

## Article

# Identification and Pre-Assessment of Former Watercourses to Support Urban Stormwater Management

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**Abstract:** The application of blue and green infrastructure in urban stormwater management has attracted increasing interest in recent years. At the same time, one can observe a heavy modification of urban watercourses by land reclamation measures aiming at canalizing, straightening, and draining existing water systems at many places around the world. In the context of sustainable urban development, the question arises, whether the reactivation of former watercourses could be an additional option to support urban stormwater management. This article introduces a process to identify former watercourses and to pre-assess their suitability to support urban stormwater management considering different hydraulic functionalities and stormwater related criteria. To prove the practicability of the approach, it was applied in a case study. Our investigations revealed that the reactivation of former watercourses can provide additional opportunities towards more nature-based and sustainable stormwater management in the urban fabric.

**Keywords:** sustainable urban development; surface runoff; sewer system; integrated planning; blue green infrastructure

## 1. Introduction

Both changes in precipitation patterns due to climate change and increased urbanization are expected to have adverse effects on existing urban drainage systems and are leading to a need for adaptation [1]. The implementation of blue green infrastructure (BGI) for stormwater management or similar concepts such as water sensitive urban design (WSUD) or low impact development (LID) to achieve this adaptation has been promoted in the past decades [2]. International literature provides several examples of practical applications. Šakić Trogrlić et al. [3] illustrate, how BGI implementation was used to increase flood resilience. Also in Germany BGI has been successfully implemented for stormwater management in several cities [4]. However, integrating BGI into stormwater management even provides additional benefits going beyond reduced pluvial flood risk [5] due to the different processes involved (retention, infiltration, conveyance) [6]. Decentralized BGI increases retention, evapotranspiration, and infiltration to restore the natural local water balance [7]. Furthermore, BGI can be used to mitigate urban heat islands [8] and decrease water pollution [9].

While the resilience of the urban structure is increased due to the multiple benefits of BGI [10], the implementation of BGI is often limited by space availability in the built areas [11]. BGIs' space demand varies between individual measures [12], and ownership structures in existing city quarters might also influence the applicability of certain BGI solutions [13,14]. To account for these aspects, Hansen et al. [15] recommend considering spatial framework conditions in the planning phase in new urban

developments. Recent BGI planning support systems already show corresponding implementations by addressing aspects as for instance different settlement structures [16,17] or ownership of land [18].

However, despite the continuous development the primary focus of recent planning processes for BGI preponderantly remains on rather technical solutions and the built environment [19]. While landscape based approaches have been promoted [20], few cases exist that integrate the natural landscape conditions (as the main component) in the planning process for BGI in already developed areas. Furthermore, today's consideration of (existing) natural landscape features into the planning of BGI seems rather restricted to specific functionalities as habitat connectivity [21] and access to green space [22]. Hydraulic perspectives of natural landscapes features in regard to BGI and urban stormwater management still appear rather little examined and a need for further research is certainly given. In this context natural landscape features in the form of former mainly dried up watercourses (that might even provide connections to existing receiving waters) could be of specific interest as they already bear an innate hydraulic function.

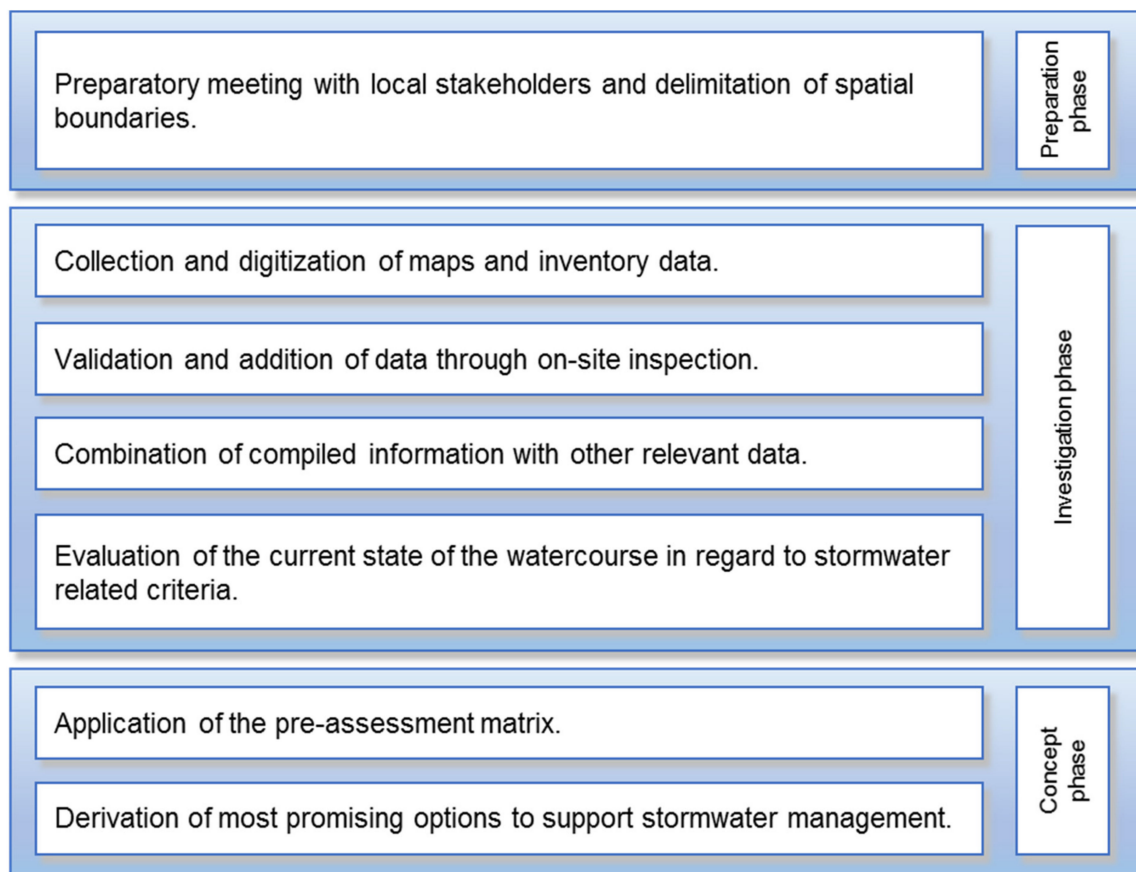
Today, a large proportion of urban water bodies in Europe has been heavily modified [23]. Through channelization, burying of streams in sewer systems and, weir or millstream construction, the appearance of urban watercourses has been changed over the decades [24]. Consequently, natural processes such as meandering were impaired and former watercourses dried up. In many cases only meander scars remain visible as signs of former watercourses in urban landscapes [25]. The changes in the extent of natural landscapes can be delineated from historic data. Doka et al. [26] have evaluated the reduction in wetland extent in rural and urban areas using historic maps. Coppolla et al. [27] used historic data to identify green infrastructure. Ioja et al. [28] analyzed the change in urban blue and green areas in Bucharest over time. The latter two cases used the data for identifying natural landscapes to facilitate BGI planning.

It can be expected, that natural landscape features in the form of former watercourses are still available in many urban areas around the world even if they do not fulfill any (hydraulic) function. Considering the limited space availability in the built area, utilizing/re-activating existing former watercourses as BGI for stormwater management could be an interesting option. To create awareness for the possibility to also consider former water courses in the BGI planning processes, this article introduces a systematic approach to (1) identify former watercourses in the urban landscape and to (2) pre-assess their suitability to support urban stormwater management. Hereby, the primary aim of the pre-assessment is to reveal whether and how identified watercourses are suitable options for urban stormwater management. The gained information from the pre-assessment concerning the most promising options provides the basis and direction for targeted subsequent (detailed) planning activities. To prove the practicability of the suggested approach, the entire process was tested in a case study in Austria. The results of the pre-assessment show that former watercourses can be an additional option for BGI in urban stormwater management in the investigated case study area. Their consideration and integration in a detailed planning process are already discussed by local stakeholders. For other sites, the presented approach for identification and pre-assessment as well as its practical application can serve as a template for local-specific investigations.

## 2. Materials and Methods

### 2.1. Identification and Pre-Assessment Process

A step-wise process to identify and pre-assess the suitability of former watercourses to support (urban) stormwater management was developed. The process shown in Figure 1 is divided into three phases following structures used in planning processes [29]. In the (1) preparation phase the problem and the framework conditions are defined. In the (2) investigation phase data is collected and combined into one database. In the (3) concept phase the gathered information is used to pre-assess the watercourses and to reveal the best options for their reactivation and future usage.



**Figure 1.** Scheme of the process for identification and pre-assessment of former watercourses for stormwater management (own presentation).

#### 2.1.1. Preparation Phase

The goal of this phase is manifold: First, the problem leading to the investigation will be stated. Then the organizational framework and spatial boundaries of the investigations must be set. This includes the identification of stakeholders relevant for and concerned by the process work as well as the identification of existing and required data-sets. The diversity of aspects to be addressed in the preparation phase necessitates the inclusion of different local stakeholders (local authorities, wastewater department, urban spatial planning, etc.) in this first phase. An early and broad common understanding of the planned activities provides a sound basis for the next phases of the pre-assessment and subsequent planning steps.

#### 2.1.2. Investigation Phase

This phase comprises four different working steps. First, the collection of available data is necessary. Historic maps showing former watercourses can be seen as a very valuable source of information, although they might have to be digitized first. These are then combined with data on existing watercourses. Second, the collected data on former watercourses is validated and amended through on-site inspection at identified areas with potential former watercourses. Third, the gathered information is compiled into one database together with other relevant data, such as fluvial flood zone delineations and information on the elevation of groundwater tables, to gain a better understanding of water-related interactions in the investigated area. Fourth, the current state/condition of the identified watercourses is described with different stormwater related criteria. For this purpose, the following criteria are applied: (i) receiving watercourse connection, (ii) open conduit cross section (in the entire watercourse or only parts of it), (iii) occurrence of vegetation covering (in the entire conduit or only

parts of it), (iv) groundwater influence, and (v) river (flooding) influence. The criteria (i), (ii) and (iii) are evaluated based on the length of the watercourse fulfilling these criteria. For the criteria (iv) and (v) the watercourse is evaluated based on its branches. If part of a branch is influenced by groundwater or the river, the whole branch is considered influenced.

### 2.1.3. Concept Phase

The key issue in this phase is to pre-assess the suitability of identified watercourses to support sustainable and more nature-based urban stormwater management. This pre-assessment interrelates the (1) hydraulic functionalities of BGI and (2) specific evaluation criteria based on the state of the watercourse identified in the investigation phase. The functionalities are based on [6] and distinguish between discharge (conveyance), storage/re-use (retention), and infiltration. The interrelations between the different functionalities and criteria are integrated into a matrix indicating “positive effect” or “negative effect” of a specific criterion on a functionality. Table 1 provides an overview of the applied concept.

**Table 1.** Pre-assessment matrix combining hydraulic functionalities of BGI and pre-defined evaluation criteria on the state of the watercourse, the effects of the criteria on the functionality are displayed in colors and with symbols indicating positive (green/+) and negative effects (red/−) (own presentation).

HYDRAULIC FUNCTIONALITY	CRITERIA									
	I Watercourse Connection		II Open Cross Section		III Vegetation Covering		IV Groundwater Influence		V River Influence	
	yes	no	yes	no	yes	no	yes	no	yes	no
Discharge	+	−	+	−	−	+	−	+	−	+
Storage/reuse	−	+	+	−	−	+	−	+	−	+
Infiltration	−	+	+	−	+	−	−	+	−	+

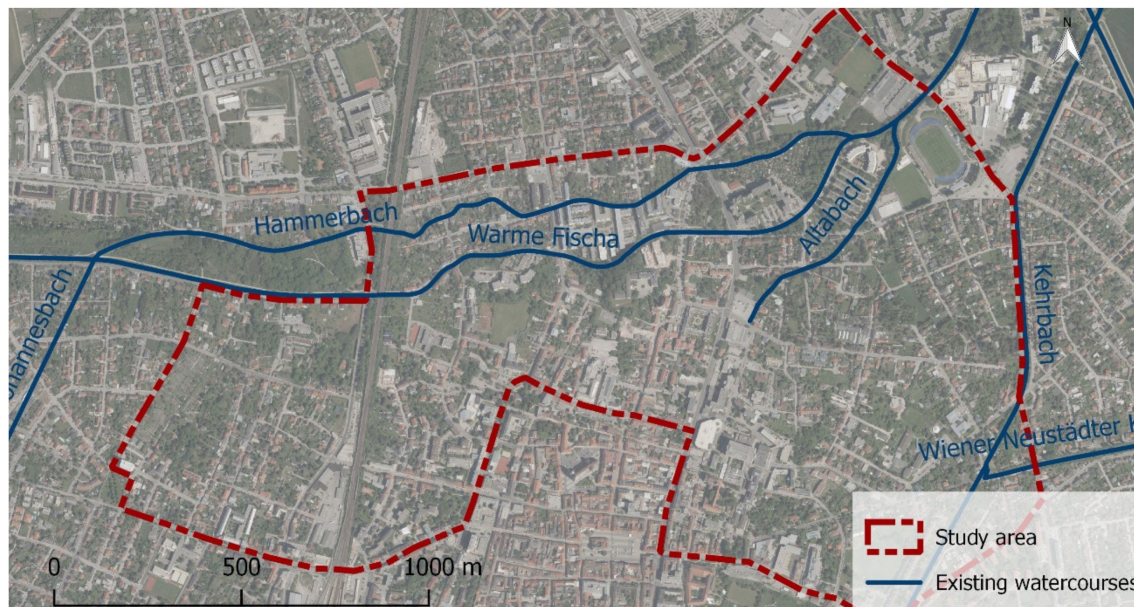
The definition of positive or negative effects is based on the following assumptions: (i) Watercourse connection: A connection between the investigated former watercourse and the existing receiving water allows conveyance of stormwater. This has a positive effect on the discharge but a negative one on storage/reuse and infiltration, respectively. (ii) Open cross section: The conduits can either be opened or piped. The former usually show larger cross sections. For discharge, this is beneficial as it allows higher flow quantities and reduces the risk of blockages. Furthermore, larger cross sections provide more storage volume. Finally, piped conduits prevent the infiltration of stormwater while open conduits provide a large surface for it. (iii) Vegetation covering: The occurrence of vegetation in the conduit (beyond shallow grass cover) presents a flow obstacle and is, therefore, not beneficial for undisturbed stormwater discharge. In the context of storage, vegetation can reduce storage volume and complicate later reuse of the collected stormwater (due to impurities as leaves, bulky wood pieces, etc.). For infiltration, the occurrence of vegetation associated with an active soil layer acting as a natural filter is considered a positive effect. (iv) Groundwater influence: The occurrence of groundwater in a conduit reduces the cross section and thus discharge and storage capacities. Furthermore, it is obvious, that it hinders (immediate) stormwater infiltration. (v) River influence: The occurrence of flooding in a conduit (from the receiving water) has the same influence on the three different hydraulic functionalities as intruding groundwater. Therefore, the effects here are defined analogously.

### 2.2. Case Study

A study area located in the city of Wiener Neustadt was selected to test the pre-assessment process. The city of Wiener Neustadt is located in Lower Austria, Austria, about 45 km south of the Austrian capital Vienna. The population of Wiener Neustadt amounts to approximately 45,300 inhabitants [30].



The city is situated in the southern Vienna basin which consists of a thick sediment layer that provides a large groundwater reservoir. The study area displayed in Figure 2 has a size of approximately 2.2 km<sup>2</sup> and is located in an area with mainly residential buildings. The majority of the area is connected to a combined sewer system, only two sections are connected to a separate sewer system.



**Figure 2.** Overview map with the defined investigation area (red) and the main watercourses (blue) in the city of Wiener Neustadt (data source orthophoto: basemap.at) (based on [31]).

A historic map from 1917 showing old watercourses was provided by the municipal utilities of Wiener Neustadt. This map was used as one of the main data sources for the identification of former watercourses. The city of Wiener Neustadt further provided data on land use including property lines and data on the location of existing drainage systems. Orthophotos were used for visualization of potential former watercourses before the on-site investigation. The orthophotos were derived from basemap.at. The digitization of the old map and the overlay were performed in a Geographic Information System (GIS) using the open-source software QGIS.

For the on-site inspection, a data entry form for assessing the status-quo of the former watercourse was designed. The form included questions regarding the actual presence/existence of the former watercourse in the presumed location, the shape, the status (open or pipe), the channel bottom for open channels, the existing vegetation, the ownership, the water flow, the connectivity to the receiving water as well as space for additional comments. The collected data was used for the validation of the location of the former watercourses and the pre-assessment of the suitability.

To gain a better understanding of the stormwater management related state of the identified former watercourses, additional data was incorporated into the GIS model. This data included groundwater levels and flood zones. The data regarding groundwater levels were provided by the municipal wastewater utility of Wiener Neustadt. The flood zones were obtained from open government data (data.gv.at).

### 3. Results

#### 3.1. Preparatory Meeting with Local Stakeholders (Preparation Phase)

In the preparation phase, the study area was defined together with representatives of the municipal administration of the city of Wiener Neustadt. The municipal wastewater utility wanted to investigate the location and state of the former watercourses to have an information basis for deciding on their

prospective utilization and maintenance in regard to urban (storm)water management. The study area was selected because of the expected presence of former watercourses. Some of the suspected watercourses are known to still function (at least to a certain extend) as a drainage system during instances of heavy rainfall events or high groundwater tables. However, neither their location/extend nor their actual potential has been assessed yet.

### *3.2. Identification of Former Watercourses (Investigation Phase)*

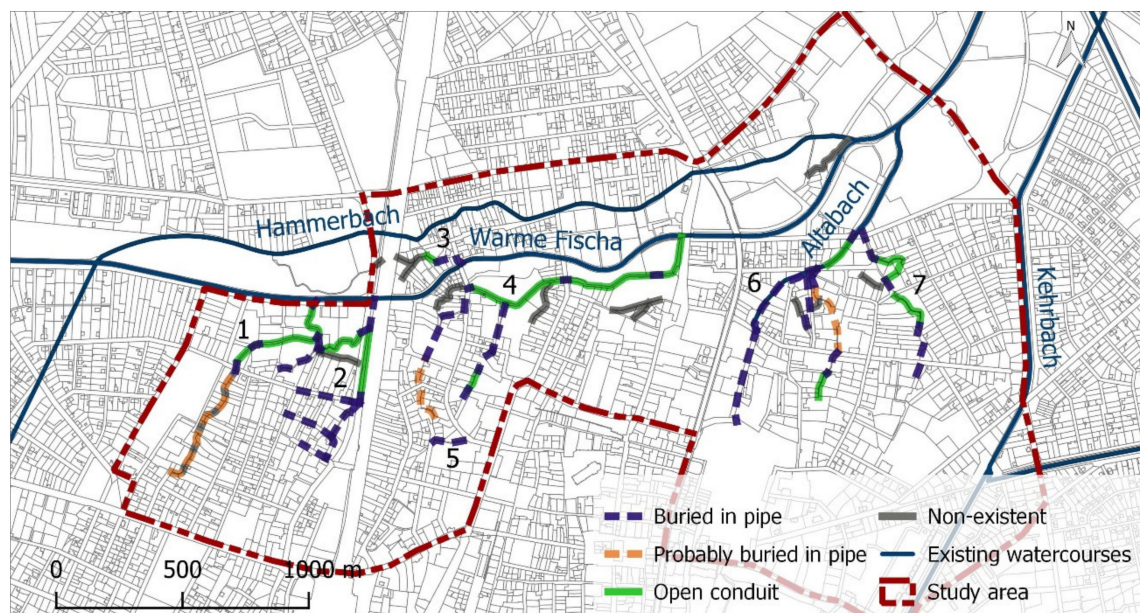
#### **3.2.1. Collection and Digitalization of Maps and Inventory Data**

The identification of former watercourses was based on a historic hand-drawn map showing that roughly 100 years ago extensive river networks existed in the study area. The digitized map was combined with maps of existing river systems, drainage systems, land use data showing property lines and orthophotos. The overlay of the different maps showed a good match between different structures. The watercourses in the historic map matched the existing river systems well, even though some distortion in the position existed caused by digitization. In some areas, drainage systems were located in the same position as previous watercourses indicating burying of watercourses in pipes. Land use data were used to identify potential former watercourses not included in the drainage system maps. Narrow and long properties were considered locations of potential watercourses. Some of these properties were labeled as watercourses in the land use data, without coinciding with the maps of existing river systems. These properties were considered an additional indication for former watercourses that can still be detected in the urban form.

#### **3.2.2. Validation and Addition of Data through On-Site Inspection**

In the identified areas of potential former watercourses, on-site investigations were performed. On-site investigations were further used to validate the existence of former watercourses in the area and to gather additional information on their condition. In total 31 sites were inspected. At 14 sites the former watercourses were buried in pipes. At nine sites dry open channels were identified. Partly buried and partly open former watercourses were found at five sites. At two sites the former watercourses were not accessible as they are partly located on private property. At one location, no indication of a former watercourse could be identified. The identified former watercourses were mainly dried up. Only at one site at watercourse 6, some ponding water was visible. Figure 3 shows the existing as well as all identified former watercourses in the investigated area. In total seven watercourses were distinguished with a total length of 4600 m. For three sections with a total length of 730 m, the state of the watercourse could not be identified. These were, therefore, excluded from further analysis.

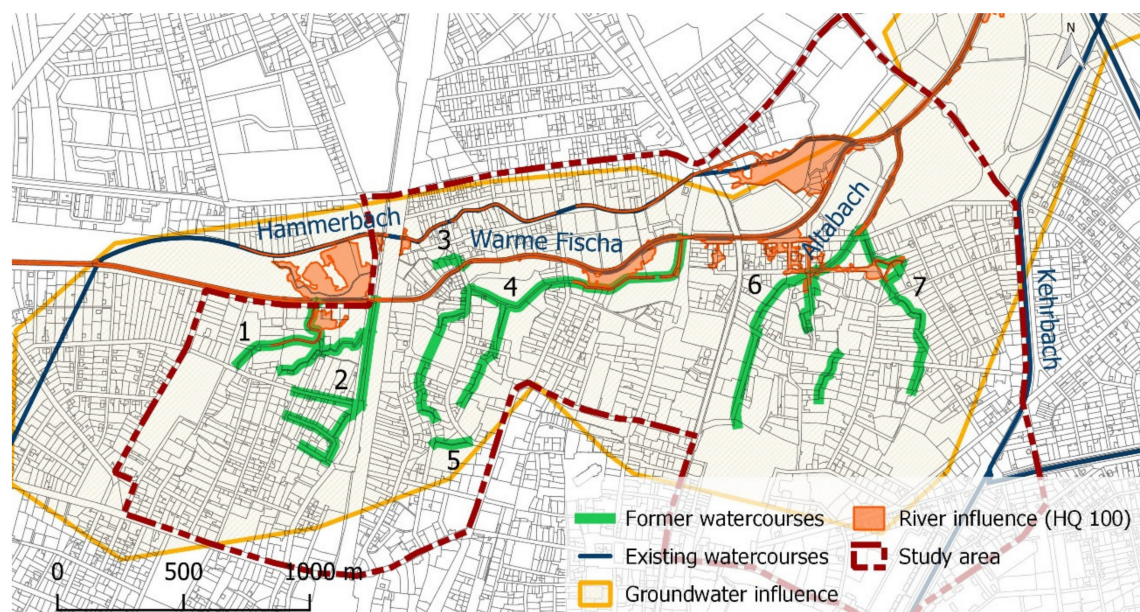




**Figure 3.** Identified former watercourses (numbered) and their current state (based on [31]).

### 3.2.3. Combination of Compiled Information with Other Relevant Data

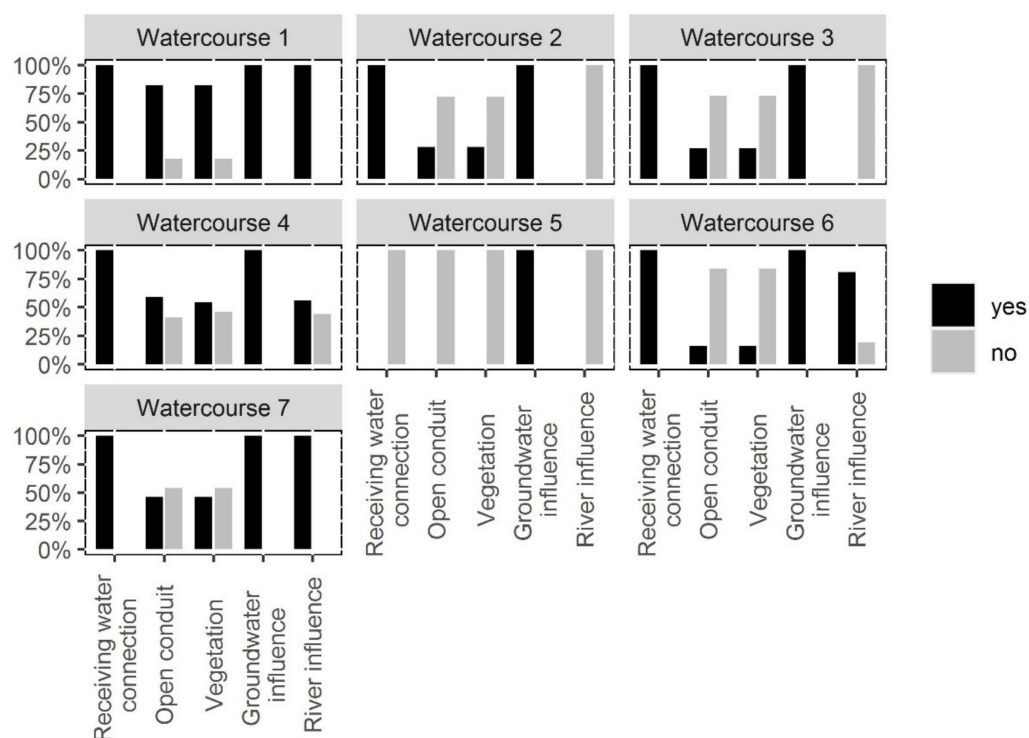
The identified former watercourses and the data collected during the on-site investigation were combined with information on groundwater tables and flood zones. The combination of the data showed that in the entire area of the former watercourses, maximum groundwater tables are less than 2 m beneath the surface. Furthermore, some areas are located within fluvial flood zones, for floods with return periods of 100 years (HQ 100). The flood zones also show the connection of former watercourses to the river system for two watercourses, as a backwater in the dry channels is visible on the map. Two watercourses are affected by floods without showing a backwater effect from the river. The influences are illustrated in Figure 4.



**Figure 4.** Overview of groundwater and river influences in the study area with the numbered former watercourses (based on [31]).

### 3.2.4. Evaluation of The Current State of The Watercourse in Regard to Stormwater Related Criteria

In the following step, the current state/condition of the identified former watercourses was described considering the five stormwater related criteria. Figure 5 shows the proportion of the different states of individual watercourses. From the seven watercourses, six are still 100% connected to the receiving water, while one is not connected at all. In two watercourses the main part of the watercourse is an open conduit. Almost all open conduits are covered with vegetation. In the other five watercourses, the piped sections predominate. As mentioned before all watercourses can be influenced by groundwater as the groundwater table is close to the surface in the whole area. In four watercourses river influence was identified in the main part of the watercourse due to the overlap with flood zones.



**Figure 5.** Distribution of the current states of the individual watercourses over their total length for the different criteria (own presentation).

### 3.3. Suitability Pre-Assessment (Concept Phase)

#### 3.3.1. Application of The Pre-Assessment Matrix

The suitability of the former watercourses in terms of their hydraulic functionalities was evaluated based on the pre-assessment matrix. The pre-assessment was again performed on each watercourse individually. The state present in the majority of the individual watercourse was used for the evaluation. In Table 2 the results of the pre-assessment of the identified watercourses are shown. It illustrates the suitability of the individual watercourses regarding the different functionalities for stormwater management. The higher the proportion of positive effects (+ /green color) the more suitable is the watercourse in regard to a specific functionality. Based on the contents of Table 2, the following sub-chapter presents the derivation of the most promising option to support urban stormwater management for each watercourse.



**Table 2.** Application of the pre-assessment matrix on the identified watercourses (own presentation).

HYDRAULIC FUNCTIONALITY	CRITERIA				
	I Watercourse Connection	I Open Cross Section	III Vegetation Covering	IV Groundwater Influence	V River Influence
Watercourse 1					
Discharge	+	+	−	−	−
Storage/reuse	−	+	−	−	−
Infiltration	−	+	+	−	−
Watercourse 2					
Discharge	+	−	+	−	+
Storage/reuse	−	−	+	−	+
Infiltration	−	−	−	−	+
Watercourse 3					
Discharge	+	−	+	−	+
Storage/reuse	−	−	+	−	+
Infiltration	−	−	−	−	+
Watercourse 4					
Discharge	+	+	−	−	−
Storage/reuse	−	+	−	−	−
Infiltration	−	+	+	−	−
Watercourse 5					
Discharge	−	−	+	−	+
Storage/reuse	+	−	+	−	+
Infiltration	+	−	−	−	+
Watercourse 6					
Discharge	+	−	+	−	−
Storage/reuse	−	−	+	−	−
Infiltration	−	−	−	−	−
Watercourse 7					
Discharge	+	−	+	−	−
Storage/reuse	−	−	+	−	−
Infiltration	−	−	−	−	−

### 3.3.2. Derivation of Most Promising Options to Support Stormwater Management

For watercourses 1 and 4, “discharge” and “infiltration” show a positive effect at two of the five criteria. The discharge potential is negatively influenced by the vegetation present in the watercourse as well as by the groundwater and river influence. Also, the infiltration potential is affected by the groundwater and river influence as well as by the existing connection to the receiving water. The only positive effect for “storage/reuse” is connected to the predominant open cross section in these two watercourses. Concludingly, these watercourses appear more promising for “discharge” or “infiltration” (each watercourse exhibiting two out of five possible positive criteria for discharge and infiltration, or 2/5), while “storage/reuse” (1/5) is less suitable.

For watercourses 2 and 3, “discharge” shows a positive effect at the majority of the criteria. “Storage/reuse” is associated with two positive effects in the five criteria. The main constraints for this functionality are the receiving water connection, the majority of piped sections, and the groundwater influence. The least suitability is found for “infiltration”. Only the lack of river influences in the watercourses has a positive effect on this functionality. Concludingly, these watercourses appear most promising for “discharge” (3/5). But even “storage/reuse” could be a (less suitable) option (2/5), while “infiltration” shows the lowest suitability (1/5).

Watercourse 5 shows the highest suitability for “storage/reuse” out of all the present watercourses. Furthermore, “discharge” and “infiltration” are evaluated with positive effects in two criteria. The piped sections and the groundwater influence are responsible for the majority of negative effects. In addition, the missing connection to a receiving water affects the discharge potential and the lack of vegetation the infiltration potential. Concludingly, this watercourse appears most promising for “storage/reuse” (3/5). But even “discharge” or “infiltration” could be (less suitable) options (each 2/5).

Watercourses 6 and 7 show the overall lowest suitability to support urban stormwater management. “Discharge” shows positive effects only in two criteria resulting from the receiving water connecting and the lack of vegetation. Also, “storage/reuse” is positively influenced by the lack of vegetation. The watercourses are not considered suitable for infiltration as only negative effects can be found. Concludingly, these watercourses appear most promising for “discharge” (2/5). “Storage/reuse” (1/5) or “infiltration” (0/5) do not represent a promising option here.

## 4. Discussion

### 4.1. The Potential of Former Watercourses as BGI

Natural landscapes in urban areas provide different ecosystem services [32]. While the evaluation of the ecosystem services provided by natural landscapes from the point of blue [28] and green infrastructure [27] has been introduced in former studies, a suitability assessment for stormwater management based on different (hydraulic) functionalities presented in this paper has not been considered yet. The individual assessment of the different functionalities allows a targeted evaluation of the identified watercourses. In this case study, it was shown that several former watercourses exist. Their potential for stormwater management has, however, not been incorporated in planning for stormwater management yet.

The pre-assessment of the identified former watercourses reveals that all of them show a certain potential to contribute to urban stormwater management based on their hydraulic functionalities. For some streams, one option is clearly more promising than the others (e.g., watercourses 2 and 3 have three out of five positive effects in regard to the functionality “discharge”). For others, the pre-assessment results in equally promising options (e.g., watercourses 1 and 4 have two out of five positive effects for both functionalities, “discharge” and “infiltration”). Here it is important to state, that the pre-assessment does not intend to provide the “best” solution. It aims at highlighting those options worth being further investigated. For the presented case study, all identified streams appear worth having a deeper look into their definite contribution to the urban stormwater management in the related (catchment) area.

The functionality of BGI, however, goes beyond their hydraulic potential. An extension of the presented assessment with ecological and social functionalities would help to evaluate the potential of the former watercourses from a more holistic perspective [33]. These functionalities, also described in other studies connected to BGI, could include human well-being [34], biodiversity [35], or impact on water quality [36]. To achieve this, the relation between the state of the watercourse and these different functionalities needs to be established. The presence of vegetation and open conduits can for example have a positive effect on human well-being and biodiversity, while a connection to the receiving water might have negative effects on its water quality as pollutants get directly discharged into the receiving water without treatment. Depending on the functionalities added, further criteria

for evaluation might be necessary. For water quality, the pollution potential of connected areas could for example be necessary. In the context of an integrated approach, all possible functionalities of the identified former watercourses (hydraulics, human well-being, biodiversity, etc.) should be considered during subsequent (detailed) planning activities.

#### *4.2. Major Points for Subsequent Planning*

The pre-assessment of the identified water courses reveals the most promising options to be further investigated. To deepen the analysis (at least from a hydraulic perspective) a more distinguished consideration of the criteria can be a next step. For the pre-assessment, all criteria are considered of equal importance. Weighting the criteria, however, could be an option to adapt the pre-assessment matrix to local conditions (e.g., planning priorities, stakeholder perception, etc.) For example, in our case study groundwater influence is considered present if the groundwater level is less than 2 m below the surface. While in this depth it can be considered an influence for the infiltration capacity, discharge and storage capacities are only influenced, if the groundwater table exceeds the surface level. The groundwater influence could be assigned a lower weight for these two functionalities. As the suitability for stormwater management may change depending on the chosen weighting, weighting should be carefully considered. A collaborative definition of weights already in the preparation phase helps to prevent bias from an individual assessment. Weighting based on local conditions and established by relevant stakeholders can further provide a stronger assignment for the detailed planning.

Based on the experiences gained from this case study, detailed planning shall further consider the following aspects of general importance: (i) clarification of property rights, (ii) detailed geodetic survey, measurement of cross sections and collection of additional data, (iii) digital inventory in a central (municipal) database (GIS - geographic information systems), (iv) inclusion in existing planning approaches/models, and (v) elaboration of maintenance plans.

In Austria, the property boundaries of existing watercourses as well as the related property rights are documented in central databases (on municipal and/or national levels). We assume this information management procedure to be comparable to many other countries in the world. However, for former watercourses, the situation might appear less clear. This is due to the fact that they often have been modified several decades ago (redirected, piped, etc.) and thus might not be adequately represented in recent databases. During our investigations, we observed several of the open former watercourses to be more or less “integrated” into private properties. Furthermore, piped watercourses in some cases cross private properties rather than follow public premises (e.g., streets). Property rights on the respective ground are linked to access rights, which are vital for periodic maintenance work and the like. If former watercourses shall be integrated into urban stormwater concepts, the clarification of property rights is a prerequisite. Otherwise, detailed planning of certain solutions might be obsolete.

Historic maps and related on-site observations are helpful for roughly identifying the location of former watercourses. However, for the geographical definition of properties as well as for subsequent planning steps in terms of stormwater management more detailed information is required. This implies a detailed geodetic survey to define the extent of the related premises. Furthermore, from a hydraulic perspective the measurement of cross sections (shape) of both, open and piped conduits is imperative (e.g., for a later determination of storage and discharge capacities). The survey of piped sections shall also include a visual inspection (crawler-based CCTV inspection, manhole zoom camera) to collect information on the structural and operational conditions and connectivity of the pipes. Depending on the intended solution even further data might be necessary (e.g., for infiltration purposes the soil permeability is crucial). The aspect of additional data collection is imperative, as only the availability of detailed data allows a quantitative assessment (calculation of technical criteria as storage volume or discharge capacity) and thus detailed planning of an intended solution.

All detailed data concerning the former watercourses (property rights, geodetic location, cross sections, structural and operational condition) must be included in a central database on the municipal level. This step is imperative to make the information accessible, not only in terms of urban stormwater



management but for all potentially concerned disciplines (local spatial planning, urban green space management, etc.). However, it is also of crucial importance to communicate the new data availabilities among the concerned municipal departments and utilities to raise interdisciplinary awareness and thus to initiate integrated planning.

Following the pre-assessment, former watercourses shall be considered in existing and future planning approaches. This implies the consideration of additional functionalities and data material. From a stormwater management perspective this could mean the integration into the existing sewerage/stormwater system, stormwater related planning concepts and hydrodynamic models (e.g., surface runoff, in-sewer flow); from a spatial planning perspective the integration into urban development concepts; and from an urban green perspective the integration into habitat connectivity plans.

Finally, also former watercourses depending on their designated role as BGI require periodic and/or on-demand maintenance. This can include, for instance, a repetitive visual inspection and assessment of the state of piped watercourses (including cleaning and rehabilitation measures) or the grooming of vegetation to prevent flow obstacles in the conduit's cross section.

#### *4.3. Strengths and Weaknesses of the Approach*

The identification and pre-assessment of former watercourses for stormwater management are based on a well-structured, simple to apply and data-extensive procedure which has also proved its practicability in a case study. For each process step (preparation, investigation, and concept phase) the key activities are described and information on potential/relevant data sources is given. The integration of different water related data provides the best possible overview of the current situation in the investigated area. The (rather qualitative) pre-assessment shall highlight those options worth investigating in detail but not provide directly a "best" solution. The simple judgment on the impact of the five different criteria (positive or negative effect) in the pre-assessment matrix supports a fast first evaluation and an objective statement based on the developed pre-assessment matrix. Hereby, the color-coding of the effects intends to give additional visual support.

However, the less technical (quantitative) character of the suggested criteria as well as their equal weighting in the pre-assessment might be seen as a weakness of the approach. An evaluation based on more detailed criteria such as storage volume, soil permeability, or discharge capacity, would certainly increase the informative value of the evaluation. At the same time, this would also increase data collection and processing requirements. In our point of view, related efforts should not be made for all possible options but only for (the most) suitable and promising ones. Consequently, a detailed analysis based on the quantification of the criteria should be implemented in the subsequent detailed planning activities.

Summarizing the above, one has to keep in mind that the suggested procedure is only the initial step leading to a detailed urban stormwater planning. We consider the integration of former watercourses as BGI as an innovative and additional aspect of holistic planning. Their utilization provides the opportunity to facilitate sustainable stormwater management without requiring additional space. The described work guides structured and targeted data collection and preparation in the course of pre-planning. At the same time, it shall raise awareness towards the opportunity of reactivating former watercourse to support urban stormwater management. Due to its rather general character, the entire procedure can easily be transferred to other regions and countries serving as a guideline and template for similar planning approaches.

## **5. Conclusions**

The existence of former watercourses in today's settlement structures is not very well documented but can be expected for many sites around the world. The preservation and reactivation of natural water/channel systems can provide a viable contribution to modern and sustainable blue and green infrastructures. In this paper, a structured approach for identifying former watercourses based on

historic and current data is presented. Furthermore, a suitability pre-assessment of the identified watercourses based on their hydraulic function in terms of stormwater conveyance, storage, and/or infiltration is introduced. The results from the pre-assessment highlight those hydraulic functions most promising to support urban stormwater management and thus provide a basis and direction for targeted subsequent (detailed) planning activities. The simplicity of the approach promotes its transferability to different regions. In the presented case study several former watercourses were identified as suitable for different hydraulic functionalities. The reactivation of former watercourses is an additional and promising option to further support development towards more nature-based and thus livable cities. This article shall inspire further research and practical applications to better use and integrated natural landscape features into planning processes for sustainable urban drainage.

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