristic to support active living (Gauvin et al., 2005; Ellis et al., 2016). Additionally, more connected networks provide convenient access to important destinations and social spaces within the city, thus fostering community cohesion (Alexander et al., 1977). Because of network connectivity's various characteristics and implications, there are many approaches to its measurement, and none is a commonly accepted standard (Ellis et al., 2016). To make sense of the various methods for evaluating connectivity, Ozbil et al. (2011) identified four main approaches, including a focus on topological distinctions in network layout (referring to organization or connections), accessibility, specific location characterization, and network configuration.

The first approach, the identification of topological distinctions in network layout, is achieved through the measurement of street network average properties such as the number of intersections (Ozbil et al., 2011). The assessment of factors impacting accessibility uses similar measures to the first approach, such as block size per area and intersection density. The characterization of specific locations within a network is achieved with measures such as pedestrian catchment area (also known as ped-shed ratio) (Ozbil et al., 2011; D'Orso et al., 2023). Pafka and Dovey (2017) identify a catchment as a "zone of potential access to any particular location" which can be applied to different variables such as street length (p.4). Peponis et al. (2008) presented metric reach, a measure of network connectivity which identifies the total length of distance which can be travelled along a given network extending out from a specific point without exceeding a given threshold value.

Metric reach considers the relationship between route segments and the role of network density (identified as a high metric reach value) in determining the potential for movement. Metric reach's strength lies in its applicability to both large and small areas, and that it can be assigned to a specific point as opposed to an aggregate value applied to a larger area (Peponis et al., 2008). This measure integrates concepts of space syntax theory and network configuration, the fourth approach to connectivity identified by Ozbil et al. (2011). The configurational approach aims to address an issue with many of the other measures of connectivity, which is their limited assessment of network permeability (Pafka and Dovey 2017).

Permeability refers to a spatial configuration which is easily reached from one point to another, meaning a volume of choices are available thus improving ease of movement (Lynch, 1960). Key characteristics of permeability is route choice, and network legibility, as permeability is also a visual quality referring to pedestrians' ability to see through, or move through space which is affected by blocks, roads, and hierarchical configuration (Urrohmah et al., 2023; Carmona 2021). Permeability and connectivity are both aspects of spatial structure, but where connectivity refers to existing connections in a route system, permeability incorporates the capacity of those connections to enable movement pointing towards ease of movement (Carmona 2021). By taking a configurational approach which assesses permeability, metric reach generates a measure which is not equivalent to other measures such as total street length, number of intersections or blocks (Peponis et al. 2008). This is demonstrated in Figure 2, which illustrates how these other measures fail to properly consider network configuration by comparing them using the same metric threshold for the calculation of reach. Even with the same total street length, number of intersections and

blocks, the right diagram in each of Figure 2A, 2B, and 2C, have a lower mean metric reach than the left depicting an orthogonal grid (Peponis et al. 2008).

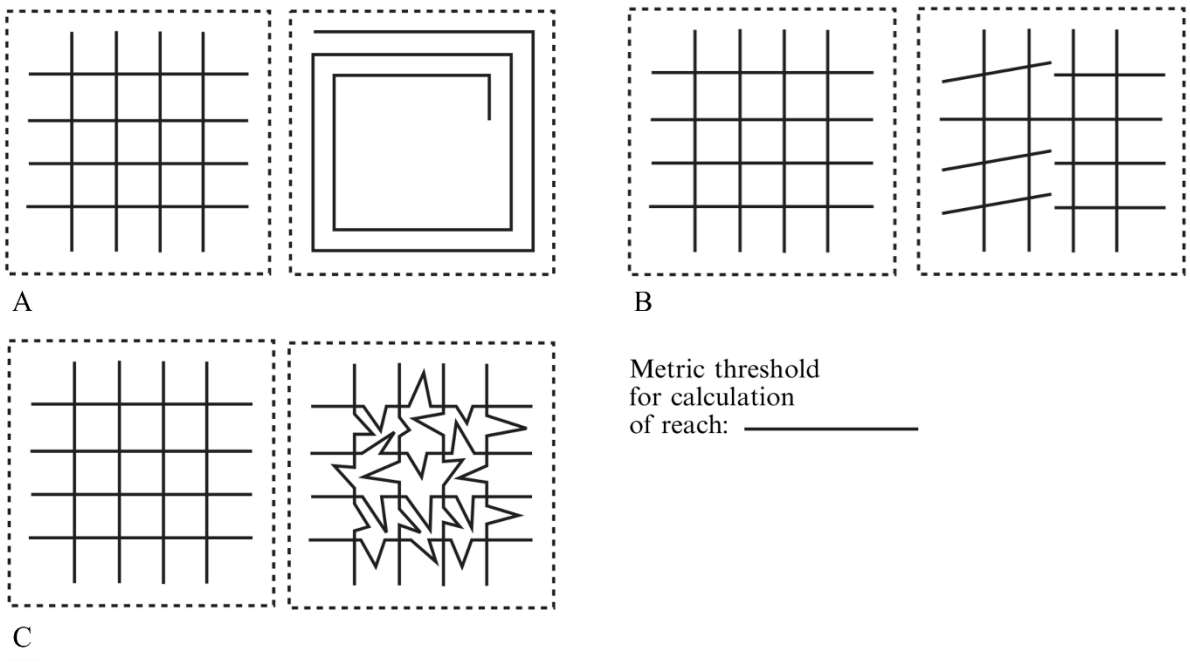


Figure 2: orthogonal grid compared to others with A) same street length; B) same street length and same number of intersections; C) same number of blocks and same number of intersections (copied from Peponis et al. 2008).

Permeability is foundational within space syntax theory, introduced as a concept in the 1970s and developed further in the 1980s, to integrate human understanding of space and distance to the assessment of urban form configuration (Hillier and Hanson 1984; Hillier and Iida 2005). This includes recognizing that human notions of distance are not purely based on measured length (e.g. metric distance), but also the topological (e.g. number of turns) and geometric (e.g. angular change in direction) properties of networks (Hillier and Iida 2005). Space syntax measures assess how line segments within the greater spatial structure are connected to identify the integration of route segments within the surrounding network, and the volume of route choice available between locations. Hillier and Iida (2005) describe a

highly integrated segment as a more attractive destination, which can be “theoretically expected to attract more movement […] purely as an effect of the structure of the network” (p.557). By taking a configurational approach, measures rooted in space syntax theory provide analysts the ability to assess the theoretical permeability and connectivity of small- and large-scale areas (Hallowell and Baran 2013; Koohsari et al., 2016; Jabbari, et al., 2021).

3.0 Framework for Evaluating Streams

This study aims to fill two gaps in the research on stream daylighting identified by Khirfan, Mohtat, and Peck (2020). Firstly, there is a lack of exploration into the connections between stream daylighting, urban design, and the built form. This study, therefore, focuses on urban streams as part of Zurich's spatial structure and considers if they act as barriers to route connectivity when reintroduced through daylighting. Secondly, there are limited case studies on daylighting as a widely applied practice as is the case in Zurich (Khirfan, Mohtat, and Peck, 2020, p. 10). Zurich's unique abundance of daylighted streams presents an exceptional opportunity to examine the practice's impact on the creation of an active living environment.

The examination is rooted in a theoretical framework which integrates the walkability definitions framework from Forsyth (2015) and the conceptual definition of an active living environment presented by Tobin et al. (2022). While alternative conceptual definitions of walkability have been presented by other scholars such as Gauvin et al. (2005), the framework presented by Tobin et al. (2022) is unique in distinguishing between natural and built neighbourhood properties. Figure 3 demonstrates how the natural, social, and built properties of neighbourhoods which constitute an ALE can be situated within the 'means' cluster of walkability definitions identified by Forsyth (2015). Cultural ecosystem services as described by Chan et al. (2012) are incorporated as a means associated with natural neighbourhood properties with 'health and wellbeing' as the outcome. Configuration, encompassing permeability, is also identified as the broader connection between a network which is traversable and compact, two means definitions of walkability identified by Forsyth (2015). Traversable is considered a characteristic of a connected network within this adapted framework, as it is a way of describing a network which has existing connections and the permeability required to facilitate movement (Lynch, 1960). As the definition of an ALE was

presented to overcome challenges with previous definitions of walkability, it is identified as both a multi-dimensional and holistic definition which encompasses the means, outcomes, and proxies.

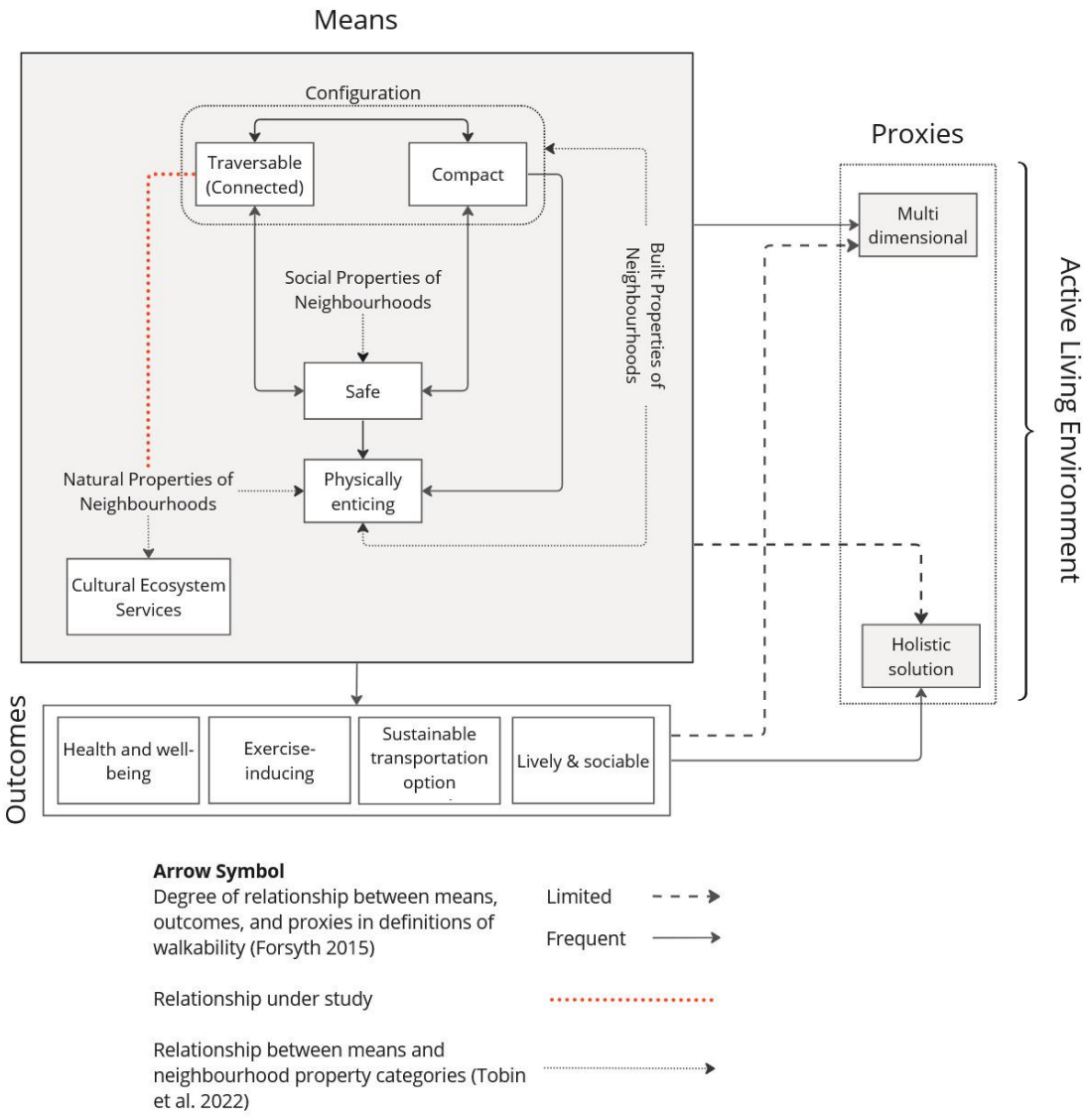


Figure 3: Framework linking definitions of walkability which integrates the relationship between Active Living Environment properties (adapted from Forsyth, 2015)

Through this framework, the study seeks to contribute to a deeper understanding of how daylighted streams can contribute to the development of active living environments while addressing the challenges they may pose to urban connectivity. To operationalize the theoretical framework proposed, a set of key indicators and variables is established to measure the impact of stream daylighting on connectivity, urban form, and active mobility (see Table 1).

Table 1: Indicators and Variables Used in Study

Attributes of environment	**Indicators**	**Variables**	**Data sources**
Built Properties of Neighbourhoods	Connectivity	Metric reach: total length that can be travelled along a given network from a point within the established cut-off.	2020 spatial data including: ➢ road centrelines (Canton of Zurich, 2021) ➢ pedestrian and bicycle path networks (Civil Engineering and Waste Management Department [CEWMD], n.d.) Georeferenced and digitized 1984 map (City of Zurich, 1984).
Natural Properties of Neighbourhoods	Presence of streams	Total length of culverted streams	2020 spatial data including: ➢ Public surface waters (Canton of Zurich, n.d.) ➢ Water ecomorphological survey (Office for Waste, Water, Energy and Air [OWWEA], n.d.) Georeferenced and digitized 1984 map (City of Zurich, 1984).
		Total length of daylighted streams	
	Predominant Stream Type	Integration with recreational amenities	WRZ, 2007
		Embankment type (natural or walled)	Google satellite imagery and Streetview
		Type of vegetation present	

Central to this framework is the utilization of metric reach as a measure of connectivity which considers configuration, enabling the exploration of changes resulting from daylighting urban streams on the surrounding route network and providing a local measure of connectivity for each stream across different time periods. The use of metric reach is guided by a framework established by Peponis et al. (2008), who introduced the method, and employed in ArcGIS Pro using the Service Area tool as done by Ellis et al. (2016). Metric reach analysis is also conducted on streams that remain culverted, and these results are then compared with those of the daylighted streams through a difference-in-difference analysis. This is to control for the influence of other variables associated with urban growth on connectivity. By comparing the impacts of daylighted streams with those of culverted streams and untouched streams over time, this approach helps to isolate the specific effects of stream daylighting on connectivity. Additionally, stream types as described by Zurich are identified as another important variable, aiding in understanding the role of intervention design in stream daylighting projects. By classifying streams according to their types, the study seeks to uncover how different stream characteristics interact with the urban environment and impact connectivity and active mobility.

Finally, photography is used for the purposes of contemplation and contemplation. Gaber and Gaber (2004) describe contemplation as the visualization of the research subject, and complementarity as the combining of methods to measure “overlapping, as well as different, aspects of a situation in order to enrich the understanding” (p.228). Photographs, add to the interpretation and analysis of urban design interventions that have occurred at stream daylighting sites and how they compare to their previous culverted state (contemplation); and offer a different approach to understanding their impact on network connectivity and the creation of an ALE, than can be achieved with spatial data alone (complementarity). While

there are challenges with the use of photographs, such as photographer bias and limitations of inclusion and exclusion within the frame, they are well suited to reflecting the complexities of urban spaces and provide an opportunity for new interpretations (Hunt, 2014).

4.0 Research Methods

4.1 The City of Zurich

This paper uses the City of Zurich as a case study to evaluate urban stream daylighting and its impact on route connectivity for active mobility. Zurich is located within Canton of Zurich (an administrative division of the country), in Switzerland. Zurich was selected as the present study's case largely because there are approximately 20km of daylighted streams distributed over around 40 projects throughout the city (Wantzen et al., 2022; Conradin and Buchli 2004), creating an opportunity to study daylighting as an incremental and networked intervention, rather than a singular large project. The volume of daylighted streams is the result of the significant number of natural streams afforded to the city by its lakeside valley geography; many of which were culverted during a time of rapid urbanization; and finally, the early adoption of a stream daylighting concept approved by City of Zurich Council as a policy in 1988.

At its origin the concept took an interconnected approach with three primary objectives: 1) to reduce volume of clean water entering the wastewater treatment plants; 2) to improve recreation opportunities within residential neighborhoods; and 3) to restore habitat thereby improving the relationship between city residents and the natural environment (Conradin and Buchli 2004). In its establishment, the concept involved significant engagement with residents and daylighted projects were developed to meet their needs and desires, providing an opportunity for children to play, and landscape beautification for residential developments (Conradin and Buchli 2004). Zurich's Civil Engineering and Waste Management Department (CEWMD) identified the public spaces in and around bodies of water and associated riparian zones, as key assets in their "*Stadträume Zürich*" (Urban Spaces Zurich) Strategy (2010)

In 2012, Canton of Zurich's Office for Waste, Water, Energy and Air (OWWEA) published their Water Action Plan (2012), which established stream daylighting and overall re-naturalization protocols, required that both the habitat and recreational function of water bodies be considered for projects to meet aesthetic and urban planning standards. This is furthered by "*Das Grünbuch der Stadt Zürich"* (the Green Paper of the City of Zurich*)*, published by Green City Zurich, a subdivision of CEWMD which guides the planning of green and open spaces in Zurich (2019). In this plan, the provision and access to bodies of water in attractive, recreational ways is identified as a key goal in open space planning; in part because of the secondary benefits of water bodies, such as improvement to the local urban climate through thermal regulation and the preservation of natural resources (Green City Zurich, 2019).

Additionally, Zurich has set a target to be climate-neutral by 2040, with strategies that include an emphasis on densification and promoting non-motorized transportation (Health and Environment Department [HED] 2021a). To ensure increased urban density does not come at the expense of an attractive built environment, or the provision of spaces for outdoor activity, green and open spaces are identified as a priority in Zurich's *Mobilität* [Mobility] plan (HED 2021b). These spaces can serve as destinations for outdoor activities that help to encourage various forms of active mobility. Due to their inherently linear quality, daylighting streams act as corridors for both nature and recreation within the built environment (Green City Zurich 2019). As such, the cultural ecosystem services associated with stream daylighting as a practice may include the creation of a more enjoyable pedestrian environment that encourages residents to travel on foot.

4.2 Stream Identification

This study uses 1984 as the reference point for a comparative evaluation of route network change, with 2020 as the contemporary point of reference. An archival map of Zurich in 1984 was used to manually identify which streams were culverted or open at that time using the map symbology (City of Zurich, 1984). Spatial data obtained at the start of 2021 (capturing conditions by the end of 2020) from Zürich and Canton of Zürich's Open Data Portals include pedestrian and bicycle path networks (CEWMD, n.d.), street centerlines (Canton of Zurich 2021), public surface water (Canton of Zurich, n.d.), and an ecomorphological survey of watercourses (OWWEA, n.d.). Water ecomorphology, refers to the structural characteristics of a body of water and its banks. This spatial data layer identifies how impacted the natural state of stream is, including if they are culverted, and was used to determine which streams were culverted or open in 2020. By comparing the status of streams between 2020 and 1984, streams that were daylighted are identified (see Figure 4).

These identified streams were also cross-referenced with Zurich reports on stream daylighting projects (WRZ 2003; WRZ 2007; WRZ 2015). Any sites that could not be identified with certainty through this process as daylighted sites were excluded from further analysis. In this way three distinct groups were identified: daylighted streams (previously covered in 1984, now open in 2020), culverted streams (covered in both years), and untouched streams (open in both years, excluding rivers). In instances where a stream has multiple segments that have been daylighted, it is considered a single multi-part stream project unless there is a significant physical barrier.

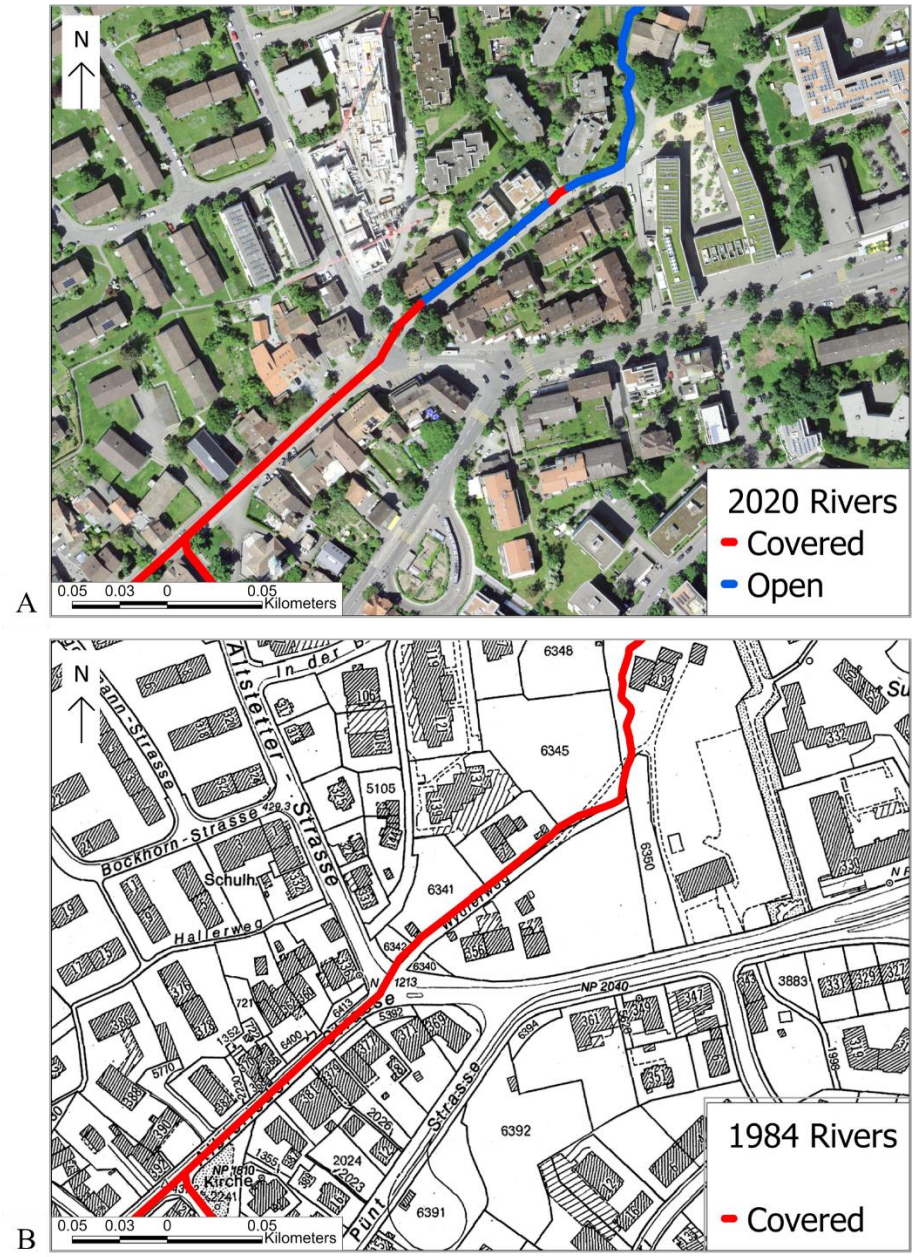


Figure 4: Process of daylighted stream identification using a) 2020 surface water spatial data; and b) 1984 archival map visual identification.

Identifying culverted streams and untouched streams is important as there are many variables other than daylighting itself that would have an impact on connectivity and influence metric reach results. Being able to compare the change in connectivity between the three groups is a

way to control for the change that occurred surrounding daylighted streams within the backdrop of urban change between 1984 and 2020. Notably, many daylighting projects occurred in undeveloped or less densely built-up areas with available land which coincides with areas where greenfield development occurred after 1984 leading to the construction of many new pedestrian paths and roads. These new developments are not a direct result of daylighting, yet they influence metric reach results. As daylighted streams were essentially culverted streams in 1984, streams that remained culverted by 2020 act as a control group for unknown and known variables, such as greenfield development, that would impact metric reach and thus better understand the effects of the treatment (daylighting).

4.3 Stream Types

Zurich classifies its streams as forest, meadow, city, park, and fallow streams to distinguish between their natural characteristics and their integration with the built environment characteristics (WRZ 2003; WRZ 2015). As each stream type has unique characteristics in how they relate to the built environment, it is worth considering if they have equally unique impacts on route connectivity due to daylighting. While these are not intended to be rigid classifications and there is often notable overlap, Table 2 presents an evaluation framework (adapted from Zurich's descriptions) used to visually identify the stream type that best describes each of the daylighted stream sites. Many streams have segments that may be attributed to various stream types, in these cases the stream type that applies most broadly is associated with the stream. Because the culverted streams are still buried, no stream type is attributed.

Table 2: Stream Type Evaluation Criteria

	Forest	Fallow	Meadow	Park	City
Natural Characteristics					
Natural Catchment Area	Yes	Yes	Limited	Limited	No
Periodically Wet Floodplain	No	Yes	No	No	No
Natural Embankment	Yes	Yes	Yes	Yes	No
Flat Grade	No	Yes	Yes	Yes	Yes
Surrounding Vegetation	Yes	Limited	Limited	Limited	No
Meander through Grassy Areas	No	Yes	Yes	Limited	No
Integration with Built Characteristics					
In Built-Up Areas	No	Limited	Yes & No	Yes	Yes
Unobstructed	Yes	Yes	Yes	Yes & No	No
Recreational Amenities	No	No	No	Yes	No

Based on descriptions in reports by the City of Zurich, forest streams have natural catchment areas and are generally located in the steep terrain areas on the hills at the periphery of the city before the water flows into smaller streams in the settlement area (see Figure 5a). Due to their non-urban setting, forest streams do not factor into this analysis and are excluded from all groups. In contrast to forest streams, meadow streams are characterized by their flat grade. These are usually unobstructed and meander through grassy areas with some vegetation which can include built-up settlement areas (see Figure 5b). Fallow streams are not too dissimilar to meadow streams, except they are broadly characterized as streams with ruderal areas where only adapted plant species grow. The use of the term ‘fallow’ refers to the larger than usual amount of space around these streams which is often dry but capable of sustaining flooding. As such they typically have more space available than is common in a settlement area (see Figure 5c). Park streams are found in loosely built-up areas, gardens, and recreational areas, alternating between densely built up and open areas. These streams are integrated into their surroundings, often lined with footpaths, and made accessible to all ages (see Figure 5d). Finally, city streams are characterized by the limited space they occupy.

Their embankments are channelized, as opposed to naturalized, at least on the side adjacent to roads, replaced with walls and concrete elements. The bed and flowing water for these streams are kept as close to nature as possible with clay liners, gravel, vegetation, and fish shelters (see Figure 5E).

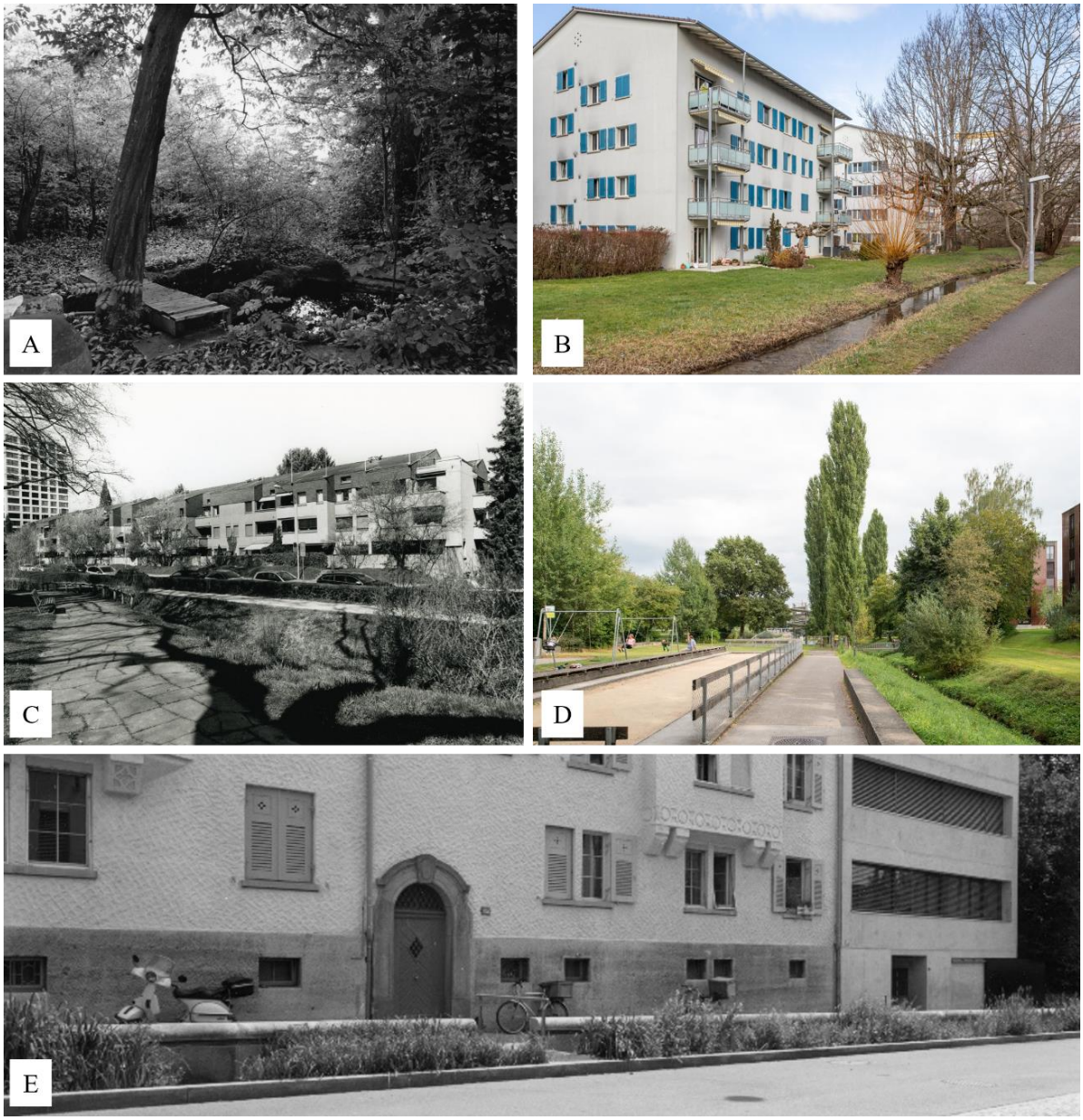


Figure 5: Five steam types including A) forest; B) meadow; C) fallow; D) park; and E) city. (Dudli, 2010; Wenger, 2023; Dudli, 2017; Haller, 2016; Hussel, 2003). Used under Creative Commons License.

4.4 Metric Reach

To enable metric reach analysis, 2020 spatial data from the City of Zurich's Open Data Portal for pedestrian path and road networks was manually edited to create a 1984 network, using the same 1984 georeferenced historical map used to identify streams (see. Section 4.2). The City of Zurich's pedestrian network data do not include many paths that go through residential areas, likely because they are not publicly owned. Because daylighted streams often flow through these spaces, the pedestrian paths were manually digitized while referencing orthophoto imagery to create a complete network. This edited 2020 pedestrian path network layer was used to create a 1984 pedestrian path network, using the same process as the road network.

Metric reach analysis was then conducted around each stream using 1984 and 2020 network data for both the pedestrian and road route networks separately. The 'Network Analyst – Service Area' tool in ArcPRO identifies the region (in the form of a polygon feature) around a location (referred to as a 'facility') which is accessible on a given network within an established cutoff distance. The Service Area tool is used to calculate metric reach but does not allow for calculation around a line feature such as a stream (depicted as a line). To circumvent this issue, point features were first generated along each stream to be used as 'facility' features. Then the Service Area is calculated using a 100m buffer, which is small for route analysis, to focus on the impacts immediately adjacent to daylighted streams. Because points along the stream were used in the calculation, the Service Area tool creates a polygon for each point which are then dissolved into a single polygon to represent the 100m service around each stream.

The service area polygons are then intersected with the network layer (which includes multiple line features), creating an output that includes only the network lines within the service area of a given stream. These line features are then dissolved to create a single feature for each stream. This feature's total length is the metric reach value, which represents the total length that can be travelled along a network (pedestrian or road network) from any point along each stream. The outputs of this process including the stream points, service area polygon, and metric reach line feature are illustrated in Figure 6.

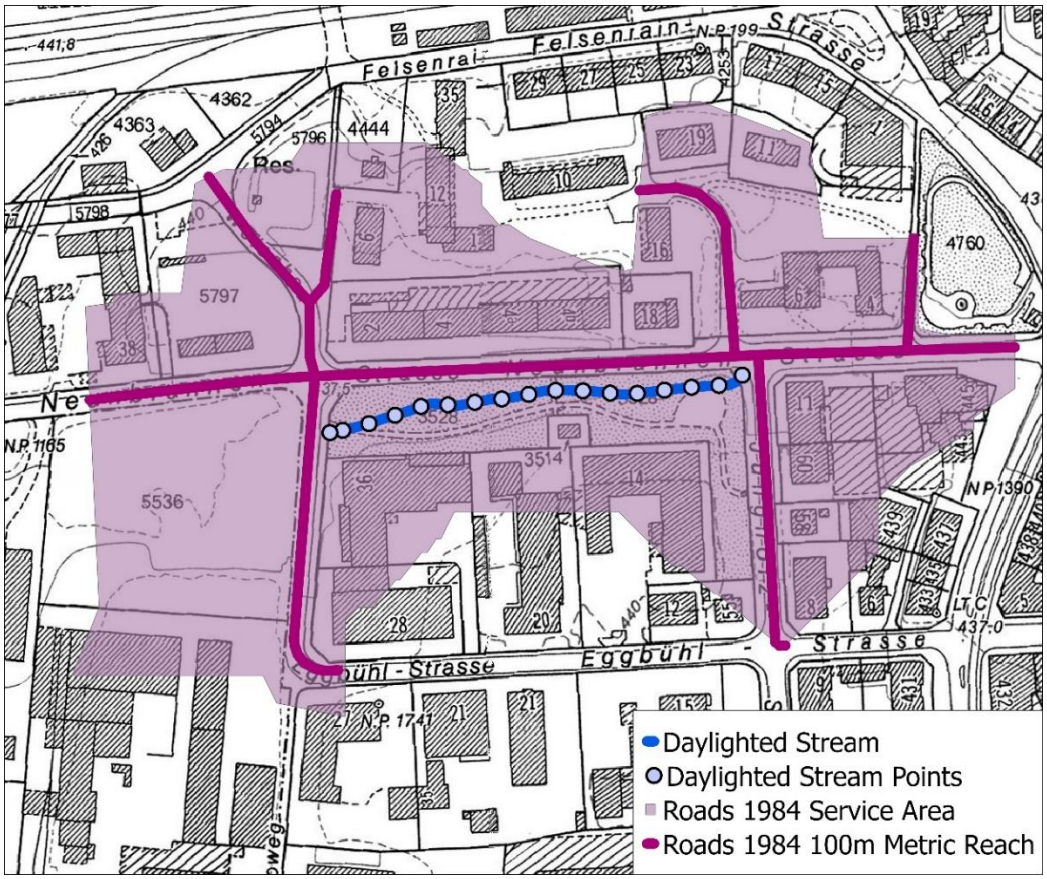


Figure 6: Illustration of spatial outputs associated with calculation of metric reach

Results of the metric reach analysis are assessed by identifying the relative difference between 1984 and 2020, and by employing a simple Difference-in-Difference (DiD) analysis

between daylighted and still culverted streams. DiD is a statistical method used to assess the impact of a treatment or intervention by comparing the changes in outcomes over time between a treated group and a control group (Wing, Simon, and Bello-Gomez 2018). DiD starts by evaluating the change in a variable (metric reach) experienced by a treatment group (daylighted streams) before and after the treatment (daylighting). The same is then done to calculate the difference in this variable for the control group (culverted streams) that did not experience the treatment. Then the difference between these two 'differences' is calculated, in this case, the difference between the difference in metric reach from 1984 to 2020 for daylighted streams and culverted streams. By examining changes in both treated and control groups simultaneously, the method accounts for any common trends affecting both groups, enhancing the internal validity of the study. This approach allows for a nuanced examination of how stream daylighting has influenced route networks, considering the broader context of urbanization and developmental changes from 1984 to 2020.

4.5 Photography

Photographs which depict streams before or after they were culverted or daylighted were identified and collected from the *Baugeschichtliches Archiv* (BAZ) [Architectural History Archive], is part of the Urban Planning Office of Zurich's Building Department. The BAZ's collection, which traces Zurich's urban development and architectural history, includes images from the late 19th century to the present, made publicly accessible through the *Eidgenössische Technische Hochschule Zürich* (Federal Institute of Technology Zurich [ETZ Zurich]) library online image service. Most photographs in the collection have also been geotagged, making it possible to manually review using their mapping interface.

Because the location of photographs is known and identified, and the collection broadly documents Zurich's built history, it is possible to manually search for and identify photographs of stream sites before culverting, while they are culverted, and with current daylighted conditions. This was done by cross-referencing the 1984 city map, the identified location of daylighted streams, and known culverted stream locations. While the comparison of network connectivity was specific to the network that existed in 1984 (before daylighting) and in 2020 (after daylighting), photographs were not limited by date.

Gaber and Gaber (2004) describe that the empirical value of photographs hinges on a methodical process for their collection and the indexing of "identifiable objects and spatial variables" they depict (Gaber and Gaber, 2004, p.223). While the collection of photographs from the BAZ is constrained by the limits of the archives collection, and can thus not be controlled, indexing was done using a framework adapted from Zurich's *Standards Stadträume* [Urban Space Standards] (Civil Engineering Department n.d.). The Urban Space Standards are an implementation tool for Zurich's Urban Spaces Strategy (CEWMD, 2010), with a searchable catalogue of elements that have been updated over time. Elements from the catalogue represent broad categories (e.g. furnishing), each with a variety of elements (e.g. benches) that in turn have various typologies to be used as determined by the type of space. The Urban Space Standards identify seven space types: 1) green spaces and bodies of water; 2) places (locations); 3) roads and paths; 4) traffic junctions; 5) engineering structures; 6) stops; and 7) parking (Civil Engineering Department, n.d.).

The culverted and daylighted streams photos collected from the BAZ, were first sorted by their space type, then indexed based on visual variables using a selection of elements from the catalogue. These are identified in Table 3 and divided into the following groups (established in the catalogue): 1) vegetation; 2) furnishing; and 3) infrastructure. The

elements included in this framework represent those that have a direct relationship with stream daylighting projects (e.g. vegetation) and pedestrian comfort as identified in the City of Zurich's element group description. The latter includes trees for shade, benches and lighting for comfort, and bollards for safety and delineation of pedestrian spaces.

Table 3: Urban Design Elements (adapted from CEWMD, 2010)

Element Groups	➢ **City of Zurich Element Group Description**	**Elements**
Vegetation: Trees/ Hedges	➢ Plants and green areas provide a contrast to the built environment. ➢ Contribute to the atmosphere of a space and the well-being of the population. ➢ Define, organize, and shape the identity of places. ➢ Provide connecting spaces Ecological benefits.	Various
		Tree Cluster
		None
		Single Tree
		Hedges
		Row of Trees
Vegetation: Green Spaces		Lawn
		Vegetation with water
		None
		n/a (water)
		Flower meadow
Furniture	➢ Reinforce spatial structure, atmosphere, and sense of place. ➢ With vegetation, they help make spaces attractive and welcoming. ➢ Invite people to linger and socialize.	Benches
		Lighting
		Fountain
Infrastructure	➢ Functional elements that should be integrated as seamlessly as possible.	Bollard
		Bike Rack

5.0 Results

5.1 Identified Streams

A comparison of the 1984 and 2020 maps reveals a total 11.6 km of daylighted streams were identified in addition to 24.7 km of still culverted streams, and 16.8 km of streams which were never culverted nor daylighted. Total length values are distributed over many stream sites, each representing a section which is largely unobstructed or continuous and ranging greatly in total length as identified in Table 4 and illustrated in Figure 7. The daylighted sites range in length from 35.6m to 902.9m and are distributed among 39 different streams. The total of 11.6km is lower than the 19.6km total length identified by Wantzen et al., (2022) due to the identification and selection criteria established (in section 4.2.), that excluded any streams that could not be identified as covered in the 1984 map and open according to the 2020 surface water data from the Canton Zürich Geodata Catalogue.

Table 4: Daylighted and culverted streams identified.

	Total Length Identified	Number of Sites	Minimum Length	Maximum Length
Daylighted Streams	11.6 km	39	25.6 m	902.9 m
Still Culverted Streams	24. 7 km	52	45 m	1.99 km
Untouched	16.8 km	46	31.6 m	2.2 km

Of the 39 stream daylighting sites, 14 are identified as ‘park’ type streams, 20 as ‘meadow’ type streams, and 5 as ‘city’ type streams. This uneven distribution is expected as most daylighting projects have occurred in the outskirts of the City of Zurich where it is more feasible due to available land and cost (Conradin and Buchli, 2004). Several streams that were identified as primarily park-type or meadow-type streams have small segments that fit a city-type design. In contrast, streams that were identified as city-type streams have no park-

type or meadow-type segments. See Appendix A for a complete overview of all identified daylighted, culverted, and untouched streams.

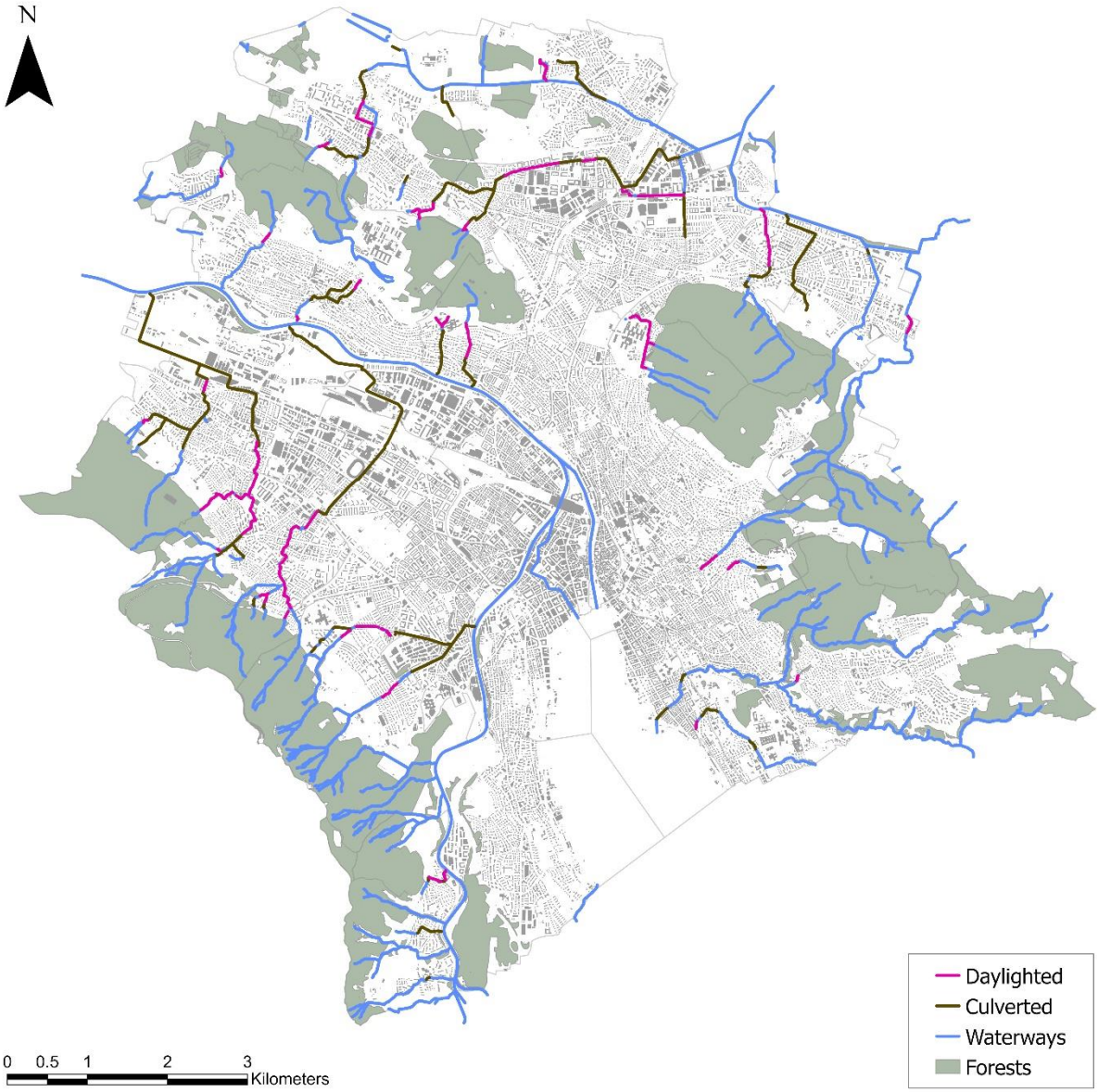


Figure 7: Map identifying the status of all waterways in Zurich, Switzerland (2020).

5.2 Relative Difference

The relative difference (percentage change between values) in metric reach between 1984 and 2020 was calculated for each daylighted, culverted, and untouched stream. The simple descriptive statistics were calculated for each group based on the relative difference values (see Table 5). For both pedestrian paths and roads, daylighted streams had on average higher positive relative difference in metric reach than culverted streams. The daylighted streams mean relative difference values of 25.1% for pedestrian paths and 10.1% for road networks demonstrate overall increases in metric reach between 1984 and 2020. Pedestrian paths around daylighted streams also had an overall maximum relative difference of 116.9% greater than the road network at 88.4%. Culverted streams had lower mean relative differences with less difference between them, at 4.0% for pedestrian paths and 3.0% for the road network. Untouched streams had similar relative difference values to that of the culverted streams, except for a much lower maximum relative difference of 11.0% for road network metric reach. This may be because the untouched stream group sites are in locations with limited space for new roads generally associated with development.

Table 5: Relative Difference of Metric Reach Between 1984 and 2020

	Pedestrian Path Network Metric Reach			**Road Network Metric Reach**		
	Min (%)	**Mean (%)**	**Max (%)**	**Min (%)**	**Mean (%)**	**Max (%)**
All Daylighted Streams	-3.2	25.1	116.9	-23.4	10.1	88.4
City Streams	-1.2	1.9	8.3	-0.3	0.1	1.0
Park Streams	-2.2	19.5	115.1	-0.5	1.2	88.4
Meadow Streams	-3.2	32.5	116.9	-23.4	13.0	78.8
Culverted Streams	-1.0	4.0	61.0	-9.0	3.0	51.0
Untouched Streams	-8.3	5.0	74.0	-8.6	1.0	11.0

Looking at the three stream types identified among daylighted streams (city, park, meadow), city streams had limited overall change. City-type streams had the lowest mean metric reach change for both pedestrian paths (1.9%) and roads (1.0%), significantly below the mean metric reach change for all daylighted streams. Moreover, city streams have the smallest range between minimum and maximum relative difference values of all stream types for pedestrian paths and roads and had a minimum change (-1.2%) that was less than the average for daylighted streams overall (-3.2%). It can be argued that city-type streams had overall limited change between 1984 and 2020 because their reintroduction is limited within strict spatial confines alongside roads. Yet, it is noteworthy that they did not significantly contribute to any loss in existing connectivity. More than not, city-type streams appear to be reintroduced without much negative or positive impact on pedestrian or road network connectivity.

5.3 Difference in Difference

A simple Difference in Difference (DiD) analysis was calculated to evaluate the impact of a treatment (stream daylighting) using the average metric reach for all streams in the daylighted (treatment group) and culverted streams (control group) respectively. Table 6 identifies the process and result of the DiD analysis. First, the difference in average metric reach between 1984 (Column A) and 2020 (Column B) is calculated for each group. Each group is identified in the rows, with the difference in their average metric reach values between 1984 and 2020 (presented in Column C). Then the difference calculated from the culverted streams is subtracted from that of the daylighted streams. This process is done for the pedestrian path and road metric reach values separately.

Table 6: Difference in Difference analysis of average pedestrian and road network metric reach at daylighted and culverted streams between 1984 and 2020

	Group	Year		Difference
		1984 (A)	2020 (B)	2020-1984 (C)
	Pedestrian Network Average Metric Reach (m)			
1	Daylighted Streams	1746.8	2112.5	365.7
Stream Types	*City Streams*	1692.52	1736.47	43.9
	Park Streams	1872.11	2156.76	284.7
	Meadow Streams	1672.63	2175.48	502.9
2	Culverted	2210.4	2262.9	52.5
3	**Daylighted – Culverted Difference**	**-463.6**	**-150.4**	**313.2**
	Road Network Average Metric Reach (m)			
4	Daylighted Streams	873.4	941.8	68.5
Stream Types	*City Streams*	820.2	821.8	1.6
	Park Streams	853.5	875.3	21.8
	Meadow Streams	900.6	1018.5	117.9
5	Culverted	1267.2	1298.1	31.0
6	**Daylighted – Culverted Difference**	**-393.8**	**-356.3**	**37.5**

The result is a pedestrian path DiD of 313.2m which represents the impact of the treatment while accounting for the difference that would have occurred without the treatment. Of note, the daylighted streams which were still culverted in 1984 – and thus in similar conditions to the culverted group being evaluated – have lower average metric reach values in 1984 than the culverted group for both pedestrian and road networks. With lower starting values, the daylighted stream group did not surpass the overall average metric reach values of culverted streams; however, they had far greater differences between the two years. For pedestrian paths, the daylighted stream group had a 365.7 m. increase in average metric reach far exceeding the 52.5 m. increase experienced by the culverted group which means the difference in average metric reach between the two groups decreased between 1984 and 2020. When applied to the roads' metric reach, daylighted streams had a difference of 68.5m and culverted streams had a difference of 31m between the two points in time, for a DiD of

37.5m. While this DiD analysis may not necessarily suggest direct causality, the results show that rather than posing an added obstacle, the estimated effect of stream daylighting is positive on route metric reach.

The DiD calculated is shown only for the daylighted stream and culverted stream groups overall because stream type cannot be attributed to the culverted streams. That said, the difference in average metric reach values for each daylighted stream type is included to provide some context on variation. For both pedestrian and road networks, all stream types had a positive difference in average metric reach, but city-type streams experienced the least difference (1.6 m), and meadow-type streams experienced the highest (117.9 m). Surrounding site conditions and impacts associated with a daylighting project vary greatly by stream type. City-type streams are generally integrated into locations with the most developed built environment, this is also why there are far fewer city-type daylighting projects. In contrast, meadow and park streams are more common in daylighting projects and situated in areas that allow more flexibility for design.

The untouched streams do not meet the assumption of a DiD analysis, in that daylighting as a treatment can only be compared to their prior condition as culverted streams. However, the difference in average metric reach values for the untouched streams is presented in Table 7**Table 7**. The untouched stream group has a difference in average metric reach of 53.85 m for pedestrian paths and 10.35 m for roads which is not dissimilar from the difference identified for culverted streams.

Table 7: Difference in Metric Reach for Untouched Streams

	Group	Year		Difference
		1984 (A)	**2020 (B)**	**2020-1984 (C)**
	Pedestrian Network Average Metric Reach (m)			
1	Untouched Streams	1469.96	1523.81	53.85
	Road Network Average Metric Reach (m)			
2	Untouched Streams	888.67	899.02	10.35

5.4 Photography

A total of 132 photos depicting streams before culverting, whilst culverted, or after daylighting were identified in the Baugeschichtliches Archiv (BAZ). Of these photos, 45 were excluded from further review as they were duplicate views or aerial photos. The remaining 87 photos include depictions of 19 stream sites before culverting, 40 culverted streams (prior to daylighting), and 28 daylighted stream sites (see detailed list in Appendix B). Of the seven space types identified in the Urban Space Standards, only ‘roads and path’ or ‘green spaces and bodies of water’ were identified (Civil Engineering Department n.d.). Roads and Path spaces represent 30 of 40 (75 percent) culverted stream site photos, and 10 of 28 (36 percent) daylighted stream site photos. Green Spaces and Bodies of Water represent 10 of 40 (25 percent) culverted stream site photos and 18 of 28 (64 percent) daylighted stream site photos. The space types were used to create two subsets of photographs from the 40 culverted and 28 daylighted stream site photos, from which the identified design elements are compared (see Table 8).

In the Green Spaces and Bodies of Water space photos, there was little variation in trees and hedges from culverted to daylighted as this space type is characterized by its greenery. Because daylighting means water is reintroduced, the significant difference in ‘vegetation with water’ identified is expected. There is little difference between the culverted and

daylighted photos in lighting, and fountains identified but a more notable difference in benches from 20% (of culverted photos) to 39% (of daylighted photos). No difference was observed for infrastructure elements (e.g. bollards and bike racks).

Table 8: Comparison of urban design elements identification in daylighted and culverted stream photos based on space type.

	Space Type	**Green Spaces & Bodies of Water**		**Roads & Paths**	
	Photo Set	Culverted	Daylighted	Culverted	Daylighted
	Total	10	18	30	10
Trees/ Hedges	Various	7 (70%)	13 (72%)	1 (3%)	1 (10%)
	Tree Cluster	1 (10%)	2 (11%)	3 (10%)	1 (10%)
	None	0	2 (11%)	13 (43%)	1 (10%)
	Single Tree	1 (10%)	0%	3 (10%)	3 (30%)
	Hedges	1 (10%)	1 (6%)	4 (13%)	1 (10%)
	Row of Trees	0	0	6 (20%)	3 (30%)
Green Spaces	Lawn	9 (90%)	9 (50%)	6 (20%)	5 (50%)
	Vegetation with water	0	9 (50%)	0	3 (30%)
	None	1 (10%)	0	23 (77%)	0%
	n/a (water)	0	0	0	0
	Flower meadow	0	0	1 (3%)	2 (20%)
Furnishing	Benches	2 (20%)	7 (39%)	0%	0
	Lighting	3 (30%)	5 (28%)	10 (33%)	3 (30%)
	Fountain	0	0	1 (3%)	0
Infrastructure	Bollard	1 (10%)	1 (6%)	0	3 (30%)
	Bike Rack	0	0	0	0

Note: Percentages are based on the total number of photos in each category

In the Roads and Path space photos, the proportion with no trees or hedges dropped significantly from 43% (of culverted photos) to 10% (of daylighted photos). Meaning, 90% of the daylighted stream photos depicting Road and Path spaces included trees or hedges compared to 57% of culverted photos. Additionally, the proportion of photos with no

vegetation identified at all dropped completely from 27% (of culverted photos) to 0% (of daylighted photos.

While the photographs of streams prior to culverting were not analyzed, as they cannot be compared directly to the daylighted streams, there are noteworthy observations. Mostly, that conditions around streams prior to culverting depict some of the same characteristics lacking in the culverted photos and present in the daylighted photos. Figure 8A presents a scene (ca.1910) wherein a stream flows through a Road and Path space, complete with trees and a water fountain, where people can congregate (as shown). By 1956, the same space has shifted away from its pedestrian oriented design towards a more car-oriented roadway without trees, but with the addition of official sidewalks, traffic bollards, and paved road surfacing (Figure 8B).



Figure 8: Stream along Wehntalerstrasse which is A) open ca. 1910; and B) culverted in 1956. (*Wehntalerstrasse*, ca. 1910; *Wehntalerstrasse*, 1956). Used under Creative Commons License.

Daylighted streams reintroduced in Roads and Path spaces always include some type of vegetation, Even the city type streams characterized by their unnatural embankments due to limited space along roadways, typically include natural waterbeds that can support vegetation (WRZ, 2007). Such is the case with the Nebelbach stream daylighted in 1991 (see Figure 9).

However, the embankments became an opportunity to incorporate seating by raising one of the sides into an unconventional bench which creates space for pedestrians to rest and socialize if desired. The greenery and aesthetic appeal of the naturalized stream bed, vegetation, and occasional fish also create a focal point for residents (Conradin and Buchli, 2004). By incorporating small footpaths located at intervals along the stream, and generally oriented toward building entrances, pedestrians are still able to cross with ease, and the added vegetation and seating have improved the quality of the space.

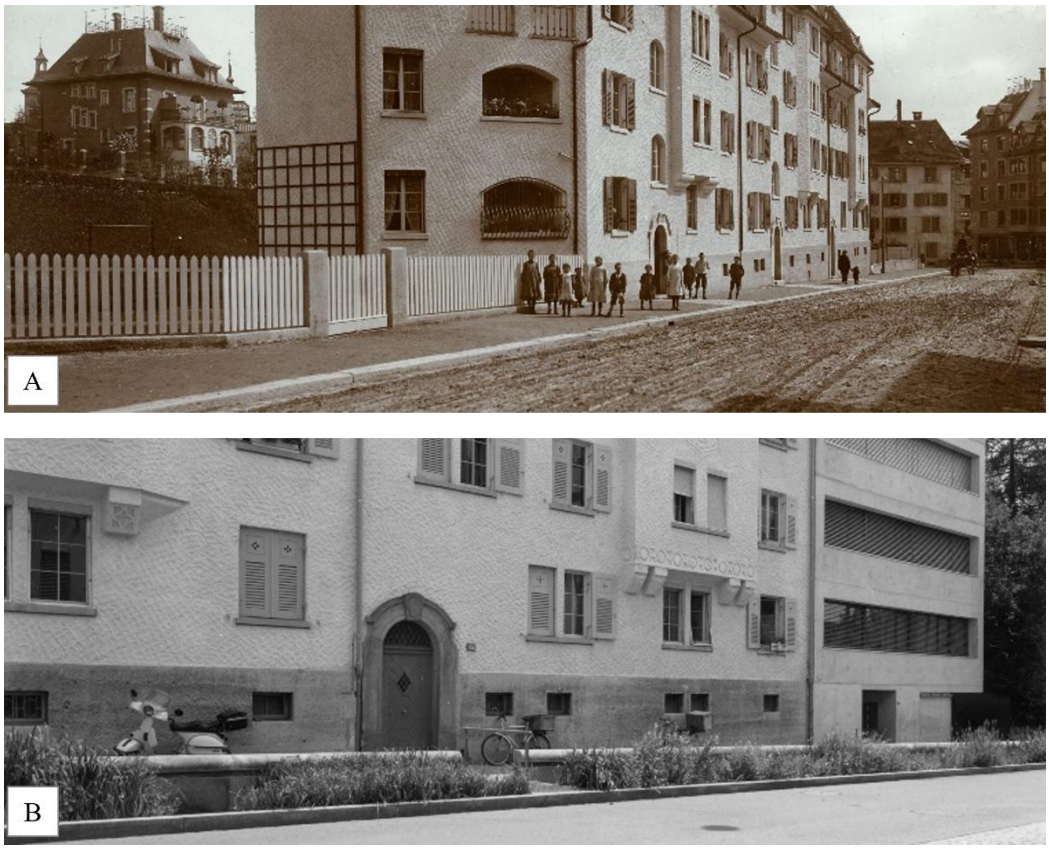


Figure 9: Nebelbach Stream A) In 1908, before daylighting; and B) in 2003, after daylighting (Hochbauamt der Stadt Zürich 1908; Hussel 2003). Used under Creative Commons License.

The use of small footbridges is not new to Zurich, it was also observed in many photos of streams prior to culverting. Figure 10A and Figure 10B demonstrate how the small

footbridges were utilized in the early 1900s to cross streams along roadways. The same style of footbridges is also applied to steams with natural embankments along a roadway (see Figure 10C), and sometime over streams within open green spaces (see Figure 10D).

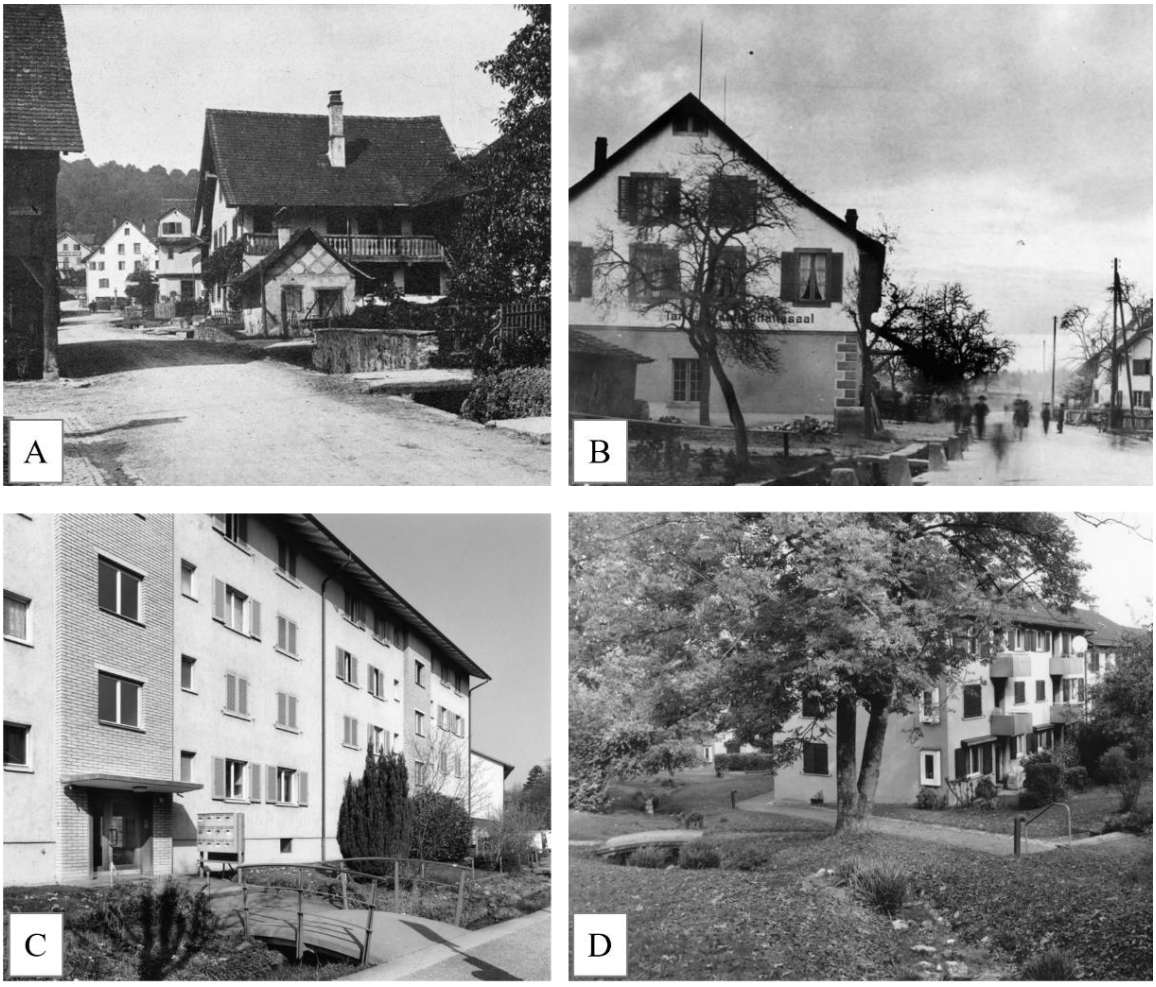


Figure 10: Footbridges used to maintain access to buildings, A) over Albisrieder Dorfbach stream; B) over presently culverted stream; over the daylighted Doltschibach C) along roadway; and, D) in park space adjacent to residential area. (BAZ, 1906; BAZ, ca. 1910; Dudli, 2022; Dudli, 2007). Used under Creative Commons License.

Not captured in the evaluation of urban design elements is the synergy between daylighted streams and parks. The integration of streams within existing parks provides additional benefit to user, while also enhancing the recreational potential of the stream. This is

exemplified in the Albisrieder Dorfbach and Friesenbergbach, depicted in Figure 11. The Friesenbergbach is a partnership between WRZ (Zurich's department responsible for streams) and a land developer (see. Figure 11A). Previously a greenfield (undeveloped) site, the stream daylighted as part of the site design and includes two ponds, one serving as a sediment collector and the other providing an opportunity for locals to swim (WRZ 2013).

To enhance the recreational potential of the Albisrieder Dorfbach, the WRZ department responsible for daylighting took the initiative to establish playgrounds and footpaths in the stream's vicinity Conradin and Buchli (2004) (Figure 11B). This strategic approach has resulted in a significant portion of the stream flowing through parks and green spaces, transforming it into a communal meeting place. WRZ (2013) identifies the stream's role in fostering community interaction and well-being as it flows through community gardens, kindergartens, and playgrounds.



Figure 11: Streams Integrated with Recreational Opportunities such as A) Friesenbergbach swimming pond, and B) Albisrieder Dorfbach at Bachwiesen Community Centre playground (Grünig, 2022; Port(u*o)s, 2014). Used under Creative Commons Licence 4.0 and 3.0.

6.0 Discussion

6.1 Metric Reach and Stream Types

Zurich's adoption of the "*Bächkonzept*" Backconcept ('stream concept') in 1988 and subsequent rapid implementation of stream daylighting projects, allowed for the evaluation of route network conditions prior to daylighting (when streams were culverted) with that post-daylighting. Despite presenting a new physical obstacle, no negative impact to network connectivity was revealed when comparing 2020 metric reach at daylighted streams to their conditions in 1984 (when they were culverted). Rather, the data suggests an overall positive association between daylighting and average metric reach. This means that rather than creating a physical barrier, stream daylighting can contribute to strategies for improving active mobility outcomes and furthering the creation of an ALE.

The positive association between stream daylighting and average metric reach is most evident among park and meadow type streams then city-type streams, due to their significant variation in design and integration within the built environment. City-type demonstrated the least change with metric reach conditions, with both pedestrian and road network conditions remaining largely consistent before and after daylighting. City-type streams are characterized by their lack of natural embankments due to limited space. While Zurich's daylighting program has since 1988, tried to create streams with the most natural conditions possible (later required by Canton of Zurich's Water Action Plan in 2012, city-type streams are characterized by their lack of natural embankments due to spatial constraints. With such limitations, the maintenance of connectivity is not an accident but rather it suggests that the possible negative impact of reintroducing streams is avoidable through careful design. This was demonstrated through the evaluation of photographs, where pre-daylighting conditions

can be more fully understood. As shown previously in Figure 9, the integration of a city-type stream can be rather elegant. In that case, the stream was situated between the sidewalk and the roadway where it's potential as a barrier is leveraged to place distance between pedestrians and vehicles but materially avoided through the incorporation of footpaths. Additionally, the photographs show how the reintroduction of streams not only reconnects nature within a highly urbanized setting but also provides an opportunity for street furniture such as seating, which both help to improve pedestrian comfort and sense of place.

In comparison, park and meadow-type streams experienced a significant increase in average metric reach for both road and pedestrian paths. A significant difference for these stream types compared to city-type streams, is the greater amount of space available. Of note, park-type streams are characterized by the incorporation or proximity to recreational facilities which are often developed or improved as part of these daylighting projects. In some cases, where a stream daylighting opportunity is situated in a greenfield or large infill site, it may even include an absolute increase in pedestrian paths when compared to 1984 conditions. This was the case with the Friesenbergbach swimming pond (Figure 11), which is the result of collaboration during the site planning stage between civil engineers from the City of Zurich and the land developer to incorporate the stream and ponds (Conradin and Buchli 2004). However, most daylighting sites are not such simple examples of greenfield development without much need to consider other existing development.

Two of Zurich's most notable daylighting projects are largely park or meadow type streams with more space than available to a city-type stream, while still facing spatial constraints. The Albisrieder Dorfbach was daylighted over 1900m of municipally owned property and an additional 600m through private property and residential developments. While it flows through some parks and open spaces, the successful realization of this project required

substantial collaboration with residents, as highlighted by Conradin and Buchli (2004) to situate the stream between the roadway and sidewalk. A similar challenge was presented for the Doltschibach's 2000m of daylighted stream, but the result is a naturalized stream flowing parallel to a sidewalk for almost its entire length providing natural beauty for those passing by as shown in Figure 10C (Conradin and Buchli, 2004). These spatial constraints are examples of how the urban form now largely dictates how streams may be reintroduced, except for greenfield sites as noted previously. This is a reversal of the historic relationship, where streams were part of the natural context that informed urban form development.

6.2 The Natural Context

In reviewing historic maps and photographs of waterways throughout Zurich, including those of streams that have been daylighted and those that remain culverted, it is evident that many streams (as part of natural context) were initially integrated within urban development seemingly accepted as guides for urban form. As shown in Figure 8, these streams were part of a pedestrian-oriented spaces often lost with streams as roadways and spaces were further developed.

This is exemplified in Figure 12A, which shows the Hornbach fully uncovered in 1881 just south of Neumünster Church and demonstrates how the natural context informed the road pattern and general urban form designed to accommodate the water. However, flooding is another key concern in Zurich which led to significant alterations and culverting of waterways, depicted in Figure 12B of the Hornbach. This same segment of the Horbach, as evidenced by Neumünster Church in the background, is shown in Figure 12C now having been channelized to manage flood water. Finally, this portion of the Hornbach was culverted,

this time perhaps to make room for modification and extension of the roadway shown in Figure 12D.

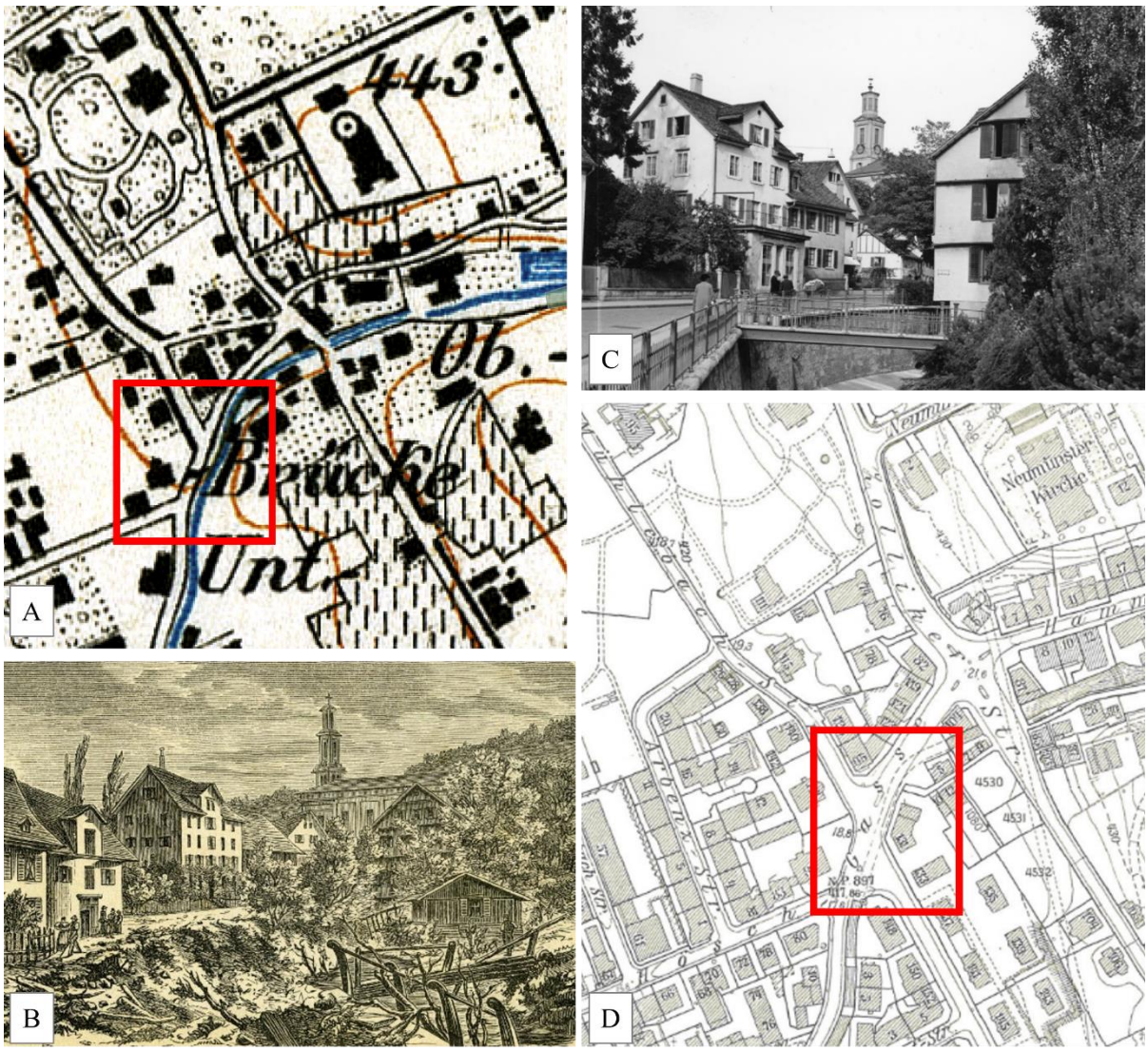


Figure 12: Horbach A) fully open in 1881; B) depiction of mass flooding; C) channelization to manage flooding; and D) full culverting (Topological Atlas of Switzerland, 1881; *Höschgasse* n.d.; *Hochwasser des Hornbaches* n.d.; City of Zurich, 1967)

Many streams were situated alongside roadways before they were culverting, and once culverted that space was often not developed for buildings but rather part of the road or

pedestrian right-of-way. In these instances, much of a network's connectivity is maintained when a stream is reintroduced because the stream informed the orientation and layout of roadways and paths from the beginning. The main challenge is associated with property ownership, whether private or municipal. The addition of footbridges as needed to maintain access, a design tool used prior to stream culverting, is all that is needed to prevent streams from creating a barrier. Where streams are culverted in what is now a green space, their reintroduction is simpler as it does not present the same property ownership challenges and they can be incorporated into recreational trails and amenities. In these spaces, streams contribute to an active living environment because, as described by Kondolf and Pinto (2017), they support social activities through 'prior programming' (e.g. walking path alongside water), or spontaneous activities (e.g. children's play). The process is thus a cycle, restoring the natural context which informed the urban form from the start.

6.3 Limitations

There are notable limitations within the present study. First, are challenges associated with the identification of stream daylighting sites. As the City of Zurich does not provide a specific data layer or an updated list of stream daylighting sites, daylighted streams were identified using a combination of available 2020 surface water data from the City of Zurich, the 1984 historical map, and other available reports (see Section 4.2). Additionally, many waterways have changed over time, or been significantly modified between the two time periods and can thus not be compared directly. To minimize the risk of error, only streams identified as daylighting sites with a high degree of certainty were included for further analysis. As a result, the total length of daylighted streams identified is lower than indicated in other sources (see Section 5.1).

Second, the analysis of pedestrian networks necessitated spatial data with a greater degree of detail than made available through the City of Zurich open data portal. As described in Section 4.4, pedestrian path spatial data from the City of Zurich had to be manually edited to ensure a comprehensive representation of the network around streams. Thus, the data used for analysis is not guaranteed to have the same accuracy. This also points to potential challenges in replicability for other studies focused on Zurich's streams or other jurisdictions that may also have incomplete representations of their pedestrian path networks. The risk of possible inaccuracy, and the challenges of replicability are also applicable (and more significant) to the 1984 pedestrian path and road network data that had to be manually produced.

Finally, there are many variables that influence route connectivity, and analysis of metric reach alone is not enough to suggest direct causality between network connectivity and stream daylighting. To try and overcome this limitation, this study used culverted streams as a control group, comparing that groups metric reach change with that of the daylighted stream group. Photography was also used to complement the metric reach analysis but was limited to the collection available through the BAZ. While the methods were adjusted to account for these limitations, this analysis is not meant to indicate causality and the results should not be interpreted as such.

6.4 Opportunities for Future Research

There are many possible avenues to build on this study, the following is not a comprehensive but rather a preliminary list. First, assessing route network change using other measures would increase the understanding of stream daylighting impacts. This could include other measures of connectivity to validate or challenge the metric reach findings. Second, this

study was limited to publicly available photographs; further study supported by field work could yield a more comprehensive set to be formally studied as part of a broader urban design evaluation. Furthermore, this could be supported by engagement with the public to better understand how they perceive and interact with stream daylighting sites. Finally, this analysis would benefit from the evaluation of stream daylighting within other jurisdictions. By focusing on the influence of municipal policies in determining the implementation and design of stream daylighting sites, more information may be gathered regarding the opportunities and challenges associated with the practice.

7.0 Conclusion

7.1 Contributions to Scholarship

This study is situated within the concept of an Active Living Environment (ALE), presented by Tobin et al. (2022) as one whose natural, built, and social neighbourhood characteristics all contribute to encouraging and enabling active living. The concept of an ALE is what Forsyth (2015) described as a 'holistic' or 'multi-dimensional' approach to walkability. While the influence of street and path networks on active mobility is frequently studied, this study shed light on the underexplored relationship between active mobility and streams as part of natural neighborhood properties. In the process, helping to broaden the scope of variables commonly considered in the promotion of active mobility within neighborhoods. In evaluating changes in route connectivity and considering urban design elements surrounding stream daylighting sites, this study focused on what Forsyth (2015) described as the 'means' to walkability. Understanding that these characteristics, a connected network, and a physical enticing space, contribute to the 'outcomes' of an environment which encourages active mobility. This includes health and wellbeing as an outcome of cultural ecosystem services offered by streams.

The results of this study found that daylighting was associated with positive changes in network connectivity, challenging the understanding of streams as physical barriers to lateral movement. Review of photography at streams sites when culverted, and after daylighting demonstrated the contributing role of natural properties in the creation of a physically enticing environment, which is largely associated with built neighbourhood properties within walkability frameworks. The findings from this study support the assertion that non-material cultural ecosystem benefits for health and well-being, which Chan et al. (2012) identified are provided by nature within the built environment, are associated with stream daylighting. This is achieved through the provision of opportunities for socialization and recreation. These findings highlight the value of the ALE concept in incorporating nature in the assessment and understanding of 'walkability'.

This study also demonstrates how metric reach can be adapted to study the relationship between a linear feature, such as streams, and network connectivity. By extending metric reach to measure connectivity along the entire water features, the method supported a more complete understanding of the role of streams in shaping neighbourhood walkability. Moreover, metric reach analysis enabled the comparison of site-specific network permeability over time. This study also employed a simple Difference-in-Differences (DiD) analysis to evaluate the impact of daylighting. When combined with a measure such as metric reach, unique to each site, and a control group (culverted streams), the use of DiD analysis provided a simple but robust framework for assessing the spatial impact of an intervention.

Finally, photography enabled the evaluation of change at daylighting sites through visual variables adding nuance to the role of stream types in moderating the relationship between daylighting and connectivity. By measuring different, but overlapping, changes associated with daylighting and the creation of an ALE could be better captured than through spatial datasets alone. This overlapping, described by Gaber and Gaber (2004) as complementarity, provides a new interpretation of how the practice could support the creation of an ALE and demonstrates the value of photography analysis in the evaluation of urban environments.

7.2 Contribution to Practice

This study holds significant implications for urban planning and design practitioners, particularly in their approach to integrating stream daylighting initiatives into neighborhood development. Findings demonstrate that stream daylighting may contribute positively to overall active mobility outcomes, contingent upon thoughtful site design and consideration of existing path connections. By affirming the compatibility of stream daylighting with the principles of ALE, practitioners can gain confidence in leveraging this strategy to enhance urban walkability without compromising on connectivity.

Moreover, the study highlights the multifaceted benefits of stream daylighting in fostering an urban environment conducive to physical activity, balancing connectivity with aesthetic appeal. Contrary to an intuitive understanding of streams as barriers, they can serve as conduits for pedestrian movement, enhancing the overall accessibility and connectivity of urban spaces. In Zürich, daylighted streams are integrated within the daily experiences of residents, present in school yards and parks, and meandering through residential buildings, along park footpaths, and sidewalks. By acknowledging the dual role of streams as ecological assets and contributors to pedestrian-friendly urban design, practitioners can adopt a nuanced approach that optimizes the benefits of stream daylighting while mitigating potential challenges.

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Appendices

Appendix A: Identified Streams Overview

Table A1: Daylighted Streams Overview

Stream Name	Stream Type	Total Length (m)	Location (City District)	Pedestrian Path Metric Reach (m)		Absolute Difference (m) (2020-1984)	Relative Difference (%)	Roads Metric Reach (m)		Absolute Difference (m) (2020-1984)	Relative Difference (%)
				1984	2020			1984	2020		
Hungerbach	City	126.00	Affoltern	827.13	827.13	0.00	0.0%	399.51	398.78	-0.73	0%
Nebelbach	City	92.34	Mühlebach	909.73	909.73	0.00	0.0%	712.69	712.69	0.00	0%
Döltschibach	City	289.30	Albisrieden	2509.21	2563.56	54.35	2.2%	1245.74	1258.51	12.77	1%
Döltschibach	City	240.29	Albisrieden	1944.45	1921.01	-23.43	-1.2%	764.61	763.35	-1.26	0%
Sägertenbach	City	440.54	Affoltern	2272.09	2460.91	188.82	8.3%	978.33	975.74	-2.60	0%
Binzmühlebach	Meadow	673.30	Seebach	1835.05	3087.59	1252.54	68.3%	1678.90	1762.70	83.79	5%
Holderbach	meadow	545.19	Affoltern	2489.97	3960.88	1470.91	59.1%	1232.66	1331.45	98.79	8%
Bannholzbach	Meadow	51.05	Oberstrass	533.03	808.94	275.91	51.8%	280.22	280.22	0.00	0%
Sagentobelbach	Meadow	237.20	Hirzenbach	869.66	1886.29	1016.63	116.9%	380.71	291.71	-89.00	-23%
Friesenbergbach	Meadow	41.19	Friesenberg	956.97	1180.76	223.79	23.4%	234.97	234.12	-0.85	0%
Rütenenbächli	Meadow	84.59	Albisrieden	634.22	634.22	0.00	0.0%	485.37	491.63	6.26	1%
Bombach	Meadow	135.31	Höngg	1024.68	1024.68	0.00	0.0%	428.67	428.69	0.02	0%
Friesenbergbach	Meadow	133.66	Friesenberg	1421.47	1434.56	13.10	0.9%	496.24	496.23	-0.01	0%
HWE Käshaldengraben	Meadow	341.64	Seebach	1000.70	1378.24	377.54	37.7%	627.36	1002.98	375.62	60%
Klosbach	Meadow	175.03	Hottingen	721.27	721.91	0.64	0.1%	554.40	558.40	4.00	1%
Thalbächli	Meadow	88.22	Altstetten	1048.75	1115.86	67.11	6.4%	367.82	368.01	0.19	0%

Steinwiesbächli	Meadow	106.99	Höngg	701.69	936.69	235.01	33.5%	530.14	719.28	189.14	36%
Raintobelbach	Meadow	71.64	Hirslanden	566.42	566.42	0.00	0.0%	328.06	388.48	60.42	18%
Schwamendinger Dorfbach	Meadow	703.95	Schwamendinge n-Mitte	3771.45	3844.84	73.39	1.9%	1900.80	1928.20	27.40	1%
Algierbächli	Meadow	760.27	Altstetten	3265.21	4372.70	1107.50	33.9%	1849.94	1844.33	-5.60	0%
Maasbächli	Meadow	113.32	Höngg	589.55	940.02	350.47	59.4%	565.67	1011.63	445.96	79%
Maneggbach	Meadow	292.94	Leimbach	1370.19	1598.87	228.69	16.7%	662.90	742.56	79.66	12%
Spitalerbach	Meadow	902.90	Oberstrass	1840.68	3984.08	2143.40	116.4%	1239.55	1659.42	419.87	34%
Wolfgrimmbach	Meadow	348.96	Wipkingen	3774.10	3652.12	-121.98	-3.2%	1924.26	1924.73	0.47	0%
Binzmühlebach	Meadow	762.00	Seebach	5037.55	6379.97	1342.42	26.6%	2243.36	2904.32	660.96	29%
Albisrieder Dorfbach	Park	561.75	Albisrieden	2346.51	3525.29	1178.77	50.2%	1375.56	1419.13	43.58	3%
Emmetbach	park	35.63	Albisrieden	335.21	376.25	41.04	12.2%	76.39	143.95	67.56	88%
Wolfbach	Park	266.64	Hottingen	1518.46	1485.17	-33.29	-2.2%	625.59	625.71	0.13	0%
Sädlenbach	Park	222.39	Albisrieden	1397.19	1397.23	0.04	0.0%	806.68	806.31	-0.37	0%
Friesenbergbach	Park	278.73	Friesenberg	1952.17	2029.97	77.80	4.0%	163.48	165.16	1.68	1%
Friesenbergbach	Park	91.18	Friesenberg	777.96	1673.73	895.77	115.1%	229.20	231.25	2.05	1%
Mühlehaldenbach	Park	45.58	Höngg	794.08	851.81	57.73	7.3%	654.47	656.85	2.39	0%
Altstetter Unterdorfbach	Park	146.39	Altstetten	475.98	866.61	390.63	82.1%	434.46	586.62	152.16	35%
Döltschibach	Park	571.32	Albisrieden	4022.16	4218.15	195.99	4.9%	1328.63	1327.71	-0.92	0%
Althoosbächli/ Schafmattbächli	Park	145.43	Affoltern	987.37	1144.65	157.28	15.9%	382.59	382.59	0.00	0%
Döltschibach	Park	246.99	Albisrieden	2307.64	2529.59	221.95	9.6%	1336.00	1337.48	1.48	0%
Albisrieder Dorfbach	Park	709.05	Albisrieden	4044.64	4842.38	797.74	19.7%	1749.55	1795.36	45.80	3%
Kolbenhofbach	Park	234.18	Friesenberg	3318.57	3314.26	-4.31	-0.1%	1954.41	1945.08	-9.33	0%
Oerisbach	Park	284.70	Wipkingen	1931.52	1939.48	7.96	0.4%	831.94	830.44	-1.50	0%

Table A2: Culverted Streams Overview

Stream Name	Total Length (m)	Location (City District)	Pedestrian Path Metric Reach (m)		Absolute Difference (m) (2020-1984)	Relative Difference (%)	Roads Metric Reach (m)		Absolute Difference (m) (2020-1984)	Relative Difference (%)
			1984	2020			1984	2020		
Albisrieder Dorfbach	1120.89	Altstetten	4602.67	4602.67	0	0%	2321.50	2329.05	7.55	0%
Albisrieder Dorfbach	1993.52	Altstetten	3372.24	4058.62	686	20%	2658.85	2990.28	331.43	12%
Altstetter Unterdorfbach	218.00	Altstetten	1671.57	1671.57	0	0%	910.32	930.36	20.04	2%
Altstetter Unterdorfbach	605.02	Altstetten	3405.76	3405.76	0	0%	1663.87	1687.16	23.29	1%
Bächligraben	406.56	Hirzenbach	1792.25	1792.25	0	0%	1408.03	1408.11	0.09	0%
Bächligraben	1232.41	Schwamendingen-Mitte	6376.95	6376.95	0	0%	3380.24	3381.86	1.62	0%
Bahngraben	307.09	Altstetten	658.97	658.97	0	0%	551.12	547.79	-3.33	-1%
Banzwiesenbach	79.77	Friesenberg	557.76	557.76	0	0%	460.75	459.83	-0.92	0%
Banzwiesenbach	75.47	Friesenberg	566.60	566.60	0	0%	294.59	292.25	-2.34	-1%
Banzwiesenbach	223.74	Friesenberg	1264.00	1264.00	0	0%	417.02	631.05	214.03	51%
Binzmühlebach	592.99	Affoltern	3292.40	3292.40	0	0%	2256.00	2251.21	-4.80	0%
Binzmühlebach	1210.32	Affoltern	5373.00	5373.00	0	0%	3262.15	3261.22	-0.93	0%
Binzmühlebach	551.46	Seebach	3663.54	3713.77	50	1%	2099.97	2098.51	-1.47	0%
Binzmühlebach	313.99	Seebach	2054.18	2110.68	56	3%	1138.11	1319.38	181.27	16%
Binzmühlebach	552.52	Saatlen	2562.15	2666.14	104	4%	1775.84	1840.09	64.25	4%
Breitloobach	88.038	Albisrieden	603.53	603.53	0	0%	422.76	421.87	-0.89	0%
Döltschibach	1027.64	Hard	4031.07	4031.07	0	0%	2299.40	2307.55	8.15	0%
Döltschibach	1111.05	Altstetten	4635.85	4635.85	0	0%	1047.34	1041.09	-6.25	-1%
Döltschibach	1015.74	Escher Wyss	3586.45	3598.81	12	0%	2074.23	2104.34	30.11	1%
Döltschibach	631.68	Albisrieden	3058.84	3104.70	46	1%	2154.99	2168.04	13.05	1%
Dorfbach Affoltern	432.61	Affoltern	1470.62	1498.48	28	2%	1051.31	1051.31	0.00	0%
Hagenbuchrainbächli	227.36	Albisrieden	1624.65	1624.65	0	0%	1098.37	1122.79	24.42	2%
Hagenbuchrainbächli	430.37	Albisrieden	2250.39	2250.39	0	0%	1240.93	1256.64	15.71	1%
Hirzenbach	47.12	Hirzenbach	379.50	531.57	152	40%	316.16	316.16	0.00	0%
Holderbach	265.36	Affoltern	2234.92	2234.92	0	0%	1055.92	1055.06	-0.86	0%
Hornbach	100.39	Mühlebach	1549.82	1549.82	0	0%	891.36	887.68	-3.68	0%
Hornbach	187.42	Seefeld	2340.81	2340.81	0	0%	1028.17	1035.34	7.17	1%
Hungerbach	487.22	Affoltern	1543.15	1543.15	0	0%	1114.54	1119.21	4.67	0%

Katzenbach	101.21	Affoltern	370.22	370.22	0	0%	636.15	639.27	3.12	0%
Katzenbach	429.27	Affoltern	815.53	1075.63	260	32%	622.01	627.60	5.60	1%
Klosbach	96.76	Hottingen	504.15	504.15	0	0%	229.04	229.37	0.33	0%
Kolbenhofbach	1036.70	Alt-Wiedikon	4022.34	4022.34	0	0%	2721.87	2731.65	9.78	0%
Kolbenhofbach	761.99	Alt-Wiedikon	2509.72	2779.33	270	11%	858.80	900.74	41.93	5%
Köschenrütigraben	907.18	Seebach	2446.04	2446.04	0	0%	650.60	645.61	-4.99	-1%
Leutschenbach	1040.72	Seebach	3829.75	3921.96	92	2%	2054.64	2448.67	394.03	19%
Maasbächli	275.49	Höngg	1907.72	1952.80	45	2%	849.76	1093.11	243.35	29%
Maneggbach	45.00	Leimbach	386.09	386.09	0	0%	241.09	244.06	2.97	1%
Maneggbach	69.05	Leimbach	675.25	833.17	158	23%	372.68	372.91	0.23	0%
Mühlehaldenbach	170.20	Höngg	2000.59	2000.59	0	0%	1094.37	1094.92	0.55	0%
Mühlehaldenbach	647.20	Höngg	3690.77	3765.53	75	2%	2074.23	2247.70	173.47	8%
Nebelbach	134.18	Weinegg	1057.66	1057.66	0	0%	764.96	699.73	-65.23	-9%
Nebelbach	255.52	Mühlebach	1756.59	1756.59	0	0%	1028.12	1027.76	-0.35	0%
Neugutbach	87.99	Affoltern	1063.39	1063.39	0	0%	660.09	669.37	9.27	1%
Oerisbach	571.21	Wipkingen	3137.74	3612.51	475	15%	1460.48	1438.29	-22.19	-2%
Risbach	45.99	Leimbach	233.83	233.83	0	0%	196.56	196.56	0.00	0%
Sädlenbach	77.60	Albisrieden	773.44	773.44	0	0%	396.73	399.68	2.95	1%
Salzwegbächli	485.99	Altstetten	1634.53	1634.53	0	0%	1217.03	1214.41	-2.62	0%
Schwamendinger Dorfbach	347.00	Schwamendingen-Mitte	2290.99	2290.99	0	0%	1446.31	1357.41	-88.90	-6%
Schwamendinger Dorfbach	106.77	Schwamendingen-Mitte	395.08	634.52	239	61%	484.37	479.48	-4.90	-1%
Thalbächli	621.79	Altstetten	3357.59	3357.59	0	0%	1824.90	1823.36	-1.54	0%
Tuschgenbach	354.27	Leimbach	2267.36	2267.36	0	0%	1636.37	1636.53	0.16	0%
Wolfgrimmbach	466.09	Wipkingen	3290.13	3270.40	-20	-1%	1977.28	1968.71	-8.57	0%

Table A3: Untouched Streams Overview

Stream Name	Stream Type	Total Length (m)	Pedestrian Path Metric Reach (m)		Absolute Difference (m) (2020-1984)	Relative Difference (%)	Roads Metric Reach (m)		Absolute Difference (m) (2020-1984)	Relative Difference (%)
			1984	2020			1984	2020		
Hornbach	city	602.09	6152.55	6190.62	38.07	1%	3094.43	3094.43	0	0%
Katzenbach	fallow	2152.64	4156.22	4362.13	205.92	5%	3221.55	3523.61	302	9%
Katzenbach	fallow	666.43	2860.52	3208.89	348.37	12%	951.06	1052.19	101	11%
Katzenbach	fallow	555.83	2057.31	2155.22	97.91	5%	1747.03	1844.38	97	6%
Leutschenbach	fallow	176.20	1328.58	1375.40	46.82	4%	933.98	933.98	0	0%
Dorfbach Affoltern	fallow	563.33	1237.75	1237.75	0.00	0%	1209.56	1209.56	0	0%
Hagenbuchrainbächli	fallow	161.31	881.13	948.73	67.60	8%	765.92	765.92	0	0%
Hungerberggraben	fallow	240.44	778.25	778.25	0.00	0%	429.18	429.18	0	0%
Banzwiesenbach	fallow	47.24	660.17	660.17	0.00	0%	370.77	370.77	0	0%
Hungerbach	fallow	160.91	429.41	429.41	0.00	0%	388.21	388.21	0	0%
Banzwiesenbach	fallow	83.78	258.69	258.69	0.00	0%	370.77	370.77	0	0%
Albisrieder Dorfbach	meadow	321.26	1024.80	1053.76	28.96	3%	572.33	572.33	0	0%
Leimbach	meadow	316.97	523.80	911.24	387.44	74%	306.33	306.33	0	0%
Gubelbach	meadow	257.34	669.61	669.61	0.00	0%	522.94	522.94	0	0%
Nebelbach	meadow	534.55	1893.44	1893.44	0.00	0%	1082.49	1082.49	0	0%
Gyrhaldenbächli	meadow	349.21	1811.24	1811.24	0.00	0%	1067.80	1067.80	0	0%
Stöckentobelbach	meadow	176.14	1403.55	1403.55	0.00	0%	784.35	784.33	0	0%
Risbach	meadow	523.98	1328.93	1328.93	0.00	0%	1313.36	1313.36	0	0%
Emmetbach	meadow	267.66	811.85	1194.65	382.80	47%	342.57	342.57	0	0%
Klosbach	meadow	402.82	1208.28	1107.47	-100.81	-8%	743.63	743.63	0	0%
Breitloobach	meadow	97.96	914.10	914.10	0.00	0%	601.12	601.12	0	0%
Friesenbergbach	meadow	69.54	859.83	859.83	0.00	0%	393.43	393.43	0	0%

Schwamendinger Dorfbach	meadow	86.39	684.28	764.21	79.93	12%	381.93	381.93	0	0%
Schwesternbungertbach	meadow	278.59	629.87	629.87	0.00	0%	402.59	402.59	0	0%
Brandbach	meadow	86.38	577.57	577.57	0.00	0%	543.65	543.65	0	0%
Leiterlibergbach	meadow	123.14	544.73	544.73	0.00	0%	193.90	193.90	0	0%
Banzwiesenbach	meadow	153.03	535.97	535.97	0.00	0%	232.97	232.97	0	0%
Altstetter Unterdorfbach	meadow	31.65	494.62	494.62	0.00	0%	366.25	366.25	0	0%
Raintobelbach	meadow	59.02	359.41	359.41	0.00	0%	101.95	101.95	0	0%
Hüslibach	meadow	68.31	276.31	276.31	0.00	0%	232.69	232.69	0	0%
Sädlenbach	meadow	65.44	245.53	245.53	0.00	0%	254.94	254.94	0	0%
Riedgraben	park	409.60	1564.44	1779.94	215.49	14%	1187.34	1187.34	0	0%
Wildbach	park	1200.10	4079.44	4079.44	0.00	0%	1884.45	1884.45	0	0%
Stöckentobelbach	park	605.60	3047.56	3047.56	0.00	0%	739.35	739.35	0	0%
Wolfbach	park	455.75	2517.89	2613.96	96.07	4%	1111.11	1111.11	0	0%
Neugutbach	park	207.55	1061.64	1061.64	0.00	0%	877.85	877.85	0	0%
Hungerbach	park	124.67	1008.74	1008.74	0.00	0%	708.20	708.20	0	0%
Bombach	park	785.68	3530.95	3533.62	2.66	0%	1989.65	1818.09	-172	-9%
Nebelbach	park	727.27	2659.11	2750.57	91.46	3%	1891.54	1982.25	91	5%
Döltschibach	park	313.81	1705.36	1705.36	0.00	0%	954.22	954.22	0	0%
Wehrenbach	park	452.45	1629.22	1629.22	0.00	0%	716.09	716.10	0	0%
Kolbenhofbach	park	235.24	1360.39	1360.39	0.00	0%	1197.51	1197.51	0	0%
Hirzenbach	park	605.64	2776.91	2934.69	157.78	6%	1454.68	1511.03	56	4%
Läufebach	park	318.00	1831.29	1831.29	0.00	0%	1512.29	1512.29	0	0%
Leimbach	park	277.45	806.28	1136.95	330.67	41%	378.45	378.45	0	0%
Altstetter Unterdorfbach	park	86.91	440.47	440.47	0.00	0%	352.65	352.65	0	0%

Appendix B: Photographs Overview

Status Today	Status in Photograph	Photo Name_BAZ	Stream Name	Stream Type	Year	Decimal Degrees (Lat/ Long)
Daylighted	Daylighted	BAZ_008577	Wolfgrimmbach	Meadow	2012	47.3952455 8.5222299
Daylighted	Daylighted	BAZ_009339	Nebelbach	City	2014	47.3538588 8.5594307
Daylighted	Daylighted	BAZ_014396	Döltschibach	Meadow	2011	47.3719009 8.4910136
Daylighted	Daylighted	BAZ_016433	Döltschibach	Park	2011	47.3759346 8.4934004
Daylighted	Daylighted	BAZ_016435	Döltschibach	Park	2011	47.3758974 8.4928276
Daylighted	Daylighted	BAZ_016437	Döltschibach	Park	2011	47.3755723 8.4926875
Daylighted	Culverted	BAZ_016638	Nebelbach	City	1976	47.3532256 8.5593313
Daylighted	Daylighted	BAZ_018241	Holderbach	Meadow	2007	47.4233084 8.5050039
Daylighted	Daylighted	BAZ_018242	Holderbach	Meadow	2007	47.4221557 8.5044474
Daylighted	Daylighted	BAZ_033279	Binzmühlebach	Meadow	2017	47.4170964 8.5435582
Daylighted	Culverted	BAZ_051408	Döltschibach	Park	1946	47.3679097 8.4920431
Daylighted	Culverted	BAZ_055820	Albisrieder Dorfbach	Park	1956	47.3828409 8.4871686
Daylighted	Culverted	BAZ_057433	Albisrieder Dorfbach	Park	1934	47.3756479 8.4849818
Daylighted	Culverted	BAZ_057840	Döltschibach	Park	1948	47.3679766 8.4919885
Daylighted	Before Culverting	BAZ_062014	Döltschibach	Park	1946	47.3678413 8.4920216
Daylighted	Before Culverting	BAZ_063504	Albisrieder Dorfbach	Park	1915	47.3768315 8.4863524
Daylighted	Before Culverting	BAZ_066734	Albisrieder Dorfbach	Park	unknown	47.3768242 8.4863283
Daylighted	Before Culverting	BAZ_070357	Albisrieder Dorfbach	Park	unknown	47.3768006 8.4863551
Daylighted	Culverted	BAZ_075933	Albisrieder Dorfbach	Park	1980	47.3759766 8.4853936
Daylighted	Culverted	BAZ_075937	Albisrieder Dorfbach	Park	1980	47.3760132 8.4854386
Daylighted	Culverted	BAZ_080136	Döltschibach	Meadow	1955	47.3719518 8.4909982
Daylighted	Culverted	BAZ_091743	Döltschibach	City	1963	47.377456 8.4964403
Daylighted	Culverted	BAZ_095777	Nebelbach	City	1908	47.3537395 8.559418
Daylighted	Before Culverting	BAZ_095779	Nebelbach	City	unknown	47.3531266 8.5591694
Daylighted	Culverted	BAZ_097199	Wolfgrimmbach	Meadow	1918	47.3952717 8.5221755
Daylighted	Before Culverting	BAZ_115637	Klosbach	Meadow	1910	47.3709426 8.5647007
Daylighted	Culverted	BAZ_119836	Maneggbach	Park	2005	47.3371748 8.5172438
Daylighted	Daylighted	BAZ_119842	Maneggbach	Park	2007	47.336359 8.5175579
Daylighted	Daylighted	BAZ_119843	Maneggbach	Park	2007	47.3371617 8.51756129999999
Daylighted	Daylighted	BAZ_131444	Nebelbach	City	2003	47.3533662 8.5593295
Daylighted	Daylighted	BAZ_134871	Binzmühlebach	Meadow	2006	47.4130033 8.5499635
Daylighted	Culverted	BAZ_134877	Binzmühlebach	Meadow	1975	47.4130941 8.5496725
Daylighted	Culverted	BAZ_141136	Friesenbergbach	Park	1950	47.3650608 8.5050247
Daylighted	Culverted	BAZ_148438	Wolfgrimmbach	Meadow	ca. 1920	47.3951482 8.5221165

Daylighted	Culverted	BAZ_148497	Wolfgrimmbach	Meadow	1959	47.3964015 8.522828
Daylighted	Culverted	BAZ_148499	Wolfgrimmbach	Meadow	1963	47.3964015 8.522828
Daylighted	Culverted	BAZ_154724	Holderbach	Meadow	1988	47.4237784 8.5054304
Daylighted	Daylighted	BAZ_155392	Binzmühlebach	Meadow	2006	47.4162153 8.5324233
Daylighted	Culverted	BAZ_155856	Holderbach	Meadow	2007	47.4202704 8.506754
Daylighted	Culverted	BAZ_156233	Algierbächli	Meadow	unknown	47.3797629 8.4846242
Daylighted	Culverted	BAZ_156704	Döltschibach	Park	1967	47.3750528 8.4918922
Daylighted	Culverted	BAZ_157127	Südlenbach	Park	ca. 1950s	47.3688666 8.4882107
Daylighted	Daylighted	BAZ_157244	Döltschibach	Park	2007	47.3675736 8.4925862
Daylighted	Culverted	BAZ_157269	Albisrieder Dorfbach	Park	1994	47.3757078 8.4850824
Daylighted	Daylighted	BAZ_158274	Altstetter Unterdorfbach	Park	2002	47.392206 8.4788339
Daylighted	Culverted	BAZ_163310	Albisrieder Dorfbach	Park	1985	47.3760132 8.4854386
Daylighted	Daylighted	BAZ_167576	Maneggbach	Park	2022	47.3371672 8.5175126
Daylighted	Daylighted	BAZ_167583	Maneggbach	Park	2022	47.3373148 8.5170881
Daylighted	Daylighted	BAZ_170336	Steinwiesbächli	Meadow	2022	47.4162246 8.4821344
Daylighted	Daylighted	BAZ_171975	Friesenbergbach	Park	2022	47.364008 8.5090909
Daylighted	Daylighted	BAZ_172023	Friesenbergbach	Park	2022	47.3640043 8.5089091
Daylighted	Daylighted	BAZ_173715	Albisrieder Dorfbach	Park	2023	47.3825896 8.4870672
Daylighted	Daylighted	BAZ_173721	Albisrieder Dorfbach	Park	2023	47.3834771 8.4873846
Daylighted	Daylighted	BAZ_173849	Algierbächli	Meadow	2023	47.3799088 8.4804105
Daylighted	Daylighted	HAL_000159	Holderbach	Meadow	2016	47.4234185 8.5051894
Daylighted	Daylighted	HAL_009770	Binzmühlebach	Meadow	2010	47.4131061 8.5586381
Daylighted	Daylighted	HAL_010738	Schwamendinger Dorfbach	Meadow	2010	47.4056423 8.572489
Daylighted	Daylighted	HAL_013688	Albisrieder Dorfbach	Park	2005	47.3824349 8.4868548
Daylighted	Culverted	WOL_001887	-	-	1952	47.3760487 8.4941964
Culverted	Culverted	BAZ_021737	-	-	2015	47.3548098, 8.5535307
Culverted	Before Culverting	BAZ_028192	-	-	ca.1928	47.3881686, 8.4866928
Culverted	Culverted	BAZ_036994	-	-	2017	47.4152646, 8.5476077
Culverted	Before Culverting	BAZ_052346	-	-	ca. 1925	47.374522, 8.4829959
Culverted	Before Culverting	BAZ_072065	-	-	1906	47.3744833, 8.4830536
Culverted	Culverted	BAZ_072230	-	-	1953	47.3874371, 8.4763952
Culverted	Before Culverting	BAZ_084678	-	-	1900	47.3750605, 8.4840612
Culverted	Culverted	BAZ_092046	-	-	1918	47.3779609 8.4974799
Culverted	Before Culverting	BAZ_092128	-	-	1899	47.3886808, 8.486704
Culverted	Culverted	BAZ_092156	-	-	unknown	47.3909004, 8.4786757
Culverted	Culverted	BAZ_092703	-	-	1897	47.3938697, 8.5129536
Culverted	Before Culverting	BAZ_095532	-	-	ca. 1895	47.3588333, 8.5571085

Culverted	Before Culverting	BAZ_095533	-	-	ca. 1910	47.3588805, 8.5571246
Culverted	Before Culverting	BAZ_096404	-	-	ca. 1908	47.3612396, 8.5167497
Culverted	Culverted	BAZ_097045	-	-	1910	47.3937939 8.5217302
Culverted	Before Culverting	BAZ_115035	-	-	1908	47.3708298, 8.559568
Culverted	Culverted	BAZ_115042	-	-	1965	47.3709433, 8.5600515
Culverted	Unknown	BAZ_118321	-	-	2007	47.3709904, 8.5700133
Culverted	Culverted	BAZ_118327	-	-	2007	47.3711467, 8.5702181
Culverted	Culverted	BAZ_125071	-	-	1958	47.3547746, 8.5606281
Culverted	Before Culverting	BAZ_125072	-	-	1958	47.3546438, 8.560486
Culverted	Culverted	BAZ_125540	-	-	1927	47.3512838, 8.5688655
Culverted	Culverted	BAZ_127770	-	-	unknown	47.3589586, 8.5571461
Culverted	Culverted	BAZ_132715	-	-	1981	47.4027183, 8.5689006
Culverted	Culverted	BAZ_136564	-	-	??	47.4170698, 8.5458468
Culverted	Before Culverting	BAZ_151411	-	-	1895	47.3384184, 8.5212008
Culverted	Before Culverting	BAZ_156139	-	-	ca. 1926	47.3740715, 8.4822771
Culverted	Before Culverting	BAZ_168910	-	-	1889	47.3936187, 8.5176506
Culverted	Culverted	WEL_1133	-	-	1933	47.3885101, 8.4866932