

# Disconnected Canal Networks, Diminished Resilience: Rethinking Bangkok’s Urban Water Management

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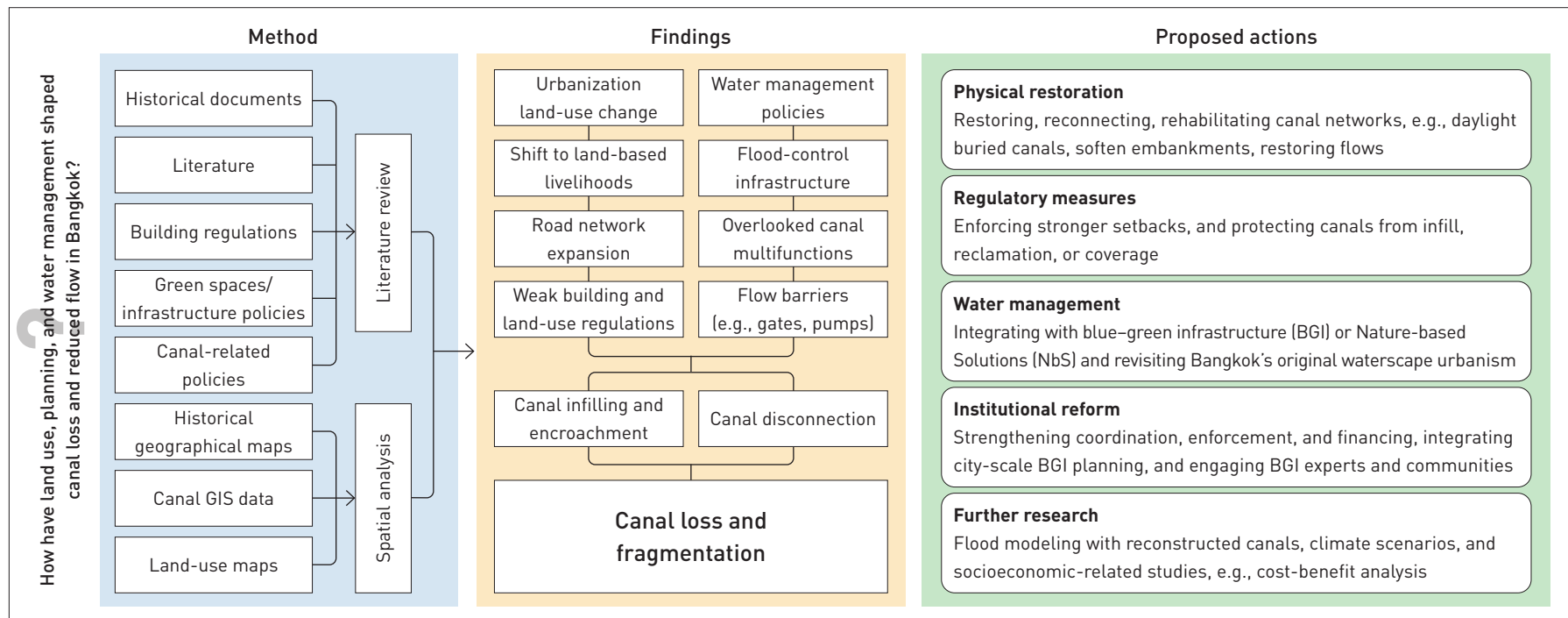
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## GRAPHICAL ABSTRACT



## ABSTRACT

Urbanization and single-purpose flood-control infrastructure have fundamentally restructured the hydrological regimes and canal networks in many delta cities, with Bangkok’s diminishing canal networks serving as a key example of this transformation. Once vital for flood mitigation, irrigation, transportation, and cultural functions, Bangkok’s canals have declined with the shift to

land-based development and single-purpose flood control. This study draws on spatial and land-use change analyses of three representative canal networks, which exhibit varying levels of urbanization and canal morphology, to illustrate different patterns of canal loss, sub-canal fragmentation, and surrounding land-use transitions over time. The findings show that canal loss closely

paralleled the expansion of impervious surfaces and land-use change, reflecting not only a shift toward rigid, single-purpose water management infrastructure but also a transformation in societal perceptions from water-based to land-based living. This dual shift has disconnected communities from their waterways, weakened urban flood resilience, and neglected the broader ecological and cultural value of canal networks. To address these challenges, strategies for restoring and reconnecting canal networks as multifunctional Blue–Green Infrastructure (BGI) are recommended, including reconstructing missing segments, enhancing lateral connectivity, and applying green engineering solutions. The study highlights the importance of incorporating historical canal data into hydrological models to support evidence-based flood mitigation strategies, and also identifies key research gaps concerning the socio-political feasibility of canal restoration and the integration of future climate scenarios into flood modeling. By reframing canal networks as critical infrastructure for urban sustainability, this study contributes to broader academic and policy discussions on adaptive water management in delta cities.

## KEYWORDS

Canal Network; Canal Network Fragmentation; Canal Restoration; Blue–Green Infrastructure; Liquid Perception; Hydrological Connectivity; Water Resilience; Adaptive Water Management

## HIGHLIGHTS

- Urbanization and flood controls fragmented Bangkok’s canal networks and disrupted water flows
- Spatial analysis shows substantial canals in Bangkok remain despite loss and disconnection
- Integrating waterscape urbanism highlights canals as cultural, ecological, and flood resilience assets
- Land use policies should integrate canal conservation to prevent further degradation
- Hydrological models must incorporate missing canals for data-driven urban planning

EDITED BY Tina TIAN

## 1 Introduction

Deltas are low-lying, flat landscapes shaped by seasonal cycles of flooding and drought, creating highly dynamic wet and dry conditions. Although once considered uninhabitable, many early delta communities worldwide adapted the landscape and their livelihood to align with natural hydrological regimes, making life in these challenging environments possible<sup>[1–4]</sup>. This form of adaptation also occurred in Bangkok, a city situated in the intertidal zone of the Chao Phraya Delta (CPD). Bangkok developed in a low-lying, fluviially active, flood-prone area characterized by annual flood pulse hydrological dynamics. Since the 18th century, early inhabitants modified the landscape using canals, ditches, and dikes as land reclamation techniques to transform uninhabited land into a productive landscape and water-based livelihoods<sup>[4–7]</sup>. These waterways served multiple purposes, including draining excess floodwater, protecting settlements from inundation, irrigating agricultural lands, and providing essential transportation routes<sup>[8]</sup> (Fig. 1). Houses, temples, orchards, and rice fields were closely interconnected with the canal network, harmonizing daily life with the rhythms of the delta’s hydrological regime<sup>[5]</sup>.

The diverse usages of Bangkok’s canals in the past reflect long-standing local knowledge and water-based adaptation strategies that have existed for centuries. Although these practices

**Fig. 1** Historical photographs of early Bangkok canals show them accommodating floating houses, bustling waterways, and interconnected communities that supported the transportation, trade, and daily life of inhabitants.



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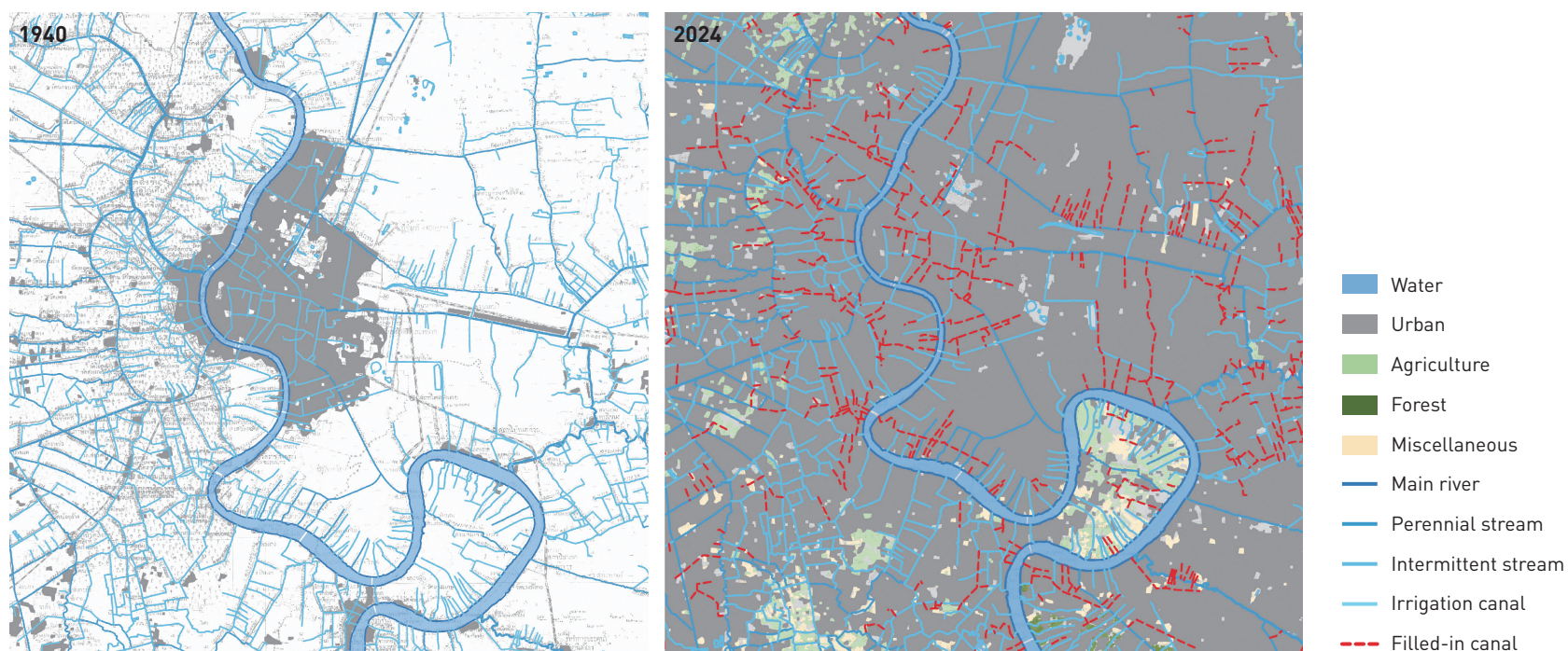
originated independently of contemporary frameworks, they share similar ideas with the concepts now described as Blue–Green Infrastructure (BGI), a network of multifunctional natural and semi-natural areas providing ecosystem services<sup>[9–15]</sup>. Bangkok’s complex network of canals can be recognized as an early form of culture-based BGI, which has fostered flood resilience, sustained biodiversity, and supported vital ecological processes such as nutrient cycling and habitat connectivity. This traditional “liquid perception” of living with water formed the foundation of Bangkok’s urban ecology and cultural identity<sup>[16]</sup>.

However, with the onset of modernization and rapid urbanization, perceptions of water shifted from coexistence to control. The construction of roads, land reclamation, and engineered flood protection systems led to the large-scale infilling and fragmentation of canal networks (Fig. 2), resulting in a diminished capacity to handle the increasing intensity and frequency of extreme rainfall events driven by climate change<sup>[17–20]</sup>. The original multifunctional BGI networks deteriorated, weakening Bangkok’s natural capacity to manage seasonal flooding and tidal fluctuations. Recently, the effects of this transformation have become increasingly evident. Conventional flood control infrastructure, which is the dominant measure practiced in

Bangkok, tends not to be enough to meet the demands of current and future climate conditions<sup>[18–19]</sup>. Combining BGI with gray infrastructure is likely the key to mitigating this challenge<sup>[10,21–23]</sup>. Canal networks are one of the important BGI components, serving as a backbone of green spaces that provide ecosystem services, including urban flood risk mitigation.

While the Bangkok Metropolitan Administration (BMA) has initiated efforts to promote more green spaces within the urban fabric, the critical role of canal networks in water management has been largely overlooked in contemporary planning. To build a more flood-resilient city, it is essential to revisit and revitalize Bangkok’s original canal-based BGI, complementing it with modern Nature-based Solutions (NbS) that integrate environmental values, flood risk mitigation, urban ecological planning, and public health considerations. In this context, this paper aims to highlight the importance of Bangkok’s canal networks by illustrating the city’s historical resilience to floods as a water-based community. Through the review of historical documents, photographs, and relevant research, this study reveals how early Bangkok settlements harmoniously coexisted with seasonal flooding, and examines how modernization, urbanization, and the shift in livelihood perceptions from water-

**Fig. 2** A comparison of historical (1940) and present-day (2024) canal networks in Bangkok illustrates the impact of urban expansion on waterways, including the filling in of canals and the reduction of agricultural areas. Data sources: land use data from the Land Development Department of Thailand (LDD); base map from the Royal Thai Survey Department (RTSD); and canal GIS data from the Bangkok Metropolitan Administration (BMA).



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based to land-based communities have transformed the city's structure. Alongside a literature review, this study incorporates a spatial analysis that compares historical and present-day canal networks to assess changes in spatial patterns and the number of canals. This interpretive and comparative approach enables a critical discussion of overlooked aspects in current BMA flood management strategies, emphasizing the need to strengthen Bangkok's resilience to natural hydrological processes and to enhance the quality of life in this delta city.

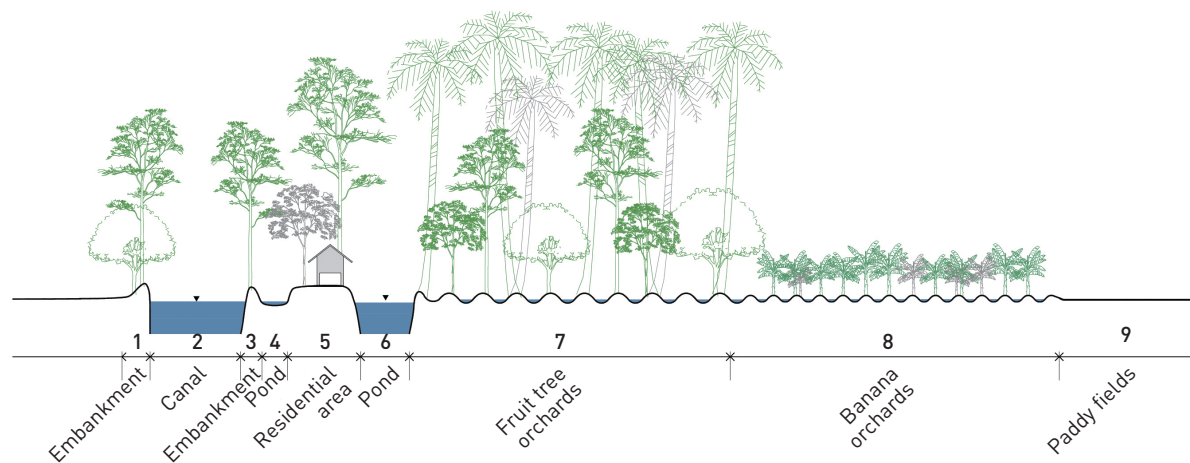
## 2 Bangkok's Landscape Characters and Natural Contexts

The early city of Bangkok was founded on a deltaic high, where its vicinity comprised an expansive lowland area with an average elevation less than 2.5 m from the mean sea level (MSL) and numerous tributaries of tidal rivers<sup>[6,7,24–26]</sup>. Flood pulse dynamics occur annually from October to December<sup>[6,27–28]</sup>, during which significant surface inundation converts the expansive lowland region from land to occasional marshland, initiating various ecological processes, such as reproductive cycles, decomposition, and nutrient cycling<sup>[6,27–28]</sup>. The soil in the lower delta is extremely soft, with poor drainage and high salinity, which offer specific conditions for living organisms<sup>[6,7,25]</sup>. Proper land reclamation was necessary in deltaic environments to modify the landscape for human habitation and settlement. The primary technique involved excavating a network of man-made canals, which later functioned as hydro-ecological infrastructure and became the backbone of a nature-based settlement system, enabling access, transportation, and land-use zoning that supported ecosystem-based livelihoods such as rice farming and fishing<sup>[4,6,29–30]</sup>.

## 3 Living With Water: Traditional Settlements and Their Adaptations

In the early 1900s, settlements in Bangkok were concentrated along canal banks, with houses and temples oriented toward the waterways and directly connected to them<sup>[4,29]</sup>. These early nature-based settlements were shaped by the city's canal networks, where houses were typically built close to canals for commuting purposes, followed by orchards and other greenery that helped control embankment erosion and acted as buffers between private properties and public waterways (Fig. 3)<sup>[6,30]</sup>. Land use near waterways mainly comprised orchards, which were integrated with networks of water channels (ditches) and low bunds (dikes) designed for irrigation and flood management in response to tidal fluctuations and seasonal flood pulses<sup>[6]</sup>. These water-adapted land modifications reflect the liquid perception practices that fostered resilience by enabling people to adjust their water management strategies and sustain ecosystem-based livelihoods in tune with hydrological regimes<sup>[16,30]</sup>. These flood-resilient practices and livelihoods gave rise to a unique urban form that has been termed "waterscape urbanism"<sup>[16]</sup>, which refers to urban landscapes shaped by dynamic interactions between human settlements and hydro-ecological systems, where water plays a central role in both spatial organization and cultural identity.

Since then, Bangkok's canal networks have benefited the inhabitants by supporting traditional ecosystem-based livelihoods<sup>[30]</sup>, while also providing multiple environmental benefits. From a socioeconomic perspective, canals facilitated transportation, provided access to water supply and natural food resources, supported irrigation for orchards and rice fields, enhanced water management, and improved drainage efficiency<sup>[6,16]</sup>. Moreover, the



**Fig. 3** This cross-sectional diagram illustrates the multifunctional use of land at the edge of Bangkok's canal networks. Key features include water transportation, residential areas, excavation for reservoirs, and orchard patches with perennial plants and coconuts, while paddy fields occupy the innermost areas. Such a water network is essential for connecting agricultural areas, distributing water supply, and enabling boat transportation (adapted from Ref. [6] with permission).

canals also served as social and leisure spaces and were recognized as part of Bangkok's cultural heritage. Apart from private properties, markets and temples were also located near canals that hosted public gatherings for entertainment and traditional activities, such as the Boat Festival and Loy Krathong Festival. These spaces and events create opportunities for hospitality and tourism, contributing to local economic growth. Beyond their social and economic value, the interconnected canal networks also functioned as hydro-ecological infrastructure, promoting the distribution of riparian plant communities, enhancing ecological flows, and creating wildlife corridors that support biodiversity<sup>[31-33]</sup>.

#### **4 The Decline of Waterscape Urbanism and the Rise of Land-based Expansion**

After Bangkok's modernization in 1907<sup>[4]</sup>, the city shifted away from a form of waterscape urbanism toward a land-based infrastructure system. Roads rapidly replaced canals as the primary transportation mode<sup>[4]</sup>. Initially, roads were constructed by piling up mounds of soil excavated from canals. However, many canals were later filled in to create more space for additional vehicle lanes. This led to the loss and fragmentation of extensive canal networks and natural distributaries (Fig. 2). To protect the land-based infrastructure and people's properties, Bangkok's water management shifted toward an engineering-driven prioritizing flood protection for key economic zones over the traditional liquid perception concept. Since the early 1910s, Bangkok implemented a polder system for water management, beginning to use sluice gates to control water levels in some major canals<sup>[34]</sup>. Later, the Department of Drainage and Sewerage (DDS) was established in the 1970s to manage and maintain Bangkok's canal networks<sup>[35]</sup>. Since then, flood control efforts have shifted toward maintaining water levels using sluice gates and pumping systems, which have suppressed natural tidal fluctuations<sup>[36-38]</sup> and resulted in stagnant canals with deteriorating water quality<sup>[38-41]</sup>. Combined with land use changes, this transition has dramatically accelerated the decline of the city's canal networks, reducing the city's resilience to floods and diminishing other ecosystem services provided by the canal networks.

One of the primary drivers behind the deterioration of the canal networks was land use change, which significantly altered the structure and function of the city's waterways. Rapid urbanization has converted green and blue spaces into built-up areas, leading to canal encroachment, narrowing, and even complete

disappearance in some cases. To better understand these impacts, this study examines three distinct zones within Bangkok and adopts a qualitative review of literature and historical records alongside a spatial analysis to explore how canal transformations correspond to land-use changes over time. The selected canal network cases are the Pra Khanong Canal (PK), Omnont Canal (ON), and Sanamchai Canal (SN), which were chosen based on the diversity of their spatial forms, historical developments, and surrounding land-use changes. The PK case exemplifies a more recent, engineered waterway characterized by a straight, geometric alignment aimed at maximizing navigational efficiency. The ON network represents an intermediate condition, combining characteristics of both natural river courses and engineered modifications. In contrast, the SN network exhibits a more natural, meandering form, modified from the original distributaries of the Chao Phraya River, and retains the least disturbed landscape among the three cases. In addition to differences in canal morphology and historical context, the selected cases also reflect varying degrees of urbanization: the surroundings of PK network have undergone extensive urban development, with a high degree of sub-canal loss and infilling, whereas the areas around ON and SN networks retain more semi-natural and agricultural characteristics.

For this comparative analysis, the historical canal networks were digitized as vector data using a compiled map of 33 geographical map sheets surveyed and produced by the Royal Survey Department between 1910 and 1940. These historical maps were georeferenced and validated by Tachakitkachorn<sup>[4]</sup>, who assessed their positional accuracy and determined the Root Mean Square (RMS) error of 37.13 m. While reflecting some expected positional inaccuracies in historical geospatial analysis, it remains within an acceptable range for hand-drawn maps and historical urban landscape studies, allowing reliable comparison with the modern coordinate system<sup>[42]</sup>. Following the digitization process, the historical canal networks were compared with current GIS data on canals and natural waterways provided by BMA. Changes over time in the canal network were analyzed by identifying the loss of canals between the two datasets, with the total loss quantified as a percentage to assess the degree of disappearance. The urban expansion, canal loss, major physical changes, and key responsible authorities<sup>[41,43-47]</sup> in the three cases between 1940 and 2024 are summarized in Table 1. The analysis results revealed how the patterns of canal loss were closely tied to the changes in land use and flood management strategies, especially how flood control interventions and land use

**Table 1: Summary of urban area expansion, canal loss, major physical changes, and key responsible authorities of the three canal network cases (1940–2024)**

Canal network area	Urban area in 1940 (ratio of the total area)	Urban area in 2024 (ratio of the total area)	Urban growth	Canal length in 1940	Canal length in 2024	canal loss (loss ratio)	Major physical changes	Intervention	Key responsible authority
PK	2.45 km <sup>2</sup> (1%)	189.17 km <sup>2</sup> (82%)	186.72 km <sup>2</sup>	683,780 m	439,720 m	244,060 (36%)	Canal loss	Canal infilled	BMA
							Riparian loss/degradation	Channelization	DDS, BMA
							Aquatic habitat degradation	Canal bed dredging	DDS, BMA
ON	30.44 km <sup>2</sup> (13%)	179.80 km <sup>2</sup> (78%)	149.36 km <sup>2</sup>	575,680 m	472,405 m	103,275 (18%)	Canal loss	Canal infilled	BMA
							Canal fragmentation and disconnected flows	Sluice gate and pumping station construction	RID, DDS
							Riparian loss/degradation	· Channelization · Flood wall construction	DDS, BMA
SN	3.10 km <sup>2</sup> (1%)	127.77 km <sup>2</sup> (56%)	124.67 km <sup>2</sup>	654,050 m	543,950 m	110,100 (17%)	Canal loss	Canal infilled	BMA
							Canal fragmentation and disconnected flow	· Sluice gate and pumping station construction · Weir construction	RID, DDS
							Riparian loss/degradation	Channelization	DDS, BMA
							Aquatic habitat degradation	Canal bed dredging	DDS, BMA

**NOTES**

1. RID stands for the Royal Irrigation Department of Thailand.

2. Source: Refs. [41,43–47].

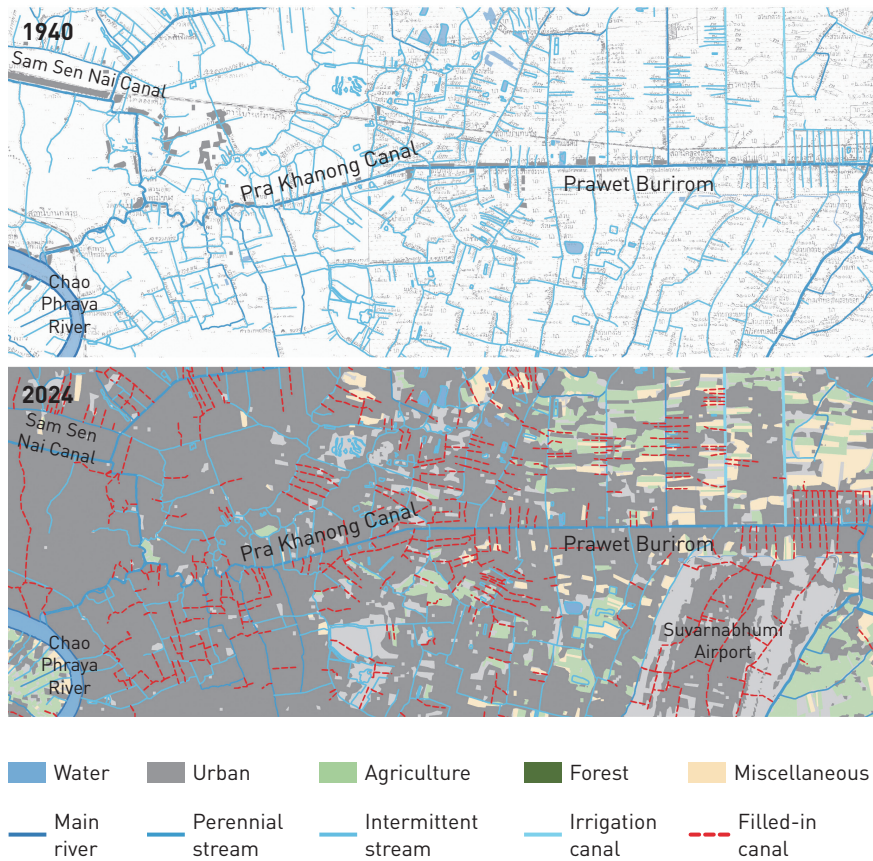
shifts contributed to canal degradation and the fragmentation of Bangkok’s historic canal networks.

**4.1 The PK Case**

The PK network, located on the southeastern side of the Chao Phraya River, is one of Bangkok’s most historically significant canals, dating back to the 19th century<sup>[41]</sup>. Originally, the canal was a natural tributary of the river, and then it was dredged to extend its length for transportation purposes in 1837 and again in 1878<sup>[41]</sup>. The latter development attracted new Thai, Chinese, and Muslim communities, leading to the establishment of settlements along its banks<sup>[41]</sup>. Over the past century, urbanization has dramatically transformed the canal’s surroundings, including itself (Fig. 4). Extensive road construction has introduced various types of land use, such as airports, railways, and residential developments,

leaving only a few orchards remaining by the late 20th century<sup>[43]</sup>. As roads became the primary infrastructure mode, the canal was gradually neglected and declined<sup>[41]</sup>. Consequently, the connection between local communities and the canal weakened as its primary function shifted to urban drainage, resulting in poor water quality and severe pollution<sup>[41,43]</sup>.

Between 1940 and 2024, the urban area ratio of the PK case expanded from around 1% to over 80%, marking the most rapid urbanization among the three cases. This growth corresponded with the increasing replacement of orchards, rice fields, and open spaces by roads, airports, railways, and residential areas. The total length of canals in the PK network decreased by approximately 36%, reflecting extensive infill and fragmentation. Together, these changes illustrate that urban expansion has directly contributed to the degradation of the canal network and



the shift from a water-based agricultural landscape to a highly urbanized environment.

#### 4.2 The ON Case

Lad Muang Nont Canal was excavated during the Ayutthaya period (17th century)<sup>[41]</sup> to shorten the navigation route through the meandering course of the Chao Phraya River in Nonthaburi. Thereby, the bypassed meandering section was transformed into the ON<sup>[41]</sup>, which was lined with traditional houses and orchards, with perpendicular ditches providing water supply and transport access to the surrounding agricultural areas (Fig. 5). Historically, the ON has served as critical drainage infrastructure along the western bank of Chao Phraya River in both Bangkok and Nonthaburi, reducing flood risk while conveying water to the local orchards<sup>[41]</sup>.

However, rapid urbanization in the late 20th and early 21st centuries transformed the area around the ON into low-density residential developments<sup>[43]</sup>. From 1940 to 2024, the urban area ratio increased from about 13% to approximately 78%. This significant shift from agricultural to urban land use corresponded with the infilling or disconnection of many smaller waterways. As vast impervious surfaces replaced productive farmlands, the complex network of irrigation ditches became disconnected<sup>[43]</sup>. The

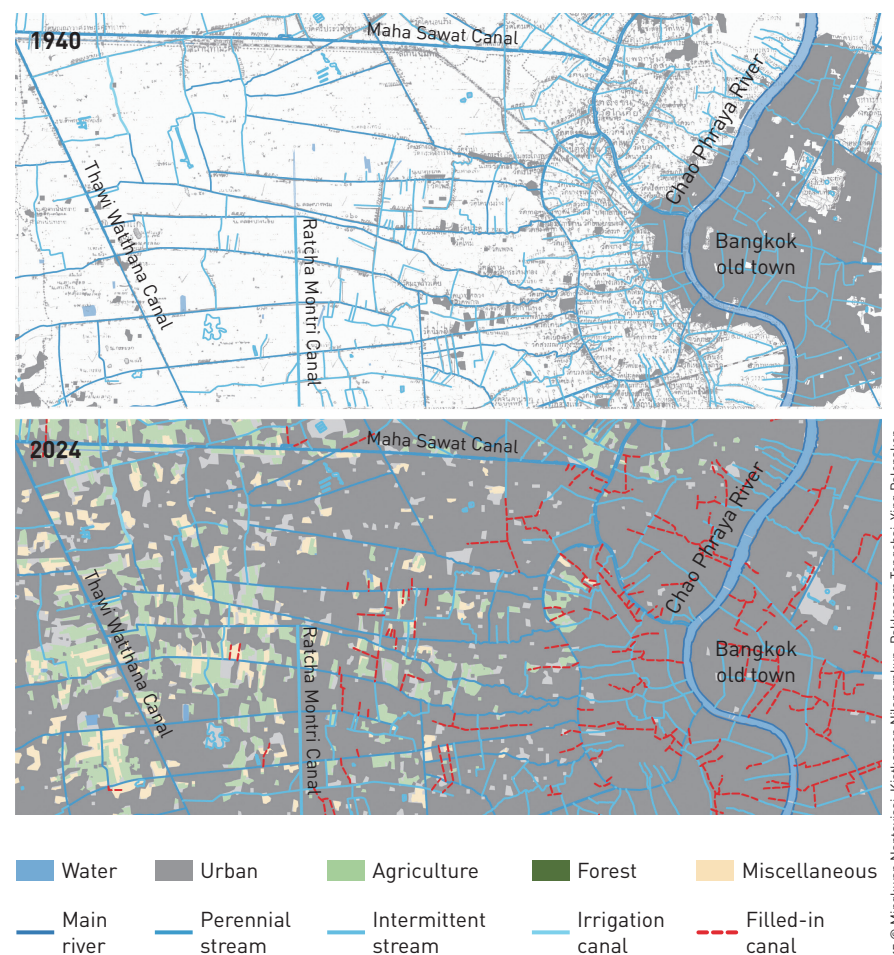
total length of canals of the ON network declined by nearly 18%, reflecting the infill, narrowing, and disconnection of secondary ditches and sub-canals, which disrupted water networks, reduced the ecosystem services of BGI, diminished canal flows, and increased pollution from runoff and illegal greywater disposal. Furthermore, the loss of BGI has heightened flood risks by decreasing pervious surfaces and limiting water retention capacity.

#### 4.3 The SN Case

The SN was dredged during the Ayutthaya period (in the early 18th century) to enhance navigation by connecting the Chao Phraya River with the Tha Chin River in the western part of the CPD<sup>[41]</sup>. The canal network is situated in the brackish zone of the CPD, an area

**Fig. 4** The changes between 1940 and 2024 of the PK network demonstrate the significant impact of urban development, which has altered land use and contributed to the decline of the canal network. Data sources: land use data from LDD; base map from RTSD; and canal GIS data from BMA.

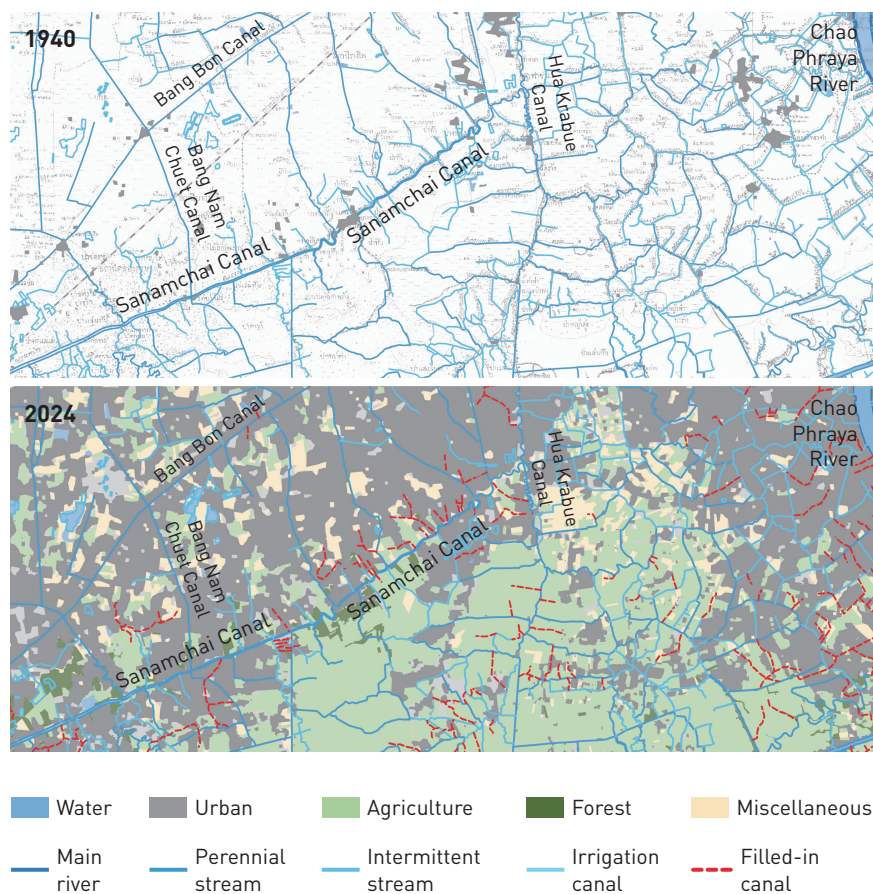
**Fig. 5** This comparison between the historical and present-day of the lower part of the ON network emphasizes the shift from orchards to urbanization, infilling canals, and the subsequent loss of water connectivity. Data sources: land use data from LDD; base map from RTSD; and canal GIS data from BMA.



characterized by the distribution of back-mangrove communities. Historically, along the SN, vast orchards and local communities once thrived, benefiting from ideal soil and water conditions that favored fruit tree cultivation and facilitated transportation, and the canal itself served as a significant route for transportation and military operations, which led to the establishment of marketplaces, temples, and numerous villages along its banks (Fig. 6)<sup>[41]</sup>.

In recent times, however, the SN network has suffered degradation due to urbanization and road expansion. The urban area ratio increased from approximately 1% in 1940 to around 56% by 2024, replacing former mangrove groves, fruit orchards, and rice paddies with residential areas, warehouses, and industrial facilities<sup>[48]</sup>. As the transition towards land-based development, the SN network shifted to serving mainly as drainage infrastructure for flood diversion, helping alleviate flooding in western Bangkok and surrounding areas, though often overlooking its ecological and socioeconomic services. The total length of canals in the SN

**Fig. 6** The SN network's evolution between 1940 and 2024 reflects a pattern consistent with other regions in Bangkok, where urban sprawl and infrastructure development have reduced the connectivity of canal networks. Data sources: land use data from LDD; base map from RTSD; and canal GIS data from BMA.



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network decreased by approximately 17%, reflecting the gradual infill and fragmentation of the network. While the SN area remains less urbanized compared with the other two cases, its land-based development has diminished the canal network's ecological and hydrological functions, reorienting its role from a socio-ecological lifeline to a single-purpose flood drainage channel.

These three cases demonstrate similar problems within the canal networks at varying levels, where changes in land use and a shift toward land-based infrastructure are the leading drivers of canal network degradation. The quantified canal loss closely mirrors the growth of built-up areas has deteriorated the connectivity, ecological functions, and water resilience once supported by its canal networks. The transition from liquid perception to a solid-state perception, from an indigenous water-based livelihood to a permanent, static, solid land-based environment<sup>[16]</sup>, has weakened the connection between people and canals. As a result, both Bangkok's inhabitants and authorities have overlooked the importance of canals beyond their drainage function, leading to neglect and, ultimately, inadequate maintenance<sup>[41]</sup>. The disregard for canal networks, coupled with permissive land development regulations, has encouraged full-scale property development, often resulting in the reclamation and infilling of parts or entire canals to maximize land potential (Figs. 4 ~ 6). This ongoing transformation not only diminishes the ecological and hydrological functions of canal networks but also exacerbates urban flooding, further highlighting the urgent need for more vigorous regulatory enforcement and sustainable urban planning.

## 5 Canals as Single-Purpose Flood Control Infrastructure: A Missed Multifunctional Opportunity

Another major factor contributing to the deterioration of Bangkok's canal networks is the shift to an engineered approach to stormwater management. Over time, this approach has evolved into a one-dimensional and short-sighted flood control strategy, prioritizing rapid drainage efficiency while overlooking the broader ecological and social services that canals can offer. BMA has tasked DDS with stormwater management, primarily focusing on expediting rainwater drainage through engineered systems integrated with Bangkok's canal networks. Therefore, the canal networks have been mostly utilized as an engineered solution for stormwater management rather than as a component of a multifunctional BGI. Most canals in Bangkok are equipped with sluice gates, flood walls, and pumping stations to control water

levels and drain water efficiently within a desirable timeframe, reducing their role to single-purpose hydraulic infrastructure<sup>[45]</sup> (Fig. 7).

However, climate change has altered precipitation patterns, making them more unpredictable compared with historical rainfall statistics<sup>[49]</sup>. These changes have resulted in more frequent and intense extreme rainfall occurring over shorter periods, further exacerbated by the expansion of impervious land surfaces<sup>[49–52]</sup>. Such drainage systems struggle to handle heavy and continuous rainfall, which will likely increase flood risk in BMA in the near future. To address these challenges, the DDS has continued to focus on adding more control systems and managing the canal networks to expedite water drainage. Nevertheless, these problems persist due to the limitations of rigid infrastructure and the failure to fully explore the potential of BGI, which serves purposes beyond recreational spaces.

Bangkok's current water management approach prioritizes conventional drainage standards, focusing on the rapid conveyance of stormwater into waterways, often with limited consideration for water quality and ecological impacts. This approach corresponds to the second (sewered city) and third (drained city) stages of urban water management, as outlined in the Urban Water Management Transition Framework<sup>①[53]</sup>. This demonstrates that Bangkok's water management remains far from the more sustainable practices envisioned in the advanced stages of the framework. Contrasting with the “liquid perception” historical water management of Bangkok, the current systems lack flexibility and constrain the resilience of the urban water management system<sup>[16]</sup>. Specifically,

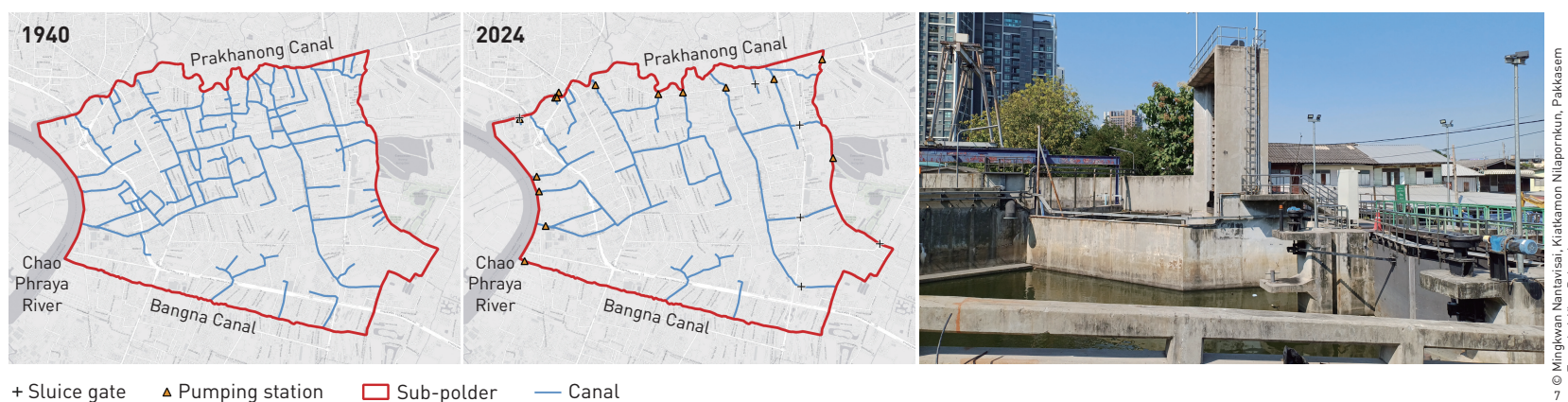
the existing flood protection systems are poorly equipped to accommodate tidal dynamics in the low-lying plains of Bangkok. To address these challenges, Bangkok urgently needs to adopt a new water management paradigm, such as BGI and NbS, while also reconsidering its original waterscape urbanism, which integrated environmental values, urban ecological planning, flood control, public health, and sustainable economics.

## 6 Discussion: Learning From the Past to Revitalize Bangkok's Culture-Based BGI

What we found in this study highlights the importance of Bangkok's canal networks as the city's structural backbone. The historical practices to manage and adapt to deltaic water regimes through canal-oriented settlements and land use exemplify the paradigm of waterscape urbanism<sup>[16,43]</sup>, which repositions urban design within the dynamic rhythms of natural hydrology, thereby strengthening the city's water resilience and delivering multiple urban benefits. These benefits to the city remain discernible, even though the canal network has undergone considerable decline and disconnection. The spatial analysis in this study shows that while the city's canal networks have been significantly fragmented,

① The framework, developed by the National Urban Water Governance Program, Monash University, defines six stages of urban water governance—water supply city, sewered city, drained city, waterways city, water cycle city, and water-sensitive city—which reflect how ideologies and technologies evolve as cities transition toward more sustainable water management (source: Ref. [53]).

**Fig. 7** Comparison of canal networks in the South Sukhumvit-Srinakarin sub-polder between 1940 and 2024, highlighting loss and fragmentation of canal networks. This area is now designed as a polder that collects precipitation and sewage, and the dredged canals have aligned with a floodwall to accommodate higher water levels in the channel. Due to the flat topography, the system relies on fossil-fuel-powered pumping engines to expedite water drainage from the polder to the Chao Phraya River. Data sources: canal GIS data from BMA; and the basemap from “Light Gray Canvas” by Esri, accessed via ArcGIS Pro basemap services.



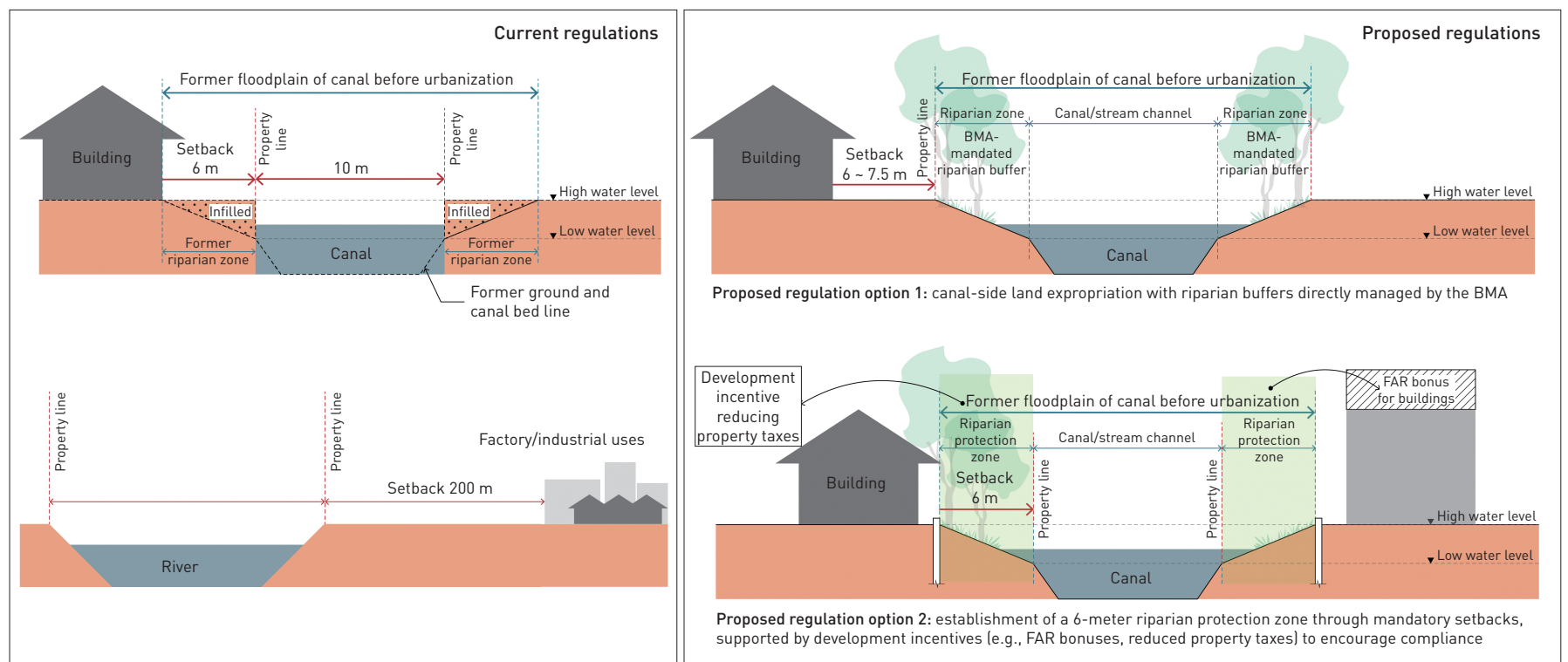
a substantial portion of the system remains physically present, which offers a clear opportunity for canal networks to be restored, reconstructed, and rehabilitated. Systematically reviving the canal networks by restoring the canals as a central structuring agent of urban form would not only enhance integrated water management but also strengthen BGI connectivity, enabling more effective delivery of ecosystem services and reinforcing the city's cultural identity. This approach embodies waterscape urbanism, which complements the BGI framework by emphasizing place-based, historically rooted, and culturally adaptive strategies to enhance resilience in delta cities. Reintegrating these spatial and cultural water logics into modern urban and BGI planning promotes a more holistic approach that aligns ecological restoration with socio-hydrological relationships.

To translate this vision into action, it necessitates integrating the canal networks into Bangkok's broader water management and BGI strategies. To reconnect Bangkok's canal networks, this should begin with reconstructing missing sections of historic canals, while also restoring or creating sub-canals to improve network interconnectivity. In more detail, site-specific interventions can

directly address the distinct forms of degradation identified in Table 1. For example, in areas affected by channelization, the removal of concrete embankments and replacement with soft, vegetated edges can help restore ecological function and improve rainwater absorption<sup>[54-55]</sup>. Where canals have been buried or covered, daylighting them<sup>[54]</sup> and transforming canal corridors into multifunctional linear parks<sup>[54-55]</sup> can further support both stormwater management and public amenity provision. In areas where canals are blocked by structures like sluice gates, pumps, or weirs, adjusting or bypassing these barriers can help reconnect the flow between canals. These measures target not only canal loss but also flow disruption, embankment barriers, and riparian degradation, all key drivers of declining canal performance in delivering ecosystem services.

Alongside physical restoration, legal regulations should be strengthened to protect canal networks from being filled, reclaimed, or covered, and prevent further degradation. For instance, stronger and more enforceable setback regulations should be implemented than those currently applied for new developments near canals to protect riparian zones and maintain open spaces, thereby

**Fig. 8** Comparison between Bangkok's current surface water protection regulations and proposed alternatives for canal-side land management. The left diagrams show that Bangkok's current surface water protection regulations are one-dimensional, focusing solely on the horizontal setback of buildings from water bodies based on their width and intended use. However, retaining walls, fences, and embankment structures are not addressed or regulated as potential impediments to canals, leading to canal infill and the loss of riparian zones.



helping restore and conserve their ecological functions (Fig. 8). Additionally, separating sewage and stormwater systems would reduce pollution loads in canals and enable the reuse of rainwater for urban landscaping and agriculture. These measures would not only enhance water quality and retention capacity but also provide more spaces for recreation while reinforcing the ecological and socio-economic values of canals<sup>[56-58]</sup>. Promoting green spaces and restoring riparian areas along canal banks can further provide wildlife habitats and enhance urban biodiversity. Collectively, these actions deliver a wide range of ecosystem services, including carbon sequestration, microclimate regulation, recreation, cultural and educational opportunities, and improved public health.

However, there are challenges in putting these measures into practice. Urban encroachment, floodwalls, and fences continue to obstruct canal access and connectivity. Moreover, government institutional challenges, including fragmented responsibilities, weak enforcement, and lack of sustainable financing mechanisms, remain significant obstacles to canal restoration and BGI implementation. An equally critical barrier is the absence of holistic, integrated planning for BGI. While the BMA has initiated green projects, such as pocket parks or isolated canal improvements, these efforts are often conceived on a site-by-site basis rather than as part of a coordinated city-scale BGI strategy. This piecemeal approach risks overlooking the systemic hydro-ecological functions that connected canal networks can provide. Compounding this issue is the limited recognition of landscape architects and other professionals specializing in BGI as strategic contributors to urban water management planning. They are often confined to site-level design rather than engaged in shaping broader, integrated BGI visions. To overcome these barriers, multi-level coordination, regulatory reform, and inclusive planning processes involving local communities, stakeholders, landscape architects, and other relevant experts are essential.

To support these proposed interventions and overcome the implementation challenges outlined above, further research is essential to provide a stronger evidence base for planning and decision-making. After reviewing the literature on BMA's historical and present stormwater management and flood mitigation policies, several critical research gaps were identified that warrant further investigation. Specifically, flood model simulations incorporating historical, abandoned, or reconstructed canals remain understudied, and few studies have examined the effects of canal network fragmentation and reconstruction on flood risk reduction, particularly at the city or provincial scale<sup>[59-60]</sup>. Addressing this gap is essential for providing policymakers with

accurate data-driven insights to formulate effective flood mitigation strategies and sustainable urban planning policies, especially regarding the restoration and reconstruction of Bangkok's canal networks, which could potentially enhance the overall resilience of urban infrastructure. Additionally, expanding flood simulation frameworks to include climate change scenarios can help improve the long-term performance of existing flood mitigation infrastructure, particularly through comparison to integrated approaches that combine current measures with BGI strategies.

In addition to technical modeling, further studies should also examine the socioeconomic dimensions of canal restoration. Future research could, for instance, conduct cost-benefit analyses that evaluate both direct and indirect costs (e.g., construction, land acquisition, maintenance), alongside potential benefits including reduced flood damage, improved public health, enhanced property values, and opportunities for recreation and tourism. Moreover, feasibility assessments on financial, institutional, regulatory, and land-use constraints are crucial for informing the practical implementation of canal rehabilitation projects in densely urbanized environments like Bangkok. Such studies will not only guide decision-makers in prioritizing interventions but also support more equitable and efficient implementation processes.

Based on the analyses and discussions presented in this manuscript, this study makes several key academic contributions to the field of water-related landscape and urban planning, with particular relevance to delta cities. It advances the discourse on climate adaptation by examining Bangkok's canal networks through the integrated lens of waterscape urbanism and modern BGI strategies. By combining historical cartographic data, spatial analysis, and policy-oriented recommendations, it offers an interdisciplinary framework that connects culturally embedded water practices with present-day resilience planning. While centered on Bangkok, the insights and methods presented here are applicable to other rapidly urbanizing delta cities facing similar challenges of climate-induced flood risks and ecological disconnection.

## 7 Conclusions

The dynamics of the wet and dry seasons of the CPD influence Bangkok's ecological conditions. Traditionally, livelihood coexisted in tandem with these dynamics, with canals providing ecosystem services that supported human settlement, transportation, irrigation, and flood adaptation. However, urbanization and the expansion of road networks, combined with inadequate

land development controls and weak building regulations, have facilitated canal encroachment and infilling, leading to the fragmentation and loss of canals. In the meantime, DDS has continued to focus on rapid drainage through engineered infrastructure, which often overlooks ecological, socio-economic, and cultural services. This approach is undergoing despite its limitations on adaptability under climate change conditions. A stronger synthesis of these findings highlights that the current one-dimensional flood control paradigm fails to leverage the multifunctionality of Bangkok's canal networks and misses opportunities for integrated, adaptive urban water management. Addressing the challenges of urban floods in Bangkok necessitates a comprehensive rethink of its rainwater management strategies. Reconstructing the canal networks to improve water flow and reduce flood risk, coupled with BGI and NbS, offers a pathway toward sustainability that also revives Bangkok's original waterscape urbanism, reconnecting the city with its historically rooted, water-oriented urban form. By reinforcing the multifunctional value of canal systems, beyond drainage alone, Bangkok can pursue a more holistic approach to water management, enhancing the city's resilience to climate change impacts, capitalize on the resource potential of urban stormwater, and promote a more sustainable and equitable urban environment.

At the same time, several limitations must be acknowledged. The study relied on scanned historical maps from 1910 to 1940, which, despite their value, may contain inaccuracies due to their hand-drawn nature and georeferencing constraints, potentially leading to slight overestimations or underestimations of canal loss or urban expansion. Furthermore, the lack of systematically collected and openly accessible spatial data, both historical and contemporary, poses a significant barrier to research and evidence-based planning. Addressing this data gap through standardized, transparent, and accessible datasets would significantly enhance future studies and the development of realistic, equitable, and long-term flood resilience strategies. In addition, further research on integrating missing or reconstructed canals into hydrological models is needed to enhance understanding of their role in urban flood mitigation. More efforts should also be made to explore the socio-economic and ecological implications of canal reconstruction to assess its cost-benefit potential to reduce the pressure of land-use changes and mitigate the impact on the declining efficiency of canal flow. Future work could also examine implementation feasibility, regulatory frameworks, and governance challenges to help translate restoration strategies into actionable policies.

## ACKNOWLEDGEMENTS

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The authors gratefully acknowledge the Office of National Archives of Thailand for granting permission to use historical photographs of Bangkok's canals for academic purposes. They also wish to thank Mr. Sirisompornkong for his valuable assistance in drafting the section of the canal and its surrounding illustrated in Fig. 3.

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**Competing interests** | The authors declare that they have no competing interests.

## REFERENCES

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- [1] Chen, O., Abdelhalim, A., Liu, Y., Rico-Ramirez, M., & Han, D. (2021). Climate change adaptations for food security in vulnerable areas of the Egyptian Nile—For tackling the overlooked nexus hazards of hydrological extremes and waste pollutions. *Water*, 13(4), 412.
- [2] Orieschnig, C. A., & Venot, J.-P. (2024). The history of hydrological studies on the Mekong floodplains—From colonial experiments to computational models. *Hydrological Sciences Journal*, 69(16), 2391–2404.
- [3] Paalvast, P., & van der Velde, G. (2014). Long term anthropogenic changes and ecosystem service consequences in the northern part of the complex Rhine-Meuse estuarine system. *Ocean & Coastal Management*, 92, 50–64.
- [4] Tachakitkachorn, T. (2010). *Bangkok morphology based on traditional orchard waterway network*. Thailand Science Research and Innovation.
- [5] Tachakitkachorn, T. (2007). Morphological study of an orchard system in the lower basin of Chao Phraya Delta: A case study of Amphawa Neighborhood. *Nakhara: Journal of Environmental Design and Planning*, 3, 37–56.
- [6] Takaya, Y. (1987). *Agricultural Development of a Tropical Delta: A Study of the Chao Phraya Delta*. University of Hawaii Press.
- [7] Takaya, Y. (1971). Physiography of rice land in the Chao Phraya Basin of Thailand. *The Southeast Asian Studies*, 9(3), 375–397.
- [8] Office of National Archives of Thailand. (n.d.). *Valuable gallery*. Fine Arts Department.
- [9] Firehock, K. (2015). *Strategic Green Infrastructure Planning: A Multi-Scale Approach*. Island Press.
- [10] Fang, X., Li, J., & Ma, Q. (2023). Integrating green infrastructure, ecosystem services and nature-based solutions for urban sustainability: A comprehensive literature review. *Sustainable Cities and Society*, 98, 104843.
- [11] Korkou, M., Tarigan, A. K. M., & Hanslin, H. M. (2023). The multifunctionality concept in urban green infrastructure planning: A systematic literature review. *Urban Forestry & Urban Greening*, 85, 127975.
- [12] Štrbac, S., Kašanin-Grubin, M., Pezo, L., Stojić, N., Lončar, B., Čurčić, L., & Pucarević, M. (2023). Green infrastructure designed through nature-based solutions for sustainable urban development. *International Journal of Environmental Research and Public Health*, 20(2), 1102.
- [13] Brears, R. (2018). *Blue and Green Cities: The Role of Blue-Green Infrastructure in Managing Urban Water Resources*. Palgrave Macmillan.
- [14] Gupta, S. K., Maurya, N., Malik, F. A., & Razzak Janjua, L. (Eds.). (2024). *Integrating Blue-Green Infrastructure Into Urban Development*. IGI Global.
- [15] Mell, I., & Scott, A. (2023). Definitions and Context of Blue-Green Infrastructure. In: C.-L. Washbourne & C. Wansbury (Eds.), *ICE Manual of Blue-Green Infrastructure*. ICE Publishing.
- [16] Thaitakoo, D., & McGrath, B. (2010). Chapter 3 Bangkok Liquid Perception: Waterscape Urbanism in the Chao Phraya River Delta and Implications to Climate Change Adaptation. In: R. Shaw & D. Thaitakoo (Eds.), *Community, Environment and Disaster Risk Management* (Vol. 2, pp. 35–50). Emerald Group Publishing Limited.
- [17] Kiguchi, M., Takata, K., Hanasaki, N., Archevarahuprok, B., Champathong, A., Ikoma, E., ... Oki, T. (2021). A review of climate-change impact and adaptation studies for the water sector in Thailand. *Environmental Research Letters*, 16(2), 023004.
- [18] Marks, D. (2016). *"It is built against nature": Floodwalls built after the 2011 floods in central Thailand*. Thailand Development Research Institute Foundation.
- [19] Marks, D., & Elinoff, E. (2020). Splintering disaster: Relocating harm and remaking nature after the 2011 floods in Bangkok. *International Development Planning Review*, 42(3), 273–294.
- [20] Saito, N. (2014). Challenges for adapting Bangkok's flood management systems to climate change. *Urban Climate*, 9, 89–100.
- [21] Long, N. V., Le, T. D. N., Nguyen, H., Khanh, D. V., The, N. T. M., Do, D. T., & Cheng, Y. (2022). From a hard to soft approach for flood management in the Vietnamese Mekong Delta: Integrating ecological engineering for urban sustainability in My Tho City. *Water*, 14(7), 1079.
- [22] Takin, M., Cilliers, E. J., & Ghosh, S. (2023). Advancing flood resilience: The nexus between flood risk management, green infrastructure, and resilience. *Frontiers in Sustainable Cities*, 5, 1186885.
- [23] Wang, Z., Li, Z., Wang, Y., Zheng, X., & Deng, X. (2024). Building green infrastructure for mitigating urban flood risk in Beijing, China. *Urban Forestry & Urban Greening*, 93, 128218.
- [24] Hattori, T. (1972). Some properties of recent sediments in the Bangkok Plain of Thailand. *The Southeast Asian Studies*, 10(2), 321–334.
- [25] Takaya, Y. (1969). Topographical analysis of the southern basin of the Central Plain, Thailand. *Japanese Journal of Southeast Asian Studies*, 7(3), 293–300.
- [26] Takaya, Y. (1972). Quaternary outcrops of the southern part of the Central Plain of Thailand. *The Southeast Asian Studies*, 10(2), 298–320.
- [27] Kaida, Y. (1973). A subdivision of the Chao Phraya Delta in Thailand based on hydrographical conditions. *Japanese Journal of Southeast Asian Studies*, 11(3), 403–413.
- [28] Kaida, Y. (1974). Pioneer settlements and water control development on the west bank of the Lower Chao Phraya Delta: Water conditions in the deltaic lowland rice fields (II). *The Southeast Asian Studies*, 11(4), 512–524.
- [29] Tachakitkachorn, T., & Shigemura, T. (2005). Morphology of the agriculture-based deltaic settlement in the western basin of the Chaophraya Delta. *Journal of Asian Architecture and Building Engineering*, 4(2), 361–368.
- [30] Thaitakoo, D. (2025). *The lost river and vanishing waterscape of the Chao Phraya River Delta, Thailand: A historical socio-hydro-ecological perspective*. The 2nd International Sociohydrology Conference in Tokyo: Expanding and Mainstreaming Sociohydrology Toward Transdisciplinary Praxis, Tokyo, Japan.
- [31] García Sánchez, F., & Govindarajulu, D. (2023). Integrating blue-green infrastructure in urban planning for climate adaptation: Lessons from Chennai and Kochi, India. *Land Use Policy*, 124, 106455.
- [32] Hermoso, V., Salgado-Rojas, J., Lanzas, M., Morcillo, F., Casals, F.,

- Oñorbe, M., ... & Sánchez-González, J. R. (2025). Identifying river corridors for the implementation of the network of green infrastructure in Spain. *Freshwater Biology*, 70(5), e70048.
- [33] Murkin, K., Shiode, N., Shiode, S., & Kidd, D. (2023). Biodiversity and the recreational value of green infrastructure in England. *Sustainability*, 15(4), 2915.
- [34] Kosaiyawat, S. (2009). Water resource development for quality of life in eastern region: The original of Thai irrigation in the reign of King Rama V (B.E. 2411–2453). *Journal of Education*, 20(2), 1–16.
- [35] Drainage Information Division. (2020). *The history of Drainage and Sewerage Department BMA*. Drainage and Sewerage Department BMA.
- [36] Jular, P. (2017). *The 2011 Thailand floods in the Lower Chao Phraya River Basin in Bangkok Metropolis*.
- [37] Nair, S., Wen, W. K., & Ling, C. M. (2014). Bangkok flood risk management: Application of foresight methodology for scenario and policy development. *Journal of Futures Studies*, 19(2), 87–112.
- [38] Wacharoen, S. (2024, March 18). *The rise and fall of Klong Ong Ang*. Bangkok Post.
- [39] Brigden, K., Labunska, I., & Santillo, D. (2010). *Investigation of hazardous chemical discharges from two textile manufacturing facilities, and chemical contamination of nearby canals connecting to the lower Chao Phraya River, Thailand, 2010*.
- [40] Chanyotha, S., Taniguchi, M., & Burnett, W. C. (2011). Detecting Groundwater Inputs Into Bangkok Canals Via Radon and Thoron Measurements. In: M. Taniguchi (Ed.), *Groundwater and Subsurface Environments: Human Impacts in Asian Coastal Cities* (pp. 143–158). Springer Tokyo.
- [41] Bunnag, P., Nopkhun, D., & Thadiniti, S. (1982). *Canals in Bangkok: History, Changes and Their Impacts (1782 A.D.–1982 A.D.)* (p. 274). Chulalongkorn University.
- [42] Gregory, I. N., & Healey, R. G. (2007). Historical GIS: Structuring, mapping and analysing geographies of the past. *Progress in Human Geography*, 31(5), 638–653.
- [43] Thaitakoo, D., McGrath, B., Srithanyarat, S., & Palopakorn, Y. (2013). Bangkok: The Ecology and Design of an Aqua-City. In: S. T. A. Pickett, M. L. Cadenasso, & B. McGrath (Eds.), *Resilience in Ecology and Urban Design: Linking Theory and Practice for Sustainable Cities* (pp. 427–442). Springer Netherlands.
- [44] Bangkok Metropolitan Administration. (2023). *Project information: Improvement of the flood protection line along the Phra Khanong Canal*.
- [45] Drainage and Sewerage Department BMA. (2024). *Action plans to prevent and solve flood problems in Bangkok for the year 2024*.
- [46] Drainage and Sewerage Department BMA. (2007). *Action plans to prevent and solve flood problems in Bangkok for the year 2007*.
- [47] Drainage and Sewerage Department BMA. (2006). *Project information: Mahachai Canal Retention Basin (Monkey Cheek) project*.
- [48] Budthimedhee, K., Nilapornkun, K., Chueasawad, T., Sangkla, P., Chutarat, A., Chuenruedeemol, W., ... & Thaitakoo, D. (2024). *The report on the International Seminar on Collaborative Partnership for Sustainable Coastal Area and Ecosystem Development in the Gulf of Thailand* (p. 116). King Mongkut's University of Technology Thonburi.
- [49] Garshasbi, D., Kitiphaisannon, J., Wongbumru, T., & Thanvisitthpon, N. T. (2025). Assessment of future urban flood risk of Thailand's Bangkok Metropolis using geoprocessing and machine learning algorithm. *Environmental and Sustainability Indicators*, 25, 100559.
- [50] Amnuaylojaroen, T. (2021). Projection of the precipitation extremes in Thailand under climate change scenario RCP8.5. *Frontiers in Environmental Science*, 9, 657810.
- [51] Limjirakan, S., Limsakul, A., & Sriburi, T. (2010). Trends in temperature and rainfall extreme changes in Bangkok Metropolitan Area. *Applied Environmental Research*, 32(1), 31–48.
- [52] Pipitpukdee, S., Attavanich, W., & Bejranonda, S. (2020). Impact of climate change on land use, yield and production of cassava in Thailand. *Agriculture*, 10(9), 402.
- [53] Brown, R. R., Keath, N., & Wong, T. H. F. (2009). Urban water management in cities: Historical, current and future regimes. *Water Science and Technology*, 59(5), 847–855.
- [54] Wantzen, K. M., Piednoir, T., Cao, Y., Vazhayil, A. M., Tan, C., Kari, F. G., ... & Sommerhäuser, M. M. (2022). Back to the surface—Daylighting urban streams in a Global North–South comparison. *Frontiers in Ecology and Evolution*, 10, 838794.
- [55] Klaus, V. H., & Kiehl, K. (2021). A conceptual framework for urban ecological restoration and rehabilitation. *Basic and Applied Ecology*, 52, 82–94.
- [56] Richter, M., Heinemann, K., Meiser, N., & Dickhaut, W. (2024). Trees in sponge cities—A systematic review of trees as a component of blue-green infrastructure, vegetation engineering principles, and stormwater management. *Water*, 16(5), 655.
- [57] Gu, H., Kim, S., Wu, Z., Dang, L., & Gu, H. (2025). Rainwater management strategies from the perspective of urban flood resilience. *Architecture Engineering and Science*, 5(4), 215–217.
- [58] Muszyński, K. (2025). Modelling of rainwater reduction and hydrological performance of selected green infrastructure (GI) facilities in urban catchments. *Environmental Protection and Natural Resources*, 35(3), 1–20.
- [59] Hanington, P., To, Q. T., Van, P. D. T., Doan, N. A. V., & Kiem, A. S. (2017). A hydrological model for interprovincial water resource planning and management: A case study in the Long Xuyen Quadrangle, Mekong Delta, Vietnam. *Journal of Hydrology*, 547, 1–9.
- [60] Padiyedath Gopalan, S., Champathong, A., Sukhapunnaphan, T., Nakamura, S., & Hanasaki, N. (2022). Inclusion of flood diversion canal operation in the H08 hydrological model with a case study from the Chao Phraya River basin: Model development and validation. *Hydrology and Earth System Sciences*, 26(9), 2541–2560.

# 水脉断裂，韧性渐失：重新思考曼谷城市水管理

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## 摘要

城市化和单一用途的防洪基础设施从根本上改变了许多三角洲城市的水文格局和运河网络，曼谷不断萎缩的运河网络便是这一转变的典型例证——曾对曼谷防洪、灌溉、交通和文化功能至关重要的运河网络，其重要性正逐渐下降。本研究对曼谷市内3个城市化程度和空间形态各异的代表性运河网络进行空间与土地利用变化分析，展现了运河消失、次级运河破碎化及周边土地利用转变的不同模式。研究表明，运河的消失与不透水表面的扩张和土地利用变化同时发生，这不仅体现了城市向刚性、单一用途的水利管理基础设施的转变，也反映了社会观念从“以水为主”转向“以地为主”。这种双重转变造成了社区与河道的脱节，削弱了城市的洪水韧性，并忽视了运河网络所具有的更广泛的生态与文化价值。为应对这些挑战，研究建议将运河网络修复、再生为多功能蓝绿基础设施，包括重建消失河段、增强横向连接，以及应用绿色工程技术。本研究强调将历史运河数据纳入水文模型以支持实证性洪水缓解策略的重要性，并指出了关于运河修复的社会政治可行性及未来气候情景融入洪水建模的关键研究空白。通过将运河网络重新定位为城市可持续发展的关键基础设施，本研究为更广泛的三角洲城市适应性水管理的学术与政策讨论作出了贡献。

## 关键词

运河网络；运河网络破碎化；运河修复；蓝绿基础设施；流动感知；水文连通性；水韧性；适应性水管理

## 文章亮点

- 城市化和防洪措施导致曼谷运河网络破碎化，扰乱了河流流动
- 空间分析显示，尽管存在损失和断裂，曼谷仍保留了大量运河
- 整合“水景观都市主义”理念，强调运河是文化、生态和洪水韧性等方面的重要资产
- 应将土地利用政策纳入运河保护，以防止其进一步退化
- 水文模型中必须涵盖缺失的运河，以支持数据驱动型城市规划

编辑 田乐